FOUNDRY ENGINEERING

Overseas Technical Cooperation Agency

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THE PROGRESS OF FOUNDRY TECHNOLOGY

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FORWARD

Casting is classified by the field of application into two main categories; one is the process to make ingots from which sheet metal is produced, and the other the process to form metals into a desired shape. In a narrow sense, however, casting refers to the latter process. Therefore, casting in this sense should have the shape and dimension that can serve the intended purposes. Ideal castings are those that can be put in use without machining after the casting process.

In parallel with the recent progress in every field of technology, machines are all required to be highly precise, efficient and uniform at the same time on a mass-production basis. This requires that cast parts for such machines to be equally precise, uniform and even suitable for mass-production.

Under these circumstances, requirements for casting as a metal processing technique are getting even severer. To answer these requirements research works on the casting technique are becoming quite active and its progress quite remarkable. In recent years a special precision casting process has made it possible to do business in castings at the tolerance of 0.13mm per 25mm. In many cases such highly precise castings may prove seemingly costly, but the overall cost could be lowered if machining can be minimized.

1. LOST WAX PROCESS

1.1. Outline

Lost Wax Process, which is also called "Investment Casting", has developed from a technique of Japanese industrial artists known as the loam mould type wax pattern process and from the inlay method of dentistry. 30 years ago T.G. Jungerson initiated the modern technique of investment casting. Around 1930 Austenal Laboratory in the United States introduced this technique into their commercial production. Parts for aircraft engines and machineguns were produced on a large scale by this technique during the World War II. In Japan the study on this process started toward the end of 1949. In April, 1950 a committee of researchers on heat-resisting materials for gas turbin was formed on a budget secured from the Ministry of Education. This committee had a division devoted to the study of this technique. In May, 1951 a Study Society of precision casting was organized. Research works were actively carried out through the cooperation of manufacturers, universities, national research institutes, and so on.

A patent filed by Austenal Lavoratory in the United States under the subject of "Casting Moulds" covering an extreemly broad scope of wax process castings was notified to public on March 9, 1955, but failed to enter into effect, because on objection against this patent was accepted by reason of the aforementioned traditional methods of casting. So in Japan there is no obstacles whatsoever in using the traditional wax process, the inlay method of dentistry, and all other lost wax processes except some very special ones. Ever since a positive use has been made of these techniques by various industries.

The principle of investment casting is simple. First, a pattern of the part required is made with a fusible material such as wax. The pattern is then wrapped with refractories and is hardened to be a mould. The wax pattern in the mould is fused out and the molten metal is poured into the hollow of the mould.

Table 1. Process of Casting

Coating grain:	Silica flour of the size under 300 mesh, Zirconia, Alumina,
Investing grain:	Silica sand of relatively wide range of grading (65 - 150 mesh)
Binding agent:	Gypsum Phosphate, Water glass, Ethyl silicate, Alumina cement
Accelerator:	Mg O (in case of ethyl silicate)

Example with ethyl silicate:

$$Si(OC_2H_5)_4 + H_2O \quad Si(OH)_2 + 4\,C_2H_5OH$$
$$\text{heating} \quad SiO_2$$

Example of Mixture Ratio:
Ethyl silicate: 10% Hydrocloric acid: Alchole: Water = 5 : 1 : 1 : 9

1.2. Characteristics

1.2.1. By lost wax process no too heavy or too light parts can be made at present. The maximum weight is about 20 Kg and the minimum approximately 1 gram. Parts weighing from a few grams up to about 5 Kg and measuring 1-10 mm in thickness are most suitable for this process.

1.2.2. Both external and internal threads can be made by this process, but the internal thread usually have finer finish than the external one. The tolerance is approximately ± 0.076 mm per 25mm. Holes can be made in any shape; round, angular, winding and so on. It is easy to make holes if the diameter is larger than 1 mm.

1.2.3. As the wax pattern is fusible, no draft is required. Any curve or intricate shapes can be produced. Therefore, parts of intricate structure can be made in one unit without any subsequent assembly job, thereby adding to its strength conspicuously.

1.2.4. Although the accuracy in measurement differs from metal to metal, shape to shape, and size to size, the tolerance of ± 0.13mm per 25mm is commonly accepted as a standard in the United States. Non-ferrous alloy castings have a higher accuracy than iron castings in general.

1.2.5. No matter how much intricate the shape may be, this process provides fine skins and it can reduce labors in machining and assembling to a fraction.

1.2.6. Heat-resisting alloys, that are always hard to forge or grind, can be used by this process in making precision parts. Such materials that are hitherto not used due to the difficulty of machining are now available in this process for very precise and efficient parts.

2. SHAW PROCESS

2. 1. Outline

This process was invented by Mr. Shaw of England and is now patented. It has been introduced to Japan, too.

A matchplate type pattern is first made with gypsum on the basis of a model. Then poured into it is a pasty mould making material made up of the mixture of fine and coarse grains of silica sand in an ethyl silicate solution. When this material reaches the jelly state, it is removed from the gypsum and is exposed to high temperature for hardening.

The mould thus heated will have a network of very fine cracks in its surface, but not to the extent that molten metal penetrates into these cracks and spoils the skin.

2. 2. Characteristics

2. 2. 1. As the pattern is not fusible contrary to the lost wax process, shapes available are somewhat limited. However, no taper allowance is required because the mould is still in the state of jelly when it is removed from the gypsum pattern and is adaptable to a slight deformation.

2. 2. 2. Castings of high fusing point alloys are available by this process as well as the lost wax process.

2. 2. 3. With this process heavy castings weighing tons can be produced.

2. 2. 4. The tolerance in dimensions is about ± 1. 0mm which is almost the same as the lost wax process.

3. SHELL MOULDING PROCESS

3. 1. Outline

The shell moulding Process is a technique invented by Johannes Croning of Germany during the World War II, so this process is also called the "Croning Process" or "C-Process".

It is a well-known story about this Process that a patent covering this technique was filed with the German Patent Office on February 1944, but it was treated as a top secret by the German Government during the World War, in which period this Process made an important contribution to the mass production of cores for grenades. After the War, this Process was compiled in the PB Report (PB-8391) of a UN Survey Team. Then, in the FIAT Final Report No. 1168 issued on May 30, 1947, the detailed informations on its fundamental experiments were reported. To Japan this process was first introduced by the "Casting" a periodical published by the Japan Foundry Association in April, 1951. Even since the Precision Casting Study Society has carried all-round research works on this process in cooperation with research institutes, foundry business circle, machine builders'circle resin and silica sand business circle, and so on.

Thanks to their united efforts, quite a remarkable accomplishment has been achieved in such a short period in popularizing and in further developing this process.

As number of different kinds of shell moulding machines are made domestically, and as high quality resin and silica sand are readily available, this process is quite applicable for commercial production. It is estimated today more than 340 establishments, big and small, have already commercialized this Process. 450-480 tons of resin are supplied every month. Castings-produced under the Shell Mould Process amounts to about 40-50 billion yen annually.

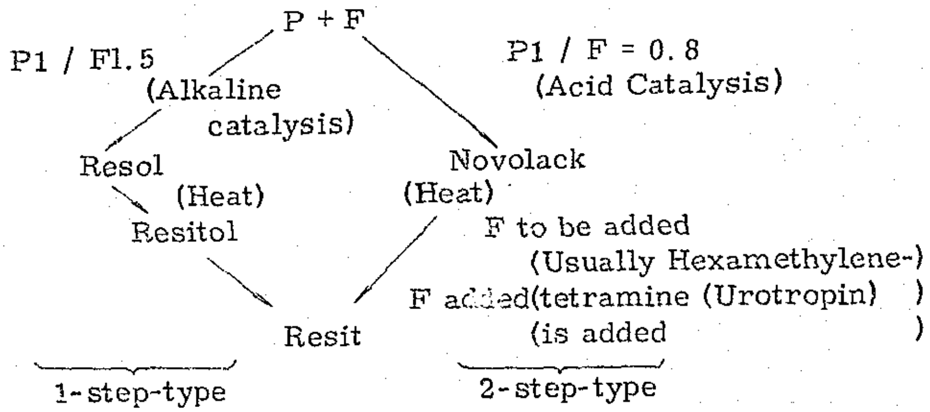
As the Japan-Germany Agreement on Industrial Proprietorship, which took effect on May 8, 1953, recognized a claim for the priority over eight basic patents covering the Shell Moulding Process including the patent of Mr. Croning, these patents were filed with the Japanese Government by Edel Stawelcke of Germany. These patents have recentry been all patented in Japan, but a license agreement signed between the Japan Shell Mould Society (Est. : Dec., 1956) and the Edel's side now authorizes the Society members to use this Process without any obligation.

The Shell Moulding Process is entirely different from the time-honored conventional concepts of moulding technique. One of the characteristics are the fact that by this process moulds can be easily produced in a mass scale. Prepare a mixture of dry silica sand and thermosetting resin to begin with. This mixture is then poured on heated metal pattern. The resin in the mixture thus poured hardens on account of the heat, and together with the grains of silica sand it becomes to be a thin shell. Two shells make a mould, into which molten is poured.

Table 2. Phenol Resin for Shell Mould

Reacting process of Phenol Resin

P: Phenol
F: Formalin



Resin currently used:
Novolack + abt. 10-15% weight% Urotropin added

3.2. Characteristics

3.2.1. The Process is so simple that no skilled labor is required. Full automatical operations are possible and it reduces labor cost to the large extent.

3.2.2. The process provides high mass-productivity. An up-to-date shell moulding machine can produce 40-50 shells an hour. This process provides stable operation so that it suits mass production plants.

3.2.3. As the shell contains no water, the percentage of rejected item is lower. The high permeability of the shell admits that molton metal runs fast at less volume of poured metal.

3.2.4. As the shell is considerably rigid, handling is easy. Shells can be stored for long time.

3.2.5. The volume of sand to prepare under the process is 1/10 the volume for sand mould. The floor space required for sand preparation is 20-30 per cent. The sand can be removed with ease.

3.2.6. The accuracy the process gives is about 0.5mm on finished castings. Cast iron surface is 10-15 and nonferrous alloy 7-10, which are better than the surface of sand mould castings.

4. CO_2 PROCESS

4.1. Outline

The CO_2 Process was patented in England in 1948 for Alfred Augstein, but it did not attract public interest at that time and was almost forgotten. Stimulated by the progress of the shell moulding process, this process was somewhat improved and commercialized in Germany. As soon as W. Schumachen and D. V. Atterton introduced this process, it absorbed public atention rapidly, and within a short period it made a remarkable progess and gained high popularity over the shell moulding process. In Japan the advantage of this process was first recognized in early 1955. After the 17th Annual Meeting of the Precision Casting Study Society held in March 1955, at which various data on the CO_2 process with water glass supplied domestically were made public, good many plants, one after another, tried this Process and in a very short period it spread over throughout the country.

The CO_2 Process is a technique by which moulds are made by mixing silica sand with Na_2O (water class), and then, blowing CO_2 gas into the mould to harden it rapidly.

Table 3. Reaction of Water Glass and CO_2 Gas

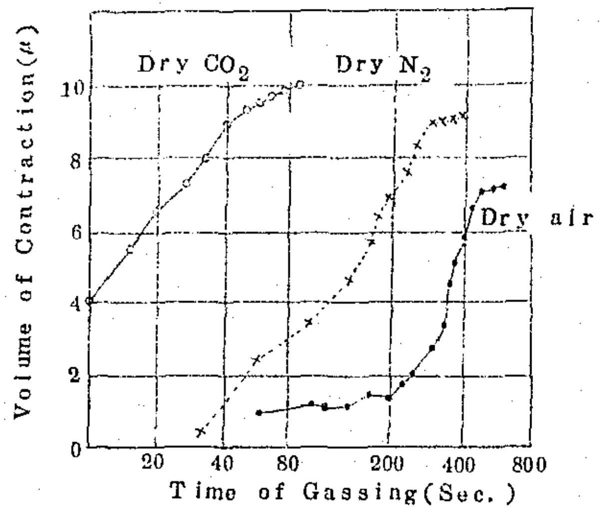
$$Na_2O\ .\ mSiO_2\ (mn + X)\ H_2 + CO_2$$

$$Na_2CO_3\ .\ XH_2O + m(Si_2O\ .\ nH_2O)$$

(Sodium carbonate)

m: Mol ratio of Water glass
n : Mol rumber indicative of water contained in silica gel
x : Mol number of water of crystallization in sodium carbonate

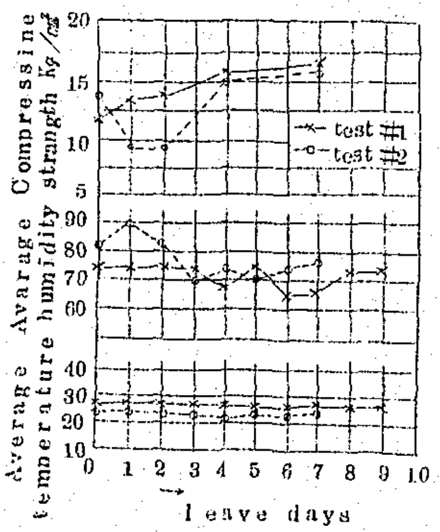
Figure 1. Gassing and Contraction by Gasses



Test piece weight:
12 g
Test piece height:
13.7 13.8mm

Besides CO_2 gas, both dry N_2 gas and dry air can harden the mould in relatively long time. This can be explained by the fact that water glass has powerful adhesity when it is dried. Therefore, drying represents an important element as well as the reaction of water glass and CO_2 gas.

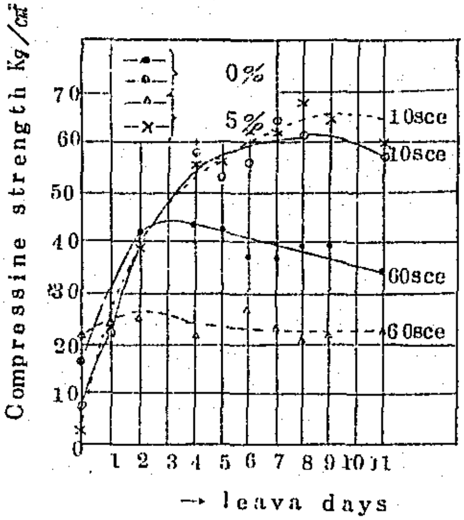
Figure 2. Influence of Weather on Strength and



The test samples cotain foreign made binder and is hardened by CO_2 gas blowing for 60 sec. Average temperature and humidity are those recorded by Nagoya Weather Bureau.
Test #1 was conducted during a week of fine weather. The strength shows a stable upward tendency.
During the test #2 the weather was changeable. It rained for the first three days and the humidity exceeded 80%. This test indicates an influence of weather on the strength.

The strength reduced on rainy days and it increased as the weather became fine.

Fingure 3. Time-Strength Relation



The test was conducted in an air-conditioned room of 20 ± 5°C temperature and 70 ± 5% humidity. The results indicates that both samples, with and without molasses, of 10 sec. CO_2 blowing have a high strength that declines only slowly. The samples of 60 sec. blowing, however, have lower maximum strength that quickly declines. These results indicate that on excessive blowing gives unfavorable influence on strength.

4.2. Characterestics

4.2.1 Cast moulds and cores can be made speedily. What is still better, wooden patterns and wooden core box will do.

4.2.2 No drying oven is required.

4.2.3. As the strength is high when hardened, no or fewer core rods (gaggers) are required.

4.2.4. Less handling of cast moulds and cores are required, and therefore the productivity per floor space is higher.

4.2.5. The Process is relatively free from such defects as blow and scab.

4.2.6. The deformation of cast mould and core is slight and the accuracy of castings high.

4.2.7. Equipment for this Process is simple and not costly. Use can be made of conventional moulding machines and core blowing machines.

5. CEMENT MOULDING PROCESS

5.1. Concept of the Cement Mould Process

In casting heavy iron or copper castings, dry sand moulds with clayeybinder have been hitherto used. But in recent years a moulding process of using cement as binder takes a part of the place of the conventional dry sand mould.

The cement moulding has the advantageous features of simple process, good sand strip and high dimensional accuracy of the casting. These merits can not be provided by the conventional fired moulds.

The Cement Mould Process has become recognized also by reason of the fact that such defects as blow-holes and scab through result very seldom under this Process.

As cement moulds are hardened by the hydration of cement, careful attention should be directed to the point that hardening time and pressure strength largely differ depending upon the water-cement ratio and the grading of silica sand.

Research works are now being carried out at various plants to reduce hardening time, drying method, and etc. Casting design in the Cement Moulding is also an important subject for the future study. It is expected that the Process will make further progress in Japan.

5.2. Advantage and Disadvantage of the Cement Mould

The process of the cement moulding and its general charactiristics-----advantage and disadvantage-----may be summaried as follows:

Advantage	Disadvantage
1. The high fluidity of the sand permits an easy moulding operation even by the unskilled.	1. The natural drying requires a spacy floor area.
2. No uneven hardening is found. The high strength enables an easy handling.	2. A long drying time is required, but the usable time is limited.

3. The drying process can almost be omitted.	3. The binding force is not powerful immediately after moulding.
4. As the snap flask is used, metal flasks can be abolished.	4. Difficult to recycle the used sand.
5. No core bar, gagger is required.	5. The alkaline characteristic of the sand can harm the workers' hand.
6. Easy to shake-out.	

Besides the above-listed, there are more advantages of the Cement Moulding Process such as low rate of rejects, low cost, and etc.

6. FULL MOULD PROCESS

6.1. Outline

A pattern, is first made with such a resin material as polystyrene that gasifys at low temperature. Then, the pattern is wrapped with casting sand in its environment. The molten metal is poured into the sand mould while the polystyrne pattern is in it. As the model gas gasifys, metal takes its place. This is the principle of the process called "Full Mould Process".

This Process is based on a new principle and has many advantageous features in comparison with conventional processes under which a hollow is usually prepared in the mould. Because of its many advantages a positive use is made of this Process in European countries.

6.2. Characteristics

This epoch-making Full Mould Process has many advantageous features, but at the same it does not have a few problems to be solved in the future. To summarize them;

Advantages

1) This Process can be applied for all kinds of metals from light alloys to steel.
2) The pattern can be made at a low cost.
3) The whole process of moulding is simple.
4) No split pattern and no core are required.
5) The conventional hollow mould can be used with this Process combined.

6) A saving of the riser can be effected by spherical blind risers.

7) As dry sand can be used within any binder, shake-out operation goes easy.

Disadvantage

1) If a high speed milling machine is not available for use, the surface of the pattern is rough and such rough surface is likely to impart a rough finish to the mould. In many such cases wax coating is required.

2) In case of dried sand without binder is used and discontinuous pouring to a mould is made, the pattern itself may be deformed.

3) It may give deffects as blister if peameability is low because of much gas generated.

7. DIE CASTING

7.1. Outline

Die Casting is a process to cast metal by die casting machines. In Japan a company incorporated in 1912 first started producing aluminum alloy parts by die casting. But no remarkable progress followed this due to the fact that many of the industrial estableishments in this country were small in production scale for this process which was only suitable for mass production. With the outbreak of the World War II, the demand for aircrafts and other military supplies increased quite rapidly and number of European type die casting machines--Polak or Eckert--were installed.

After the War, the Die Casting showed a rapid progress since 1953 in parallel with the growth of automotive, electric and photographic industries. Zinc die casting were commercialized on an active scale during this period and the number of such industrial establishments has increased. The machines installed in recent years are bigger and much more improved. For instance, Lester, Cleavland, H.P.M., etc. for aluminium alloys PECO, Read-Prentice, Cleavland for zinc alloys. Such big machines for aluminium and zinc die casting are also built in Japan, and many of them are already in operation. Those big machines made in Japan are of nominal size of 800, 1,000 or1,500 tons. Even 2,000 ton machines are operated now.

7.2. Making Process

7.2.1. Metallic Mould

The metallic mould is the most important Part of die casting, and whether or not a good metallic pattern can be obtained will directly affect the quality.

As mould metal, chrome steel or nickel-chrome steel are used for zine alloy castings, and chrome-vanadium steel or chrome-tungsten-cobalt steel are often selected for use with aluminium alloy die castings. In any cases materials are all used after they are properly heat-treated.

In designing the mould, careful attention should be directed to gate, vent hole, injection mechanism, core breaker, mould matching pin, and so on. Those should be designed to best suit the castings to make and the machine to be used. The life of the mould is not always the same, but it is usually longer with zine alloys than with aluminium alloys.

7.2.2. Die Casting Machine

The die casting machine can be divided into two main groups.

a) Hot Chamber Type

In this type the melting furnace and the die casting machine section are combined to be one block. The presure chamber dips in the molten metal, and the pressurized metal is fed into the mould through a nozzle. This type is also called "Goose neck type" because of the shape of the pressure chamber. PECO, Reed-Prantice, Cleveland, etc. fall into this type. These are mainly used for zinc alloy die casting.

b) Cold Chamber Type

The melting furnace and the die casting machine are built independently in this type. The molten metal is bailed out to be poured into the pressure chamber, from which it is pressed into the mould by a plunger. As the pressure chamber is set up outside the molten metal, this type suits such metals that melt at high temperature. Aluminium alloys and even copper alloys can be processed. Some of the examples of this type are Eckert, Polak, Lester, H. P. M. and so on.

7.3. Characteristics

7.3.1 As Die Castings have a smooth skin and are so highly accurate that no machining is required. Grinding and assembly processes can be considerably reduced.

7.3.2. The accuracy of dimensions differs from metal to metal, shape to shape and size to size. In zinc alloy die casts the tolerance is about ± 30μ/100mm and in aluminium alloys ± 50μ/100mm.

7.3.3. Both outside and inside threads are castable, but the outside thread is more accurate than the inside thread. The maximum number of thread that are castable is 30 threads in zinc alloys, 20 in aluminium, and 10 in copper alloys.

7.3.4. Very intricate shape and cavities that can hardly be machined are castable by die casting. It required, high temperature metal can be cast-in with other metals.

7.3.5. Die Casting is very applicable for mass production. The most up-to-date machine is able to cast in such a large scale as more than 2,000 pieces a day. What is still better, the products are quite uniform. However, the metallic mould used for die casting is costly because those are made of heat-resisting steel. All in all, the die casting is most suitable for mass production. The economical minimum output differs depending upon shape, size, accuracy, metal, and etc., but it is usually more than 1,500 pieces.

Table 4. Zine Alloy Die Casting JIS H 5301

	Chemical elements added	Permissible Amount of impuritty	Tensile strength kg/mm^2	Elongation %
Zinc alloys die cast 1-class Zn ADC 1	Al 3.5 ~ 4.5 Cu 0.75 ~ 1.25 Mg 0.03 ~ 0.08	Pb < 0.007 Fe < 0.10 Cd < 0.005 Sn < 0.005	33	7

	Chemical elements added	Permissible Amount of impurity	Tensile strength kg/mm^2	Elongation %
Zine alloys Die cast 2-class Zn ADC 2	Al 3.5 4.5	Pb < 0.005 Fe < 0.10 Cd < 0.004 Sn < 0.003	29	10

The amount of permissible impurities is very low because these impurities will cause active intercrystalline corrosion. The amount of Mg should be very carefully determined because it acts as an inhibitor against the harmful Pb which is the main cause of intercrystalline corrosion.

8. GRAVITY DIE CASTING

The process to cast molten metal into a metallic mould by only gravity without using any injection device such as die casting machine is called "Metallic Moulding" or "Gravity Die Casting". In Europe this Gravity Die Casting is much more popular than Die Casting, is widely used in the automotive industry. Particularly at Fiat's plant in Italy engine blocks as well as pistons are produced by this technique. On the market are specialized machines for each of these applications. By these machines, metallic moulds are bound up, and, after pouring, castings are drawn from the mould automatically. Taking the production scale into account, automotive plants in Japan should make more positive use of this method just as in Europe.

9. LOW PRESSURE DIE CASTING

9.1. Outline

The Low Pressure Die Casting is a process to cast molten metal into mould by pushing up the metal through a pipe by a low pressure gas pressing the surface of the molten metal in a closed container. This is an old invention. In 1910 E. F. Lake obtained a patent for it as a process to be applied to a zinc or tin alloy processing equipment. It was not industrialized, nor did it make any noticeable progress in spite of various repeated trials. After the World War II this process has caught the attention of E. C. Lewis of England, who established

Alumasc Company in 1945 and devoted himself to the study of the production technique. In 1947, he succeeded in producing aluminium household utensiles, and in the following year rain tub and other products appeared on the market. In 1950 he made beer barrels of aluminium alloys and advanced into the territory of wooden barrels of beer. He could make as big barrels as 86 cm high and more than 80 kg in weight.

Alumasc Company, that thus brought up the low pressure die casting principle to a practicable level, attracted public attention as an unique company. In 1956 Karl Schmidt obtained the licenseeship and as the result of their active research works for development they could make a great success in casting light metal automative parts such as aluminium cylinder head. In 1958 the Chevrolet Division of G. M. sent some engineers to Schmidt Co. and Alumasc Co. for surveying on these companies in connection with the manufacture of engine. As these engineers admitted the superiority of this process, they at last signed a license agreement with both of these European companies and started the production of cylinder head, crank case, clutch housing by this casting process. They have installed their low pressure die casting machines in their new plant at Massena. 80 machines are now in operation there.

The G. M's introduction of low pressure die casting created a world-wide sensation, particularly in the automobile industry, and popularized this technique quite rapidly. In Japan the Low Pressure Die Casting Study Society was organized in September, 1961 with the object of studying this process jointly. Its projects were actively carried out. At present this organization has nearly 100 member-companies. There are four or five companies dealing in low pressure die casting machines. Air-cooled cylinder heads for light cars, break drums and etc. have been already in mass production with this process.

9. 2. Equipment and its Operation

The low pressure die casting equipment consists of such basic parts as the pressure gas intake, through which the gas to press the molten metal in a closed chamber is fed in, and the stock which leads molten metal to the mould together with the mould clamping mechanism and controlling device of gas pressure and pressure-time. At present this technique is mainly used for processing aluminium alloys, and the mould used are metallic. On aluminium alloys as a low pressure as 0 0.1 - 0.5 kg/cm^2 is sufficient. When the poured metal solidifys, the pressure is normalized and then the casting is taken out of the mould.

9.3. Characteristics

9.3.1. As conventional techniques all require considerably big risers, runners and gates, the molten metal yield under these processes is often as poor as 50%. By this Process, however, an extreemly small gate can provide sufficient feeding. The yield can be raised up to 80 - 90%. Therefore, material can be used economically.

9.3.2. Because of its directional solidification characteristics the casting is so solid that it is almost perfectly free from porosity and shrinkage.

9.3.3. As the clean metal taken from the middle of the closed furnace is filled in the mould, there seldom are castings that contain oxide in them.

9.3.4. The cast iron mould is sufficient for this Process. Sand cores can be used.

9.3.5. The equipment is less costly in comparison with die casting. But the productivity is much inferior to die casting.

9.4. Low Pressure Die Casting in the Future

Although the present application of low pressure die casting is mainly confined to aluminium automotive parts, already in the United States steel wheels are being made by this process at Griffin Wheel Company. Provided that a proper close-type container of molten metal, a stoke and moulds are obtained, copper alloys, iron and even steel, just as mentioned above, can be processed by this technique. In the future this technique will perhaps be applied to various different fields, besides more casting, such as casting ingots or handling molten metals.

10. CASTINGS OF TITANIUM AND ZIRCONIUM

Titanium is now the focus of attention in the chemical industry, for it has excellent corrosion and heat resisting properties and is light in weight, while zirconium is an important metal as the material of atomic reactor. Both of these metals, however, are difficult to be formed by casting, and it is required that the metal should be melted in argon atomosphere and in a pot of the some metal; i. e. titanium, for instance, should be melted in a titanium pot. This process is called ''Skull Melting'. The casting manipulation can not be carried out in the air, but in argon atomosphere. The mould should be made of a material that does not react to the metal to melt. In Japan The Government Industrial Research Institute of Nagoya has succeeded in casting some sample parts containing cores with these metals. Recently a Nihon Shinku Company has commercialized titanium casting by the technique developed by this Institute.

11. CAST METAL ALLOYS

11. 1 Nodular Graphite Cast Iron
(Ductile Cast Iron)

In In 1947 J. H. Morrogh succeeded in nodulizing the graphite by adding cerium. Coincidently, A. P. Gagnebin of International Co. invented making nodular graphite cast iron by adding magnesium. As the graphite is spherical, the stressconcentration can be remarkably relieved, so the toughness becomes as high as cast steel. This cast iron is good in wearresistance. Grain growth is seldom found after frequent heating.

Table 7. American Specifications of Nodular Graphite Cast Iron

Tensile strength kg/mm^2	Yield point kg/mm^2	Elongation %	Hardness BHN	Remarks
63.2	45.6	2.0	225-265	Pearlitic Structure, High strength, Wear-resistance, ascast
56.2	42.2	5.0	195-225	High class cast iron, as cast
42.2	31.6	15.0	140-180	Annealed to be ferritic

42.2	31.6	15.0	140-180	Annealed to be ferritic structure, Elongation first.
56.2	42.2	Not specifed	230-290	Limit of P not strict. As cast.

The matrix structure of nodular graphite cast iron is classified into three: ferrite, ferrite + pearlite, and pearlite. The nodular graphite cast iron of pearlitic structure is the best in strength.

11.2. Meehanite

Meehanite Cast Iron which Meehan of the United States first successfully made in 1926 is the most famous high class cast iron containing graphite, of which shape and distribution pattern are controlled by inoculation. Its fine pearlitic matrix structure is produced by distributing flake graphite evenly by inoculating calcium silicide. It is one of the excellent cast iron that has a tensile strength of as high as 40 kg/mm^2, low mass effect, high wear resistance and little shrinkage cavity, and little quench rack. Meehanite is also well-known for that fact that a very detailed operation standard has been established for this cast iron as a result of the research works carried out for years and years.

There are several other techniques of improving cast iron by inoculation such as the Lime Nitrogen Process originated by Dr. Hisatsune of Nagoya University and the ferro-silicon addition method and so on.

Meehanite Metal for General Machinery

	GM	GA	GB	GC	GD	GE
Min. thickness	12	12	9	9	6	3
Tensile strength	38	35	31	28	24	21
Yield strength	34	32	24	21	18	16
Elastic modulus	1.54 x10^4	1.4 x10^4	1.26 x10^4	1.18 x10^4	1.02 x10^4	0.84 x10^4
	104	102	102	101	100	85
Charpy impact value 30mm dia. rod, 450mm fulcrum	1.1	1.0	0.8	0.6	0.5	0.3

Transverse strength	1500 1700	1400 1600	1350 1550	1300 1500	1200 1350	900 1200
Flexibility	7 8.5	7 8.5	7 8.5	6.5 8.5	5.5 8.5	5 8.5
Fatigue strength	17.5	15.5	13.5	12.2	10.5	9.5
Machinability, Cutter pressure	25	24	22	22	20	17
Hardness BHN	227	217	207	196	192	183
Min. hardness BHN	217	207	196	192	183	174
Specific gravity	7.34	7.31	7.28	7.25	7.22	7.16

11.3. Other Cast Iron

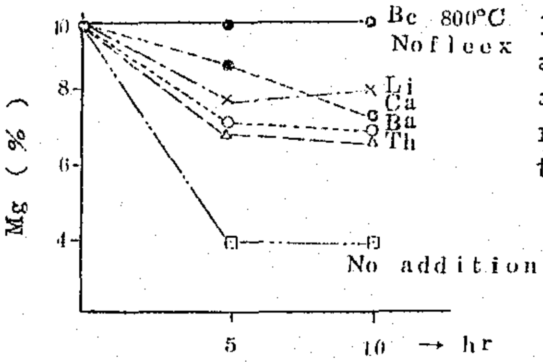
The high class cast iron of a fine, uniform eutectic graphite structure produced by treating the molten metal with the slag containing titanium oxide is an invention of Dr. Sawamura of Kyoto University and is called "SH cast iron". Sendite of Dr. Honma is a high class cast iron made by inoculation after treating with highly reducing slag containing alkaline metal.

Still other cast iron of an improved matrix structure is the acicular cast iron which is also called "needle structure cast iron". This cast iron contains 1 - 2% of nickel or copper added to it. By this addition it is intended to distribute graphite in fine homogenious flakes, and also to produce bainite matrix structure by heat-treatment.

11.4. Non-ferrous Alloy

11.4.1. Al- 10% Mg alloy (Hydronelium, Alcon 220, SAE 320) is a corrosion-proof alloy that has the highest strength among aluminium alloys. It has a tensile strength of 20 kg/mm^2 and an elongation of over 1% in "as cast", and has a tensile strength of 30kg/mm and an elongation of over 12% after heat-treatment. Therefore, this alloy is suitable for use where strength and impact resistance are particularly required. In melting this alloy for casting, the trouble of the oxidation and loss of magnesium should be avoided. The beryllium treatment can answer this purpose.

Figure 11. Influence of Addition Elements on Al - 10% Mg Alloy.



The trouble of the oxidation of Mg is very conspicuous in 10% Mg Hydronalium. The addition of Be in small amount is the most effective measure to prevent this trouble.

11.4.2. Al - 18-20% Si alloy is a hypereutectic alloy containg silicon in excess, and it precipitates Si in the primary crystal contrary to silumin. The tensile strength of this alloy in normal temperature is 17 - 19 kg/mm^2 and the elongation 0.5 - 1.0%. These are slightly lower than Y alloy, but is a temperature of 250°C the strength is 10 kg/mm^2 which is little different from Y alloy. It has better thermal expansion characteristics than Y alloy. The linear thermal expansion coefficient of about 18 x 10^{-6} is favorably compared with the coefficient of Y alloy; approx. 24 x 10^{-6}. As the Si percentage is high, it weighs higher than aluminium. The specific gravity is some 2.6. It reported that the wear resistance, too, is superior to Y alloy. As this alloy is hypereutectic, castings made by an ordinary process can not be used due to large primary crystals of silicon. By modification with phosphorus these crystals can be made finer. There are various different methods to add phosphorus. But the most simple and economical way is to use superphosphate of lime. This is a result of the research works at the Government Industrial Research Institute, Nagoya.

Fig. 12 Expansion Coefficient of Al-Si system.

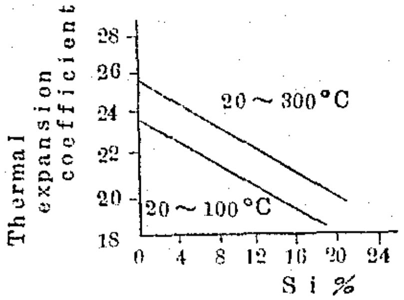
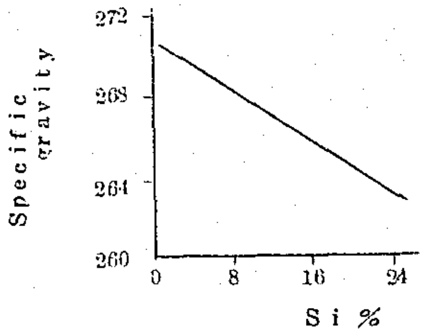


Fig. 13 Specific Gravity of Al-Si system.



11.4.3. Mg alloy - It was only after the end of the World War I (around 1919) that magnesium alloy was put to practical use. Since then, however, there has been no noticeable development of the use of this alloy due to the considerable difficulty in handling and the insufficient corrosion resistance. But at present this alloy can be relieved from the trouble of combustion by adding a small amount of beryllium, thereby reducing casting defects. The improved surface treating technique has improved its corrosion resisting quality. These progresses have stimulated the demand for this alloy. Automobile and light vehicle builders have introduced AZ 63 alloy (Mg - 6% Al - 3% Zn) into their production.

12. AUTOMATION OF FOUNDRY

Today there are many automation features in foundry machines and equipment. For instance, sand screening, sand mixing, moulding, knock-out after pouring are often found automated with timers and buttons to a certain specifications. Most of them, however, are not equipped with a feedback mechanism, and the proper control of the operation in accordance with the change of the situation is not maintained at present. A sand preparation equipment recently installed in the United States has a feedback de vice which controls the volume of water in accordance with the volume of the sand taken in.

The casting process is complicated that automating this process is not an easy task, but a completely automated foundry has already been in operation in Soviet Russia. This foundry produces pistons of aluminium alloy. The operation commenced in 1950, and improvements were made in the following years. The present facilities were completed in 1955. Once Aluminium ingots were put through pouring, heat-treating, machining a and packing until each 6 pieces of finished goods come out in a box. It is said that this equipment produces 3,400 pieces of pistons during 24 hours. This foundry is now regarded as the m most advanced foundry of full automation in the world.

13. CONCLUSION

Most of the metal products we are using owe to casting technique. Needless to say castings, sheets and pipes are all made either rolling or extrusion from ingots that are castings. Therefore, casting technique takes an important role as the basis of the metal processing, and whether this technique advances or not has a signifcant influence on the whole industry. It is particularly true with machine industry. Certainly careful attention and efforts should be directed to casting.

Now, as regards the composite nature of casting. A pattern is made in the first place, and then sand moulds followed by pouring. It is a usual process of casting, but at the same time it is a complicated process which you cannot find anywhere else in metal processing.

Therefore, for the advancement of casting technique, a fine cooperation of various different fields covering a very wide scope is required. It is possible only when the efforts in chemical, pottery, electric, mechanical and metallurgical engineerings are all combined together. The recent remarkable progress in casting is certainly a success of such a combined effort.

Without the favorable understanding of mechanical engineers, an ingenious use of any easting technique, no matter how highly advanced it may be, cannot be materialized successfully. Even the most highly advanced casting technique does not affect the fact about casting that the molten metal change into solid substance. This phenomenon, therefore, sometimes creates various defects. To get rid of these defects, the designing of cast parts should naturally concur with the theory of solidification, and in this sense the cast crank shaft is a good example of fully deliberated designing.

It is expected that casting technique will advance further and further by the help of knowledges in various fields. It is my firm belief that introducing these knowledges is certainly important and that here is something mechanical engineers cannot overlook.

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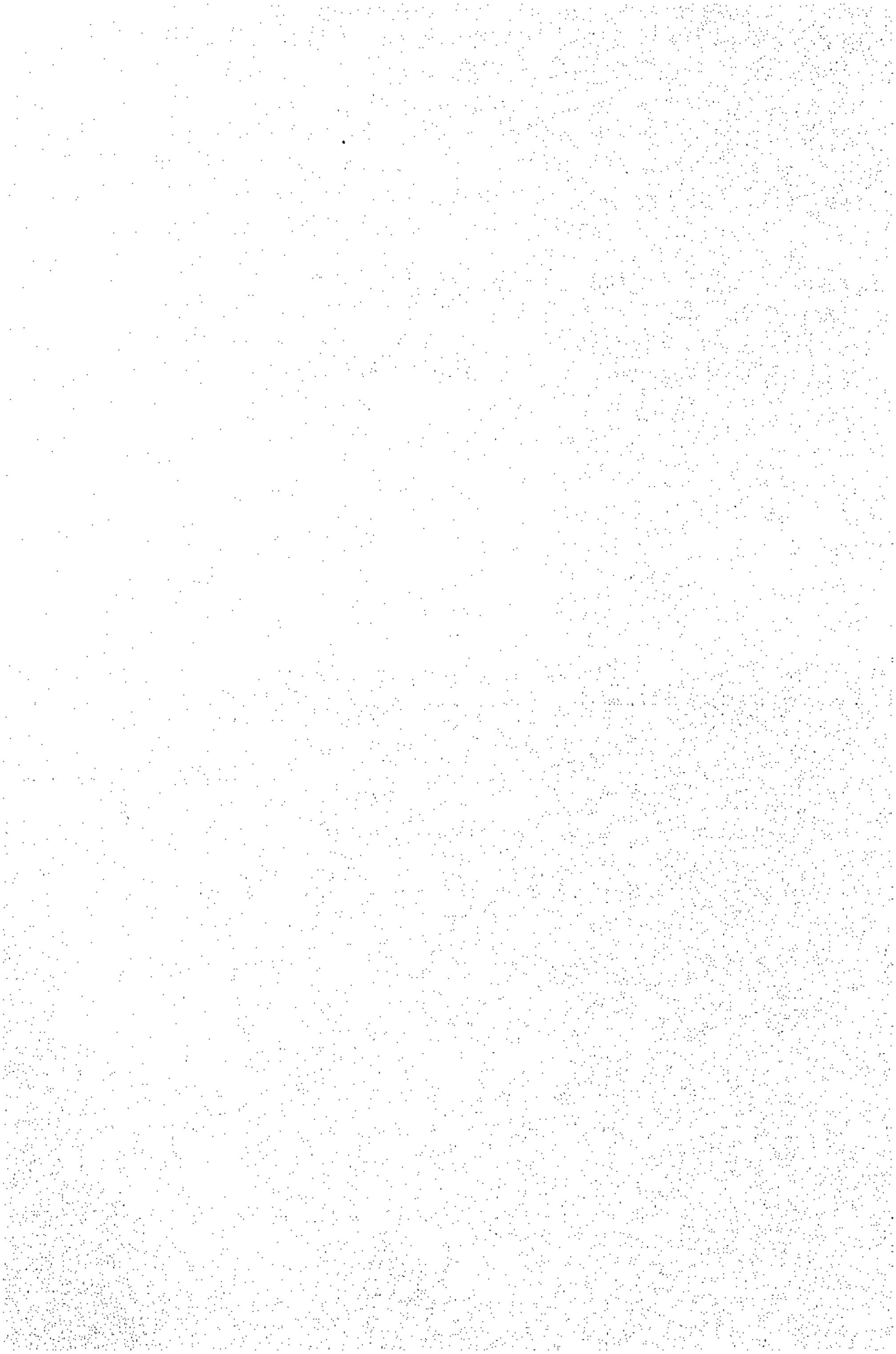
PATTERNS



PATTERNS

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PREFACE

Pattern is a principal tool for casting. Type of pattern must be selected to suit the given product with due regard to the quality, quantity and precision required by the casting, and also its cost. A precision pattern of proper material and adequate design contributes not only to increase casting efficiency but also remove several casting defects which cause high production cost.

1. STANDARD SHAPES OF CASTING

What comes before the design and making of a pattern is the determination of shape and dimensions of the product that fit casting. The following are the basic considerations thereof.

1.1. Basic Considerations

1.1.1. The wall thickness of casting should be as uniform as possible. Sudden change in shape must be avoided, and corners be made round.

1.1.2. Simple shape is desirable. The shape that makes casting easier is such as made up with circular arcs and straight lines, with draft or cylindrical surfaces but with few level surface.

1.1.3. The structure with closed parts should be avoided; if not avoidable, a cored hall as large as possible be made there. Open-type structure is preferable.

1.1.4. It is desirable that the surfaces for machine finish exist on one side. Delicate surface can be obtained by casting the finish surface in the drag.

1.1.5. Processing on both surfaces of casting should be avoided as much as possible. Especially, in case of pressuretight casting, at least one cast surface is desired to be left as it is.

1. 1. 6. Reinforcing ribs for gray cast iron should not be used against compressive stress, but not against tensile stress. They should be connected with the thick section in curved line of circular arcs.

1. 1. 7. In the design of casting, strength should be so planned as to obtain it rather from the structure than from wall thickness, which may be limited to where casting is feasible.

1. 1. 8. The locating point should be predetermined in the part which need machining process. In casting work, the locating point must be so selected that the point is least subject to warping.

1. 1. 9. In the design of a pattern, thorough investigation should be made about the plan for the making thereof and molding as well. Anything wrong in the casting work should be taken up as the subject of talk with the designer of the product. If necessary, the plan for such part may be altered.

1.2. Standard Cast Dimensions

The knowledge of standard cast dimensions is necessary for the designing of its pattern. The Table 1 to 10, show dimensional tolerance, thickness tolerance, draft allowance, minimum wall thickness, machine finish allowance for cast iron and steel by sand mold, and dimensional tolerance for shell mold casting.

1.3. Sectional Shapes

In designing and making pattern care should be taken for the shapes of sections of the cast not to give sudden change in wall thickness and not to cause local heavy section. Shown as follows are the standards thereof;

1. 3. 1. Thickness changing section (see Fig. 1, 2)
1. 3. 2. L and V-crossing section (see Fig. 3-8)
1. 3. 3. T-crossing section (see Fig. 9 - 11)
1. 3. 4. Crosswise section (see Fig. 12, 13)
1. 3. 5. Roundness at edges (see Fig. 14, Table 11)
1. 3. 6. Cored holes (see Fig. Table 12)

2. DIMENSIONS OF PATTERN

2.1. Shrinkage Allowance

Usually each easting material has a shrinkage rule of its own, which however varies according to the shape and casting plan, even if made up of same material. Distortion in cast can be prevented to some extent by machine finish allowance, which however can not be applicable to everywhere. To those sections shrinkage rule should be applied with the help of experiences or dependent on actual results of casting. Sometimes shrinkage rule is not used when the cast is smaller than 30 mm in size, or a pattern is made smaller than in the drawing for a part smaller than 10 mm, if the method of pattern draw permits it. Swelling in pattern is almost negligible when molding machine is used for drawing metal pattern with vibration (see Table 13 - 15)

2.2. *Machine Finish Allowance*

The standards of this allowance are shown in Table 7 - 9. Some examples of machine finish allowance by pouring state are given in Table 16. A minimum of machine finish allowance, however, is the constant demand of mass production, and practically this allowance is smaller than those shown in Table 16. This allowance for sections to be finished only by grinding machine, like in case of chilled casting, is from 0.5 to 1.5 mm - varies according to the shape and size of the cast.

2.3. Draft

Table 3 shows standards of draft allowance. Three methods are conceivable as those for making draft, as shown in Table 15. The method should be determined according to the shape of the cast and its use. Common in use is a plus draft of 10 mm to 25 mm per 1 m. Sharper draft is needed in inside than in outside of the pattern. In case the shape and distance from the parting line do not permit standard draft, an easier draft should be made. In most cases, however, draft is made as sharp as possible for easier drawing of pattern. Especially, to print and the section of loose piece 10/100 to 20/100 draft is applied.

2.4. Print

The print is made strong enough to endure the pressure and buoyancy of the metal flow, when pouring is conducted on the pattern with its core fixed. Consideration also should be taken to let it work to remove the gas produced in the core. Fig. 16 shows examples of prints.

2.5. Distortion Allowance

If a distortion arising in a certain section of the cast can not be covered by shrinkage rule and machine finish allowance, dimensions or shape of the pattern is required to be corrected so that the actual dimensions of the cast conform exactly to those in the drawing after the said distortion occurred. This is called distortion allowance.

2.6. Parting Line

The parting line should be so arranged as to ensure easy molding. The locating point should be predetermined at the time of designing pattern, and be arranged on one side of the parting surface, not on the cored surface.

3. DESIGN AND MAKING OF PATTERNS

In respect of molding method, investigation of wide scope should be conducted on such data as the size, quantity, precision of the cast to be produced, molding equipment etc. Accordingly, the molding method can not be confined within definite limits. Principal items of investigation follow:

3.1. Previous arrangements be made with the foundry shop. If the green sand is not used for molding, then the pattern must be prepared to suit some other method.

3.2. The maximum quantity of production be checked first. To meet a large quantity of production special regard should be paid to the structure and material of the pattern, which in this case may be of metal or metal-reinforced wood.

3.3. Structure and precision of the finished pattern should be investigated, checking up with the requirements in dimensional precision of the cast to be produced.

3.4. Investigation and making of flask plate, gauge etc., needed to be fixed to the pattern for casting then follow. The following are the details of patterns classified by quantity of production: Pattern for 5,000 to 50,000 Castings

The pattern and core box should be made of metal such as cast iron, brass, bronze or magnesium. Smooth surface be finished with exact dimensions. The cope and drag pattern may be fixed to the pattern plate or cast on alminum cope and dry plate. In case of small casting, a number of patterns may be arranged on the match plate together with gating system. The large pattern is fixed to the stable board of mahogany, and steel wearing plates are applied to the wearing edges and the flask rest of board. For ribs and loose pieces aluminium is used as their material (Fig. 17, 18, Table 18). Wearing plates should be applied to the wearing surfaces of the core box; blow holes and vent holes be arranged too. On the other hand, required number of dryers (Fig. 19, 20), core setting and pasting gages (Fig. 21) must be prepared.

This type of pattern is used for parts of automobile, typewriter, parts of office instruments, large marine and stationary engines, parts of truck, farm implements etc.

Pattern for 500 to 5,000 Casting

In case of large size, pattern should be made of hard wood and must be of high production. For small size, aluminium match plate or hard wood pattern is used, fixed to aluminium plate.

As to the reinforcement at wearing points and arrangements attached to the pattern, same things are applicable as in the preceding paragraph. Hard wood is sometimes used for the core box but in this case consideration should be taken thoroughly against wearing.

Pattern for 100 - 500 Casting

For the production to this extent, the pattern is made of hard wood or pine. But the pattern and core box should be of solid structure. The cope and drug patterns are fixed to hard wood or composite board. Aluminium is preferable for ribs and loose pieces. Pine is used for exceptionaly large size pattern. It costs cheaper than hard wood or aluminium.

Pine is rather soft and the pattern and core box are required to be trimmed with hard wood. Coating is applied four times carefully to the pattern. Dryers and core gage are prepared when necessary. Attention be paid to the possibility that precision and molding efficiency make a sudden drop when this type of pattern is used more than was planned.

Pattern for 10 - 100 Casting

Loose pattern made of pine of good quality is adopted here. Split type is preferable, if possible. For easier drawing of pattern, napping plate is fixed thereto. The fragile pattern should be fixed to the wooden or metal plate. Three times may be enough for coating.

Pattern for 1-- 10 Casting

Pine or cedar is usually used for large type. It is of loose type, and two times be enough for coating. The use of this type of pattern is limited to a very few casting just for temporary or experimental purposes, and the cost of pattern be reduced to a minimum. Hard wood is preferable for small but complicated structure. This ensures good quality and precision at no high cost of material. This type of patterns is limited only to the use for very few quantity of jigs or replacement parts. They are cast away after use, because of storage troubles.

Other than stated above, special metal pattern, like shell mold, should be prepared for the requirement of the cast in large quantity with exceptionaly high precision. The material that is apt to be distorted or excessively swollen is not fitted for the shell mold which is operated between 200 C and 300 C. Desirable material is of such nature as good heat conductivity and large heat capacity. Ejector pin is arranged for the pattern plate and core box. Source of heating is gas or electricity. Tools usually used in pattern making are lathe, drilling machine, milling machine, shaper and grinding machine. For large quantity of metal patterns diesinker etc. are used. Finishings of filing, scraping and polishing are all hand works. Recently, patterns of good precision are made of cast, which needs no machine finish, by means of precision casting like shaw process.

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Table 1. Dimensional Tolerance (mm)

(JIS)

Length	Cast iron		Cast steel	
	Higher precision	Ordinary precision	Higher precision	Ordinary precision
100	± 1.0	± 1.5	± 1.5	± 2.0
100 - 200	± 1.5	± 2.0	± 2.0	± 3.0
200 - 400	± 2.0	± 3.0	± 2.5	± 4.0
400 - 800	± 3.0	± 4.0	± 4.0	± 5.0
800 - 1600	± 4.0	± 5.0	± 6.0	± 7.0
1600 - 3150	——	± 7.0	——	± 10.0

Table 2. Thickness Precision (mm)

(JIS)

Length	Higher precision	Ordinary precision
5	± 0.5	± 1.0
5 - 10	± 1.0	± 1.5
10 - 20	± 1.5	± 2.0
20 - 30	± 2.0	± 3.0
30 - 40	± 3.0	± 4.0

Table 3. Draft Allowance

(JIS)

Outward or Inward Draft	Higher precision	Ordinary precision
Outward	= 20/1000	= 30/1000
Inward	= 30/1000	= 50/1000

Table 4. Minimum Wall Thickness For Gray Cast Iron (mm)

Materials	Minimum thickness
FC 10	3
FC 15	4
FC 20	5
FC 25	7
FC 30	10
FC 35	12

Table 5. Minimum Thickness For Cast Steel (mm)

(JSME)

Length	Minimum Wall thickness
200	4
200 - 500	6
500 - 800	8
800 - 1500	12
1500 - 2200	16
2200 - 3000	20

Table 6. ---"GENERAL RECOMMENDATIONS ---MINIMUM SECTION FOR CASTINGS (A. F. S.)

Metal	Minimum Section Size, in.				
	Sand Castings	Die Castings		Permanent Mold	Plaster Mold
		Over Large Areas	Over Small Areas		
Aluminum Alloys	1/8-3/16	0.075	0.045	1/8 over small areas	0.040 over small areas 0.093 over small areas
Copper Alloys	3/32	0.100	0.060	1/8 over small areas	0.060 over small areas
Gray Irons *	1/8-1/4	----	----	3/16 over small areas	----
Lead Alloys		0.075	0.040	----	----
Magnesium Alloys	5/32	0.080	0.050	5/32-3/16	----
Malleable Iron	1/8	----	----	----	----
Steel	3/16	----	----	----	----
Tin Alloys		0.060	0.030	----	----
White Iron	1/8	----	----	----	----
Zinc Alloys		0.045	0.015	----	----

* While 1/8-in. sections can be readily poured, a heavier section is less susceptible to hard spots.

Table 7. Bore Finish Allowance, One Side (mm)

(JSME)

Diam. of Hole	Finish Allowance	
	Cast iron	Cast steel
< 200	3	4
200 - 300	4	5
300 - 400	5	6
400 - 700	6	7
700 - 1100	7	9
1100 - 1600	9	11
1600 - 2200	10	13
2200 - 3000	12	15

Table 8. Surface Finish Allowance (mm)

(JSME)

Distance from Locating point	Finish Allowance	
	Cast iron	Cast steel
< 200	3	4
200 - 400	4	5
400 - 700	5	6
700 - 1100	6	7
1100 - 1600	7	9
1600 - 2200	8	11
2200 - 3000	9	13

Table 9. Machine Finish Allowances- Various Metals (A. F. S.)

Pattern Size, in.	Allowances, in.		
	Bore Surface		Cope Side
Cast Iron			
Up to 6	1/8	3/32	3/16
6 to 12	1/8	1/8	1/4
12 to 20	3/16	5/32	1/4
20 to 36	1/4	3/16	1/4
36 to 60	5/16	3/16	5/16
Cast Steel			
Up to 6	1/8	1/8	1/4
6 to 12	1/4	3/16	1/4
12 to 20	1/4	1/4	5/16
20 to 36	9/32	1/4	3/8
36 to 60	5/16	1/4	1/2
Non-Ferrous			
Up to 3	1/16	1/16	1/16
3 to 8	3/32	1/16	3/32
6 to 12	3/32	1/16	1/8
12 to 20	1/8	3/32	1/8
20 to 36	1/8	1/8	5/32
36 to 60	5/32	1/8	3/16
Admiralty Metal			
Up to 24	1/4	1/4	3/8

Table 10. Dimensional Tolerance For Shell Mold Castings (mm)

(JSMA)

Length	Cast iron, Cast steel, Copper alloy		Light alloy	
	Parallel to parting surface	Vertical to parting surface	Parallel to parting surface	Vertical to parting surface
<50	± 0.20	± 0.30	± 0.10	± 0.30
50 - 100	± 0.25	± 0.40	± 0.15	± 0.40
100 - 200	± 0.40	± 0.50	± 0.20	± 0.50
200 - 300	± 0.50	———	± 0.30	———
300 - 400	———	———	± 0.40	———
400 - 500	———	———	± 0.50	———

Table 11. Minimm of Roundness at Edges (mm)

Materials	Wall thickness of Cast goods			
	3 - 5	6 - 10	13 - 20	25 - 40
Gray iron	1	1	2	3
Malleable iron	1	1	2	3
Steel		3	4	5
Al alloy	1	1	2	3
Cu alloy	1	1	2	3

Table 12. --- MINIMUM SIZE OF CORED HOLES (A. F. S.)

Sand Castings	D = 1/2 t; D = dia. core in in., usually not less than 1/4-in., and t = section thickness in in.
Permanent Molds	D = 1/2 t, usually greater than 0.25-in. D.
Die Castings	
Copper Base	3/16-in. dia.
Aluminum Base	3/32-in. dia.
Zinc Base	1/32-in. dia.
Magnesium Base	3/32-in. dia.
Plaster Molds	Cores under 1/2-in. dia. normally drilled.

Table 13. Relations among Shape, Material and Shrinkage Rule

Shrinkage rule Material & Shape	10-12/1000	13-15/1000	20-23/1000	24-26/1000
Material	Cast iron	Cast iron	Cast Steel	Cast Steel
Shape	Complicated or thin	Simple or thick	Complicated or thin	Simple or thick

Table 14. Rates of Contraction by Metal

Material	Cast iron	Cast steel	Copper alloy
Rate of Contraction	7-8/1000	16-17/1000	11-12/1000

Table 15. ---PATTERN SHRINKAGE ALLOWANCES (A. F. S.)
(Before specifying consult the patternmaker and foundryman)

Casting Alloys	Pattern Dimension, in.	Type of Const- ruction	Section Thick- ness, in.	Contraction, in. /ft.
Gray Cast Iron[1]	Up to 24	Open		1/8
	from 25 to 48	Open		1/10
	over 48	Open		1/12
	up to 24	Cored		1/8
	from 25 to 36	Cored		1/10
	over 36	Cored		1/12
Cast Steel[2]	up to 24	Open		1/4
	from 25 to 72	Open		3/16
	over 72	Open		5/32
	up to 18	Cored		1/4
	from 19 to 48	Cored		3/16
	from 49 to 66	Cored		5/32
	over 66	Cored		1/8
Malleable Cast Iron[5]			1/16[3]	11/64[4]
			1/8	5/32
			3/16	19/128
			1/4	9/64
			3/8	1/8
			1/2	7/64
			5/8	3/32
			3/4	5/64
			7/8	3/64
			1	1/32
Aluminum	up to 48	Open		5/32
	49 to 72	Open		9/64
	over 72	Open		1/8
	up to 24	Cored		5/32
	over 48	Cored		9/64 to 1/8
	from 25 to 48	Cored		1/8 to 1/16
Magnesium	up to 48	Open		11/16
	over 48	Open		5/32
	up to 24	Cored		5/32
	over 24	Cored		5/32 to 1/8
Brass				3/16
Bronze				1/8 to 1/4

Table 16. Finish Allowance classified by size and surface

Size of Casting	300	300 600	600 1000	1000 1500	1500 2000	2000 3000
Upper Surface	4~5	5~7	7~10	10~12	12~15	15~20
Side Surface	3~5	5~6	6~7	7~9	9~11	11~15
Bottom	2.5 ~4	4~5	5~6	6~7	7~9	9~12

Table 17. Composition of Metal Pattern Material.

% Metals	Cu	Sn	Zn	Pb	Al	Si	Fe	C
Cost iron						1.90 ~2.10		3.10 ~3.30
Copper alloy	83	4	10	3				
"	87	6	2	5				
Aluminum alloy	8~12				92 ~88			
"	6~8				91 ~89	3		
"	2~3		12 ~15		81	1.5	1.5	

Table 18.

l_1	b_1	$l_1 = l_1 + 110^{2)}$	h_1
315	315	425	
400	315	510	
400	355	510	
400	400	510	
500	315	610	
500	355	610	80
500	400	610	100
500	450	610	
500	500	610	125
630	400	740	150 (180)
630	450	740	200
630	500	740	250
630	630	740	(275)
800	400	910	300
800	500	910	
800	630	910	
800	800	910	
1000	630	1110	
1000	800	1110	

$r = \frac{t}{2}$ or $\frac{T}{3}$

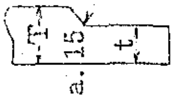
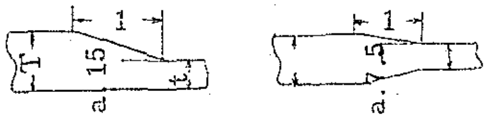


Fig. 1
Thickness Changing Section -

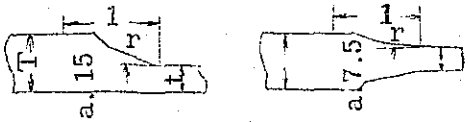
t T 3/2t

$1 = 4(T - t)$ $1 = 4(T - t)$



(A) Where length is available enough for draft

$1 = 4(T-t),\ r = \frac{t}{2}$ or $\frac{T}{3}$ $1 = 4(T-t),\ r = \frac{t}{2}$ or $\frac{T}{3}$



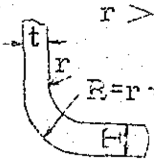
(B) Where length is not enough for draft

Fig. 2 Thickness Changing Section -

$r = \frac{t + T}{2}$

$R = t + T = 2r$ or

$r > \frac{t+T}{2}$



$R = r + \frac{t + T}{2}$

Fig. 3
L-crossing Section -

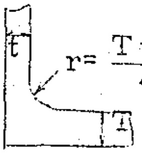
$r = \frac{t+T}{2}$

$R = t + T = 2r$ or

$r > \frac{t+T}{2}$

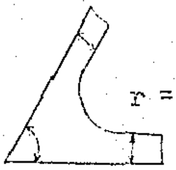
$R = r + \frac{t+T}{2}$

Fig. 4 V-crossing Section -



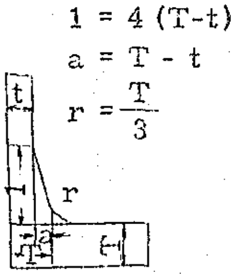
$r = \frac{T+t}{4} + 5$

Fig. 5 L-crossing Section,
Outside pointed, -



$r = \frac{T+t}{4} + 5$

Fig. 6 V-crossing Section,
Outside pointed,
Note: Not applicable
where $\alpha < 60$

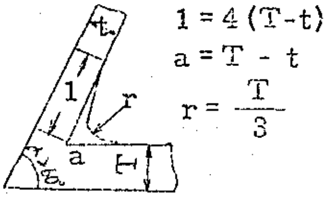


$1 = 4\,(T-t)$

$a = T - t$

$r = \frac{T}{3}$

Fig. 7
L -crossing Section,
Outside pointed, -

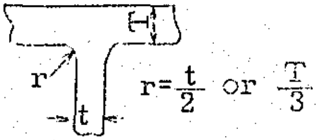


$1 = 4\,(T-t)$

$a = T - t$

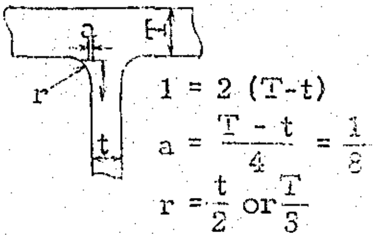
$r = \frac{T}{3}$

Fig. 8 V-crossing Section,
Outside pointed, -
Note: Not applicable
where ∡ < 30



$r = \frac{t}{2}$ or $\frac{T}{3}$

Fig. 9 T-crossing Section-

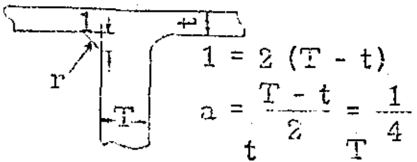


$1 = 2\,(T-t)$

$a = \frac{T-t}{4} = \frac{1}{8}$

$r = \frac{t}{2}$ or $\frac{T}{3}$

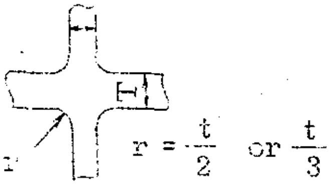
Fig. 10 T-Crossing Section-



$1 = 2\,(T - t)$

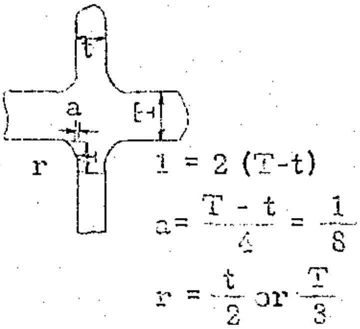
$a = \frac{T-t}{2} = \frac{1}{4}$

Fig. 11 $r = \frac{t}{2}$ or $\frac{T}{3}$
T-Crossing(thick and thin)
Section -



$r = \frac{t}{2}$ or $\frac{t}{3}$

Fig. 12 Crosswise Section -

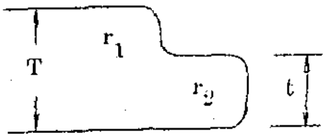


$1 = 2\,(T-t)$

$a = \frac{T-t}{4} = \frac{1}{8}$

$r = \frac{t}{2}$ or $\frac{T}{3}$

Fig. 13 Crosswise Section-



T , t :

r_1 , r_2 :

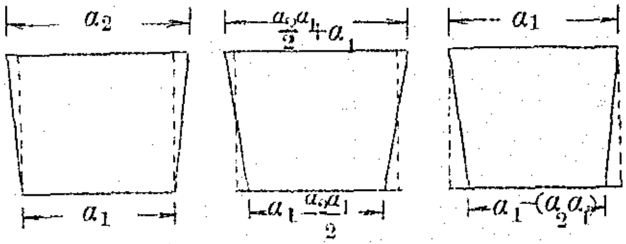
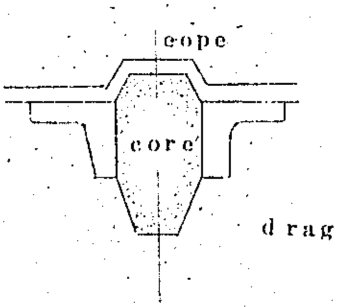


Fig. 15 Draft (+) Draft (±) Draft (−)

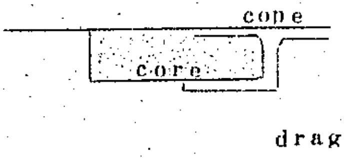
a_1= Dimention in drawing

a_2= Dimention in drawing + 2Xdraft

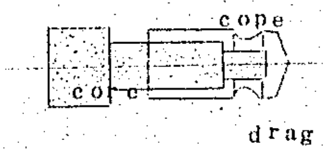
a_2-a_1= 2Xdraft


cope
core
drag

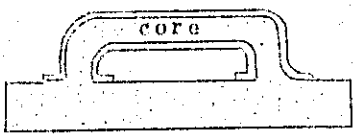
(a)


cope
core
drag

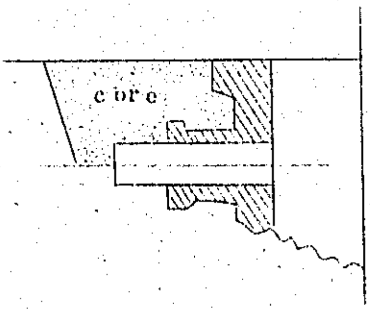
(b)


cope
core
drag

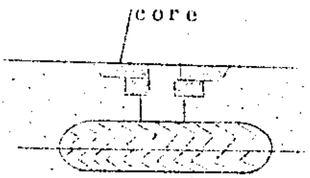
(c)


core

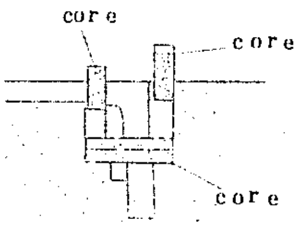
(d)


core

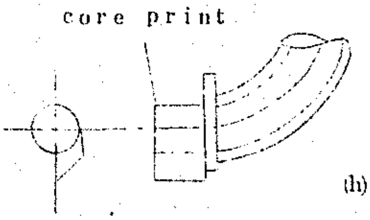
(e)


core

(f)

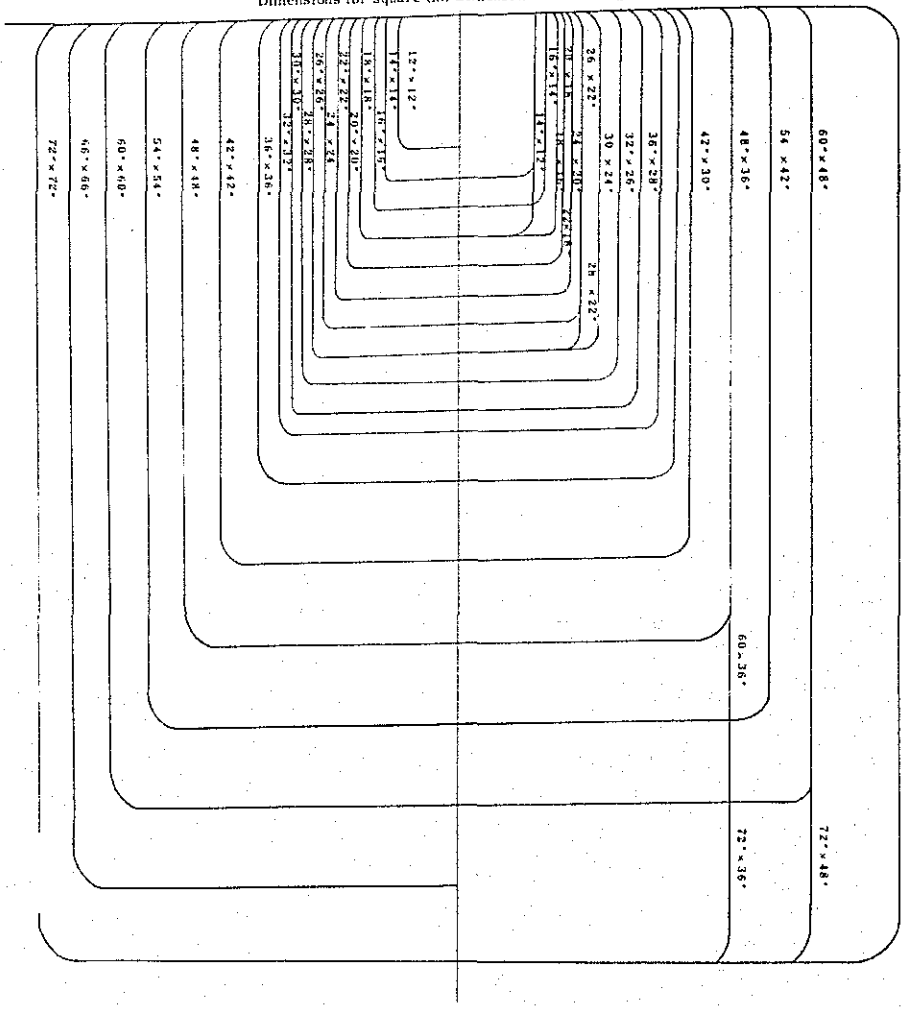

core
core
core

(g)


core print

(h)

Dimensions for square (in) Dimensions for rectangle (in)



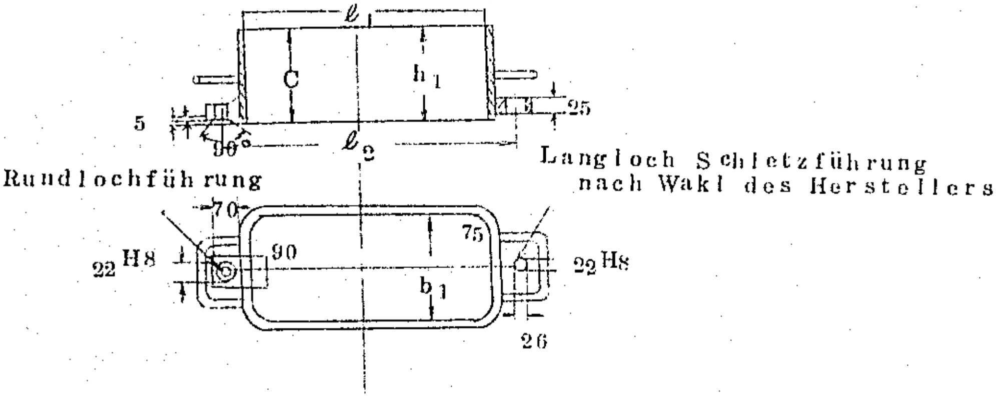


Fig 18

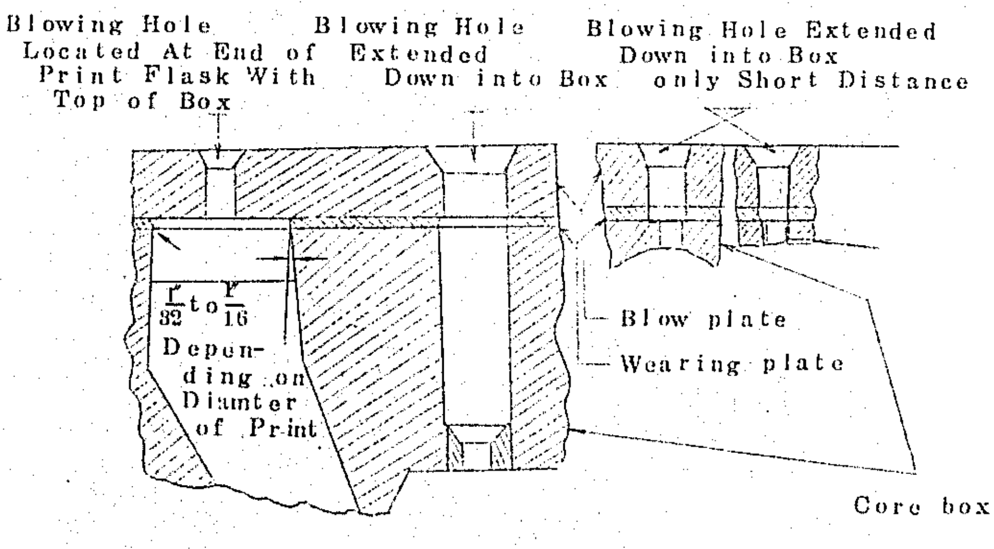
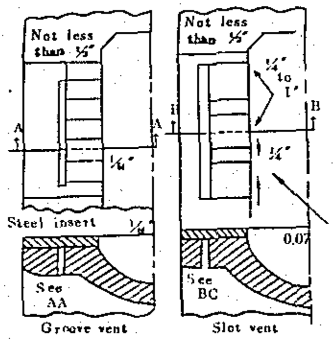


Fig 19 Typcal Blowing Hole Arrangements



Groove vent

Slot vent

Steel inserts as shown are recommended for use with groove and slot vents to increase life of box

Venting screen backed by supporting plate drilled with several 1/5" to 1/4" holes and covered in front BxA 1/32" to 1/16" thick steel plate perforated with 3/16" dia hols

1/4 Land required between slots for support during clamping

These holes should be sufficiently large in size and number to quickly bleed air from vents

Various types of core box vent in common use

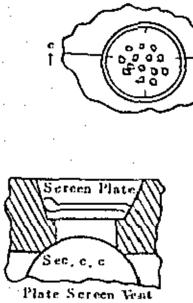
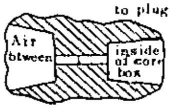
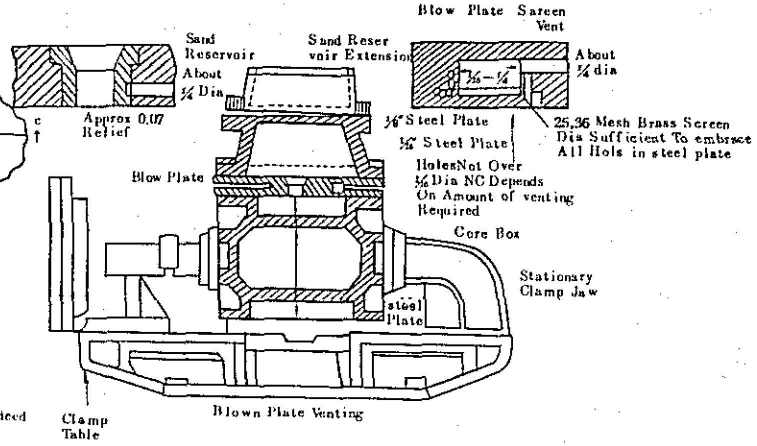


Plate Screen Vent

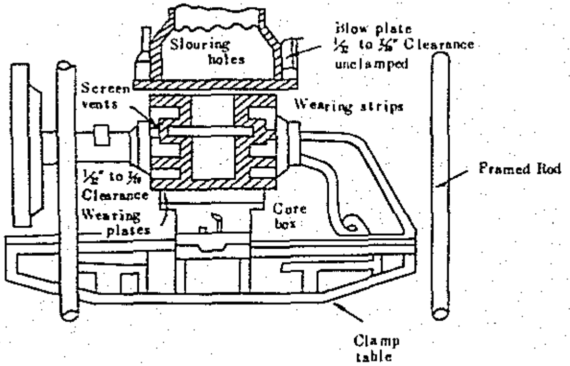
Brass plug drive fit in driced hole

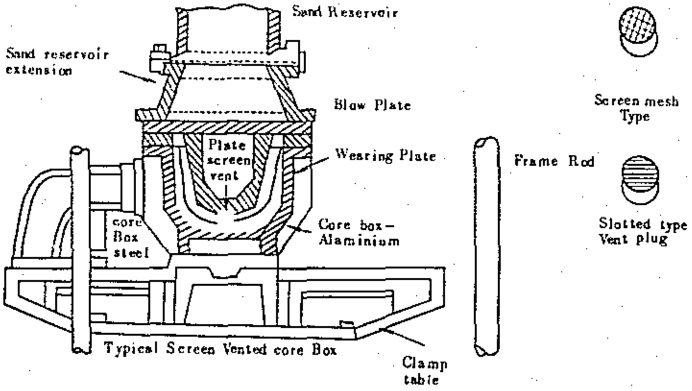


Plug Screen Vent



Blown Plate Venting





Typical Screen Vented core Box

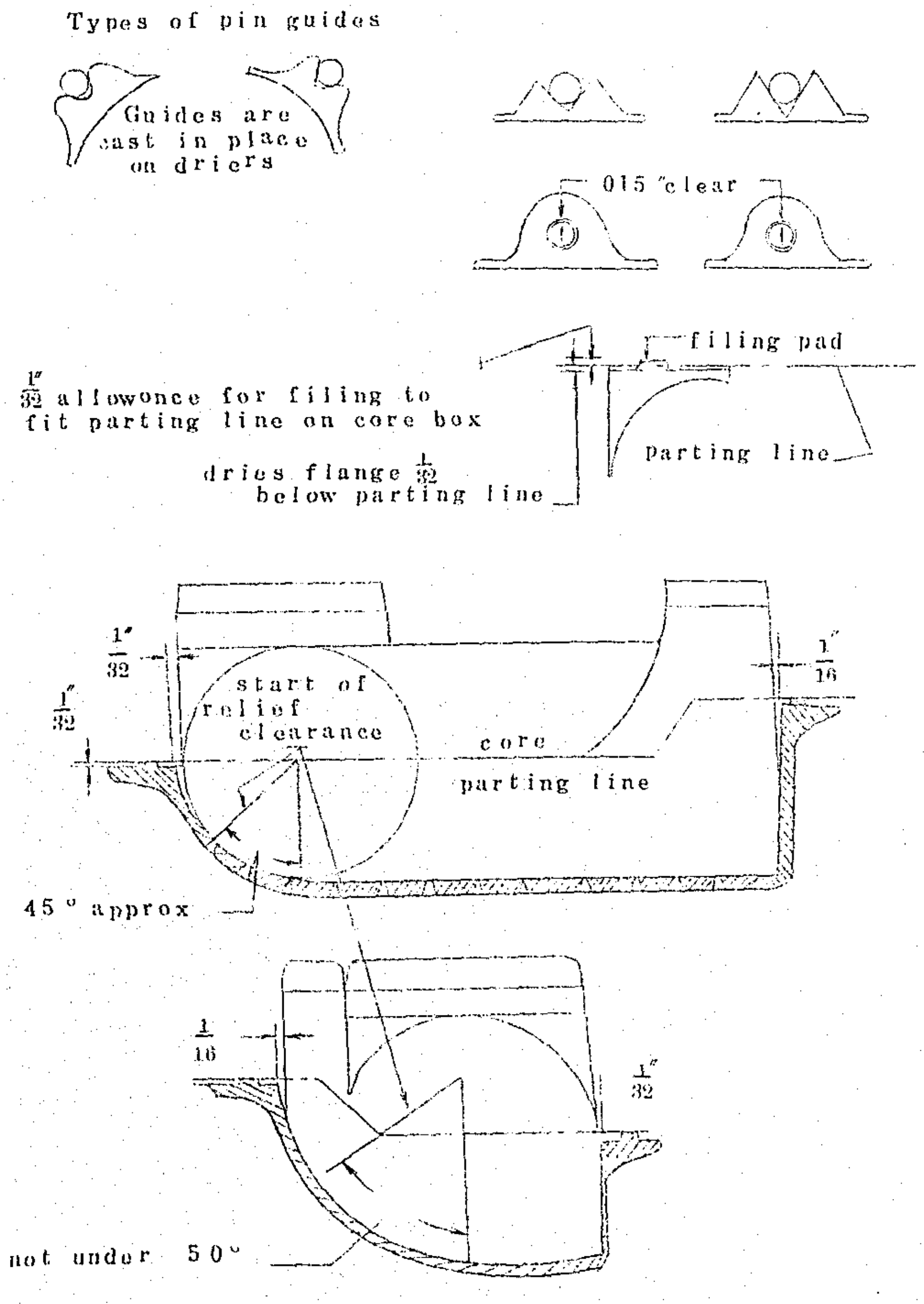
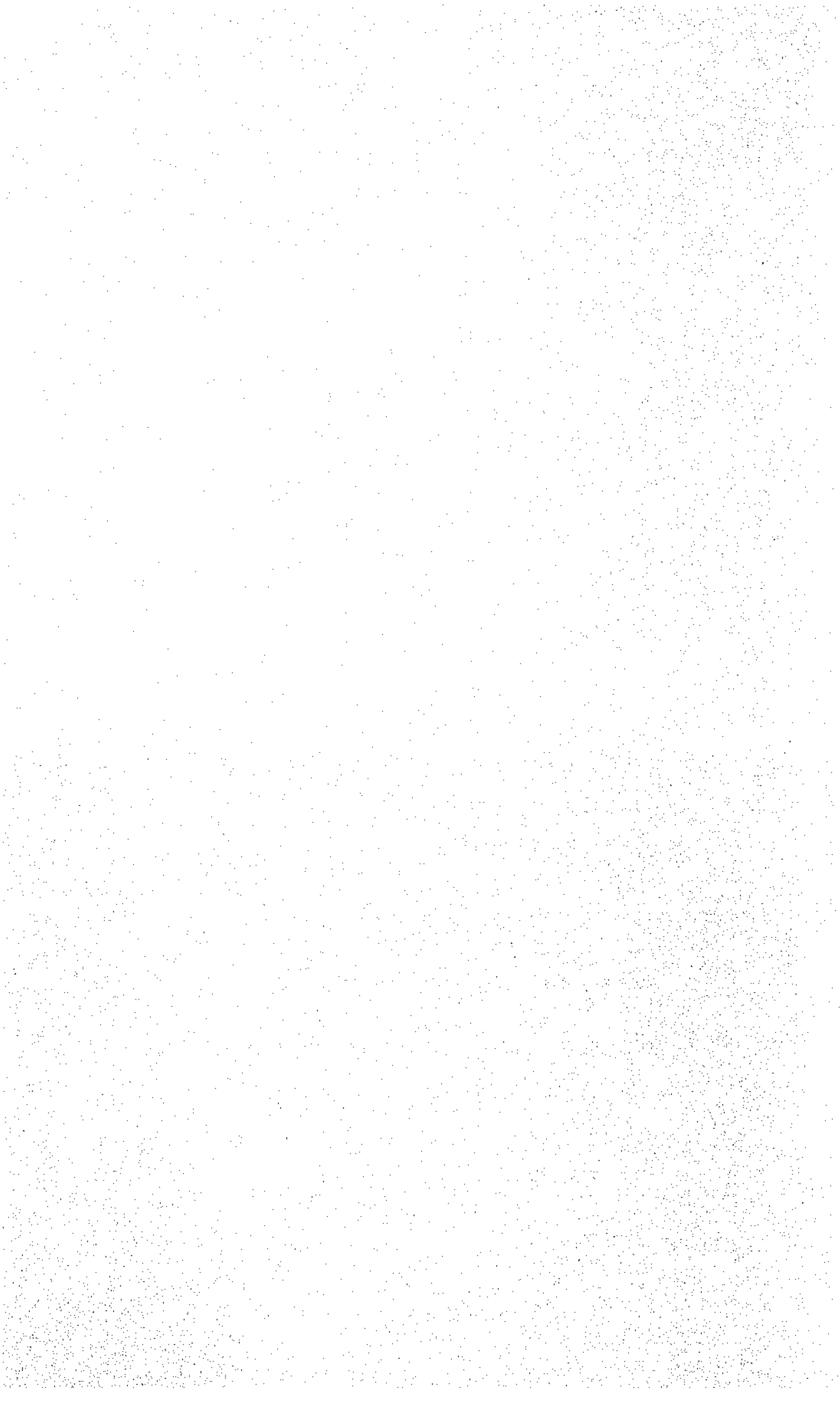


Fig 21 Typical Core Dryer Design

CASTING PLANS



CASTING PLANS

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Iron Foundry Dept.
Howa Machinary, Ltd.

1. BASES FOR CASTING PLANS

1. 1. Introduction

1. 1. 1. Purposes of Casting Plans

Good castings are possible only through proper casting method. Proper casting method can be practiced through comprehension of principles of casting process, scientific orientation of large number of experiences, and utilization of those experiences on the basis of good technique and efficient system of equipment and facilities.

In the process of making a cast, many operational factors are involved, which affect the quality of final product in many ways. It is, therefore, necessary that a casting plan be prepared with minute attention to the detail of each step of the process. While it is important that every effort must be exerted to cast good-quality casting, it is needless to say that an enterprise, to make a reasonable profit, must produce castings quickly and at low cost. There are many ways and means of producing castings. Which one to choose depends upon different conditions of a particular plant.

Casting plans form the basis of quality and process controls. Casting plans mean how to cast quality casting quaickly and at low cost.

1. 1. 2. Items to be Considered in Making Casting Plans and Their Order. Casting plans should be made in the order of the items shown in Table 1.

Table 1. - Item to be Considered in Making Casting Plans

A. Pattern --- 1. Type of pattern.
2. Core print (Out er wooden case)
3. Machining allowance
4. Correction allowance

5. Shrinkage allowance
6. Sprue and riser.
7. Gauge.
8. Markings on the master pattern and core box.
9. Pattern draft.
10. Rapping.
11. Rapping bar.
12. Center line.
13. Number of master patterns and core boxes.
14. Mold board and mold flask.

B. Mold --- 15. Type of the mold.
16. Type of the core.
17. Order of molding.
18. Warp.
19. Chiller.
20. Core grid and rope.
21. Sand thickness of the pattern and core.
22. Usage of nails.
23. Vent.
24. Filler (rounding)
25. Coating.
26. Tie piece.
27. Drying.
28. Setting of mold flask.
29. Construction of core.

C. Pouring-- 30. Composition of the material metal.
31. Weight
32. Weight of casting.
33. Pouring method.
34. Pouring cup.
35. Pouring time.
36. Pouring temperature.

D. Finishing- 37. Shake-out.
38. Cleaning.
39. Finishing of cast.
40. Annealing.
41. Straightening
42. Transportation of the final product.

1.2. Gating System

to produce a perfect cast, dimensions, shapes, number, and positions of the sprue, runner, gate, flow-off, riser and pouring cup must be proper for the dimension and shape of the cast. Following points must be observed in determining the gating system.

(1) Pour with caution but as quickly as possible.
(2) When there is no need to fear the mixing of the slag in the metal or breakage of the mold, pour the upper part of the cast first whenever possible.
(3) Be certain that all mold cavities are uniformly filled with molten metal.
(4) Avoid pouring to the direction which might give an unusual impact against the mold wall.
(5) Design the gate and runner so as to separate the slag from the metal.

The above points and the dimensions and shapes of the sprue, gate, and riser are usually determined based on many experiences and intuition. However, in order to determine these dimensions and shapes scientifically, it is necessary to compute them on an empirical formula. From this point of view, I wish to describe some of the basic matters of the gating system.

1.2.1. Pouring Time

Pouring must be done quickly but with caution. Cautious pouring, however, tends to prolong the pouring time, thereby causing the following defects.

(1) For thin castings, uneven distribution of the metal occurs, thereby causing the separation of the section.
(2) Scab and wash tend to appear in front of the gate due to the gate always gets heat.
(3) Radiant heat of the molten metal tends to cause pull down on the surface of the upper portion of the cast.

On the other hand, quick pouring eliminates the above defects but tends to cause the following:

(1) Metal gives an impact against the mold, often damaging it.
(2) Air in the mold cavities is not allowed sufficient time to escape and raises the inner pressure, thereby lifting

the mold or causing blow-holes in the cast.

(3) The gate is enlarged resulting in low yield.

Thus, pouring time is often dependent upon and must be determined by the nature of the mold. Of course, pouring and temperature. An example of the formula for computing pouring time is given below:

$T = S\sqrt{W}$ (H.W. Dietert)

T = Pouring time (sec.)

W = Weight of casting (kg)

S = Coefficient due to casting thickness

Casting thickness	S
2.8 - 3.6	1.63
4.0 - 8.0	1.85
8.4 - 15.5	2.2

$T = (A + t^{0.8}\ W^{0.3}) \times 10$ (Dr. Kusunose)

A=varies with size of core and permeability of sand

t = casting thickness

w=casting weight

1.2.2. Area of the Gate

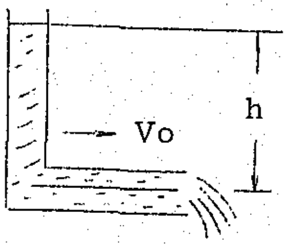
If the pouring time is to be determined by any formula, then it is necessary to determine the proper area of the gate. When the molten metal enters into the mold through the sprue, metal velocity at the gate is adversely affected by various resistance forces and the actual velocity (v) becomes smaller than the theoretical velocity (vo).

$v_o = \sqrt{2gh}$ ----- (1)

v_o = metal velocity

h = level of the pouring basin above the gate

g = acceleration due to gravity



$v = c\ \sqrt{2gh}$ ------- (1)

c = coefficient of metal flow.

Quantity of the metal poured within the unit pouring time (V) is as follows:

$V = VA$ ---------- (2)

A = area of the gate (cm^2)

If the pouring time is determined, the following formula may be established:

$$w = v.A.T. \text{ --------- } (3)$$

$$\frac{w}{T\,\gamma.} = v.A \text{ --------- } (3)$$

γ = density of the metal (g/cm^3)T=pouring time (sec)
w = casting weight (g.)

Theoretically speaking, A may be determined using the above formula. In practice, however, the problem is how to choose v and A. Following is an explanation of empirical formula for the purpose of determining A based on actual numerical values of coefficient of quantity of the metal poured:

$v = c.\alpha\,\beta\sqrt{2gh}$
v = velocity of liquid at gate
c = coefficient due to metal flow
a = coefficient due to resistance of sprue wall
B = confficient due to resistance at gate

$$C = 1.34 - \frac{l^{0.27} + d^{0.23}}{10} \text{ ------- } (5)$$

with d $\leqq$ 60 mm, l $\leqq$ 1000 mm

Also, values of $\alpha\,\beta$ are as shown in Table 2. Thus, when $\alpha\beta$ is determined, v may be determined using formulas (5) and (4), then A may be determined using formula (3)'.

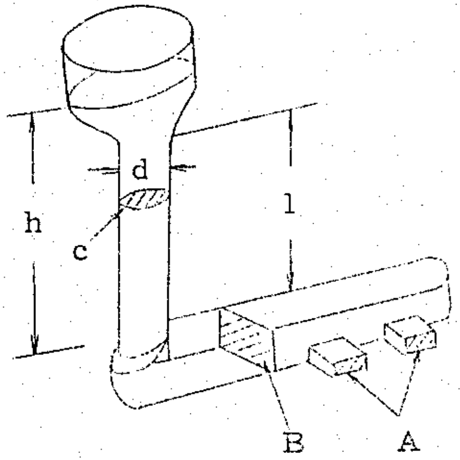


Table 2 - Values of $\alpha\ \beta$ (with the length of runner at 500 mm or less)

Gating Ratio	Value $\alpha\ \beta$
$\alpha\ \beta$ (directgate)	1
C. B. A. = 1 : 2 : 1.2	0.95
C:B:A: = 1 : 2 : 1	0.85
C:B:A: = 1 : 2 : 0.8	0.75

1. 2. 3. Gating Ratio

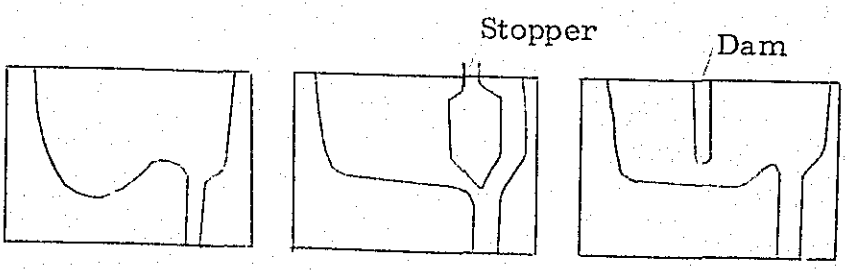
As previously mentioned, dimensions of gating system depend to a large extent upon the pouring time. Several examples of area ratio of the sprue, runner and gate are shown in Table 3.

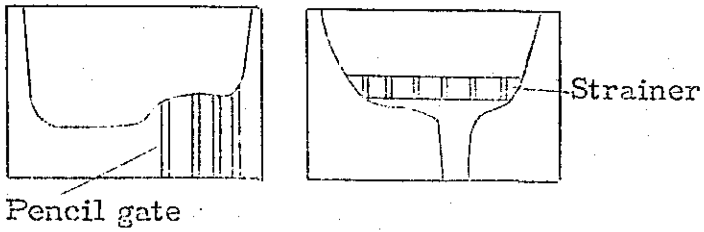
Table 3 - Gating Ratio

Tasting Ratio	Remarks	Studied By
1:0.75:0.5		Doliwa
1:0.81:0.625	For more than 10-ton cast	Hess
1:0.86:0.715	For less than 10-ton cast	Hess
1:0.96:0.9	For thin plate-like cast	Hess
1:0.75:0.5	For casting with two sprues	Miakowski
1:0.75:0.25		
1:1.2:0.9		Osann

1. 2. 4. Shape of the Gating System

(1) Sprue cup - - - The function of sprue cup is to hold the molten metal before it flows into the mold so as to let the impurities, such as slag, float to the surface. The dimension of the sprue cup is said to be preferable when its cross section is 40 times of that of the gate. Several shapes of sprue cups are shown in Fig. 1.





Sprue should not be in center of the cup because molten metal may include slag & air.

Pencil

Fig. 1 - Shapes of the Sprue Cups

(2) Sprue - - - Cross section of the sprue is usually round for the reasons that it is easier to shape and it has effect of delaying cooling of the metal because of relative smallness of the area. When the molten metal drops through the perpendicular sprue, the lower it reaches, the smaller the area of its cross section becomes as shown in the equasion. (6). As this is liable to separate the molten metal away from the wall of the sprue and cause the surrounding air to get mixed with the metal, the cross section of the sprue should be tapered as shown in Fig. 2 (b) so that the molten metal always fills sprue completely.

$$\frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}} \quad \cdots\cdots\cdots \quad (6)$$

where

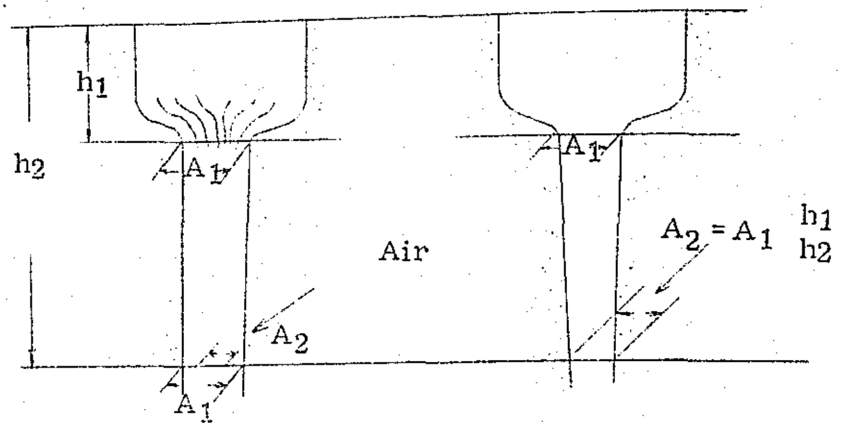
A_1 = Area of sprue entrance

A_2 = Area of any other location in the sprue

h_2 = Distance from top of the pouring basin to the location of A_2

h_1 = Level of the pouring basin

above the sprue entrance.



a) Straight Sprue b) Tapered Sprue

Fig. 2

(3) Runner and Gate - - The function of the runner is to distribute the molten metal entering through the sprue to proper locations inside the mold. The temperature of the metal tends to drop during its course through the runner. Therefore, it is desirable to make the dimension of the runner fairly large. Besides, as it is also the last device to remove the slag and sand, which might be rolled into the metal, the shape of the runner must be devised with special consideration. Some of the shapes of the runner are shown in Fig. 3.

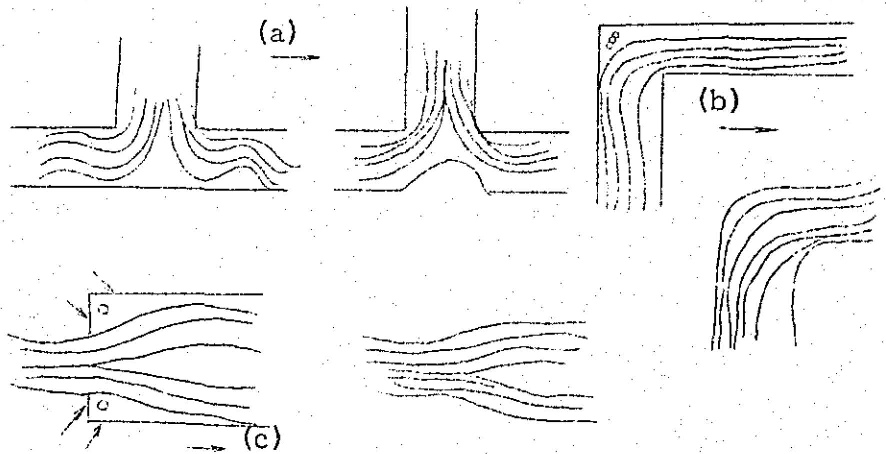


Fig. 3.

Fig. 4 shows some of the methods for slagging off in the runner.

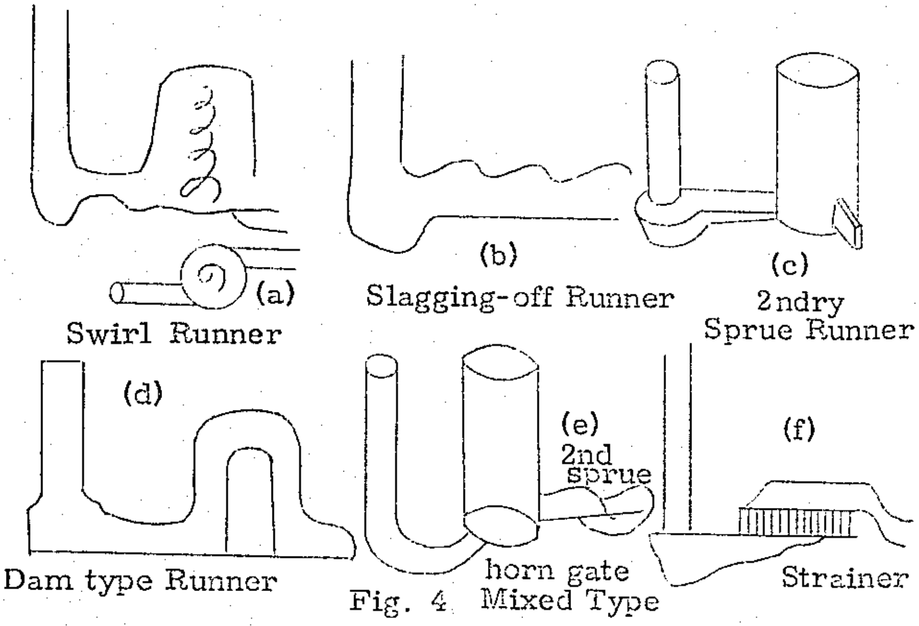
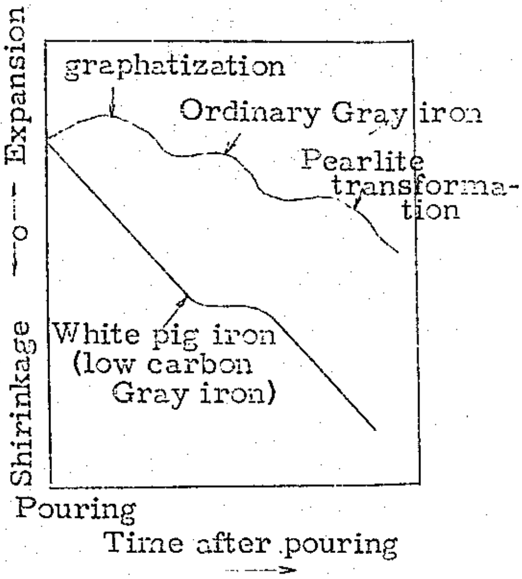


Fig. 4

1.3. Riscring

The function of the riser is to compensate for shrinkage of metal during solidification. Therefore, it is necessary that the metal in the riser solidify more slowly than the cast itself. Conditions of solidification vary in accordance with the different chemical composition of the metal. Therefore, the dimension of the riser must be varied in accordance with the chemical composition of the metal. Fig. 5 shows the processes of swelling and contraction of gray iron and white pig iron during cooling. The smaller the amount of standard carbon, the larger the contraction ratio, thereby making



larger riser necessary. However, for gray iron, when the cooling speed is delayed by means of risering, growth of graphite takes place, thru affecting adversely the quality of which one should be careful. Also, to make the riser effective, one should consider carefully the positions of the riser and the gate so that the metal is always given directional solidification. The dimension of the riser may be roughly computed using the following equasions:

For ordinary gray iron $$X = 1 + \frac{0.033}{Y - 0.03}$$

For low carbon gray iron $$X = 1 + \frac{0.067}{Y - 0.03}$$

$$Y = \frac{\text{Volume of riser}}{\text{Volume of cast}}$$

$$X = \frac{\text{Surface area of cast/volume of cast}}{\text{Surface area of riser/volume of riser}}$$

1.4. Pouring Temperature

The higher the pouring temperature, the more heated the mold becomes, causing the sizes of graphite to become larger. It is considered that this affects adversely on the mechanical properties of the cast. On the other hand as higher temperature gives better fluidity of the metal, it tends to lessen such defects as poor distribution of the metal, inclusion of sands and blow-holes. As the metal tapped at high temperature contains much gas in it, it is necessary to let it settle for a while. Due to the above reasons, proper temperature must be chosen for pouring in accordance with the thickness of the wall of the cast and the type of the mold.

1.5. Chiller

The chiller is used for the purposes of making the solidification of thick portion of the cast and/or the portion of high temperature properly, and also of making the material metal dense in order to avoid blow-holes and cracking.

1.5.1. Size of the Chiller

Size of the chiller is determined in accordance with the thickness of the cast and the chilling capacity which, in turn, is dependent on the material of the chiller. Generally speaking, gray iron or steel is used as a chiller. The thicker the chiller is, the larger its chilling effect is. However, the chilling effect is dependent on the thickness of the chiller only to a certain extent, over which the chilling effect does not increase. According to the results of experiments at 0.7t - 1.0t, while t is the thickness of the portion of the cast which is applied directly to the chiller. Fig. 6 shows the usage of the chiller.

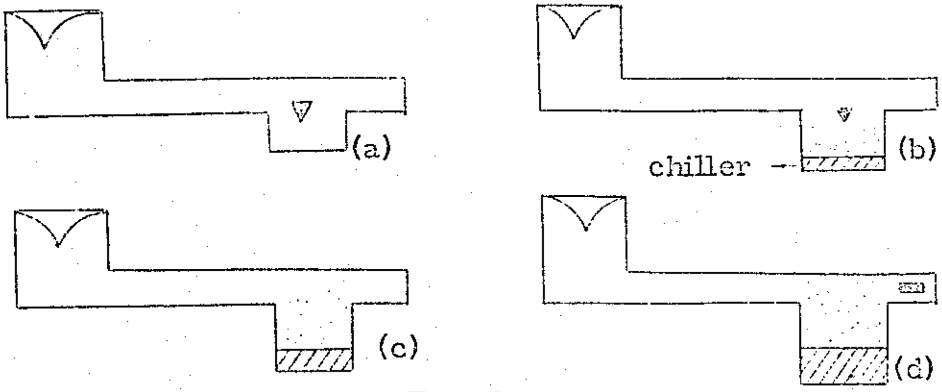


Fig. 6

1.5.2. Placement of the Chiller

Even if the chiller is of the appropriate thickness, hot tear sometimes occures at the edge of chiller as shown in Fig. 7. In order to prevent this from occurring, shape of the chiller must be designed so as to lessen the temperature curve of solidified section and the solidifying section.

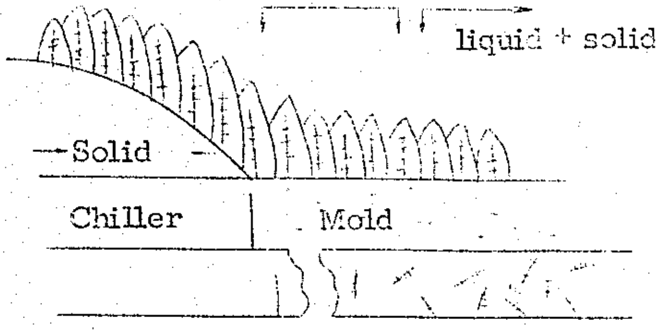


Fig. 7

1.6. Cautions Against the Casting Strain

Strain takes place in the cast because the cooling speed and resistance to the contraction of the core metal differ in various sections. Strain also occurs when cast is shaken out prematurely or is given impact while still hot. Cautions against the strain are as follows:

(1) Core should be hollow whenever possible to allow the better shrinking. Rope may be would around the core metal. Also, core should be formed in a way it is easy to change its form.

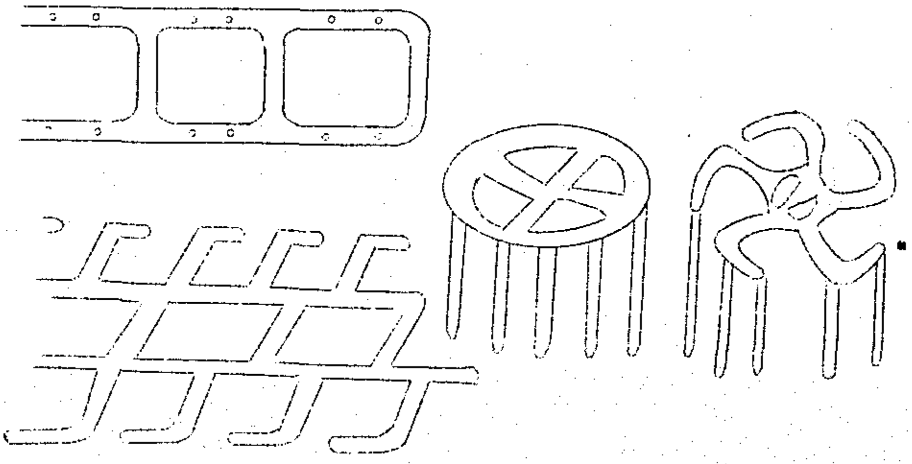


Fig. 8

(2) The gate, sprue, and riser should be placed where they do not become obstacles to shrinking.

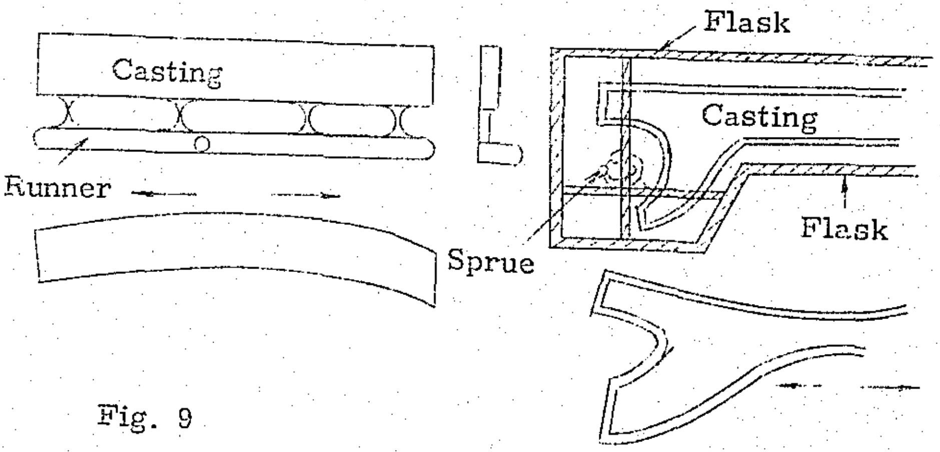


Fig. 9

(3) Where the mold and core resist shrinking tie piece should be attached.

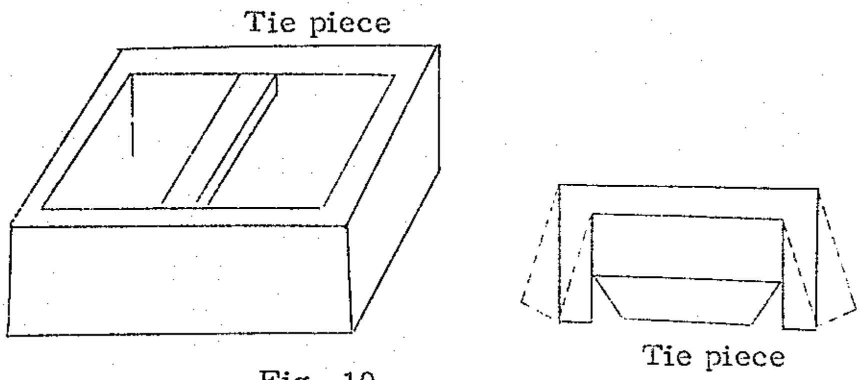


Fig. 10

(4) For the mold and core which are liable to warp, reverse warp should be given to the pattern.

(5) Early shake-out frequently causes warpage. Therefore, shake-out should be done after sufficient cooling time.

2. EXAMPLES OF CASTING PLANS

2.1. Sylinder for Carding Machine

A. Specifications for the Product.

(1) Material	FC 25
(2) Weight	Pouring weight 990 kg. Casting weight 790 kg.
(3) Others	(a) Tolerance for balance - - - within 7.5 kg. (b) Stress-relieving annealing should be performed after rough grinding.

B. Pattern	Gray iron metal pattern. Sweeping mold for the core.
C. Molding Plan	Contraction rule : 10/1000

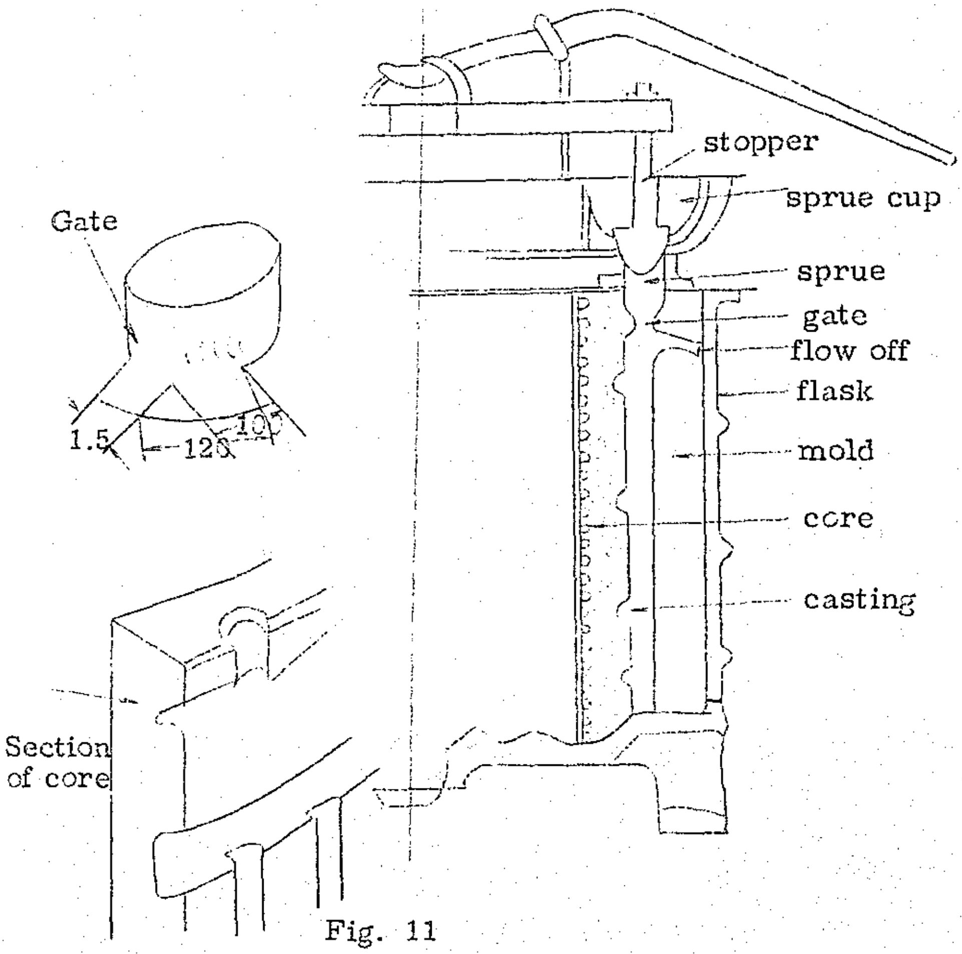


Fig. 11

D. Materials to be Used

(1) Molding sand is dry sand with the compositions shown below:

(a) Master mold

Material Mixing Ratio	Old Sand	No. 2 Silica Sand	No. 4 Silica Sand	Kibushi Clay
Weight	50	20	30	4.5

Properties

Moisture	Permeability	Green compressive strength	Dry compressive strength	Clay content
7.0-8.0%	450-550	400 - 500	3500 - 4500	12-14%

(b) Core sand is the same with the above with the exception of clay contents at 10 instead of 4.5

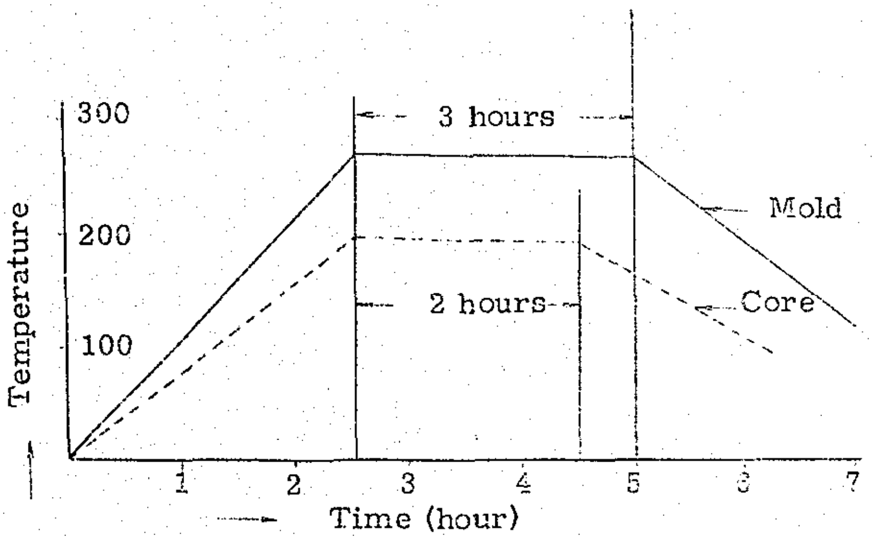
Properties	Moisture	Permeability	Green compressive strength	Dry compressive strength	Clay content
	6.0-7.0%	350-500	800 - 900	4500 - 5500	15-17%

No. 5 silica sand with 10 - 11% clay and 25 - 30% water is used as loam.

(2) Coating material
Moldax No. 2 solved in the water to the specific gravity of 1.28-1.30 is used.

(3) Rope. 7.5mmϕ, 9mmϕ, 18mmϕ are used.

E. Drying of the Mold.



F. Melting

Melting is done in a 3.5 - ton cupola.

(1) Combination

Pig Iron No. 1. B	Pig Iron No. 1. D	Steel Scrap	Fe - Si	Fe - Mn
60 kg	90 kg	150 kg	1.0 kg	1.5 kg

(2) Standard composition

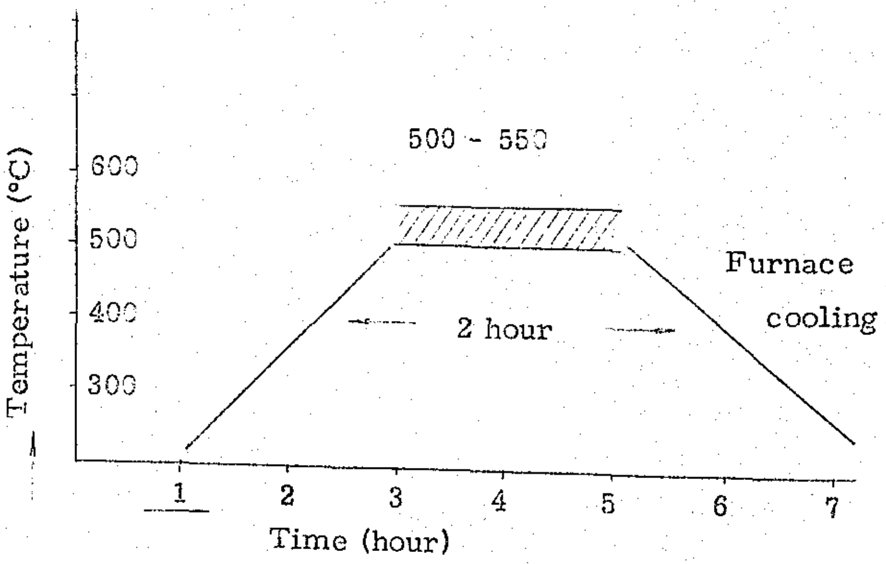
C %	Si %	Mn %	P %	S %
3.3-3.5	1.4-1.6	0.7-0.9	0.15 Max	0.12 Max.

(3) Melting temperature 1480°C - 1520°C

(4) Pouring temperature 1350°C - 1380°C

(5) Pouring time 55 - 65 (sec.)

G. Annealing for Stress Relieving

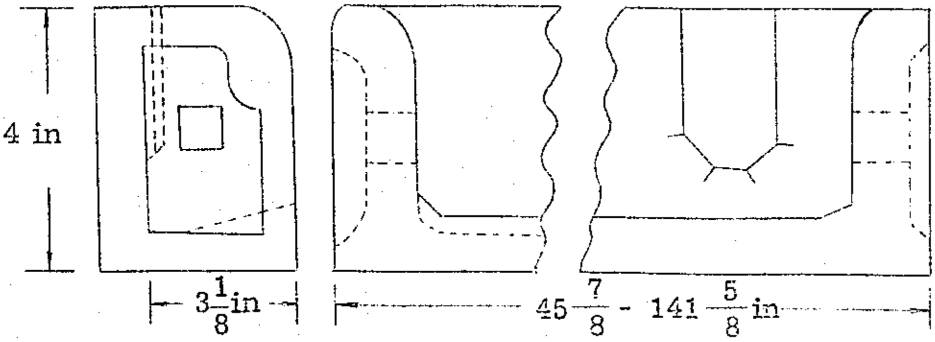


2. 2. Roller Beam for Spinning Machine

A. Specifications for the Product.

(1) Material FC 25

(2) Shape of product.



(3) Others

Take extra caution because the shape is conductive to warpage.

B. Pattern

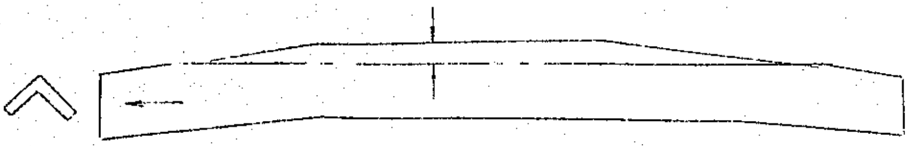
(1) Construction

Gray iron metal pattern with the maximum length of approximately 3,600 mm.
Locations of seats and the total length are determined by using gauge for each product.

(2) Machining allowance. 3.2mm

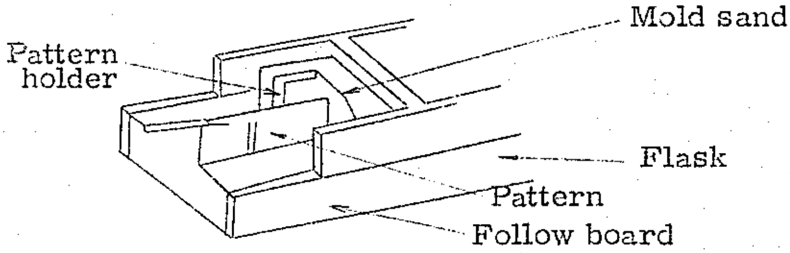
(3) Contraction rule : 12/1000

(4) Reverse warpage

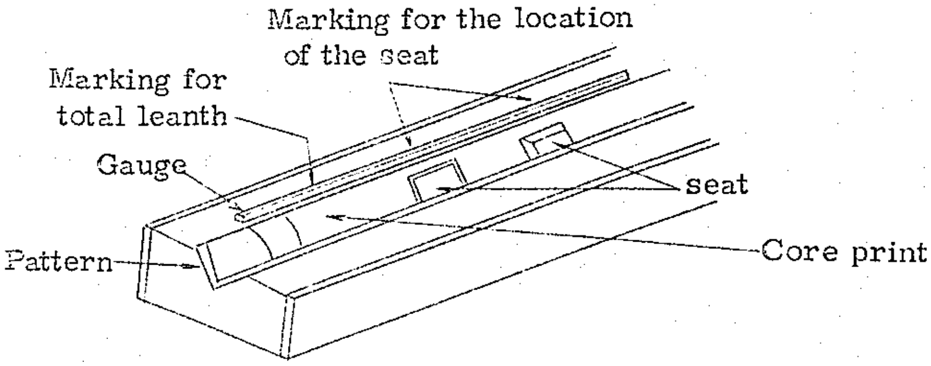


C. Molding Plans

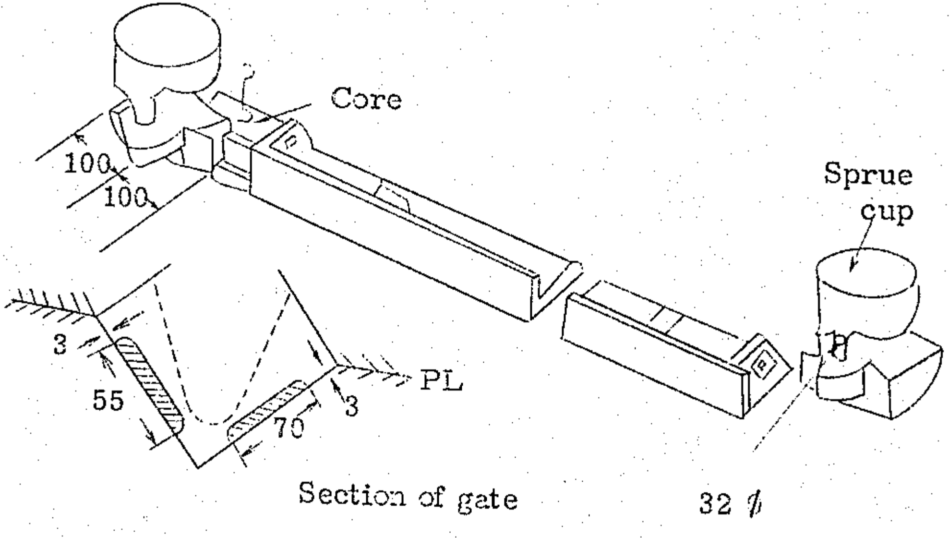
(1) Drag half of the mold



(2) Cope half of the mold



(3) Design of the sprue



D. Molding Sand

(1) Facing sand

Old Sand	Natural Sand (Noma fine)	Natural Sand (Noma Coarse)
80	10	10

Properties are

Moisture	Permeability	Green Compressive Strength	Dry Compressive Strength	Clay Content
7.5-8.5	35 - 45	550 - 650	4500-5000	15-17%

(2) Back Sand

(a) Composition
Old sand 60%
Natural sand (Noma) 15%

(b) Properties

Moisture	Permeability	Green Compressive Strength	Dry Compressive Strength	Clay Content
8.5-9.0	30 - 40	500 - 600	3500-4500	14-16%

E. Material

(1) Combination

High Si Pig Iron (10s)	Pig Iron No. 1. D	Steel scrap	Home scrap	Fe - Mn
30 kg	50 kg	140 kg	80 kg	1.5

(2) Standard Composition

C	Si	Mn	P	S
3.0 - 3.2%	1.8 - 2.1%	0.6 - 0.8%	0.15	0.12

(3) Tapping temperature --- 1480°C - 1520°C

(4) Pouring temperature --- 1370°C - 1400°C

F. Shake-out

(1) Cast should be shaken out after one hour from pouring. At this point the temperature of the cast is 500°.

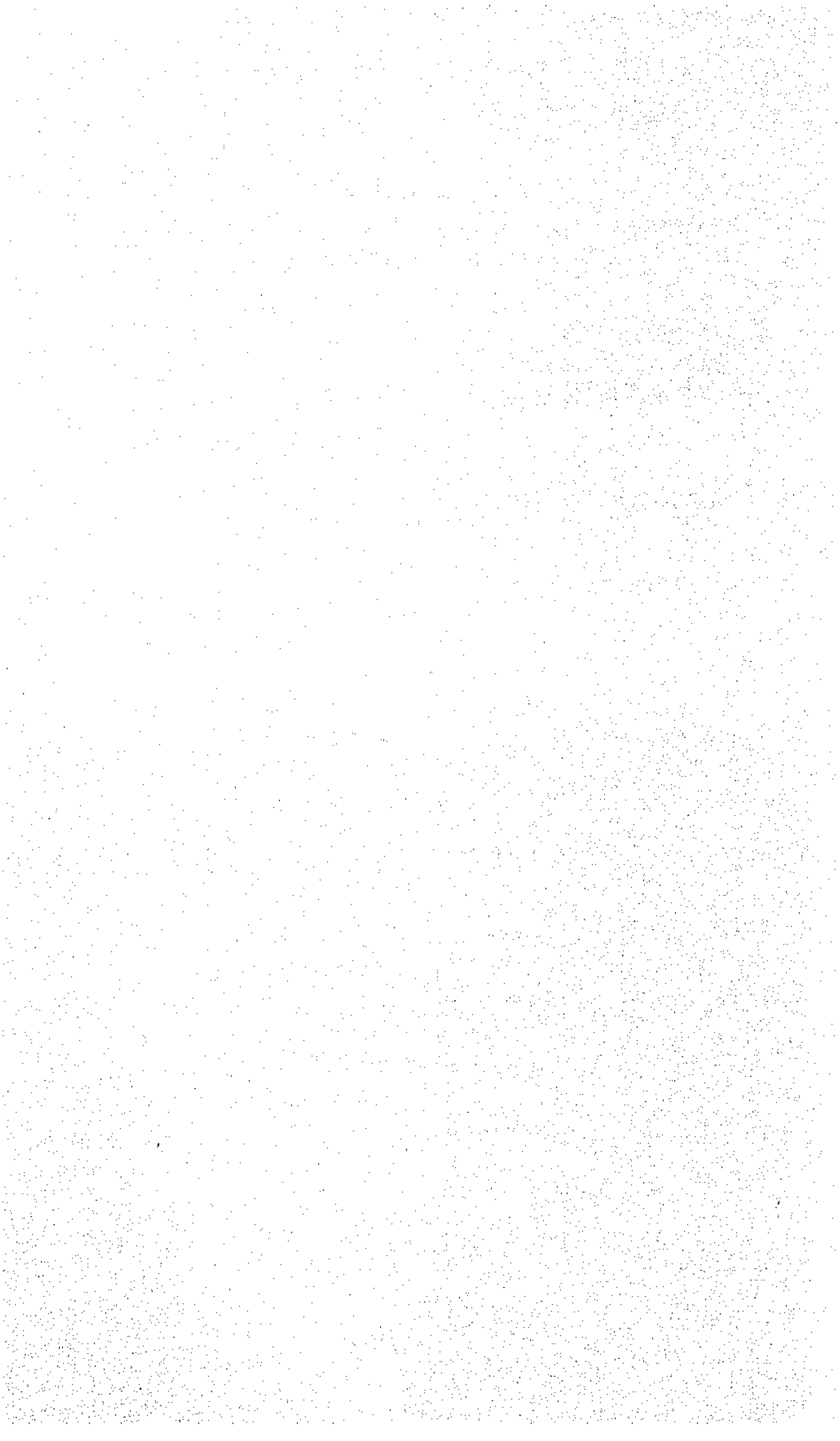
(2) Cast shaken out should be hung by supporting at both edges with the face to be machined turing downward. Gate should be broken at shake-out.

G. Annealing

Stress-relieving annealing should be performed

* * * * * * * * * *

GREEN SAND MOLDING PROCESS



GREEN SAND MOLDING PROCESS

by: Kazuo Tsunoda
Industrial Research
Institute, Aichi Prefecture

1. FOREWARD

Molding processes where sand is used to make the mold produce by far the largest quantity of castings. Among the sand molding processes, green sand molding is the most widly used, since this process has advantages as follows:

(1) Usually the most direct rout from pattern to mold ready for pouring is by green sand molding.

(2) Green molding sand can be reused many times by reconditioning it with water, clay and other additives.

(3) Green sand molding is ordinarily the least costly method of molding.

Green molding sand may be defined as a plastic mixture of sand grains, clay, water and other additives. The sand is called "green" because of the moisture present and is thus distinguished from dry sand.

2. BASIC STEP IN GREEN SAND MOLDING

2.1. Preparation of the pattern

2.2. Making the mold

2.3. Core setting

2.4. Closing

2.5. Weighting

3. METHOD OF MOLDING

3.1. Flask Molding

(Fig. 1)

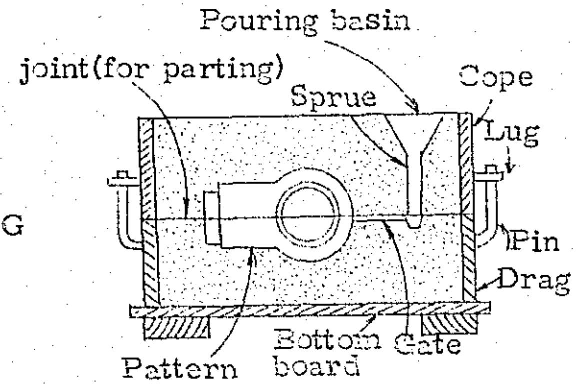


Fig. 1 Cope mold rammed up.

3.2. Pit Molding (Floor molding)

(Fig. 2)

3.3. Open Sand Molding

(Fig. 3)

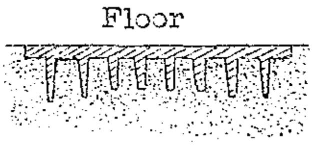


Fig. 3

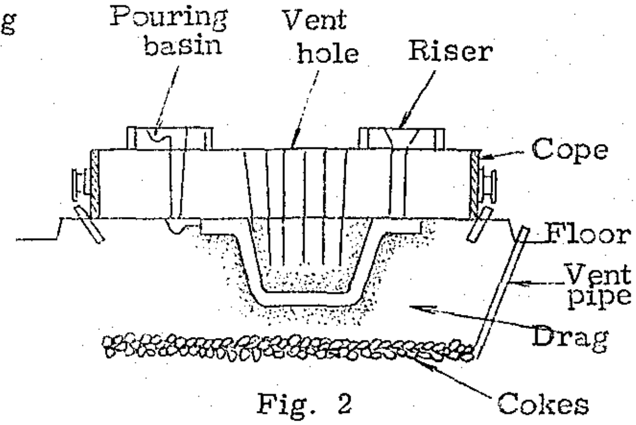


Fig. 2

3.4. Molding by means of Sweeping Pattern

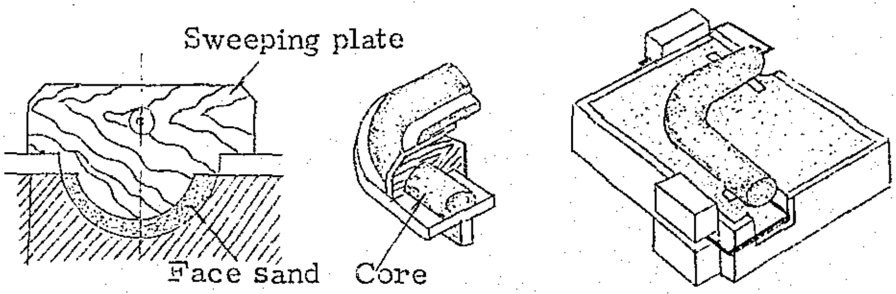


Fig. 4

3.5. Molding by means of Strickling Pattern

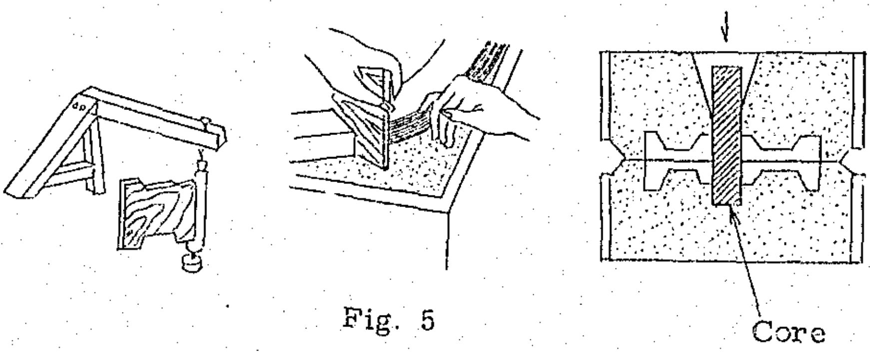


Fig. 5

3.6. Machine Molding

3.6.1. Jolt molding

Packing of molding sand is caused by work done by the kinetic energy of the falling sand.

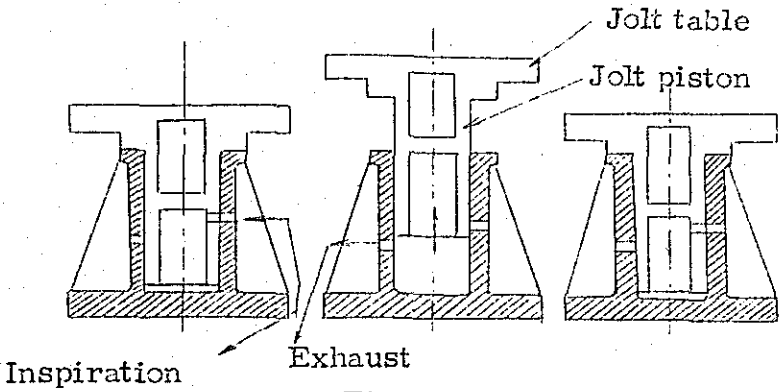


Fig. 6 Jolt

3.6.2. Squeeze molding

The molding sand is pushed against the pattern by pressure which is applied pneumatically through a squeeze head or plate. Molding pressures of 1.5 ~ 3.5 kg/cm^2 are in common use.

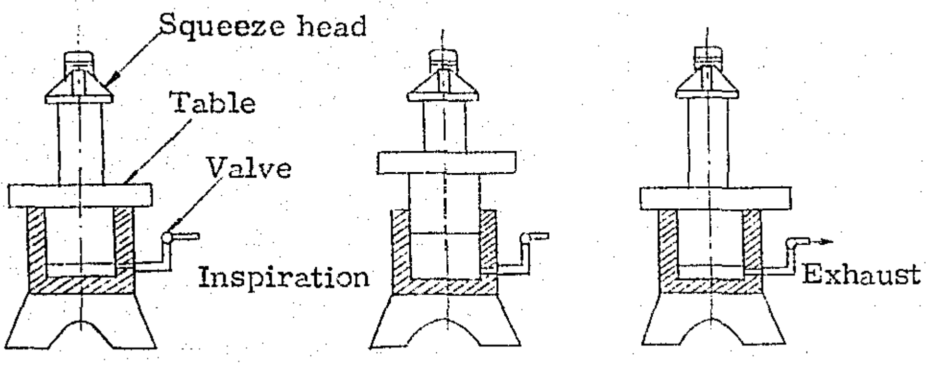


Fig. 7 Squeeze

3. 6. 3. Sand slinger molding

The molding sand is packed by the impact on the pattern of sand moving at high velocity (about 50 m/s).

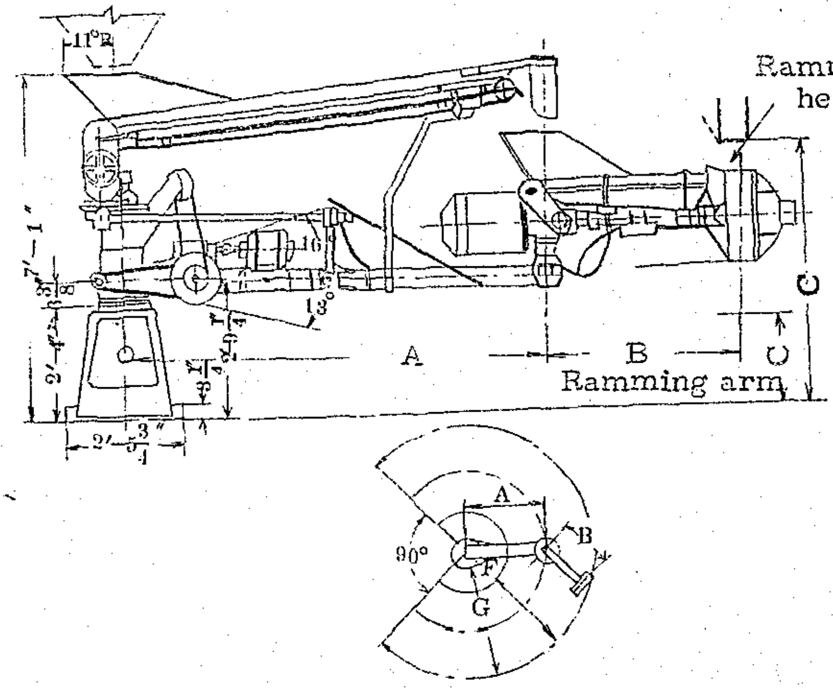


Fig. 8 Sand Slinger

4. MOLDING INSTRUMENTS

4. 1. Mold Flask

Wooden flask is used generally in bench molding.

Metal flask is used for mass production or production of large castings.

Mold flasks may be classified as follows:

4. 1. 1. Removable flask

The removable flask is used for cope and drag molding of small to moderate size. After the mold is made, the flask is removed and replaced with a jacket and poured.

4.1.2. Tight flask

The tight flask remains on the mold until after the casting is poured and shaken out.

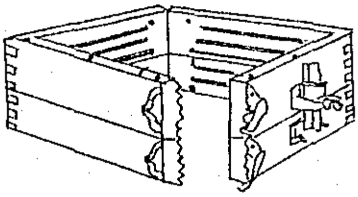


Fig. 9 Removable flask

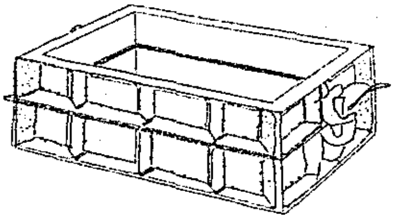


Fig. 10 Tight flask

4.2. Mold Board

4.3. Molding Tools

a) Stamp. Bench rammer. Air rammer

b) Spatula. Trowel

c) Shovel

d) Swab. Flat flush

e) Small hammer

f) Riddle

g) Strickling board

h) Vent wire

i) Rapping bar

j) Sprue bar

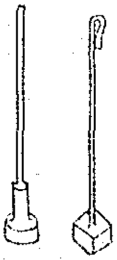
k) Blow pipe

l) Leveller

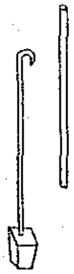
m) Scale

n) Compas

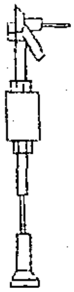
o) Mirror. Flash light



Stamp



Bench rammer



Air rammer

Riddle

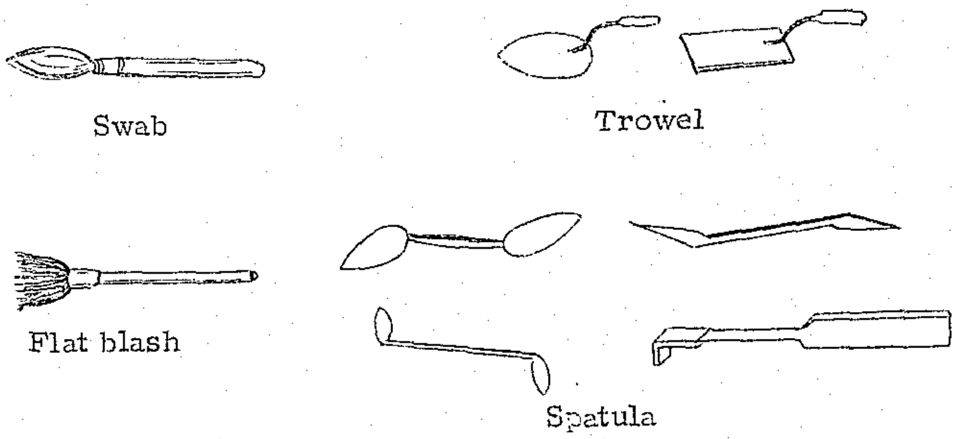


Fig. 11 Molding tools

4.4. Weight

The cope mold half must be held down to keep it from floating when the molten metal is poured. Metallostatic pressure exerts a buoyant effect on the cope which can be calculated from the following relationship:

$$\text{Weight} \quad W = k \cdot P \cdot A$$

where P = metallostatic pressure at cope parting surface (kg/cm^2)

A = projected mold-cavity area at cope parting surface (cm^2)

K = safety factor ($1.5 \sim 2.0$)

P is calculated as follows:

$$P = w \cdot h$$

where w = weight per cm^3 of molten metal (kg/cm^3)

h = effective height of metal head above cope (cm)

4.5. Chaplet

Chaplet is metal forms placed between mold and core surfaces. This is often used to overcome vertical movement of the core due to buoyancy.

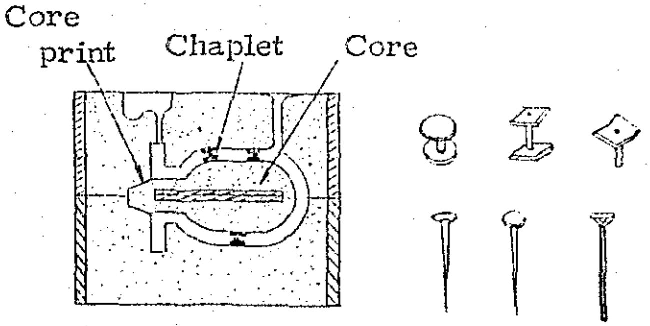


Fig. 12 Chaplet

5. BASIC OPERATION OF BENCH MOLDING

5.1. Setting of mold board

5.2. Selection of mold flask

Dimension and shape of mold flask are dependent of dimension and shape of pattern.

5.3. Placing drag-half of flash.

5.4. Placing drag-half of pattern.

5.5. Sprinkling of face sand.

Sprinkle face sand on the pattern with even thickness of 20 ~ 30mm, using riddle.

5.6. Filling with back sand.

5.7. Ramming

Sand can be rammed relatively hard near the wall of flask since the area does not effect venting strongly and also strong adhesion of sand to flask is necessary. However, sand around the pattern should not be rammed in excess since this can cause poor permeability.

5.8. Striking off excess sand.

5.9. Roll over the drag-half of mold

5.10. Cleaning of parting line.

5.11. Placing cope-half of pattern

5.12. Sprinkling parting powder

5.13. Preparing of cope-half mold

Place patterns of sprue and riser in loation of sprue and riser, mat cope and drag flask, and make cope-half of mold following same process used for drag-half making.

5.14. Use of vent wire

5.15. Removing the sprue bar (riser pattern)

5.16. Tally mark

5.17. Taking off the cope-half mold

5.18. Runner and gate making

5.19. Removing pattern

Moisten area around the pattern with swap.
Rapping bar is attached to center of gravity of the pattern and the pattern is drawn carefully not to destroy the mold.

5.20. Coating

If necessary, sprinkling or flash brushing of graphite or mica powder is used for coating of green sand mold.

5.21. Core setting

5.22. Closing

5.23. Weighting

6. MACHINE MOLDING

6.1. Jolt molding

In the jolt molding, the maximum molding force is applied at the pattern surface. The mold would thus be hardest at the mold-cavity face.

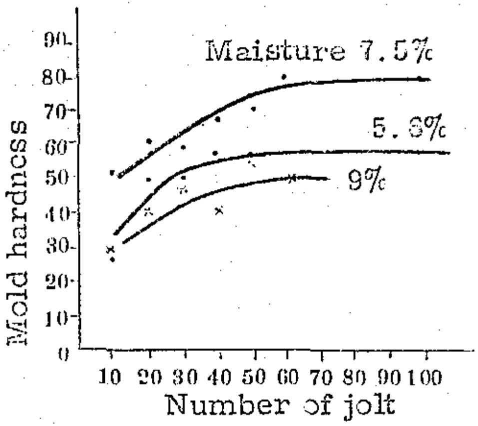


Fig. 13 Number of jolt and mold hardness

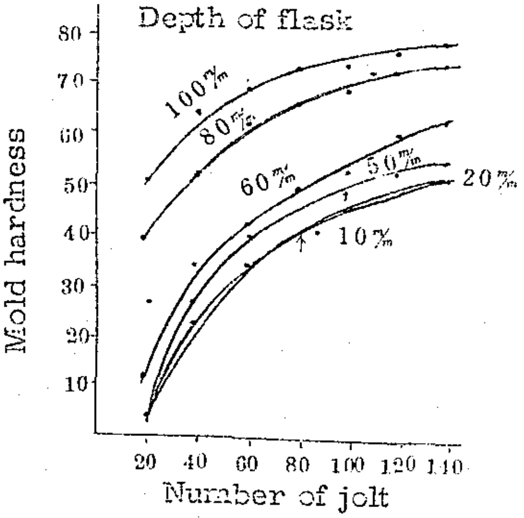


Fig. 14 Depth of flask and mold hardness

6.2. Squeeze molding

Molding by squeeze pressure alone will become less effective for a given pressure as the depth of the mold-half increases. Therefore, sand density is at a minimum adjacent to the pattern and the hardness of the mold is less than that next to the squeeze head. There is a limit to flask depth which may be properly molded by squeezing which is dependent on the squeeze-machine capacity, pattern contour, molding sand, etc.

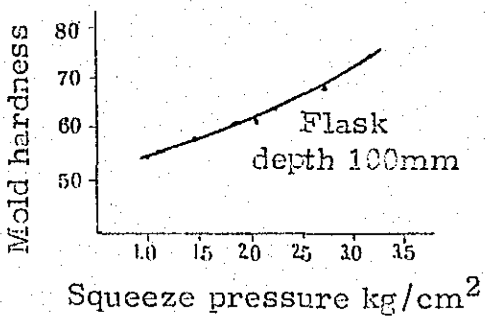


Fig. 15 Squeeze pressure and mold hardness

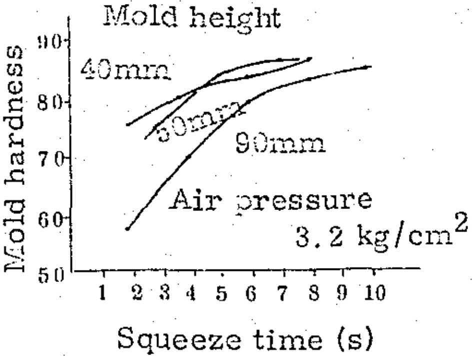
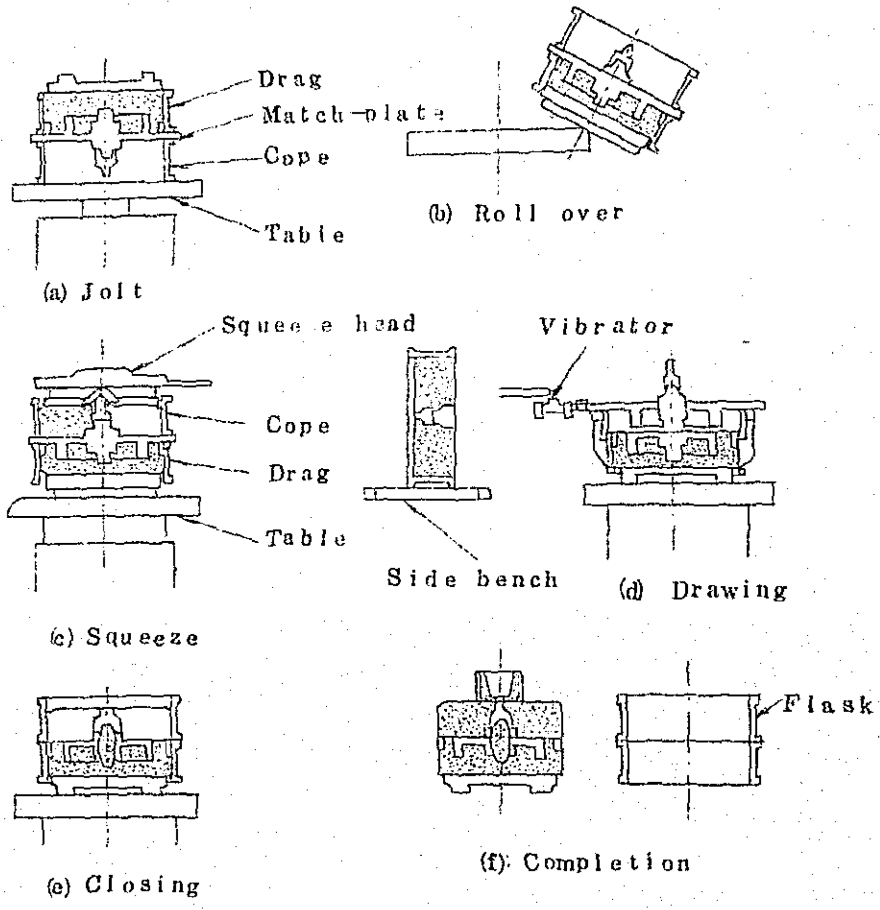


Fig 16 Squeeze time and mold hardness

6.3. Jolt-squeeze molding

To obtain more uniform backing, the squeeze method of molding is used in combination with the jolt method.



(a) Jolt

(b) Roll over

(c) Squeeze

(d) Drawing

(e) Closing

(f) Completion

Fig. 17 Jolt-squeeze molding

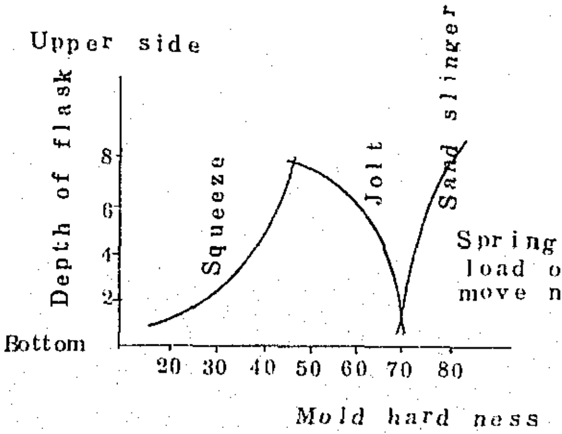
6.4. Sand slingers molding

Slinger have great versatility in size of mold, width, length and depth which can be rammed.

Slingers are able to ram molding sand harder and greater density than the other molding methods.

Table

Distance from mold board to slinger head (mm)	Mold hardness
1.300	85.5
1.050	85.4
820	83.6
530	85.7
340	85.5



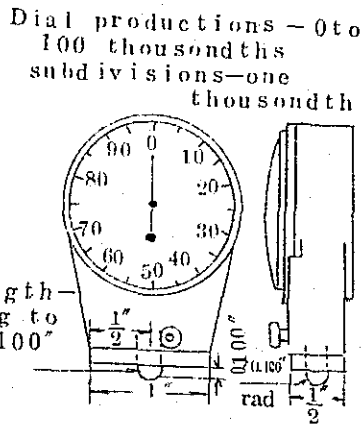


Fig. 19.Mold–hardness tester.
(From American Foundrymen's Society.)

Fig. 18 Molding methods and mold hardness

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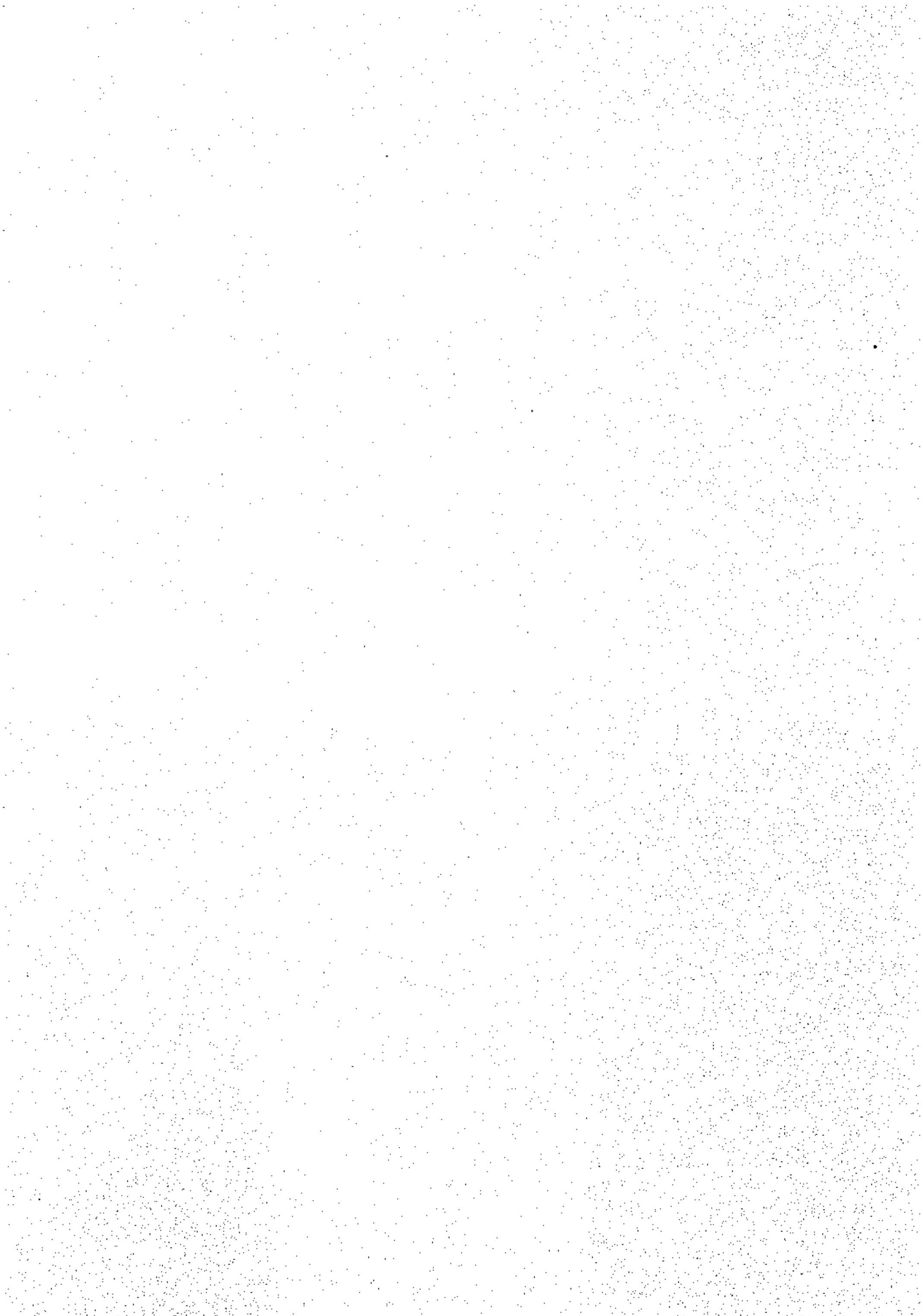
FOUNDRY SAND



FOUNDRY SAND

by: Toshio Okuyama
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1. MOLDING SAND

Foundry sand is used for sand casting, and for foundry sand, silica sand (SiO_2) is most commonly used. When silica sand is used as molding sand, a suitable bonding agent (usually clay) is mixed or occurs naturally with the sand; the mixture is moistened with water to develop strength and plasticity of the clay and to make the aggregate suitable molding.

Sands and clay are formed by chemical and mechanical weathering of rocks; deposits are found wherever left by wind, water, or glacial action.

Frequently sands are found in intimate contact with clay, and in these cases the sand-clay mixture may be used essentially as mined -- the molder has only to mix water with the aggregate and the clay develops the strength and plasticity for molding. Such sand are termed natural bonded sands.

When molding sands with certain characteristics conductive to the making of casting goods are wanted, such sands must be prepared artificially by mixing clay and other material.

For this purpose, silica sand free of clay is many times used as base material instead of natural sand. Although the basic ingredients of sand "mix" are only sand, clay and water, other materials are often added in small amounts for special purposes. They are designated as synthetic sands.

Natural sands usually contain 13 to 25% foundry clay and are found with particles varying in size. 3 to 10% of water is added to use them as molding sand. Natural sand contains clay, but even used as silica sand, it contains too much impurities. Although its fire-resistence is weaker than that of synthetic sand, the easiness of its handling and its low cost lends itself still for nonferrous metal iron cating, but the recent trend is toward synthetic sands at an increasing rate.

2. MERIT AND PROPERTY OF FOUNDRY SAND

Molding sand plays a great part in the production of foundry products with clean surface and accurate dimention under consistently controlled conditions in which the rate of rejects is small and a yield is large.

The availability of sand best suited to the casting of certain products is likened in its significance to the availability of best-suited farm land for raising certain crops.

In America, there are many publicly available data dealing with the characteristics of molding sands for various casting purposes. Data compiled by Dietert Co. is best known. (See an attached table)

"Foundry Sand Data" published by Gray Iron Research Institute gives detailed descriptions of base sands for various foundry products, additives to be selected and treated and characteristics of prepared sands.

German data are also included in attached charts. Japanese data already published are many in kind, but very little of it is well organized and concise.

Control Sand Test Data which have proven satisfactory for various type of castings in U.S.A.

Quality of foundry sand / Type of Castings	Moisture %	Permeability AFA	Green Compression Strength lbs/in^2	Clay Substance %	Finess No. AFA	Sintering Point °F (°C)
Al-Castings	6.5 - 8.5	7 - 13	6.5 - 7.5	12 - 18	225 - 180	2350 (1290)
Brass and Bronze Al-Castings	6.0 - 8.0	13 - 20	7.0 - 8.0	12 - 14	150 - 140	2350 (1290)
Cu-Ni Al-Castings	6.0 - 7.5	37 - 50	6.5 - 8.0	12 - 14	130 - 120	2400 (1320)
Light grey Iron (Stove plate castings)	6.5 - 8.5	10 - 15	6.0 - 7.5	10 - 12	200 - 180	2350 (1290)
Light gray iron (Molding machine use)	6.0 - 7.5	18 - 25	6.2 - 7.5	12 - 14	120 - 1807	2400 (1320)
Medium gray iron (green or molding)	5.5 - 7.0	40 - 60	7.5 - 8.0	11 - 14	86 - 70	2400 (1320)
Medium gray iron (Synthetic sand)	4.0 - 6.0	50 - 80	8.5 - 9.5	4 - 10	75 - 55	2450 (1340)
Heavy gray iron (Green or dry mold)	4.0 - 6.5	80 - 120	7.5 - 8.9	8 - 13	61 - 50	2500 (1380)
Thin Malleable iron Castings	6.0 - 8.0	20 - 30	7.5 - 8.5	8 - 13	120 - 92	2500 (1380)
Light Steel Castings (green mold)	2.0 - 4.0	125 - 200	7.5 - 8.5	4 - 10	56 - 45	2600 (1430)
Heavy Steel Castings (green mold)	2.0 - 4.0	130 - 300	7.5 - 8.5	4 - 10	62 - 38	2700 (1490)
Steel Castings (dry mold)	4.0 - 6.0	100 - 200	7.5 - 8.5	6 - 12	60 - 45	2600 (1430)

Characteristics of German Mold Sands
As appeared in Giesserei Kanlender 1959

		Moisture %	Permeability	Compression gr/cm^2
Gray Cast Iron (green)	Radiater	5.0 - 6.5	30 - 50	1,080 - 1,565
	Heater Large	7.0 - 8.0	50 - 70	1,200 - 1,700
	Heater Small	6.0 - 7.0	40 - 50	830 - 900
	Mechanical casting	4.0 - 5.0	90 - 100	1,100 - 1,200
	"	5.0 - 7.0	45 - 60	-------
	"	5.0 - 5.5	60 - 35	640 - 770
	"	5.0 - 5.5	30 - 45	800 - 910
(Dry)	Mechanical Casting	——	130 - 150	8.6 - 10.0 kg/cm^2
	"	——	50 - 60	18.9-20.0kg/cm^2
Steel Cast-ings (green)	Molding M.	3.2 - 4.4	80 - 107	600 - 700
	"	5.0 - 5.5	125 - 130	685 - 845
Steel Cast-ings (Dry)	I		180 - 190	6.7 - 7.4 kg/cm^2
	II		165 - 195	6.3 - 8.9 kg/cm^2

The necessary properties of foundry sand are enumerated below:

1. Adequate permeability
2. Adequate strength
3. Adequate distribution of grain size and chemical analysis
4. Adequate fire resistence
5. Usefulness for multiple purposes
6. Consistency and stability of quality
7. Availability at low prices
8. Others

The process of formation of foundry sand consisting of SiO_2 is that granite and quartzite and melted and interfused to produce through crystallization quartz and feldspar (which later turns into clay). After exposed to erosion by wind, quartz is separated, washed away by rain finally deposited in lakes, swamps and sea bottoms, as there are beach sand, river sand and mountain sand. Sands are thus sorted out into various kinds by the process of natural selection and found deposited with varying particle sizes, clay inclusion and chemical analysis.

In determining the right kind of molding sand at a foundry shop, test specimens are often used to find out the suitability of certain sand to a given type of foundry product.

The basic criteria of selecting certain sand are its strength, permeability, moisture and grain characteristics.

In preparing these mold sands, it is recommended that if there is mountain sand near-by, it should be used as it is (with preferably a little treatment such as screening, mulling and aeration). When the scale of production is quite large and adequate mountain sand is not available and silica sand is easily obtainable, a care must be given to the properties of silica sand as the raw material of synthetic sand.

For both natural and silica sands, it is important to be familiar with the conditions of areas where these sands are mined.

3. SAND CONTROL

Once a right kind of molding sand is chosen at a foundry shop, attention should be directed to maintaining the constant quality of molding sand. This is called sand control. The quality of molding sand should be controled along with other raw materials shipped to the shop. A tester is used in this case or inspection.

It is desirable that the permiability, strength and moisture are tested every day, and grain size distribution and chemical analysis are tested a few times in a month.

After molten metal is poured into a mold, SiO_2 in the molding sand changes into a state where it is easily broken down into fine pulverization, and clay looses its bonding property, with the result that the strength of sand is reduced, its permeability deteriorated, its fire-resistibility reduced and sand is easily burned and sticks. This called "deterioration phenomenon." For this reason, measures should be taken to keep as much as possible to the sand sticking on castings from getting mixed with molding sand, and care should be given to replacement of pulverized sand with new sand and reinforcement of caly supply therein. Continued vigilance is also required for separation of iron pieces and fines from mold sand and retaining of moisture.

4. SAND PREPARATION

Sand preparation consists of the following six steps:

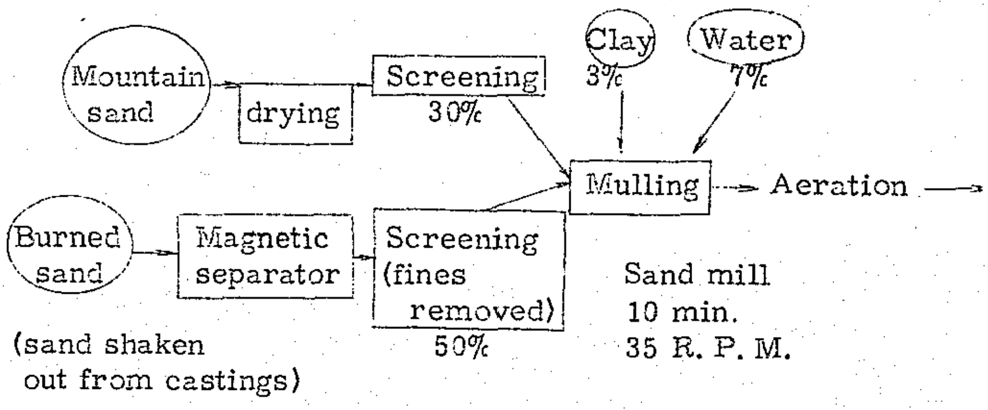
1. Drying
2. Separation --- screening (standardizing particle size), separation of iron piece
3. Mulling ------ Mixing included (mixing by shovel is not included.)
4. Aeration
5. Reclamation of old sand

6. Shipment

The desired molding sand can be obtained by regulating its characteristics with the above six steps of sand combined. The centeral work in sand preparation is mulling. The binding of sand grains with bonding agent is done by mulling. It can not be done by mixing with shovel only. Aeration also is the adequate process to develop molding sand properties.

With regard to shipment, care must be taken of material handling at a foundry shop as it directly affects its efficiency. The larger the amount of molding sand handled, the more care it requires.

The process of sand preparation, using natural sand as raw material for facing sand is shown below:



In this case, mountain sand equivalent to the total amount of burned sand is supplied into back sand which is watered and aerated.

Type of sand			Facing sand for small castings		Facing sand for medium castings		Facing sand for large castings	
			A	B	A	B	A	B
Ratio of mix %	Base sand	Returned sand	60 70	70	70	70	60	75
		New Natural sand	30 40		30			
		Silica sand		30		30	40	25
	Ad-ditives	Clay		Bent-onite 8		Bent-onite 8	Clay 10 13	Clay 10 13
		Carbon powder	2	0.8	1.0	0.5 2.0	5 10	7
		Wood flour				0.5	2	
		Alginic acid		2				
Sand mix-ing time min.	Before water added		5	10	5	10	10	7
	After water added		10	15	10	10	15	10
	Total		15	20	15	20	25	17
Pro-per-ty	Mostrue % Aeration		7	5 6	7	5	6	9 12
	Aeration		10 20	30 50	30 60	50 70	100 150	150
	Compression strength		400 600	500 800	700	800	300 500	400

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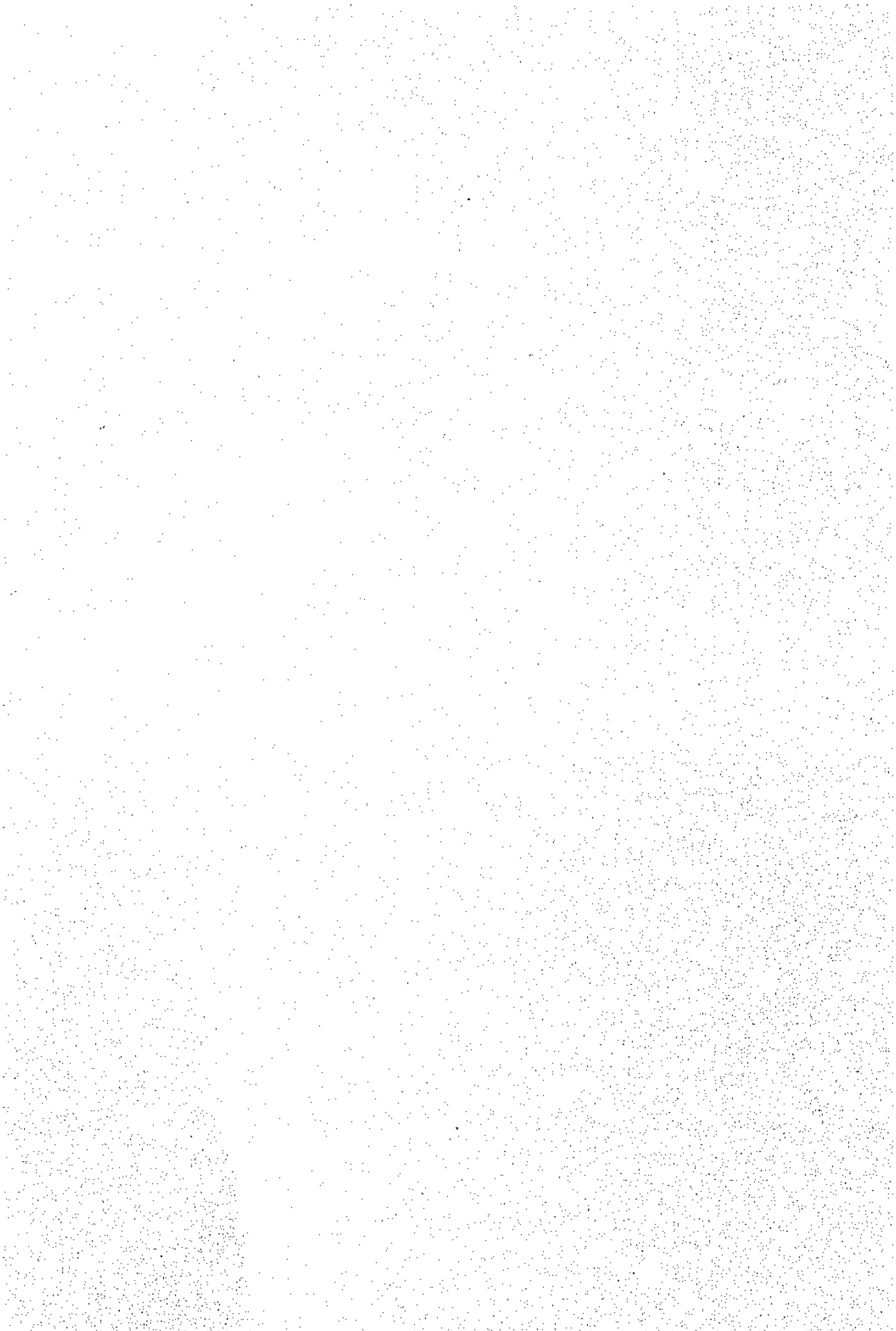
BINDERS



BINDERS

by: Mitsuo Isotani
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1. PREFACE

Clay, sands and s tones have been mainly applied as the molding material so far which may be classified into loam mold, dry sand mold and green sand mold depending on the kind of mold.

What is in common to these three kinds of mold are of an in-organic binder consisting of clay and bentonite as main compound. These in-organic binders are of all natural resources which can be obtained comparatively cheaper cost, however, it had been found out that they are varied with kind and the property of material change according to the water content.

When considering the casting as the modern industry, what is required as molding binder is it must be uniform in property and whenever, wherever or whoever applied the binder, the same quality as well as the same casting products must be exactly produced. From this point of view, the natural binders had been gained no satisfactory result in spite of an outstanding property. Consequently, a number of researches have been carried out so far on other kind of binders which are comparatively controllable with regard to these properties.

As the in-organic binders besides the clay and bentonite, there are sodium silicate and cement and as the organic binders, there are resins, saccharide, oils and cereals which are all superior with regard to the property of re-molding. The summery on property and the use of various binders will be given below.

2. IN-ORGANIC BINDER

2.1. Clay and Bentonite

The chemical property of clay and bentonite can be determined according to the kind and quantity of the impurities of clay contained to.

Clay can be generally classified into 1) Kaolin group, 2) Montmorillonite group and 3) Illite group respectively in accordance with the chemical analysis, X-ray analysis and thermal analysis. Of 1) group, the most common binder is Kaolinite and Kibushi clay consists of maninly this Kaolinite. Bentonite is the typical one that belongs to 2) group containing Na, Ca, bentonite etc., depending on the kind of substitution metal and each of which has different property respectively. 3) group is related with the mica containing more moisture, therefore this has hardly been applied as the foundry binder.

Judging the caly from its producing condition, they are classified into two groups: a) The one being placed as almost parellel with the stratigraphic layer; b) The one being placed as the state of irregular lump in the rock; c) The one being placed as the ingredience of the soil on the ground surface. The one of a) is the typical case to be produced, and those of Gairome or Kibushi clay belong to this group. The one b) had been produced by the action of volcanic hot water and the bentonite belong to this group. The one c) is usually called as natural sand which can be used as the mold sand as it is.

Clay and bentonite is used by adding a certain amount of sand and water, clay expands when added with water, develops viscocity and becomes pasty. Binding strength decreases when water is added in excess. The water content which gives maximum strength is called an appropriate water content for molding sand. Considering from the binding material, a certain amount of water is necessary in order to obtain the strength of mold and actually it is very important. One of outstanding characteristics of clayey binder is that it has an excellent refractoriness and even they are heated at high temperature, the decrease of binding strength is comparatively less. With these reasons, they are used for large castings as the binder. Moreover, the less change of heating makes it possible to use the mold sand repeatedly permitting economical operation.

The testings of clay and bentonite are usually comprised the practical test and rational analysis. From the view point of using as mold binder, the former is the test to examine the various properties of the sand when binder is added, and comprises wet and dry strength test, permeability test and high temperature test.

The latter or rational test is comprised various test such as chemical analysis, X-ray analysis, thermal analysis and so forth. The rate of swelling test and liquid limit test are specially applied to bentonite.

2.2. Sodium Silicate

CO_2 process is the method of molding to harden the mold through CO_2 gas by adding the sodium silicate as the binding material to the sand particles.

Hygroscopicity and collapsibility of mold after pouring and possibility of repeated use of binder are the main point when sodium silicate is used as binder. In this lesson, the primary properties of sodium silicate related to the said problems will be explained. The reaction when CO_2 process mold is affected by CO_2 gas is quite complicated and such gel as Na_2CO_3, SiO_2 and H_2Si_206 are said to be produced as the reaction products. However, as sodium silicate is of water soluble compound, it is the matter of course that it has hygroscopicity if un-reacted water glass is existed inside the CO_2 process mold and when the reaction is proceeded to a certain extent, it has considerable hygroscopicity because Na_2CO_3, SiO_2 gel are both hydrophilic.

Therefore, careful control must be exercised on operation to mold which the residual water content becomes problems or when CO_2 process core is used for green sand mold. When CO_2 process mold is exposed to the high temperature, sodium silicate will be again produced by reaction between SiO_2 and Na_2CO_3 contained in the sand particles.

Sodium silicate produced in this case is different in construction from those colloidal compound as it is comparatively strongly connected as silicate and also is considered to effect the collapsibility to a certain extent.

For an improvement of collapsibility, a small quantity of carbonic compound proves an effective action because this destroys the bridge between the sand grains.

It is not economical unless the molding sand for CO_2 process is repeatedly used and the used sand particles are reclaimed after washing. But they are also applied by dropping down the over all sodium content by adding a large quantity of fresh sand. The measurement of mol ratio and viscocity generally carried out is for controlling sodium silicate. Mol ratio is directly related with the quantity of CO_2 gas, while the viscocity affects the workability at the time to mix CO_2 process molding sand.

2. 3. Cement

This is the method to make the mold utilizing the property of hardening of hydration of cement. Those sand mold used 15 - 20% clay binder had been required for long hours to be dried under the temperature of 350 - 400°C so far but by the use of cement as binder, a considerable process has been reduced and only cold drying process is required permitting less drying cost.

Portland cement is mainly used and the percentage of which is more/less 7%.

It must be born in mind to use as fresh cement as possible. In order to detect the usable hour of cement, the weight connectted with wire is dropped from the certain height and is measured according to the depth that the weight got into the cement.

3. ORGANIC BINDER

3. 1. Resin

Most typical molding process to use resin is a shell mold process. Considering from the common sense with regard to in-organic binder which is comparatively stabilized thermally, this method is a fairly jamped idea, however, it is evidently proved that this method has an excellent possibility that the mold strength is mainatined for comparatively long hour under the condition of less supply of air when pouring the molten metal to the mold.

Resin may be classified in accordance with the raw material into phenol resin, urea resin, flan resin, lignin resin, etc. When observing the resin according to the chemical property, they are thermosetting, thermohardening and normal temperature hardening properties.

For the normal temperature hardening, there are two methods: the method to apply the chemical reaction by adding hardening agent and another method is the one by oxidation by air. What is required as the mold binder is thermohardening and normal temperature hardening characteristics. The powdered resin is applied in two ways: mixed to the silicon sand or in the liquid state to stick on the surface of silicon sand.

Shell mold or metal mold are usually applied for mas production and the molding by means of normal temperature hardening is applied for large castings of small quantity permitting excellent results. In order to control the resin property, those softening point, melting point, pouring point and gelation hour are measured. To measure the softening point, fill the resin into the capillary tube, heat and when the resin begin to contract, it is judged by this temperature and melting point is also judged by the temperature when resin become transparent. To measure the pouring point, place the resin sample on the pre-heated and inclined glass plate and is compared with the length of sample that softens and flows out. Gelation hour is measured that the resin is to be hardened under the constant temperature.

3.2. Oils and Fats

Fat may be classified into two kinds: dry oil such as hempseed oil, paulownia oil which are the typical one and other oils are to be aimed at dilution to the dry oil.

Mineral oil and tar oil belong to them. Dryness of fat is expressed by iodine number and the larger number the better in dryness. The outstanding characteristic of animal or plant oil used as the binder is to make the thermal polymerization by oxidation when it is heated and is apt to be hardened. The supply of oxygen is necessary for thermal polymerization, therefore, careful consideration must be paid when drying. Fish oil can also be used as the binder for core making by adding appropriate hardening accelerator.

3.3 Saccharide

There are molasses and pulp waste lye, "Orgin". Molasses is a by product in sugar refining, however, it is easily metamophized in stock. Due to the less binding power it is used as subsidiary binder. Orgin is a byproduct of sulphurous acid pulp manufacturing and to be made by neutralization and concentration of the sulfite solution. And when this is used alone, the dry strength is a little inferior to that of linseed oil. The demerits of it used as a binder, are of large gas generation, and of hygroscopic property. Regarded with quality control to it is to measure its specific gravity, solid matter content % and alkalinity.

3.4. Cereals

Cereals binder is used to the core or mold with its high wet and dry strength but also has the moisture absorbency. This is also used for small castings of non-ferrous alloy due to its quicker pyrolysis as compared with fats and oils.

4. CONCLUSION

The foregoing explanation are the summery of binder. In view of the recent development of binders as well as new method of molding, general and appropriate property as the binder shall be as follows;

1) Molding process shall be able to be mechanized, that is, no special molding skills be required.

2) Shall be less cost

3) Shall have high heat-resistance.

Consequently, it is believed that the various methods of molding of using sodium silicate will make rapid advancement in the future.

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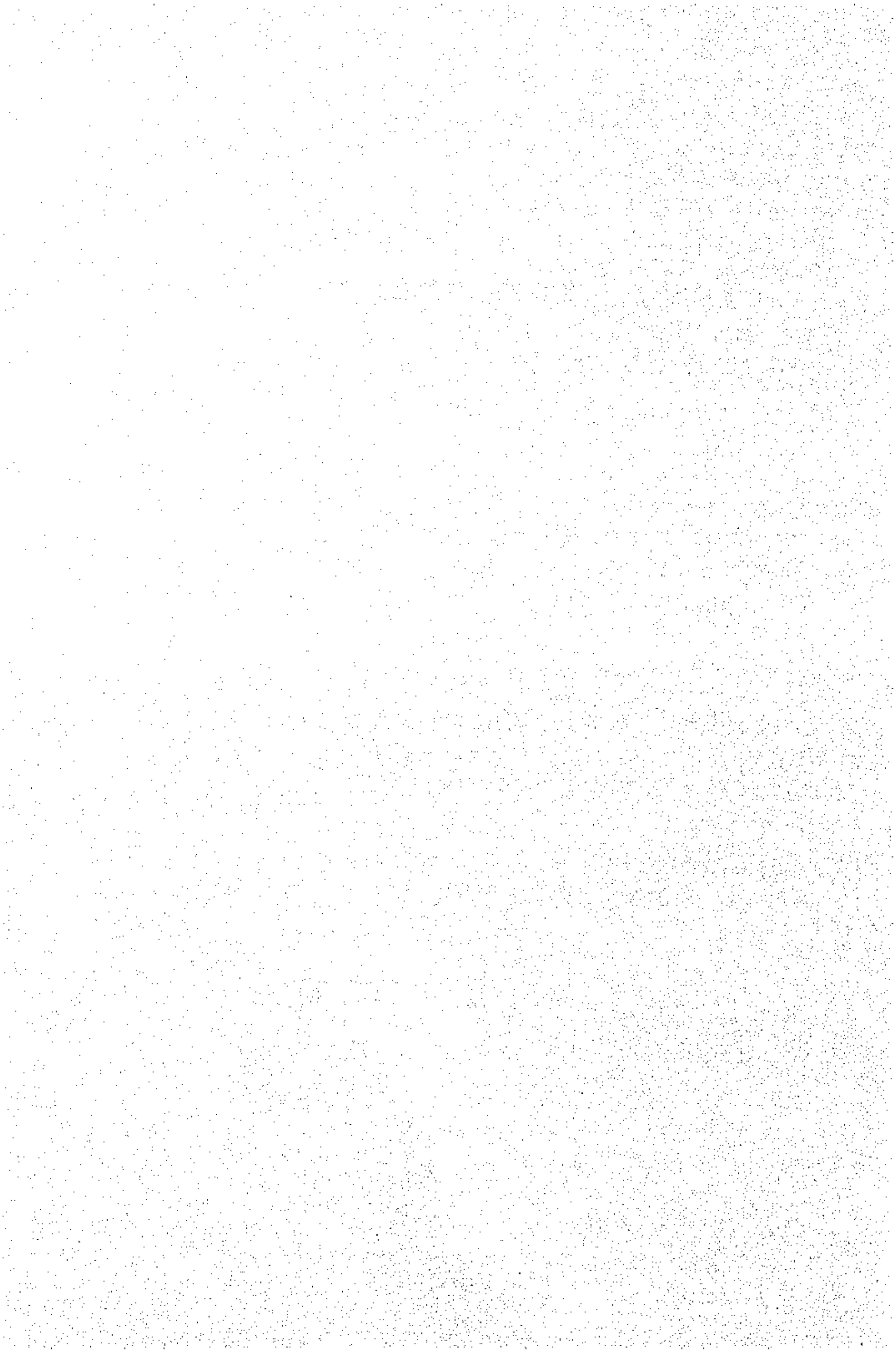
MELTING EQUIPMENTS



MELTING EQUIPMENTS

by: Yasunori Yokoi
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1. MELTING FURNACE

1.1. Type of Melting Furnace

Metals and alloys are oxidized and reduced by furnace gas and change their components and mechanical properties, and it is necessary to watch following points for furnace selection.

(1) Melting point of raw material

(2) Volume of material melt and its quality

(3) Chemical reaction of melting

(4) Economy of fuel

(5) Efficiency

(6) Maintenance control and its method

Following chart shows various melting furnaces used at present,

- Melting furnace
  - Ore smelting
    - Blast furnace, Open furnace
    - Convertor, Electric furnace, Electrolysis furnace
  - Remelting
    - Cupola — Cold blast, Hot blast
    - Electric furnace - High frequency, Low frequency, Arc. furnace
    - Reverberatory, Crucible furnace

1.2. Cupola

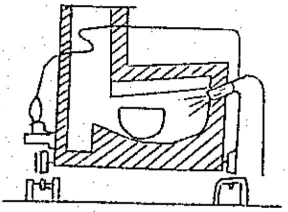
This is used most widely for melting of cast iron and is known for low construction cost, fuel cost and high efficiency. Recently, engineering development brought water cooled hot blast cupola into wide usage and there are many de-lux furnace of this type. Hot blast cupola has many advantages, especially its relatively high construction cost induced by metallurgical problems is offset by its much faster depreciation than that of cold blast type. But, it should be noted that these advantages make careful selection and control necessary.

1.3. Crucible Furnace

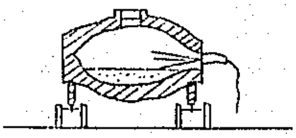
Melting is done with crucible within furnace, and oxidation and cementation effects by fuel gas are low but heat efficiency is not too high. There are heavy oil and coke fired, natural draft and forced air circulation type. Capacity of furnace is shown with its crucible size, for example if a furnace has No. 100 capacity, this means that this furnace has crucible which can melt 100 kg material. There are different type of crucible, namely, non-ferroa alloy, cast steel, tilting, and special type. Crucibles are highly moisture absorbtive and thorough drying before use is very important.

1.4. Reverberatory Furnace

Large furnace of this type is used when a volume of molten metal is needed, but mostly small reverberatory furnaces are used in common plant for Bronze, Light alloy, etc. melting. Dust coal, coal and heavy oil are used as fuel and melting is done by radiation or reflected neat from incandescent arch ceiling and side walls. Fig. 1(a), (b) are common reverberatory furnaces which are heavy oil fired and for Bronze and Light alloy, Fig. 1(c), (d) are same but coal and producer-gas fire and slightly larger.



(a)



(b)

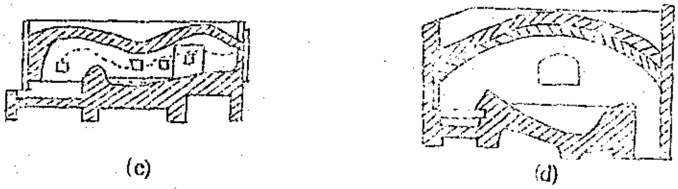

(c) (d)

Fig. 1 Reverberatory

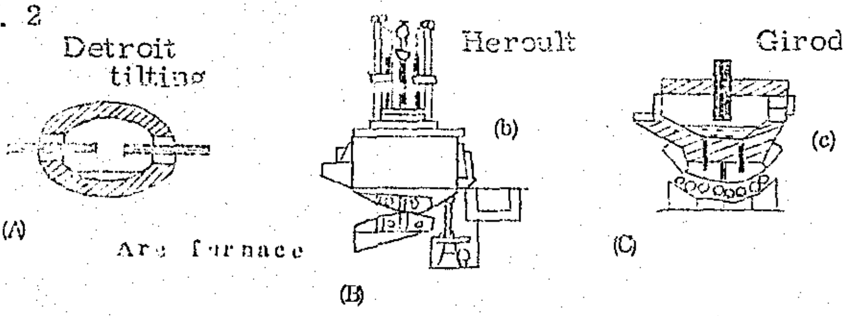
1.5. Electric Furnace

Melting is done by electric heat of are resistance and induction.

Table 1. Type of Electric Furnace

Type	Classification	Name	Use
Arc furnace	Direct Arc	Héroult Girod	Malleable cast iron, Cast steel, Cast iron
	Indirect arc	Detroit furnace	Cu-alloy, Malleable Cast iron.
Induction furnace	High frequency induction furnace		Alloy steel, Cast iron
	Low frequency Induction furnace		Malleable cast iron, Cast iron, Non-ferrous alloy
Resistance furnace	Criptol Tanman		Laboratory

Fig. 2

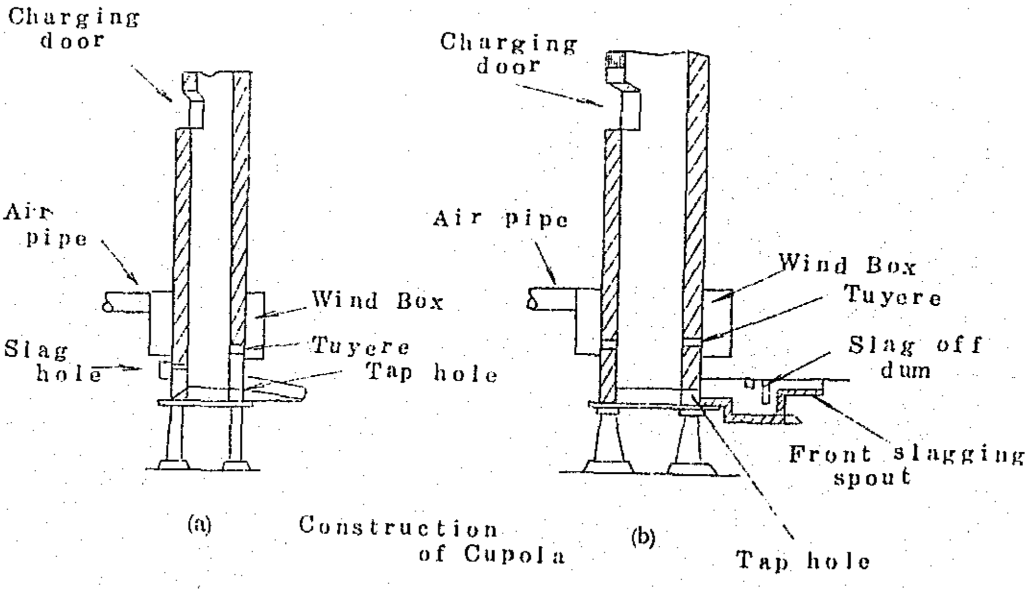


2. STRUCTURE OF CUPOLA

2.1. General Structure

Cupola is widely used for cast iron melting. Fig. 3 shows its general structure. Shell is built cylindrically with steel plate, and inside is lined with refractory. Wind Box is located in center of furnace and works as a reservoir to evenly air the furnace for combustion of coke. Holes to send air from wind box to furnace interior are called Tuyere. Peep hole is located on extended part of tuyere for observation of furnace interior during operation. Melting material is charged through charging door on top side of furnace. On one end of furnace bottom, single or multiple tap holes and drafts are located, and slag hole runs in different direction at slightly higher level.

Bed is made for easy cleaning of iron and coke after operation and also for convenient furnace wall repair.



(a) Construction of Cupola (b)

Fig. 3

2.2. Nomenclature of cupola parts and dimensions

For discussion of melting and chemical reaction inner furnace, cupola height is divided into various zones as shown in Fig. 4.

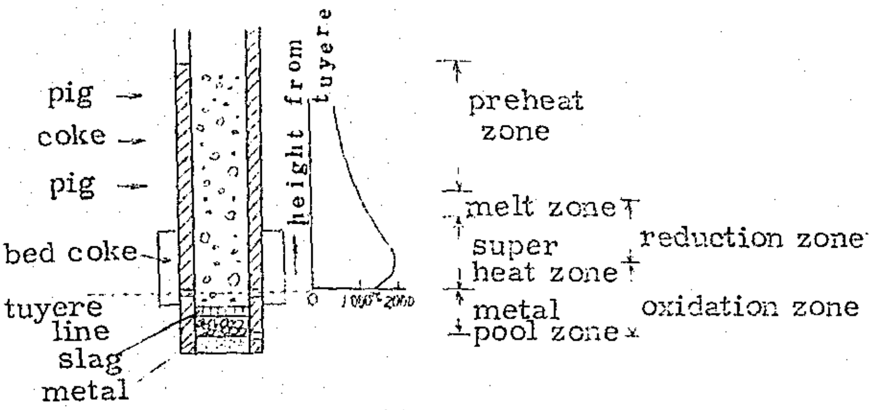


Fig. 4 Cupola height

To show the size and capacity of cupola unit such as ton and cm are used, these unit mean material melt per how and inner diameter of taper respectively. There is a certain relation-ship between cupola's melting capacity and its inner diameter.

Table 2 shows melting velocity of cupola with different inner diameter, and Table 3 shows dimensions of main parts of cupola.

Table 2. Standard Melting Velocity of Cupola

Inner dia. D (mm)	Section Area A (m^2)	Melting Velocity W (t/h)		
		$\frac{V}{A} = \frac{\text{Air Volume}}{\text{Area}}$ (m^3/min-m^2)=141-160	$\frac{V}{A}$=121-140	$\frac{V}{A}$=101-120
400	0.126	0.7	0.6	0.5
500	0.196	1.3	1.1	0.9
600	0.283	2.0	1.8	1.6
700	0.385	3.0	2.7	2.4
800	0.503	4.1	3.7	3.4
900	0.636	5.3	4.9	4.4
1000	0.785	6.6	6.1	5.6
1100	0.950	8.2	7.5	6.9
1200	1.131	9.8	9.1	8.4
1300	1.327	11.6	10.8	10.0
1500	1.767	15.6	14.6	13.5
Coke Ash %		10 >	10 >	12 >
Suitable coke ratio %		17 - 22	12 - 17	10 - 12
Molten Metal Tap Temperature °C		> 1500	1450-1500	1400-1450
Object of Operation		High Temperature Melting of Steel scrap used.	Common Melting	Economical Melting

Table 3. Standard dimensions of cupola parts

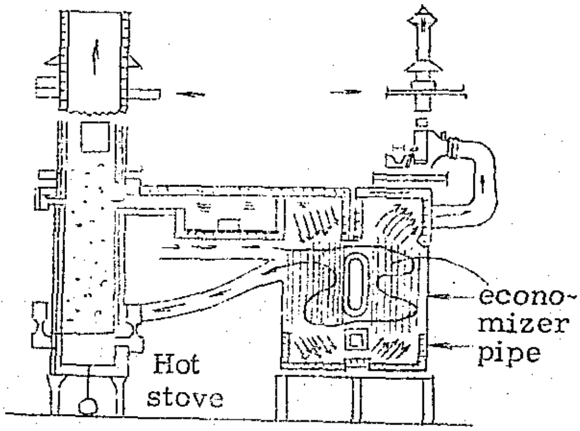
Inner dia. D(mm)	Section Area A(m^2)	Tuyere ratio A/a		Height ratio H/D	Charge Material Height H (mm)	Depth of Bed from tuyere h (mm)		In. dia. of Air supply pipe d (mm)	Thickness of Linning T (mm)
						Non Fore hearth	With Fore hearth		
400	0.126	4	9	6	2400	450	300	140	120
600	0.283	4	9	6	3600	630	400	200	190
700	0.385	5	10	5	3600	680	400	230	240
800	0.503	5	10	5	4000	720	450	270	240
900	0.636	5	10	5	4500	740	500	300	310
1000	0.785	5	10	5	5000	760	500	340	360
1100	0.950	5	10	5	5500	780	500	370	360
1200	1.131	8	13	4.5	5500	800	550	410	430
1300	1.327	8	13	4.5	5800	810	550	450	430
1500	1.767	8	13	4.2	6300	830	600	570	430

2.3. Hot Blast Cupola and Water Cooled Cupola.

2.3.1. Hot Blast Cupola

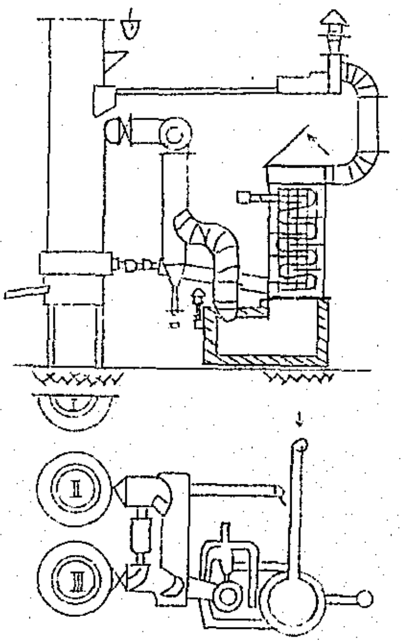
Blast air is heated to better heat efficiency and to obtain high temperature molten metal. Various types and structures are as follows:

(1) Exhaust gas latent heat type
CO in exhaust gas is combusted as CO_2 and heat blast air, Figs. 5, 6 and 7 are typical example of this type.



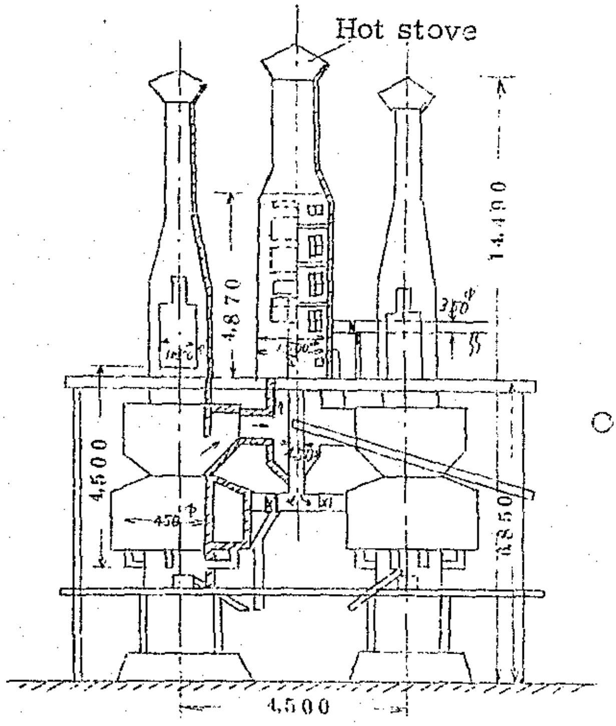
Griffin type

Fig. 5



Dr. Shack

Fig. 6



Okuma Type

Fig. 7

(2) Exhaust gas apparent heat type
Blast air is heated with temperature of exhaust gas, Fig. 8 shows this type, (designed by Moore)

(3) External Combustion type - Oil, gas, coal, etc. is combusted near cupola and Air heat exchanger is equiped in this type.
Comparison of Hot blast and cold blast Cupola is shown in Table 4.

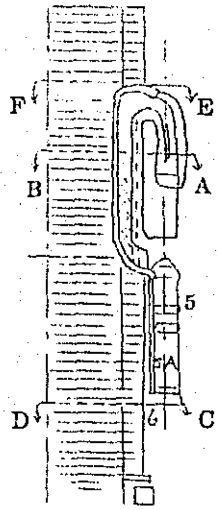


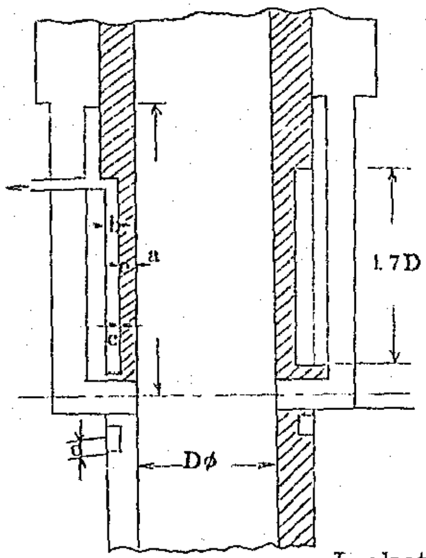
Fig. 8

Table 4. Hot blast v. s. cold blast cupola

Item	Hot blast	Cold blast	Item	Hot blast	Cold blast
Installation cost	large	small	Silicon & manganese loss	small	large
Maintenance cost	large	small	Iron loss	small	large
Fuel cost	small	large	Increase of sulphur	small	large
Use of low grade coal	yes	no	Metallurgical reaction, rate of	high	low
Tapping temperature	high	low	Lining errosion, rate of	high	low
Carbon pick up	high	low	Suspended phenomena	not much	much
Melting velocity	high	low	Equipment Control	much	not much

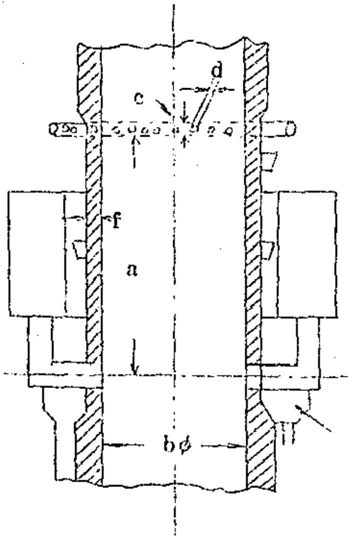
2. 3. 2. Water Cooled Cupola

Life of cupola lining is long with this type cupola and long time operation is possible. Furnace condition is stable and material of metal tapping is uniform. Slag control is easy and refining within furnace is possible. However, small cupola of this type has tendency to produce unstable material due to its low temperature moltenmetal as a result of uneven furnace combustion with cooled furnace wall. Consequently, i it is wise to offset this disadvantage by adoption of hot blast type. Types of furnace wall cooling are jacket type and shower type.



Jacket type

Fig. 9



Shower type

Fig. 10

3. FORE-HEARTH AND LOW FREQUENCY INDUCTION FURNACE

3.1. Fore-hearth and Spout

Generally, slap is not poured into fore-hearth, and slag is separated and removed at spout which is located between cupola molten pool and fore-hearth, this is shown in Figs. 11, 12. Fig. 13 shows a type of fore-hearth U-shaped spout, there also is one with ladle type spout which is widely used recently because tapping by tilting is very easy with this type spout.

Fig. 11

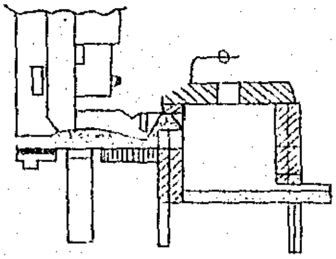


Fig. 12

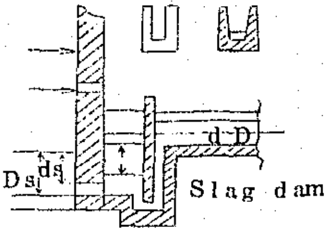
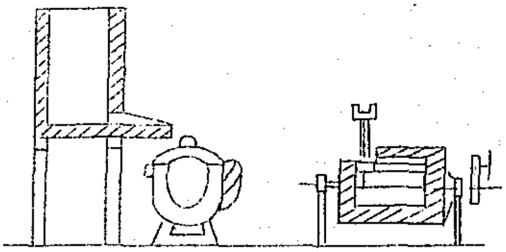


Fig. 13



3.2. Low Frequency Induction Furnace

This type furnace is electric furnace which has excellent handling character and other advantages plus being economical, and usage has been extended recently for melting of various type metals. Especially, it has become to be used as forehearth of cupola, also. This type furnace can be further classified into careless type and core type, approximately.

4. MEASUREMENT

4.1. Temperature Measurement

This measurement is an important melting operation measurement because temperature of molten metal has immediate relationship with change of furnace condition, material of molten metal, flowability of molten metal, etc. For this measurement, optical pyrometer and thermo-couple meter are widely used.

4.1.1. Optical Pyrometer

Structure is shown in Fig. 14, temperature is read very conveniently as lamp, resistance which is adjusted to give matching luminosity to instrument's lamp with luminosity of material measured.

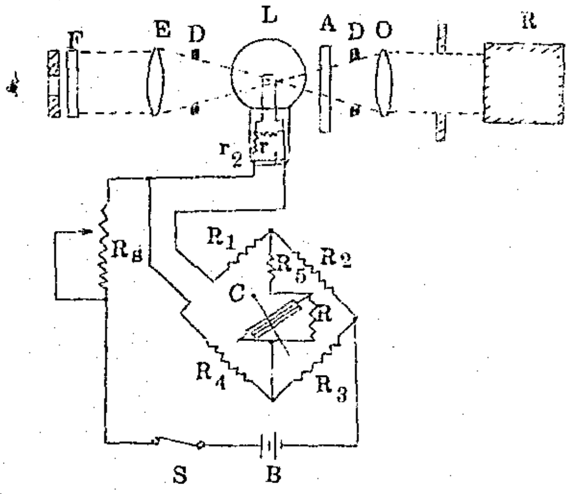


Fig. 14

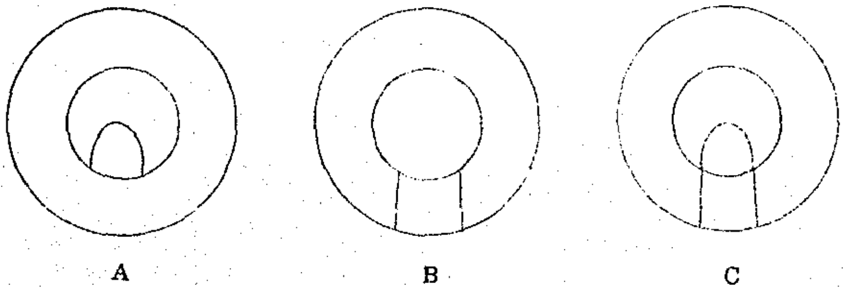


Fig. 15

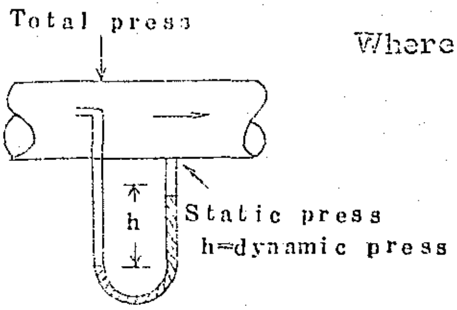
4.1.2. Thermo-couple Meter

Thermo-electricity is obtained when one end of connected two different metal or alloy wires is heated. Strength of this electricity depends on height of temperature differencial, with this thermo-couple connected to high sensitivity ammeter one can measure its electromotive force. For thermo-couple, Iron, Nickel, Constantan, Nickel-Chromium, Almel, Chromel, Platinum, Platinum-Rodhum, Indium, etc. are used.

4.2. Air Measurement and Control

Air measurement of cupola is important. For this measurement, Pitot-tube and orifice are used. As is shown in Fig. 16, pitot-tube measures air pressure (Total pressure = static press. + dynamic press.) parallel and vertical with air flow and from the difference of those two pressures, volume of air is known by following formula,

$$W = 60\ A\sqrt{\frac{2gh}{r}}$$



Theory of pitot-tube

Where: W: Volume of air, m^3/Min.
A: Cross-sectional area of air pipe, m^2
h: Dynamic press. of Pitot-tube, kg/mm^2=mmAq.
g: Earth's gravity, 9.8 m/sec^2
r: Density of air, kg/m^3 (20°C, 1 Atm., Wet 70%, 1.233 kg/m^3)

It is necessary to adjust manually a valve attached to air blower after air measurement is made, recently, however, this adjustment was automated hydraulically, pneumatically and electrically, examples are shown in Fig. 17, 18.

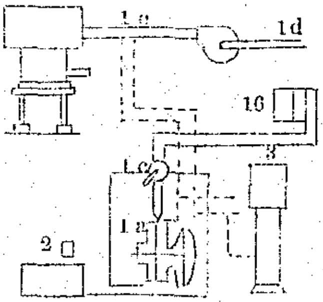


Fig. 17

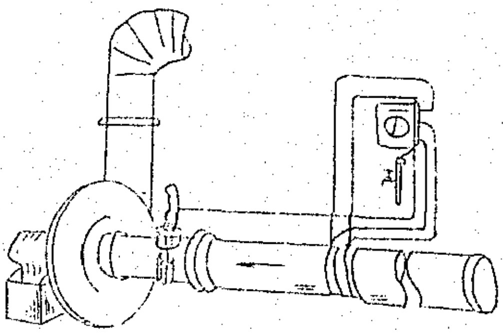


Fig. 18

5. AUXILIARY EQUIPMENT FOR CUPOLA MELTING

5.1. Blower

There are Root type and Turbo type blower for cupola.

(a) Root blower — With constant rpm, volume of discharged air is roughly constant regardless of its pressure. Volume of air is adjusted by rpm change.

(b) Turbo blower — This type is most widely used for cupola. Followings are main characteristics of this type with constant rpm,

- (i) With increased discharged air pressure, volume of air and required power decrease.
- (ii) Flow of air is continuous and without pulse.
- (iii) Maximum air pressure is obtained with 60% design air volume.

(c) Selection of blower

- (i) Volume of air and its pressure for max. melting.
- (ii) Temperature of air entering the blower
- (iii) Range of air volume adjustment.
- (iv) Type of cupola used and method of melting operation.

5.2. Raw Material Charging Equipment.

Charging of cupola is done both manually and mechanically. The former is mostly for smaller cupola and raw material is put on charging platform. For smaller cupola manual charging is most desirable, however, for the purpose of higher efficiency and labor condition improvement mechanical charging is taking over, recently.

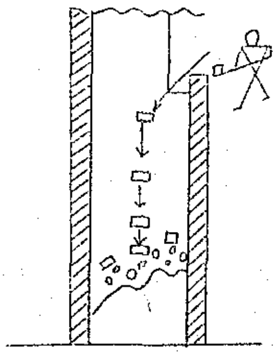


Fig. 19 Hand Charge

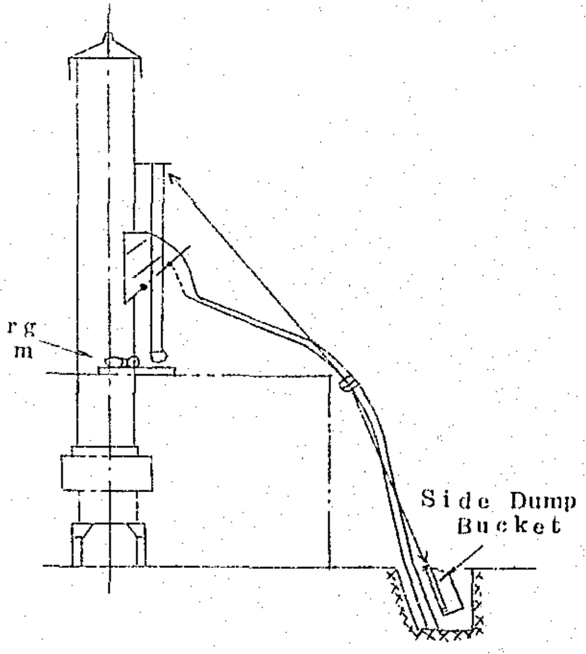


Fig. 20 Inclined Side Damp Skip Charger

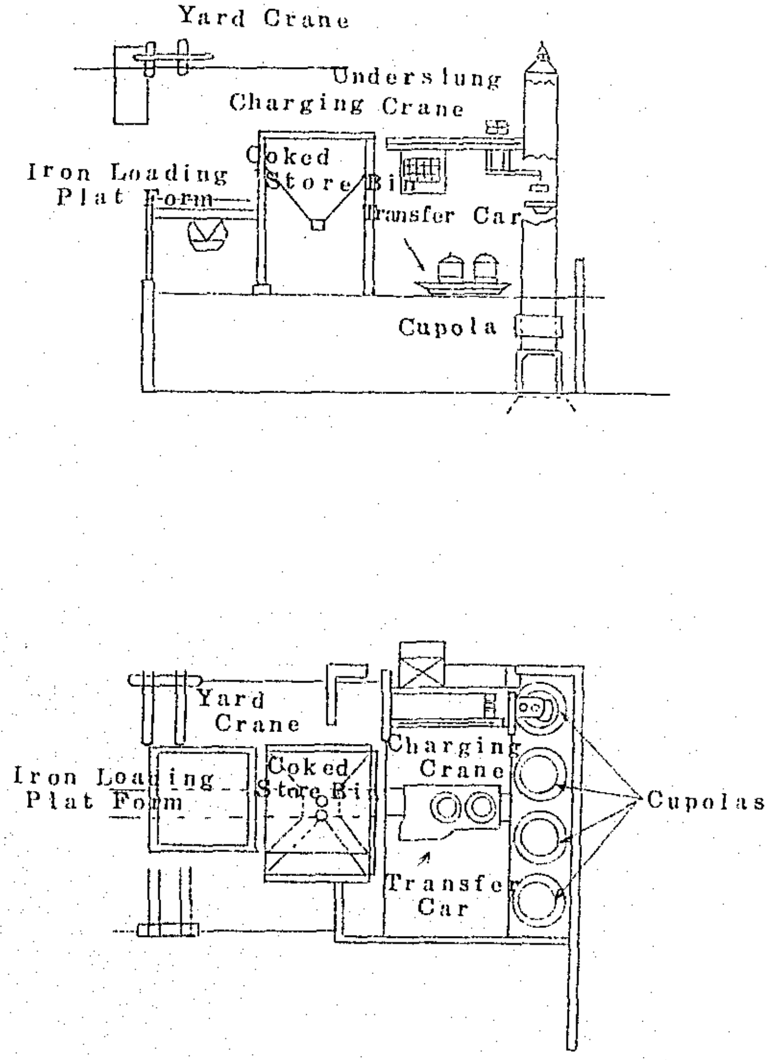


Fig. 21 Underslag type crane charging system

(1) Selection of charging equipment

Following items must be considered for selection

1 Number of cupola.
2. Number of cupola operated simultaneously.
3 Max. melting velocity of cupola,
4 Max. number of charging per hour,
5 Max. charge of iron per cupola,
6 Volume density of charged raw material.
7 Height of opening for charging
8 Material handling lay-out for cupola.

(2) Charging equipment and backet

There also is skip and backet type charging equipment. Four typical examples of this type are shown in Fig. 22.

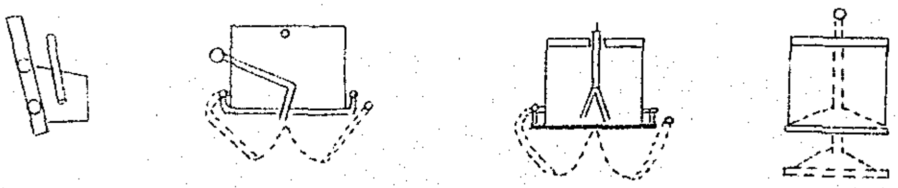


Fig. 22 The kind of bucket

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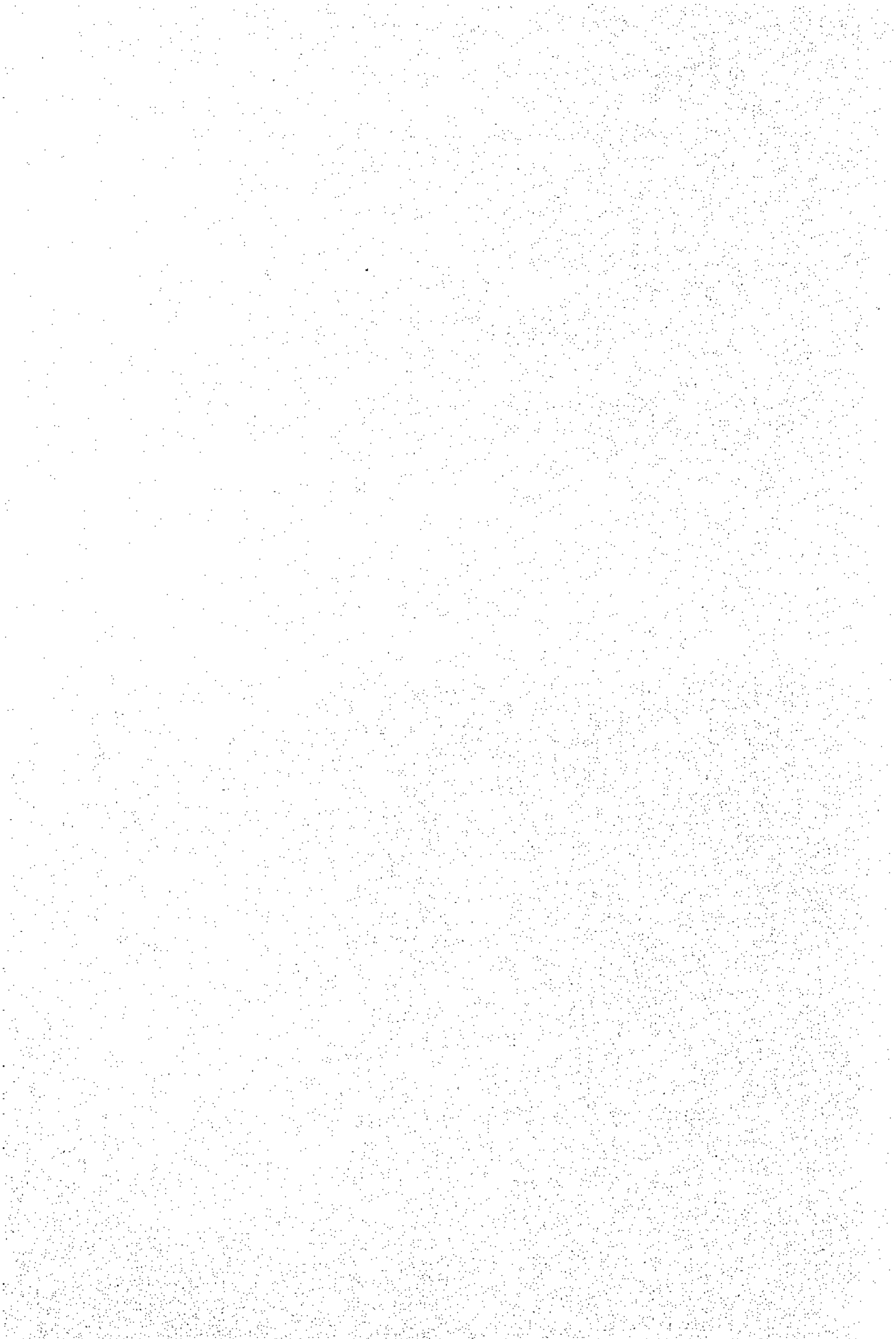
MELTING METHOD



MELTING METHOD

by: Yasunori Yokoi
Chief Engineer
Okuma Chuzo Co.

1. CHEMICAL REACTION

1.1. Heating Temperature

Quality of Cast iron is improved by high-temperature melting.

1.2. Combustion Reaction of Coke

Cast iron melting in cupola is done with combustion of coke by blown air, iron is melt in its atmosphere. Through chemical reaction which is accompanied by the above mentioned combustion, phenomenon such as melting velocity, temperature, carbon absorption, oxidation, etc. occur.

$$C + O_2 = CO_2 + 8080 \text{ Kcal/Kg}$$

$$CO_2 + C = 2CO - 3265 \text{ Kcal/kg}$$

Fig. 1 shows the case where all oxygen of air is combusted into CO_2 gas and also the relationship between CO_2; N_2; CO during the gradual change of all of this CO_2 gas into CO.

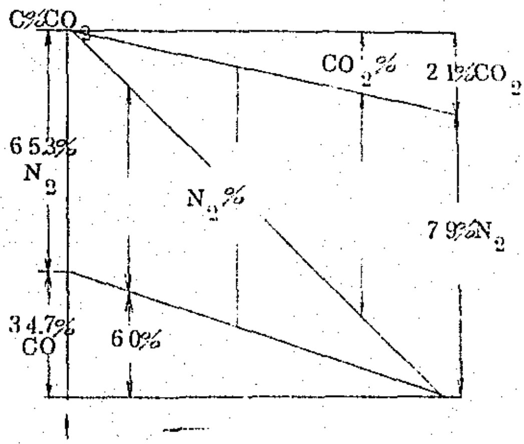


Fig. 1

1. 3. Furnace Gas and Temperature Distribution

Inside cupola, the distance of change in which all oxygen changes into CO_2 is 4-5 pieces of coke long. Similarly, coke grain size also affects gas distribution, with small grain the distance of oxidation reaction is short and heat generation and furnace temperature are uneven, this immediately promotes CO_2 reduction, then with CO-rich upper atomsphere the temperature drops suddenly. With larger grain, this distance of oxidation reaction increases, and with even heat generation CO_2 reduction does not progress fully, consequently upper atmosphere becomes rich with CO_2.

The above cases are shown in Fig. 2.

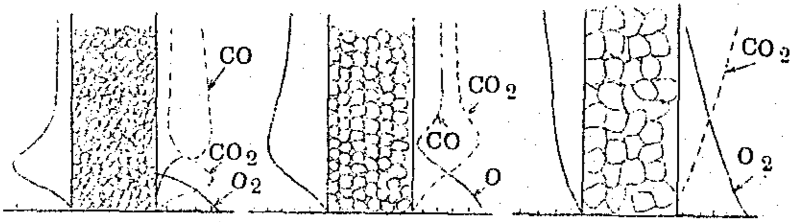


Fig. 2 (A) (B) (C)

1. 4. Deoxidation

1. 5. Oxidation and Carbon Absorption

1. 6. Slag reaction

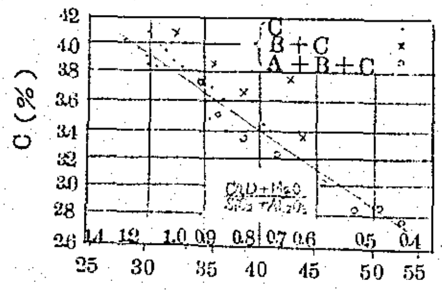


Fig. 3

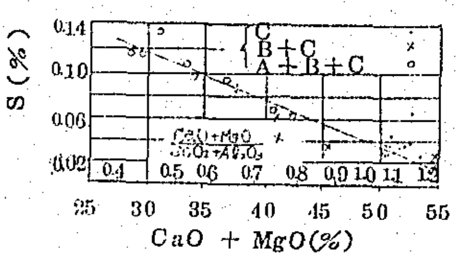


Fig. 4

2. CUPOLA OPERATION

2. 1. Operation Preparation

2. 1. 1. Repair of Melting Zone

Lining of melting zone of cupola is erroded deeply from previous operation 700-1000 mm away from Tuyere and this is repaired as specified by regulations.

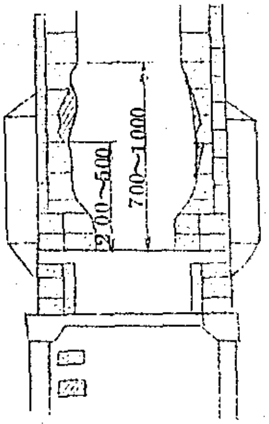


Fig. 5

Important points

1 Repair must be made with high-quality brick which is accepted by sonic-inspection at the time of receiving.

2 Brick must be moisture-free.

3 Minimise brick setting boundary.

4 Finish size of Tuyere with precision

5 Slag on furnace wall must be thoroughly removed.

2. 1. 2. Construction and Drying of Cupola Bottom

When furnace lining is completed, bottom sand is stamped with bottom door shut, then wood is inserted as Fig. 6 and is fired for drying.

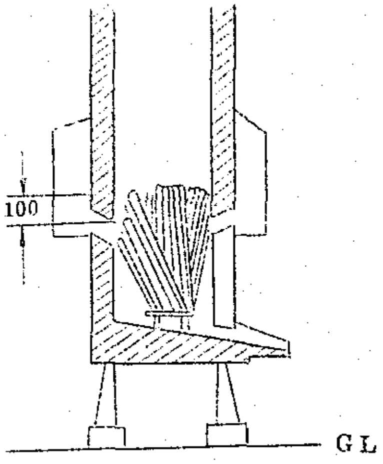


Fig. 6

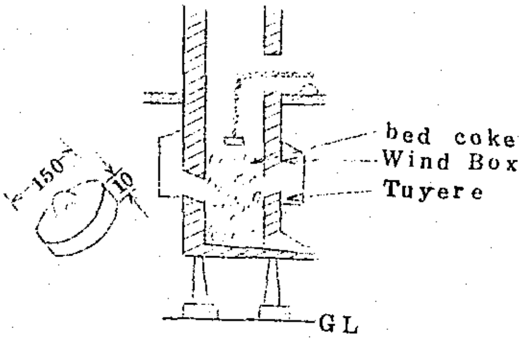
2.1.3. Firing of Bed Coke and Preheat of Fore-hearth.

After the wood is fired, bed coke is set afire. This operation starts 2-4 hours prior to the beginning of air blowing and coke is burnt with natural draft. During this process fire hole, tap hole, tuyere and slag hole are kept open. All of the necessary amount of coke should not be charged at one time but this amount must be put in at about ten different times within 2-3 hours.

For this initially charged coke which forms melting zone, slightly larger grain high-quality coke should be selected, so as to withstand the weight of charged iron and also to keep the level of melting zone at constant height.

After bed coke firing is complete, (3-4 hours after fire setting) air is temporary blown in for 3-5 minutes to promote the combustion and to remove the dust, with well-sunk bed coke, the height of bed coke is accurately measured from charging door as Fig. 7 and additional coke is fed if necessary.

After keeping natural draft until additional coke is well afire, material is charged in good order and prepare for air blowing, firing hole, tap hole and tuyere are shut during this time.



Measurement of bed coke height

Fig. 7

2.1.4. Bed Coke

Quality, grain-size and height of bed coke affect cupola operation very sharply and care must be exercised for the control of these elements. Bed coke should be of high quality and larger and uniform grain-size is chosen for better air draft. Minimum height of bed coke is obtained from the following formula, (this height is of above center of tuyere)

$$\text{Bed coke height} = 45 \times \sqrt{\text{Wind box pressure (mm } H_2O)}$$

In actural operation, height of this bed coke height plus 150 mm gives best results.

2.2. Material for Melting

2.2.1. Volume of Charged Iron and Coke per Layer.

Weight of charged iron per layer is determined by weight of charged coke. For cupola smaller than 850 mm dia., height of one layer of coke is 140-180 mm, for cupola larger than 850 mm dia., this height is 180-200 mm. Best grain size is 1/7-1/10 of cupola diameter. Standard number of charge is ten per hour.

2.2.2. Extra Coke

2.2.3. Flux

2.2.4. Material

2.2.5. Cupola Charge Calculation

(1) Components change

In cupola melting, component change occures in charged material through chemical reaction within furnace, mixing ratio of charged material is calculated with this change in mind. Table 1 shows general pattern of this change of chemical elements.

Table 1. Increase & decrease of elements %

Fe	C	Mn	Si	S	P
-1	Steel scrap 2.4 - 2.9	-20	-8	+20	0
-2	Hype entectic cast iron 3.3 - 3.6	-25	-15	+40 of sin coke	+10

(2) Example of calculation

2.3. Air Blowing

2.3.1. Start of blowing

Pre-heating of charged iron, coke, Lime-stone, etc. by natural draft is a necessity, this is done for 20 - 40 minutes.

2.3.2. Valume of air blown and its pressure

(1) Determination volume of air.

Following formula gives theoretical amount of air necessary for combustion of coke.

$$Q_o = \frac{1000W}{60} \times \frac{K}{100} \times \frac{K}{100} \times L = \frac{WKkL}{60}$$

Where Q_o : Volume of air (m^3/min.)

W : Melting capacity (t/h)

K : Amount of coke necessary to melt 100 kg of iron (kg)

k : Amount of carbon contained in 100 kg of Coke (kg)

L : Volume of air necessary to burn 1 kg of carbon (m^3/Kg c)

Volume of air needed for carbon combustion is

to make 1 Kg of C into CO ········ 4.45 m^3

to make 1 Kg of C into CO_2········ 8.90 m^3

Therefore, to get L in above formula, it is necessary to determine rate of combustion of furnace-top-gas of the cupola.

$$\text{Rate of combustion } \eta = \frac{CO_2}{CO_2 + CO} \times 100$$

This rate is usually 50 - 70%, L values of different rate of combustion are shown in Table 2.

Table 2

η %	50	55	60	65	70
L (m/Kg (c))	6.675	6.898	7.120	7.343	7.565

(2) Determination of air pressure

Air pressure depends on charge material height, charged iron, coke, grade & grain size of Lime stone, rate of tuyere, etc., and through fight control of these elements air pressure should be kept at certain level without change during operation, it is recommended that air pressure for each cupola be pre-set to certain degree.

Air pressure is obtained by next formula.

$$P = K\sqrt{Q}$$

Where P : Air pressure (mm H_2O)

Q : Theoretical volume of air Qo + Extra air 10% (m^3/min.)

K : Constant 56 - 68, 62 is found as ideal.

2.4. Other Points of Care for Operation

2.4.1. Inspection of tuyere

2.4.2. Inspection of charging door

2.4.3. Formation of cavity

2.4.4. Bridging

2.4.5. Clogging of tap hole

3. CHEMICAL AND PHYSICAL CONTROL

Slight change of operational conditions affect the quality of molten metal, therefore it is necessary to inspect property of molten metal quickly before it is poured into mold so as to avoid defects of cast products. Molten metal temperature, molten surface figure, fluidity, chill test, etc. are performed for inspection of molten metal and recorded for future operational data.

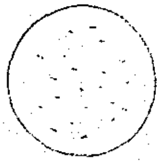
3.1. Chill Test.

As a method of cast iron quality control test-wedge and test-plate-chill are made, and for inspection of graphitization of molten metal, depth, width and coarseness of flactured surface are checked to know the quality.

3.2. Molten surface pattern

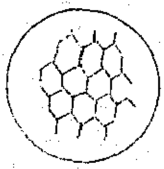
Various figures appear as the oxidiation film of molten metal surface is broken when molten metal cools to approx. 1400°C or less, unless oxidation is too severe.

1



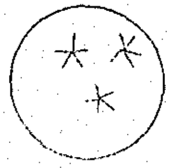
Polka-dot

2

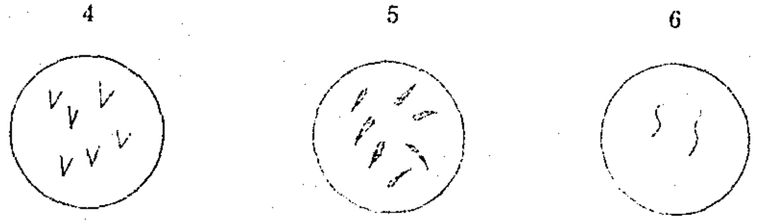


Turtle-back

3



Jute-leaf



Pine-leaf Bamboo-leaf Not-clear

Fig. 8

3.3. Fluidity Test

This test is to judge the ease of casting and quality of molten metal, and spiral test is mainly used.

4. DEFECTS RELATED TO MELTING

4.1. Grain Growth

(1) Components of molten metal.

(2) Melting method and raw material.

4.2. Mass hardness

4.3. Blow hole

4.4. Shrinkage cavity

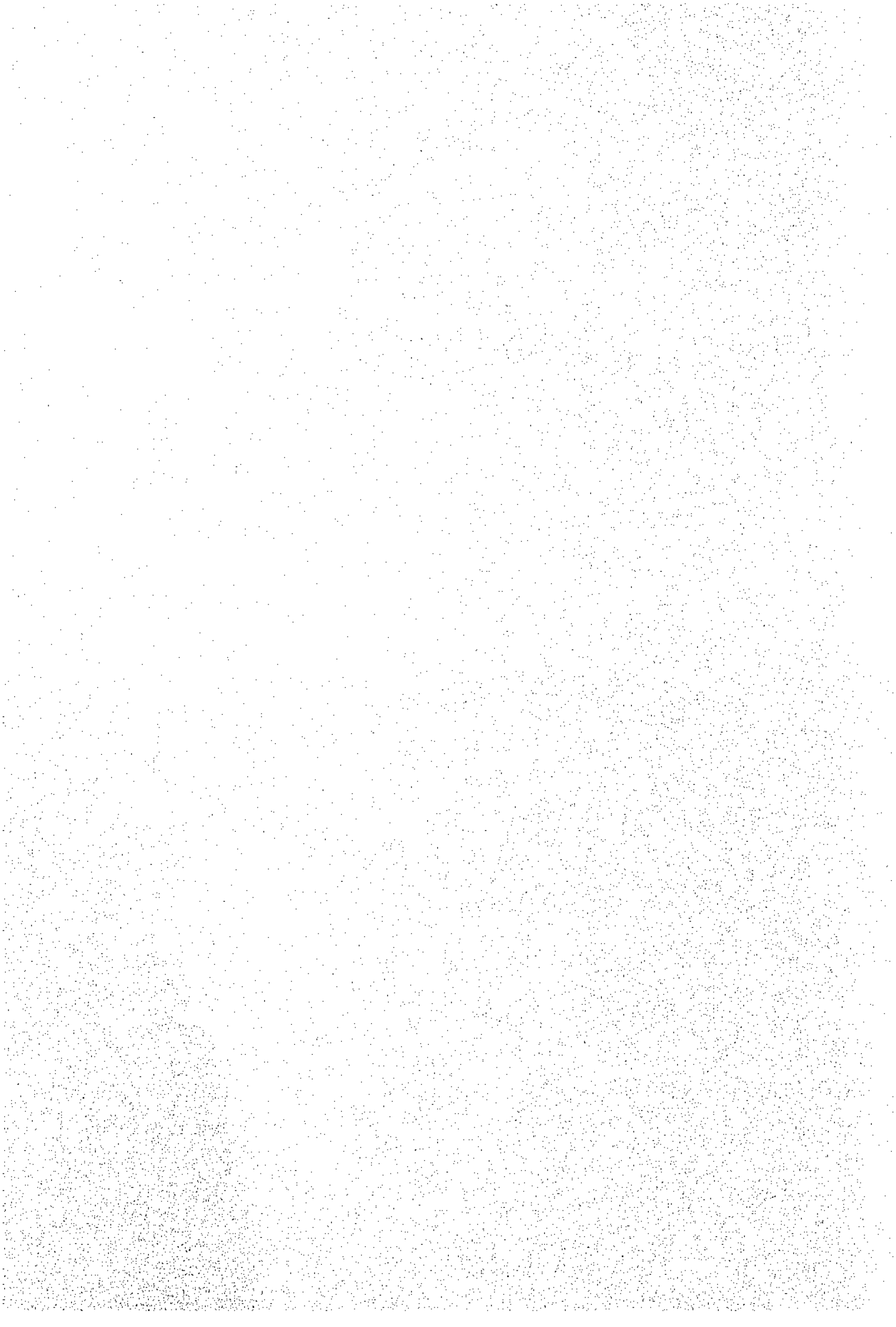
4.5. Crack

4.6. Cold shut

5. RECORD OF OPERATION

In cupola operation melting is continuous, and occurence of charge within the furnace affects molten metal in various way. For the control of cupola operation, recording of time table iron charge, volume of blown air, air pressure, tapping temperature, amount of tap condition of furnace, atmospheric temperature, humidity, weather condition, etc. is important, and through analysis of recorded results future operation can near the completion.

CAST IRON



CAST IRON

By: Dr. Yoshisada Ueda
Nagoya University

1. INTRODUCTION

Metals and alloys once melted are cast into certain molds, and used either as cast or after subjected to working and rolling. Cast iron belongs to the first case of utilization.

Distinction between steel and cast iron is made as follows:

As can be seen in Fe-C system equilibrium diagram (Fig. 1),

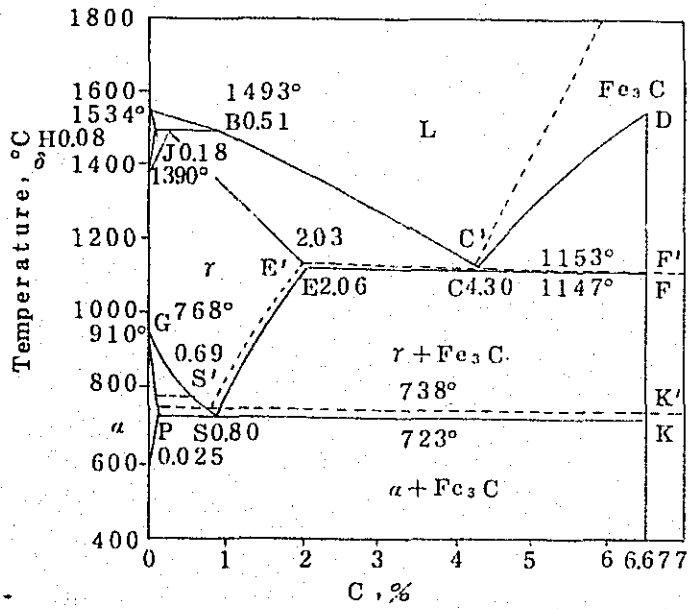


Fig. 1 Equilibrium Diagram of Fe-C System

the solubility limit of C in iron at the eutectic temperature of 1147 degree C is 2.06%. If the carbon content is below this solubility limit, the material is steel, whereas anything above this limit is cast iron In addition to carbon, the quantity of silicon in the composition of cast iron may be considered quite important, in controlling most of its characteristics.

Moreover, a small amount of Mn, P and S is also contained, and the effect of other microelement is also becoming a matter of concern.

Iron castings have been in use since old days. In those days, the only requirement of cast iron is that it is complete with the desired outside shape and inside structure and with very little heed paid to its strength. Therefore, iron high in C, Si and P which is readily castable was preferred. With the demand increasing in recent years for machine part castings, requirement for strength has become severe. Previously, the tensile strength of cast iron was 10 to 15 kg/mm^2. After World War I, it was improved to 30 to 40 kg/mm^2, and with practical application of spheroidal graphite cast iron after the World War II, its tensile strength went up as high as 60 to 80 kg/mm^2.

For the purpose of finding out the relative importance of cast iron in casting products and the areas of its application, Table 1 shows Production of Castings Recorded in 1959, 1960, 1963 and 1964 in Japan, and Table 2a and 2b show Production of Iron Castings and Malleable Iron Castings by Product Recorded in last years.

Table 1. Comperative Tonnage of Castings (In Metric Ton)
Japan

		1959	1960	1963	1964
Gray Iron	Commercial	1,358,424	1,806,107	2,114,699	2,407,465
	High grade	124,693	182,017	422,480	544,866
	Total	1,483,117	1,988,124	2,537,179	2,952,331
Malleable iron		99,480	129,053	173,478	201,968
Cast Steel		272,310	349,098	392,968	451,957
Copper alloy		55,476	72,571	78,975	90,280
Light alloy		26,138	34,874	44,399	56,954
Die Casting		25,297	40,309	78,643	88,115

Remarks: Commercial iron T.S. < 30 Kg/mm^2
High grade iron T.S. $\geqq 30$ Kg/mm^2

Table 2b Annual Tonnage of Malleable Cast Irons for Various Applications (Japan)

In metric ton

Applications	1963	1964
Industrial machinery and equipment	14,230	16,407
Agricultural implement and fishing equipment	3,648	3,110
Pipe fitting	75,251	87,030
Electrical appliance and communication equipment	12,583	12,370
Automobile	55,909	67,747
Bicycle	2,167	2,405
Industrial vehicle	849	1,000
Railroad	1,325	1,882
Others	7,515	10,017
Total	173,487	201,968

Table 2a Annual Tonnage of Cast Irons for Various Applications (Japan)

in metric ton

Application	1963	1964
Industrial machinery and equipment	875, 536 (129, 850)	958, 552 (149, 936)
Roll	77, 981 (18, 753)	88, 046 (20, 118)
Textile machinery and equipment	111, 138 (2, 123)	121, 436 (2, 283)
Casting mold and bottom plate	437, 454 (19, 138)	552, 100 (24, 768)
Agricultural implement and fishing equipment	56, 284 (8, 059)	57, 387 (8, 632)
Electrical appliance and communication equipment	87, 773 (4, 268)	112, 806 (4, 214)
Automobile	252, 166 (54, 804)	310, 431 (70, 036)
Industrial vehicle and bicycle	12, 742 (1, 072)	15, 495 (903)
Railboad	21, 119 (1, 214)	21, 854 (1, 126)
Port, harbor and vessel	66, 941 (18, 171)	81, 401 (21, 831)
Daily goods	89, 324 (--)	88, 394 (--)
Others	137, 534 (7, 054)	159, 399 (9, 423)
Pipe	301, 188 (157, 974)	384, 930 (231, 596)
Total	2, 537, 179 (442, 480)	2, 952, 331 (544, 866)

2. STRUCTURE OF CAST IRON

2.1. Fracture and Structure

A study of fracture section of wedge-shaped test piece, cast by molten cast iron, indicates that slow cooling area or area with thick wall shows gray fracture, while fast cooling area or area with thin wall shows white fracture, and in the intermediate area, the color is a combination of white and gray. This white area is called white cast iron, the gray area gray cast iron and the intermediate area mottled cast iron. The microstructure of each of these cast irons is that, gray cast iron is of ferrite structure, which surrounds flaky graphite existing in pearlite (Fig. 2a), or of the structure consisting of pearlite and graphite only (Fig. 2b), while white cast iron consists of cementite and perlite (Fig. 3)

Fig. 2a Gray cast iron (1)
(graphite, ferrite and pearlite)

Fig. 2b Gray cast iron (2)
(graphite and pearlite)

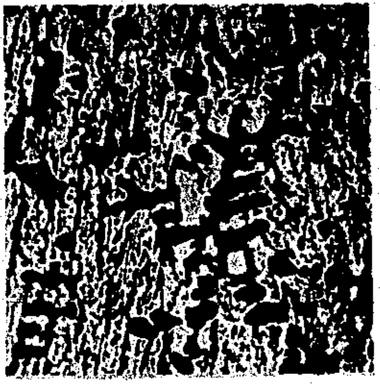


Fig. 3 White cast iron (Pearlite and Cementite)

This pearlite is what has been transformed from its initial crystallization, austenite, which is also co-crystallization of ledeburite. Mottled cast iron is of the structure in which both gray and white cast iron are interfused. (Fig. 4).

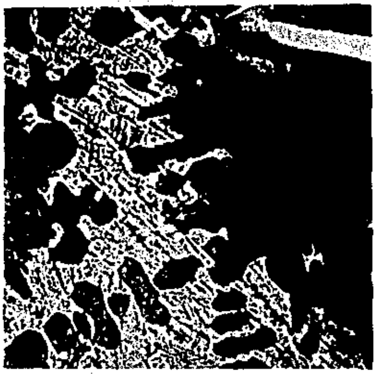
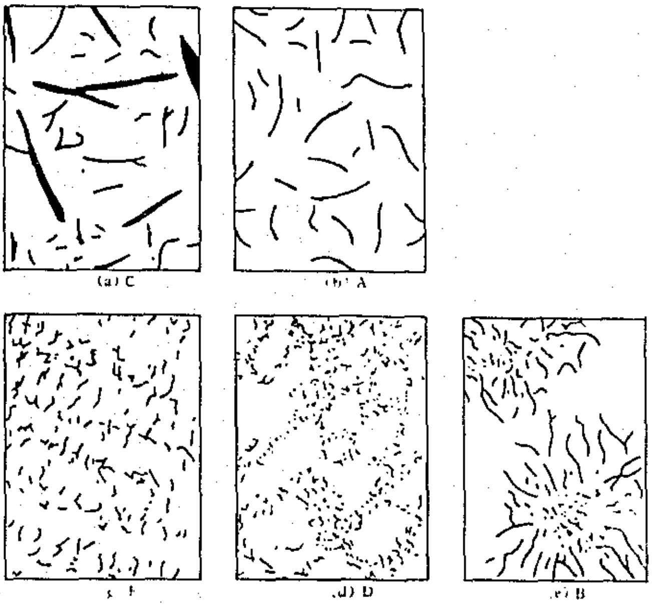


Fig. 4 Mottled cast iron (pearlite, graphite and cementite)

Thus, the fact that the structure of cast irons even of the same composition does change with the difference in cross section or in cooling rate is of great importance in considering the composition of cast iron. Also, any slight change in melting conditions, i. e., heating temperature, affects fracture, but greatest effects come from variation in C and Si contents. When C and Si are low, the iron easily turns into white iron, and with an increase in C and Si contents, mottled iron and gray iron are made. Even in gray iron, its fracture is light gray with very tiny particle sizes in some cases, and near black with coarse particle sizes in some other cases. This is due to the difference in the size and distribution of graphite flake; and the matrix structure namely, graphite in the light gray fracture is thinly distributed with its matrix consisting only of pearlite. It appears in materials with relatively low content of C and Si. The cast iron of this structure is called pearlite cast iron. The cast iron of this structure in which graphite is curved a little and thinly distributed has high strength. Meehanite cast iron belongs to this kind of structure which is called in other way high grade cast iron. The black gray fracture of coarse particles is of coarse flaky graphite with the matrix mostly of ferrite. The cast iron of this structure is called soft cast iron.

This structure tends to appear in casting of thick wall or when C and Si contents are high.



2.2. Relation of Structure and Equilibrium Diagram, and Maurer's Structural Diagram

Generally, the structure of alloy is illustrated by the equilibrium diagram. Also in the case of general alloy, the cooling rate during solidification affects only the shape and fineness of crystal grain. But, in the case of cast iron, depending on the cooling rate, the casting is made into white iron or gray iron, or in other words, different cooling rates produce cementite some time, and graphite at some other time. This phenomenon can be conveniently explained by a double equilibrium diagram (Fig. 1), according to which the formation of white iron structure is illustrated by Fe-Fe_3C system (solid line), and the formation of gray iron is illustrated by Fe-graphite system (dotted line). Furthermore, cast iron changes usually into white iron by quick cooling and into gray iron by slow cooling. For this reason. Fe-Fe_3C system is called the metastable diagram, and Fe-graphite system the stable diagram.

The following discussion concerns important effects exerted by carbon and silicon on different structures of cast iron.

Silicon is always contained unexceptionally in all cast irons in the range of 1 to 3%. Given a same cooling rate, the higher the Si content, the more likely it is that iron becomes gray iron, and given the same content of silicon, the higher the C content, the more likely it is that iron becomes gray iron. The structure of cast iron is thus controlled by correlation of C and Si contained. Maurer's structural diagram illustrates this correlation (Fig. 5). In this diagram, Range I (SEB) shows white iron, Range II (B'ED') pearlite iron, Range III (area to the upper right of EA) ferrite iron, Range IIa (BEB') mottled iron, and Range IIb (D'EA) iron mixed of pearlite and ferrite. This is pretty much in line with the results of actual operation. Particularly within a hatching zone, pearlite structure appears both in heavy and light sections in the order of 10 to 90 mm. High grade cast iron aims at this range as a target.

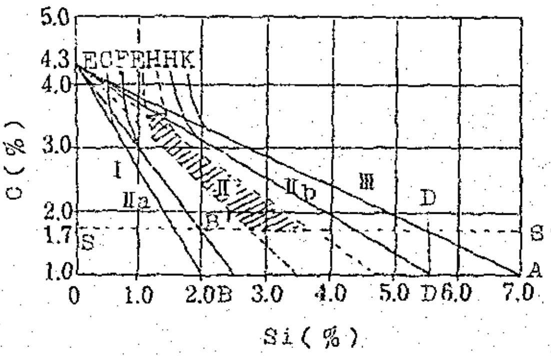


Fig. 5 Maurer's structural diagram

2.3. Effect of Other Elements on Structure

2.3.1. Mn: Mn is ordinarily contained in cast iron in the range of 0.4 to 1.0%. It gives very little effect to the structure of cast iron containing a considerable amount of Si. Mn combines with S to become MnS which either floats on top of molten iron or remain inside molten iron and turns into greenish gray inclusion after solidification, giving in both cases very little harmful effect to the characteristics of cast iron. Mn is a desirable element which neutralizes the harmful effect of S. Mn, further, is dissolved in ferrite, makes double carbide and dissolves into Fe_3C to increase its stability. These effects are not too conspicuous, however, when Mn content is less than 1%. With the increase of Mn content, pearlite size becomes tinier and it becomes difficult for ferrite to appear. So, in pearlite case iron, the more Mn, the better it is.

2.3.2. S: When Mn is not contained or contained only in a small amount, S becomes FeS accelerating the formation of white iron and the occurence of hard spot. It is believed th that the presence of S in excess had harmful effect to the fluidity of molten iron, which drawback, however, may be eliminated by Mn. The tendency of S to aid in the formation of Fe_3C is also sometimes taken advantage of.

2.3.3. P: P contained in cast iron is partly dissolved in ferrite but most of P is present as steadite.
Steadite is the ternary eutectic of Fe-Fe_3C-Fe_3P and its eutectic temperature is 980 degrees C. As its microstructure is of a peculiar shape, it is easily indentifiable.

Since the presence of P in cast iron lower its melting point and improves its fluidity, it is helpful for an artistical casting. But an increase of P brings about an increase of steadite, making cast iron hard and brittle.

2.3.4. Other elements: In addition to the above mentioned elements, other elements may be divided into those related to the formation of white iron and those related to the formation of gray iron.

White iron-related — Cr, V, Mo, Bi, B, Te, Mg, Ce, O, N.
Gray iron-related — Al, Cu, Ni, Ti, Zr, Sn.

Generally, those elements which related to white iron stabileze pearlite, and Cr, V, Mo. Ni and Cu render pearlite finer and harder, at the same time making graphite thinner. Sn is the graphitinging element as Si, Al and Ni, and helps to form coarser graphite from melt, but disturbs the appear of ferrite. So, by adding these elements singly or in combination, a structure suited for a given purpose may be formed. Furthermore, in connection with casting in a metel mold, Si powder is coated to prevent the surface formation of white iron, or Te powder is coated to facilitate the surface chilling of casting in a sand mold.

2.4. Effects of Melting Condition on Structure

The structure of cast iron is most susceptible to its chemical composition. However, melting conditions may alter the structure of cast irons even of the same chemical composition. It is for this reason high temperature melting is recommended. In fact, good graphite structure may be obtained by the high temperature melting of cast iron of more than 3.5% of C, but over-heating in the case of low carbon exerts harmful effects. In case like this, strong cast iron can be obtained by inoculation of ferro-silicon or calcium-silicide. The length of heating has similur effect as beating temperature, but this effect is not notable.

2.5. Effects of Cooling Condition on Structure

Changing in the structure of cast iron prompted by a cooling rate was mentioned already. Fig. 8 indicates the results of study made by Greiner and Klingenstein regarding the relationship between C + Si % and the thickness of section in the same manner as Maurer's structural diagram. Since C and Si give different effects each other, Fig. 7 takes into consideration this fact. Difference in casting temperature changes cooling speed and effects to structure. The higher the casting temperature, the more the mold is heated and the slower the cooling speed becomes.

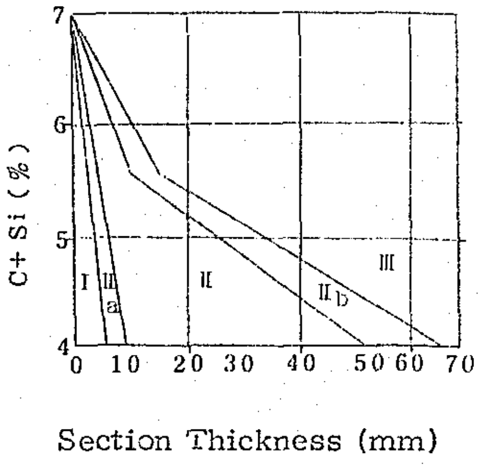


Fig. 6 Structural Diagram of Greiner and Klingenstein

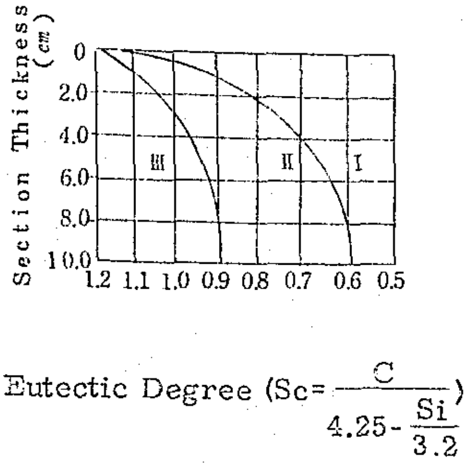


Fig. 7 Eutectic Degree and Structure.

I. Mottled cast iron
II. Pearlite cast iron
III. Soft cast iron

2.7. Inoculation

The effects of various common elements on the structure and therefore the properties of cast iron have been described above, as well as their relationship to the all-important effect of cooling rate. These effects are generally proportional to the amount of element involved, and quantitative relationship have been determined experimentally in most cases.

However, if an element such as silicon is added to a ladle of molten iron while filling or otherwise added after the iron is molten, the effect on the eventual structure of the iron wholly out of proportion to the amount added. Silicon, usually as crushed ferrosilicon, as a ladle addition is effective in amounts as low as 0.05 to 0.10 per cent, which would be hardly detectable in effect normally. The practice of adding a material to the molten iron is termed inoculation, since one of the explanations of the effectiveness of the practice is that small seeds or nuclei of undisolved or precipitated material are thereby created in the iron to serve as centers of solidification. The mechanism is actually still not well understood.

The effects may be summarized as:

(1) A decrease in chilling tendency or white iron formation, without appreciable effect on pearlite stability.

(2) Marked improvement in randomness of graphite flake distribution and decrease in flake size.

(3) Decreased section sensitivity.

The effects result in increased strength, better toughness, improved machinability, and the ability to make castings of wide variation in section thickness with gray, machinable corners and thin sections, and heavy sections of satisfactory strength and hardness. The benefits are so pronounced that a considerable proportion of all gray iron produced today is inoculated.

Crushed natural or artificial graphite is widely used for simple control of chill depth in production, as is crushed ferrosilicon. Combinations such as calcium-silicon-manganese-zirconium, and silicon-chromium are effective in controlling chill depth while decreasing section sensitivity due to the pearlite retaining effect of the carbide stabilizing element involved.

Inoculation must be carried out with iron which is at least 2650 F (1455 C) and preferably hotter, and the melting conditions must be taken into consideration.

2.7. Graphitization of Cementite on Annealing

Fe_3C, when heated, produces graphite. The same phenomenon is true of cementite both in ledeburite and pearlite. According to "double diagram", graphitization in this instance is induced by the following mechanism.

Fig. 8 shows that if white iron of X composition is heated up to a temperature of T for annealing, C contained in austenite is saturated to the level of Acm line or saturated with Fe_3C at this temperature. However, the concentration of C in austenite here is super-saturated against the level of Agr line, and hence through precipitation of graphite it is reduced to the Agr line. Since this condition is unsaturated against Fe_3C, Fe_3C is further dissolved and tends to raise its concentration to the level of Acm. This dissolving of Fe_3C into austenite and the recurring precipitation of graphite result in the disappearance of Fe_3C and in the form of graphite precipitation.

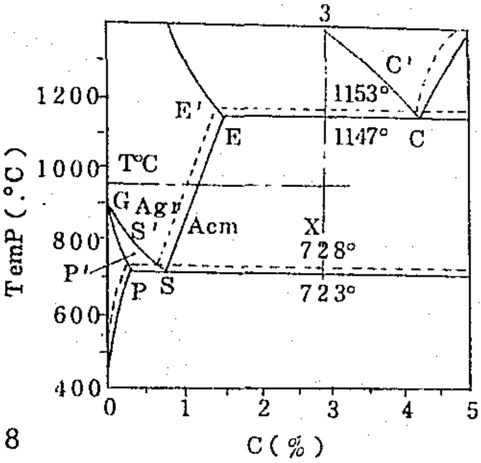


Fig.8

Fig. 8

2.8. Heat Treatment of Cast Iron

Casting stress occurs on the interior of iron casting whenever there is variation in a cooling rate resulting from the uneven wall thickness of the product. Stress relief annealing is performed to eliminate this residual stresses which may reduce its strength, can cause distortion, and, in some extreme cases, may even result in failure or Cracking of the Casting. The optimal temperature of stress relief annealing is 550 to 600 degrees C and its optimal time is 6 to 10 hours. For precision castings like machine parts, annealed cast products are sometimes put through seasoning in which the casting is exposed to air outdoors for a long period of time.

In order to soften a cast iron for free cutting, it is recommended that anneal is at 700 to 750 degrees C for 2 to 3 hours. For the purpose of complete removal of massive cementite, it is necessary to anneal casting at 900 to 955 degree C.

In terms of structure, cast iron is regarded as steel mixed with graphite. Like steel, it is capable of being quenched and tempered. When gray cast iron is quenched at a temperature of 900 degree C, its matrix turns into martensite with graphite remaining unaltered. When the speed of quenching is slowed down somewhat, the cast iron changes into either troostite or sorbite. If cast iron is quenched too fast, it tends to result in cracks, and for this reason, oil quenching is preferred. Quenched cast iron is high in hardness, low in strength and brittle, but by tempering it at temperatures of 200 to 600 degrees C, its tensile strength and ductility may be improved. These methods of heat treatment are more effective and either to handle when given to alloy-added cast iron, rather than to ordinary cast iron.

3. PROPERTIES OF CAST IRON

3.1. Physical Properties

The physical properties of cast iron are largely affected by its composition and structure. Table 3 shows the physical constants of commercial cast iron.

Table 3. Physical Properties of Cast Iron

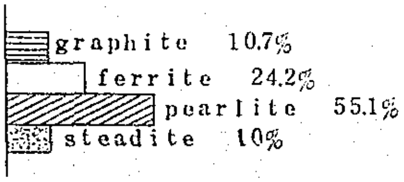
Specific Gravity	Melting Range (°C)	Specific Resistance ($\mu\Omega/cm^3$)	Thermal Conductivity (cal/cm. sec. °C)	Coefficent of Thermal Expansion, 0 - 100°C	Specific Heat, 0 - 100°C
7.10~ 7.30	1130~ 1300	30~ 150	0.07~ 0.13	10~ 11×10^{-6}	0.13

3.2. Mechanical Properties

The mechanical properties of cast iron, like its physical properties, are affected not only by composition, but also by the quantitative ratios and distribution of ferrite, pearlite and graphite. Table 4 shows the mechanical properties of each phase of cast iron structure:

Structure / Property	Ferrite	Pearlite	Sorbite	Cementite	Steadite	Graphite	MnS	FeS
Tensile Strength, kg/mm^2	36.6	84.4	112.4	3.5	none	none		
Elongation %	40	15	15	none	—	none		
Brinell Hardness Number	95	240	255	550 or more	400	—		
Specific Gravity	7.86	7.74		7.66	7.32	2.20 2.55	4.00	5.02

Fig. 9 shows the ratio of volume of each phase of structure.
(common)



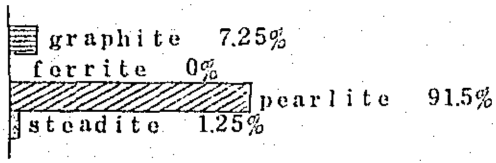


Table 5. J. I. S. Specification on Gray Iron Casting

JIS G 5501 (1956)

Class	Mark	Approx. Wall Thickness, mm	Diam. of Test piece as Cast mm	Tensile Test		Transverse Test		B. H. N.
				Diam. of Test piece, (mm)	Tessile Strength, Kg/mm2 (min.)	Load, Kg (min.)	Deflection mm(Min.)	(max.)
Gray Iron No. 1	FC 10	4 to 50	30	20	10	700	3.5	201
Gray Iron No. 2	FC 15	4 to 8	13	8	19	180	2.0	241
		over 8 to 15	20	12.5	17	400	2.5	223
		over 15 to 30	30	20	15	800	4.0	212
		over 30 to 50	45	32	13	1700	6.0	201
Gray Iron No. 3	FC 20	4 to 8	13	8	24	200	2.0	255
		over 8 to 15	20	12.5	22	450	3.0	235
		over 15 to 30	30	20	20	900	4.5	223
		over 30 to 50	45	32	17	2000	6.5	217
Gray Iron No. 4	FC 25	4 to 8	13	8	28	220	2.0	269
		over 8 to 15	20	12.5	26	500	3.0	248
		over 15 to 40	30	20	25	1000	5.0	241
		over 30 to 50	45	32	22	2300	7.0	229
Gray Iron No. 5	FC 30	8 to 15	20	12.5	31	550	3.5	269
		over 15 to 30	30	20	20	1100	5.5	262
		over 30 to 50	45	32	27	2600	7.5	248
Gray Iron No. 6	FC 35	15 to 30	30	20	35	1200	5.5	277
		over 30 to 50	45	32	32	2900	7.5	269

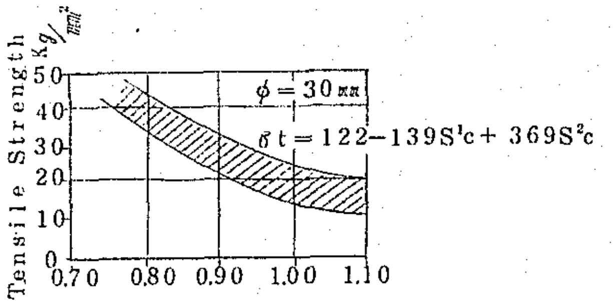
(Remarks) :

i. Hardness test is not performed unless specifically asked for by a customer, and no mechanical test is ordinarily given on Grade No. 1 (FC 10).

ii. The Mechanical properties of cast iron, when its main wall thickness is not specified, shall be the values specified for a test piece as cast with the diameter of 30 mm.

iii. The method of specifying the main wall thickness of cast iron, and requirement on the mechanical properties of cast iron with its main wall thickness up to 4 mm and over 50 mm are to be determined by agreement between a customer and a producer.

3.2.1. Tensile strength



Eutectic Degree (Sc) $Sc^* = \dfrac{C}{4.25 - \dfrac{Si}{3.2}}$

Fig. 10 Relation of Sc and Tensile Strength

* The similar expression in place of this is carbon equivalent.

$$(C.E. = T.C. + \frac{Si + P}{3})$$

The strength of cast iron is measured in terms of tensile strength. It decreases as the contents of carbon and silicon go up. Particularly, the effect of C content on the tensile strength is outstanding. This relationship is shown in Fig. 10. As evident from this Fig., the strength of cast iron of even the same composition varies considerably. All this signifies the importance of a melting method. These data are based on the result of test conducted with a test rod of 30 mm diameter. Since the strength of cast iron changes sharply with its wall thickness, it is better to use an actual-size test rod to find the strength of casting in question. J.I.S. has provisions in it, as shown in Table 5, covering test piece dimensions and wall thickness of cast iron by grade.

3.2.2. Maximum Load of Transverse Test

When subjected to this maximum load of transverse test, cast iron breaks without being bent because of its brittleness. Stress under which this breakage occurs is about 2 times as much as its tensile strength is small, and about 1.5 and 1.8 times as much as its tensile strength is more than 25 kg/mm^2. Cast iron sags to a degree when it breaks, and the greater the sag, the more ductile it becomes. Consequently, tensile strength, transverse load and deflection serve as an effective clue to finding out the real quality of cast iron.

3.2.3. Hardness

Hardness increases proportionately with strength due to composition and structure, and it is especially sensitive to the amount of C and Si contained (Fig. 11). In the case of ordinary cast iron with the tensile strength of 30 kg/mm^2, its hardness goes up to 230. Since hard cast iron is difficult to machine, the desirable properties of cast iron are high strength and low hardness. Exception should be made with the cast iron of B.H.N. of over 240, of which cutting ability becomes increasingly difficult.

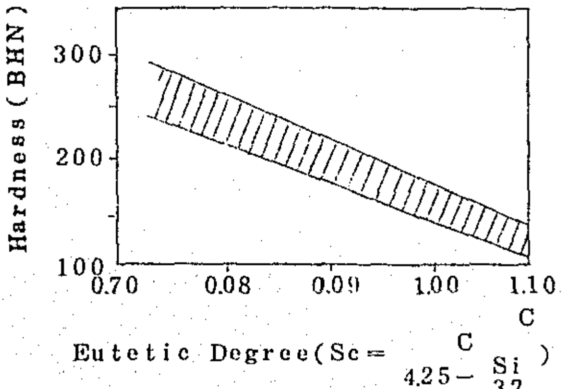


Fig. 11 Relation of Sc and Hardness

3.2.4. Compressive Strength

Cast iron possesses remarkable high compressive strength. Cast iron of even low tensile strength usually has the compressive strength of about 45 kg/mm^2. When the tensile strength is about 30 kg/mm^2, its compressive strength goes up above 100 kg/mm^2. The compressive strength of cast iron is considered to be within the range of 45 to 120 kg/mm^2 or about 3 to 4 times as much as its tensile strength. This is one advantage accuring from the quality of cast iron, while the compressive strength of steel as well as tensile strength of it are about equal.

3.2.5. Relative Harte, Reifegrad

Within σt is 15-40 kg/mm^2, there exists the relation $H_B = 100 + 4.3\sigma t$. Then Relative Harte RH is defined as followed:

$$RH = H_B / [H_B] = \frac{H_B}{100 + 4.3\sigma t}$$

RH $<$ 1 good material, RH $>$ 1 undesirable material.

Next, there is a relation σt and Sc.

$$[\sigma t] = 102 - 82.5Sc \quad (d=30mm)$$

Reifegrad RG is defined as followed

$$RG = \sigma t / [\sigma t] \times 100 = \frac{100\ \sigma t}{102 - 82.5Sc} \quad (\%)$$

RG $>$ 100 % good material, RG $<$ 100% is undesirable material.

3.3. Other Properties

3.3.1. Wear Resistance

It has been long proven that cast iron is most useful when used at parts of sliding friction. Cylinder liner and piston of internal combusion engine are most typical examples. As regards the reason why cast iron is fit for such application, no definite answer has been yet found. What little is known for sure is that graphite present in structure plays an essential role. Graphite functions as a lubricant against dry wear, and for wet wear, adding lubricant against dry wear, and for wet wear, adding lubricant oil is held in graphite structure. Low modulus of elasticity, pretty thermal conductivity, resistivity for thermal shock and bardness of cast iron may be reason for those uses. But even among cast irons of the same kind, there are variations in the degree of wearresistivity property. Cast iron with graphite distribution non-oriented and pearlite matrix has better quality. It is known that cast iron with dendrite distribution of graphite and matrix mixed with free cementite has poor wear resistivity. Hithertofore, high phosphor content used to be desirable, as it added to the wear resistivity of cast iron in a certain, limited application, but generally, low phosphor is believed to be safe now.

3.3.2. Damping Capacity

Vibration in one form or another is always inherent with an ordinary industrial machine. If nothing is done about this vibration, it results in resonance, giving adverse effect on the accuracy of the machine and also on its useful life. When a piece of steel is striken, its reverberation does not die away quickly, but in the case of cast iron, its reverberating sound can be instantly hushed away. Cast iron, in other words, has excellent vibration absorbing property which is very useful in an industrial machine. Fig. 12 shows an amplitude of vibrations purposely given to steel and cast iron and recorded till it vanished away. This property is called damping capacity which is one of the important characteristics of cast iron.

3.3.3. Heat Resistance

Below a temperature of 500 degrees C, cast iron is more difficult to oxidize than steel, for while steel has an active tendency of ridding itself of oxide film from its surface, oxide film on the surface of cast iron is tightly adhered and not easily peeled off. Oxidation is prevented from infiltrating into cast iron. Above 700 degrees C, however, growth occurs on cast iron by which dimensions are extended. If heating and cooling are repeated alternately, it would eventually cause damages on cast iron. This is one large drawback of cast iron, which can be corrected to a considerable degree by adding Cr, Si or Sl.

3.3.4. Corrosion Resistance

It is generally believed that cast iron is weak to corrosion, but it is fairly corrosion resistant against plain water or soil, as in the cast of water pipe line of which life lasted over several decades. To acid, cast iron is more sensitive than steel, but it resists alkali fairly well. Corrosion resisting resisting properties are improved by adding Ni, Cr, Cu, and the like.

4. APPLICATIONS AND STANDARD COMPOSITIONS OF GRAY CAST IRON

The application of cast iron extends over wide areas. There are usual compositions of cast iron fit for each different application which is given in Table 6.

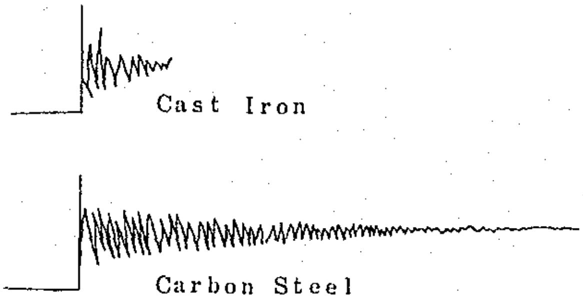


Fig. 12 Curves indicate the difference between internal damping capacity of cast iron and carbon steel

5. SPECIAL CAST IRON

5.1. Malleable Cast Iron

While it is easy to make cast iron, it can not be bent like steel. Malleable iron was developed in an effort to improve this unfavorable quality of cast iron. It is lower in carbon than gray iron casting. Malleable iron is annealed white cast iron with ferrite and graphite structure.

Malleable cast iron is divided into two kinds. One is called while-heart malleable cast iron. White iron is annealed for a long time with mill scale at a high temperature 850 - 1000°C in order to decarbonize the carbon in cementite by oxidation. Its application is limited to small and thin castings. The other is called black-heart malleable cast iron. By annealing white iron first at 850 to 950 degrees C for 30 to 40 hours and next at 680 to 720 degrees C for 30 to 40 hours, cementite structure is changed to ferrite and graphite structure and softened, so that it becomes tough and resistant against impact. It is widely used as automobile parts, transmission line parts, pipe joints, etc.

Table 7 shows chemical compositions of white-and blackheart malleable cast iron, and Table 8 and 9 show J.I.S. provisions on white- and black heart malleable cast iron. Table 10 shows J.I.S. provisions on pearlite malleable cast iron.

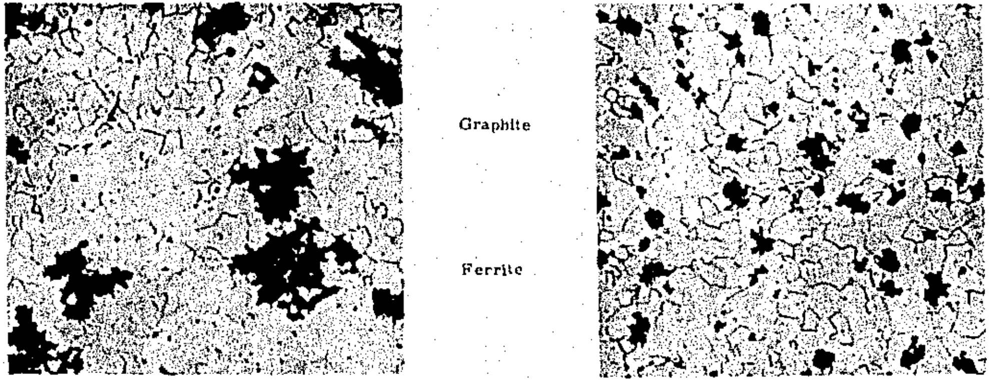


Fig. 13 Microstructure of Malleable Iron

Table 6. Applications and Compositions of Cast Iron.

Applications	TC %	Si %	Mn %	P %	S %	Ni %	Cr %	Cu %	Mo %
Parts for Agricultural Implement	3.25~3.35	2.0~2.5	0.6~0.65	<0.80	<0.10				
Main Parts for Machine Tools	3.20~3.40	1.40~1.80	0.70~0.90	0.20~0.40	<0.12				
Main Parts for medium Internal Combustion Engine	3.00~3.40	1.20~2.00	0.70~0.90	<0.30	<0.10				
Ingot Molds	3.6	1.40~1.80	<0.80	<0.30	<0.07				
Brake Drums	3.10~3.50	2.25~2.75	0.75~1.10	<0.30	<0.10	0.15~1.50	0.20~0.50	0.40~0.60	
Camshafts(Automobile)	3.00~3.20	2.00~2.25	0.65~0.90	<0.18	<0.15	<0.40	0.80~0.90		0.40~0.50
Cylinder Heads	3.10~3.30	1.50~2.00	0.60~0.80	<0.30	<0.10			0.50~	
Fire Grates (Steam Engines)	3.00~3.20	1.40~1.60	0.60~0.80	<0.20	<0.10		0.40~0.60		
Cylinder Liners (Medium Diesel Engines)	3.00~3.10	1.30~1.40	0.80~0.90	<0.20	<0.10				
Large Gears	3.05 3.25	1.40 1.62	0.75 0.95	<0.20	<0.12			1.50	
Crankshafts (Gasoline Engines)	3.00 3.15	2.00 2.30	0.85 0.95	0.10 0.15	0.10 0.12	1.50 1.75			0.80 0.95
Brake Shoes	2.80 3.20	1.00 1.20	>0.5	<0.40	<0.10				
Light Sections (up to 20mm section)	>3.5	2.00 2.40	0.50 0.70	0.20 0.40	<0.08				
Heavy Section (over 20 mm section)	<3.4	1.40 1.80	0.50 0.80	0.20 0.40	<0.08				

Table 7. Chemical Composition of White-, and Black-heart

Kind	C	Si	Mn	P	S
White-heart	2.8-3.5	0.4-0.8	0.2-0.4	<0.15	<0.20
Black-heart	2.2-2.8	0.8-1.2	0.2-0.35	<0.20	<0.08

Table 8. J.I.S. for Black-heart Malleable Iron

JIS G5702-1960

Classification		Mark	Tensile Test		Bend Test	
			Tensile strength kg/min (min.)	Elongation % (min.)	Max. Bend Angle (min.)	Radius of Bend (min.)
Black-heart Malleable Iron	No. 1	FCMB28	28	5	90°	40
	No. 2	FCMB32	32	8	120°	
	No. 3	FCMB35	35	10	150°	
	No. 4	FCMB37	37	12	150°	

* When iron with ferrite and temper carbon is heated above a temperature, and coold fairly rate, it results to pearlitic malleable cast iron with only pearlite and graphite. Mn up to 1%, Cr 0.1-0.25%, or Mn up to 1% are effective to make pearlitec cast iron.

Table 9. JIS for White-heart Malleable Iron JIS G5703 (1960)

Classification		Mark	Approx. Wall Thickness mm	Tensile Test					
				Diam. of test Piece, mm	Tensile Strength, kg/mm2 (min.)	Elongation %(min.)	Wall Thickness of test Piece mm	Max. Bend Angle (min.)	Radius of Bend, mm
White-heart Malleable Iron	No. 1	FCMW 34	5	6	32	8	4	120	40
			5 - 9	10	34	5	6	120	
			9 - 15	14	36	3	9	60	
	No. 2	FCMW 36	5	6	34	14	4	150	
			5 - 9	10	36	8	6	150	
			9 - 15	14	38	6	9	90	

Table 10. JIS for Pearlitic Malleable Iron JISG5704 (1960)

Classification		Mark	Tensile Test			B. H. N
			Tensile Strength kg/mm^2 (min.)	Yield Strength kg/mm^2(min.)	Elongation % (min.)	
Pearlitic Malleable Iron	No. 1	FCMP40	40	25	6	152-217
	No. 2	FCMP50	50	34	3	179-241
	No. 3	FCMP60	60	42	2	201-269

* Yield strength .... 0.2% offset

Fig. 13 shows microstructure.

5.2. Corrosion Resisting and Heat Resisting Cast Iron

Cast iron has a property of being easily attacked by acids. Acid-resisting cast iron was developed to correct this defect by adding alloy elements into ordinary cast iron. Alloying elements used are Si, Cr, Ni, Al. Table 11 shows a typical composition of acid resisting cast iron.

As explained before, cast iron has a tendency to form growth (of grain) when heated above 700 degrees C. Heat resisting castings were developed to cope with this tendency by adding such alloy elements as Al, Si, Cr and Ni. Table 12 shows a typical analysis.

Table 11. Corrosion-resisting Cast Irons

Composition % / Applications	C	Si	Mn	P	S	Ni	Cr	Cu	B. H. N.
Durriron (Acid-resisting)	0.2~06	14.0~14.5	0.15~0.35	0.16~0.2	0.05				300
Ni-Resist (for Sea Water)	2.80~3.00	2.0~2.20	1.00~1.10	<0.20	<0.10	14~16	2	5.50~6.50	160~180
Pot for Caustic Soda	3.40~3.60	0.60~0.80	0.40~0.60	0.15~0.20	0.10~0.12	0.3~2.0	0.30~0.50		240~270
Casting for Alkaliresisting	2.80~3.00	1.00~1.50	0.4~0.6	0.15~0.20	<0.10	2.0~5.0	Sb~ 0.4 0.7		
Silal (for Heat-resisting)	2.80~1.60	5.00~10.0							

Table 12. Heat-resisting Cast Irons

Composition % / Applications	C	Si	Mn	P	S	Ni	Cr	Cu	B. H. N.
Clinker Pot	1. 50~ 2.00	1. 50~ 2.00	0. 3~ 0. 75	0. 12	0. 1		22~ 26		300 ~ 350
Stoker-link	3. 00~ 3.50	1. 75~ 2.25	0. 5~ 0. 8	0. 4	0. 14		0. 85~ 1.25		200~ 300
Fire-grate	3. 00~ 3.50	1. 75~ 2.25	0. 5~ 0. 8	0. 4	0. 14		0. 85~ 1.25		200~ 300
Ni-Resist (for Heat-resisting)	2. 90~ 3.00	1. 40~ 1.60		0. 20	0. 10	14~ 16	2. 0~ 2.5	5. 50~ 6.50	110 ~ 180

5.3. Spheroidal Graphite Cast Iron (Ductile Cast Iron, Nodular Cast Iron)

In 1947, it was discovered that graphite in casting turned spherodical as a result of adding cerium into molten cast iron. By further adding Mg, its industrial application was made possible. As can be understood from its microstructure in Fig. 14, this particular kind of cast iron has high toughness close to steel and can iron, high-quality product can not be obtained. It is necessary that pig iron of low S and P content is chosen as raw material. The ductile cast iron with the tensile strength of 50 to 70 kg/mm and elongation of 1 to 8% is in popular use. Table 13 and 14 show the specifications of Japan and U.S.A.

Table 13. J.I.S. Specification of S.G. Cast Iron JIS G 5502-1961

Class	Mark	Tensile Test		Elongation
		Tensile strength kg/mm^2 (min.)	Yield Strength kg/mm^2 (min.)	%(min.)
No. 1	FCD 40	40	28	12
No. 2	FCD 45	45	30	5
No. 3	FCD 55	55	38	2
No. 4	FCD 70	70	48	1

Table 14. Specification of S.G. Cast Iron in U.S.A.

Designation	Usual Condition	Min. Tensile Strength, psi	Min. Yield Strength, spsi	Min. Elong. in 2 in., %	B.H.N.
60-45-15	Annealed	60,000	45,000	15	140-180
80-60-05	As Cast	80,000	60,000	5	195-225
90-65-02	As Cast	90,000	65,000	2	225-265
90-60-00		80,000	60,000		230-290

5.4. Acicular Cast Iron

Ordinary cast iron turns into acicular cast iron turns with the tensile strength of 40 to 50 kg/mm^2, highly resistant against shock and fatigue, with its matrix changing to bainite as cast when 1.5 to 5% of Ni and 0.8 to 1.0% of Mo are added. It is commonly used for cams and crankshaft of Diesel engine and press hammer parts.

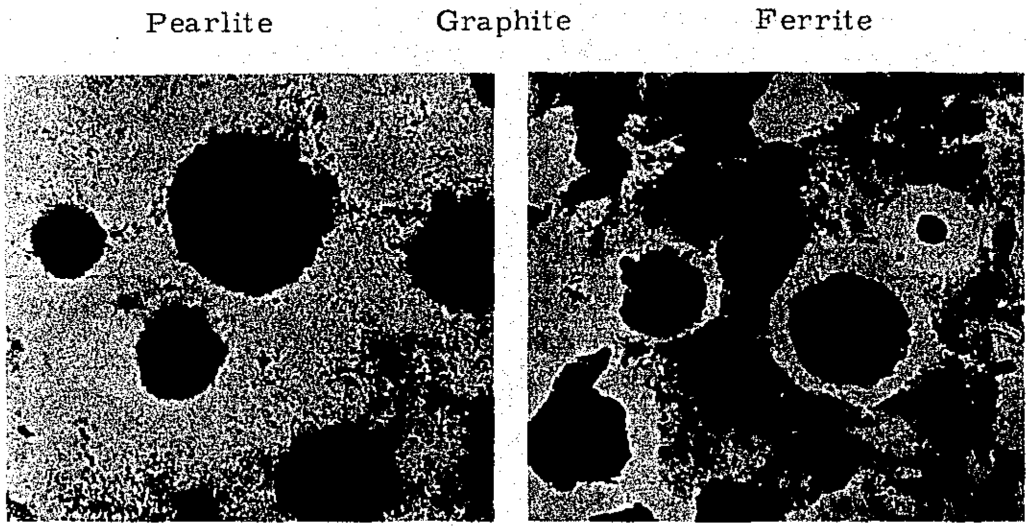


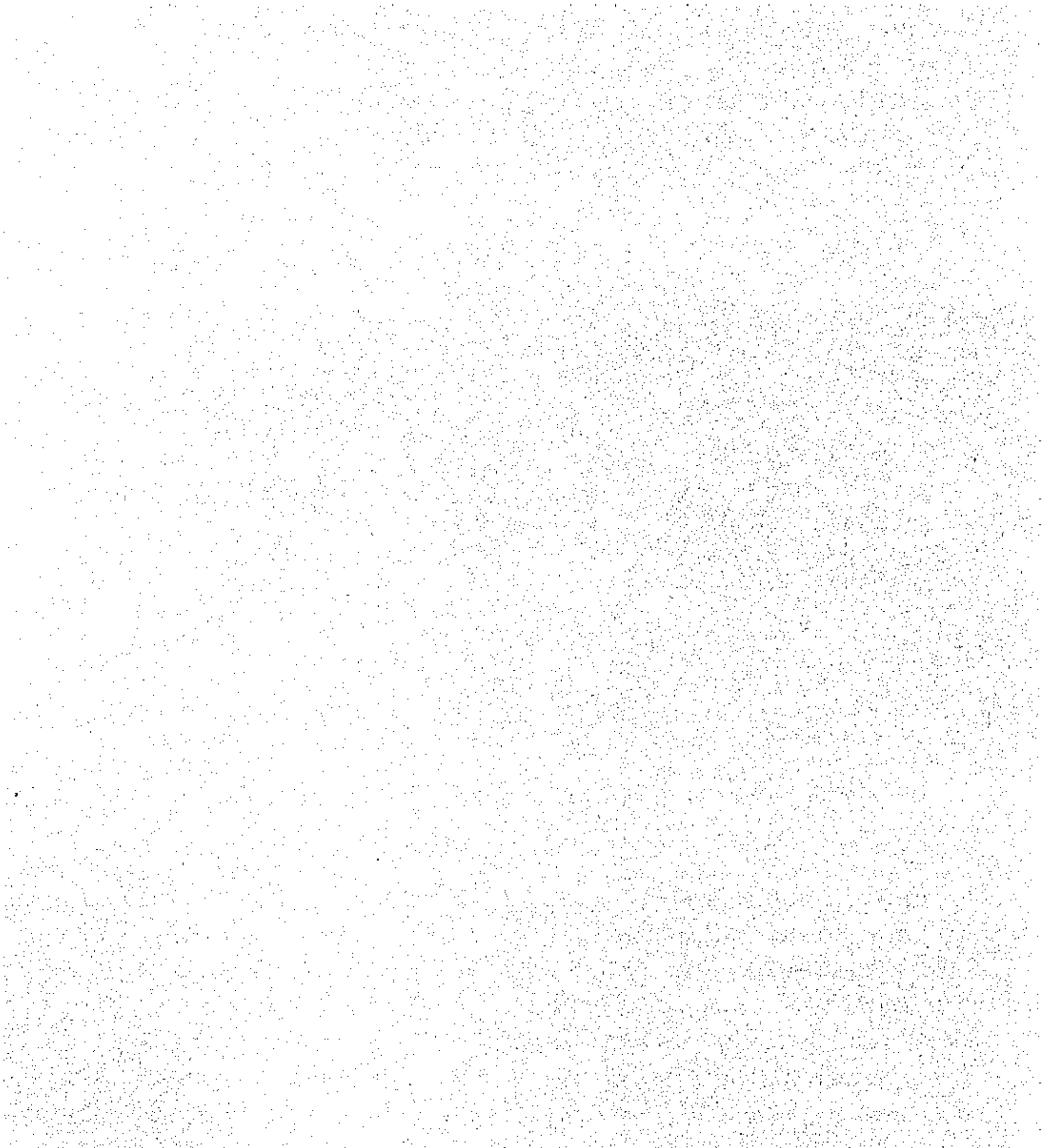
Fig. 14 Microstructure of S.G. Cast Iron

5.5. Meehanite Cast Iron

Meehanite cast iron so frequently talked about in foundry industry are the cast iron made at a foundry plant operating under a technical licensing agreement with Meehanite Foundry Co., of the United States. It belongs to the classification of high grade cast iron, rather than that of special cast iron. Its characteristics are excellent mechanical property and high dependability of products made of this cast iron. To make this cast iron, an equi-blast method is applied to a cupola, lots of steel are mixed and melted at a high temperature and calcium silicide is inoculated to molten iron in front of a furnace so as to aid in grapharization and even distribution of fine curved graphite. Another advantage of this cast iron is that high quality products can be made from it by subjecting it to adequate process control in all phases of foundry technology.

* * * * * * * *

STEEL CASTING



STEEL CASTING

By: Tatsuhide Tsukimoto
Nippon Sharyo Co., Ltd.

1. A BRIEF HISTORY OF THE STEEL CASTING INDUSTRY

Steel castings, by their very nature, require molten steel in their process of manufacture. Molten steel was unknown prior to the year 1750. True enough, steel was well-known centuries earlier, as the Damascus and Toledo blades of legendary fame will testify, but this steel was forged from posty masses of iron produced, in the Catalan forge. In the year 1750, in England, Huntsman originated the Crucible process which first produced steel that could be poured as a liquid. This method of steel making came into wide favor but its use was confined to the production of small ingots which were in turn worked into the desired shape.

It was not until 1845 that steel castings, i.e., steel cast to final shape appeared on the scene. On July 14 of that year, Johann Conrad Fischer, the Swiss metallurgist, exhibited various small castings produced from crucible steel. On July 23, 1845 Fisher applied to the British Patent Office for priority rights to a "new way of making horseshoes" which consisted of casting steel in sand molds.

It was in 1882 that the steel castings were first produced in Japan: the steel was melted in a crucible at the Navy Armory located at Tsukiji, Tokyo. The first commercialy operated steel foundly was the Sumitomo Metal Industries Ltd. Where were manufactured in 1900 by a Sciemen's type open-hearth furnace. (Acid furnace of the capacity of 3.5 tons)
In 1919, on starting to manufacture steam Locomotives, the Nippon Sharyo Seizo Co. Ltd. (belong to me) produced the steel castings by a converter and then, in 1930, this company began to produce then by the Heroult type electric arc furnaces.

2. ADVANTAGE IN THE USE OF STEEL CASTING

1. The structure of steel castings is uniform, it is free from directional propeties resulting from flow lines, producing a structure of great strength with excellent resistance to shock and stresses.
2. Steel castings offer a wide range of mechanical properties from which the engineer may make a selection for diversified product requirements.
3. Steel castings are readily weldable for use in composite structures.
4. Steel castings are easily machined.
5. Streamlines appearance of steel castings results in a more salable product.
6. Steel castings have high fatigue resistance and excellent high temperature properies which are ideal qualities for critically stressed parts.
7. The low temperature notched-bar impact properties of cast steel are similar to those of wrought steel.
8. Steel casting requires less machining than a wrough product.
9. Steel casting are tough and durable; they can also be made hard and wear resistant, heat and corrosion resistant.

3. STEEL CASTING DESIGN

3.1. What should Designers Know about Steel Castings?

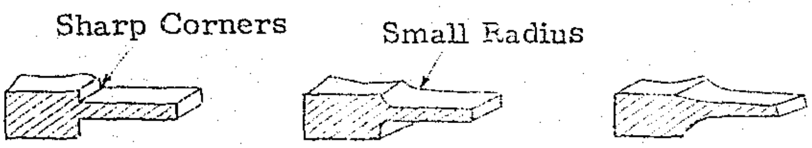
(1) low fluidity
(2) high shrinkage
(3) low strength at 2,700°F
(4) high cooling stresses

What defects can be eliminated by good design ?

(1) hot tears
(2) shrinkage cavities
(3) misruns
(4) Sand inclusions

3.2. Rules of Good Steel Casting Design

3.2.1. Changes in section size



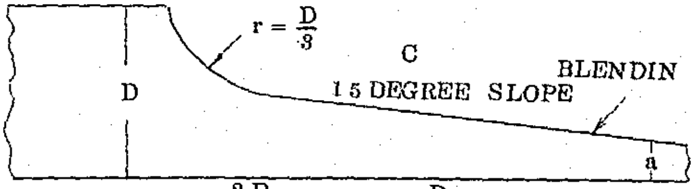
Poor Design Not Recommended Fair

Good Best No change Recommended

Fig. 1 Section Change

$1FD > 1.5''$ AND $d > \frac{2}{3}D$ THEN $r = D/3$

$1FD < 1.5''$ AND $d > \frac{2}{3}d$ THEN $r = \frac{1}{2}''$



$1FD > 1.5''$ AND $d < \frac{2D}{3}$ THEN $r = \frac{D}{3}$ WITH A 15 DEGREE SLOPE BETWEEN THE TWO PARTS FOR EXAMPLE

$d = \frac{1}{2}''$ $D = 2''$ $r = \frac{2D}{3} = \frac{4}{3} = 1.5''$

Fig. 2 Section Changes on One Side

3.2.2. Uniform thickness in casting design

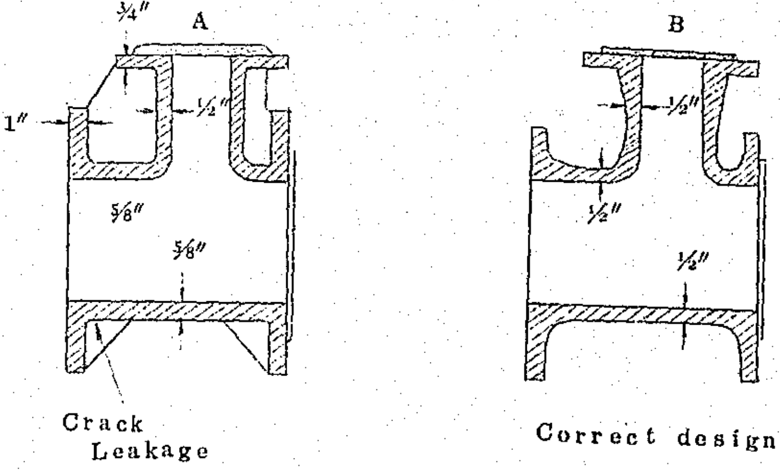
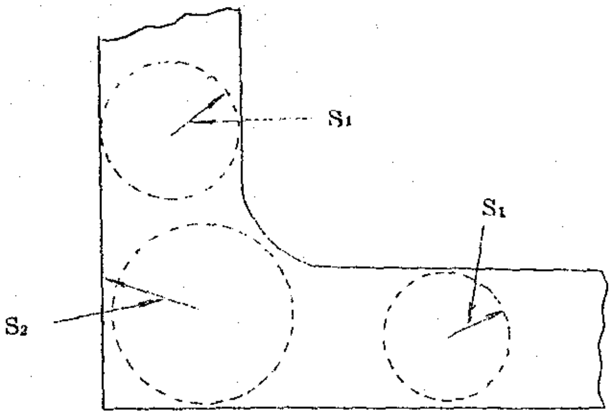


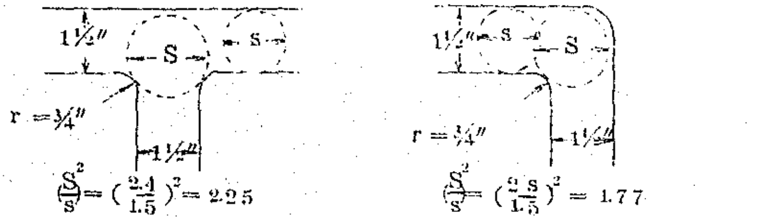
Fig. 3 Uniform section design is recommended

3.3.3. Designing to prevent the formation of hot spot and shrinkage cavities.

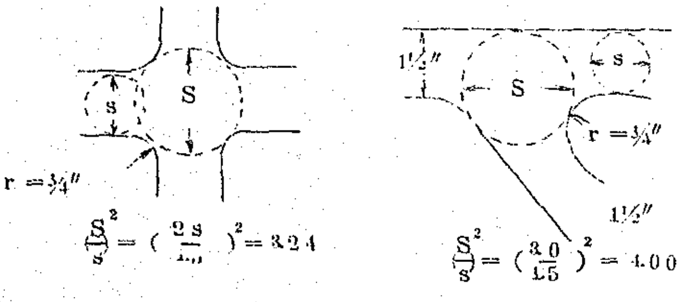


Position of a hot spot S2 can be illustrated

Fig. 4 Position of a hot spot S2 can be illustrated by inscribed circles.



INCREASE OF MASS 125%   INCREASE OF MASS 77%

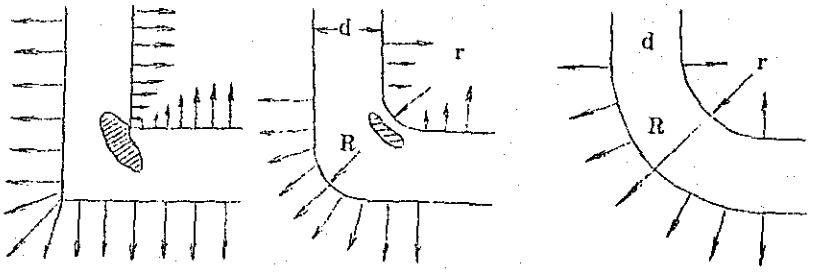


INCRCASE OF MASS 224%   INCREASE OF MASS = 300%

Fig. 5 The use of inscribed circles to determine effect of mass.

3.3.4. The designing of joining sections

"L" sections



A
Bad design

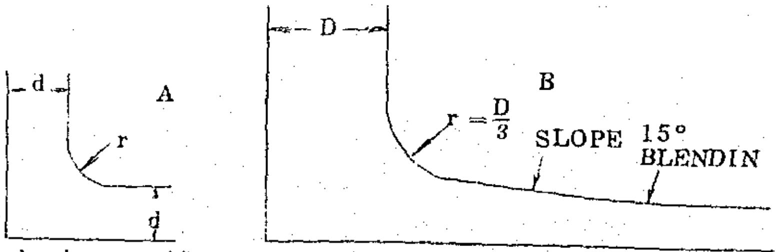
B
Poor

C
Good
$r = d$
$R = 2d$

▨ - Shrinkage cavity

Shrinmge cavity

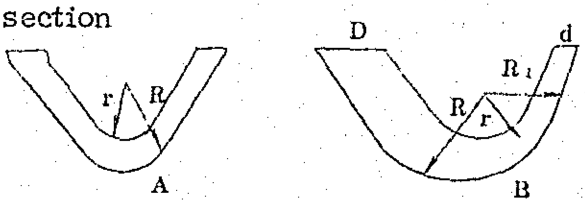
Fig. 6 Evolution of the "L" design



$r = d$ when $d < 1''$
$r = 1''$ when $d < 1''$ BUT $< 3''$ $r = d/3$ when $d > 3''$

Fig. 7 "L" design with extorio corners

"V" section

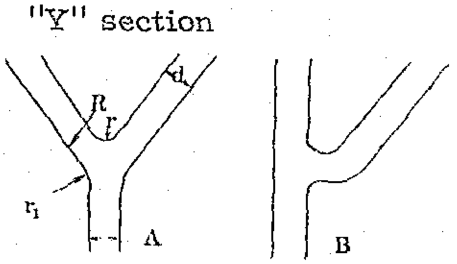


GOOD { $r = 1.5d$ BUT NOT LESS THAN $1''$
$R = r + d$

BEST { $r = 1.5d$
$R = 1.5r + d$

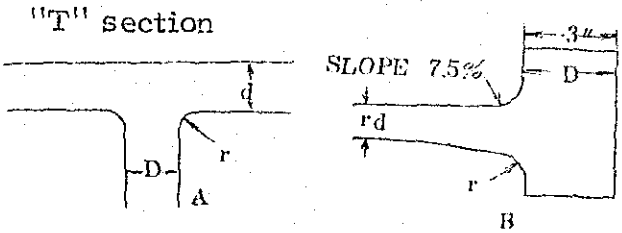
$r = \frac{D+d}{2}$ BUT NOT LESS THAN $1''$
$R = r + d$
$R_1 = r + d$

Fig. 8 Recommended "V" design



$r = 1.5d$ BUT NOT < 1½"
$R = r + d$
$r_1 = r + d$

Fig. 9 Recommended "Y" design



r = D BUT NEVER LESS THAN ½" OR GREATER THAN 1"
IF = D IS < 1.5d : THEN r = D AS SHOWN IN "A"
IF = D IS > 1.5d : THEN r = D AS ABOVE WITH A
7.5% SLOPE TO FIT THE RADIUS AS SHOWN IN "B"

Fig. 10 Recommended "T" design

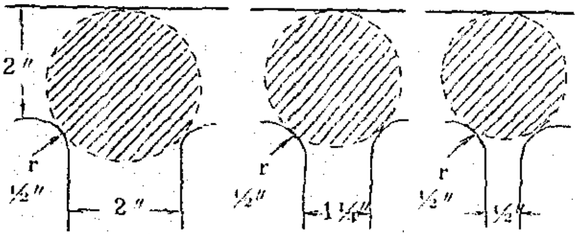
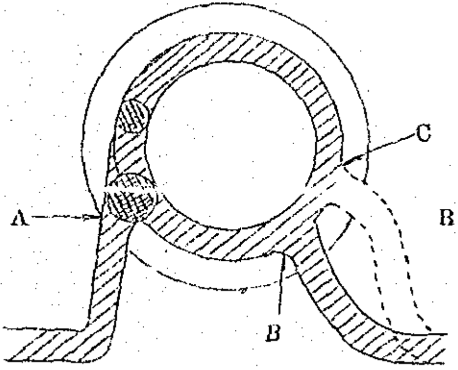


Fig. 11 Tie-in members in the form of T sections



A – JUNCTION DEFECTIVE
B, C – JUNCTION IMPROVED

Fig. 12 Cross-section of a motor frame casting

"X" sections

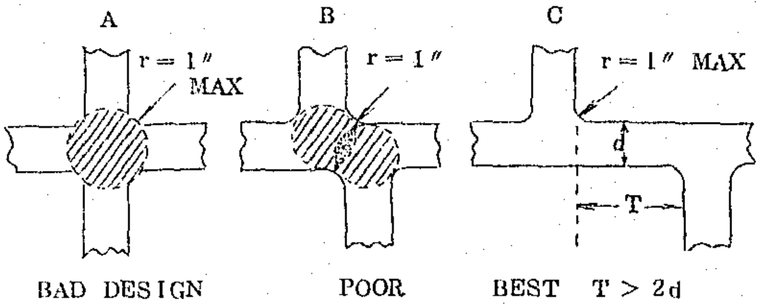


Fig. 13 Recomended "X" design

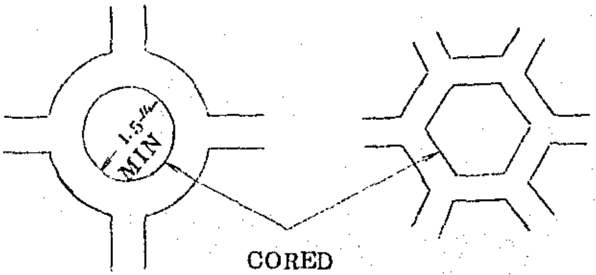
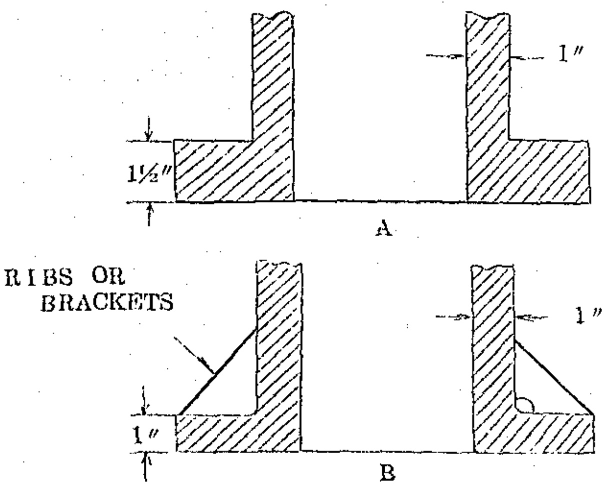


Fig. 14 Cored "X" section

3.3.5. Design of reinforcing Members



Right Rib
is improved

Fig. 15 The use of bracket

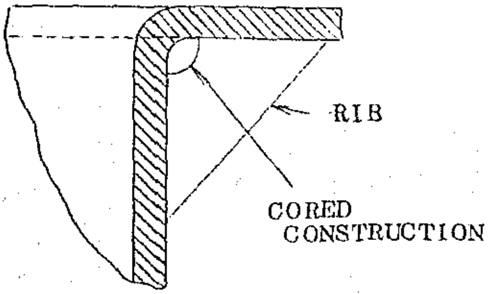
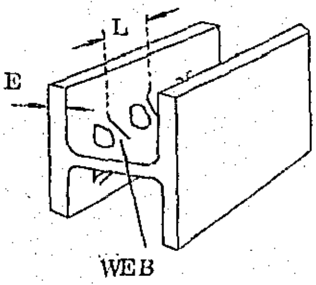


Fig. 16 Cored rid construction



SIDE = E
BRACKET < ½E BUT NO LESS THAN ¼″
CHANNEL = ⅔F
L = 4 TO 6 INCHES

Fig. 17 Reinfocing a chanel section

3.3.6. Wave construction

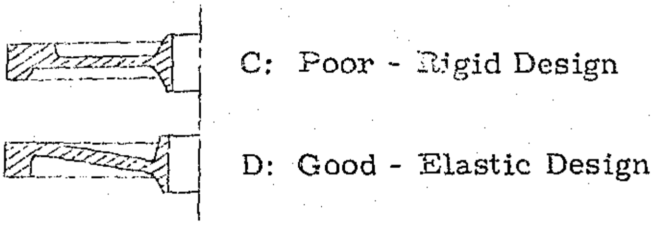


Fig. 18-a Wave construction
(Elastic design)

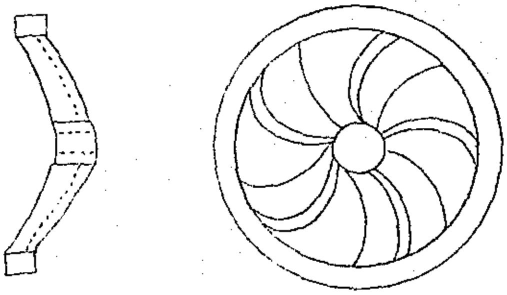


Fig. 18-b Wave construction

4. STEEL MELTING

4.1. Melting Practice

Steel melting for castings is currently carried on in various furnaces, but the basic-electric arc furnaces are employed most widely and the acid open-hearth and basic open-hearth furnaces come to the next. Only a few acid-electric arc furnaces are operated in Japan. In the case of preparing the heats of low and high alloy steels and the heats for small castings, the high frequency induction furnace is employed.

The most preferred size of electric arc furnace is the one having a maximum capacity of 10 tons and those used exclusing for cast steel melting is less than 3 tons of capacity. The majority of the electric arc furnace is of this size.

The trend of modernization of the electric arc furnace is aimed to shorten the melting down time and to cut down the KWH per ton with consuming large amount of eletricity at high voltage by the use of a transformer of large capacity. Also, there is a tendency to adopt top charge system to a relatively large sized furnace intending to reduce charging time, and to raise production. As to automatic current unit, the Amplidyne system is widely used. Oxygen Bessemerizing process was first introduced to open-hearth furnace and then it was also adopted to the electric arc furnace in the case of melting high alloy steels such as stainless steel and so on. It has become very popular nowadays to use this process in the practice to melt common or low alloy steels. By adopting this practive, it is generally driving out the refining method by the use of iron ore alone. The necessity of vigorous boiling at high temperature has emphasized to degassing. By vigorous boiling, detrimental gasses and nonmetallic inclusion can be elimenated. Care should be taken to the selection of charging material and the drying of ferro-alloys and fluxes to avoid the increase of hydrogen gas in the molten steel. It is under consideration to employ the vacuum degassing process in steel melting, which has recently been put in-to practice. The suitable amount of aluminum as a deoxiden are ranges from 0.02 to 0.1%. An example of heat for a basic-electric furnace operation is shown in Table 1. Artificial graphite electrodes are being used as the electrodes. As to refractories, magnesia clinker is used for bottom, silica bricks and chromite magnesite unburned basic bricks are for side walls and silica bricks are for roof.

Table 1. Furnace Record of a Heat of Carbon steel in 10 ton Basic Electric Arc Furnace

Size of heat = 24,475 lbs.

Analysis desired = %

(C)	(Mn)	(Si)	(P)	(S)
0.23 to 0.27	0.60 to 0.80	0.30 to 0.40	0.035 max.	0.030 max.

Charge :

Pig	Purchased scrap	Return	Turning	
2,425	11,000	8,515	2,535	(lbs.)
10	45	35	10	(%)

Time	Analysis C% Mn%	Temp. (F°)	Activity
23 : 45			Previous heat tapped, charging
0 : 0			Power on
1 : 30	0.50 .30 (P .043)		Melt down slag off Add: lime stone 330lbs. flousper 44 lbs.
1 : 45	0.45 .21 (P .030)		Slag off Add: lime s tone 330lbs. Spar 44 lbs., ore 66 lbs Fe-Mn 33 lbs.
1 : 55		2,970	Oxygen Blown
2 : 0.7 2 : 12	0.20 .23 (P .018)		Slag off Add: Fe-Si-Mn 132 lbs. Span 66 lbs. lime stone 550 lbs. C. P. 5 lbs.
2 : 25			Add: Fe-Si 132 lbs. C. Powder 33 lbs.
2 : 35	0.23 .60		Add: Fe-Si-Mn 35 lbs.
2 : 53	0.23	2,930	Tapped: Aluminium 7.3 lbs.
3 : 00			Add. to the ladle

Ladle analysis: (%)

C	Mn	Si	P	S	Ni	Cr
0.22	0.69	0.34	0.019	0.012	0.06	<0.05

4.2. Reactions in the Basic Process.

4.2.1. Oxidation Reactions

Carbon, $[C] + [FeO] = CO\uparrow + [Fe]$

Silicon, $Si + 2FeO = SiO_2 + 2Fe$

Manganese, $Mn + FeO = MnO + Fe$

Phosphorus, $2P + 2FeO \rightleftharpoons 5Fe + P_2O_5$

$2P + 5FeO + 3\ CaO \rightarrow 3CaO \cdot P_2O_5 + 5Fe$

Sulphur, $FeS + CaO = FeO + CaS$

$FeS + Mn = MnS + Fe$

4.2.2. Reducing Reactions

Iron oxide, $3FeO + CaC_2 \rightarrow CaO + 2CO + 3Fe$

$3FeO + 2Al \rightarrow Al_2O_3 + 3\ Fe$

$2FeO + Si \rightarrow SiO_2 + 2Fe$

$MnO + Si \rightarrow SiO_2 + 2Mn$

Manganese oxide is reduced in a like manner according to similar reactions.

Sulphur, $2CaO + 3MnS + CaC_2 \quad 3CaS + 2CO + 3Mn$

$2CaF_2 + 2MnS + Si \quad 2Cas + SiF_4 + 2Mn$

4.2.3. Slag Controll

The control of basic slags has resulted almost entirely in correlating the slag composition with slag appearance. Also, the formy appearance of the slag while in the furnace is a rough indication of its basicity. Slag samples are taken on spoons and dipped into cold water and then observed. The color indicates the amount of iron oxide % in the slag.

Table 2. Slag Analysis of 2-slay heat for steel carbon

	per cent.				
	Oxidiging Slag	Refining Slag			Tapping Slag
	No. 1	No. 2	No. 3	No. 4	No. 5
CaO	41.02	43.28	49.91	51.84	51.35
CaF_2	--	6.98	7.30	7.96	7.05
CaS	0.22	0.28	0.41	0.46	0.71
CaC_2	--	0.16	0.70	0.58	0.59
FeO	23.90	11.55	0.88	0.43	0.67
MnO	7.00	8.42	2.96	0.91	0.30
Al_2O_3	1.96	1.61	1.76	1.50	2.12
MgO	9.56	7.69	9.08	7.42	9.60
Cr_2O_3	0.75	0.56	0.08	0.02	0.02
P_2O_5	0.98	0.32	0.21	0.07	0.02
SiO_2	14.56	19.72	27.68	29.30	27.18
Color	Black	Kark-brown-green	light brown	white	white
Sampling time	12:32 P. M.	1:05 P. M.	1:25 P. M.	1:40 P. M.	2:12 P. M.

5. MOLDING AND CORE MAKING

The use of greensand molding has been increased rapidly Since 1950 and in company with the modernization of sand preparation and reclamination units, it has become possible to make most of the small size castings and some of very large castings weighting from 3 to 5 tons with green-sand molds in some foundries. But the percentage of dissemination of greensand yielded in Japan usually containes rather low percentage of SiO_2 and rather high percentage of foreign elements such as a feldsper, as that the artificial silica sand made by crushing and sieving the sand stone of high purity of SILICA, is used in consideravle amount. Generally the type of sand grain is subangular. Compared with the molding sand occurring in U.S.A., ours' is of inferior greatly in grain distribution and uniformity of compositions. The grain size of silica sand classified by the percentage of utilization is tabulated as follows: (Table 3.)

Table 3.

Grain size	Artificial	Natural	Total
No. 1	1.1 %	3.7 %	3.1 %
2	3.9	5.1	4.8
3	24.7	13.4	16.1
4	27.0	15.0	17.9
5	24.0	46.9	41.4
6	15,5	15.6	15.5
7	3.8	0.3	1.2
Total	100.0	100.0	100.0
Percentage of Artificial & Natural	24.0	76.0	100.0

As the grain size of natural silica sand becomes smaller, the percentages of foreign materials become greater, and this causes a great trouble. Resulted by suitable mixture and control, fine grain size of sands like No. 5 to 6 become possible to be used these days as the facing sand of small and medium size of molds. By the use of these fine sands, the surface of casting is improved. Lately, many foundries are using zircon sand to particular parts of the mold so as to prevent burning-on ; it is all imported from Australia.

Olivine sand is presently under trial use, especially good result obtained in the case of producing Mn steel casting.

Bentonite and clay are being used as the major binders; the former is used for green molds and the latter for dry molds. The properties of U. S.'s bentonite is much better than that of Japan's in the bonding strength and ignition loss. A comparative test of these two bentonite is being carried on by the sponsorship of Japan Cast Steel Society.

Molasses, corn flour, dextrine (cereal binders) and vegetable oil are used in considerable large amount as the subsidiary binders. Oil is mainly used to make cores, but recently the consumption increases gradually as the increasing use of blowing machines. Linseed oil is most popularly used. Trial use of air setting oils becomes very active.
The formula of the molding sand varies by the foundry and it is difficult to state here in general. The example of molding and mixes is as follow:

Example 1. Green and mixture:

100 lbs.	No. 6 New sand	Moisture 3 - 4.5%
100 lbs.	No. 5 "	
112 lbs.	Bentonite	Green comp. 5 - 8 lbs/in^2
1 lbs.	Dextrine	Permeability 200 - 300
1 lbs	Cereal Binder	

Example 2. Dry sand mixture:

100 lbs.	No. 5 New sand	Moisture 6 - 8%
100 lbs.	No. 4 "	
12 lbs.	Bentonite	Green Comp 8-10 lbs./in^2
3 lbs.	Clay	Dry Comp. 100-150 lbs/in^2
0.4 lbs.	Cereal Binder	Permeability 400 - 500

Example 3. Dry sand mixture:

50 lbs.	No. 5	Moisture 6 - 8%
50 lbs.	No. 4	
50 lbs.	No. 3	Green Comp. 8-10 lbs/in^2

50 lbs.	Silica Flour	Dry Comp 120 - 170 lbs/in^2
25 lbs.	Clay	Permeability 120 - 170
1-3 lbs.	Molasses	

Example 4. Oil sand mixture

100 lbs.	No. New sand	Moisture 4 - 5%
100 lbs.	"	
4 lbs.	Linseed-oil	Dry comp. 200 - 280 lbs/in^2
2 lbs.	Dextrine	Permeability 250 - 350

Example 5. CO_2 sand mixture

100 lbs.	No. 5 New sand	
100 lbs.	No. 6 "	
14 lbs.	Nodium-Silicate	Comp. 200 - 300 lbs/in^2
1 lbs.	Dextrine	Permeability 350

6. GATE AND RISERING SYSTEM

As the gate and risering system has a very important function to the quality and yields of the finished casting, so that steel foundrymen have long been aware that a successfully made casting must be properly gated and risered.

6. 1. Ratio of Sprue, Runner, Ingate and its Shape

(a) A ratio of sprue to runner to ingate in cross sectional area is normally considered depending upon the pouring speed, which shall be mentioned latter, and a suitable distribution of metal flow should be considered according to the shape of castings.

(b) The places where the defects such as blow holes or cracks are apt to form, must be apart further from ingate.

(c) Sprues should be positioned at the places where more efficient feeding of the casting and where the cut off can be done very easily.

(d) Gates must be designed so that the flowing metal runs into the casting smoothly and it replaces with fresh metal easily. The gone where the flowing stream will be thrown would be eroded by the stream and would result in scap, rat tail, cuts and washes, so that the molding sands of suitable strength and expansion or the sleeve or elbow made of refractory bricks should be used locally.

6. 2. Risering

A lot of studies have been carried on as to the size and shape of the riser and its effective feeding range. They are based on the theories established by J. B. Caine, W. S. Pellini and H. F. Bishop. These have been used in conjunction with the empirical formula.

See Fig. 20 - 23

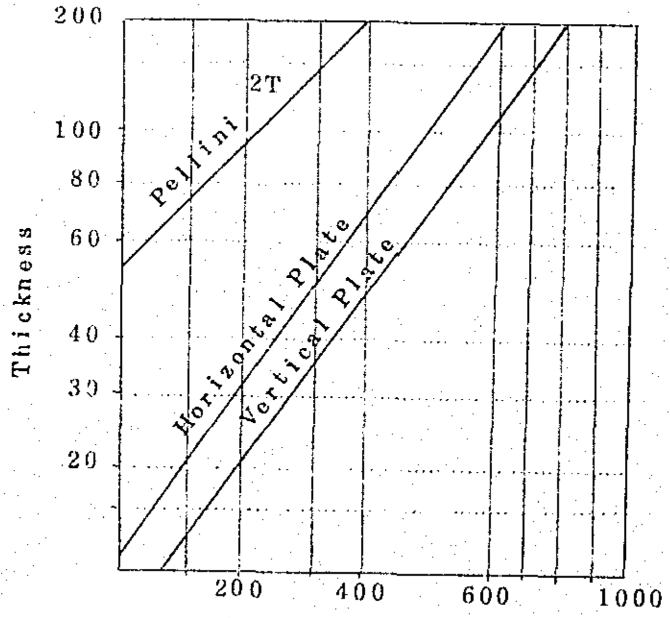
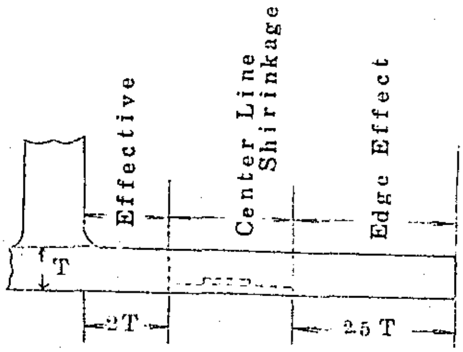
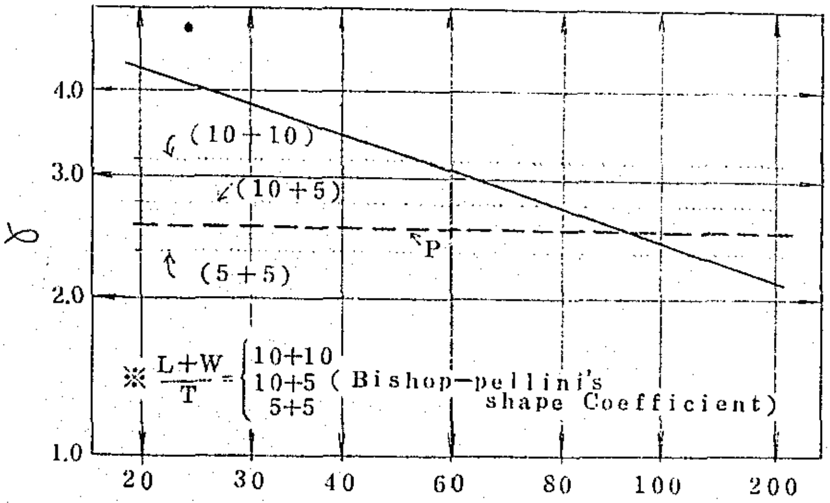


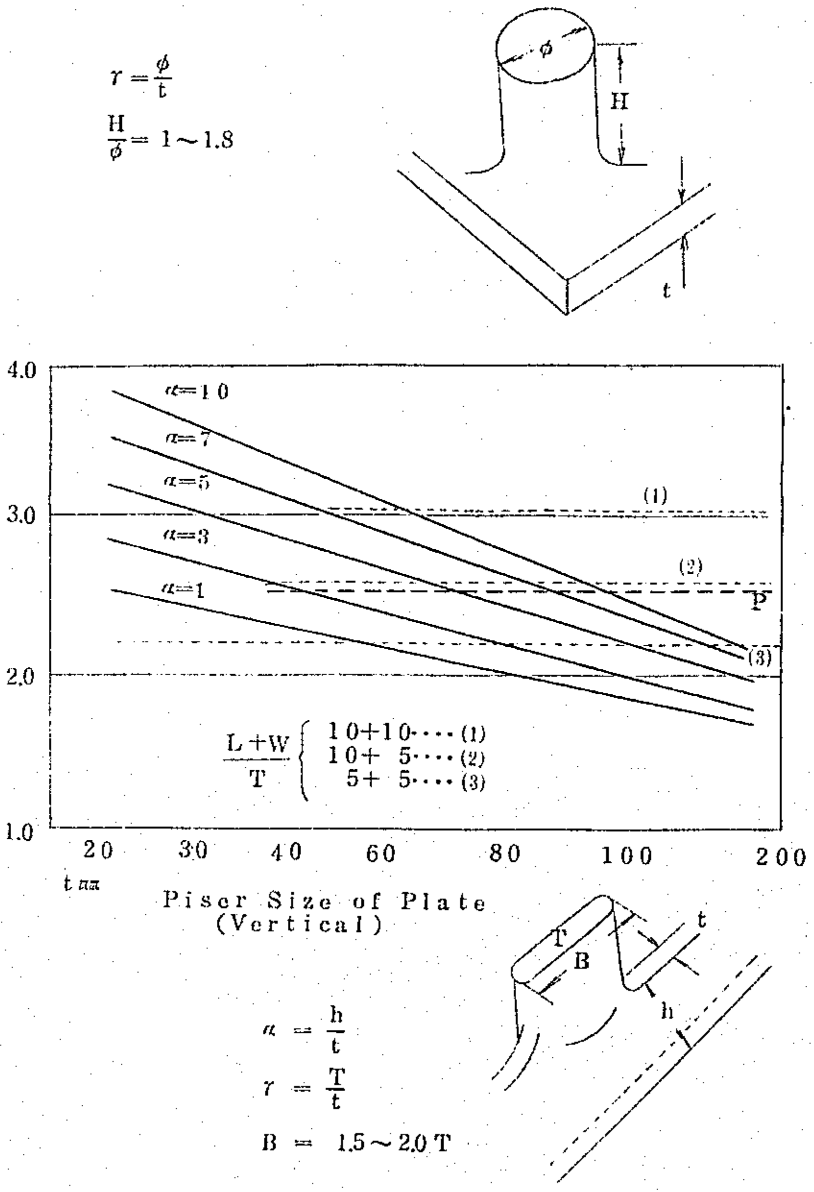
Fig. 20 Effective distance of riser


Effective
Center Line
Shirinkage
Edge Effect
T
2T
2.5 T


γ
4.0
3.0
2.0
1.0
(10+10)
(10+5)
P
(5+5)
※ (L+W)/T = 10+10, 10+5, 5+5 (Bishop−pellini's shape Coefficient)
20
30
40
60
80
100
200

$$\gamma = \frac{\phi}{t}$$

$$\frac{H}{\phi} = 1 \sim 1.8$$



$$\frac{L+W}{T} \begin{cases} 10+10 \cdots\cdots (1) \\ 10+5 \cdots\cdots (2) \\ 5+5 \cdots\cdots (3) \end{cases}$$

$$\alpha = \frac{h}{t}$$

$$\gamma = \frac{T}{t}$$

$$B = 1.5 \sim 2.0\,T$$

Fig. 22

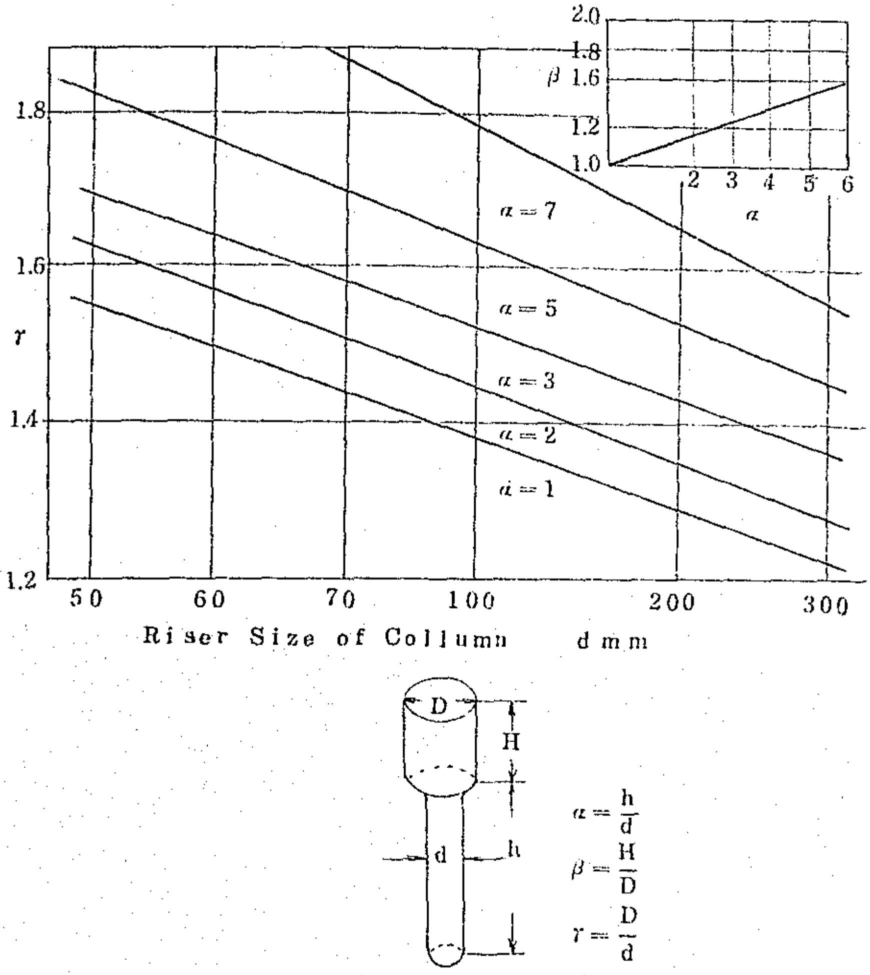

2.0
1.8
β 1.6
1.2
1.0
2 3 4 5 6
α
1.8
1.6
γ
1.4
1.2
α = 7
α = 5
α = 3
α = 2
α = 1
50 60 70 100 200 300
Riser Size of Collumn d mm
D
H
d
h
α = h/d
β = H/D
γ = D/d

Fig. 23

6.3. Chilling

Chills are used to the places where the effect of riser does not reach. The size of chill are determined according to the following standard.

Thickness of outer chill

$t = (0.7 \sim 1.0)\,T$ T: thickness of casting

Dia of outer chill rod L: length of chill

$d = (3/4 \sim 1)\,T$ But $L < 10\,d$

Dia of inner chill rod

$D \leqq 1/3s$ s : inscribed circle dia

Fig. 24 is an example of outer chillers.

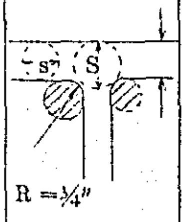
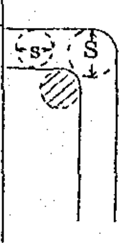
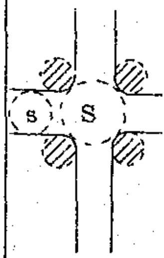
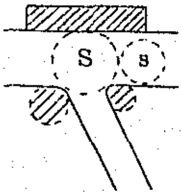
t = 1 1/2" R = 3/4" D = s (Same Thickness)				
$(S/s)^2$	2.25	1.77	3.24	4.0
Mass Increase %	+ 125 %	+ 77%	+ 224 %	+ 300 %
Effect of chill	Sound	Sound	Sound	Sound

Fig. 24 Outer Chill ※But s<2" L≦ 10D.

6.4. Pouring Temperature

Small Casting	2,840 - 2,900°F
Medium Casting	2,760 - 2,840°F
Large Casting	2,730 - 2,800°F

Pouring Rate:

Table 4.

Weight of metal poured lbs.	Pouring Rate sec/ton
300	25 - 35
300 - 600	25
600 - 2,000	20
2,000 - 4,500	10 - 15
4,500 - 10,000	8 - 12
1,000 - 20,000	5 - 8

7. FINISHING AND HEAT TREATMENT

After pouring is made, the casting is shaken out and it is given cleaning operation by means of pneumatic chisel shot-blast, sand-blast, tumbler, or hydroblast before removing gates. risers and pads from the casting.

In the case of cleaning a large size of casting, hydroblast is the best means from the view points of both efficiency and the danger of silicosis. The installation of hydroblast is not yet popular but it is gradually installed.

In the case of low carbon steel casting containing less than 0.3%C, gates, risers and pads are removed from the casting by oxy-acetylene, oxy-propane torch, cold saw, abrasive wheel grinder knock off hammer or arc-air-blast after the cleaning operation. Chaplets and minor surface blemishes are removed by Gouging machine, swing grinder or portable grinder. Harring repaired these depending on the material and thickness.

The full annealing is done above the temperature of AC3, and the holding time in the annealing furnace is determined by the rate of 1''/hr, then the casting is cooled to a temperature lower than 300°C in the furnace.

The casting taken out from the annealing furnace is given scale off operation by shot blast, etc., and then mechanical testings, dimentional checking and visual inspections are made. The casting member which has been detected inspection by the dimenstonal inspection after annealing is subjected to stress-relief treatment using bydraulic press or other means, and those of found defects are repaired by welding and the stress-relief annealing is given, if necessary.

In the cases of plain carbon steel castings containing more than 0.3% carbon, structual alloy castings, stainless steel castings, and heat-resistant steel castings, it is a matter of course the gas or electric-arc or powder cutting should be done after preheating or annealing the castings and then they must be heat treatment specified by JIS. Heat treating of 13% Mn steel castings should be carried on in accordance with water-quenching from 1,050 - 1,100°C.

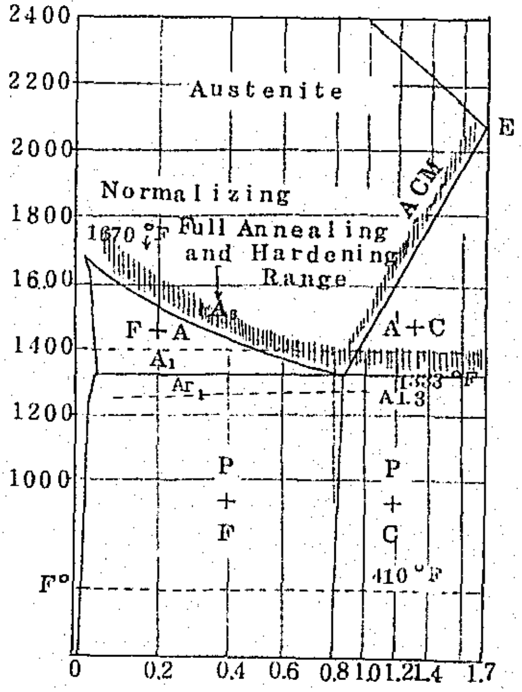
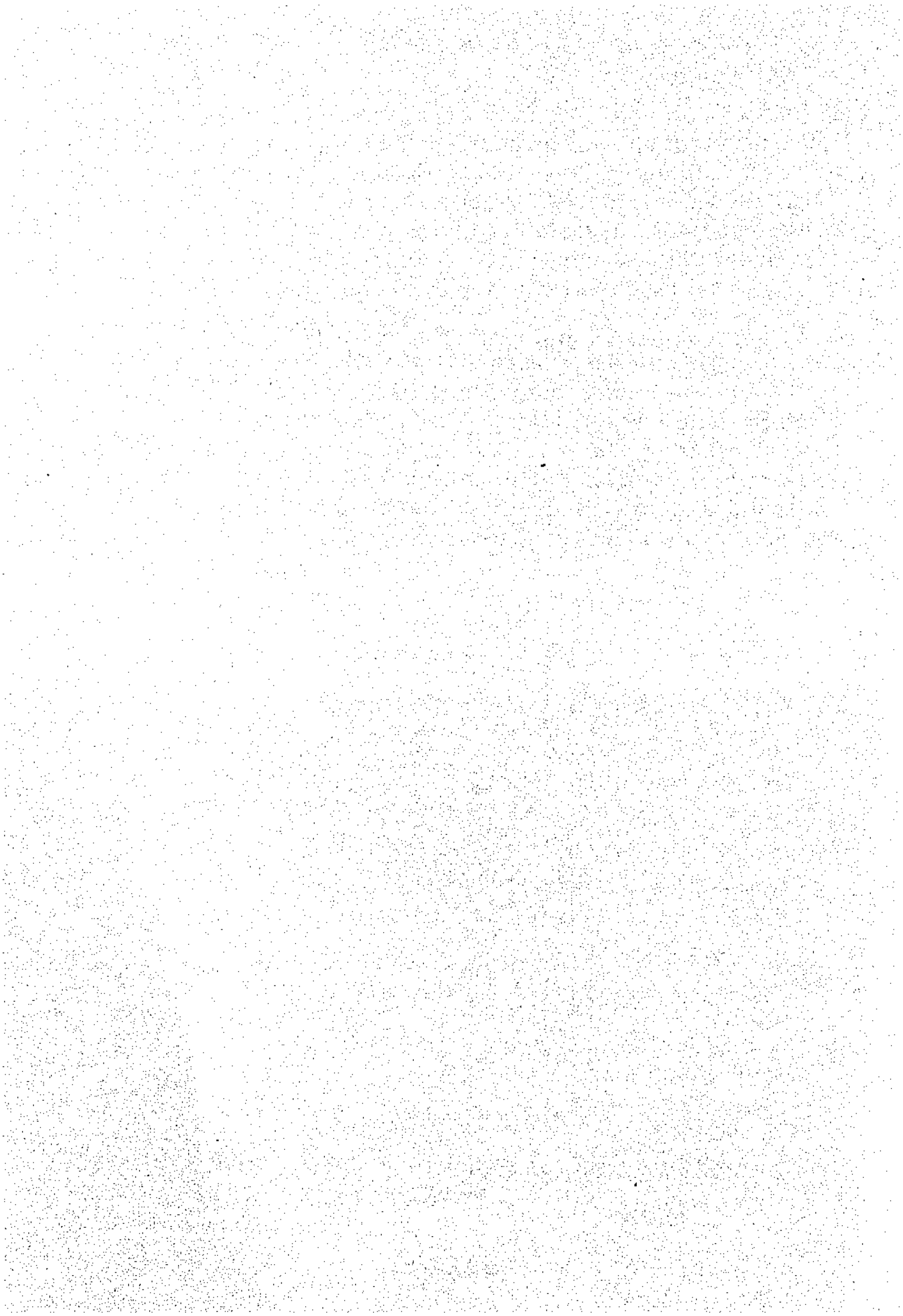


Fig. 25 The Iron-Carbon Diagram as Used for the Heat Treatment of Steel

NON-FERROUS CASTING ALLOYS



NON-FERROUS CASTING ALLOYS

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1. PREFACE

In this booklet, the main subject is Copper Alloys among various non-ferrous alloys of general use, rather than Aluninium Alloys of which outline is given though. It is because non-ferrous Alloys cover all metalic materials with the only exceptions of Iron and Steel, Cast-Iron, and Cast Steel, which are ever so much in volume to describe in this booklet.

Non-Ferrous Alloys, though having inferiorities in the quantity of resources, of production, and in the costs as industrial materials, have many advantages over iron and steel; and there are used many of their kinds.

2. COPPER AND COPPER ALLOYS

2.1. Pure Copper

Solid Copper is used very few for cast-items, and mainly used as part of various electric machineries in which is required high electric conductivity of pure copper cast. Pure copper is very easy to be oxidated when being melted or cast, taking too much of H_2 gas into the molten matter, and consequently it is very hard to obtain the cast items of pure copper.

2.2. Copper Alloys

Copper alloys are divided into 3 big categories; (1) various brass consisting of Cu and Zn with some contents of Pb, Sn, Si, Mn etc., (2) various bronze consisting of Cu and Sn being attached with Zn, Pb, and P, and (3) Aluminum Bronze composing of Cu and Al with Ni, Mn, Fe, etc.

2.2.1. Brass

Brass has good anti-corrosivity, and is not easy to be rushed and also has good mechanical advantageous features which enable it easy to be cast, be cut or ground. Moreover, being comparatively cheap in its costs, brass is used in good quantity covering wide range from various machineries, instruments, to daily necessities, artistic articles, metal accessories etc.

(a) Brass of 2 Elements of Cu and Zn.

Zn is found much in Cu as solid solution. The one that is used generally is of α, and $\alpha + \beta$ systems. The tensile strength is in proportion of the increase of Zn contents and suddenly becomes much stronger with the appearance of β'- phase, then shows the maximum with the 45% of Zn. The elongation reaches to the maximum at the 30% contents of Zn, and decreases down to nil with 50% of Zn. For casting, brass with Zn less than 20%, and that with the Zn contents of 30% to 40% are most widely used. The alloy with Zn contents of 10-15% is called as Tombac, which corresponds to the specification of JIS, Bs C, and is used for casting various flanges etc. The alloy around 40% of Zn contents is so-called 6:4 Brass, and is named after the inventor Muntz, and Muntz Metal, which corresponds to the JIS Specification of Bs C_3. The usages are for various parts of machineries.

(b) The influences when added with other chemical elements.

When added with Pb, Sn, Fe, Al, Mn, Si etc., alone respectively or in combinations, there come out various types of brass castings with particular features, which are now actually used. Being often taken up used metals as base, these elements mentioned just above are apt to be mixed up as impurities, and the Standards restrict not so severely towards those impurities. Even if attached with the 3rd elements, there appear no special systems, as long as the quantity is small; and the element is melted into the α and β solid solution.

Pb ----- About 2.5% of Pb are often added to Brass for casting to improve the castability and machinability. (JIS Bs C_2) But Pb gives action of precipitation to the grain boundary to make the material be weakened and at the same time easily be melted, therefore not welcome for the high strength castings, so it should be kept within 0.5%.

Sn ----- If added in small quantity, the fluidity of brass would be increased and the castings be fortified; however, the adding of 2% of Sn would bring malignant influences towards the brass, so generally 1.5% should be added, and been made out of 6:4 brass replacing about 1% of Zn with Sn, corresponding to B5C4 equivalent to Naval Brass, is used more for the parts of anti-salt water machineries. The composition of it is of Cu 62%, Zn 37%, Sn 1%, which exceeds in anticorrosion over 6:4 brass.

Fe ----- The addition of Fe to brass would cause the microscopic change of the crystal increasing the hardness and tensile strength but decreasing the elongation.

Mn, Al, Si ----- As to be described afterwards, Mn, and Al is added as main elements to make Mn Bronze, while Si, for Silzin Bronze.

(c) Manganese Bronze ----- The brass alloy with Mn is called customarily Manganese bronze instead of as Manganese brass. By replacing of a part of Cu of 6:4 brass, with Mn less than 5% and besides Al, Fe, Sn or Ni in some case added, and obtain a complicated alloy which is so-called Manganese Bronze, and some of them show the tensile strength of 60 kg/mm^2. It is also splendid in its resistance against corrosion and water pressure, which is used for various parts of vessels especially for propellar, and valves. Manganese Bronze is classified as High Strength Brass Castings in Japanese industrial Standard.

(d) Silzin Bronze ----- The alloyed metal exploited in Japan by Dr. Ishikawa, which has a unique characteristic not to contain the expensive Sn. This bronze has good casting characteristics and strength, and also good in corrosion resistance but very sensitive towards impurities; they do not use so much in countries abroad. This type of Bronze, classified to JIS S2BC 1-3, having the main components of Zn 10-15% and Si 3-5%, is an alloy of Cu-Si type with Zn added, from the point of view of its construction. Used for the valves and other parts of water-pumps of sea-water and steam.

2.2.2. Bronze

(a) Cu-Sn Dual-element type ----- Solutionness of the solid solution is very changeable according to the temperature, and being apt to take segregation, is not so easy to obtain the equilibrium. Consequently, the structure and properties of the castings varies remarkably according to the cooling speed. The tensile strength shows its maximum at the Sn contents of about 20%, and the miximum of hardness around Sn 30%.

(b) Influences when added with other elements ----- This Bronze, when being melted, delivers SnO_2 which makes the quality of the cast inferior, and consequently in actual production of the alloy, they add Zn or P, both of which has deoxidation properties. Pb is added to the alloy for bearings.

Zn ----- Bronze in JIS. BC3 that is composed of Cu 88%, Sn 10% and Zn 2% has long been noted as Admiralty Gun Metal, having splendid mechanical, anti-corrosive properties, which is widely used for casting various parts of machineries, valves, cocks, gears etc.
Other compositions of Cu-Sn-Zn type alloys are about 2-15% of Sn, Zn 1-10%, and often 0.5% - 10% of Pb; the one of Cu 85%, Sn 5%, Zn 5% and Pb 5% is well known as 85-5-5-5 Alloy (JIS BC6).

Pb ----- Leaded Bronze ----- Pb is very little solid soluted into Cu, and the Pb added solidifies around the grain-boundary of the solid solution. Consequentely, this bronze has better properties for the bearings than any other ordinary bronze. Even not for making bearings, the small Pb addition improves the castability, machinability, and the resistence against wear and water pressure. The representative example of the kinds is the afore-mentioned 85-5-5-5.

P ----- Phosphor Bronze --- P is an effective agent for deoxidation; the bronze just used P for deoxidation and leaving no P, or leaving purposely a very little P, are both called as Phosphor Bronze, the former is classified to JIS PBCI and the latter to JIS PBC2 and C3. P can be melted up to about 0.15% into the Cu-Snα solid solution, however, the extra of that is crystallized as Cu_3P. This Cu_3P is very hard which effectively increases the wear resistence of the alloy, and therefore, adapted for making various gears, bearings etc.

2.2.3. Al Bronze

(a) Cu-Al Dual Elements Type ----- This type of bronze with Al less than 7.4% is an alloy of α single phase, and has little tendency of segregation when being cast. The standard quantity of Al addition to the alloys of practical use is 9%, of which composition shows the maximum strength. The alloy with Al over 9% is of β single phase at the time of just after the solidification, however, it α phase gradually precipitates along with the decrease of temperature, and is to become, of α - single phase, at the temperature of 600°C or under at the equilibrium state. Even in actual casting, however, the afore-mentioned changes would not be taken place completely. The composition of the castings with Al of 9% alloy has, besides the α -phase secondary precipitated, β phase remains of which is to be eutectoid transformed into $\alpha + \gamma_2$ in case of the equilibrium status. But, this would not actually be decomposed, while changed into β' - pretentive-stable-phase. And therefore, the composition of the alloy would be of $\alpha + \beta'$ phase. In case of large castings, there comes the decomposition of β into $\alpha + \gamma_2$, which makes the castings to be brittle because of gradual cool. This Phenomena is called as Self Annealing. So, for the large castings, rapid cool method should be applied. But when Fe, Ni, Mn etc. added, no self-annealing will occur because they eliminate velocity of eutectoid decomposition remarkably.

(b) Influences of other elements added.

Fe ----- Alloys of practical use, (IJS ALBC 1, 2, 3) always contain 4-5% of Fe, because the Fe added is to make the crystal structure outstandingly finer; which reinforces the tensile strength and hardness, and eliminates the shrinkage cavity of the castings.

Ni ----- Ni is solid soluted into the α -phase in comparatively small quantity, but as the solubility of α -phase decreases remarkably in low temperature, it brings out good effects of heat-treatment.

Mn ----- Mn has good effects in deoxidization, improves the corrosion and wear resistance, and increases the tensile strength without harming the elongation; so generally about 3% or less of Mn is added. The multi-element-Al bronze castings is excellent in corrosion, erosion and wear resistance, and also is good in strength and plasticity; therefore used for making propellar of vessels, gears, valve bases, etc.

3. AL ALLOYS

Though there are many types of Al-Alloys for castings, they are divided roughly into Al-Si type, Al-Cu type, Al-Si-Cu type, Al-Cu-Mg type, Al-Mg type, and Al-Zn type.
The Alloys of Al-Si type, having good castability, are widely used for castings, and called as Silumin. The Alloys of Al-Cu type have long been used industrially as the light-alloys, and is called in Europe as American Alloys because the said alloys have been exploited in the States with the development of automobile Industry.

The Alloys of Al-Si-Cu type have been developed in Germany, and are used more for the general castings than the alloys of Al-Cu type,

The Alloys of Al-Cu-Mg type are called as Y-Alloys when added with Ni, and widely used for making pistons or others that require high heat-resistence. This alloy has been developed in England many years ago, but still is used in the same compositions in most countries. The Alloys of Al-Mg type, were also invented in Germany, but not so much used at that time because of the inferior quality as Al of good quality was rather difficult to be obtained then. Still however, if the alloys contain very few of impurities, they show very excellent corrosion resistance and are, at present, widely used for casting various parts of vessels and others that require high corrosion resistance, and familiarized as to be called Hydronalium.

The Alloys of Al-Zn type are used very seldom in Japan.

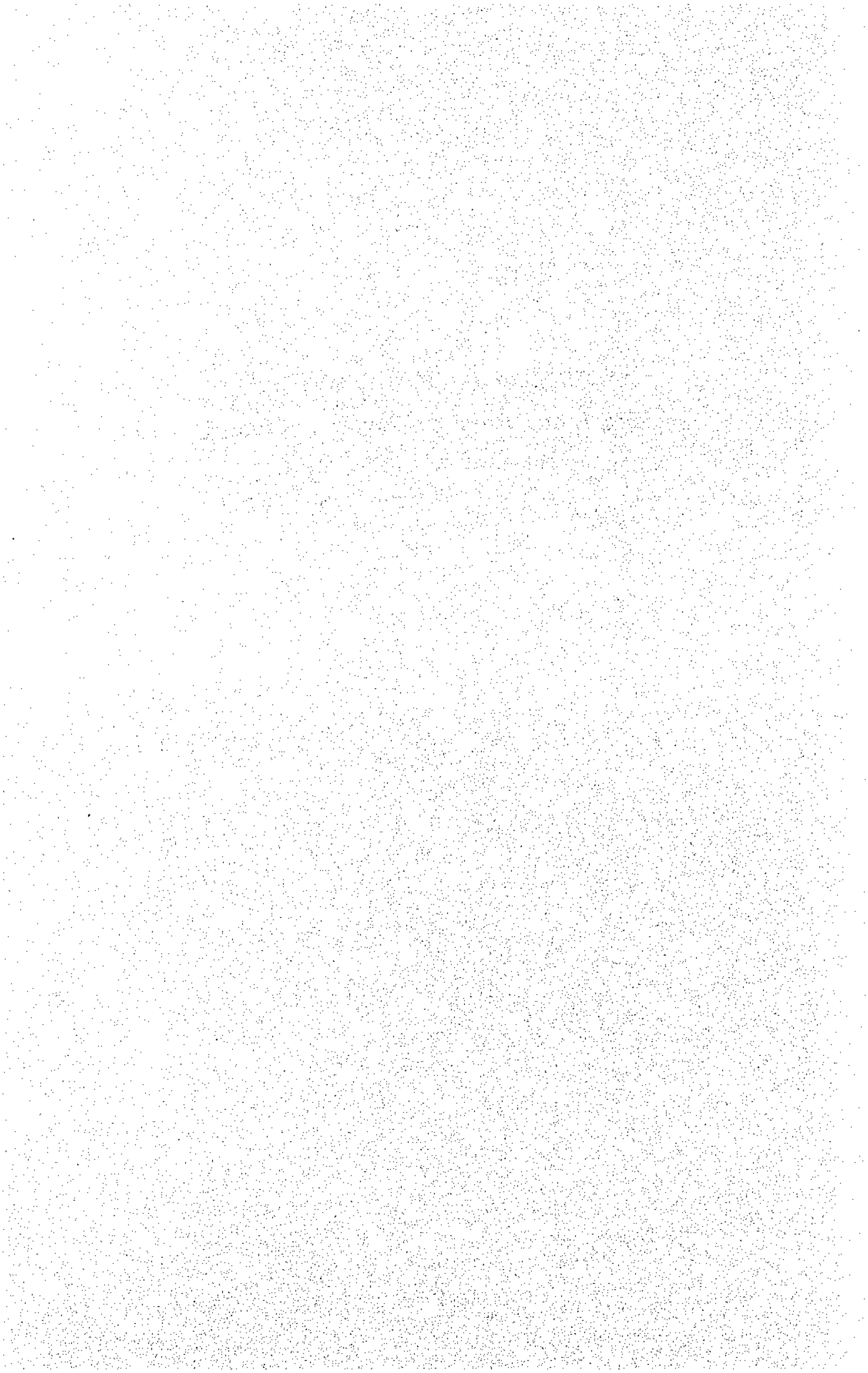
Following Fig. 1, shows the alloys of practical use in Japan.

Fig. 1 Al-Alloys of Practical Use in Japan

Type of Alloys	JIS	Composition				Names of the alloys	Remarks	Use
		Cu	Si	Mg	Ni			
Al - Cu	ACIA	4.5				195	S. P.	Fly-wheel housing, Crank case
Al - Cu - Si	2A	4	5			Lautal	S. P.	Manifold, Crank case, and for general use
Al - Cu - Si	2B	4	6			Lautal, SAE 329	S. P.	Crank case, Cratch housing & for general use
Al - Si	3A		12			Silumin	S. P.	Case, Cover, housing, & for general use
Al - Si - Mg	4A		9	0.5		γ -Silumin	S. P.	Brake-Drum, crank case & for general use
Al - Si - Cu	4B	3	9			Cu-Silmin	S. P.	Parts for Engines & for general use
Al - Si - Mg	4C		7	0.3		356	S. P.	Water-cooled cylinder-block, parts for oil-pressure machine
Al-Si-Cu-Mg	4D	1.3	5	0.3		355	S. P.	Water-cooled cylinder head, sylinder block
Al-Cu-Ni-Mg	5A	4		1.5	2	Y-alloy, 142	S. P.	Air cooled sylinder head piston
Al - Mg	7A			5		Hydronalium 214	S. P.	Foods, chemicals, architecture, decorations, parts for vessels.
Al - Mg	7B			10		" 220	S. P.	Parts for coaches, planes, that require hardness and anti-shock feature.
Al-Si-Cu-Ni-Mg	8A	1	12	1	2	Low-X, A132	P	Piston, Pully
Al-Si-Cu-Ni-Mg	8B	3	9	1	1	Low-X, D132	P	Piston, Pully

FOUNDRY RAW MATERIALS

(Pig Iron, Ferro-alloys and Scrap)



FOUNDRY RAW MATERIALS

By: Taku Sugiura
Chief of Research Dept.
Yahagi Iron Works, Ltd.

1. PIG IRON

1.1. Iron Ores

1.1.1. Classification of iron ores

hematite (Fe_2O_3, Fe = 70.0),

magnetite (Fe_3O_4, Fe = 72.4),

limonite ($2Fe_2O_3\ 3H_2O$, Fe = 59.8),

siderite ($FeCO_3$, Fe = 48.2),

iron sand (Fe_3O_4), pyrite cinder (Fe_2O_3),

purpleore (Fe_2O_3), etc.

1.1.2. Agglomerates

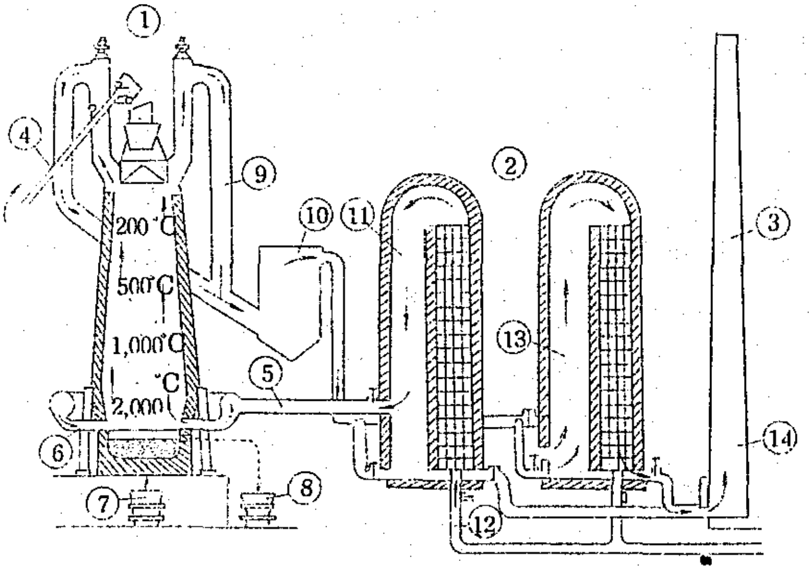
Sinter (self-fluxing sinter or lime-sinter), pellet

1.1.3. Requirements for characteristics of iron ores

(1) Fe content - high (60%),
(2) Content of detrimental elements (P. S. Cu, Cr, Sn, As, etc.) - low,
(3) Size - moderate,
(4) Reducibility - good,
(5) Strength (during heating or reducing) - high.

1.2. Blast Furnace

1.2.1. Construction of blast furnace (Fig. 1)



(1) blast furnace
(2) hot (blast) stove
(3) chimney
(4) skip indine
(5) hot blast piping
(6) tuyere
(7) pig iron ladle car
(8) slag ladle car
(9) blast furnace gas
(10) gas cleaning plant
(11) hot balst
(12) cold blast
(13) combustion chamber
(14) exhaust gas

Fig. 1 Sectional diagram of blast furnace installation

1.2.2. Chemical reactions in the blast furnace

(1) Fe

1. $Fe_2O_3 + CO \rightarrow 2FeO + CO_2$ (Indirect reduction)
2. $Fe_3O_4 + CO \rightarrow 3FeO + CO_2$ (" ")
3. $FeO + CO \rightarrow Fe + CO_2$ (" ")
4. $FeO + C \rightarrow Fe + CO$ (Direct reduction)
5. $3FeO + 5CO \rightarrow Fe_3C + 4CO_2$
6. $3Fe + 2CO \rightarrow Fe_3C + CO_2$

(2) Mn

7. $MnO_2 + CO \rightarrow MnO + CO_2$

8. $Mn_3O_4 + CO \rightarrow 3MnO + CO_2$

9. $Fe + MnO + C \rightarrow Fe\text{-}Mn + CO$

(3) S

10. $CaSO_4 + Fe + 3C \rightarrow CaO + FeS + 3CO$

11. $FeS + CaO + C \rightarrow CaS + Fe + CO$

(4) Si

12. $SiO_2 + 2C + Fe \rightarrow Fe\text{-}Si + 2CO$

(5) P

13. $3CaO \cdot P_2O_5 + 3SiO_2 + 5C + 6Fe \rightarrow 3CaO\ SiO_2 + 5CO + 2Fe_3P$

(6) C

14. $2CO \rightarrow C + CO_2$ (Carbon deposition)

15. $CO_2 + C \rightarrow 2CO$ (Carbon solution)

16. $C + O_2 \rightarrow CO_2$

Combustion of cokes

(7) $CaCO_3$

17. $CaCO_3 \rightarrow CaO + CO_2$

18. $CaO + Al_2O_3 + SiO_2 \rightarrow$ Silicates

(8) H_2O

19. Evaporation of moisture

20. H_2O (combined water) $+ C \rightarrow H_2 + CO$

21. H_2O (in blast) $+ C \rightarrow H_2 + CO$

1.2.3. Control of chemical composition of pig iron

C: Molten iron is saturated with carbon under the given conditions in the furnace hearth. It is difficult to control carbon content independently.

Si: High temperature operation, slow driving rate, low basicity slag - high Si, Si 1% - coke 70 kg.

Mn: 40 ~ 60% of charged Mn is reduced.

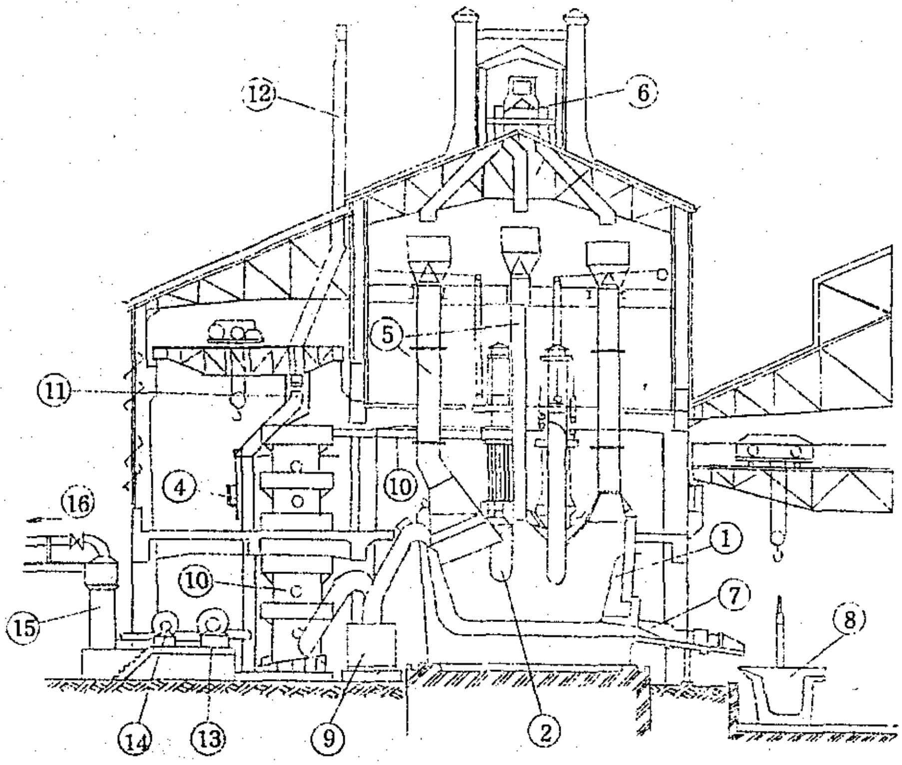
S: 4 ~ 6% of charged S is dissolved in the liquid metal. High temperature operation, high basicity slag - low S.

Ti: 20 ~ 40% of charged TiO_2 is reduced and dissolved by the iron.

P, Ni, Cr, Cu, As, V: It is difficult to eliminate these elements during blast furnace operation.

1.3. Electric Smelting Furnace

1.3.1. Construction of electric smelting furnace (Fig. 2)



(1) furnace body
(2) Soderberg self-baking electrode
(3) secondary conductors
(4) transformer
(5) charging pipe
(6) belt conveyer
(7) tapping hole
(8) ladle
(9) water seal
(10) spray tower
(11) bleeder valve
(12) bleeder
(13) theisen washer
(14) washing blower
(15) mist separator
(16) to gas holder

Fig. 2. Sectional diagram of electric smelting furnace installation (closed type)

1.3.2. Chemical reactions in the electric smelting furnace

$FeO + C \rightarrow Fe + CO$ (Direct reduction)

1.3.3. Control of chemical composition of pig iron

Si: high A/V, high basicity slag, high coke rate - high Si
1% Si -- 120 kWh

1.4. Pig iron

1.4.1. Classification of pig iron

According to;

(1) Use	Pig iron for steel Pig iron for casting (Foundry pig iron) Ordinary foundry pig iron Malleable pig iron Pig iron for nodular graphite cast iron
(2) Furnace	Blast furnace pig iron Electric furnace pig iron
(3) Reducing material	(Coke pig iron) Charcoal pig iron
(4) Chemical composition	(High carbon pig iron), Medium carbon pig iron, Low carbon pig iron, Silvery pig iron (high silicon pig iron), high phosphorus pig iron, low phosphorus pig iron, alloy pig iron.

1.4.2. Chemical composition of pig iron

(1) JIS - Pig iron for casting (Table 1)

(2) Examples of maker's specification (Table 2 - 4)

(3) Fe-C-Si diagram and chemical composition of pig iron (Fig. 3).

Table 1. Pig Iron for Casting

JIS G 2202

Classification			Chemical composition %						Application
			C	Si	Mn	P	S	Cr	
Class 1	No. 1	A	>3. 40	1.40~1.80	0.30~0.90	< 0.450	< 0.050	-	Pig iron used ordinarily; No. 1 subdivided into A, B, C and D chiefly by the variation of Si content.
		B	"	1.81~2.20	"	"	"	-	
		C	>3.30	2.21~2.60	"	"	"	-	
		D	"	2.61~3.50	"	"	"	-	
	No. 2		"	1.40~3.00	0.30~1.00	< 0. 600	< 0.080	-	
Class 2	A	No. 1	>3.50	1.00~2.00	0.20~0.50	< 0. 100	< 0.040	< 0.030	Pig iron used for the malleable cast iron. A: mainly for electric furnace B: mainly for cupola or duplex melting C: particularly high in Si content
		No. 2	"	1.00~2.50	"	< 0.150	< 0.045	< 0.035	
	B	No. 1	>3.00	2.51~4.50	0.50~1.10	< 0.100	< 0.040	< 0.030	
		No. 2	"	"	"	< 0.150	< 0.045	< 0.035	
	C	No. 1	<3.30	>4.51	< 1.10	"	< 0.040	< 0.030	
		No. 2	<3.50	"	"	< 0.200	< 0.045	< 0.035	
Class 3	No. 1	A	>3.40	< 1.00	< 0.50	< 0.100	< 0.040	< 0.030	Pig iron used for the nodular graphite cast iron. No. 1 subdivided into A, B, C and D chiefly by the variation of Si content.
		B	"	1.01~1.40	"	"	"	"	
		C	"	1.41~1.80	"	"	"	"	
		D	"	>1.81	"	"	"	"	
	No. 2		"	< 3.50	"	< 0.150	< 0.045	< 0.035	

Remarks: For Ti and As in Class 3 and other chemical composition which disturb the spheroidizing of graphite, the content thereof may be the subject of agreement between parties concerned.

Table 2. Ordinary foundry pig iron

Classification	Chemical composition %				
	C	Si	Mn	P	S
A1	>3.90	1.40~1.60	0.40~0.90	<0.150	<0.050
A2	″	1.61~1.80	″	″	″
B1	″	1.81~2.00	″	″	″
B2	″	2.01~2.20	″	″	″
C1	″	2.21~2.40	″	″	″
C2	″	2.41~2.60	″	″	″
D1	>3.80	2.61~2.80	″	″	″
D2	″	2.81~3.00	″	″	″
D3	>3.70	3.01~3.20	″	″	″
D4	″	3.21~3.40	″	″	″
D5	″	3.41~3.50	″	″	″

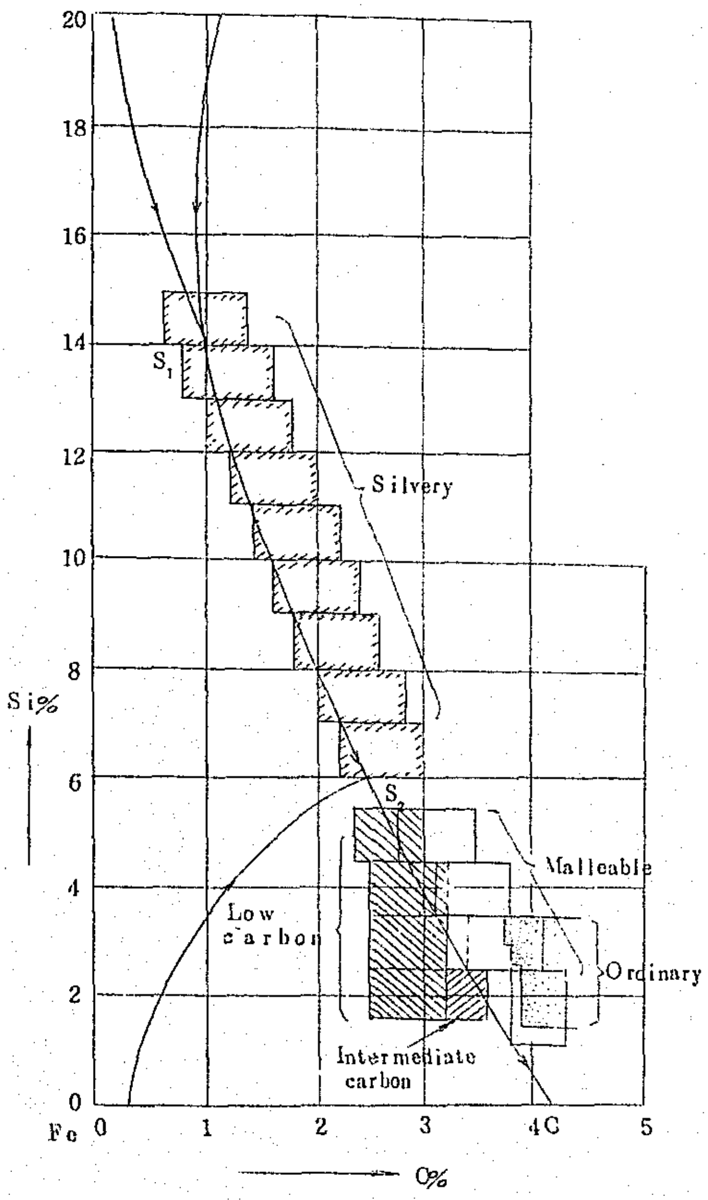
Table 3. Malleable pig iron

Classification	Chemical composition %					
	C	Si	Mn	P	S	Cr
No. 2	3.80~4.30	1.00~2.50	< 0.50	<0.100	<0.035	<0.030
No. 3	3.40~4.10	2.51~3.50	0.60~1.00	″	″	″
No. 4	3.10~3.80	3.51~4.50	0.60~1.10	″	″	″
No. 5	2.70~3.50	4.51~5.50	″	″	″	″

Table 4. Special pig iron

Classification		Chemical composition %				
		C	Si	Mn	P	S
Silvery	7S	2.20 3.00	6.00 7.00	0.70 1.20	< 0.100	< 0.035
	8S	2.00 2.80	7.01 8.00	"	"	"
	9S	1.80 2.60	8.01 9.00	"	"	"
	10S	1.60 2.40	9.01 10.00	"	"	"
	11S	1.40 2.20	10.01 11.00	"	"	"
	12S	1.20 2.00	11.01 12.00	"	"	"
	13S	1.00 1.80	12.01 13.00	"	"	"
	14S	0.80 1.60	13.01 14.00	"	"	"
	15S	0.60 1.40	14.01 15.00	"	"	"
Intermediate carbon		3.20 3.50	1.50 2.50	0.40 0.70	< 0.100	< 0.050
Low carbon	2LC	2.50 3.20	"	0.50 0.80	"	< 0.035
	3LC	"	2.51 3.50	"	"	"
	4LC	"	3.51 4.50	0.50 1.00	"	"
	5LC	2.30 3.00	4.51 5.50	"	"	"

Fig. 3 Fe-C-Si diagram and chemical composition of pig iron



2. FERRO-ALLOYS

2. 1. Method of Manufacture

(1) Electric smelting furnace (cf. Fig. 2)
(2) Blast furnace (6 ~ 12% Si silvery iron, ferro-manganese) (cf. Fig. 1)

2. 2. Chemical Reactions

Standard free energy of formation of oxides (Fig. 4)

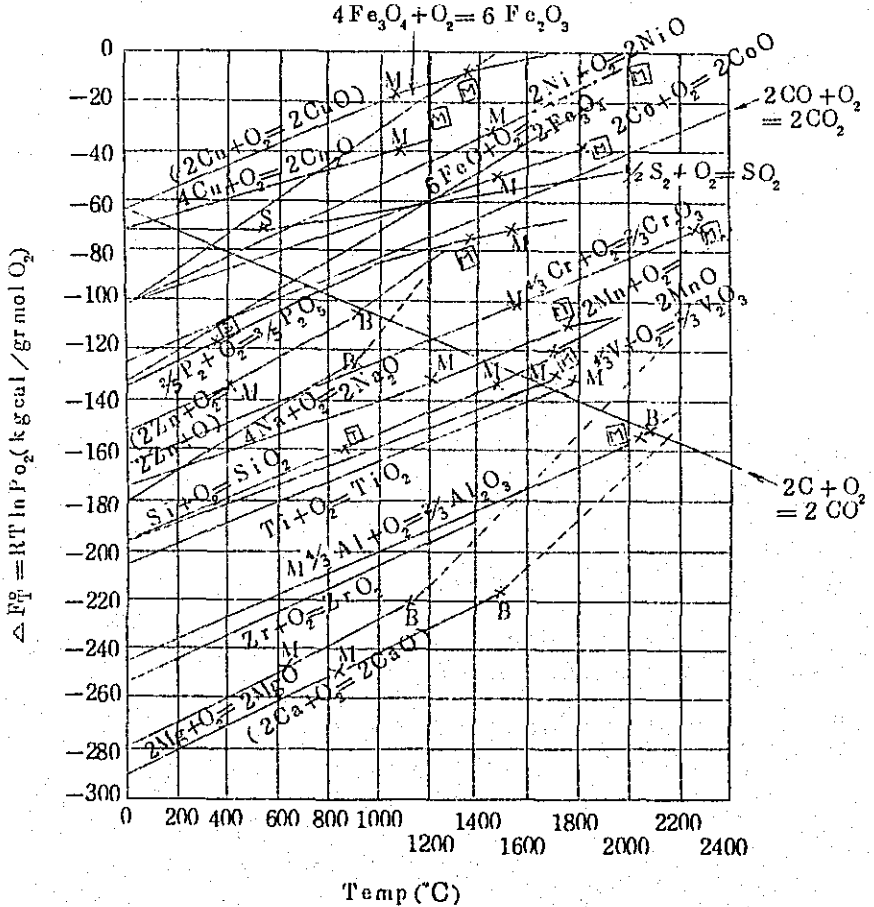


Fig. 4 Standard free energy of formation of oxides

Melting point: $\boxed{\text{M}}$(element), M (oxide),
Boiling point: $\boxed{\text{B}}$(element), B (oxide),
Sublimation point: $\boxed{\text{S}}$ (element), S (oxide),
Transformation point: $\boxed{\text{T}}$ (element), T (oxide)

2. 3. Objects of ferro-alloy addition

(1) Regulation of chemical composition of ordinary cast iron (for example, Fe-Mn, Fe-Si)

(2) Addition of special element for alloy cast iron

(3) Inoculation

2. 4. Time of addition

(1) Cupola (2) Ladle

2. 5. Suggestions in use of ferro-alloy

For better yield of alloying elements and uniformity of chemical composition of produced metal, attention should be paid to the following characteristics of ferro-alloys.

(1) Chemical composition (content of alloying elements, impurities and gas.)

(2) Size

(3) Melting point boiling point

(4) Specific weight

(5) Graphitizing tendency for cast iron etc.

2. 6. Chemical composition of ferro-alloy

(1) Ferrosilicon (Table 5) and metallic silicon (Table 6)

Note: 50%Si — Eutectic composition, low melting point, high specific gravity and low gas content.

(2) Ferromangdnese (Table 7), metallic manganese and spiegeleisen (Table 8)

(3) Silicon-manganese (Table 9), Calcium-silicon (Table 10)

Table 5. Ferrosilicon

JIS G 2302

Classification		Code	Chemical composition %			
			Si	C	P	S
Ferro-silicon	No. 1	FSi1	88 ~ 93	<0.2	<0.05	<0.02
	No. 2	Fsi2	75 ~ 80	"	"	"
	No. 3	FSi3	40 ~ 45	"	"	"
	No. 4	FSi4	25 ~ 30	<0.8	<0.10	<0.10
	No. 6	FSi6	14 ~ 20	<1.3	<0.05	<0.06

Note: C, P and Al contents may be specified as follows.

Chemical composition	Code	Content %	
C	F Si 2	<0.1	<0.05
P	"	<0.04	<0.03
Al	"	<1.0	<0.5

Table 6. Metallic Silicon

JIS G 2312

Classification		Code	Chemical composition %				
			Si	C	P	S	Fe
Metallic Silicon	No. 1	MSi1	>98.0	<0.10	<0.05	<0.05	<0.7
	No. 2	MSi2	>97.0	"	"	"	<1.0

Table 7. Ferro manganese

JIS G 2301

Classification		Code	Chemical composition %				
			Mn	C	Si	P	S
High carbon	No. 0	FMnH0	78~82	<7.5	<1.2	<0.40	<0.02
	No. 1	FMnH1	73~78	<7.3	"	"	"
	No. 2	FMnH2	"	<7.0	<3.0	"	"
Medium carbon	No. 0	FMnM0	80~85	<1.5	<1.5	"	"
	No. 2	FMnM2	75~80	<2.0	<2.0	"	"
Low carbon	No. 0	FMnL0	80~85	<1.0	<1.5	<0.35	"
	No. 1	FMnL1	75~80	"	"	<0.40	"

Note: P, C and Si contents may be specified as follows.

Chemical composition	Grade	content %
P	All grades	<0.30 <0.20 <0.15 <0.10
C	Low carbon	<0.50 <0.20 <0.10
Si	High carbon Med. carbon Low carbon	<0.5 <0.3 <0.5 <1.0

Table 8. Metallic Manganese and Spiegeleisen

JIS G 2311
JIS G 2305

Classification	Code	Chemical composition %						JIS
		Mn	C	Si	P	S	Fe	
Electrolytic manganese	MMnE	rest	<0.01	<0.01	<0.01	<0.04	<0.01	G2311
Spiegeleisen	SP	20~25	>3.5	<2.0	<0.30	—	—	G2305

Table 9. Silicon-manganese

JIS G 2304

Classification		Code	Chemical composition %				
			Mn	Si	C	P	S
Silicon-manganese	No. 0	SiMn0	65~70	20~25	<1.5	<0.30	<0.05
	No. 1	SiMn1	"	16~20	<2.0	"	<0.02
	No. 2	SiMn2	60~65	"	"	"	<0.03
	No. 3	SiMn3	"	14~18	<2.5	"	"

P content may be specified as follows.

Grade	content %
All grade	< 0.20, < 0.15, < 0.10

Table 10. Calcium-silicon

JIS G 2314

Classification		Code	chemical composition %			
			Ca	Si	C	P
Calcium-silicon	No. 1	CaSi1	>30	55~65	< 1.0	<0.05
	No. 2	CaSi2	25~29	"	"	"

3. SCRAP

3. 1. Classification of Scrap

3. 1. 1. Iron scrap

(a) Return scrap or home scrap

Sprues, gates, risers and defective castings.
Proportion of return scrap to the metal melted - 10~50%-depends on the type of castings and gating.
chemical analysis is known and uniform. -- desirable to separate according to the average analysis.

(b) Purchased scrap

Chemical analysis and size are variable. -- contaminated with other materials such as steel shafting, bearing metals, non-ferrous materials including copper- and aluminum-base alloys and other miscellaneous materials.

Iron castings for given applications are often made to a fairly standard analysis range. -- for example automotive castings, machine tool castings.

3.1.2. Steel scrap

(a) New material of known analysis, the bye-product of some fabricating process.

(b) Old scrap, dismantled obsolete or worn-out structures and machines. -- variable composition and size, containing tramp alloys or non ferrous attachments.

3.2. How to Select Scrap for Foundry Use

3.2.1. Cast scrap

(a) Pieces of iron scrap which show evidence of machining operations will be high enough in carbon and silicon to yield a gray fracture in the sections involved.

(b) Chilled casting or castings showing white fracture are almost invariably of low silicon content.

(c) Burnt and heavily oxidized scrap is always dangerous. It is low in carbon and silicon, high in sulfur, and introduces variable quantities of unwanted oxide into the metal.

(d) Some types of iron castings such as railroad brake shoes, sash weights, mill stars and many white iron parts are traditionally melted from the poorest grades of scrap.

(e) Cast scrap should not contain appreciable amounts of steel.

(f) Material which shows ductility and bends when struck with a hammer is steel, wrought iron, malleable iron oi nodular graphite cast iron.

(g) Pieces which do not rust or are not lifted by the electro-magnet are high in alloy content.

(h) Non-ferrous attachments such as aluminum, copper alloys, bearing metals, etc., are dangerous and should not be present in properly prepared scrap. The same is true of galvanized or tinned parts.

3.2.2. Steel scrap

(a) Structural steel (angles, beams, etc.) usually is unalloyed and contains relatively low carbon, approximately 0.2% with manganese at about 0.50%. Silicon usually is very low with sulfur and phosphorus 0.05% max.

(b) Ship plate, boiler plate, tanks and other commonly used plate will analyze 0.25% max. carbon, 0.75% manganese, 0.35% max. silicon, 0.04% max. phosphorus, and 0.05% max. sulfur.

(c) Sheet and strip scrap often purchased bundled usually analyzes 0.10% carbon, 0.40% manganese and is low in silicon, sulfur and phosphorus.

(d) Railroad rails are made of unalloyed high carbon steel analyzing 0.70% carbon, 0.75% manganes, and 0.10 to 0.23% silicon.

(e) Forgings may be unalloyed carbon steel, but for heavy duty applications alloy steels of various types are often used.

(f) Small steel parts which involve considerable machining are often made from free-machining steels containing from 0.08 to 0.30% sulfur.

3.2.3. Size

(a) Very small pieces of scrap are objectionable, particularly in steel scrap. Such material in large amounts tends to make an excessively tight charge, preventing proper penetration of blast in the case of cupola melting. Very small pieces also may migrate from charge to charge as the cupola settles, thus arriving at the melting zone ahead of the balance of the charge.

(b) Very thin pieces are also objectionable. Thin steel plates carries an excessive percentage of rust and much oxide is formed on its surface during descent in the cupola, resulting in excessive melting loss of silicon and manganese.

(c) An excessive amount of flat plate stock in steel scrap is objectionable in that flat plates tend to overlap and force the blast up the cupola walls.

3.2.4. Tramp elements in scrap

Among the tramp elements which usually are not harmful in small amounts are the alloys nickel, chromium, cobalt, copper, molybdenum, titanium, vanadium, etc. Most of these elements are often added to molten iron to improve the properties of the castings.

Al: pinholes, sluggish metal, aross

Bi: decrease in strength

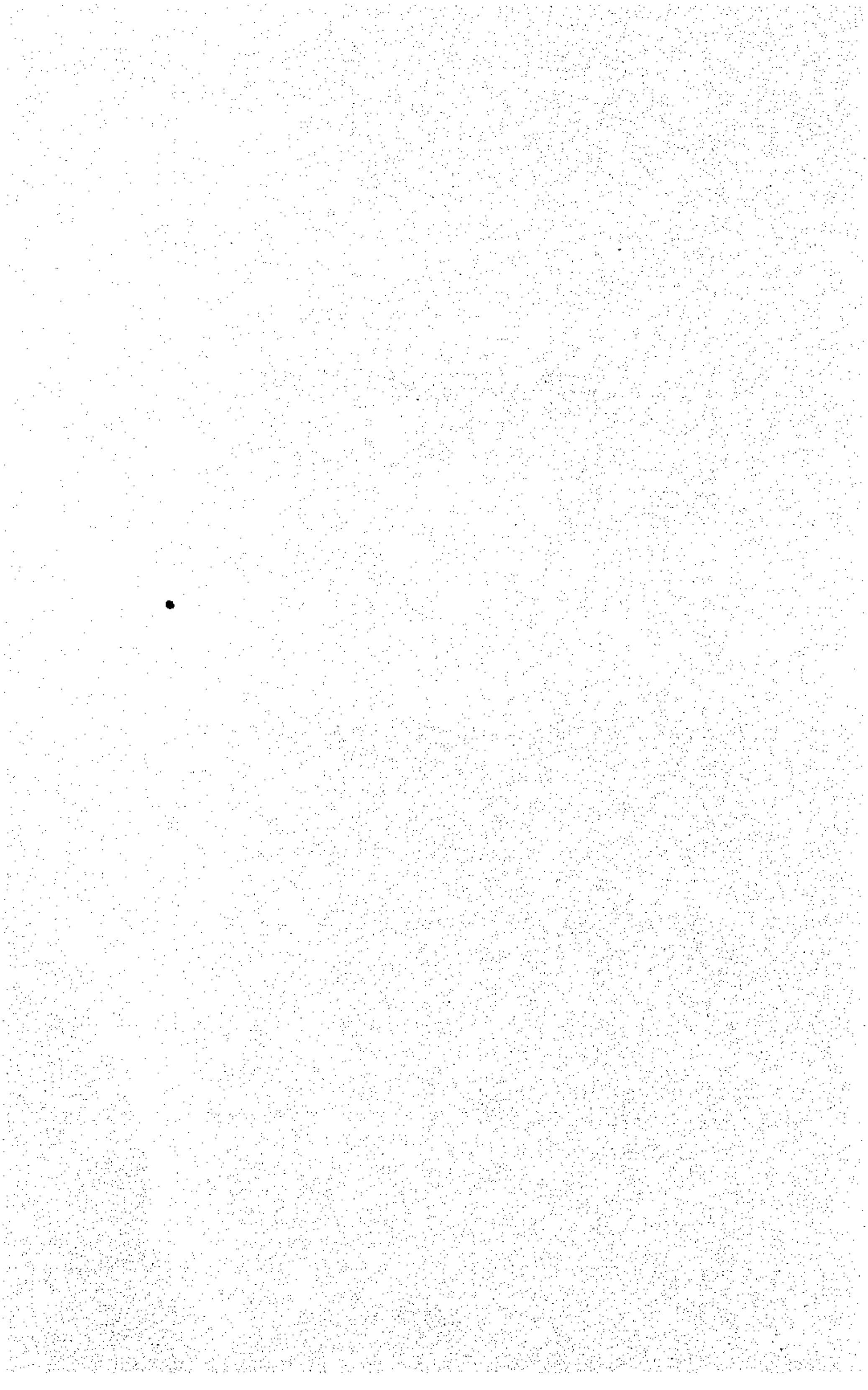
Pb: gas porosity, decrease in strength

Te: chilling effect

Zn: decrease in impact and tensile strength, especially when added as a constituent in brass scrap.

* * * * * * * *

FUEL (FOUNDRY COKE)



FUEL (FOUNDRY COKE)

By: Ichiro Saeda
Asahi Coke Industry Co.,Ltd.

1. MANUFACTURING PROCESS OF FOUNDRY COKE

In old days, charcoal used to be the fuel for melting iron at a foundry shop. With the development of coke industry, foundry cupola depends exclusively on hard and high quality coke for its fuel. The quality of foundry coke is determined by the quality, blending ratio, grain size and carbonization process of its raw material, coal.

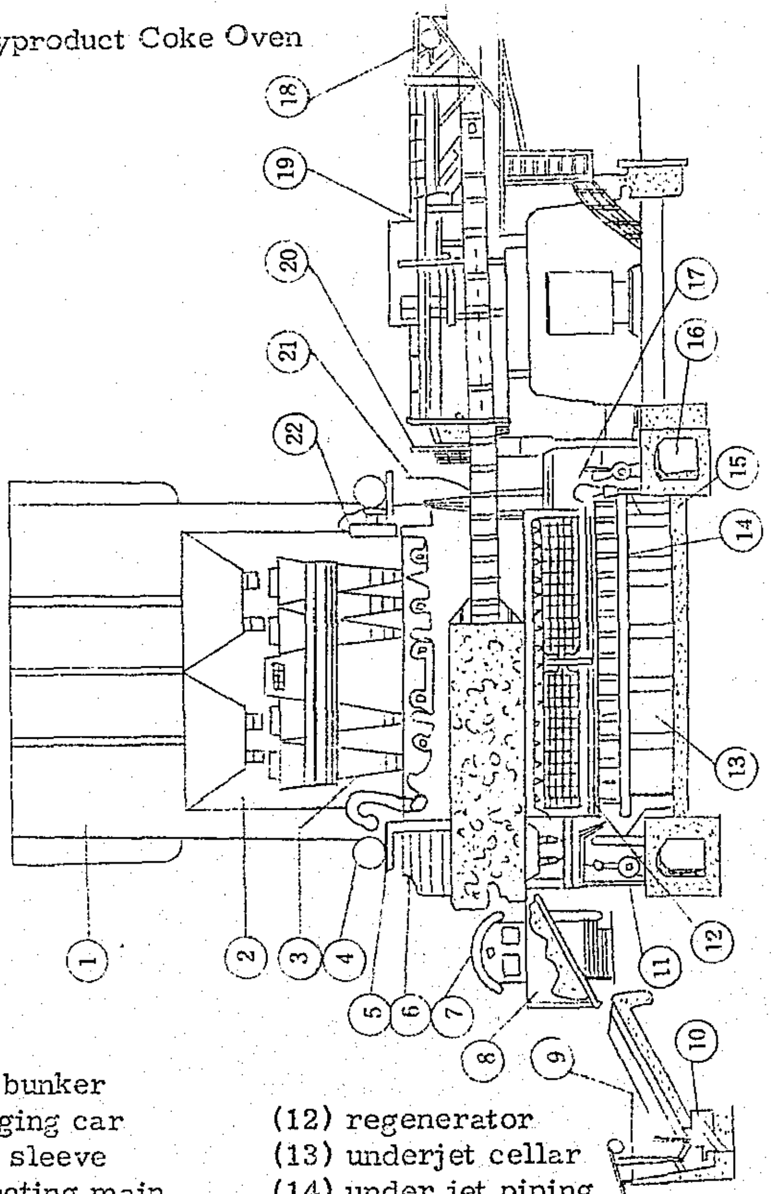
In Japan, the principal types of raw coal for foundry coke are high volatile bituminous coal, low volatile vituminous coal, anthracite coal, pertoleum coke and pitch.

These coking coals are properly blended, crushed and charged into a coke oven. Air is then shut off from the oven, and the crushed coal charged is heated for 20 to 26 hours to a temperature of approximately 1,000 degrees C. Through this heating process, moisture in the coal is evaporated, and the coal begins to soften and swell at a temperature of approximately 500 degrees C, at the same time emitting gas.

Rising to a temperature near 900 degrees C, the material ceases swelling and producing gas and begins to shrink; continuedly heated up to 1,000 degrees C, it is finally made into foundry coke at a high temperature carbonization. Gas produced at the time of carbonization is coal gas in which tar is contained. This tar is then separated and extracted as coal tar which serves as the raw material of chemical industry.

There are two types of coke oven in which the carbonization of coal takes place; Beehive Coke Oven, and Byproduct Coke Oven. At the present time, the Byproduct Coke Oven is in use almost exclusively. Figure 1 is a diagram of the Byproduct Coke Oven, and Figure 2 illustrates the process of carbonization.

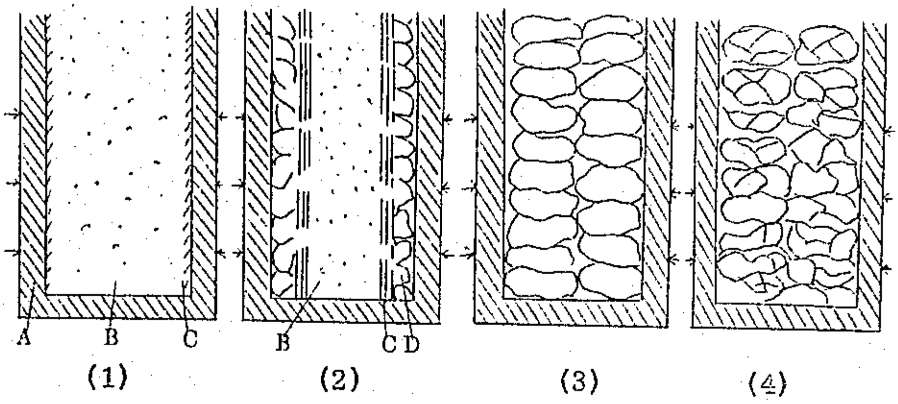
Fig. 1 Byproduct Coke Oven



(1) coal bunker
(2) charging car
(3) drop sleeve
(4) collecting main
(5) ascension pipe
(6) coke guide
(7) coke quenching car locomotive
(8) coke quencing car
(9) coke whart
(10) coke belt conveyor
(11) lean gas main
(12) regenerator
(13) underjet cellar
(14) under jet piping
(15) rich gas main
(16) waste gas flue
(17) reversing valve
(18) leveller
(19) pusher machine
(20) oven door on extractor
(21) coke pusher ram
(22) liquor spraying nozzle

The Byproduct Coke plant consists of batteries of 10 to 20 ovens. Each oven is an externally-heated retort; gas is combusted at flues on an external wall of the oven for the heating purpose. The Beehive Coke Oven is an internally-heated retort in which coal-emitted gas is directly burned inside the oven. In this type of oven, carbonization takes a longer time and temperature adjustment is difficult.

Fig. 2 Process of carbonization in a coke oven



A. Furnace wall B. Raw material coal layer C. Dewatering layer, shows the state when coal inserted into Coke Oven	D. Coke layer, carbonization is going on. Expansion and shrinkage starts in (D) coke layer and generation of dehydration gas is active.	Coking completes.	Still to be heated and coke has cracks grown into finer pieces.

2. CHARACTERISTICS OF FOUNDRY COKE

The characteristics of foundry coke used for a cupola play an important role in the performance of a cupola, for the foundry coke not only supplies heat necessary for dissolving iron, but also performs numerous, metallurgically important functions such as providing molten iron in the cupola with carbon, reducing and refining iron, silicon and manganese metals and supporting a melting zone as bed coke, etc. For these reasons, unlike ordinary coal for which calorific value is regarded as important, the following physical and chemical properties are considered important in regard to the foundry coke:

2. 1. Physical Property

2. 1. 1. Strength

Soft coke or coke of insufficient hardness crushed into fines at a great rate during the process of handling and charging into the bed of a cupola with the result that the effectively usable portion of the coke is reduced and the size of grain becomes unevently distributed. Also, due to the crush, wear and decomposition of such coke, in-oven resistance increases disrupting the normal operation of the oven.

Two testing methods -- (1). Shatter test and (2). Tumbler test -- are used for measuring coke hardness. In the case of foundry coke, the shatter test is the standard method.

By this shatter test, the hardness is expressed by the percentage ratio of coke still remaining on a 50m/m screen on which 25kg. of coke is dropped four times from the height of 2m. The standard hardness of foundry coke in Japan ranges from 87 to 96.

The tumbler test expresses the hardness in terms of grain size measured after the coke has been twirled round 30 times at 15 R. P. M. in a drum of 150cm diameter and length. It is considered that while the shatter test finds out the strength of coke against impact, the tumbler test indicates the strength or the hardness of coke against tear and wear.

In addition to the coke hardness at a normal temperature, the same property at a high temperature is also important. This is to say that even the coke with high strength at a normal temperature and with uniform grain sizes would collapse and disable the normal operation of the oven, if its strength becomes low when exposed to a high temperature after charged into the oven.

2. 1. 2. Grain size

The particle size of coke for foundry use is one of the most decisive factors for the successful operation of a cupola.

Uniformity is the first and foremost requirement in the particle characteristics. Lack of uniformity in the particle size renders blast pressure constantly variable which in turn results in unstable combustion within the oven.

The next important requirement is that the particle size should be proportionate to the hearth diameter of cupola. Should the particle size of coke be too small, the total surface areas of coke become larger, resulting in the slowing down of reaction to oxygen and in the excess reducing reaction of CO_2. The optimal ratio of hearth diameter and coke particle size is believed to be 1/8 to 1/12.

As already explained, coke is made through a carbonization process in which pulverized raw coal charged into an oven is solidified (coking action); as a result, the particle size of coke discharged from the oven is not uniform at all, and, therefore, sizing becomes necessary. At Asahi Coke Company, raw coal is briquetted in advance of charging into a coke oven, and carbonized coke briquetts are sold on market under the trade name of "Forma" of which particle size is perfectly uniform. "Forma" is entirely new foundry coke with improved hardness.

2.1.3. Porosity

Porosity is a ratio between apparent specific gravity and true specific gravity. Its equation may be as follows:

$$\text{Porosity} = \left(1 - \frac{\text{Apparent specific gravity}}{\text{True specific gravity}}\right) \times 100$$

The average porosity foundry coke in Japan is 25 to 35 approximately, while in America it is 40 to 50. This is due to the different raw coking coal used between the two countries. The true specific gravity related to porosity does not vary much with any brand of coke, averaging at about 1.8 to 2.0. Hence, the apparent specific gravity can be estimated with the known porosity. Also, the smaller the prosity, the larger the ratio of volume (kg/cm^3) is.

2.2. Chemical Property

2.2.1. Volatile matter

Volatile matter is expressed by the amount reduced at the time of heating of permanent wet test specimen at a temperature of 925 degrees C ± 5 degrees C for 7 minutes with air completely shut off, according to the provisions of J.I.S. Since the carbonization temperature of foundry coke is higher than this J.I.S.-specified test temperature, the volatile matter of foundry coke is generally not too much, averaging below 2%.

2.2.2. Ash

Ash is the residual of coke after it is combusted. Its amount is already fixed even before carbonization takes place by the amount of ash in raw coal. The amount and composition of ash have large effects on various reactions of coke within a cupola such as combustion, carbonization, reduction and slag formation. The grading of foundry coke in Japan is based on ash content is the order of 10%, 8% and 6%. Low ash coke with the ash content of less than 6% is marketed in Japan for special high temperature melting, but for general melting purpose, coke with the ash content of about 8% is popularly used as a tendency. The remaining lement after volatile matter and ash are determined in the industrial analysis of coke is fixed carbon, or to put it in another way;

$$\text{Fixed carbon} = 100 - (\text{Volatile matter} + \text{Ash})$$

It is this fixed carbon that fixes the value of coke in the cupola as fuel. The amount of blast into the cupola should be balanced by the product of fixed and coke ratio.

2.2.3. Sulphur

Sulphur contained in foundry coke is usually in the range of 0.8% to 0.5%. The most standard sulphur content is 0.65%.

Since sulphur in raw coal is reduced to a half through carbonization with the other half remaining in coke, coke with low sulphur can be made from coal of low sulphur. However, because of ash and hardness considerations, it is difficult still at the present time to produce coke with the sulphur content of less than 0.5%.

About 1/3 of sulphur remaining in coke is absorbed by iron during melting, which means if the same cupola charge materials are reduced over and over, the sulphur content is to gradually increse. Special care is required in this regard.

2.3. Reactions of Foundry Coke Inside a Cupola

2.3.1. Reactions of combustion and reduction

The combustion of coke differs from coal in that there is no emmission of gas caused by thermal decomposition, and oxidation takes place through a direct contact between oxygen in the atmosphere and carbon on the surface of coke, as a result of which combustion is induced and temperature rises enhancing the oxygen absorbtion of carbon, and thereby combustion progresses. Since such combustion occurs on the surface, it is called surface combustion and differentiated from decomposing combustion as is the case with coal. In the surface combustion, carbon on the surface is different from carbon inside, and since its coherence (atomic value) is unsaturated and activated, oxygen molecule is easily absorbed.

Carbon is combined with oxygen on the surface of coke to produce whether only CO_2(Formula 1) or also CO (Formula 2) simultaneously. No sure finding is as yet made on this point. In any event, at areas immediately close to a tuyere, 02 in the atmosphere is completely used up for combustion, at which time the maximum content of CO_2 is 21%. Next, CO_2 gas which rose through a combustion zone is reduced by C of red hot coke into CO, or

$$C + CO_2 = 2CO \text{ ——— (Formula 3)}$$

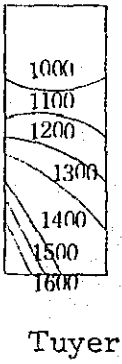
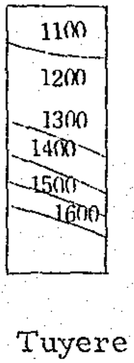
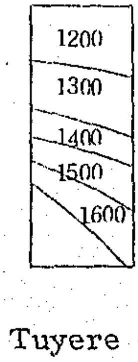
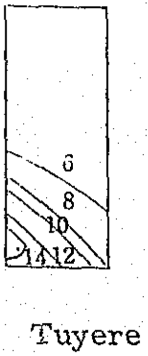
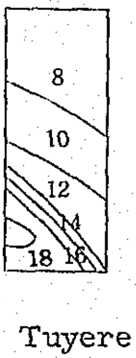
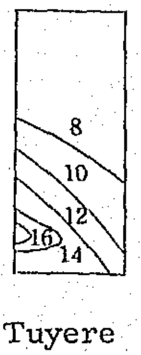
In this case, the longer the time of contact between C at a high temperature and CO_2, the more likely it is that all CO_2 is changed into CO, CO_2 0% and CO 34.7%. But, due to the great flow speed (uprising speed) of CO_2, actually CO_2 at a furnace top is 9 to 15% and CO is between 8 and 21%. This percentage figures are of course dependent on the grade, reaction, grain size, coke ratio and blast amount of coke.

CO gas coming out of the furnace top could be burned off in flame, if it is high in density and its temperature is high enough for combustion.

$$2CO + O_2 - 2CO_2 \text{ ——— (Formula 4)}$$

Figure 3 shows the results of test conducted with a midget-sized cupola with one tuyere and an internal diameter of 20cm in order to find out the condition of combustion inside a cupola.

Fig. 3 Distribution of Temperature and CO_2 Inside Cupola

	Coke small (hearth dia 1/10) Blast $30m^3/min/m^2$	Coke large (hearth dia 1/5) Blast $30^3/min/m^2$	Coke large (hearth dia 1/5) Blast $50m^3/min/m^2$
In-furnace temperature (Deg. °C)			
Inside furnace (CO_2 %)			

From this test, it can be reduced that the furnace wall just opposite from the tuyere is the center of a cupola with an internal diameter of 40cm.

Also, from this test, it is obvious that the condition of combustion in the furnace varies greatly even with the change of coke size and blast amount.

That in-furnace temperature rapidly goes down as CO_2 is reduced is due to the reaction of heat absorption whereby CO_2 is reduced into CO (Formula 4).

Air (or blast) does not permeate to the center of furnace; instead, it is believed that air is dispersed according to the speed of oxidation reaction which is determined by blast amount, flow speed, coke size and grade. In other words, the intensity of oxygen adsorption in surface combustion is the determining factor for the distribution of CO_2 and temperature.

2.3.2. Reaction of carbon pick-up

The carbon of coke in a cupola is picked up by iron, adding up to the carbon content of iron. Carbon pick-up takes place each at a melting zone, combustion zone and crucible. It progresses better, the high in-furnace temperature is. Needless to say, the extent of carbon pick-up is greater, if the ash content of coke is lower. Even with coke of the same ash content, the degree of carbon pick up still differs depending on the composition of ash, its reaction and surface condition.

Carbon pick up increases if the carbon and silicon contents of charge materials are higher. Conversely, if these contents are lower, carbon pick-up decreases.

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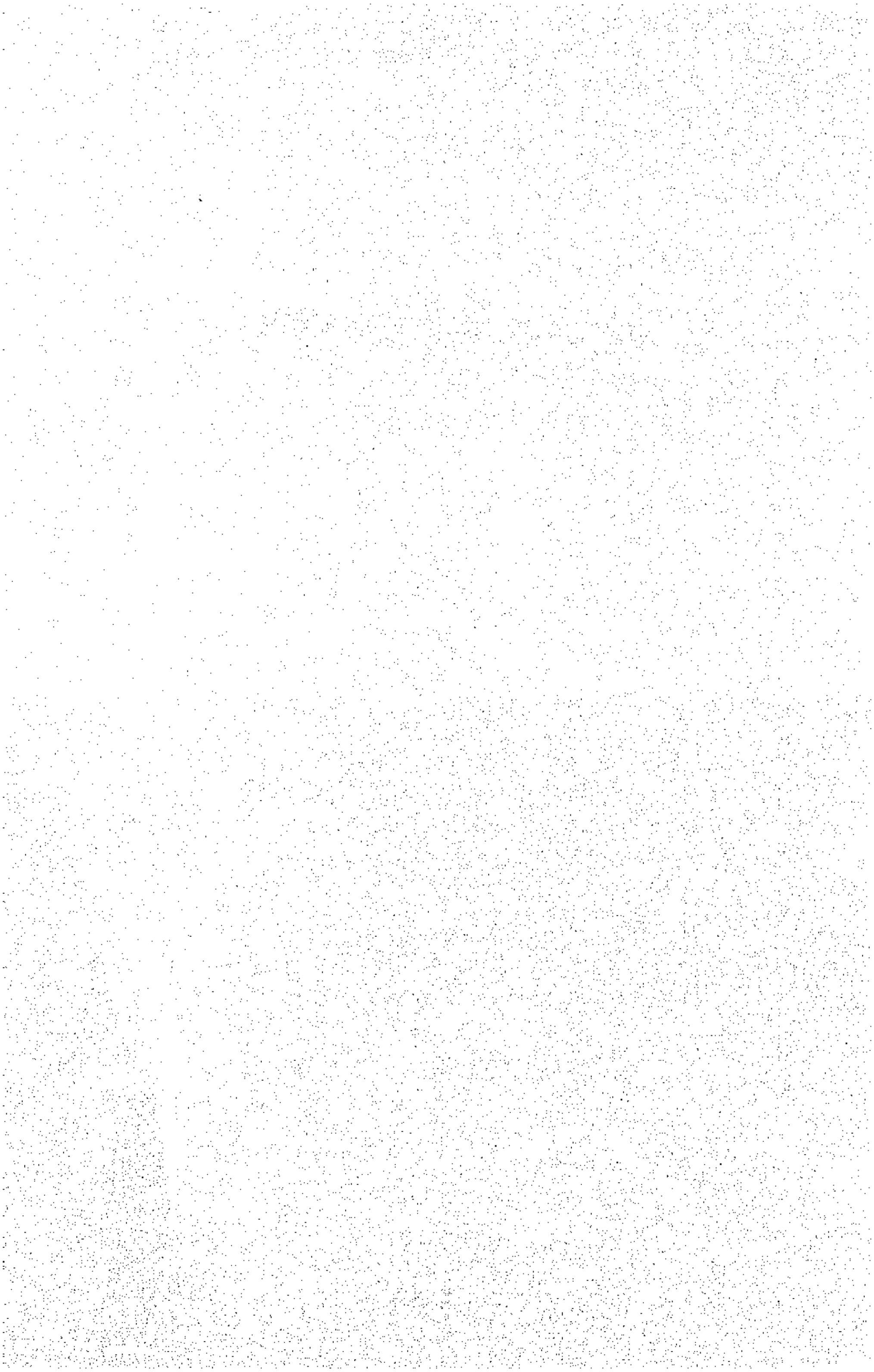
REFRACTORIES FOR CUPOLA



REFRACTORIES FOR CUPOLA

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1. FOREWORD

Of various refractories, those which are comparatively related with cast iron melting will be discussed in this article.

"Refractory" is a general term for nonmetal inorganic materials which are difficult to melt even at a very high temperature. According to the industrial standards of various countries, such materials which soften and melt at SK 26 (1,580°C) or more are called "refractory".

Refractories are consumption materials and not for permanent use.

Such being the case, an economical viewpoint should be taken when refractories are used.

At present the acid operation system is widely adopted for cupola. But the basic operation is desirable for the melting procedure of high-class cast iron.

2. GENERAL PROPERTIES OF REFRACTORIES

2.1. Refractoriness

KF number is used to express the degree of refractoriness of refractory materials. SK is an abbreviation for Segel Kegel. This is considered as a kind of pyrometer.

2.2. Porosity

This is a factor which exert the greatest influence on the wear of refractories and its influence is greater than that of refractoriness. Porosity is also related with the shrinkage by burning and it determines the quality of refractory brick.

2.3. Strength

This is important in determining the appropriateness of shrinkage by burning.

2. 4. Spalling

Spalling means the occurrence of breaks or cracks in the refractory at the changes in temperature. As for cupola, a less degree of porosity provides so much less wearing, therefore the degree of spalling should not be given a primary consideration in the case of cupola.

2. 5. Corrosion Resistance

Corrosion resistance is a property of refractory materials, which is determined by the degree of the chemical reaction shown by the materials at a high temperature.

Since the chemical reactions of refractories which take place at a high temperature are, on the average, acid or basic reactions, they are considered as ironic reactions.

Acid refractories are composed of polymoecule irons of silica and basic refractories are composed of alkali or alkali earth irons. When these materials contact each other at a high temperature, a chemical reaction takes place with the result that softening materials are produced and the refractories are corroded. Such being the case, a general tendency of corrosion can be known if the chemical composition of the refractories and slags are determined. However, the rate of corrosion is largely dependent on temperature, coarseness of particles composing the refractories and atmosphere.

The acid, neutral and basic materials composing refractories are shown below:

Acid: SiO_2, B_2O_3, PO_4
Neutral: Al_2O_3, Fe_2O_3
Basic: CaO, MgO, BO, BaO, Na_2O, K_2O, LiO, FeO, MnO

3. REFRACTORIES FOR CUPOLA

A Cupola can be divided into the following three zones:

(1) Charging zone (2) Melting zone (3) Well

The refractories used for making the charging zone is not exposed to high temperature while the cupola is in operation and it also does not suffer from the corrosive action of slags.

The melting zone is worn off to some degree by the charged materials but it suffers to the greatest extent from the corrosive action of slags heated to a high temperature. Of the refractory material used for a cupola, those for this melting zone are most important.

There is no wearing off of the well. This part is exposed only to the corrosion by slags.

3.1. Acid Refractories

Acid refractories are composed of the compounds of SiO_2-Al_2O_3. The materials abounding in SiO_2 are called siliceous which are the refractories with the highest degree of acidity.

3.1.1. Siliceous Refractories

Siliceous refractory is manufactured by the following process: Well calcinated siliceous stones are crushed into small pieces and a small quantity of clay or lime is added to them and the mixture is shaped and burnt.

The advantages of this kind of refractories are that they have a high degree of compression strength at high temperature and retain sufficient viscosity to maintain their shapes even the working temperature has risen above the fusing point.

But they have shortcomings that they are weak against palling and basic slags.

3.1.2. SiO_2-Al_2O_3 Refractories

As the refractories used for casting, there are two kinds of fireclay and roseki (agalmatolite). Generally speaking, the degree of refractoriness of the SiO_2-Al_2O_3 materials depend on the amount of Al_2O_3 contained in them. The more Al_2O_3 contained the greater is the refractoriness.

However, the corrosion resistance of these materials very largely depending on the degree of the shrinkage by burning.

3.1.2.1. Clay or Chamotte

These materials are lowest in price. The shamotte refractories which are made from clay produced in Japan has the refractoriness of SK29 - 36. Chamotte bricks or well baked refractory bricks are crushed into small pieces and 5 to 15 percent of green clay is added thereto and shaped and then burned to an extent where they have a refractoriness of SK 10 or more. Of these refractories, those with a comparatively low refractoriness is weak against high temperature slags and those with a high refractoriness is apt to result in inadequate shrinkage by burning with the result that if they are corroded the slag and the like penetrate deep into the bricks.

Those with refractoriness of SK 33-34 are most widely used at present.

3.1.2.2. Roseki Refractories

Roseki refractories can be said to be the special product of Japan and popularly used for cupola and ladle. Roseki is called "agalmatolite", which means a stone for sculpturing figures. This material is produced in Japan, mainly in the Mitsuishi area in Okayama Prefecture and also in some other prefectures such as Yamaguchi, Nagasaki, Nagano and Fukushima.

The mineral composition of roseki is pyrophyllite Al_2O_3. $4SiO_2$. H_2O. and the amount of the contained SiO_2 is 50 - 70% on the average.

The ignition loss of roseki is somewhere around 5% and its shrinkage by burning is so small that it does not need to be made into chamotte. The crude rokei can be crushed and mulled for processing in the same manner as the case of chamotte.

Its refractoriness is about SK30, slightly lower than that of clay refractories. However, the rokei refractories have such advantages as follows: The shrinkage by burning is good, highly resistant to CO gas and lime.

The production of good quality roseki has been gradually decreasing in Japan and some counter-measures are being taken to cope with such a situation.

3.2. Basic Refractories

As for the basic refractory, magnesia (MgO) is considered to be best. Since magnesia is produced only in a merger quantity in Japan, dolomite is widely used.

Magnesia can be used for making either bricks and mortar but dolomite cannot be used to make bricks, so it is made into mortar and used for lining.

3.2.1. Magnesia Refractories

Magnesia refractories are made mainly from $MgCO_3$. $MgCO_3$is roasted at a temperature over 1,650° - 1,800°C to obtain hard magnesia, which is used to make the refractory. If the roasting is insufficient, no well-stabilized crystals of MgO can be obtained and it becomes ready to be slaked. The slaking action is most active for CaO.

Acid refractories cannot be used for the basic operation of cupola because the basicity of slags is very high in this case and consequently the bricks used for this purpose are more expensive.

3.2.2. Dolomite Refractories

If dolomite ($CaCO_3$. $MgCO_3$) is heated and $CaCO_3$ and $MgCO_3$ are separated at 500°C and violent dissociation takes place at 710° - 730°C. At this temperature, $MgCO_3$ is decomposed and becomes MgO. $MgCO_3$ is decomposed at 600°C and becomes MgO. At 900°C even $CaCO_3$ is decomposed and becomes CaO. If no impurity exists in this case, MgO and CaO will not combine even when heated to a high temperature.

Due to this CaO, dolomite cannot be made into bricks.

Researches are now being carried out to find a way to prevent the slaking of dolomite.

If fireclay, silicic acid and the like are added dolomite, it becomes ready to soften at low temperatures and shows increased reaction to slags.

3.3. Refractory Mortar

The strength of joint is largely responsible for the breaking and wearing of the walls of cupola. Such being the case, the mortar used for this purpose should be a matter of serious concern. Precautions should be made on the following points:

(1) The ramming should be done with special vigor.

(2) Clay with strong binding force should be used but the use thereof in an excessive amount should be avoided.

(3) The materials with high refractoriness should be used but the use of those which show no shrinkage by burning should be avoided.

In the above respects, roseki is an ideal material.

Of late researches are making a progress for the manufacture of unburned bricks to take the place of burned bricks and even amorphous refractories which are castable and plastic are being used on a trial basis.

4. THE RELATIONSHIP BETWEEN METHOD OF OPERATION AND REFRACTORIES

As was stated before, refrac tories are only the materials to be consumed, therefore it is wrong to attach the greatest consideration to the refractory materials in the operation of cupola. However, the breaking and wearing of the refractories can be reduced to a minimum only by some small precautions even when the cupola is operated under the same conditions.

The following are the precautions recommended to prevent the breaking and wearing of the walls of cupola as far as the refractory materials are concerned.

(1) Avoid sudden heating of the walls of cupola.

(2) Avoid excessive charging of lime when acid refractories are used.

(3) The atomosphere inside the cupola should not be oxidized.

(4) Avoid super heating in the melting zone.

(5) Avoid sudden cooling of cupola after the completion of melting operation.

As concerns the precaution (1), the walls of cupola should be well warmed up during the period from the kindling of the cupola to the commencement of the blasting. As for (2), when lime is charged, it should be located in the center of the cupola. As for (3), the oxidized atomosphere will increase FeO in the slag and accelerate the corrosion of the bricks.

Refractory materials of good quality should be used for the melting zone of cupola in the case where great quantities of steel scraps are used or a very high wind pressure is required or oxygen gas is used.

5. CONCLUSION

I have so far stated in brief about the refrac tory materials used for the manufacture of cupola. High temperature physical and chemical reactions take place inside the cupola, therefore it is necessary to make clear the physical and chemical properties of various materials at high temperatures. Since the metallurgical reaction is based on high temperature reactions, it is of special necessity to know about the behavior of high temperature reactions.

This article did not touch on such a difficult subject. But the results of studies on various basic questions concerning the subject have already been published by many scientists, so the readers are requested to see such materials for their information.

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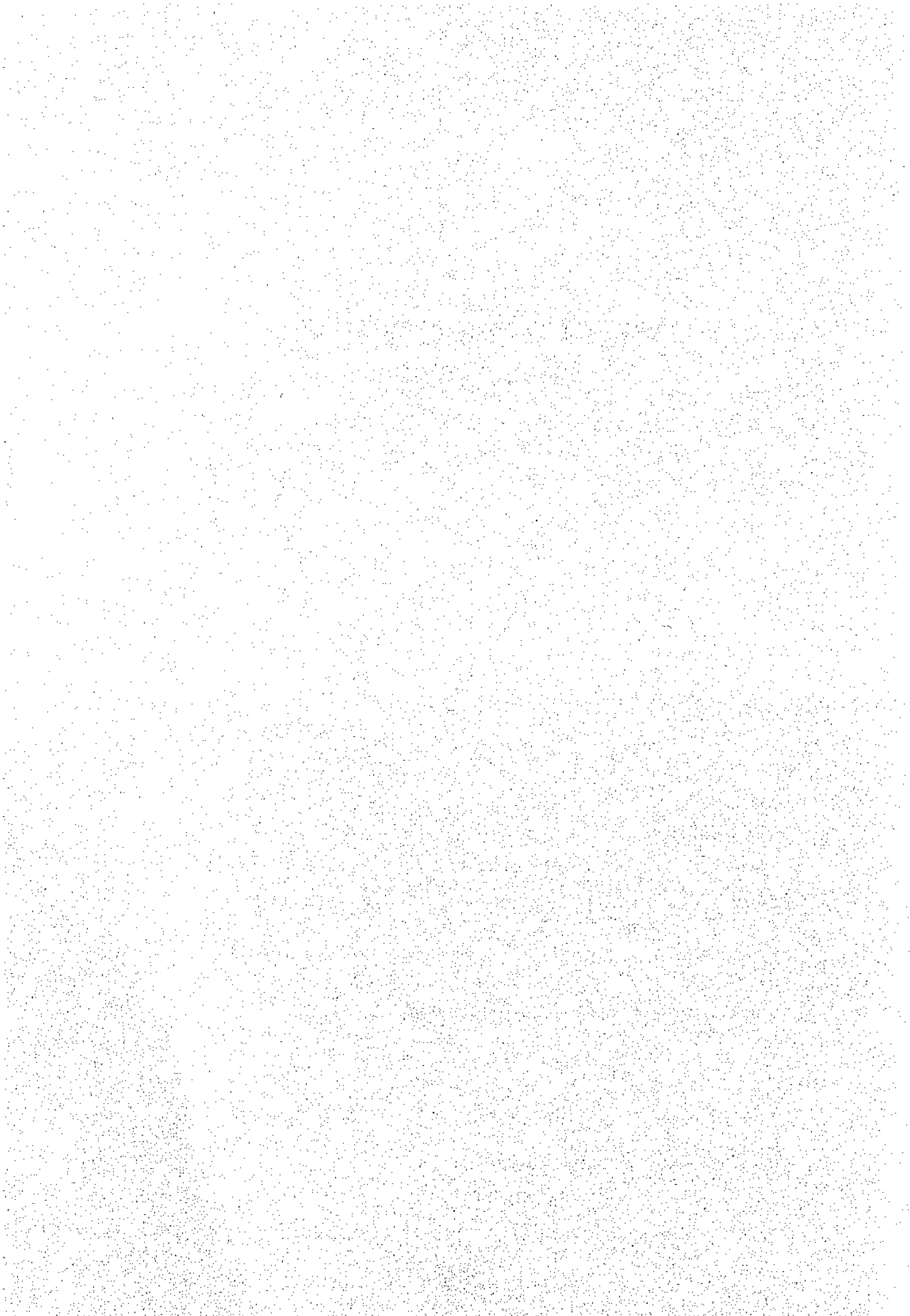
INSPECTION AND TESTING OF CASTINGS



INSPECTION AND TESTING OF CASTINGS

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1. INTRODUCTION

The quality of casting depends upon raw materials which come into plant such as pig iron, steel scrap, coke, molding sand etc., and also foundry processes such as melting, molding, pouring, and finishing. At the foundry, the inspection is performed to find a respective cause from the casting defects. The quality control is planned and performed through the application of testing and inspection.

The inspection and testing of castings are as follows:

1. 1. Visual Inspection:

The inspection of dimension, casting surface, fractured surface, macroscopic inspection, and sulphur printing.

1. 2. Mechanical Testing:

The testing of tensile strength, transverse strength, Young's modulus, damping capacity, hardness, impact test, and wear resistance.

1. 3. Non-destructive Inspection:

Stethoscope test, oil whiting test, ultrasonic inspection, fluorescent inspection, and radiography (X-ray or gamma ray).

These are also classified into two sorts of destructive and non-destructive inspection which have been made considerable progress and applied for the quality control of castings.

2. TESTING AND INSPECTION

Commercial testing is concerned principally with checking the acceptability of materials under purchase specifications or with the control of production or manufacture. Generally, the type of test has been specified by the Japanese Industrial Standard (JIS), and the object is simply to determine whether the properties of the material or part fall within required limits.

Inspection has to do with the observation of the processes and products of manufacture or construction for the purpose of insuring the presence of desired qualities. In many instances, inspection may be entirely qualitative and involves only visual observation of correctness of operations or dimensions, examination for surface defects. Inspection aims at the control of quality through the application of established criteria and involves the idea of rejection of substandard material. In testing, the aim is to determine quality, i. e., to discover facts regardless of the implications of the results.

3. VISUAL INSPECTION

3. 1. Inspection of Dimension

After the finishing, the inspection of dimension is done to check major dimensions from the center line, and then wall thickness and finishing allowance etc.. This inspection is very important for a new designed pattern, and afterward it must be performed periodically.

3. 2. Inspection of Casting Surface

This inspection is performed to visually check the defects such as rough surface, missrun, shrinkage cavity, cracks, and inclusions etc., and judges either to accept or to reject by the degree of these defects.

3. 3. Inspection of Fractured Surface

Through the appearance of fractured surface, this inspection checks whether or not exist coarse graphite, mottled graphite and chill part, and also shrinkage cavity, pin hole etc..

3. 4. MACROSCOPIC INSPECTION

The macroscopic inspection is widely used as a routine control method in steel production, because it affords a convenient and effective means of determining internal defects in the metal. Macro-etching may be reveal one or more of the following three conditions:

3.4.1. Crystalline heterogeneity, the presence and extent of which depend upon the manner of solidification and the crystalline growth of the metal or alloy.

3.4.2. Chemical heterogeneity, the result of impurities in the metal or alloy or localized segregation of certain chemical constituents. Such segregation may be intentional or may be unintentional and undesirable as, for example the agglomeration of sulphur or phosphorus that is so often found in cast steels or gray cast irons.

3.4.3. Mechanical heterogeneity, resulting from the effects of cold-working or any process that introduces strain into the metal. Such heterogeneity seldom occurs in cast metals, but its presence is of importance in cold-rolled metals forgings etc..

Etching the sample in a suitable reagent at a particular temperature for a recommended length of time. The inhomogeneities of a given metal are revealed only because of the difference in the chemical relations between the structural components of the metal and selected etching reagent. Surface defects, inclusions, segregated area, etc., are selectively attacked by the reagent.

3.5. Sulphur Printing

Sulphur may exist chemically in iron or steel in one of two forms, either as manganese sulphide or as iron sulphide, the amount of the latter depending upon the amount of manganese originally present.

The surface that is to be tested for sulphur segregation should be reasonably smooth and free from foreign matter, such as dirt and grease. Photographic bromide paper is soaked in a 2% solution of sulphuric acid in water for approximately 3 or 4 min. The paper is removed from the acid solution and allowed to drain free from excess solution. The emulsion side of the paper is then placed in direct contact with the prepared specimen surface and allowed to remain in contact under moderate pressure for 1 or 2 min. This operation, as well as the entire process of sulphur printing, may be carried out in daylight, contrary to the usual requirement for the handling of photographic paper.

The reaction of the sulphuric acid with the sulphide region of the steel produces hydrogen sulphide gas, which reacts with the silver bromide in the paper emulsion, forming a characteristic brown to gray-black of deposit of silver sulphide. Any dark area on the print, therefore, indicates the presence of sulphur in the steel and show exactly the position in the piece where segregation has taken place. The darker and more numerous the marking are, the more sulphur is indicated present.

4. MECHANICAL TESTING

The mechanical properties of casting are very important values since they give a basic value of machine design. In this properties, tensile strength, transverse strength, and hardness are more usefull and follow by Young's modulus, damping capacity, impact strength, and wear resistance etc..

4.1. Tensile Test

This test is most frequently performed to determine certain mechanical properties. Universal testing machine (Amslar type) is commonly used for this test (Fig. 1). The dimension of test piece is specified by JIS (Table 1 No. 4 for cast iron and No. 8 for cast steel, malleable iron and non-ferrous alloy). A prepared sample is placed in the heads of the testing machine, and an axial load is placed on the sample through a mechanical lever loading system. The force is indicated on a calibrated dial. If the original cross-sectional area of the specimen is known, the stress developed at any load may be calculated. The deformation or strain is measured at fixed length, usually 50 mm. In some cases, an electrical strain gauge may be used to measure the total strain.

The relation between unit stress S and unit strain e, found experimentally, is represented by the stress-strain graph in Fig. 2 for a ductile material such as cast steel, ductile cast iron, and copper alloy etc. and in Fig. 3 for brittle material such as gray cast iron.

Elastic limit -- If a small load on the test piece is removed, the extensometer needle will return to zero. If the load is continually increased, then released after each increment and the extensometer checked, a point will be reached at which the extensometer needle will not return to zero. This indicates that the material now has a permanent deformation. The elastic limit may therefore be defined as the minimum stress at which permanent deformation first occurs. For most structural materials the elastic limit has nearly the same numerical value as the proportional limit.

Yield point -- As the load in the test piece is increased beyond the elastic limit, a stress is reached at which the material continues to deform without an increase in load. The stress at point Y in Fig. 2 is known as the yield point. This phenomena occurs only in certain ductile materials.

Ultimate strength -- As the load on the test piece is increased still further, the stress and strain increase, as indicated by the portion of the curve Y M (Fig. 2) for a ductile material, until the maximum stress is reached at point M. The ultimate or the tensile strength is therefore the maximum stress developed by the material based on the original cross-sectional area. A brittle material breakes when stressed to the ultimate strength, where as a ductile material will continue to stretch.

Elongation -- This is determined by fitting together, after fracture, the parts of the specimen and measuring the distance between the original gauge marks.

$$\text{Elongation } (\%) = \frac{L_f - L_o}{L_o} \; 100$$

L_f= final gauge length, in mm
Lo= original gauge length, usually 50 mm

4. 2. Modulus of Elasticity of Young's Modulus

This is obtained by determining the slope of the initial straight-line portion of the stress strain diagram or the tangent of the angle θ (Fig. 3). At the laboratory the Martens Mirror method (Fig. 4) or the resonant bar method are used for the measurement of the initial Young's modulus.

The modulus of elasticity is the proportional constant that connects stress and strain below the proportional limit. This is an indication of stiffness of a material. For a example, the Young's modulus of gray cast iron decreases with increasing of graphite in it (Fig. 5a, 5b). This property is important in the design of beams and colums.

4. 3. Damping Capacity

The damping capacity of a metal is derived from measurement on a vibrating system in which all the elastic restoring force is contributed by the specimen. Apparatus for testing specimens in the form of bars of uniform section vibrating at one of their natural frequency is highly developed. On the transverse vibration method, the specimen is suspended at a point corresponding to nodes in it, and is oscillated by magnetic driving, and then its oscillating amplitude is freely decayed.

The logarithmic decrement is defined in terms of the maximum amplitude of successive cycles of a free decaying vibration An and $An^{+}1$,

$$\text{by } \delta = \log e\left(\frac{An_{+1}}{An}\right) \text{ or } Q^{-1} = \frac{1}{\pi}\,\delta = \frac{1}{\pi}\log e\left(\frac{An_{+1}}{An}\right)$$

The damping capacity of cast irons, as illustrated in Fig. 6, increases in order to cast steel, nodular cast iron, malleable cast iron, Meehanite metal, and gray cast iron. Also these damping capacities that depend on strain amplitude may be affected to both amount and shape of graphite in cast irons.

4. 4. Transverse Bend Test

The transverse bend test is used for the evaluation of strength and toughness of hard and brittle metals such as hardened tool steels, sintered carbide and cast iron. As previously mentioned, the elongation of cast iron is much smaller than that of other metal casting. Therefore, the transverse bend test is usefull to determine the toughness of gray cast iron, for which purpose it has been standardized by the JIS.

The test bars of cast iron, called arbitration bars, are cylindrical bars, cast separately, but under the same sand mold. The four common sizes of test bars are given in Table ( ). It has been recommended that they should be cast oversize and machined to final size, for several reasons. Machining removes the surface irregularities inherrent in the casting. The presence of blowholes, pinholes, and cracks is more clearly revealed. They are tested as simple beams under center loading on spans depending on the size of bar.

The highest tensional stress in the beam section is given by:

$$S = \frac{2.546\ P\ L}{D} \quad \text{for a round beam}$$

where: P breaking load, in Kg
L span length or distance between supports, in mm
D diameter of test bar, in mm

For a example, test results shown in Fig. 7 have been obtained on cast iron bars, 60 mm sq. and 400 mm long with 300 mm span length.

4.5. Bending Test

The bending tests offer a simple, somewhat crude, but often very satisfactory means of obtaining an index of ductility. Essentially the test consists in sharply bending a bar through a large angle and noting whether or not cracking occurs on the outer surface of the bent piece. The angle of bend at which cracking starts is determined. The severity of the test is generally varied by using different sizes of pins about which the bend is made. The test specimens are usually rectangular in cross section, with rounded edge, and are required in the specification for cast steel or malleable cast iron, particularly in the form of rod and plate (see JIS).

Although rough qualitative tests on the job are often made by use of a hammer and vise or anvil, in the laboratory some special apparatus or procedures are usually employed. The essential features of cold bend apparatus are shown schematically in Fig. 8 (Olsen cold bend machine).

4.6. Handness Tests

The fundamental physics of hardness is not yet clearly understood. However, the fundamental idea that hardness is measured by the resistance to indentation is the basis for a variety of instruments. The indenter, either a ball or a plain or tuncated cone or pyramid, is usually made of hard steel or diamond and ordinarly is used under a static load. Either the load that would produce a given depth of indentation or the indentation produced under a given load could be measured. With most of the dynamic machines, however, the force, whether developed by a drop or a spring load, is of fixed magnitude, as with the Scleroscope, for which the height of rebond of the indenter is taken as a measure of the hardness.

Indentation and rebond type tests, because of their simplicity, have become one of the important quality-control tests for castings. The most commonly used hardness tests for castings in this country are the Brinell, Rockwell, and Shore-Scleroscope tests.

Brinell test -- The Brinell test consists in pressing a hardened steel ball into a test specimen. In accordance with the JIS specification, the provisions of which are followed herein, it is customary to use a 10-mm. ball and a load of 3000 Kg for ferrous matals, a load of 500 Kg for soft metals, and a load of 100 Kg for very soft metals.

The principal features of a typical hydraulically operated Brinell testing machine are illustrated in Fig. 9. Load is applied by pumping oil into the main cylinder, which forces the main piston or plunger downward and presses the ball into specimen. The full load is applied for a minimum of 10 sec. for ferrous metals, after which interval the load is released and the diameter of the indentation is measured to the nearest 0.01 mm. with the microscope. Often, however, a 30-sec. interval is used for ferrous metals and a 60-sec. interval for other metals.

The Brinell hardness number is the applied load divided by the area of the surface of the indentation, which is assumed to be spherical. If P is the applied load (in kilograms), D is the diameter of the steel ball (in mm), and D is the diameter of the indentation (in mm), then

$$\text{Brinell hardness number} = \frac{\text{load on ball}}{\text{indented area}} = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)}$$

In practice the Brinell numbers corresponding to a given observed diameter of indentation are taken from tables, such as given in ASTM specification. Although the Brinell test is a simple one to make, several precautions are necessary in order to obtain good results. It is not adapted to testing extremely hard materials, because the ball itself deforms too much, nor is it satisfactory for testing thin pieces such as razor blades, because the usual indentation may be greater than the thickness of the piece. For an example, a relation between tensile strength and Brinell hardness of gray cast iron is shown in Fig. 10.

Rockwell test -- The Rockwell test is similar to the Brinell test in that the hardness number found is a function of the degree of indentation of the test piece. It differs from the Brinell test in that the indenters and the loads are smaller, and hence the resulting indentation is smaller and shallower. It is applicable to the testing of materials having hardness beyond the scope of the Brinell test, and it is faster because it gives arbitrary direct reading.

The test is carried out by slowly raising the specimen against the indenter until a fixed minor load (10 Kg) has been applied. The dial is set at zero on the scale, and then the major load is applied through a loaded lever system. After the dial comes to rest, the major load is removed and, with th the minor load still acting. The Rockwell hardness number is read on the dial gauge.

A variety of indenters and loads may be used, and each combination determines a particular Rockwell scale. Indenters include steel ball 1/16, 1/8, 1/4, and 1/2 in. in diameter and a 120° conical diamond point. Major loads are usually 60, 100, and 150 Kg on the normal tester and 15, 30, and 45 Kg on the superficial tester. The most comonly used Rockwell scales are the B (1/16-in, ball indenter and 100 Kg load) and the C (diamond indenter and 150-Kg load), both obtained with the normal tester. The Rockwell hardness readings at increasing distance from the tip of a cast wedge section are shown in Fig. 11.

Elastic hardness (Shore Scleroscope hardness): Scleroscope hardness is expressed by a number given by the height of rebound of a small pointed hammer after falling within a glass tube from a height of 10 in. against the surface of the specimen. The standard hammer is approximately 1/4 in. in diameter, 3/4 in. long, and weights 1/12 oz., with a diamond striking tip rounded to a 0.01- in. radius.

This instrument usually has a self-indicating dial so that the height of rebound is automatically indicated. When the hammer is raised to the starting position, it has a certain amount of potential energy. When it is released, this energy is converted to kinetic energy until it strikes the surface of the test piece. Some of the energy is now absorbed in forming the impression, and the rest is returned to the hammer for its rebound. The height of rebound is indicated by a number on an arbitrary scale such that the higher the rebound, the larger the number and the harder the test piece. This test is really a measure of the resilience of a material, that is, the energy it can absorb in the elastic range.

Advantages and disadvantages of the different hardness test -- The selection of a hardness test is usually determined by ease of performance and degree of accuracy desired. Since the Brinell test leaves a relatively large impression, it is limited to heavy sections. This is an advantage, when the material tested is not homogeneous such as gray cast iron or casting bronze etc. The surface of the test piece when running a Brinell test does not have to be so smooth as that for smaller impressions : however, using a microscope to measure the diameter of the impression is not so convenient as reading a dial gauge. Because of deformation of the steel ball, the Brinell test is generally inaccurate above 500 BHN.

The Rockwell test is rapid and simple in operation. Since the loads and indenters are smaller than those used in the Brinell test, the Rockwell test may be used on thinner specimens, and the hardest as well as the softest materials can be tested.

The principle advantage of the Scleroscope are the small impressions that remain, the rapidity of testing, and portability of the instrument. However, results tend to be inaccurate unless proper precautions are taken. The tube must be perpendicular to the test piece, thin pieces must be properly supported and clamped, the surface to be tested must be smoother than for most other testing methods, and the diamond tip should not be chipped or cracked.

4.7. Impact Test

Although the toughness of a material may be obtained by the area under the stress-strain diagram, the impact test will give an indication of the relative toughness. The most commonly used impact tests for cast steels or malleable cast irons etc. in this country are the Charpy and the Izod tests, both of which employ the pendulum principle. Ordinarily these tests are made on small notched specimens broken in flexure. In the Charpy test, the specimen is supported as a simple beam (Fig. 12a, 12b), and in the Izod test it is supported as a cantilever.

The results appear to be particularly sensitive to variations in the structure of steel as affected by heat-treatment and as affected by certain minor changes in composition which tend to cause embrittlement, such as variations in the sulphur or phophorous content.

The significance of impact tests for cast iron is not clear. Cast iron is not often used in parts that must have high shock resistance, and it is felt by some that the results of the static flexure test give most of the information needed for estimating the relative energy capacity of cast iron. However, a number of investigations on impact resistance of cast iron have been made, and a variety of procedures have been employed. Unnotched specimens appear to be more satisfactory than notched specimens. Cast iron is not so notch sensitive as steel : this may be due to the notchlike effect of the graphite flakes in cast iron, which is not greatly increased by an additional effect of an external notch.

4.8. Testing of Wear Resistance

Since wear is not a simple phenomenon, wear resistance is represented by fewer standardized tests than other engineering properties. It is generally accepted that a universal wear test is not feasible. Therefore, equipment for wear testing must be designed to simulate actual service conditions.

5. NON-DESTRUCTIVE TESTING

Often it is desirable to know the characteristic properties of a casting without subjecting it to destructive tests. Although non-destructive tests do not provide a direct measurement of mechanical properties, they are very valuable in locating casting defects that could impair the performance of a machine member when placed in service. Parts may also be examined in service, permitting their removal, in some cases, before failure occurs.

The most common method of non-destructive testing or inspection for castings are : Stethoscope test, oil-whiting test, Ultrasonic inspection, Fluorescent-penetrant inspection, and Radiography.

5.1. Stethoscope Test

When a solid homogeneous object is struck with a piece of metal it emits a clear ringing sound. This fact has long been the basis for one of the oldest non-destructive tests. Although it is highly satisfactory for simple forms, experience has shown that complicated shapes modify the sounds and tend to confuse the inspector.

5.2. Oil-whiting Test

The oil-whiting test is one of the older and cruder tests used for the detection of cracks too small to be noticed in a visual inspection. In this method the piece is covered with a penetrating oil, such as kerosene, then rubbed dry and coated with dry whiting. In a short time the oil that has seeped into any cracks will be partially absorbed by the whiting, producing plainly visible discolored streaks delineating the cracks.

A test used occasionally for detecting cracks in malleable iron involves immersion in kerosene for several hours, and then cleaning of all surface by sandblasting. In a short time the oil that has penetrated any appreciable cracks present will seep out and show a darkened line on the cleaned surface.

5.3. Ultrasonic Inspection

This is a non-destructive method of testing or inspection which utilizes waves of frequency above the audible range : hence the terms ultrasonic. The frequencies most commonly used range from 1 to 5 million cps. The high frequency waves are reflected from surfaces and flaws much the same way as light is reflected from a mirror. In an ultrasonic machine, called a reflectoscope, a high frequency current, generated by a suitable electric circuit, is applied to a searching unit. This searching unit contains a crystal, usually quartz, such that the electric vibrations cause the crystal to expand and contract, thereby producing a compressional sound wave of the same frequency. As the sound wave enters the material being tested, part of it is refrected back to the crystal where it is converted back to an electrical impulse. This impulse is amplified and rendered visible as an indication or pip on the screen of the oscilloscope. If there is a flaw between the front and back surfaces of the material, it will show as a third pip on the screen between the two indications for the front and back surface. Since the indications on the oscilloscope screen measure the elapsed time between reflection of the pulse from the front and back surface, the location of a defect therefore be accurately determined from the indication on the screen.

Under favorable conditions, with clean metal of small grain size, holes as small as 0.025 mm in dia. have been detected, but dirty metal or unfavorable structure can yield a back ground of reflection that may reduce the sensitivity far below. Therefore, roughness of the surface at contacting point also reduces the sensitivity. A rough casting should at least be touched to a grinding wheel at the contacting area.

5.4. Fluorescent Penetrant Inspection

This inspection is a sensitive, non-destructive way of detecting minute discontinuities open to the surface, such as cracks, shrinkage, and pores. Penetrant materials most commonly used are oil-base, water-emulsifiable penetrant, which washes cleanly off surfaces of all types by a forced spray of water ; and dry powder developer, dusted on parts after excess penetrant has been removed and the parts have been dried. And viewing, by fluorescence under near-ultraviolet radiation or black light, minute amounts seeping back out from discontinuities. Lines indicate cracks and similar discontinuities; dots indicate pores.

Fluorescent penetrant inspection may be applied in locating cracks and shrinkage in castings made of aluminum, magnesium, brass, iron, and other metals. Therefore, this inspection is applicable to castings, particularly as a means to improve quality. When defects do appear, it is important to be able to check back to the cause quickly and to correct it before much material of low quality is produced.

Although light metals constitute the natural field for fluorescent penetrant inspection, simplicity of procedure has made this method useful for testing other metals, such as malleable cast iron.

5.5. Radiographic Test

The radiography of castings may be carried out using either X-rays or gamma rays. X-rays are produced when matter is bombarded by a rapidly moving stream of electrons. When electrons are suddenly stopped by matter, a part of their kinetic energy is converted to energy of radiation of X-rays. Resently, the magnetic induction accelerators (Betatron or Linear accelerator) are developed and offers the most promise for producing high-energy X-rays.

On the other hand, gamma rays of radio isotope are also used for radiography. The sorce may be Co^{60} or Se^{137}, all of which emit radiation of considerably more penetrating wave length (less contrast) than that of X-rays.

A radiograph is a shadow picture of material more or less transparent to radiation. The X-rays darken the film so that region of lower density, which readily permit penetration, appear dark on the negative in comparison with areas of higher density, which absorb more of the radiation.

In castings, certain sections that are thinner because of the design, and intentional cavities, such as cored holes, are regions of low density and are revealed as darkened areas. Specimens containing variations in thickness caused by the unintentional absence of metal are also more transparent, resulting in darkening of the film. Excess metal and inclusions more dense than the base metal appear as light regions. Gas cavities, blowholes and minute gas porosity appear as well defined, spherical or rounded darkened area.

When influential factors are carefully controlled, voids 0.5 to 1.0 % of the thickness of an aluminum alloy or steel will be revealed on the radiograph. The sensitivity of 2 % is relatively easy to obtain and sufficient to meet the requirements of the various specification for castings. However, the sensitivity of the gamma ray is inferior to that of the X-ray for most application. Its sensitivity is between 2 and 5 %.

6. OTHER TEST

Hydrostatic pressure tests are applied to castings for special uses involving high temperature, high pressure, or both : for example, certain valves, fittings, flanges and such. Other tests - creep, endurance and the like - are used for special investigations or development.

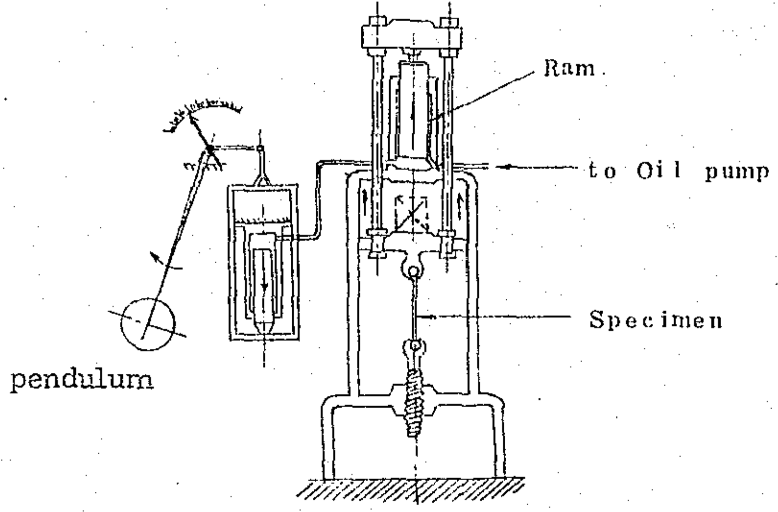


Fig. 1 Essential Features of Hydraulic Testing Machine

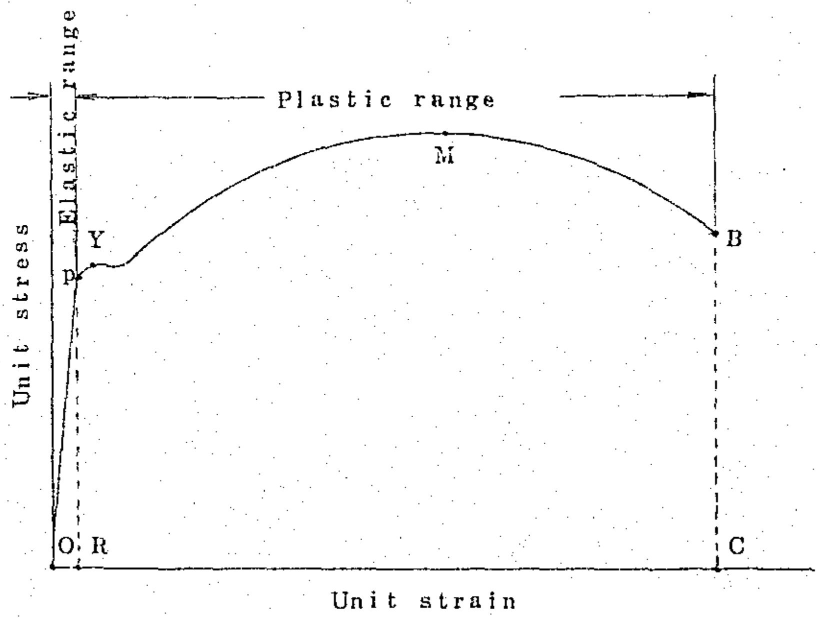


Fig. 2 Stress-strain diagram for a ductile steel.

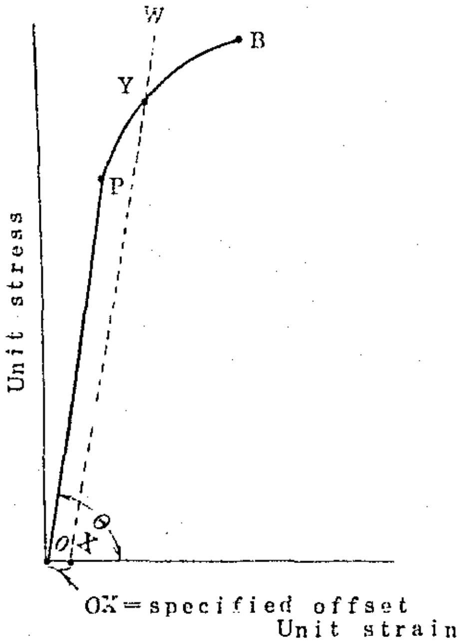


Fig. 3

Stress-strain diagram for a brittle material.

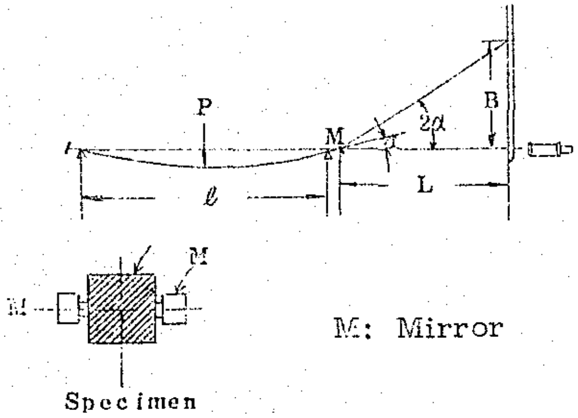


Fig. 4 Martens Mirror Method for measurement of Young's modulus

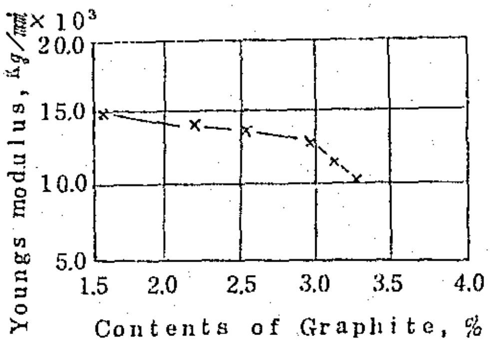


Fig. 5

Fig. 5a Relation between graphite contents and Young's modulus of gray cast irons.

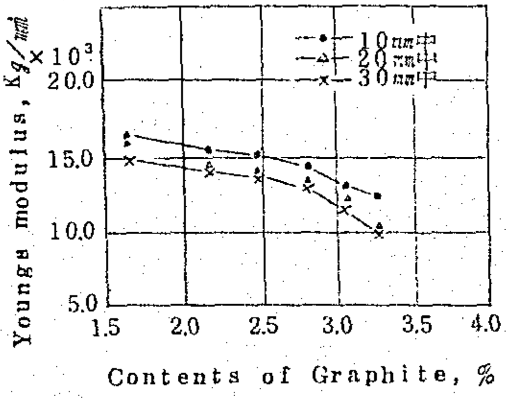


Fig. 5b Effects of thickness on Young's modulus of various Fe-C alloys.

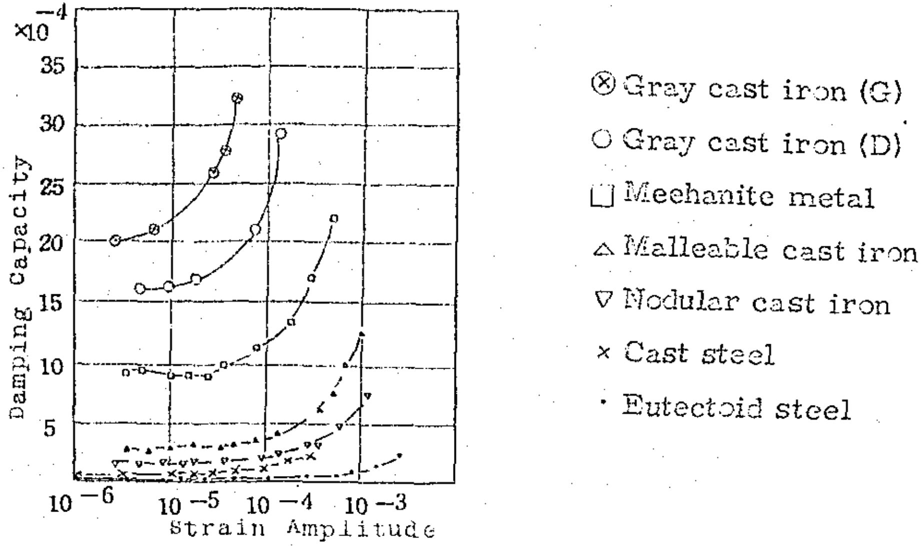


Fig. 6 Damping capacities of various cast irons and steels.

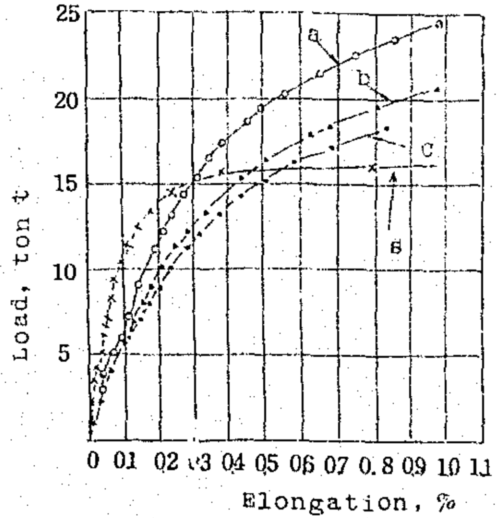
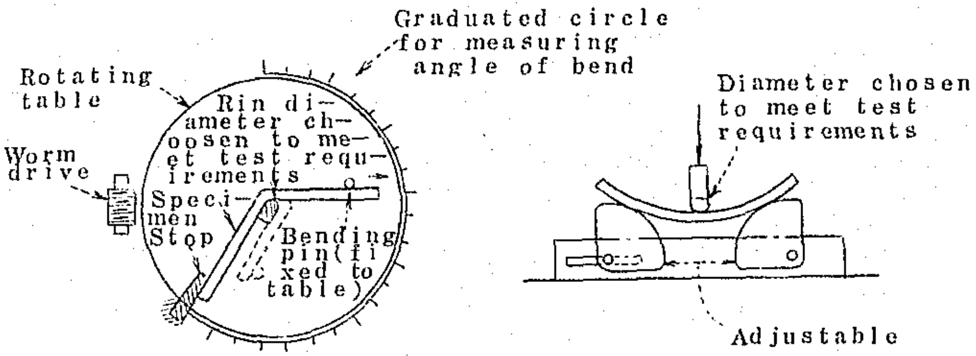


Fig. 7 Transverse bending load versus elongation of various cast irons (a, b, c) and steel (s)



A. Olsen cold bend machine

B. Scholer device for making cold bend test

Fig. 8 Cold-bend Test Apparatus.

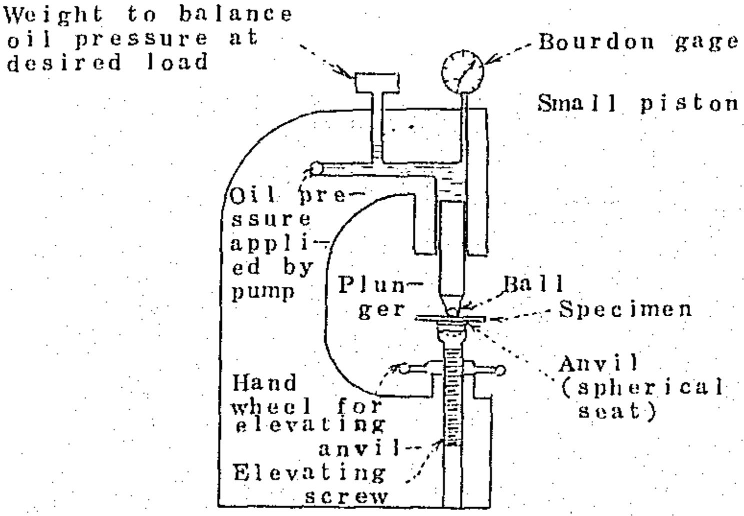


Fig. 9 Features of Hydraulic Type Brinell Machine.

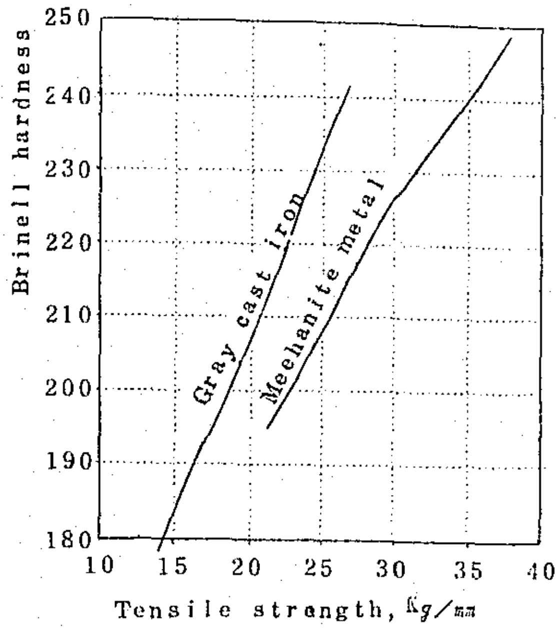


Fig. 10 Relation-ship of tensile strength and Brinell hardness of cast irons

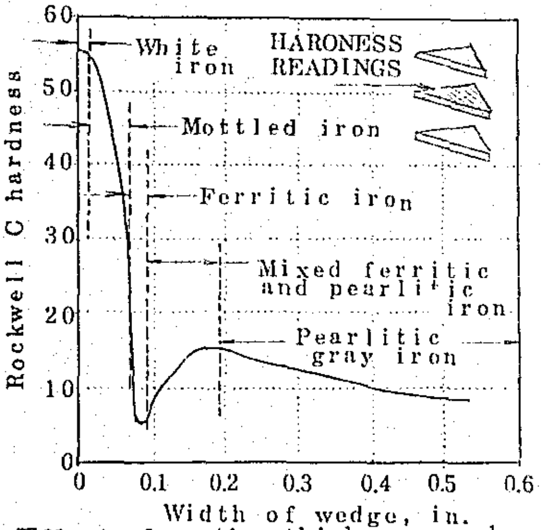


Fig. 11 Effect of section thickness on hardness and structure of wedge casting.

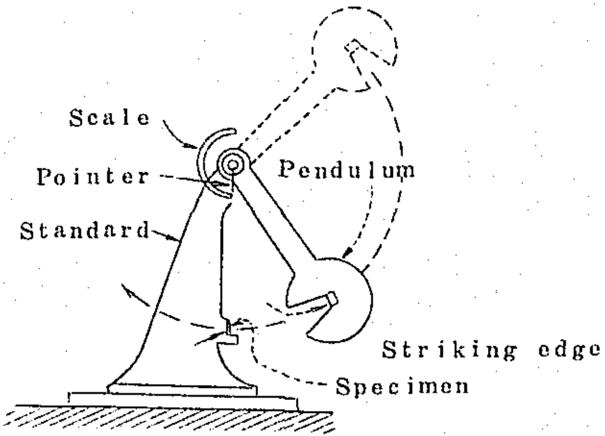
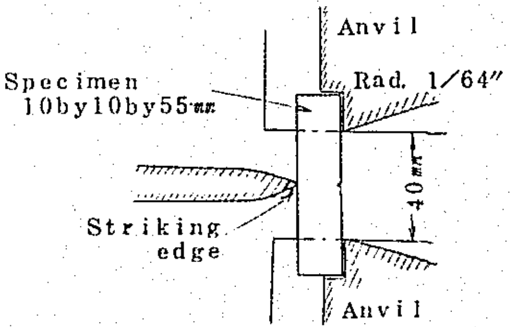


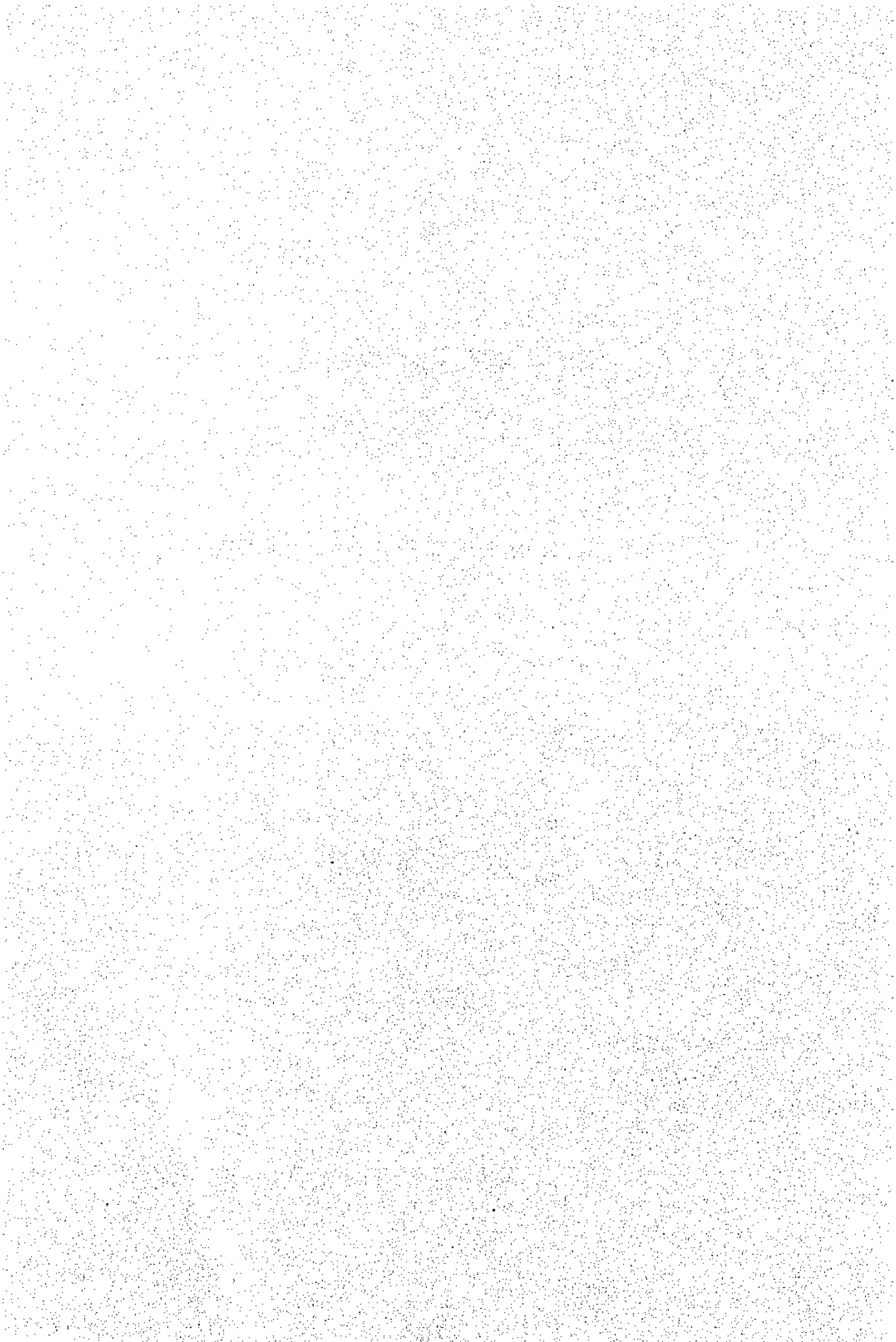
Fig. 12a Charpy Impact Machine.



C-Arrangement of specimen in machine (Top view)

Fig. 12b Charpy Specimens.

QUALITY CONTROL



QUALITY CONTROL

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1. FOREWARD

The role of industrial management is to create profits by manufacturing goods and to contribute to the happiness of people by providing them with better and cheaper goods. To fulfill this aim, products of satisfactory quality should be produced and supplied in sufficient quantity whenever they are required.

In recent years the development and progress of engineering technology have been outstandingly remarkable. It is particularly true with each proper engineering technology, but technologies for management or control have also developed very rapidly to the extent that they are utilized commonly. All of these development and progress are motivated by the aim I have just mentioned.

Among many technologies for management or control, quality control technology in particular has spread over very widely owing to the field results proving this technology can contribute a great deal to the progress of industry.

In the field of casting, however, it is still heard people say, "Casting is a matter of chance." How could this state possibly remain any further only in the foundry circle. It is strongly hoped that efforts are made on the stabilization of quality and finally on cost reduction through the study and practice of quality control and various other methods of control, keeping pace with the progress of proper engineering techniques.

2. WHAT IS QUALITY CONTROL ?

2. 1. What does good quality really mean ?

Let us first think of products that are world-widely recognized as superior quality products. Omega watch, Kodak color film, Indanthrene color, and among Japanese-made products; Nikon camera, Sony tape-recorder and etc.

When we say these are good products, we don't mean this particular Omega watch or this particular Nikon camera, but we mean to say all watches bearing Omega brand or all cameras of the Nikon make are good products.

In other words, it means that products of this or that brand are equally good to buy to our satisfaction without uneasiness of success or failure. All the good products are uniform in quality of them. And it means they have no dispersion.

More responsible for the problem of dispersion is the workshop or the manufacturing department than the designing department. To explain about this more in detail, it is a problem of the control technology, but not of each proper technology, because it means there are proper technologies but no control technologies in them to get only two pieces which satisfy the given quality level out of ten finished pieces.

Now, no matter how uniform all the products may be, they are still not salable if their quality standard is too low or excessively higher than users' requirements, or if they are too expensive to buy, or not attractive in appearance, or they have unnecessary quality. Unless products are salable, business won't be business any longer. Therefore, the quality of products should meet the needs of users and should perform a function that deserve the price. It is the designing department that is mainly responsible for incorporating these elements into the product. This aspect of quality is called the Quality of Design, and the other aspect described in the previous paragraph is called the Quality of Conformance or Quality of Performance.

In discussing about quality it is important to bear in mind that quality has these two meanings.

2.2. What Does Control Mean ?

Let us imagine a ship now leaving Yokohama Port for Hong Kong. Under the present techniques of navigation it is impossible to let the ship said fully automatically by only setting on equipment before departure and doing nothing more, not only because of such un-predictable happenings as typhoon but also because of more decisive fact that such an equipment would be extremely expensive to install and would never pay at all.

Therefore, the crew have to sail the ship by checking the ship's position from time to time and making necessary adjustment to keep the ship on the most suitable course leading to the destination of Hong Kong.

To check an action to confirm if it is properly directed to its goal and then to make necessary corrective actions is called "control". Control is therefore the most economical aid in achieving a given goal.

3. PURPOSE AND EFFECT OF QUALITY CONTROL

3.1. What is the Purpose of Industrial Production ?

The most common definition in the world at present is as follows:

> "to supply consumers with the products of required funcions in sufficient quantity at a reasonable price any time on demand"

3.2. What is the Purpose of Quality Control ?

In order that a product satisfys the consumer's needs it should have the maximum usefulness that can answer the purpose of the user.

Quality control is the activity for manfucturing a product into which quality is designed, built and maintained at the most economical levels which allow for full customer satisfaction.

3.3. The Effect of Quality Control

What are the advantage of practicing quality control ? Let us list up the field results actually proven in Japan.

(1) The quality of products becomes uniform and free from dispersion.
(2) The quality itself improves.
(3) The loss of rejects decreases.

(4) The reliability of the product increases.
(5) Unnecessary works and reworks reduce.
(6) Production increases.
(7) Excessive quality (unnecessarily too high quality) can be improved.
(8) Production cost reduces.
(9) Engineers can concentrate efforts to their essential works. Techniques become higher.
(10) The cost of inspection and testing reduces.
(11) Contract with the suppliers of materials, sub-contracters, and consumers can be made more favorably and in much more rationalized manners.
(12) Products becomes in good demand.
(13) The innerdepartmental and intra-firm communications and activities within a plant or a company become much smoother.
(14) Test and research works become much speedy and the results more accurate.
(15) Wrong data can be eliminated.
(16) The maintenance and repair of equipment and machinery can be rationalized and concentrated to essential sections.
(17) Operations become of higher standard.
(18) The necessity of frequent meetings decreases, and each meeting requires less time.
(19) Paper work reduces.
(20) Operations become speedy.
(21) The rationalization of the company's organization become possible.
(22) The company become rationalized in many aspects. More profits can be obtained by employees, stockholders, and consumers.

4. ON QUALITY AND CONTROL

Let us discuss about quality and control more in detail.

4. 1. In analyzing what manufacturers call quality, it is advisable that you classify it.

Consumers usually make up their mind whether or not they buy a product examing the price and the function of the product.

Therefore, "salable products" means that the quality of the keeps a good balance of price and function.

4.1.1. Quality of Aim

It is the quality that should be. It is wishful quality that should be obtained in the future regardless of the present characteristics of the material and the process capability.

The specifications or standards based on Quality of Aim should not be given to workshop.

4.1.2. Quality of Design

It is the quality that is indicated in the drawings and specifications prepared on a careful consideration of the harmony of (fully recognized) consumers' requirements with manufacturing cost, and materials and parts available and the process capability of the workshop. In short, it is probable quality. It is the quality on a level where products of such quality can actually be produced, but not the wishful quality that cannot be produced.

4.1.3. Quality of Performance

It is the quality actually produced, or in other words, the quality that products have. It is the quality built in products. It is entirely different from Quality of Design.

As this quality will be brought over to consumers, it should be within the range of Quality of Design.

Confusions may occur if Quality of Aim, Quality of Design and Quality of Performance are mixed up in discussing quality.

It can be said that quality control practiced at workshops means the activities to bring Quality of Performance toward Quality of Design.

4.1.4. Quality of Design and Cost

Quality grade is raised from 1 to 2 . B is much larger than A. From grade 2 to 3. D is small when compared to C. Should aim at 2 for quality of design.

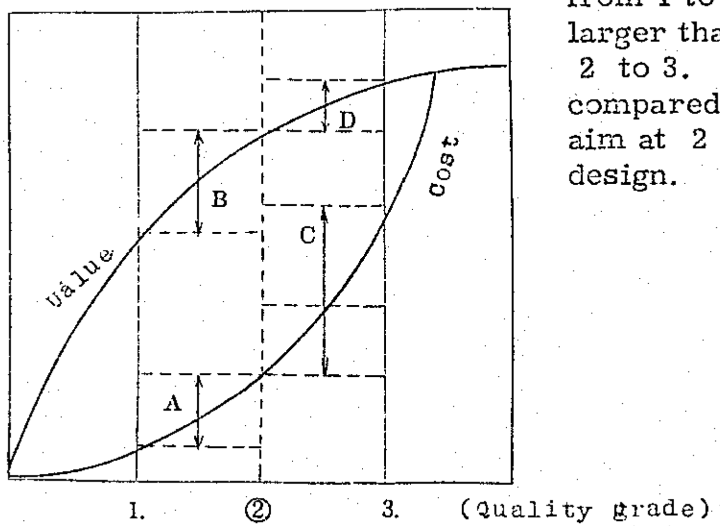


Fig. 1 Quality of Design should be Chosen Grade "2".

4.1.5. Quality of Performance and Cost

The more invested to the control, the loss will be eliminated.
The optimum point is the most economical. Quality of performance should be aimed at this point.

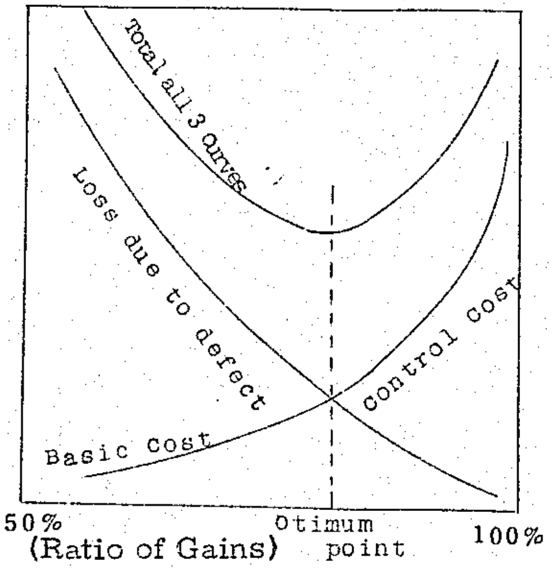


Fig. 2 Quality of Performance should be the "Optimum".

4.2. Let us see Control Furthermore

It is to check operations to confirm if they are properly directed into a give direction, or they are in accordance with instructions, programs and standard, and to correct the differences between if found, and further to take necessary operations and instructions and so on actions if any problems to solve exist."

4.2.1. Steps of control

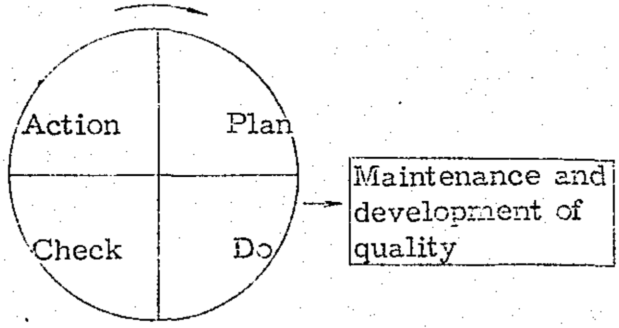
(1) Clarify the purpose. Decide the method to adopt. (Plan)
Market research, Designing, Operation standard.

(2) Provide education and training. Put them into practice. (Do)
Materials Processing Assembly

(3) Check the result.
"after service" Design improvement, Defect improvement, Feed-back.

(4) Take the action.
Sales, Inspection, Quality Confirmation test.

Fig. 3 Deming Circle



Morale
- Quality mindedness
- Responsibility for Quality

4.2.2. Deming Circle

The Deming Circle is a circle showing the steps of quality control. It indicates that by rotating this circle incesantly quality can be improved and as the result the business will advance and will make more and more progresses.

The Deming Circle can be applied to any of the entire organization of whole corporation, department and groups in different scales. To rotate this circule smoothly will prove a clue to success.

4.3. Standardization

In practicing quality control you will find standardization quite indispensable. If you have a policy to follow and a target to achieve and yet you have no standard to apply, how can you possibly check the process of development ? This suggests that standardization takes the main part in rotating the circle of control.

Standardization should be systematic and complete by itself. It should not contain any contradictions. In introducing standardization it is important (1) to establish, (2) to follow and (3) to improve the standard. Usually it is relatively easy to set up standards, but the effort to keep them up, or in other expression, education and training workmen, and also the effort to constantly improve the standard are very likely to be neglected.

Standardization, simplification and specialization are often referred to as 3S. The significance of these three S's are never independent. There is a correlation which makes them inseparable.

It should be repeatedly emphasized that standardization is the major premise of quality control.

4.4. Quality Control Organization

The real effect of quality control cannot be expected unless it is carried out organically through on adequate organization. Therefore, it requires flezible way of thinking. Furthermore quality control cannot be successfully practiced by any single person, and it does require cooperative attitude of all involved.

It is particularly true in a company of the line-staff organization.

5. SYSTEM OF QUALITY CONTROL

How can we apply the step of quality control to our own plant ? What section should do what kind of activities to control the quality of products effectively ?

5.1. Planning → Design of quality and Design of process

(1) Market research (quality required by the customer)...
Research, Sales Dept. Designing Dept.

(2) Evaluation of process capability (requirements for processing).....
Production Dept. → Designing Dept.

(3) Research and pilot model making (confirmation of production).....
Laboratory → Designing Dept.

(4) Determination of drawings and specifications for production

The Quality of Design is determined in accordance with the abovementioned conditions and the policy of the management.

5.2. Production → Production plan and Manufacture

5.2.1. Establishment of operation standard

From among number of factors that influence the Quality of Performance, major factors (characteristic values) are selected, and the determination or instructions, of control points for controlling these factors follows. After this spot it is necessary to establish on operation standard containing such control points.

5.2.2. Manufacturing → Performance and assurance

Checking and corrective actions in accordance with the instructions are made in order to maintain a given standard constantly.

Available as measures to control characteristic values are Qc Process Chart, Check Sheet, Control Chart, etc.

The system in which the workmen themselves check and assure that works are all within the range of instructions and permit them to move on to next process is the Voluntary Control. Under this system the workman is to correct irregularity as the finds it, and thereby loss can be minimized.

5.2.3. Action and Disposal

Unusual Data was found should be corrected quickly.

Only when adequate measures to prevent the repeat of the abnormal happenings of the same cause are taken by, for instance, repairing the equipment or machinery, improving manufacturing techniques, changing designs and so on, the circle of quality control rotates, and quality control can perform its function.

5.3. Sales, Quality Assurance and Claim Sales Dept. → Designing and Production Dept.

The quality assurance for products is due to operators. Inspectors are a more proxy, so to speak, for operators regarding the quality of the products to be assured to consumers. Good products cannot be produced from inspection. They are made during the process of manufacturing. Rember following famous words. It is "Quality must be built into a product, it can not be inspected into it."

5.3.1. Claim

It is important for us to know there are two sorts of claims.

Revealed claim	Compensations Preventive measures
Vailed claim	It is not easy to catch this kind of claims, but it does influence the salability of the product to a great extent. The evaluation of this kind of claim should be made in the course of sales activities.

5.3.2. Claim Disposal

It is the general tendency that the higher the price of the product, the more claims are filed. This fact possibly implies that the consumer gives up his claim when the price is not high, but he would never attempt to buy such products any more. Therefore, it is important to treat the revealed claim and the vailed claim separately. What we really fear is the latter claim.

In order that you are always ready to inquire into claims and take adequate preventive actions, it is important to make the following studies and to prepare for the future.

(1) study on the quality that the consumer may expect on the product.
(2) study on your competitors and their products
(3) study on the supply and demand position of the market
(4) study on the characteristics of the customers

Besides the lack of these studies, the following facts may also cause claims.

(1) consumers' inadequate choice of products
(2) more advanced quality of competitors' products
(3) out-of-date model after a model change
(4) market claim (request for discount, etc.)
(5) faults of other aspects than quality (faults in the salesman's behaivior, dazzling advertisement, etc.)

The most important matters in disposing the releaved claim are as follows:

(1) timely action and sincere attitude
(2) preventive measures against the phenomena causing the claim
(3) preventive measures against the repeat of claims by improving the system under which quality control is performed

Timely action is the most important of all. No customer will accept any action if you make it "after very careful investigation". As for the actions that you should take inside the company, on emphasis should be placed on the prevention of repeat. Such action should not be confined to the prevention.

of claims as phenomena, but should reach the system of quality control if the disposal in a real sence of claims is sought at all.

6. STATISTICAL THINKING

The science of statistics has remarkable progressed in recent years, and is continuously advancing at present. In quality control it is necessary to have the knowledge of this kind of thinking.

6.1. Purpose of Collecting Data

(1) for the purpose of controlling
  (a) policy making (research)
  (b) adjustment
  (c) checking

(2) for the purpose of analysis

(3) for the purpose of inspection

The purpose of collecting data may apply to some of these purposes. The first step of the statistical thinking is to determine a clear purpose of collecting data. In modern science of statistics action is always taken into consideration. It is imperative that the data to collect should be all accurate without any false informations.

6.2. Relationship between Data, Sample and Population

It is not the purpose of gathering data to obtain the knowledge of samples, but it is the purpose to obtain the knowledge of the population in order to make actions. This relationship is shown in the Figure 7.

6.3. Dispersion

Data always contain dispersion. This fact means that there is a distribution of data. This distribution can be grasped by showing the data on a histogram. And to show the distribution quantitatively, Mean Value, Range, Standard Deviation, Variance are usually utilized.

6. 4. Random Sampling

There being the distributions in the data, also the population shall have distributions. Therefore, when a sampling work is conducted, an attention should be paid for a random sampling. From random sampling, it is understood that how much the mean value, range and standard deviation (called statistics) show. Consequently, by the random sampling, we can judge the data under the basis of the distribution rule of the statistics.

6. 5. What Make Dispersion of Manufacturing Processes

There are two kinds of causes that influence the manufacturing processes and lead to the dispersion of products.

6. 5. 1. Chance causes

It is the causes that cannot be prevented in advance under the present techniques. These are indefinately great in number a scientific sense and are not avoidable.

6. 5. 2. Assignable causes

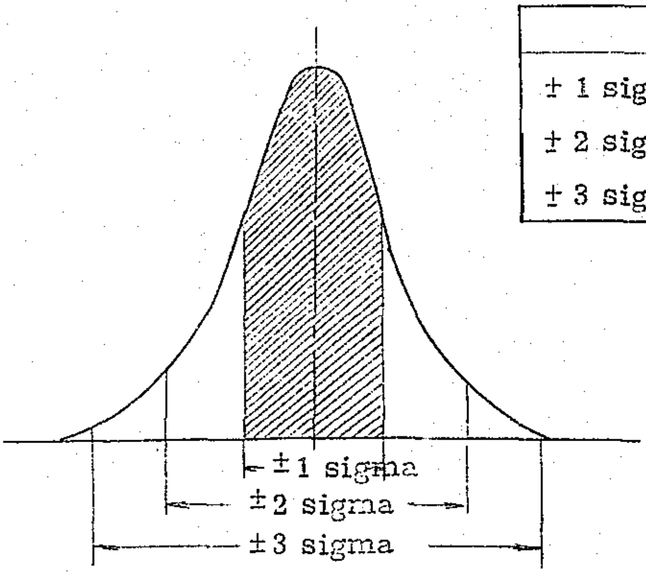
It is causes that bring about abnormal happenings in the manufacturing process. These should not be overlooked. The dispersion of products resulting from the chance cause usually has a normal dispersion and is called "controlled dispersion". The state of a manufacturing process in which the dispersion is fully controlled is called "controlled state". The dispersion resulting from assignable cause is called "uncontrolled dispersion", and the state of a manufacturing process in which uncontrolled dispersion is contained yet is called "uncontrolled state".

The indication used in distinguishing these causes objectively and economically by statistical methods is the control limit in the control chart.

6. 6. Concept of probability, Errors of the first kind and Errors of the second kind.

Many of the distributions we often encounter with is of a bell shape as shown in the Figure 4. (normal distribution).

Fig. 4 Normal Distribution and Probability



	Inside	Outside
± 1 sigma	68%	32%
± 2 sigma	95%	5%
± 3 sigma	99.7%	0.3%

By dividing this distribution by standard deviation as shown in the Figure 4, the ratio of each area to the whole can be obtained. Each ratio indicates the probability of choosing data from the corresponding area in random sampling. You may note that the probability of choosing samples beyond ± 3 sigma is as low as 3/1000. If such a case happens, therefore, we judge that the distribution has changed, or the process has changed, or the process has become abnormal. However, this judgement is not 100% correct. The error that may intrude into this judgement is called "the error of the first kind" in the science of statistics. On the other hand, the error that may be resulted form overlooking abnormal happenings is called "the error of the second kind".

The statistical judgement (testing) is based on the possibility of committing these errors in making judgements.

6.7. Test and Estimation

As has been so far discussed, the statistical test is a method of judging whether or not the average of process has changed in an answer of "Yes" or "No". When you discover a change of the average, you have to know the average of the current process. The procedure to take samples from a process or from a lot for evaluation and then to grasp the average quality in the process of the lot is generally called estimation. There are point estimation and interval estimation. The point estimation is the mean value itself, and interval estimation is a way of estimating the reliability that the mean value comes within an interval. The interval of estimate may be wide or narrow depending on Reliability, the Size of Data and Standard Deviation.

7. QUALITY CONTROL METHOD

It is considered some effective method of quality control, among which is a Statistic Quality Control Method based on Inductive Statistics.

7.1. Stratification

7.1.1. The quality of products, such as, for instance, the components, the hardness, the compositions, the surface etc. of the cast are not uniform or imperatively non-uniform. Then, how those dissimilarities come out ? It is because there function various causes. By classifying the products, even though we do not know of such causes, however, according to their qualities, in other words, to the conditions at production, such as machines, charges, cupolas, men weather, water contained, sand etc. We can find the causes of the difference between classified groups. Such classification is defined as Stratification. And, in case such causes that differenciate the quality would not be found out, it is suggested to make another minute classification basing on other conditions, and at this classification, the accurate datas which have not been crooked purposely are imperatively required.

7.1.2. The methods of Stratification

It is advisable to pay attention on the following points when making analysis on defectives.

(1) To take, first, accurate data.
(2) To take data. according to the phenomena of the defectiveness.

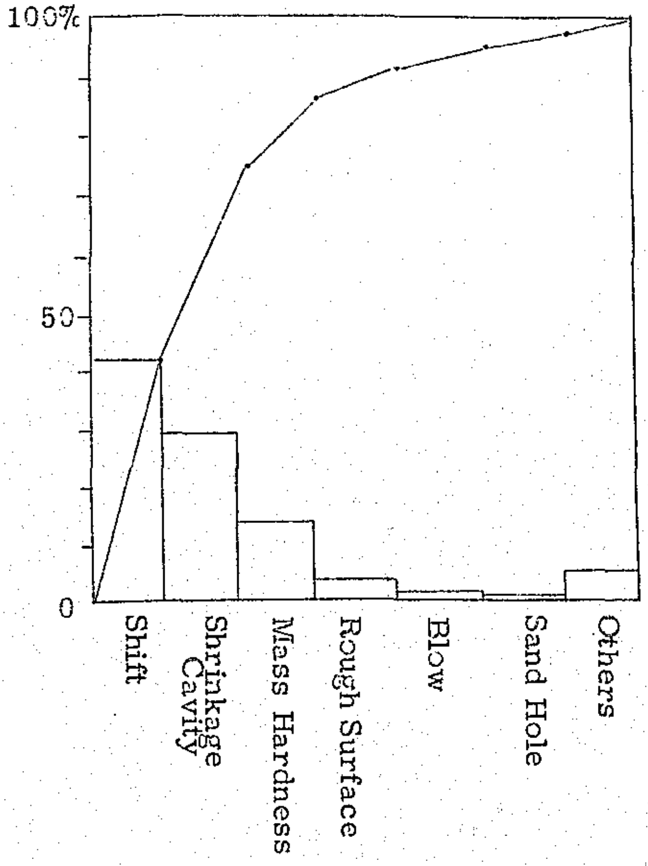
(3) To take data according to the positions of the defectiveness.

(4) To take data according to the production conditions of of the defectiveness.

7.1.3. Pareto Diagram

If the problem, for instance, here we take the defectiveness, is put on a line graph, by turns of the frequency or the value etc., it is easy to find, by sight, what is the problem at the moment, and what disposition is to be taken. Such graph, we call Pereto Diagram.

Fig. 5 Pareto Diagram.



As column graph will help to find the situations easily; the aggregated line is called as Pareto Curve.

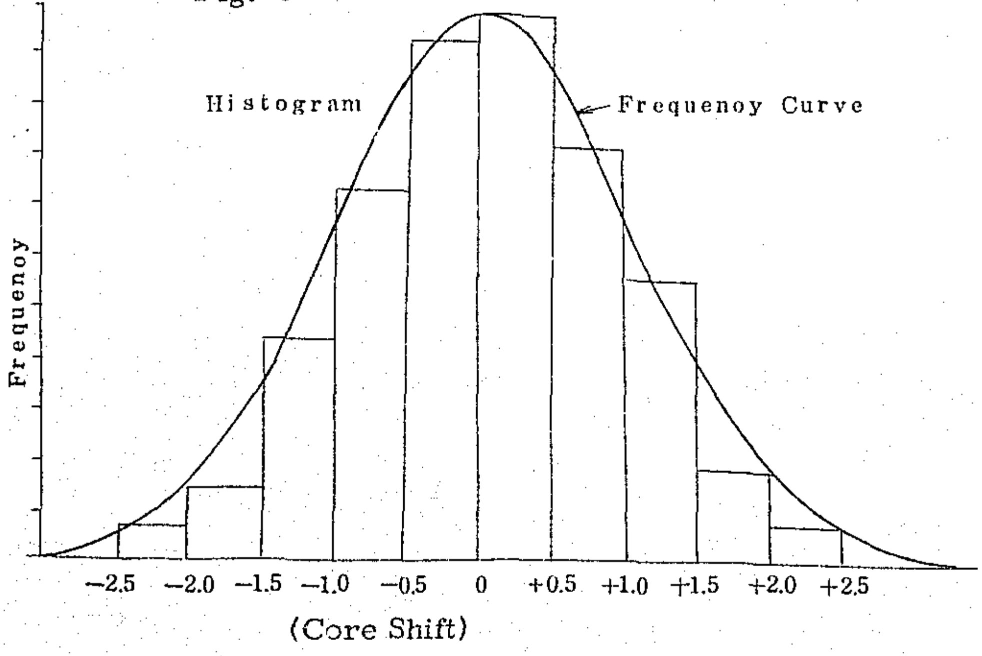
7.1.4. Histogram

(1) The statistic view means to appreciate the objects correctly and accurately, to take the certain data quantitatively, and to decide the points of dispositions that have to be taken.

(2) The Histogram is one of such methods, and very convenient to indentify the qualities as group.

(3) To make a histogram, it is advised to stratify according to the characteristic value of the articles in details, to check the appearance-frequency, and to make the line graph.

Fig. 6



(4) By connecting such histograms, it can be obtained a curve that is called Frequency Curve. And if the histograms are of frequency, then can be available Frequency Distribution Curve.

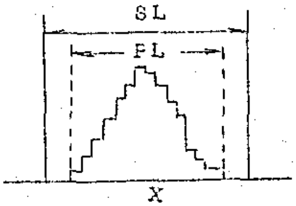
(5) In the next pages are shown the way of appreciating such histograms and Curves.

Comparisons with standard value.

Let's take examples hereunder: (PL : Production Limit,
SL : Standard Limit)

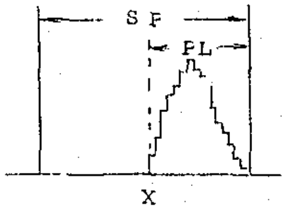
Fig. 7

(a)



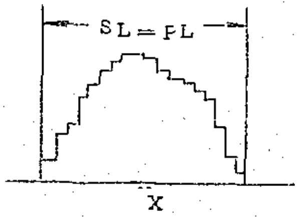
a) PL is fully inside of SL, and the process average also got into right in the center; moreover, as the SL positions at the points of about 4 times of standard deviation which has been obtained from the histograms, this is an ideal case.

(b)



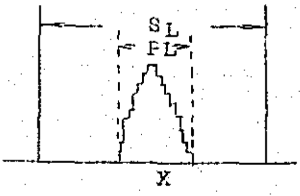
b) Even though the PL is inside of SL, the process-average being so close to the upper limit of SL, it is feared that out-of-standard articles would come out by slight changes of process.

(c)



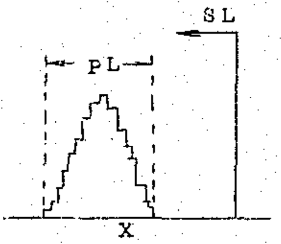
c) PL conforms exactly to SL, however, the rooms being few, cautions are required.

(d)



d) SL is very much wider than PL; as there are much rooms, it is advisable to change process for saving costs by either (1) having SL narrowed or (2) PL widened.

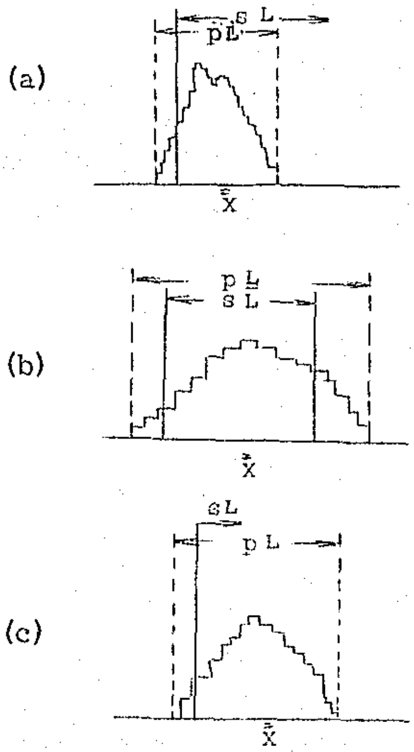
(e)



e) In case the SL is given as either below or over a certain value, the PL stands completely satisfactorily.

The case of data of products meeting to the standard.

Fig. 8



a) The process-average is too much leaned to left. If there is any possibility to change technically the average value easily, it is suggested to put $\bar{\bar{x}}$ at the central value of SL.

b) Too much scattered are the processes. It is necessary to lessen the scattering or widen the SL by changing the processes; otherwise all of the products have to be checked.

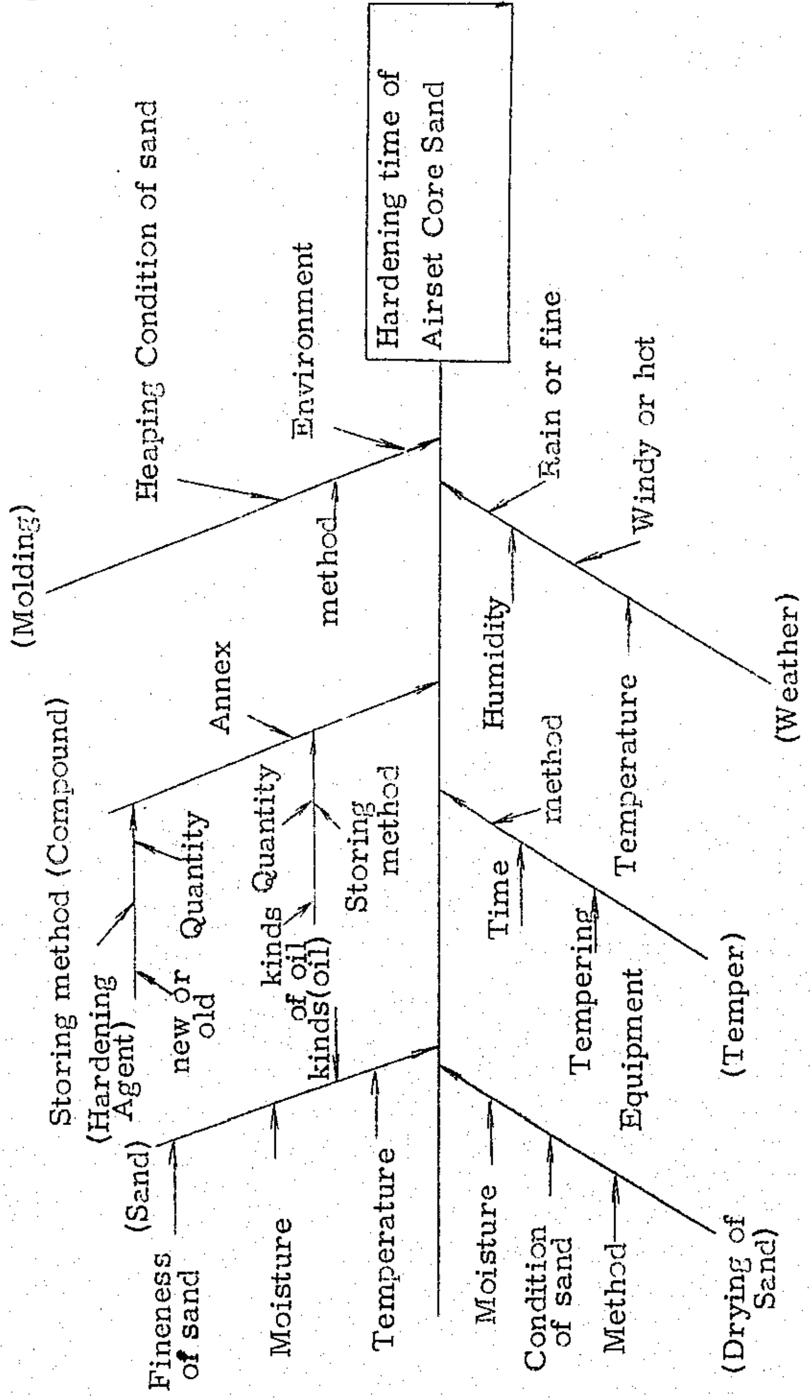
c) If the standard is over certain kg/cm^2, it is suggested to make some changes enlarging the $\bar{\bar{x}}$, lessening the scattering or by some other ways.

The case in which the products do not meet to the standard.

7.1.5. Characteristic Factor Chart

A characteristic factor chart is a chart in which are shown various factors that influence towards the making of characteristics of quality, in a manner of like fish bones shape; and one can grab the whole picture or the relations inbetween by sight. Moreover, from the chart one can think of the factors in a manner of chain-links, and can also easily compare the importance of such factors. Another feature of the chart is that one can expect remarkable effect when using the chart on the occasions of analyzing the problems, taking dispositions against defects etc.

Fig. 9


Hardening time of Airset Core Sand
(Molding)
Heaping Condition of sand
Environment
method
Storing method (Compound)
Annex
(Hardening Agent)
new or old
Quantity
kinds of oil
Quantity
Storing method
kinds(oil)
(Sand)
Fineness of sand
Moisture
Temperature
(Weather)
Rain or fine
Windy or hot
Humidity
Temperature
(Temper)
Time
method
Tempering Equipment
(Drying of Sand)
Moisture
Condition of sand
Method

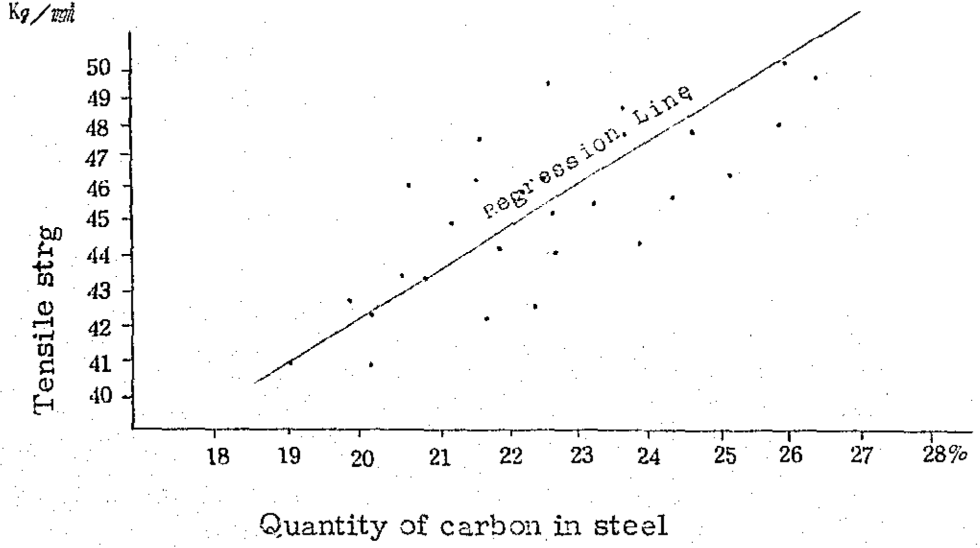
7. 1. 6. Correlation Graph & Scatter Diagram

It can be estimated, by making many test-pieces and testing those, whether there are any relations between the tensile strength and the carbon contents of the steel. And if it would be found out that there are some relations between 2 tested values, such relations can be expressed quantitatively by making the relative-formulas.

These relation is called correlation, and test based on correlation is called regression.

The Test and Estimation based on the Regression line are called as Regression Analysis.

Fig. 10 Scatter Diagram



It is suggested to make relative-formulas on the following for easier way of analyzing problems.

The ventilation situations of sand mold & the blow;

The water content in Sand and the Porosity;

The Casting temperature and The Cavity;

The Chill and the carbon quantity.

7.1.7. Inspection

(1) Inspection is an imperative work to confirm the quality of the products, and has been considered to be important to assure the quality to the consumers. The work of inspection itself cannot change the quality of products, but has only a significance of selecting the qualities. Therefore, it is wiser to prepare the production abilities to get better and uniform quality in products without inspection.

(2) The ideal of the quality control management is "No Inspection", which is partly being executed in the fields of Plant Industry and Machinery Industry. But, at foundries, under present circumstances, it is still difficult to materialize this No Inspection system.
If the conditions at a process be certain, perhaps can be expected No Inspection judging from proceeding data ; however, at foundries, the factors influencing products are so many, and consequently cannot be expected full control of such factors or even if possible, it is still cost-taking.

(3) Consequently, a method of checking the qualities in known as Sampling Inspection based on statistic theory, is taken up, This is method to select the most economic certainty avoiding the expensive way as all products inspection, by deciding, beforehand, the standard of sampling and the allowance of the defects.

(4) Limited sample. At the foundries, the quality controlling owes many to the Sensory Test. The Surface, Pinhole etc. are those. And in this case, if the limited sample is to be fixed beforehand, the scattering according to the individual difference of the inspectors themselves would become very few.

8. HOW TO APPLY THE QUALITY CONTROL MANAGEMENT IN FOUNDRIES

So far, you got the general idea on the quality control management. Then, how you can apply such methods in foundries ? Hereunder, are described such methods by turns.

8.1. Quality Control Mindedness

First of all, it is imperative that the proprietors have to get the mind of executing the quality control, and for that purpose, they have to know the merits thereof. It is important to have the proprietors understood the merits of quality control by showing them various data.

8.2. Staff Member for Quality Control

Secondly, are required the men in charge of quality control and the staff engineers to promote such control. As mentioned above, the quality control cannot be performed unless everybody cooperates, and therefore are required the responsible staff who take the leading parts, without whom is unavailable the quality control. And such staff have to know, of course, the quality control, to be meek in their personalities as well as having strong spirits, and to be cooperative with others.

8.3. System

The systems of quality control have to be set up based on the scales of the respective foundry.
Who would be responsible for the quality ?
What kinds of dispositions are to be taken when any defective products come out ?
How to give the informations on qualities ?
Who would make the standards of the works, who would execute, who would check them etc. ?
For your guidance. please refer to the Tables 1 and 2.

8.4. Educations and Training.

Quality Control sets its principle on everybody's participation. A minute educations and trainings are required for proprietors, managers, and workers respectively. Needless to say is that the quality control staff have to keep up with the best knowledge or methods that are ever advancing, thru constant studies.

8.5. Operation Standard

It is necessary to make the standard for operation that is right and most effective as well as economic. And in making the standard the boss of operators has to participate. The standards made only by the staff are apt to be inferior, or should not be adopted even if they are good. The operation standards which stipulate in too many details are inefficient, for it is required more efforts for the designing in such a time like present when the tempo of the progress of operating is so rapid.

The operation standards will be okay, if they contain the indispensable control points; they are to be easily looked at and executed, and also understopd by anybody.

8.6. To Rotate the Control Circle.

Deming Circle will be the whole factory in its larger scale, or cetain groups in workshops in minor. Therefore the quality control staff has to keep assisting constantly to have the Deming Circle circulated well.

The Control Circle, namely, the circle of "Plan-do-check-action" has its significance in the circulation made by each workshop voluntarily. But, at the beginning, the staff has to act as the core, and to take the method of gradually transferring the activities among others.

If the Deming Circle cerculates well, it is quite sure that the wastefulness, unreasonableness, and unevenness would decrease and the quality would be improved as well as having more profits.

8.7. Foundry Work Management

Let us consider the practical phases of quality controlling in the foundries.

8.7.1. *Management on Raw Materials*

Regarding the main materials like Pig Iron, Steel Chips, Return Scrops, etc., and the subordinate materials like cokes, limes, sand, woods, etc., it is important to check if the qualities are conforming with the result-lists which are to be submitted by the meterial suppliers at the time of delivery by sampling. On the other hand, at the factories, it is suggested to keep more distinctive area not to be mixed up with other articles, and better preservation.

8.7.2. Control on melting operation

The mixture of raw materials is to be based on the operation-guideance slip which shows the articles and quantities; such mixture records have to be kept by respective charge for elucidating the qualities.

The analysis are recommended on the respective charge taking out the test pieces thereof cor checking if the mixture was right, for the records of quality, and for using as future reference of the adjustment of the charge.

8.7.3. On molding

The water content among the mixed sand is to be adjusted according to the standard.
On the mixing of the sand, a control graph is not so significant, but the standard for adjustment would be just enough. According to the casts themselves, the standard as to the mixing ratio of new sand, used sand etc., would be given.

8.7.4. On measuring instruments

Periodical checkings on the measuring instruments which are necessary for casting works, either attached to the machineries or used separately, such as thermometer, barometer, wind-meter etc., are required.

And for these managing, a specification is required to be set up.

8.7.5. Actions to reduce failures

On the defective products which would have come out, certain methods of rescuing such defectives are to be taken; and actions are necessary not to get such defective products again.

On such occasions, the best advisable way is that the boss at the workshop where the inferiorities came out would make the plans for which the quality control staff would help.
For, the responsibility lies in the very factory where the defective products came out and consequently they know right in there the situations very well.

The judgement if the products are good or inferior is to be done by the operators at the workshop, and in case such judgement would be rather difficult, the boss is to ask for the suggestions of the Staff.

And such judgements are not to be asked to the 3rd party, because the people who knows the quality and situations is the operator, the boss, and the staff.

On making plans against defective products, the bosses at the mold-making, casting, finishing processes etc. have to get together to study, receiving helps from the staff.

Constant activities mentioned above would lead to good circulation of Deming Circle.

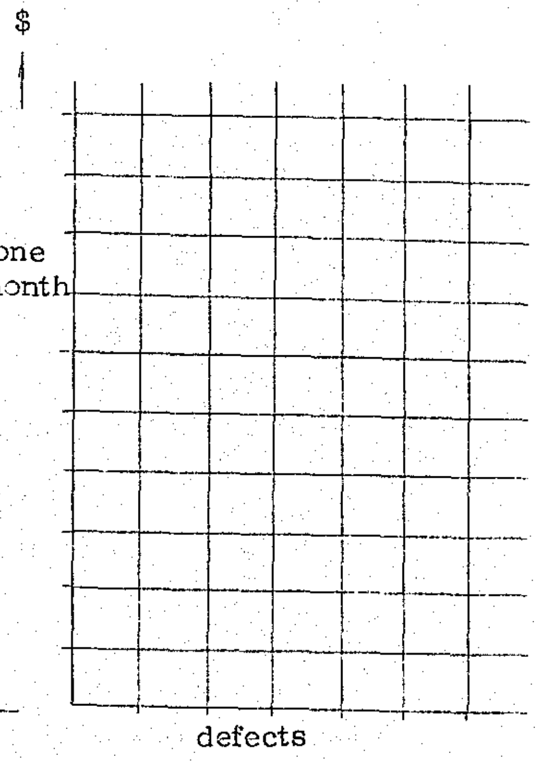
8. 8.

To conclude the lesson, hereunder are given the words of Dr. J. M. Juran:-
"In your factories are buried gold bullions everywhere, and the Quality Control is the pick to dig out such bullions."

ACTIVITY

(1) By atratifying the loss of defective at foundries, following amount has been obtained. Make the pareto Diagram and write down the kinds which you would take up for the dispositions.

1) Chill	$ 2,000
2) Shrinkage Cavity	18,000
3) Scar	38,000
4) Blow	5,000
5) Hard Spot	3,000
6) Shift	22,000
7) Core Raise	7,000
8) Rough Surface	5,000
	$ 100,000



(2) Thru an analysis on the carbon quantity of a cast article, the following graph is obtained as this Histogram. Is it okay to keep the casting operation as it ? How would you judge on this, and what kind of dispositions you would be taking up ? Standard limit: 20 - 22 %

Answer:-

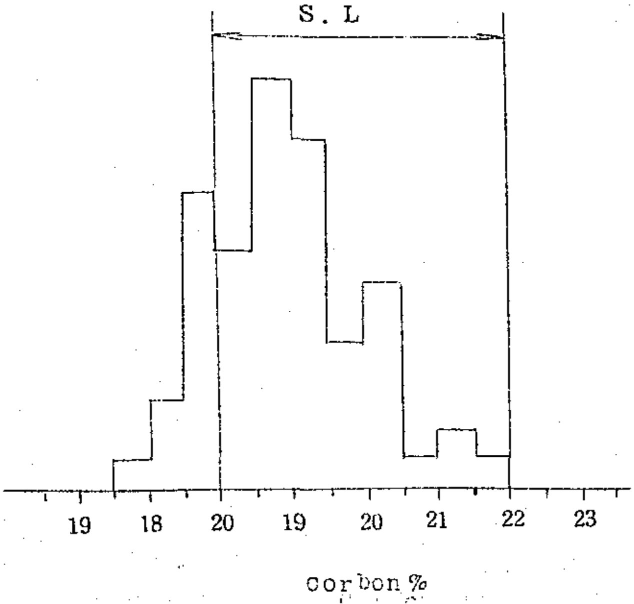


Table 1. Casting operation Process chart

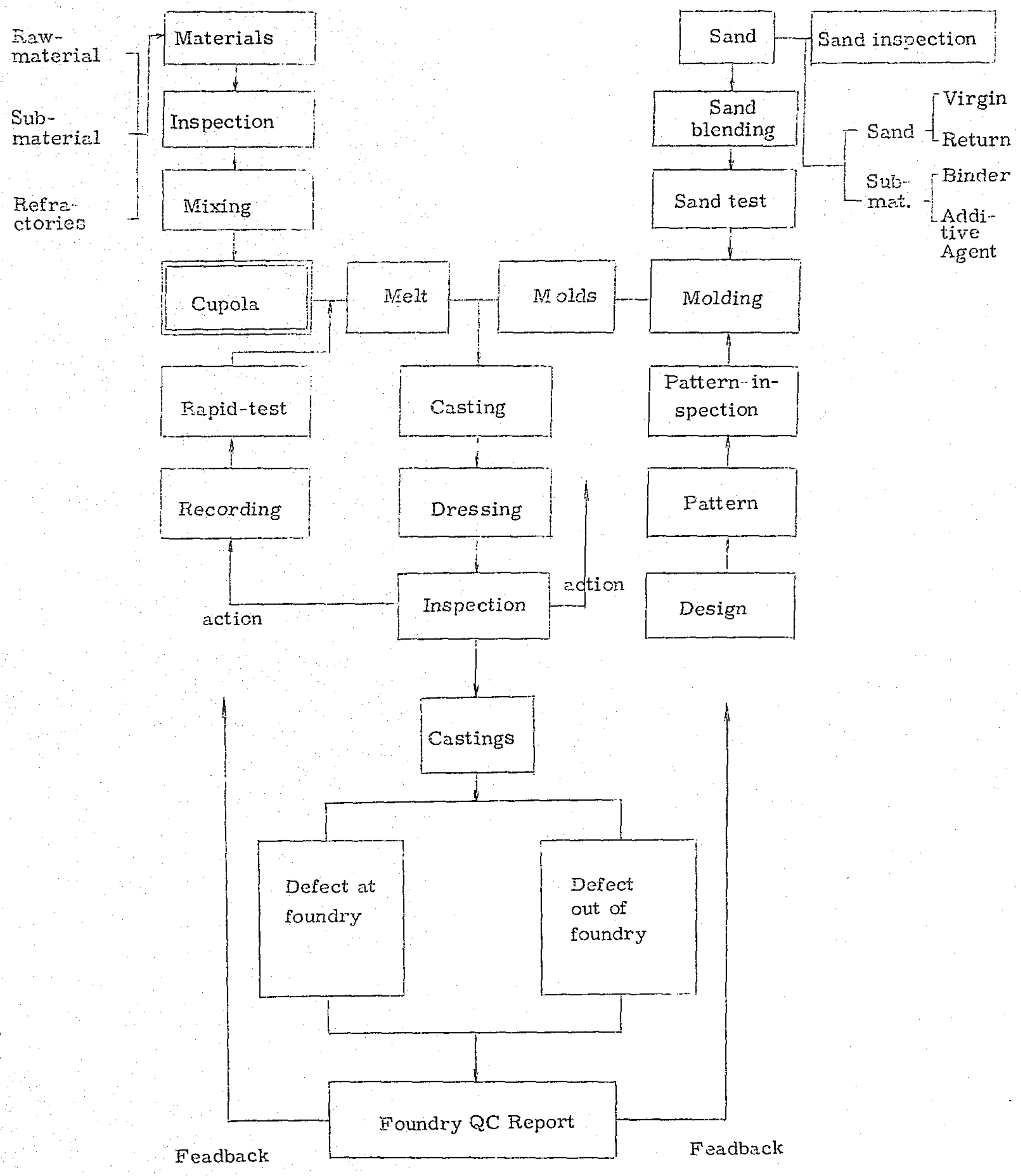


Table 2. Organization chart

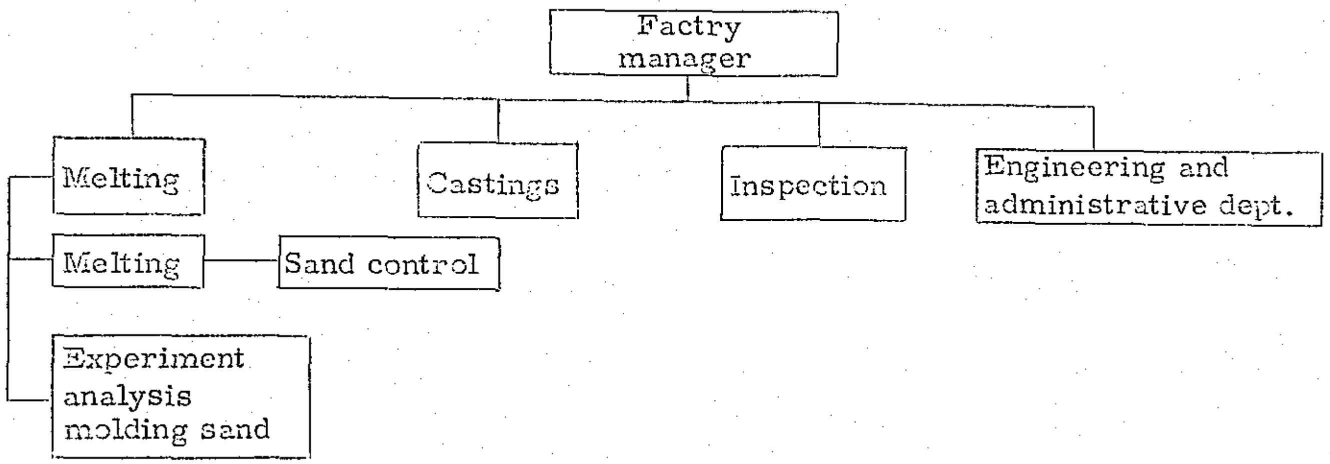


Table 3. Example of procurment standard of pig iron

Appearance	Should be a chill-cast pig iron, have smooth surface, and no sand, slag or other alien substances, Should not have too much cracks.
Fracture	Should not have abnormal structure, such as cavity deemed detrimental, oxidized substance, internal chill, kish graphte, etc.
Chemical element	C: 3.90-4.30 Si: 1.80-2.20 Mn: 0.50-1.00 P: <0.150 S: <0.035 Cr: <0.07 Cn: <0.20 Ti: <0.10 Remarks: 1) It is not acceptable if Ti is more than 0.121. Shall be decided on negotiation if it is p.101-0.120 2) (a) Product shall be divided into a lot by tap and shall not be mixed with alien lot. (b) Analysis record of chemical elements shall be attached to each lot.

Table 4

Example of procurement standard of foundry sand

Name	Finess of sand	Roughing sand		Average sand		Granule sand			Caly (A.F.S.)	Moisture	Chemical element				
		More than mesh	%	Peak mesh	Range	%	Less than mesh	%			SiO_2	Al_2O_3	Fe_2O_3	AaC+Mgo	I. 1
											%	%	%	%	%
A (mountain sand)	85-100	50	<5	100	70 pan	>85	-	-	<10	<15	>85	<10	< 5	< 1	< 3
B (shore sand)	51-58	40	< 7	70	50 100	>88	140 <5	<5	<0.5	<0.2	>85	<10	< 2	< 1.5	< 1.5

Classification	Facilities	Check frequency
A	Cupola, core oven, molding machine, sand controller.	Every day
B	Shell molding machine, hoist, shovel-car	Every other day
C	Blower molding machine, sand-mill, shot-tumbler	Twice a week
D	Compressor, baby-conveyor, cutter, pulverizer	Once a week

Table 5. Example of maintenance work standard of molding facilities

Table 6.

Inspection record

Form No.																											
Class No.						Monenclature										Material							Weight				
Year	No. of inspection	Inferiority																			Re-turn		Correction				
Date		A Pattern	B Material	C Crack	D Shrinkage	F Blow	G Slug	H Cold shut	K Stripping	L Scab	M Casting surface	N Size	P Form	Q Run	R Others	S Design	T Repair	V Heat treatment	W Other works	X Loss and damage	Total	Breakdown of inferiority	Filling of cavity	Curve	Tinkering	Special treatment	Total

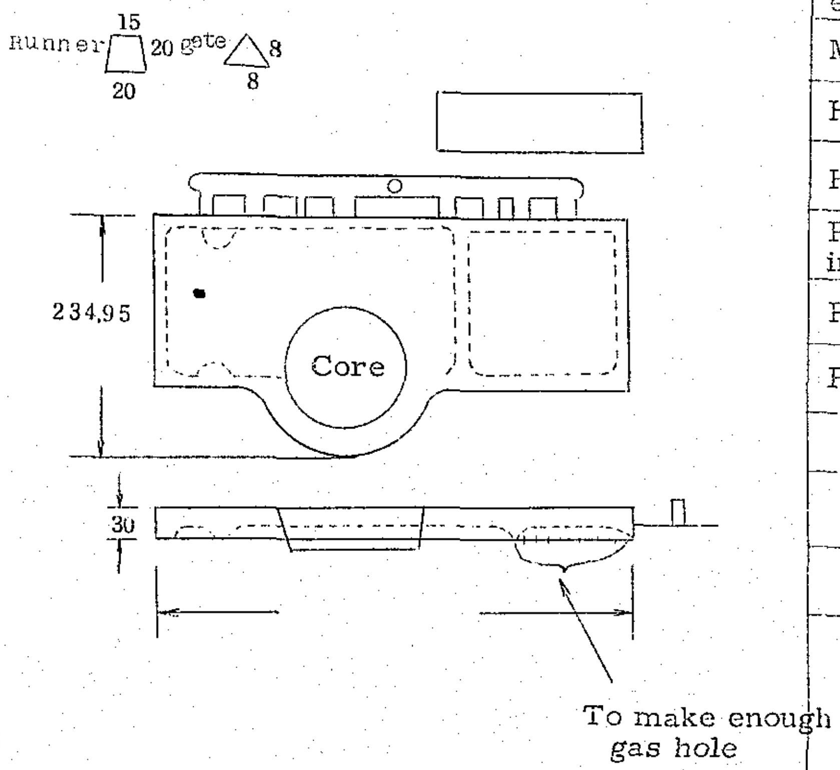
Fig. 7 Example of guide card for molding Work process

Mold H	Core sand H	Weight
1.56	0.08	4,530 kg

Form. A B C Name: Cover De sign No. X12345

Kind of outside mould	Green sand Half -fired Fired
Kind of core	Flax combination. CO2
Molding method of outside mould	Bench-molding. Machine molding, Slinger
Core molding method	Bench-molding, Core shooter. Stripper
Flash size	5L
Gauge	Presence No.
Core gride	/
Chiller	/
Tools	/
Kind of wodden pattern	Sweeping. Same. Split
Material of wooden pattern	Cypress 0. 2 ft^3
Work unit in pattern making	35 h.
Metal mould finish	/
Metal mould Cand W	/
Material of metal mould	/
Material FC 15	(signature)

Gate stuk 25



Outside mould 1
Inner mould 1

(Jignature)

Tapping temp-erature	over 1,550
Molding temp.	1,400
Hardness	/
Heat treatment	/
Pressure inspection	/
Pickling	Necessary Not nessary
Painting	Necessary Not necessary

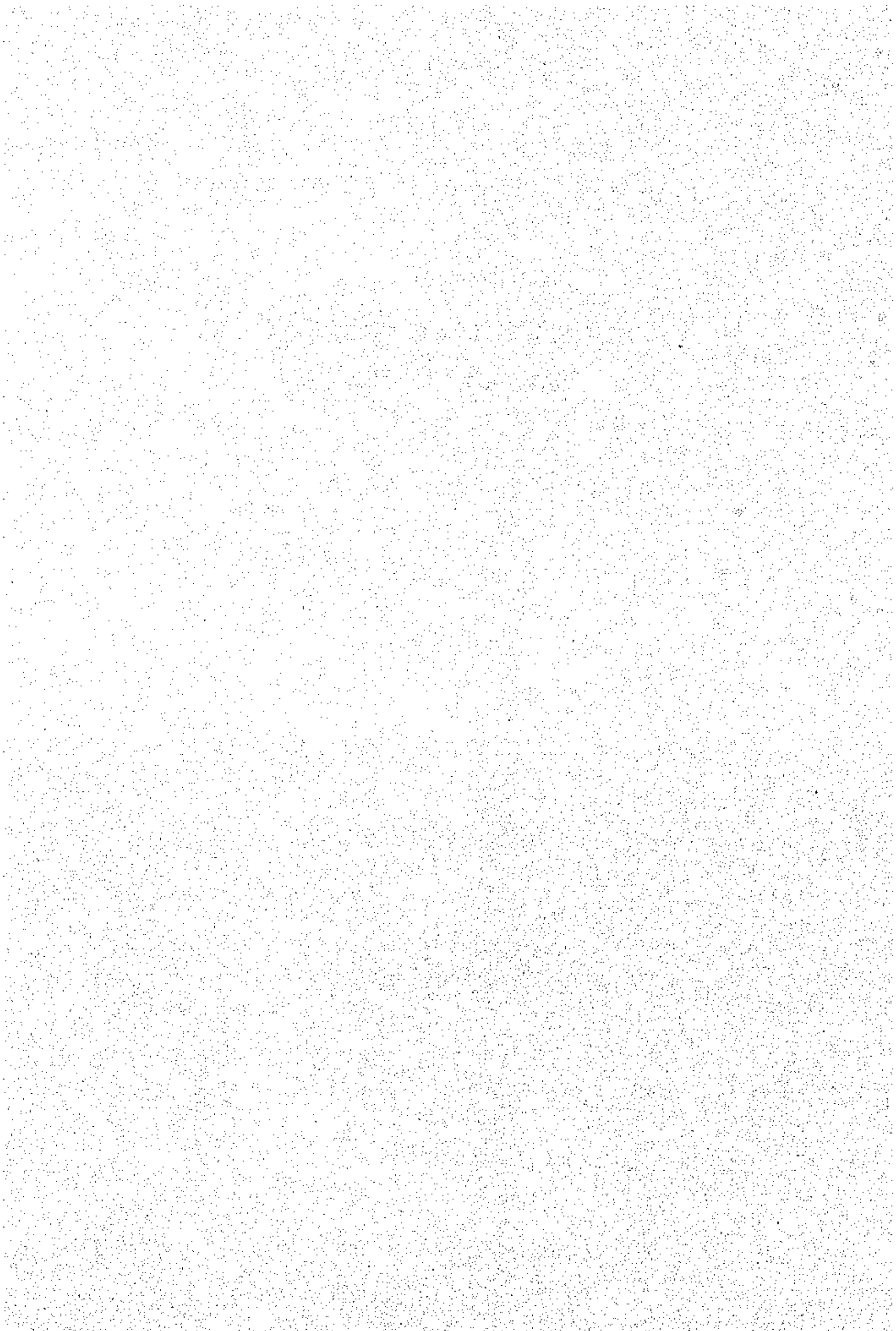
Direction

Matters to be improved

Designated molding machine

Large one

PRODUCTION MANAGEMENT OF FOUNDRIES



PRODUCTION MANAGEMENT OF FOUNDRIES

By: Tsutomu Shimomura
Sakurai Seikosho Co., Ltd.

1. DEFINITION OF THE TERM

Being conveneient, the term PRODUCTION MANAGEMENT is so often used by many people. But the trouble is that it is not always meant by the same import according to the nuance of the persons who would use the term.

For the sake of consistency in my session, I would like to give you the definition of my own that "ALL THE MANAGERIAL ACTIVITIES INVOLVED IN THE PROCESS OF PRODUCTION OF WHICH OBJECTIVES ARE TO MAKE THE PRODUCTS IN PREFERRED QUALITY, AT LOWEST COST AND WITHIN POSSIBLE SHORTEST TIME." This definition is rather broad, and will involve many activites such as; plant lay-out, design of production process, production planning, quality control, operations of workers, supervision of performances in each process, etc..

I will refer only briefly to plant lay-out today because it is not my main subject. Originally, plant lay-out is that planning of allocation of all the construction as well as machines within a factory so as to make the flow of raw-materials, goods-in-process, and products as smooth as possible in each production line. At the same time, in foundry, lay-out designer should pay a good deal of his attention to the ventilation ficilities and dust-collectors which would affect workers' health very much.

Of course, types of the machines are one of the important elements to be taken into consideration in plant lay-out. Furthermore, there are at least three more factors that must be considered:

(1) Types of the product
(2) Sizes of the product
(3) Lot-size

I am sure, foregoing factors will be discussed more in detail by other lecturers during this seminar.

So, let me change my topic to the next. Fig. 1 indicates the role played by production management within entire management of an enterprise. From this we can see that there are three main elements in production management, namely; quality, operations and process. Each one of them can be regarded as an independent activity, whereas, they are related with each other so closely as are combined into one management device, namely, cost control. For example, operations might be controlled from the views of process, and vice versa. The same applies between quality and other two elements.

In regard to the management techniques for controlling quality, operations and process, there have been reported in rich variety with diferent nominations. What is most important for the foundry to adopt those techniques is that they take full considerations of such conditions as, capacity of the factory, the level of their administrative as well as technical capacity, and types of physical facilities, so that optimum decision may be made as to how and to what extent should they be accepted. By no mean, those managerial approaches be aplied in an orthodox way as is usually given in the textbooks; otherwise, they may create more chaos than improvement in foundry management.

2. PROBLEMS CONCEIVABLE IN PRODUCTION MANAGEMENT OF FOUNDRIES

2.1. Economy of time required for handling materials

It has been widely accepted that the foundry is one of the indsutries of which production time is much spent during the process of materials-handling. According to the report of a specialist, 200 tons of materials are being handled per casting tonnage in U.S.A., and that 30 to 40 % of the cost are spent for handling those materials.

Mr. Watanabe made a research in this field by classifying raw materials into two categories, metals and sands. He made it clear that the weight of sands handled in foundry shops is twice as much as that of metals. This fact is very symbolic of the features of the foundry-industry. He further reports that even in larger foundries where materials-handling-techniques are considerablly advanced, 20 % of the direct-workers' time has been spent for handling materials.

(In this case, time required for handling molton metal by ladles is included for the data.) As the next topic, I will discuss on the principles of materials-handling which may summarized in the following three items:

(1) Economize storage-time to the possible extent.
(2) Eliminate handling operations whenever possible, and materials in transit should be moved as close to the next point as possible.
(3) Economize workers motions.

To reduce storage time may rather be the problem of process-control, but to economize time for receiving as well as sorting of products or goods-in-process would be one of the most challenging problems of materials-handling, since they have been unreasonably ignored.

It goes without saying that if the techniques of materials-handling are to be applied in an ideal way, analysis should be made in regard to the following points; weight of castings, transit distance, frequency of handling operations, time required for each operation and power consumed. Then a flow-chart will be drawn to show each of these data on it.

When such analysis is not feasible, pick up a line of operations which is easy to tackle with, then investigate. For instance, operations between storage-pit to melting-spot would be one of the cases. Even this simple investigation it will enable us to draw fairly clear picture of the infuluence of materials-handling upon the cost composite.
Taking foregoing principles in consideration, we must search for the solutions of the problems involved in materials-handling. Followings are the general rules :

(1) Select such machines as are versatile whenever possible.
(2) Standardize unit-load as well as package-containers
(3) Improve flow of process so as to eliminate storage-time of products and goods-in-process.
(4) When storage is unavoidable, leave materials in the package-containers, through which loading-time would be economized.
(5) Utilize vertical spaces to the possible extent.
(6) Fix transit path according to the types of materials; metals, sands, castings and goods-in-process.

(7) Place materials as close to the operator as possible, and easy to handle.
(8) In moving materials both space and time should never be wasted.
(9) Safety rules should never be ignored.

No matter how mechanized the material-handling manual operations would never be exterminated. It is known that even the modern foundry shops, 60 % of handling time is being spent in handling materials manually. However, limit of manual operation, according to Mr. Horikawa's report, surprisingly low. Those data are given in table 1.
The table ( ) shows the relation between the degree of machanization in materials-handling equipment and the number of workers required in melting operations by cupola.

2.2. Setting standard time in moulding process

Standard time, first of all, must be measured before workable production schedule can be organized, and also practical means to control production cost be devised.
Followings are the main steps for setting standard man-hours:

(1) Analyse the time consumed by the operations in respects to; base time and various allowances such as; setup and cleanup, etc..
(2) Decide allowances. In this step the sum of personal and fatiegue allowances must be lower than 5 %.
(3) Calculate average for actual man-hours from the data available in records.
(4) Measure man-hours per moulds. We might as call this ratio as ideal man-hours. (No allowance considered).
(5) Calculate standard man-hours from, average & ideal man-hours, and allowances decided.

Needless to say, foregoing ratios would differ, in an exact sense, according to each worker as they have difference in abilities, skills, mental attitude and physical conditions.
In order to make those ratio relevant, such workers as can be regarded with average potentiality should be selected as samples for analysis.
The analysis show us a variety of measuring methods, but so far as the foundries are concerned, they are still in a primitive

stage for measuring standard time. Therefore, I would rather recommend the foregoing approaches that measure standard man-hours which is more practical than the formal ones that would pre-requisite standard time measurement.

After the standards are decided through the steps mentioned above, our next concern would be how to make the workers accept them so that they are put into real effect. In case, even after the standard for molding is set as 200, if actual output fluctuates widely, say, from 250 to 140, it would indicate that the significance of the standards is not fully recognized by those who concerned. There are two main things to be practiced for making the standard effective, namely; make the workers well informed of the standards, and make them observe to it whenever possible as working principles.

In Table 4, are given the data for the standard time in relation to the motion elements of manual operations in molding process. As is mentioned before, if the standard man-hours are to be measured in ideal steps, it would pre-requisite the performance standards, which is only possible after the motion study is conducted. Measurement of standard time in relation to each motion element would be the consecutive steps after all of those steps have been taken.

2.3. Problems Conceivable in Process Control

Whatever the factory it may be, process control is one of the most important management actions. Today, I will start my discussion from the relationship between process and cost. Rush orders, or frequent changes of delivery dates will definitely require additional man-hours to cause the cost eventually higher. At any rate, it is desirable that in setting the date for dilivery, proper length of period for production should be counted without fail.

In case the period is too short to make trial castings, or to check flasks and moulds, unavoidable is the high reject-ratio, and difficult is to take effective counter measures. Reversely, if the period is so set as the same size of flasks can be used for various castings, and production can be centralized thereof, the cost would surely be economized. In other words, in order to economize the cost, the production schedule should be so prepared as various castings can be processed in one lot, or at least by the same size of flasks.

Mr. Robinson reports that, by means of standardizing the size of flasks (adjustable to some extent by partition-plates) which represent 80% of casting sizes in a foundry, production could be centralized to the effect of reducing the cost outstandingly. Process control in the foundry depend upon the casting-plan which should basically depend upon standard man-hours. The factors that will infuluence the flow of process are listed below:

(1) Errors in estimating rejects
(2) Errors in calculating standard man-hours
(3) Unbalanced capacitly of shops within foundry
(4) Errors in estimating absenteeism of workers
(5) Rush orders

Those who are responsible for process control, therefore, must be capable enough to handle those intricated factors satisfactorily. Production planning should be checked in the light of the output, because, it will give us some clues to find problems for further investigation.

In designing work order sheet, in additions to such items as; Product Name, Quantity and Date for completion, the followings are to be considered:

(1) Standard man-hours (or standard production)
(2) Types of the flasks
(3) Types of the core sands
(4) Others

2.4. Maintenance of the Moulds

It goes without saying that patterns and flasks should be placed in good order whenever possible, and must be checked before they are handed to workers, this practice alone will help prevent rejects to a large extent. Furthermore, it is desired that for each flask and pattern, a record should be filed. In the record, following items would be needed:

(1) Date made
(2) Check points, and descriptions therein.

(3) History for the repair and adjustment.
(due to design changes will be included)

As a matter of fact, there are quite a few casting rejects owing to the careless use of; core patterns wore out, flasks with loose guide-pins, and in an extreme case, main patterns wore out.

2.5. Quality Control and Cost Control

As my discussion have come near to close, I will refer just briefly to quality control and cost control, both of which are important managerial actions in foundry.

(1) Statistical quality control is hardly recommendable to the foundries.
(2) First of all, standardize operations.
(3) Do not try to control the castings, but control the processes for casting. For instance, operations for preparing face sand, or for care drying oven are important for obtaining uniformity of casting quality.

In any foundry the reduction in production cost would be one of the major concerns for management. To attain this end, it is necessary to take such positive means as raising productivity on one hand, the slow-but steady approaches, such as eliminating the causes for rejects one after another would not be ignored. Following approaches are considered effective for the latter:

(1) Analyse the cause for deviations between standard versus actual man-hours.
(2) Analyse the causes for deviations between standard versus actual cost.
(3) Counter measures for rejects.
(4) Constantly pay effort to find substitutive materials with lower prices.

3. CLOSING

Today, I could only pick up some of the most influential problems conceivable in production management of foundries, since it is impossible to discuss all the phases of it within limited length of time assigned to me. Now, I want to close my seminar with the following comment of my own.

As the foundries constitutes the foundation of the machinery industry, it eventually becomes one of the integral elements of the industries of Japan as a whole. In such a country where machinery industry is highly developed, moulding machines with superior capacity are readily available; and where chemical industry is advanced, casting materials with preferable specifications would be accessible in reasonable prices. However, in a country where education level is not sufficiently high, it would be difficult to make the good use of those machines and materials.

Furthermore, the standard of living has much to do with the production cost. For example, in U.S.A., for 400 dollars of the materials for moulds, average wage amounts to 500 dollars; while in Japan, for the materials that costs 80,000 Yen, average wage is 40,000 Yen.

As previously mentioned, the foundry can never exist independently. The problems in production management, therefore, should be considered in the light of national environment versus the level as well as the scale of each foundry.

Table 1. Limit of Manual Operation (by Horikawa)

	Weight	Time *	Distance	Height lifted
Male	32kg	12 sec.	5m	70cm
Female	15kg	10 sec.	"	50cm

* Data indicate the repititive operations in 20 times

Table 2. Comparison of Weight Handled

Net Weight	Foundry A	Foundry B	Foundry C
Metals (a)	472	511	1,661
Sands (b)	2,184	1,075	2,430
(a) / (b)	4.6	2.7	1.5

(Mr. Watanabe's data)

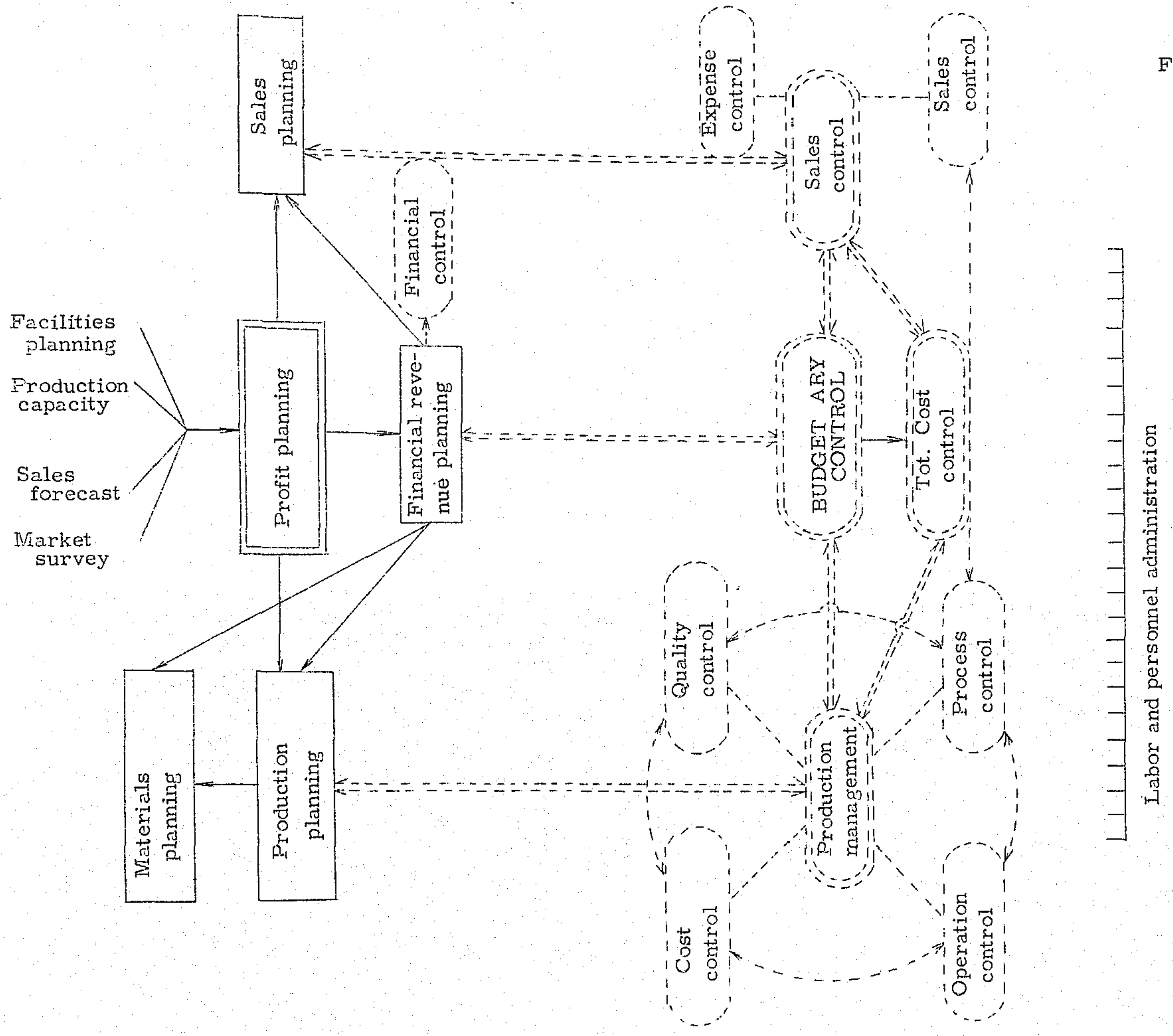


Fig. 1 Composition of Managerials actions

Fig. 2 Control of Molten Slag (A. F. S.)

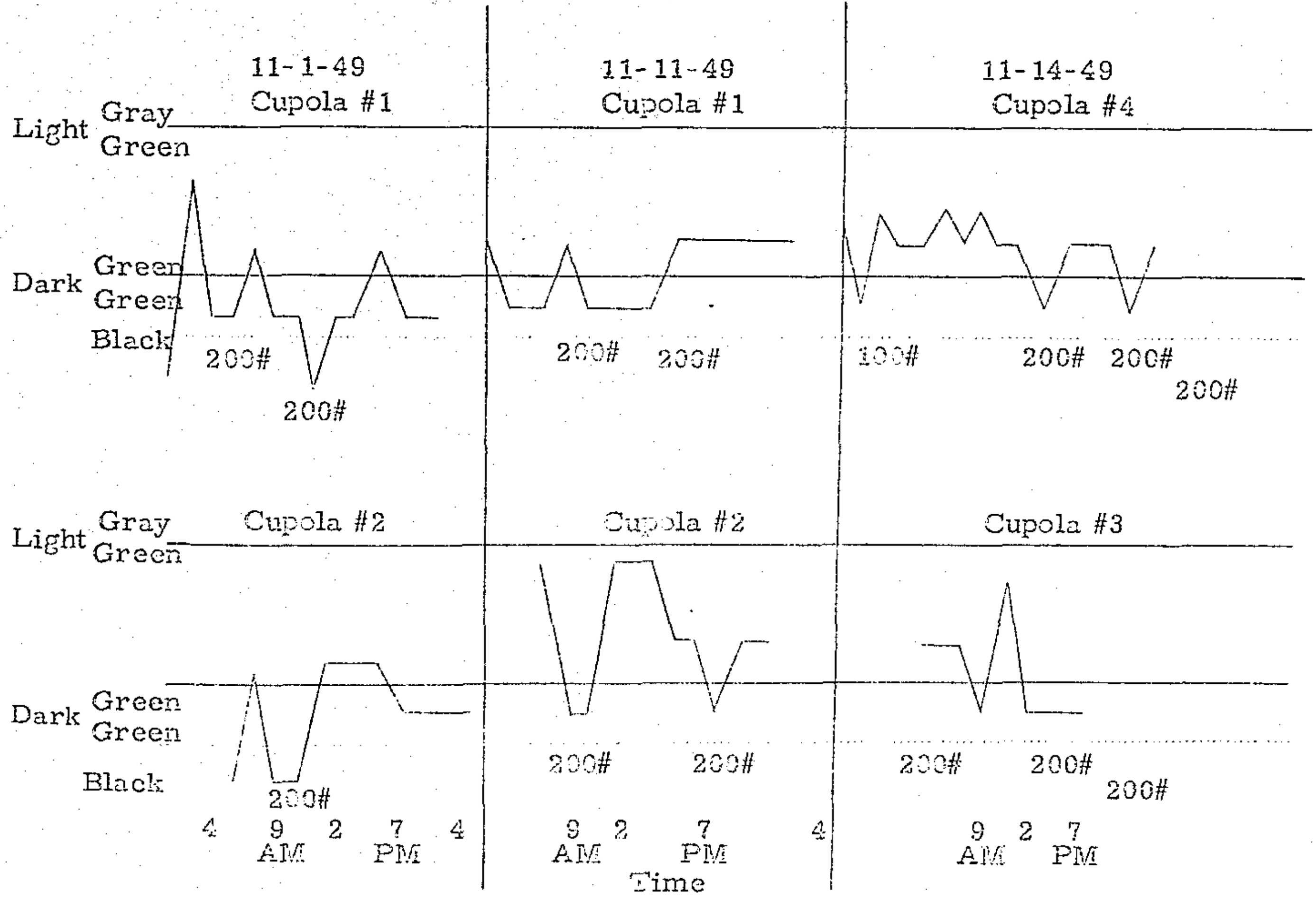


Table 3. Standard Time for Molding

(Minute)

(G. H. R. Foundry, Tamasaki)

Dimension of flask (in)	Total				Height of Flask (in)					
	7	8	9	10	11	12	13	14	15	16
10 x 10	1.79	1.82	1.85	1.87	1.92	1.97	2.04	2.12	2.21	2.33
14	1.91	1.94	1.98	2.02	2.07	2.14	2.22	2.30	2.41	2.54
16	1.96	2.01	2.05	2.09	2.15	2.22	2.31	2.40	2.51	2.64
18	2.02	2.07	2.11	2.16	2.23	2.31	2.39	2.49	2.61	2.75
11 x 22	2.20	2.27	2.33	2.40	2.48	2.57	2.68	2.79	2.92	3.08
12 x 12	1.91	1.95	1.99	2.03	2.09	2.15	2.23	2.32	2.43	2.55
14	1.99	2.03	2.08	2.12	2.19	2.26	2.34	2.44	2.55	2.69
16	2.05	2.10	2.15	2.20	2.27	2.35	2.44	2.55	2.63	2.81
17	2.09	2.15	2.20	2.26	2.33	2.41	2.51	2.61	2.73	2.88
24	2.33	2.40	2.48	2.56	2.65	2.76	2.87	3.00	3.14	3.31
13 x 16	2.10	2.16	2.21	2.27	2.34	2.43	2.52	2.62	2.75	2.89
19	2.22	2.28	2.35	2.41	2.50	2.59	2.70	2.82	2.95	3.11
30	2.63	2.73	2.83	2.94	3.06	3.19	3.33	3.49	3.63	3.85
14 x 14	2.08	2.13	2.18	2.24	2.31	2.39	2.48	2.58	2.70	2.84
16	2.13	2.22	2.28	2.34	2.42	2.51	2.60	2.71	2.84	2.99
15 x 22	2.49	2.57	2.66	2.75	2.88	2.97	3.10	2.23	3.39	3.57
16 x 16	2.29	2.36	2.42	2.49	2.58	2.68	2.78	2.90	3.04	3.20
18 x 18	2.54	2.62	2.71	2.79	2.90	3.01	3.14	3.27	3.43	3.60
20 x 20	2.71	2.82	2.92	3.03	3.15	3.29	3.43	3.59	3.76	3.96
22 x 22	3.14	3.27	3.39	3.52	3.67	3.82	3.99	4.17	4.37	4.58
24 x 24	3.51	3.66	3.86	3.96	4.15	4.31	4.51	4.71	4.93	5.17

Table 5. Relationship between Types of Casting and Foundry Sand in the United States.

	Moisture (%)	Aeration	Compressive Strength of Green Sand (Lbs)	Deforming Capacity	Clay (%)	Clay Grain size index (AFA)	Refractoriness °F (°C)
Aluminum Casting	6.5 ~ 8.5	7 ~ 13	6.5 ~ 7.5	0.018 ~ 0.024	12 ~ 18	225 ~ 160	2350 (1290)
Brass and Bronze Casting	6.0 ~ 8.0	13 ~ 20	7.0 ~ 8.0	0.014 ~ 0.020	12 ~ 14	150 ~ 140	2350 (1290)
Nickle Bronze Casting	6.0 ~ 7.5	37 ~ 50	6.5 ~ 8.0	0.014 ~ 0.020	12 ~ 14	130 ~ 120	2400 (1320)
Thin Iron Casting	6.0 ~ 8.5	10 ~ 15	6.0 ~ 7.5	0.018 ~ 0.022	10 ~ 12	200 ~ 180	2350 (1290)
Thin Iron Casting	6.0 ~ 7.5	18 ~ 25	6.2 ~ 7.5	0.019 ~ 0.022	12 ~ 14	120 ~ 87	2400 (1320)
Medium Iron Casting	5.5 ~ 7.0	40 ~ 60	7.5 ~ 8.0	0.010 ~ 0.014	11 ~ 14	86 ~ 70	2400 (1320)
Medium Iron Casting (Syntletice Sand)	4.0 ~ 6.0	50 ~ 80	7.5 ~ 8.5	0.012 ~ 0.017	4 ~ 10	75 ~ 55	2450 (1340)
Heavy Iron Casting	4.0 ~ 6.0	80 ~ 120	5.0 ~ 7.5	0.012 ~ 0.016	8 ~ 13	81 ~ 50	2500 (1380)
Thin Mallcable Cast Iron	6.0 ~ 8.0	20 ~ 30	6.5 ~ 7.5	0.017 ~ 0.020	8 ~ 13	120 ~ 92	2500 (1380)
Heavy Malleable Cast Iron	5.5 ~ 7.5	40 ~ 60	6.5 ~ 7.5	0.012 ~ 0.018	8 ~ 13	85 ~ 70	2500 (1380)
Thin Steel Casting(Green sand)	2.0 ~ 4.0	125 ~ 200	6.5 ~ 7.5	0.020 ~ 0.030	4 ~ 10	56 ~ 45	2600 (1430)
Heavy Steel Casting(Green sand)	2.0 ~ 4.0	130 ~ 300	6.5 ~ 7.5	0.020 ~ 0.030	4 ~ 10	62 ~ 38	2700 (1490)
Steel Casting (Dry mold)	4.0 ~ 6.0	100 ~ 200	6.5 ~ 7.5	0.030 ~ 0.040	6 ~ 12	60 ~ 45	2600 (1430)

Table 6. Status of Foundry Sand Control at American Malleable Iron Casting Plant.

Plant	Main Products	Average Weight of Product (Lbs.)	Casting Surface Requirement.	Interval of Control	Point of Control
No. 1	Tractor Farm Implement } Parts	0.8 - 0.9	Moderate Rigid on small items	A. M. P. M. } Once	Strength & Aeration
2	Automobile Parts	Over a wide range	"	A. M. Once	Strength, aeration and moisture
3	Railway Parts	6	Relatively severe	Once or twice a week	Ditto
4	Automobile Farm Implement } Parts	2 - 3	Moderate	At each mill	Ditto
5	Pipe joint	1/2 - 50	Rigid on plated items	A. M. P. M. } Once	Ditto
6	Pipe joint and valve	1	Minute	Every hour	Ditto
7	Railway Road Machine } Parts	22 - 32	Moderate	everyday	Attention is paid to sand strength at high temperature.
8	Railway Farm Implement } Parts	1.5	Relatively smooth	Every other day	Aeration, strength (Attention is paid to sand strength at high temperature.)
9	Overhead Power Line	4.7	Moderate	At each mill	Aeration, strength and moisture.
10	Truck and Tractor Parts	15 - 65	Ditto	Every 30 minutes	Aeration, strength and moisture clay is controled on a hourly basis.
11	Automobile Railway Equipment	1 1/2	Ditto	Ditto	Special attention is paid to sand at high temperature.
12	Chain	0.4	Ditto	Once a week	Moisture and aeration
13	Truck, Railway and other parts	7	Ditto	A. M. P. M. } Once	Aeration, strength and moisture.
14	Truck Tractor } Parts	11.4	Ditto	Once a day	Moisture and aeration.

Table 7. Tabulation of Defect of Gray Cast Iron and Its Causes

Indicates relatively infrequent cause
Indicates major causes

Defects	A Design	B Pattern	C Foundry flask & its equipment	D Gate device	E Sand	F Core	G Molding method	H	I Melting method	J Casting method	K Others	Number of factors in each casting process for various defects
Blow	○		※	○	※	※	※	○	※	※	○	10
Scar	○	○	○	○	○	○	○	○	○	○	○	11
Iron shot		○		※	※	○	○			○		6
Shrinkage cavity	○	○	○	○				○	○	○		7
Hot tear and sliver	○	○	○	○	○	○	○	※	○	○	※	11
Mass hardness					○	○		※	○	○	○	6
Hard spot & chilled spot	○	○	○	○	○	○	○	○	○	○	○	11
Warped casting	○	○	○	○	○	○	○	○	○	○	○	11
Coarse structure	○	○		○			○	※	○	○	○	8
Defficient flow and bump Misrun	○	○	○	○	○	○	○	○	○	○	○	11
Inclusions	○			※	○	○	○		○	○	○	8
Cut and wash	○			※	※	○	○			○		6
Erosion scab			○	○	※	※	※			○		6
Swell	○		○	○	※	○	○			○	○	8
Crush		○	※		○	○	※			○	※	7
Drop	○	○	※	○	※		※			○	※	8
Sticker	○	※	○	○	※	○	○					7
Rough surface	○	○	○	○	○	○		○		○		9
Peneteration	○	○	○	○	※	※	※	○		※		9
				○	※	※	○			○		5
	○	○	○	○	※	○	※			○		8
	○	※	○			○	○			○		6
	○	○		※	○	○	○			○	※	8
Ram-off		○	○	○	※		※					5
Core defects		○	○			○	○					4
Run-out		○	○	○	○	○	○			○	○	8
Damaged cast	○										○	2
Inverse chill								○	○	○		3
Poured short										○		1
Kish								○	○			2
Defective test specimen											○	1
Number of defects caused in each casting process	19	19	19	22	22	22	24	13	12	25	15	

Table 4

Table of Standard Time for Manual Operations in Molding

Type	No.	Operations	Starting & end point for measurement	Influential factors conceivable
Plate	1	Floor levelling	From hands on shavel to off the shavel after floor levelling	Floor conditions & Plate size
	2	Plate handling	A step towards plate and place it	Plate size, weight & distance
	3	Plate fixing	Place the plate on the floor and hands off	Plate size & weight
Drag	4	Assembling		
	5	Pattern handling		
	6	Pattern fixing		
	7	Spray powder		
	8	Sieve handling		
	9	Face sand screening		
	10	Face sand handling		
	11	Insert face sand		
	12	Crane preparation		
	13	Drag Setting		
	14	Back sand mix		
	15	Back sand fill		
	16	Back sand fill up		
	17	Back sand ramming		
	18	Stamping		
	19	Off the excess sand		
	20	Floor levelling for drag setting		
	21	Clamp drag & plate		
	22	Crane preparation		
	23	Drag roll-over		
	24	Clamp off		
	25	Mold repair		
	26	Mold cleaning		
	27	Parting sand & powder handling		
	28	Spray powder		
	29	Spray Parting sand		
	30	Blow parting sand		
Cope	31	Pattern handling		
	32	Assembling		
	33	Pattern setting		
	34	Core print fix		
	35	Sieve handling		
	36	Face sand screening		
	37	Face sand handling		
	38	Face sand fill		
	39	Cope preparation		
	40	Crane preparation		
	41	Cope setting		
	42	Gate setting		
	43	Back sand fill		
	44	Back sand fill up		
	45	Ramming		
	46	Stamping		
	47	Off the excess sand		
	48	Gate pattern off & repair		
	49	Marking		
	50	Gas venting		
Flask	51	Floor levelling for cope		
	52	Crane preparation		
	53	Upper flask off		
Drag pattern draw	54	Drag surface cleaning		
	55	Nailing		
	56	Watering for draw		
	57	Pattern draw bolt off		
	58	Pattern loose & draw		
	59	Loose piece off		
	60	Mold repair		
	61	Graphite powdering		
Cope pattern draw	62	Cope surface cleaning		
	63	Cope face levelling		
	64	Nailing		
	65	Gating		
	66	Cope draw watering		
	67	Bolt off		
	68	Pattern draw		
	69	Loose piece off		
	70	Mold repair		
	71	Graphite powdering		
Core	72	Core cleaning		
	73	Core Setting		
Closing	74	Crane preparation		
	75	Cope roll-over & close		
	76	Clamp cope & drag		
	77	Pouring cup finish		

Inspection Seal			

No.

DAILY MELTING REPORT

Date ____________

Job classification ____________ Weather ____________

Charge Weight	Pig iron	#	Kg
		#	
	Steel Scrap		
	Gate		
	Scrap		
	Total		Kg
Refining Agents	Lime stone		Kg
	Fe - Si		
	Fe - Mn		
	Al		
	Cu		
Amount of melt			
Fuel	Coal	Lump coal	Kg
		Fine coal	
	Coke	Weight	
		Coke ratio	%
	Heavy oil		ℓ
	Charcoal		
	Kindling wood		

	Temperature	Humidity	Airpressure	Operation Start time	Blast Start time	Blast End time	Melting time	Tapping Temp.	No. of Tapping Operation	
1 st										
2 nd										
3 rd										
4 th										

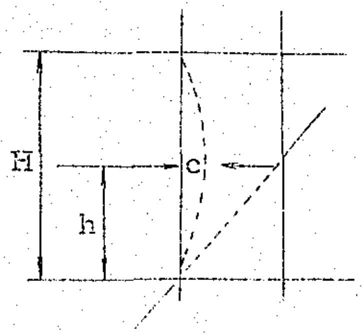
	Variation of Analysis			
	C	Si	Mn	S
Calculated Value				
In Furnace				
Rate of Increase Decrease				
Yield				

Time								
Blast pressure								
Blast temperature								
Heat exchange heat time								
Blast pressure								
Blast amount								
CO_2 (%)								

Analysis

	Slag %			Metal %						
	FeO	SiO_2	CaO	C	Si	Mn	P	S	Cr	Cu
1 st										
2 nd										
3 rd										
4 th										

In - furnace corrosion



H =
h =
c =

Melting speed (Heavy oil) ____________
(Fine coal) ____________

Amount of flno 1 2 3 4