12. Procedure

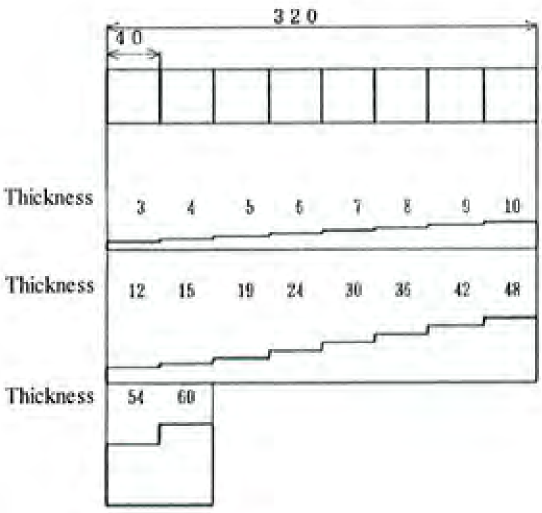
12-1 Thickness measurement

Thickness measurement is conducted to check whether the thickness of tube satisfies the thickness required (tsr)

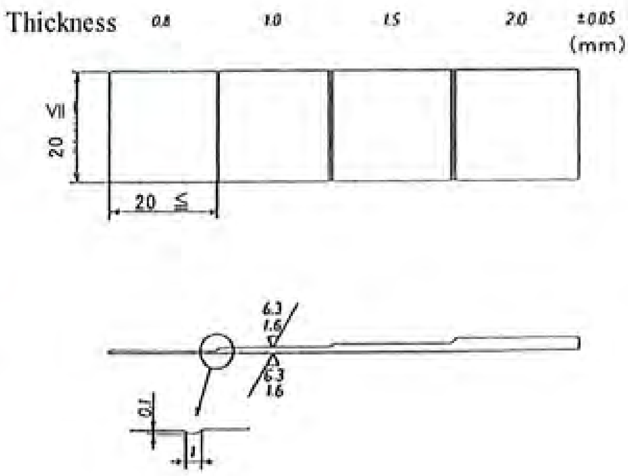
1) Detecting equipmentDMS Krautkramer Handheld Ultrasonic Thickness Gauge with A- Scan verification
   and on-board Data Recorder

2) CouplantGlycerin paste or glycerin solution with the 75% concentration or more.
3) Reference block Reference block: RB-T and RB-E (for regular interval checking and daily checking)

RB-E



RB-T



4) Selection of measurement point

Measurement point are determined by measurement purpose, object and scope etc.One representative point of each segment area divided properly (Flat plane with smooth surface)

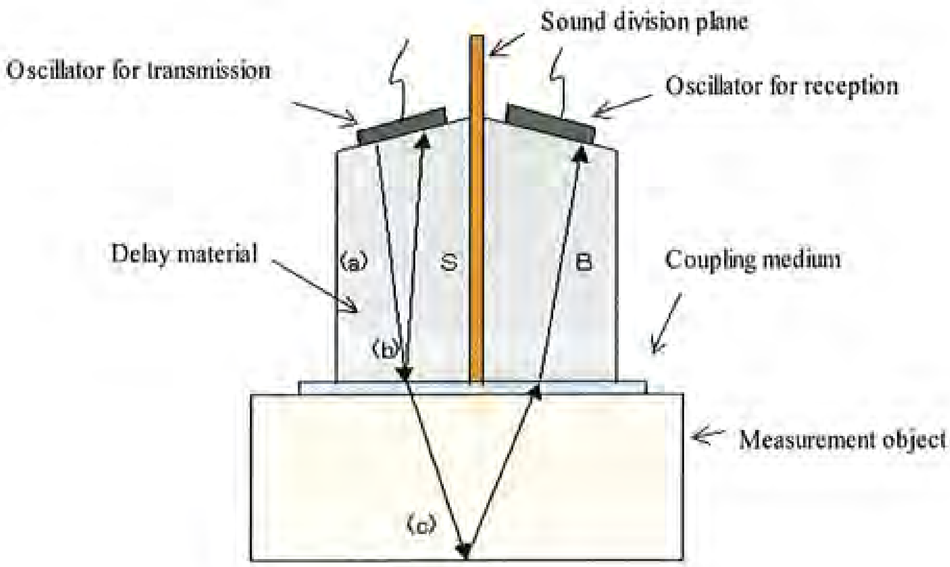
- A several representative points of each segment area divided properly. (to check partial thinning)
- Intersections in cross grid lines at appropriate spacing in measured area. (general maintenance inspection)
- Necessary point or line selected by condition of measurement object (in case of remarkable corrosion).

5) Preparation for surface conditionFinish up with wire brush or grinder removing rust and Slag.

6) Contact of probeTo get stable value, the probe contacts the object covered with couplant with appropriate pressure.

7) Measuring method for tube thickness

Double oscillator vertical probe is set at right angles with axial direction of the measurement object to get stable measurement value



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8) Acceptance Criteria

Measurement result are judged by the calculated value (tsr: thickness required) based on "Technical standards for thermal power generation facilities" and JIS B 8201 : 2005.

$tsr = (Pd/2\sigma_a + P) + 0.005d$ (JISB8201)

tsr: Minimum thickness of tube (mm)

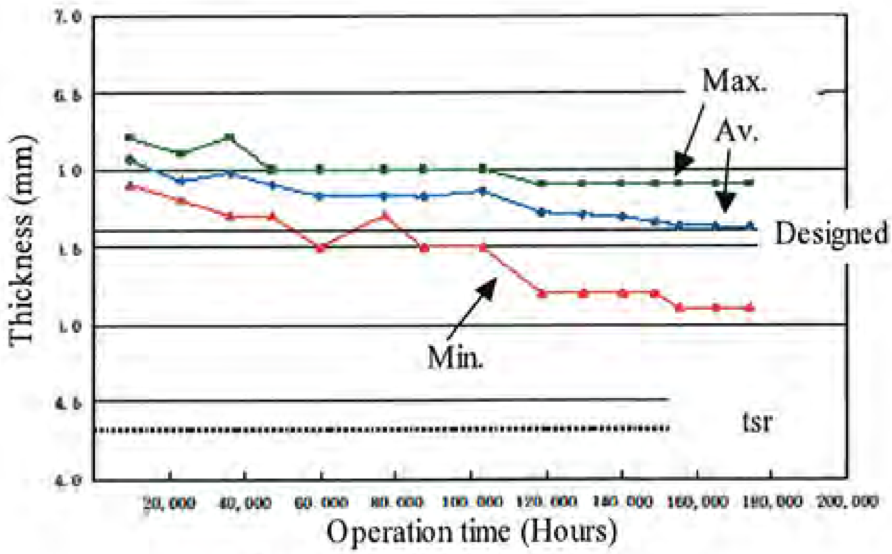
P:Maximum operating pressure(MPa)

d:Outside diameter of tube (mm)

σ_a: Allowable tensile stress of the material (N/mm^2)

9) Acceptance Criteria

Measurement results are taken into thickness trend graph, to check the thickness decrease tendency.



Example of thickness trend graph

12-2 Detection technique for scale deposition of SUS (Austenite Steel) boiler tube inside

1) Development Background

Oxide scale of austenitic stainless steel tubes used for SH tubes and RH tubes in thermal power plant during long term operation, exfoliates and chokes the inside of tube. As conventional detection method, γ-ray transmission test method is applied. However from the view point of efficiency and safety, the other method is studied without radiation utilization. This equipment which detects the magnetic scale inside of nonmagnetic tube as electrical signal based on the principle of induction makes the detection of deposit become speedy and safety.

2) Detection principle

When the magnetic field measurement apparatus is placed perpendicular to the field line of permanent magnet, no output arises in the magnetic field measurement apparatus as shown in Fig.1 (a). As the magnetic field measurement apparatus approaches to the magnetic scale, the apparent length of permanent magnet changes with the change of the field line direction through the magnetic field measurement apparatus, the detective coil make output which depends on the permeability of the magnetic scale and deposition volume Fig.1 (b).

The output of the magnetic field measurement apparatus depends on the scale deposit, since the permeability of the magnetic scale from boiler tube is considered to be almost same.

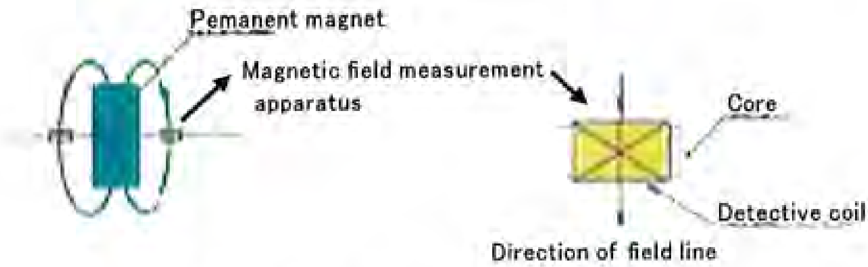


Fig.1 (a) Detection principle

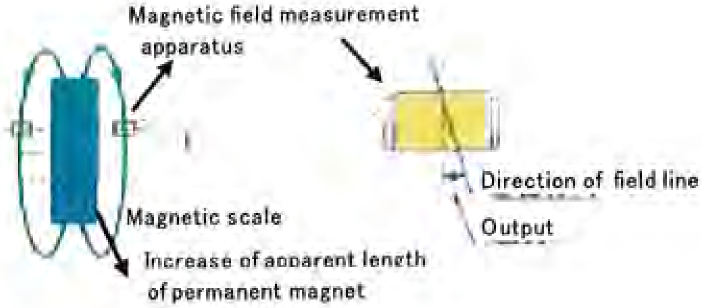


Fig.1 (b) Detection principle

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3) Measurement technique

① Primary measurement

The primary measurement is used for judging the existence of scale. The sensor are scanned the objective area touching on the downward plane of austenite steel tube.

② Precise measurement

The Precise measurement is applied to the points where the scale was detected.

By the recorded output with the sensor touching on side plane of austenite steel tube, the deposit volume is estimated with a standard curve as shown in Fig.3.

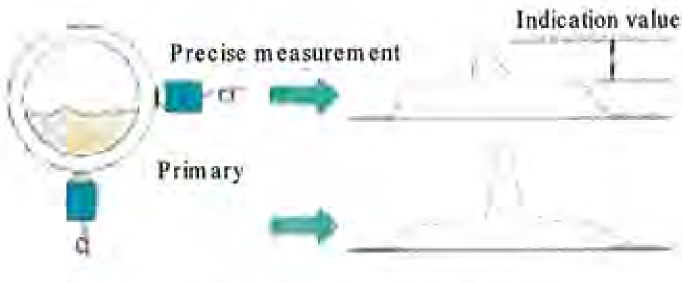

Fig.2 Measurement technique

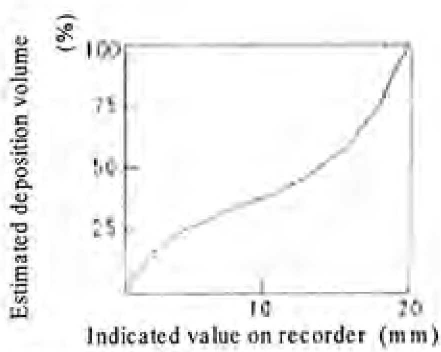

Fig.3 Example of standard curve

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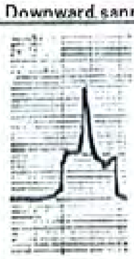
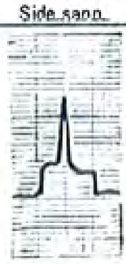
Equipment and measurement image

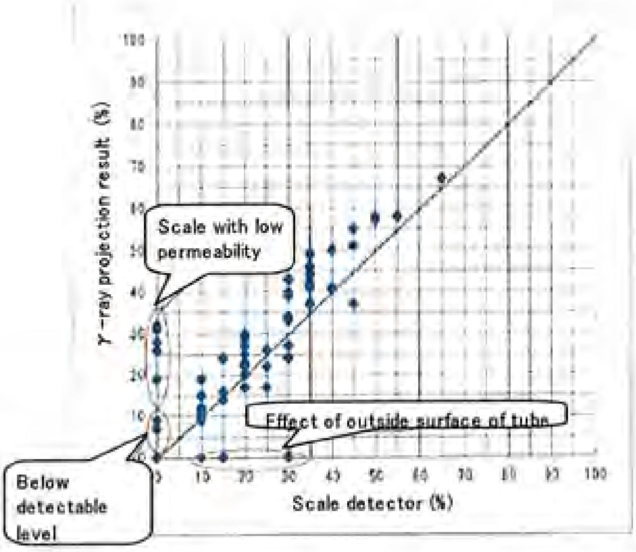
Measurement equipment

Measurement image

An example of output

No. of tube	Downward scan	Side scan
2nd SH Boiler rear #48-a Fullness 55%		

4) Comparison between γ-ray projection and scale detector results



5) Detectable level

The evaluation of scale detector indicates the proportion of the scale deposit to inside cross section of the tube with the detectable level ≧ 10%.

6) Effect of outside surface of tube

In some case, scale detector indicates a suspected signal because of the effect of magnetic scale on the tube outside and local magnetization of the tube.

Suspected signals require to be confirmed by γ-ray detection, because of difficulty in distinguishing these signals from scale deposition signal by scale detector.

7) Scale with low permeability

Scale deposit is estimated by scale detector based on the condition that the deposit scale permeability is same as reference scale. So, the deposit scale with lower permeability than one of reference scale is not detected occasionally.

As the scale with low permeability, austenitic stainless steel tips by cutting and limescale etc. are considered.

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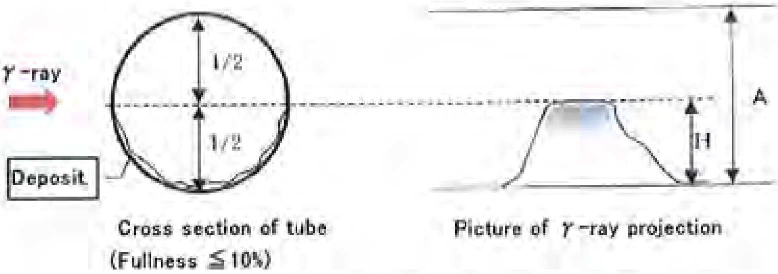
8) The dependence of evaluated value by γ-ray detection and scale detector on the difference of deposition condition.

The evaluation by scale detector indicates the proportion of the scale deposit to inside cross section of the tube. On the contrary the evaluation by γ-ray detection indicates the height of the scale deposit.

In case of the deposition condition shown in Fig.4, the evaluated value by γ-ray detection is 50% fullness, while by scale detector is no deposition.

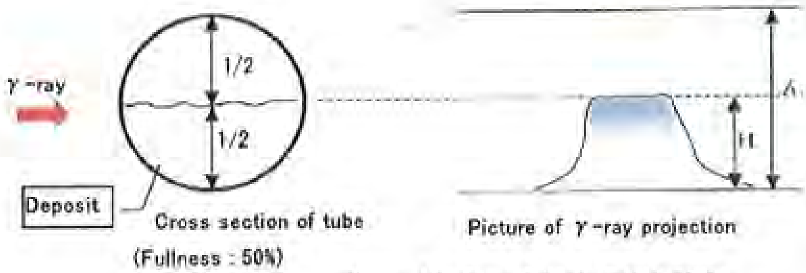
In case of the deposition condition shown in Fig.5, the evaluated value by γ-ray detection is same as scale detector.



γ-ray detection: fullness = H/A =50%
Scale detector: no deposition

A: Diameter of tube inside
H: Height of deposit scale

Fig.4 Diposit condition that the fullness is overestimate by γ-ray detection.



γ-ray detection: fullness = H/A =50%
Scale detector: fullness=50%

Fig.5 Diposit condition that the fullness evaluated by scale detector is same as γ-ray detection.

9) Confirmation of scale deposition

It is preferable to apply γ-ray detection besides scale detector, in order to recognize the effect of the outside surface of tube and the existence of the scale with low permeability.

Sampling inspection by γ-ray detection will improve the clarification of scale deposition.

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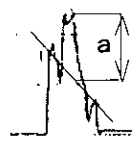
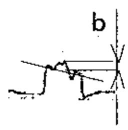
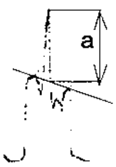
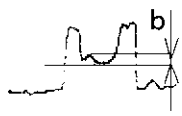
<u>Measurement procedure of SUS scale detection technique</u>
<u>in case of magnetization of austenitic tube materials.</u>

1. Primary measurement (Scanning from bottom surface)
   - ・Connecting the points at which are considered to be no deposit as a base line. (scanning start point and scanning end point)
   - ・Read the diffrence "a" between the base line and peak value.
     Scanning start point: Horizontal tube point, Scanning end point: Vertical tube point
     Table 1 and Fig.1 as reference
   - ・If the read value "a" is less than 10% that is detectable limit in scanning from bottom surface, the fullness is taken as 0% fullness
   - ・If the read value "a" is 10% or more in scanning from bottom surface, the fullness is estimated by precise measurement.

2. Precise measurement (Scanning from side surface)
   - ・Connecting the points at which are considered to be no deposit as a base line. (scanning start point and scanning end point)
   - ・Read the diffrence "b" between the base line and peak value.
     Scanning start point: Horizontal tube point, Scanning end point: Vertical tube point
     Table 1 and Fig.1 as reference
   - ・The fullness is estimated with the read value "b" and a standard curve.

The γ-ray detection is recommend for confirmation since the precision of estimation in magnetized tube is considered to get worce than in no magnetized case.

Table 1

Location	SINGURAULI Final SH #14 panel at bend portion of frontside	
	Scanning from bottom surface	Scanning from side surface
Fullness 15%		
Location	UNCHAHAR Final SH #27 panel at bend portion of rearside	
	Scanning from bottom surface	Scanning from side surface
Fullness 15%		

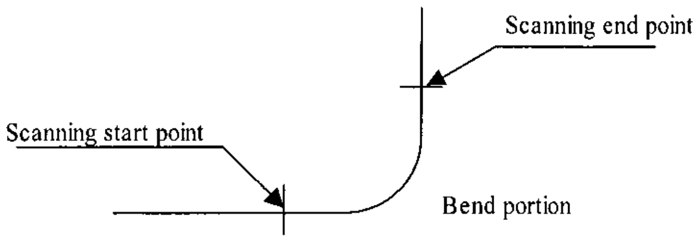
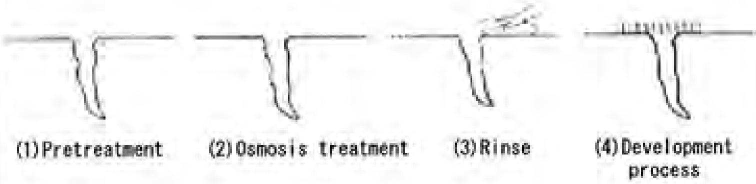


Fig..1

12-3 PT (Liquid Panetrant Testing)

Liquid Panetrant Testing is a method to detect cracking of the surface and blowholes, using a red or fluorescent inspection liquid with high permeability. This technique is widely applied to metallic and non-metallic materials because of the detectability for the opening cracks on the surface.



Principles of liquid panetrant testing method

Process			Content
Pretreatment			Remove oil and dirt on the surface using cleaning agents with the defect opnening, then dry thoroughly.
Osmosis treatment			Penetrant is painted on the surface. Keep for 5 to 60 minutes, so that penetrant penetrates enough into the defect.
Removal / cleaning process			Penetrant on the surface is removed with dry waste cloth. Then wiped up with moisturized cloth.
Development process			Developing powder is coated on the surface with a thin and uniform coating, after stirring developing powder spray sufficiently. Development time is usually 10 to 30 minutes.
Observation			Observe the surface of test material in a bright place. Crack (flaw) appears as red indication on a white background.

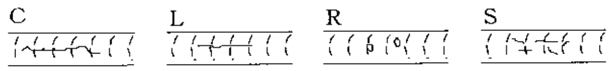
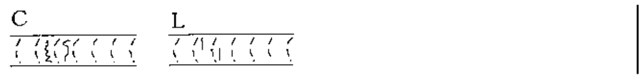
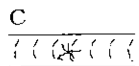
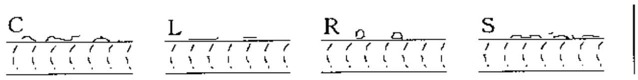
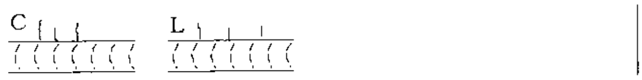
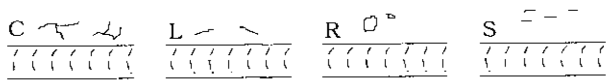
1) Classification of penetrant indication and Classification by the position and direction in weld.

Based on JIS Z 2343-1:2005 「Non-destructive testing—Penetrant testing—Part 1 : General principles—Method for liquid penetrant testing and classification of the penetrant indication」

*Classification of the penetrant indication

Classification of the penetrant indication		Mark	Definition
Isolated penetrant indication	Indication by cracking	C	Indication by cracking
	Indication with linear pattern	L	Indication in length more than 3 times as width except for cracking
	Indication with circular pattern	R	Non linear indication except for cracking
Continuous penetrant indication		F	A number of indication exisisting on a line
Dispersed penetrant indication		S	A number of indication exisisting in a constant area

*Classification by the position and the direction in weld

Position and direction of penetrant indication	Mark	illustration (C, L, R , S in figures show classification of the penetrant indication
Longitudinal direction along weld line	A	
Horizontal direction perpendicular to weld line	B	
In weld metal	X	
Longitudinal direction along HAZ line	C	
Horizontal direction perpendicular to HAZ line	D	
In Base metal	E	

8 x 2 F : More than 2 indications with 8mm in length on a line

(0．5) : 0.5mm depth of flaw

2) Criteria for indication by "Technical standards for thermal power generation facilities"

Based on JIS Z 2343-1:2005 「Non-destructive testing—Penetrant testing—Part 1 : General principles—Method for liquid penetrant testing and classification of the penetrant indication」

- No penetrant indication by crack
- No linear penetrant indication and indication by linear flaw with longer than 1mm in length.
- No circular penetrant indication and indication by circular flaw with longer than 4mm in length.
- In case of 4 or more circular penetrant indications or circular indications by circular flaw located in a line, the spacing between adjacent indications needs to be longer than 1.5mm.
- No more than 10 or more circular penetrant indications or circular indications by circular flaw are included within the rectangular area of 3750mm^2(short side length is longer than 25mm)

12-4 UT (Ultrasonic testing)

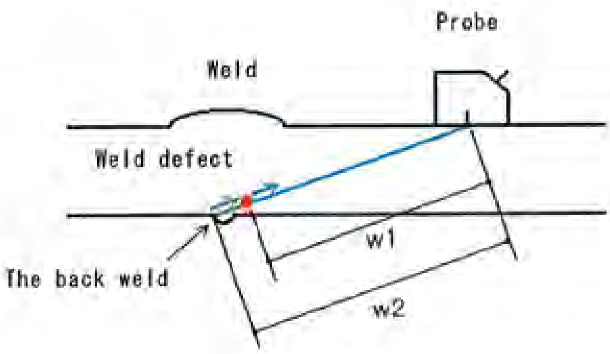
Radiographic testing and ultrasonic testing are the typical nondestructive testing that inspects the inside of weld of tubes and pipes. In general, when setting Radiographic film is difficult, the ultrasonic testing is applied.

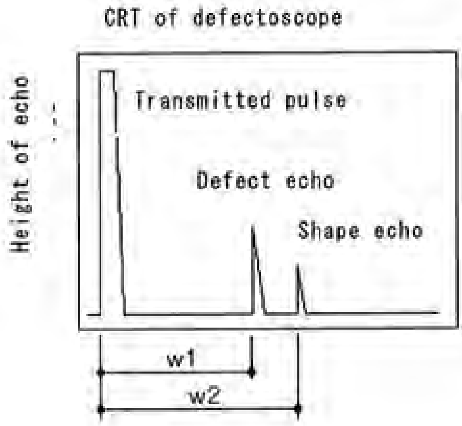
1) Detecting equipment and Couplant

- Detecting equipment :DSM35 Krautkramer Universal UltrasonicFlaw Detector
- Couplant: Glycerin paste or glycerin solution with the 75% concentration or more.

2) Principle of ultrasonic testing (UT)

As for the butt-weld joint, "angle beam method" is usually applied because of weld reinforcement.





3) Calculation of defect position

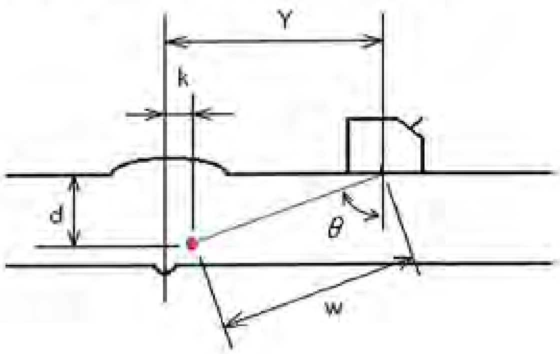
Y can be measured with the scale and W can be read from CRT.

The position of the defect can be calculated by the following formula.

$d = W \times \cos\theta$, $k = Y - W \times \sin\theta$

θ (angle of refraction) is measured beforehand,

usually using nominal value 40,45,60,65,70.

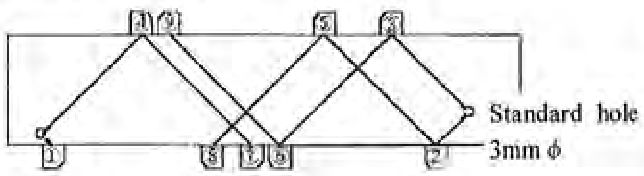


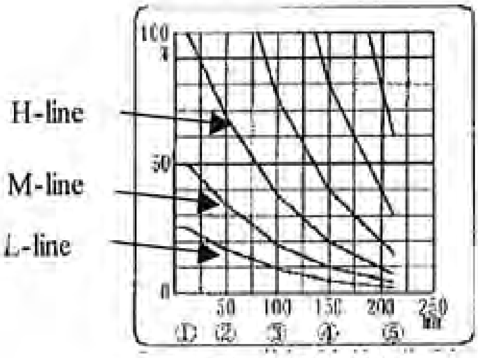
4) Distinction of defect and measurement of echo height

The echo that appears on CRT is judged whether a defect or not (shape echo) from the reflection source and the echo height. The reflection source is calculated from d and k in equations. If it is located in the weld, the echo is judged to come from a weld defect.

The H-line is defined by linking the heights of the echo on CRT that reflects at the drilled hole with 3mm in the diameter of reference test block RB41. M -line is a half of H-line (-6db), L -line is a quarter of the height of H-line (-12db). These lines are called as "Dividing curves of echo height "That is made before flaw detection. The echo that exceeds L line in this echo height area during scanning the probe for flaw detection is judged to be a defect based on L line .

Reference test block RB-41

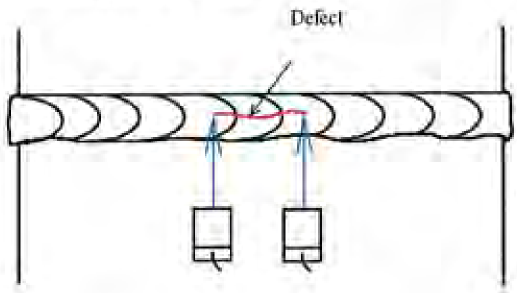


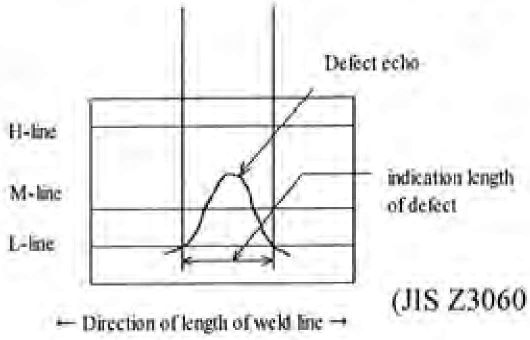


(JIS Z3060:2002)

5) Measurement of length of defect

The range that exceeds L line during scanning the probe along the direction of the weld line is defined as "the indication length of defect".





(JIS Z3060:2002)

6) Classification of flaw

Echo height area and classification of flaw by indication length of flaw

Area / thickness (t) / Classification	Ⅲ in case of level M detection Ⅱ and Ⅲ in case of level L detection			Ⅳ		
	18 ≦t	18 <t≦ 60	60 <t	18 ≦t	18 <t≦ 60	60 <t
The first class	≦ 6	≦ t/3	≦ 20	≦ 4	≦ t/4	≦ 15
The second class	≦ 9	≦ t/2	≦ 30	≦ 6	≦ t/3	≦ 20
The third class	≦ 18	≦ t	≦ 60	≦ 9	≦ t/2	≦ 30
The fourth class	The one exceeding the third class					

JIS Z3060:2002

from appendix 7 of examining ultrasonic wave of welded steel joint

7) Acceptance Criteria

To satisfy either of the following ① or ②

①Height of the reflected wave from the flaw in the weld on CRT must be below the height of reflected wave from the reference hole corrected by the probe to flaw distance.

②The length of the flaw from which the height of the reflected wave on CRT beyond the height of reflected wave from the reference hole corrected by probe to flaw distance, must be the value or less as shown below.

*Based on Technical standards for thermal power generation facilities.

12-5 TOFD (Time of Flight Diffraction) Inspection

1) General Description

①Scope

This procedure is applied to TOFD flaw detection testing for the butt weld of plates.

② Reference

- NDIS 2423-2001 "Method of Measuring Defect Height by using TOFD Technique"
- ASME Sec.V article4 AppendixⅢ

③ Test engineer

Engineers engaged in ultrasonic testing, was certified by the Association of Non-Destructive Inspection "ultrasonic test level 2 or level 3 technician". The evaluation is conducted by a "level 3 technician ".

2) Testing equipment and materials

① Detecting equipment

μ -Tomoscan(R/D Tech)is used. Detecting equipment satisfies the following conditions.

- Amplitude linearity: Amplitude linearity is within ±3% based on JIS Z 2352 4.1.
- Time scale linearity: Time scale linearity is within ±1% of full scale based on JIS Z 2352 4.2.

② Transducers and Wedges

Transducers for transmission and receiver are the longitudinal wave angle beam probe with the same performance, then selected from the follows.

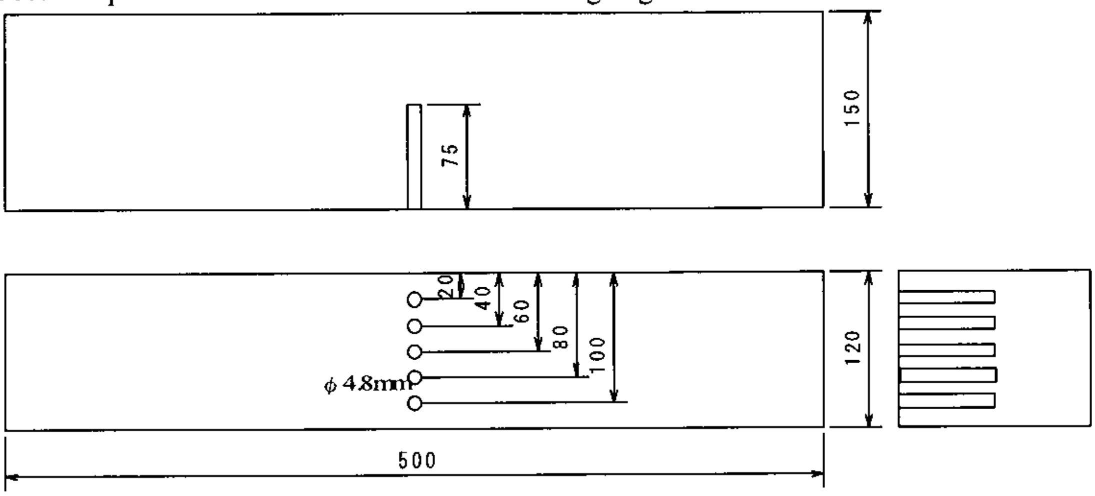
- Wave frequency: 2～10MHz
- Resonator dimensions: 0.25in～0.5in
- Wedges: the longitudinal wave angle 45° or 60°

③ Couplant

Glycerin paste or glycerin solution with the 75% concentration or more is used.

④ Test sample

Test sample used is described in the following Figure.



Test sample shape and dimension

3) Preparation for test

① Surface conditioning for test

Floating scale on the surface, significant corrosion and painting that prevent the ultrasonic wave from propagation are removed.

② Flaw detection for base metal

The vertical flaw detection for the base metal in which the ultrasonic wave pass through is conducted in advance as needed to ensure that there is no flaw to hinder the detection.

③ Selection of transducers and transducers spacing

TOFD transducers and transducer spacing are selected taking into account of the thickness of the specimen. In case of thick specimen, the flaw is detected at each divided area in depth.

Examples for detection of the sample 25mm thick and 90mm thick are shown in Table below.

Typical configuration example of TOFD transducers

Thickness of sample (mm)	Number of pair of transducers	Center wave frequency (MHz)	Dimension of transducers (mm)	Nominal refractive angle (°)	Transducers spacing (mm)
25	1 pair	5～10	2～6	60	58
90	2 pairs	5～10	2～6	60	69
		2～5	6～12	45	140

④ Sensitivity of detection

The sensitivity of detector is adjusted at the 80% of echo height from the horizontal cave that is the lowest echo. Also the noise level is kept at lower than 5 to 10%.

⑤ Adjustment of scanning equipment

The scanning equipment is adjusted to keep the transducer in a good acoustic coupling with the detected surface.

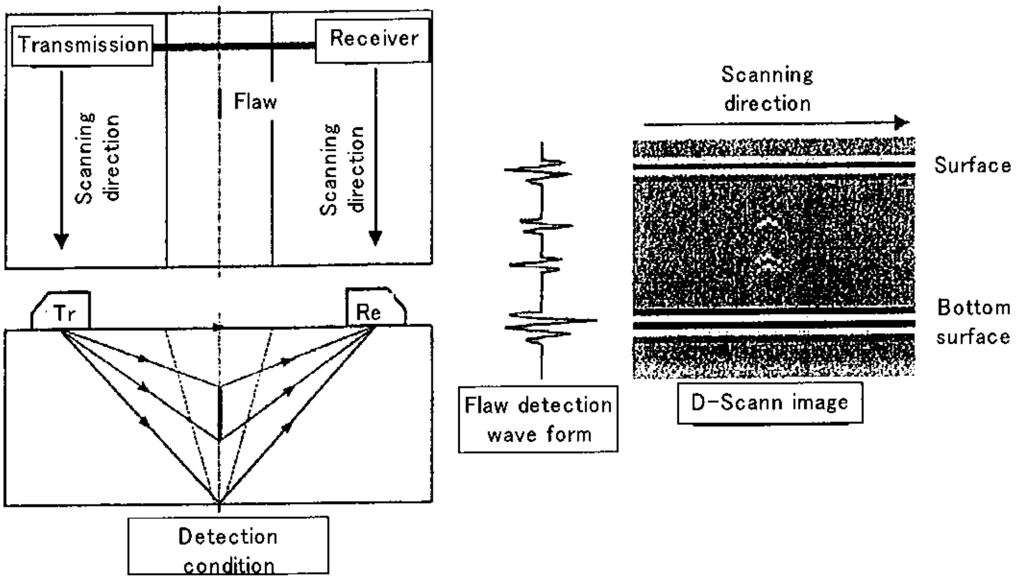
⑥ Timing of adjustment and inspection for equipment

Adjustment and inspection of equipment is conducted at the start of work and within each eight hours working.

4) Flaw detection

The flaw detection from the one surface side is ordinal, the flaw detection from the other surface is conducted, if necessary.

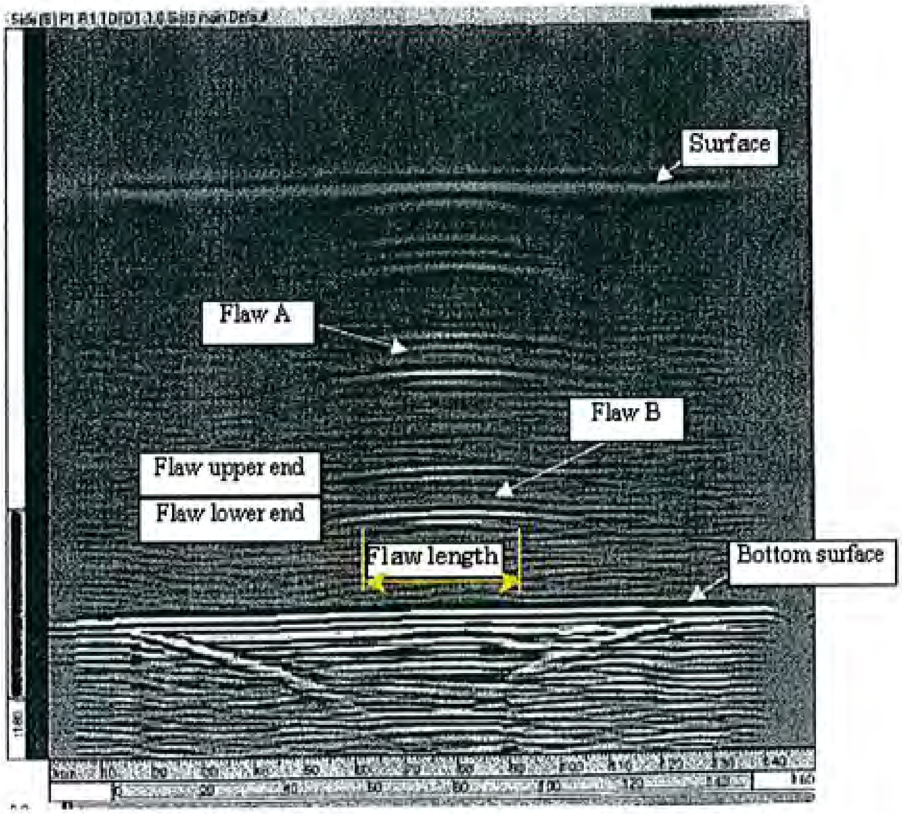
The pair of transducers across the weld line is manually scanned in the direction parallel to the weld line, as shown in the figure below. During scanning, the status of coupling is checked with the lateral or bottom reflected waves. The range of flaw to detect is within the extent to 1 inch(25.4mm) away from weld potion.



Detection method

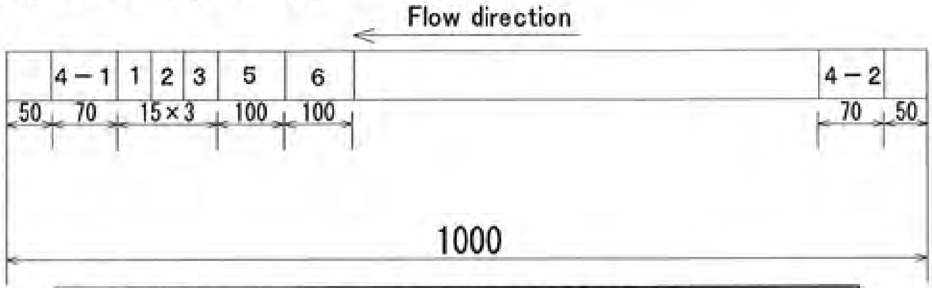
5) Evaluation

Evaluation of flaw (depth, length and height)is conducted by D-scan image. An example of flaw image by D-scan is shown below.



An example of flaw image

12-6 Sample tube inspection 1) Examination items



1： Scale thickness on inner surface of tube・Microstructure
2： Hardness
3： Tube Dimension
4－1： Scale volume on inner surface of tube (upper side)
Observation of scale surface
4－2： Scale volume on inner surface of tube (under side)
5： Scale composition ・Appearance of tube
6： Preservation

2) Tube appearance observation

Cutting the tube — 100 mm in length

↓

Acid cleaning

Dissolute in the acid solution
H_2O.........77.6 ml
HCl.........22.2 ml (8%)
Inhibitor......0.2 ml (2%)
at 60±5℃ for 1～2Hr

or

Dissolute in the ammonia solution
H_2O......58.8 ml
HCl.........40 ml (10%)
H_2O_2 ...1.2 ml (1.2%)
40 ~ 50 ℃ for 60 to 90 minutes
(until Cu is removed.)

↓

Observation

Appearance of fireside of tube outside

As received — After acid cleaning

Appearance of fireside of tube inside

As received — After acid cleaning

3) Tube Dimension Measurement

Cutting the tube — 12～18mm in thickness

↓

Acid cleaning — hydrochloric acid ammonia solution
HCL(35%) …29ml
Inhibitor………1ml (60±5℃)

or

Ammonia (28%) …16ml
Bromine acid soda…… 1 g
Bicarbonate of ammonium 1.2g
(room temperature)

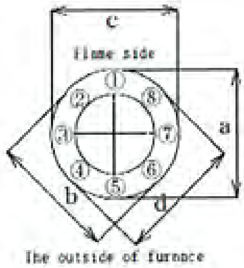
↓

Grinding — # 80 → # 600 waterproof SiC paper

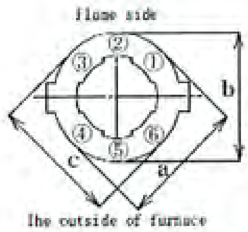
↓

Measurement

- Comparison with designed dimension
- Local thinning (High temperature corrosion, local corrosion
- Deformation (Bulging)



a～d:Outside diameter
①～⑧:Thickness



a～c: Outside diameter
①～⑥: Thickness 4

4) Hardness measurement

Cutting the tube

↓ 12～18mm in thickness

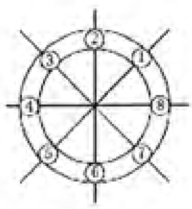
Grinding

↓ # 80 → # 600 water proof SiC paper

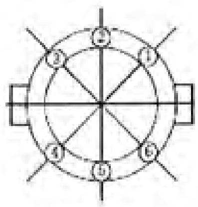
Measurement

Vickers hardness test
or
Rockwell hardness test

- Comparison with virgin material data



No fin tube



:Fin tube

Average of 3 times measurement for each points

5) Scale composition analysis

Cutting the tube — 100 mm in length

↓

Dissolution of scale on inside surface

Dissolute in the acid solution
- H_2O.........77.6 ml
- HCl.........22.2 ml (8%)
- Inhibitor......0.2 ml (2%)
- at 60±5℃ for 1～2Hr

or

Dissolute in the ammonia solution
- H_2O......58.8 ml
- HCl.........40 ml (10%)
- H_2O_2 ...1.2 ml (1.2%)
- 40 ~ 50 ℃ for 60 to 90 minutes
- (until Cu is removed.)

↓

Evaporation to dryness

↓

Dissolution in the acid solution for chemical analysis

Dissolute in the acid solution HCl 10cc, before HNO_3 10cc

for Atomic Absorption Spectrometry analysis

↓

Atomic Absorption Spectrometry analysis

Analysis elements

Fe, Cu, Ni, Mn, Zn, Al

Fe_3O_4 : Fe=1.38 : 1 ∴ Fe_3O_4=Fe×1.38

CuO=Cu×1.25, NiO=Ni×1.27, MnO=Mn×1.29,

ZnO=Zn×1.24, Al_2O_3=Al×1.89

6) Scale adhesion volume

Cutting the tube — 70 mm in length

↓

Removal of slag on outside surface with grinder

↓

Cutting the tube into furnace inside and outside

↓

Weight measurement with electronic balance

↓

Removal of scale with electrical polishing

Electrolyte composition (10%sulfate)
- Sulfate(H_2SO_4 (98%) 85 ml
- Inhibitor......8 ml (2%)
- Thiourea (CSN2H4) 30g
- Distilled water

Total 1500ml

↓

Measurement of weight loss with electronic balance

Scale weight of unit area mg/cm2

7) Scale observation

Cutting the tube — 12～18mm in thickness

↓

Mounting — Cold mounting with epoxy resins or acrylic resins

↓

Grinding — # 80 → # 1500 water proof SiC paper

↓

Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μm→0.1 μm.

↓

Scale observation

Scale on water wall tube inside

Scale on SH tube inside

The area at which the scale thickness is measured at fire side is observed with optical microscope ×100～×200 in magnification

Cutting the tube — 12～18mm in thickness

↓

Mounting — Cold mounting with epoxy resins or acrylic resins

↓

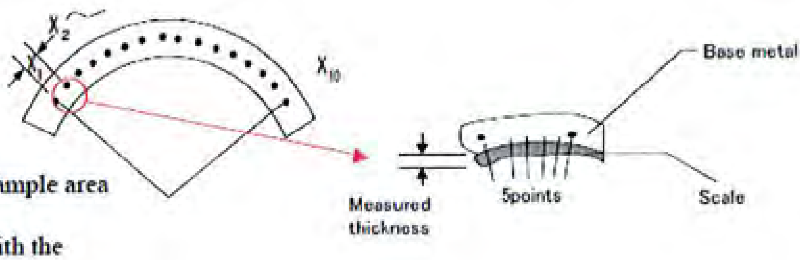
Grinding — # 80 → # 1500 water proof SiC paper

↓

Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μm→0.1 μm.

↓

Scale thickness measurement

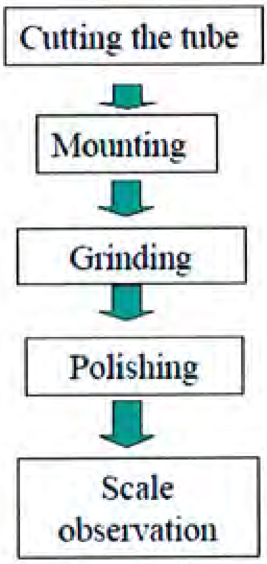


- Average thickness in 90° (180°) of sample area
- Maximum thickness of scale
- Scale conversion rate (Combined with the results of scale volume)

  Scale conversion rate = μm／mg・cm²

585

9) Microstructural observation



12～18mm in thickness

Cold mounting with epoxy resins or acrylic resins

80 → # 1500 water proof SiC paper

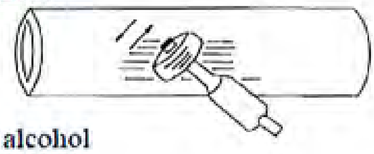
Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.

The area at fire side is observed with optical microscope ×100, ×400 in magnification

12-7 Sampling of replica and extracted replica

1) Degradation factor to be evaluated

Grinding — Grinding with handy flexible grinder wheel until #120 roughness



↓

Fine grinding — Grinding with PVA (polyvinyl alcohol (PVA)-based porous elastic grinding wheel until #60 ~#1000 roughness

↓

Polishing — Polishing with 3 μm ~0.25 μm diamond particles.

↓

Chemical etching — **Etchant**

For carbon steel.low alloy steel :

Nital (Ethanol 100ml + 2~5ml HNO_3)

For Austenitic alloy steel:

Villella's solution (Ethanol 94ml+ HCl 5ml + picric acid 1g)

↓

Drying — Wash out the etchant with ethanol and dry with air spray.

↓

Replica sampling — Stick a replica film on dropping the methyl acetate.
Take off the replica film after drying out, paste it on a slide glass.

→ **OM, SEM observation**

↓

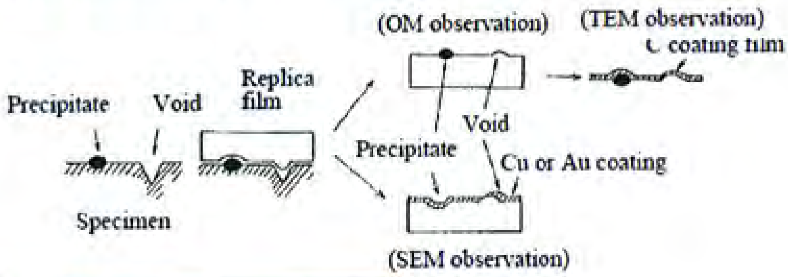
Polishing — Polishing again with 1 μm diamond particles.

↓

Chemical etching

↓

Extracted Replica sampling



→ **TEM observation**

12-8 Boiler remaining life assessment technique

1) Degradation factor to be evaluated

Creep rupture remaining life (Designed temperature beyond 450℃)

2) Components to be evaluated Furnace evaporation header

- Super heater header or Main steam pipe
- Reheater header or High temperature reheat pipe

Representative points among high heat loaded and high stressed portion in these components

3) Method to assess the remaining life

More than one method used as shown in table below.

In this study, microstructural comparison method is applied.

Method	Guideline		This study	
	Base metal	Weld (HAZ)	Base metal	Weld (HAZ)
Hardness measuring	—	O		
Electrical resisitance	—	O		
Chemical composition of carbide	O	O		
Creep cavity evaluation	—	O		
Microstructural comparison	O	O	O	O
Urtra sonic scattering noise	—	O		
Interparticle spacing	O	—		
Crystal grain deformation	O	—		
Destructive test	O	O		
Analytical method	O	O		

O : applicable, − : not applicable

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4) Effective (countable) remaining life

1/ 2 of remaining life evaluated by above methods

5) Microstructural comparison method outline

Remaining life synthetically evaluated by three types of damage related to the creep damage ratio as shown below.

【Base metal】

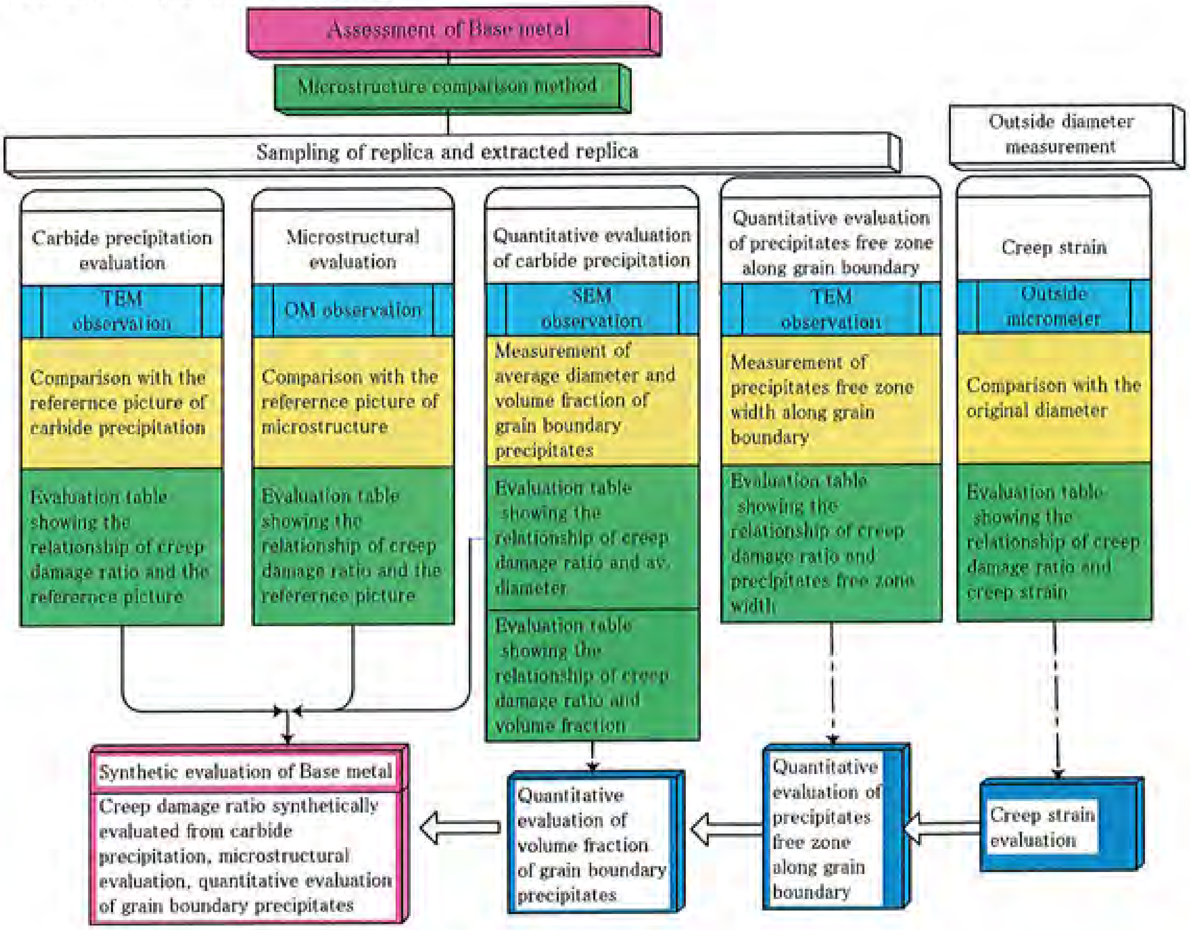
- Evaluation of average diameter of grain boundary precipitates
- Comparison with the reference picture of microstructure
- Comparison with the reference picture of carbide precipitation

【Weld metal】

- Comparison with the reference picture of creep void and micro crack
- Comparison with the reference picture of microstructure
- Comparison with the reference picture of carbide precipitation

6) Microstructural comparison method in this study

【Evaluation flow for base metal】



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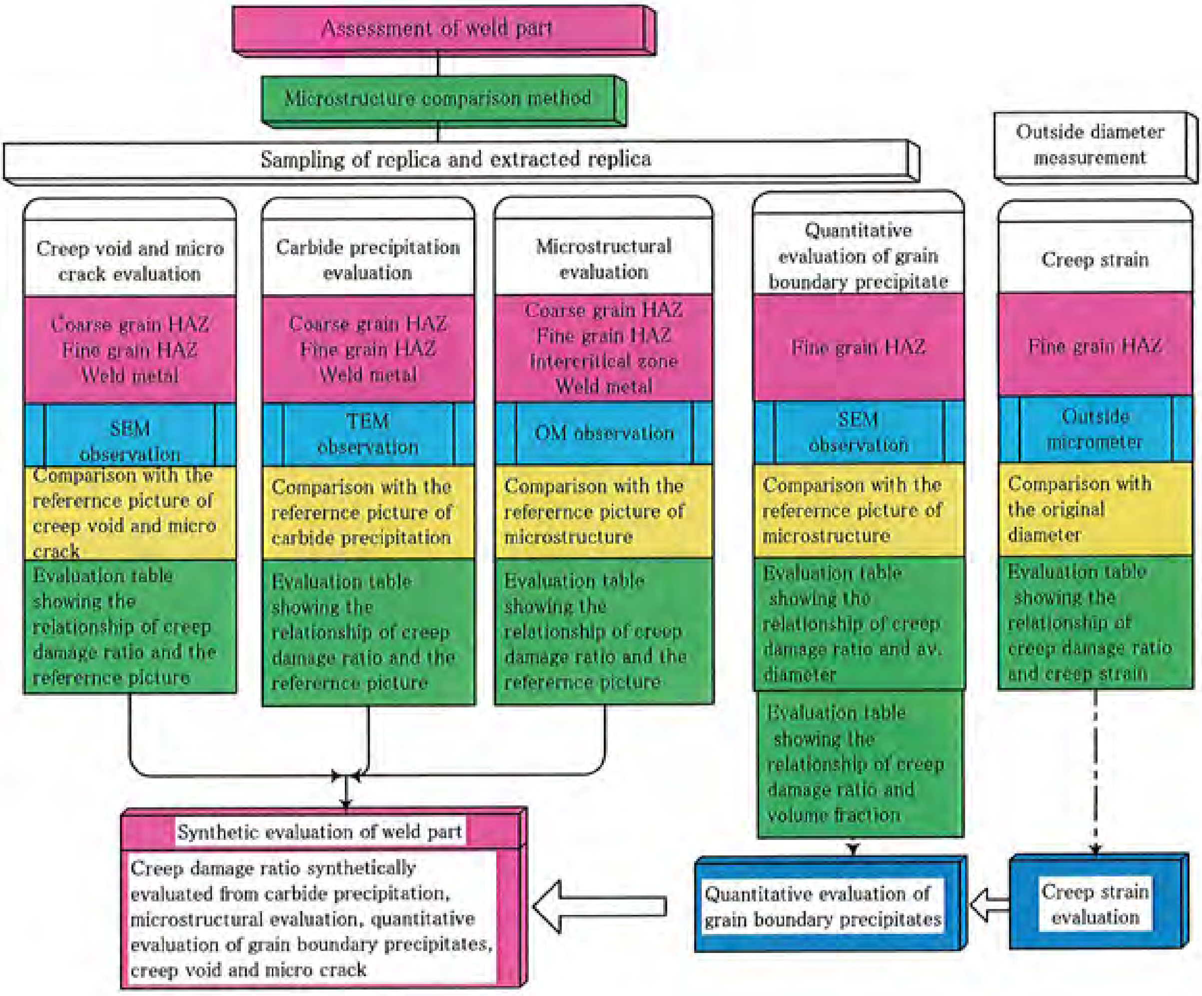
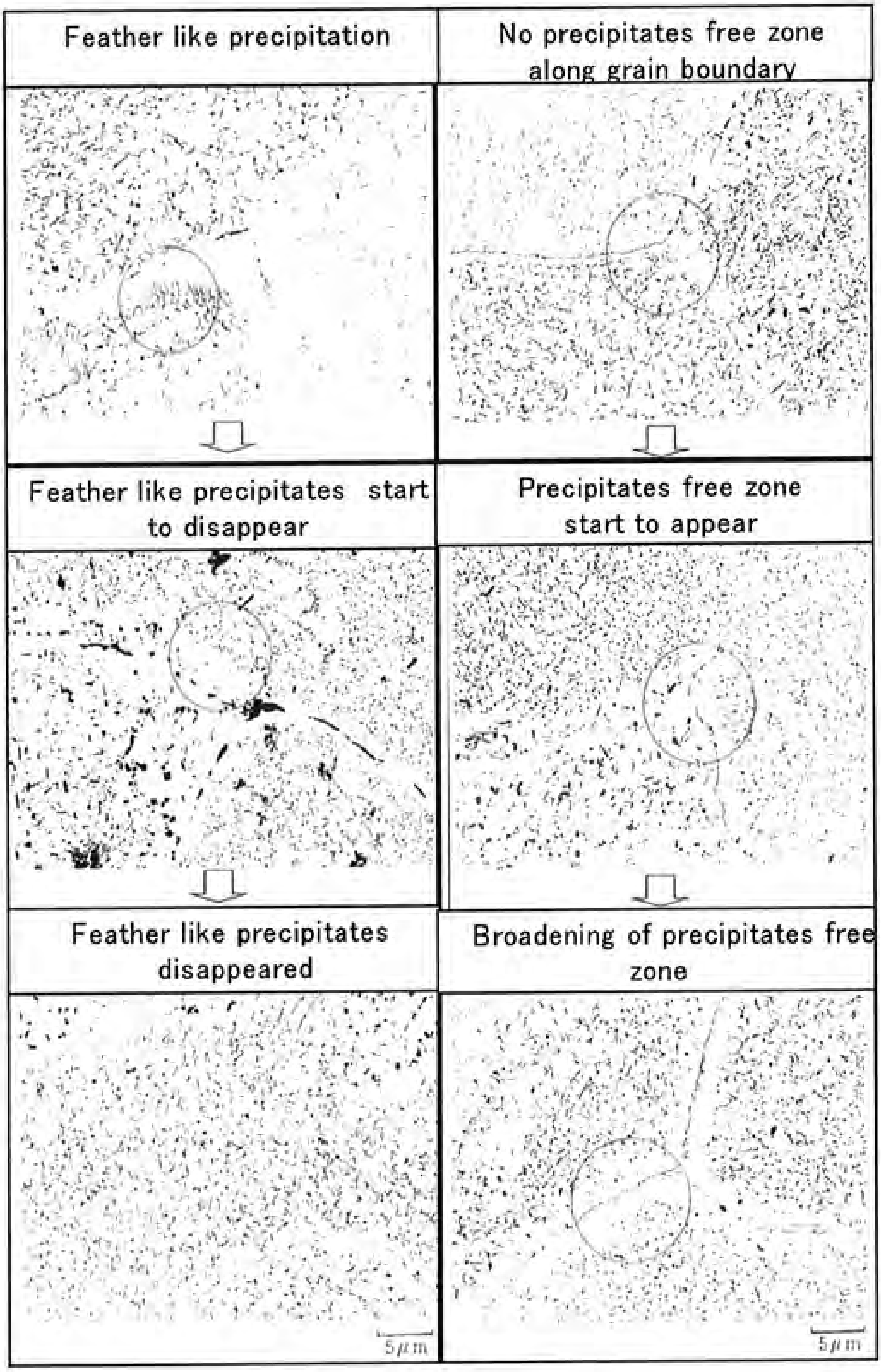
【Evaluation flow for weld part】



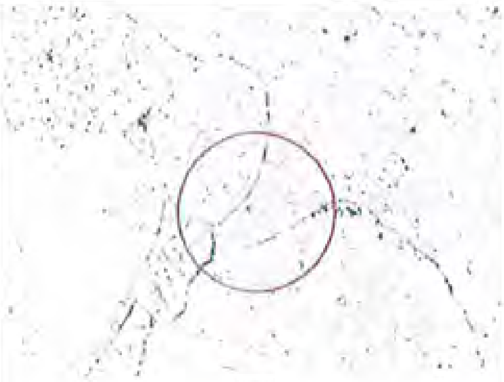
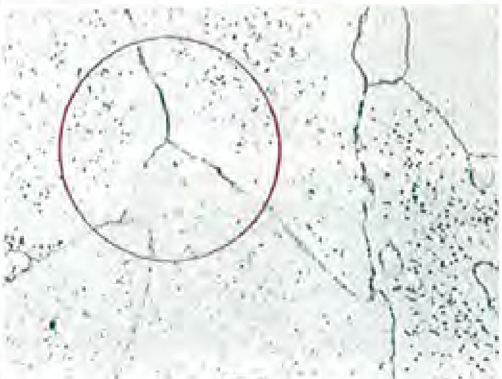
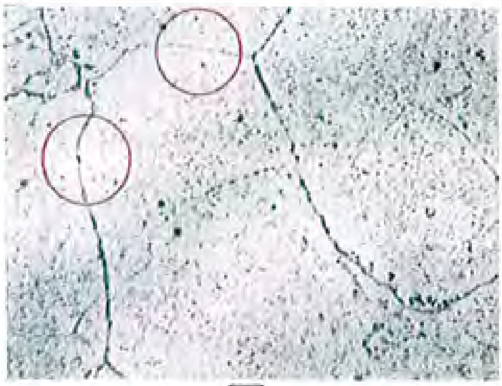
069

【Example of reference picture of carbide precipitation evaluation】



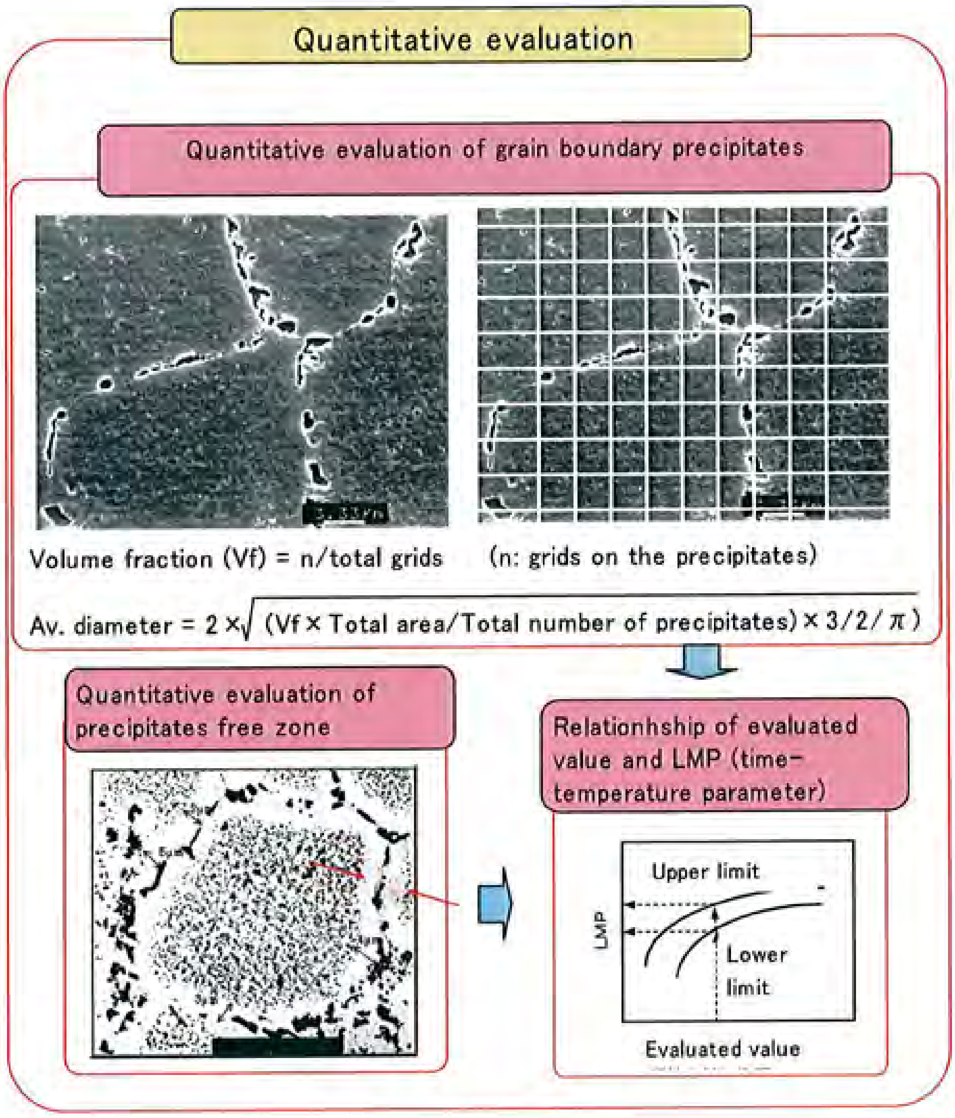
【Example of reference picture of microstructural evaluation】

×1000

No precipitates along grain boundary	No precipitates free band along grain boundary
	
Precipitates appears along grain boundary	Precipitates free band appears along grain boundary
	
Grown precipitates along grain boundary	Significant precipitates free band along grain boundary
	

【Example of quantitative evaluation】

- Evaluation of average diameter of grain boundary precipitates
- Evaluation of volume fraction of grain boundary precipitates
- Evaluation of width of precipitates free zone along grain boundary



【Procedure for microstructural change related to creep damage ratio】

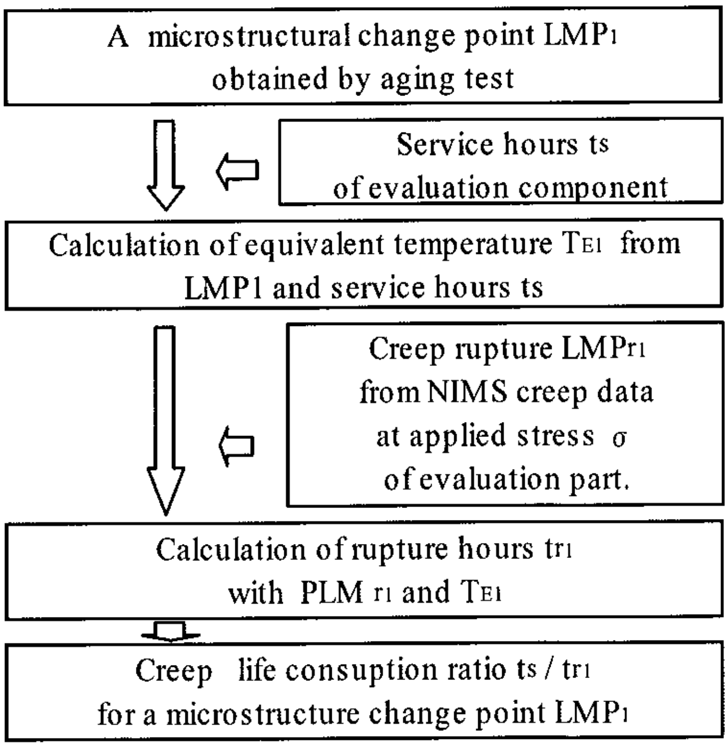
Change of microstructure, carbide precipitation including grain boundary precipitates and precipitates free zone along grain boundary, is considered to be a kind of the degradation by keeping at high temperature environment for a long time without.the effect of stress.

This kind of degradation can be related to Time-Temperature Parameter, such as LMP (Larson-Miller parameter).

LMP corresponding to change points of reference pictures were obtained by aging test in the laboratory test. Comparing replica observation results with the reference pictures, LMP1 value corresponding to replica observation results can be obtained.

The equivalent temperature can be calculated from LMP1 value and operation hours.

Creep damage (creep life consumption) ratio is obtained from calculated equivalent temperature , applied stress, operation hours and creep rupture data of the virgin material.



$LMP=(273+T)(C+\log t)$, T:temperature, t: time

【Example of creep strain evaluation and creep void and micro crack evaluation】

Creep strain, creep void and micro crack are considered to be a kind of the direct damage by creep. These items are related directly to Creep damage ratio.

Creep strain evaluaton

【Example of the relationship between creep damage ratio and creep strain ε】

Creep strain ε＜1.0%	: 0～70%
Creep strain 1.0%≦ ε ≦2.0%	: 50～80%
Creep strain ε ≧2.0%	: 70～100%

Reference picture of creep void and micro crack

Grade	×1600	
1	——	No void
2		Isolated void
3		A number of voids on grain boundary
4		Chained voids to micro crack
5		Macro crack beyond 50 μm

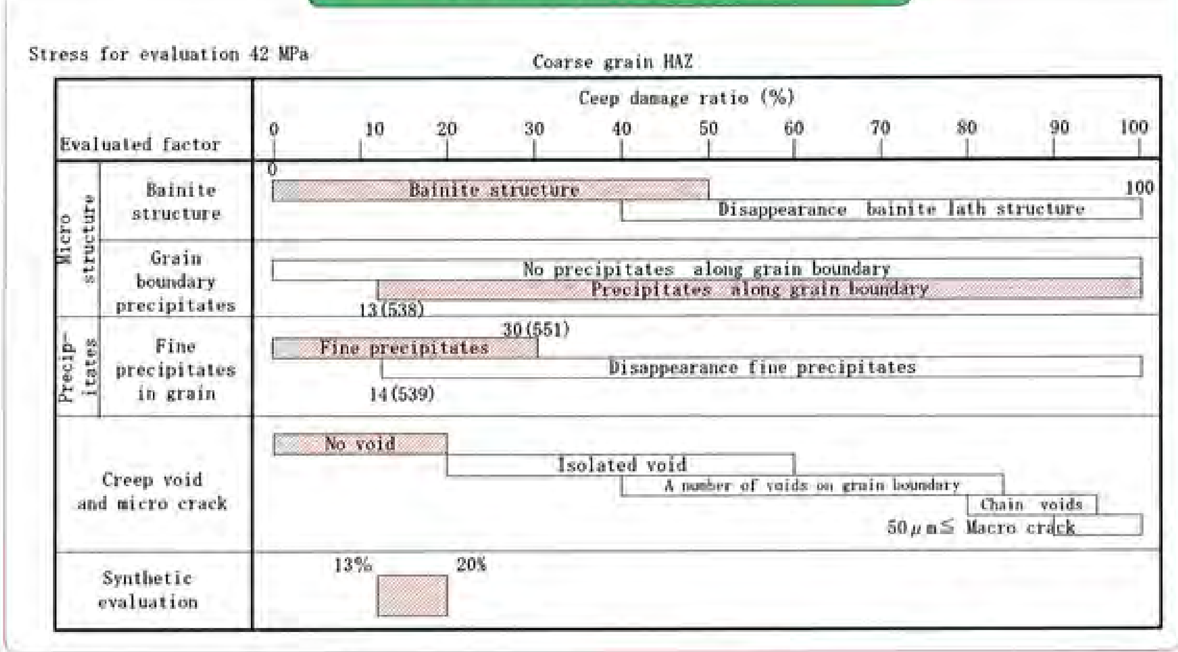
↕stress

【Synthetic evaluation】

Creep damage ratio is finally determined from these evaluated items for each area such as base metal, fine grain HAZ, coarse grain HAZ.

In the range of creep damage ratio below 60%, microstructure, carbide precipitation including grain boundary precipitates and precipitates free zone along grain boundary are effective for evaluation. In the range of creep damage ratio 60% or more, creep strain, creep void and micro crack related to creep rupture directly are effective.

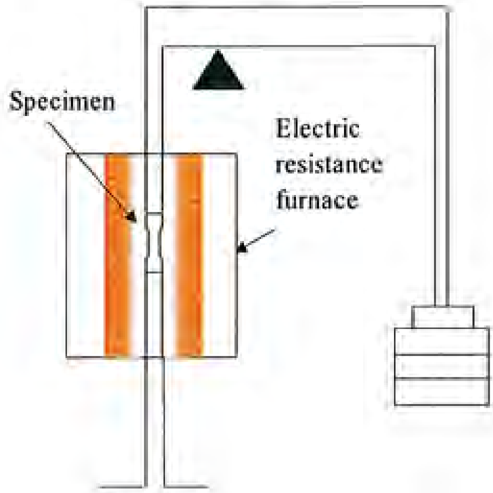
Example of synthetic evaluation



12-9 Creep rupture test

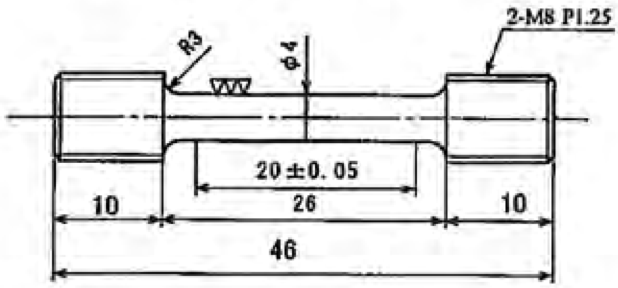
1) Testing machine

- Capacity: 1.5ton
- Lever-typed Electric resistance furnace (~900℃)
- In air



2) Example of specimen for creep rupture test

The specimen size depends on the tube sampled. The larger size of specimen is better because of oxidation during the test. The figure below is an example of shape of specimen.



3) Test condition

Test condition is determined based on the hoop stress under operational condition.

In order to shorten the test time, test stress or temperature are usually set at higher than operational condition.

4) Example of test condition and result by parameter method

➢ **The lowest stress is almost same stress as operational stress .**
The temperature is set so that the estimated creep rupture time is within about 3000hrs .

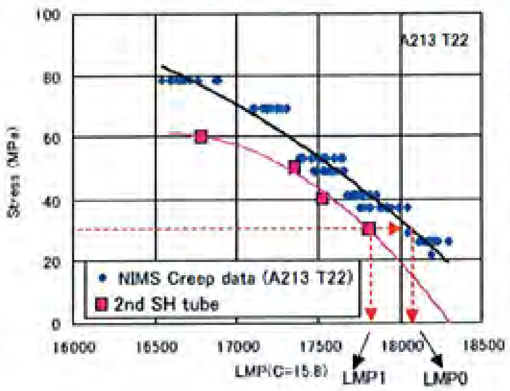
➢ **With the test temperature and rupture time, LMP (Larson-Miller parameter) is obtained.**

Sample	Material	Test condition		Estimated rupture time (h)	Rupture time t (h)	Rupture LMP C=15.8
		Temperature T (℃)	Stress (MPa)			
2nd SH tube	A213 T22	670	30	2,500	1,200	17,806
		670	40	1,500	600	17,522
		670	50	800	400	17,356
		670	60	400	100	16,788

LMP = (273.15+T) (C+log t)

➢ **The test result is platted in LMP-stress graph to compare with the virgin material data.**

➢**If the reliable virgin material data is available, the equivalent temperature can be estimated and remaining life is evaluated with the equivalent temperature instead of designed temperature, as follows.**



Creep rupture LMPo of virgin material

$$LMPo = (273.15+T_E)\ (15.8+\log(to+tr))$$

$$tr=10^{(LMP1/(273.15+T_E)-15.8)}$$

T_E : equivalent temperature

to : Operation hours

⇒ T_E, tr

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5) Example of test condition and result by Iso stress method

- **The stress is set same as operational stress .**
- **The lowest temperature is set so that the estimated creep rupture time is within about 3000hrs .**

Sample	Material	Test condition		Estimated rupture time	Rupture time
		Temperature T (℃)	Stress (MPa)		t (h)
2nd SH tube	A213 T22	650	30	2,500	2,400
		675	30	1,000	1,200
		700	30	200	400

- **The rupture time is extrapolated to operation temperature.**