秘

独立行政法人 国際協力機構
インド国電力省
インド火力発電公社

インド国
火力発電所運用改善計画調査

ファイナルレポート
Volume II

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電源開発株式会社
九州電力株式会社
中国電力株式会社

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(2) Unchahar Unit 2
(3) Rihand Unit 2

< Objectives of boiler components>

(1) Water wall
(2) Super heater
(3) Reheater
(4) Super heater header
(5) De super heater pipe
(6) Reheater header
(7) Main steam pipe

< Procedure>

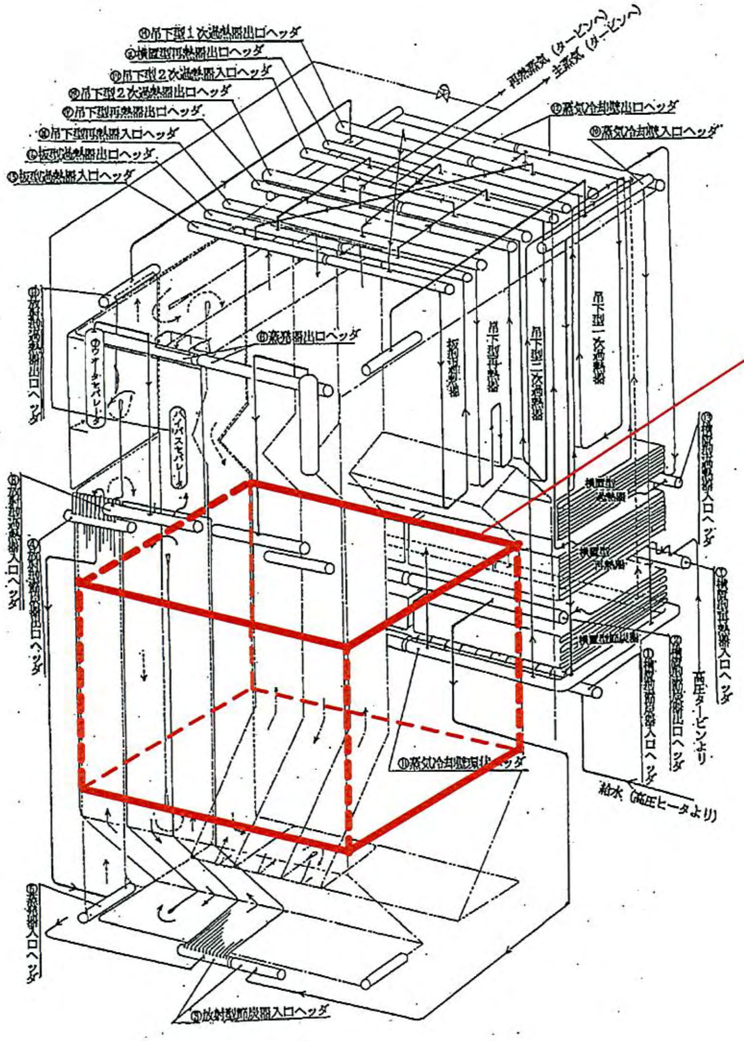
Boiler remaining life assessment will carried out based on the following procedure.

NO.	Parts	INSPECTION	**Singrauli 6**	**Rihand 2**	**Unchahar 2**	Reference
1	WATER WALL	VT	･Mainly at burner level ･Erosion part		*	
2		THICKNESS	･20 points(5points each from 4corners)		*	8 -4 - 1 - 1
3	SUPER HEATER	VT	･Mainly Platen super heater		*	
4		THICKNESS MEASUREMENT	･50 points around soot blower		*	8 -4 - 1 - 2
5		SAMPLE TUBE INSPECTION	･ 1 tube with 1m length for Platen SH including weld joint portion		*	8 -4 - 1 - 3
6		CREEP RUPTURE TEST (inspected in Japan)	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.		*	8 -4 - 1 - 4
7		SUS SCALE DEPOSITION INSPECTION	･50 points of bottom bend portion of austenitic steel tubes		*	8 -4 - 1 - 5
8	REHEATER	VT	･Mainly around soot blower		*	
9		THICKNESS MEASUREMENT	—		*	
10		SAMPLE TUBE INSPECTION (inspected in Japan).	･2 tubes with 1m length for Final RH (one each from furnace inside and penthouse) including weld joint portion		*	8 -4 - 1 - 3
11		CREEP RUPTURE TEST (inspected in Japan) for 1 tube with 1m length.	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to the one of the above sample tubes		*	8 -4 - 1 - 4
12		SUS SCALE DEPOSITION INSPECTION	･50 points of bottom bend portion of austenitic steel tubes		*	8 -4 - 1 - 5
13	SUPER HEATER HEADER	VT	･Visual inspection in penthouse ･If the fiber scope is shipped in time, fiber scope inspection is carried out for outlet header		*	
14		PT(DPT)	･4 portions at stub weld of Inlet header		*	8 -4 - 1 - 6
15		UT	･1ring of circumferential weld of outlet header with UT and TOFD identical to the replica portion		*	8 -4 - 1 - 7
16		REPLICA INSPECTION	･1 point on 1ring of circumferential weld of left outlet header ･1 point on base metal of left outlet header	･2 point on 1ring of circumferential weld of outlet header	*	8 -4 - 1 - 8 8 -4 - 1 - 9 8 -4 - 1 - 10
17	DE SUPER HEATER PIPE	REPLICA INSPECTION	･2 points (one each from 2rings of circumferential weld)		*	8 -4 - 1 - 8 8 -4 - 1 - 9 8 -4 - 1 - 10
18	REHEATER HEADER	VT	･Visual inspection in penthouse		*	
19		REPLICA INSPECTION	･2 points (one each from circumferential weld of left and right of out let header	･2 point on 1ring of circumferential weld for outlet header	*	8 -4 - 1 - 8 8 -4 - 1 - 9 8 -4 - 1 - 10
20	MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	･2 points on circumferential weld of left main steam pipe	･2 points (one each from left and right side)	*	8 -4 - 1 - 8 8 -4 - 1 - 9 8 -4- 1 - 10

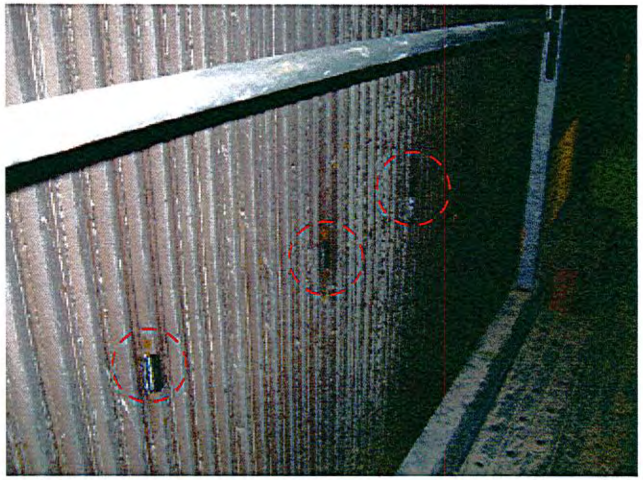
*:Decided after site meeting, basically followed by items of the other two units.

･BUILDING OF SCAFFOLDS, REMOVAL OF THERMAL INSULATION ,
AND REMOVAL OF DUST IN BOILER FURNACE SHALL BE COMPLETED IN ADVANCE.

Thickness Measurement (Water wall tube)



Bird's eye view of boiler



Example of measurement points

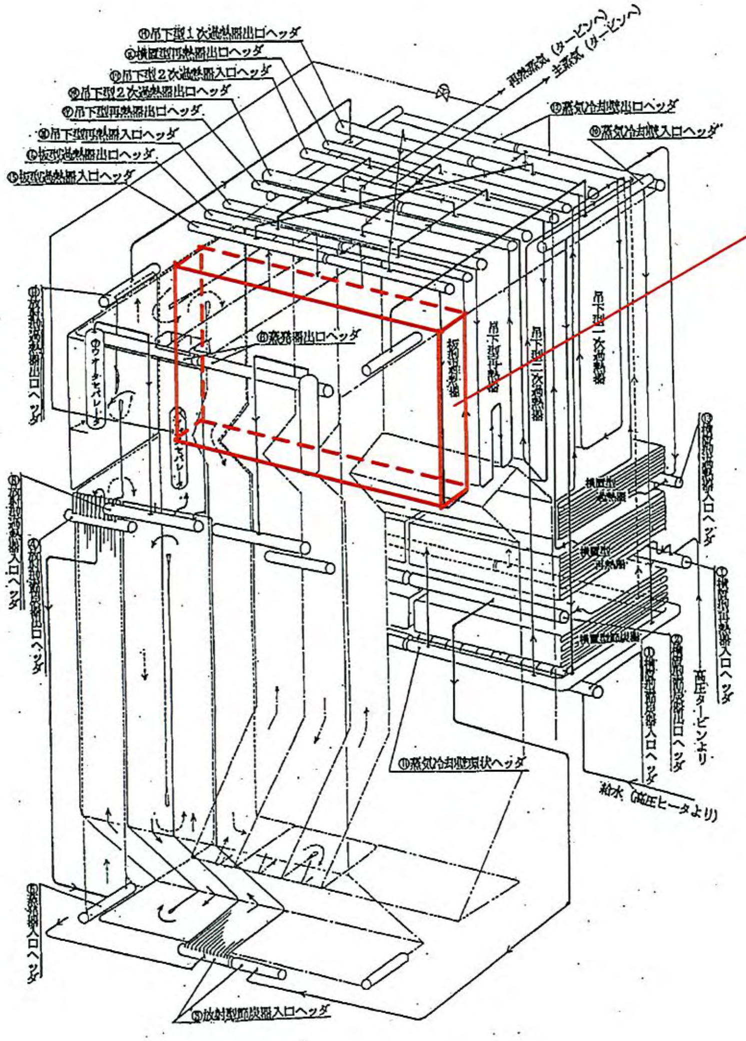
Selection criteria

・The most severe heat load potion like the upper part of the burner level .
(Available metal temperature data would help the selection)

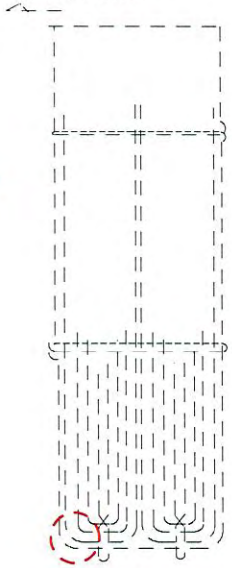
Measurement points and quantity

・5 points of each corner.

Thickness Measurement (Super heater tube)



Bird's eye view of boiler



Inspection portion

Example of measurement points

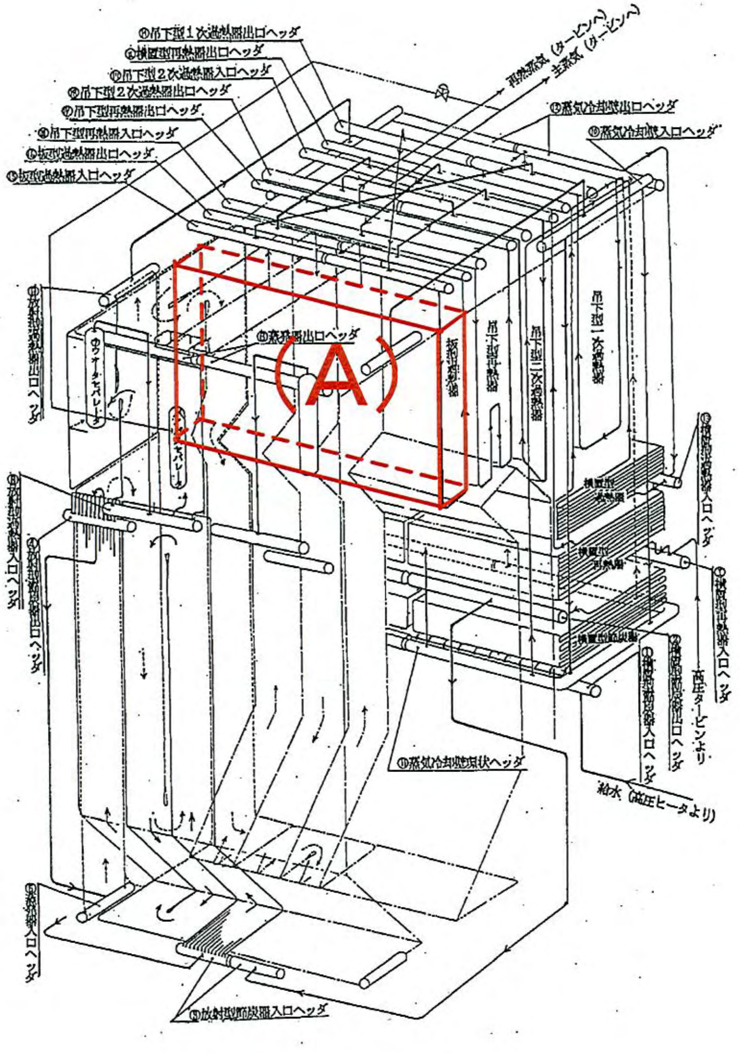
Selection criteria

- The highest temperature portion of super heater tubes (or reheater tubes) .
- The portion directly exposed to combustion gases from the furnace with the risk of thickness loss by oxidation from outside.

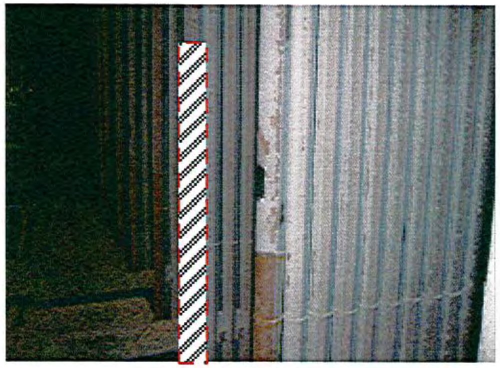
Measurement points and quantity

- Total 50 points of the straight portion of outer tube (1–3rd) around soot blower for selected final superheater panel.

Sample Tube Inspection (Super heater tube, Reheater tube)



Bird's eye view of boiler



Example of sampling point for SH

Examination item

1.Appearance inspection
2. Inner and outer suface inspection
3. Inner scale examination (adhesion thickness, composition(water wall tube))
4.Hardness test
5. Tube dimensions measurement
6. Microstructure examination

Selection criteria

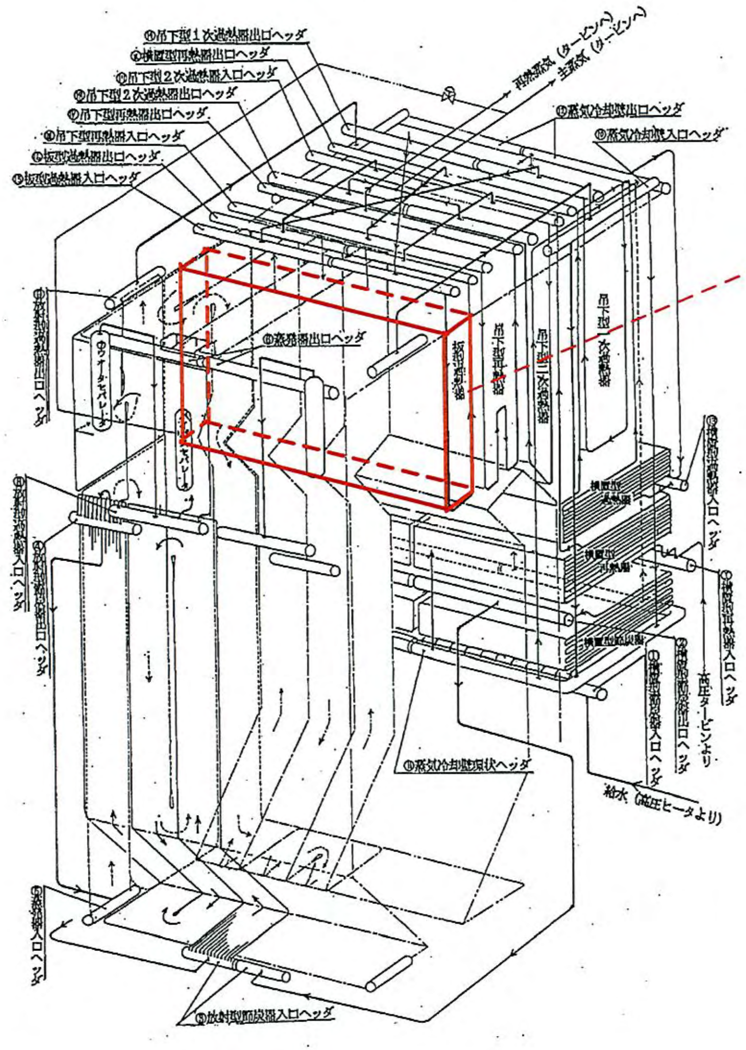
[Super heater tube]

- The highest temperature portion of super heater tubes (or reheater tubes) .

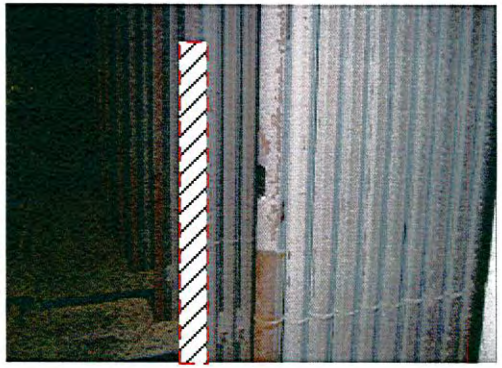
Measurement points and quantity

[Super heater tube]	1 tube with 1m length including weld joint portion.
[Reheater tube]	2 tubes with 1m length for Final RH (one each from furnace inside and penthouse) including weld joint portion.

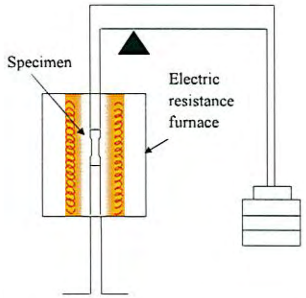
Creep Rupture Test (Super heater tube, Reheater tube)



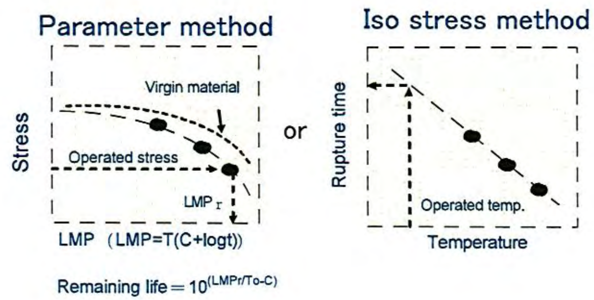
Bird's eye view of boiler



Example of sampling point for SH



Schematic view of creep tupture test



RLA by creep rupture test

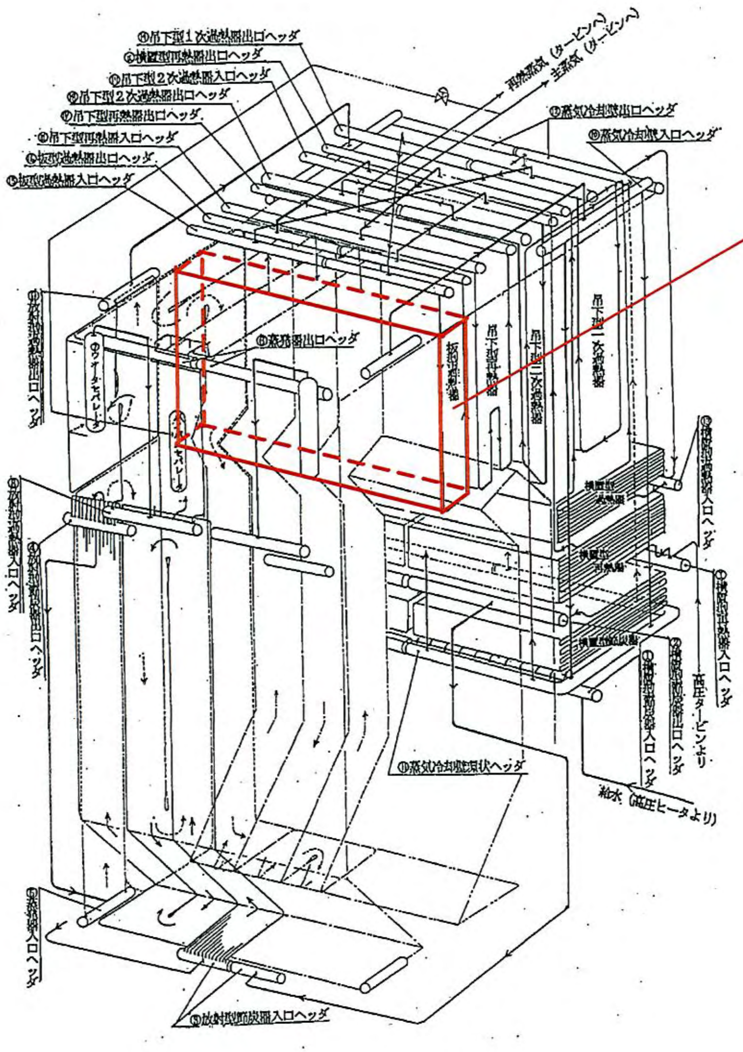
Selection criteria

・The highest temperature portion of super heater tubes and reheater tubes (Including circumferential weld portion)

Measurement points and quantity

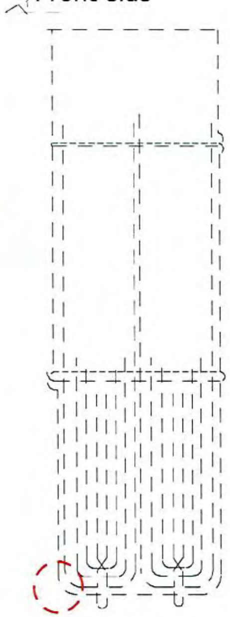
- 1 tube with 1m length including circumferential weld portion of super heater (Base metal and weld potion evaluated separately (test peices total 6))
- 1 tube with 1m length including circumferential weld portion of reheater (Base metal and weld potion evaluated separately (test peices total 6))

SUS Scale Deposition Inspection (Super heater tube, Reheater tube)

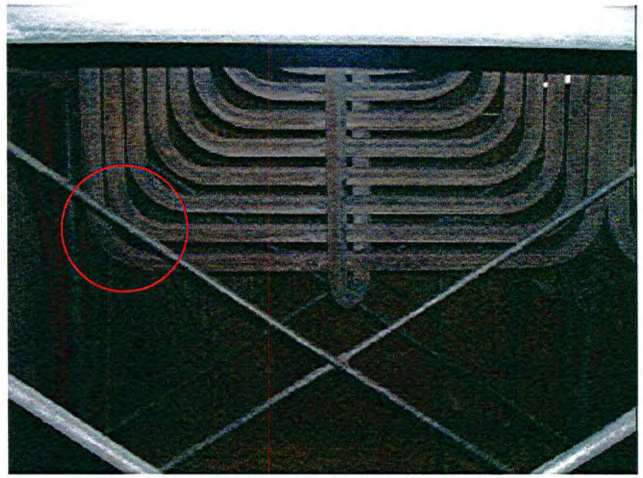


Bird's eye view of boiler

Front side



Inspection portion



Example of inspection points

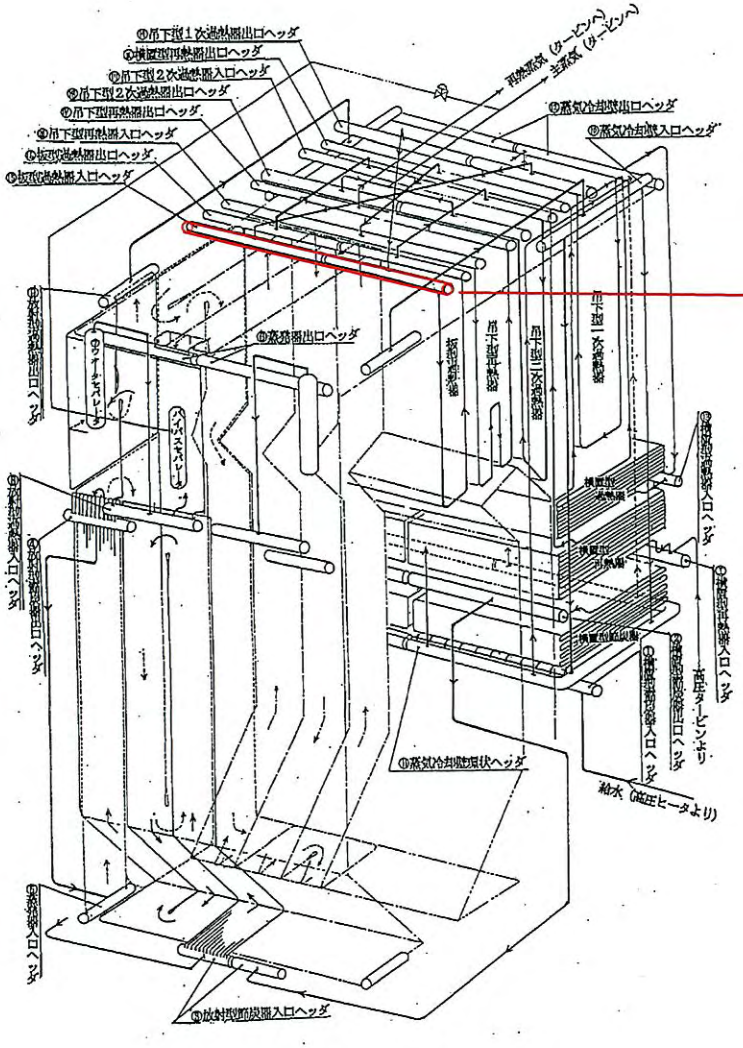
Selection criteria

- Portion of super heater tubes and reheater tubes where austenitic stainless steel is used.
- Bottom bend portion where exfoliated steam oxidation scale from inner surface of tube by thermal expansion and contraction during start-stop is expected to fall and pile up.

Measurement points and quantity

- 50 points of bend portion of austenitic stainless steel for selected final superheater panel.
- 50 points of bend portion of austenitic stainless steel for selected rerheater panel.

Penetrant Testing (Stub portion of final super heater header)



Bird's eye view of boiler

Example of inspection points

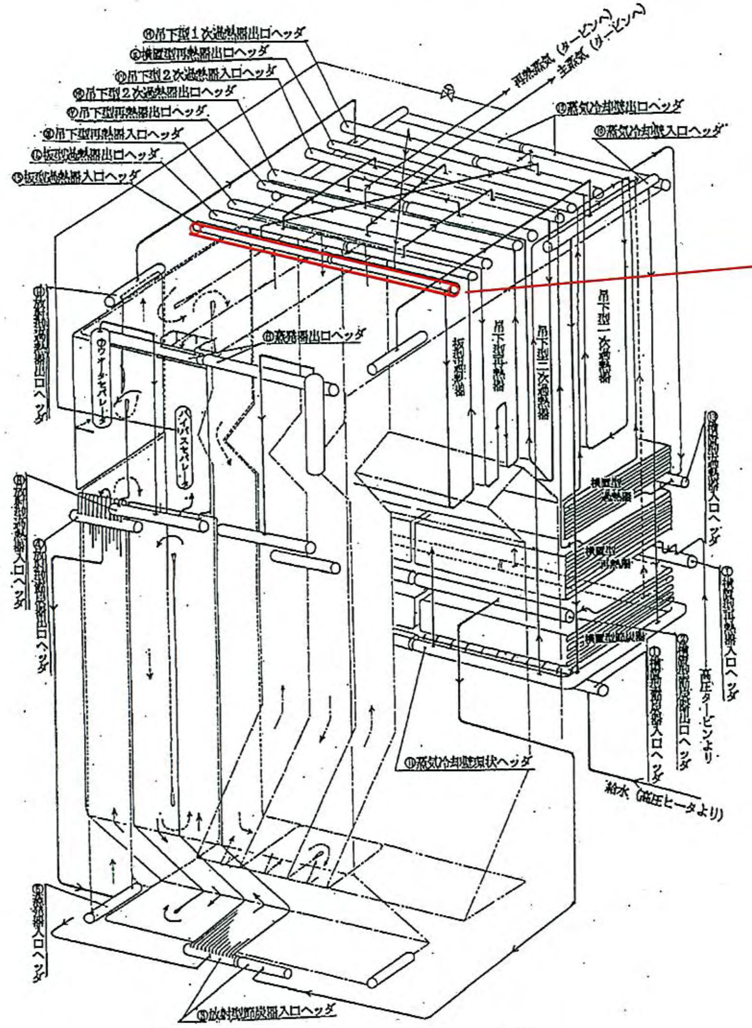
Selection criteria

- The highest temperature stub, if metal temperature data is available.
- The high stressed stub by structural constraint, if metal temperature data is not available.

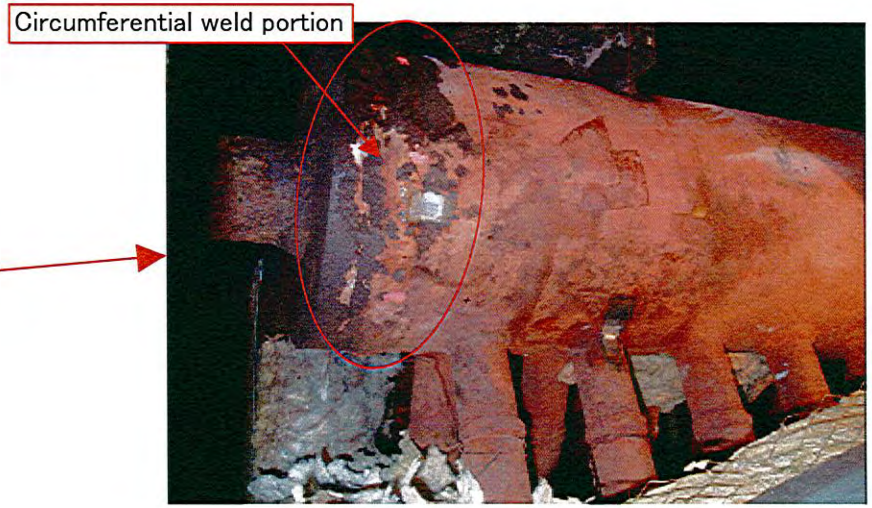
Measurement points and quantity

- 4 points with high temperature portion among axial direction, if metal temperature data is available.
- 4points of stubs with high stressed portion by structural constraint, if metal temperature data is not available.

UT Inspection、TOFD Inspection(Final super heater header circumferential weld portion)



Bird's eye view of boiler



Example of inspection points

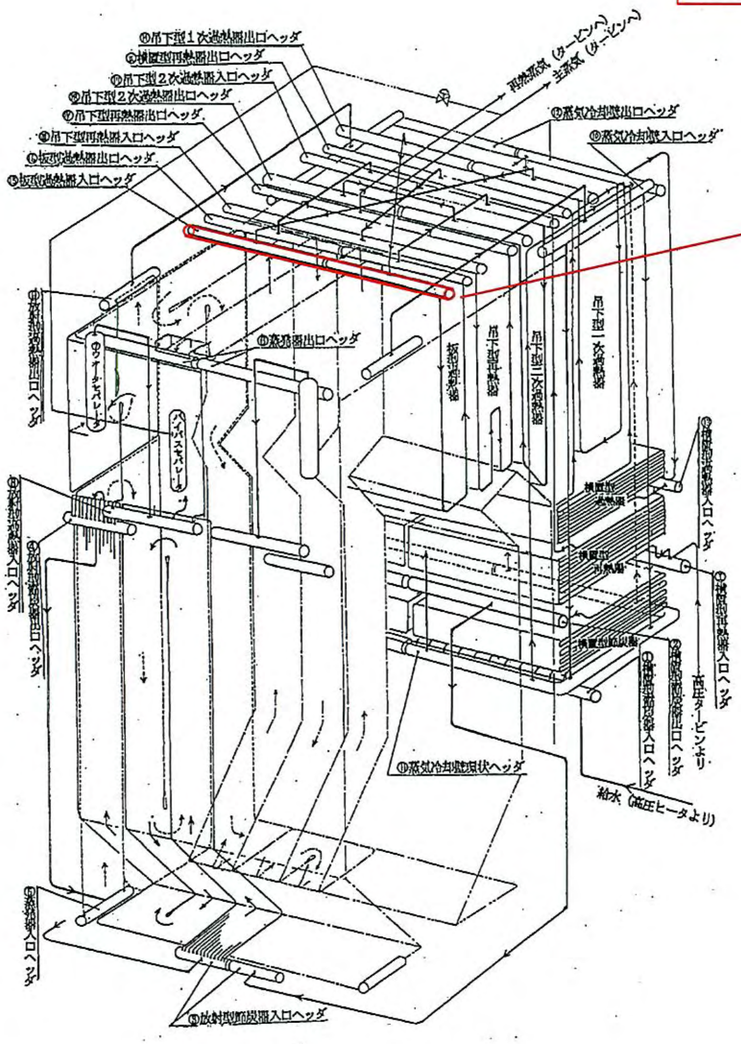
Selection criteria

・Circumferential weld portion with the highest temperature , if metal temperature data is available.
・The high stressed circumferential weld portion by structural constraint, if metal temperature data is not available.

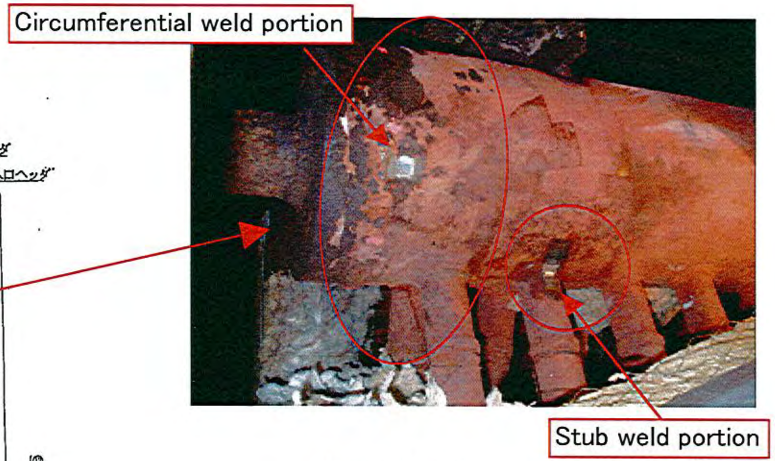
Measurement points and quantity

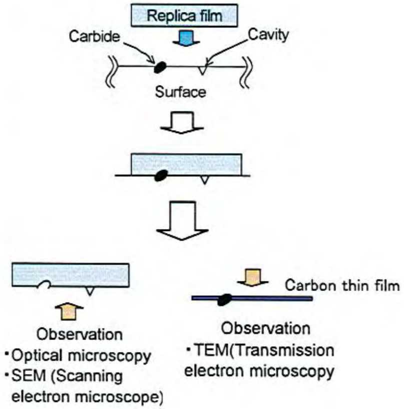
・All around one circumferential weld (1Ring), except interference portion with stubs.

Replica Inspection (Final super heater header, Desuper header, Reheater header and Main steam pipe)



Bird's eye view of boiler





Example of inspection points

Selection criteria

[Circumferential weld and stub weld portion]

- The highest temperature portion , if metal temperature data is available.
- The high stressed weld portion by structural constraint, if metal temperature data is not available.

Measurement points and quantity

[Circumferential weld potion]

- 2 points on 1ring of circumferential weld in final super heater header
- 2 points (one each from 2rings of circumferential weld) in desuper heater pipe.
- 2 points on circumferential weld in reheater header.
- 2 points on circumferential weld in main steam pipe.

Examination Technique of Remaining Life Assessment for Boiler High Temperature part

Japanese RLA guidline

(1) Degradation factor to be evaluated
・Creep rupture remaining life
(Designed temperature beyond 450℃)

(2) Components to be evaluated and the method to assess the remaining life

【Components】
・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

【Method to assess the remaining life】
More than one method shown in table

(3) Effective (countable) remaining life
・1/ 2 of remaining life evaluated by above methodes

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

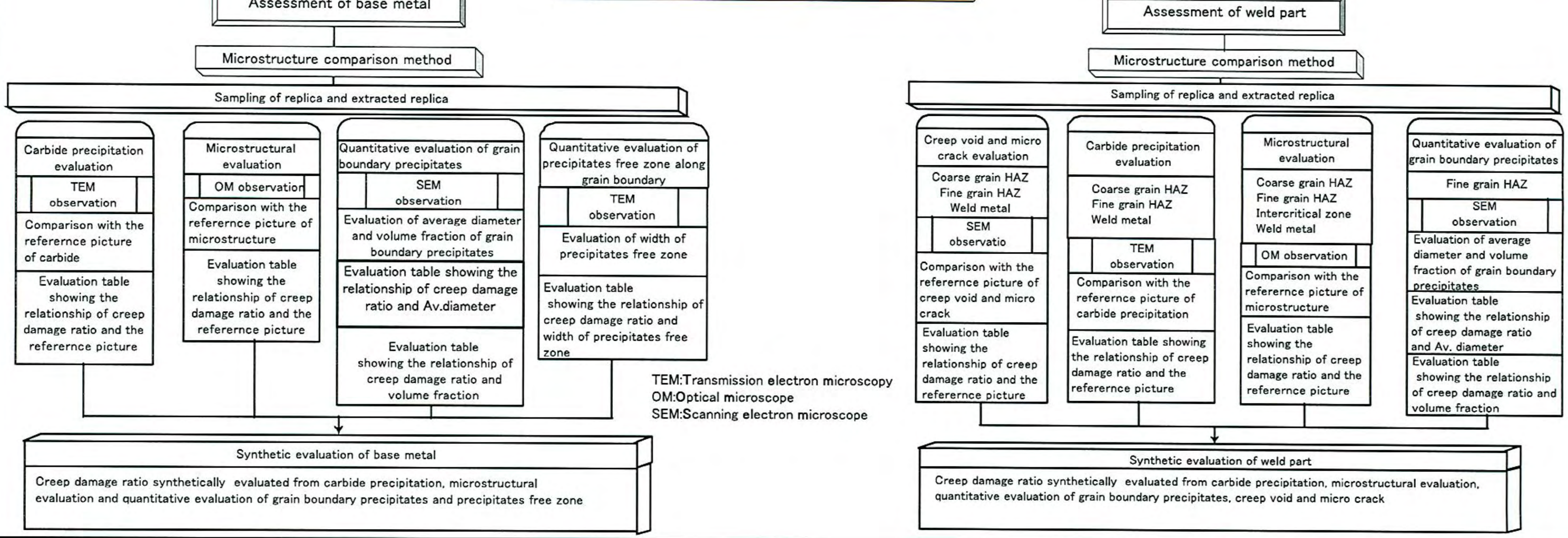
○: applicable, −: not applicable

(Microstructural comparison method outline)
Remaining life synthetically evaluated by three types of damage as shown below.

【Base metal】
・Evaluation of average diameter
・Comparison with the referernce picture of microstructure related to creep the damage ratio
・Comparison with the referernce picture of carbide precipitationrelated to the creep damage ratio

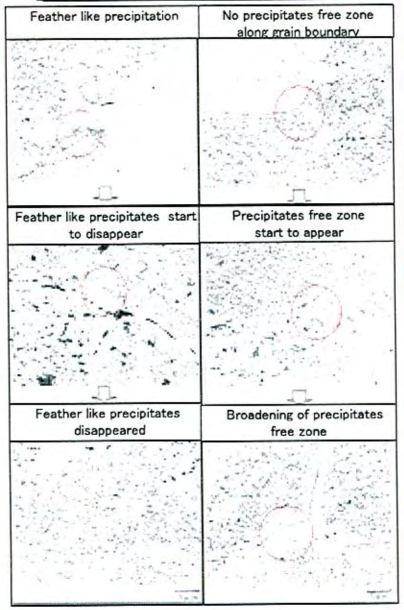
【Weld metal】
・Comparison with the referernce picture of creep void and micro crack related to creep the damage ratio
・Comparison with the referernce picture of microstructure related to creep the damage ratio
・Comparison with the referernce picture of carbide precipitationrelated to the creep damage ratio

Microstructural comparison method in this study

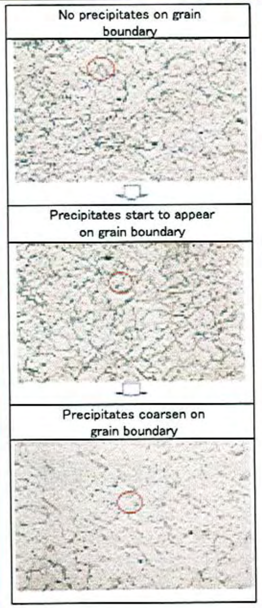


Microstructural Comparison Method (Weld portion)

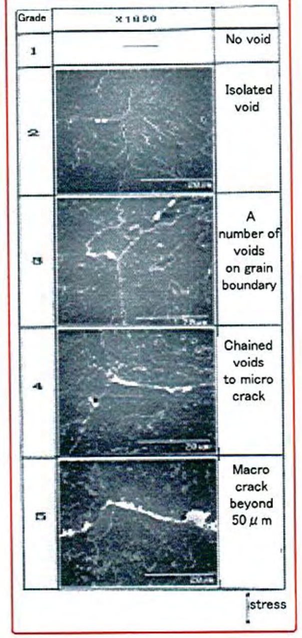
Referernce picture of carbide precipitation



Referernce picture of microstructure

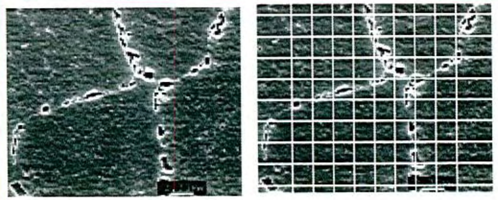


Referernce picture of creep void and micro crack



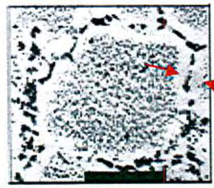
Quantitative evaluation

Quantitative evaluation of grain boundary precipitates

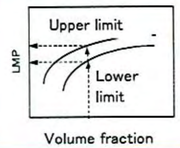


Volume fraction = n/total grids
(n: grids on the precipitates)

Quantitative evaluation of precipitates free zone



Relationhship of evaluated value and LMP (time-temperature parameter)



Procedure for microstructural change to creep damage

A microstructural change point LMP_1 obtained by aging test

↓ ⇦ Service hours t_s of evaluation component

Calculation of equivalent temperature T_{E1} from LMP1 and service hours ts

↓ ⇦ Creep rupture LMP_{r1} from NIMS creep data at applied stress σ of evaluation part.

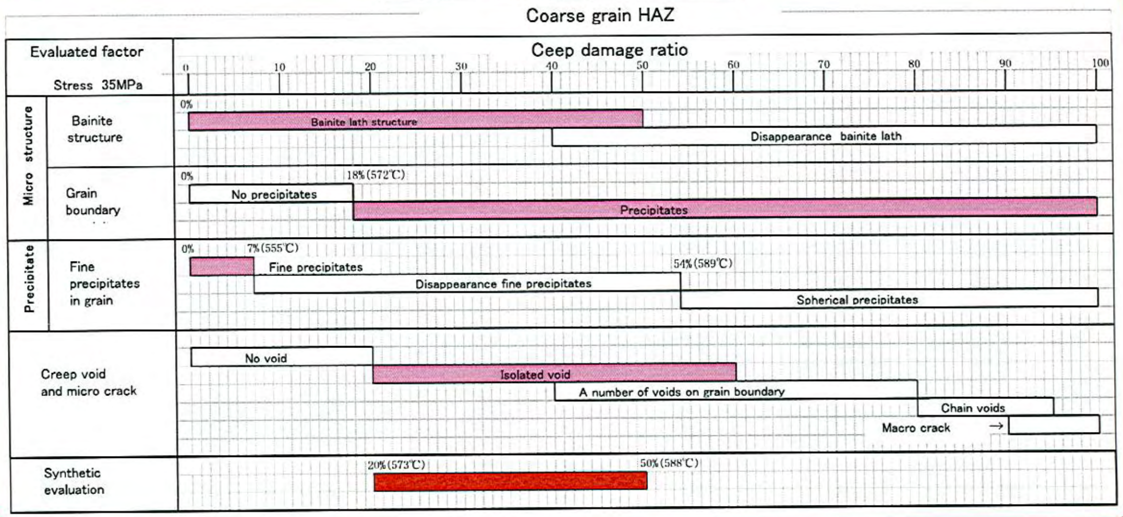
Calculation of rupture hours t_{r1} with PLM_{r1} and T_{E1}

↓

Creep life consuption ratio t_s / t_{r1} for a microstructure change point LMP_1

LMP=(273+T)(C+logt), T:temperature, t: time

Example of synthetic evaluation



Schedule of work for Boiler RLA

Item・Contents			In charge	1week before	Day 1	2	3	4	5	6	~2010 Feb.
Boiler Cooling & Scaffolding Assembly			P.S.								
Cleaning of boiler inside			P.S.								
Removal of heat insulation stuff			P.S.								
Checking of work site			JST,JSC		All members						
Meeting before work			JST,JSC		All members						
Water wall tube	Visual check		JST,JSC			A,D					
	Thickness measurement of tubes	Grinding	JST,JSC			B,D					
		Measurement				B,D Demo					
SH tube	Visual check		JST,JSC			B,C,E,F,G,H					
	Thickness measurement of tubes	Grinding	JST,JSC			B,D					
		Measurement				B,D					
	SUS scale deposition inspection	Grinding	JST,JSC			E,F					
		Measurement					E,F	Demo			
	Tube sampling	Cutting	P.S.								
		Restoration									
		Preparation for shipping of tube	JSC								
		Examination of tube									
		Creep rupture test of tube									
RH tube	Visual check		JST,JSC			B,C,E,F,G,H					
	SUS scale deposition inspection	Grinding	JST,JSC			E,F					
		Measurement					E,F				
	Tube sampling	Cutting	P.S.								
		Restoration									
		Preparation for shipping of tube	JSC								
		Examination of tube									
		Creep rupture test of tube									
SH header	Visual check		JST,JSC			A,C,G,H					
	PT (stub)	Grinding	JST,JSC				G,H				
		Inspection					G,H Demo				
	UT (Circumferential weld)	Grinding						G,H			
		UT(TOFD) detection							E,F,G,H Demo		
	Replica inspection	Replica sampling	JST,JSC				A,C Demo				
		・Examination of replica ・Remaining life assessment	JSC								
Desuperheater	Visual check		JST,JSC			A,C,G,H					
	Replica inspection	Replica sampling	JST,JSC					A,C	Demo		
		・Examination of replica ・Remaining life assessment	JSC								
RH header	Visual check		JST,JSC				B,D				
	Replica inspection	Replica sampling	JST,JSC					B,D			
		・Examination of replica ・Remaining life assessment	JSC								
Main steam pipe	Visual check		JST,JSC				B,D				
	Replica inspection	Replica sampling	JST,JSC						B,D		
		・Examination of replica ・Remaining life assessment	JSC								
Preparation for shipping of inspection instruments			JSC								

・JST Hayakawa
・JSC member A
・JSC member B
・JSC member C
・JSC member D
・JSC member E
・JSC member F
・JSC member G
・JSC member H

JST : JICA Study Team, JSC : Japanese Service Compar

Boiler RLA demo in
Singrauli #6unit & Unchahar #2

JICA Study Team for Enhancing Efficiency of Operating Thermal Power Plant
in NTPC-India

Boiler RLA
&
Kyudensangyo Co.,Inc

27.October 2009 -11.November 2009

Schedule for Boiler RLA demo

Schedule for Boiler RLA

	Month	October								November											～January
	Day	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	
	Day of the week	Sa	Su	Mo	Tue	We	Th	Fr	Sa	Su	Mo	Tue	We	Th	Fr	Sa	Su	Mo	Tue	We	
Singrauli UNIT6	Boiler Inspection				10/27-11/1																
Unchahar UNIT2	Meeting																				
	Boiler Inspection												11/4-11/9								
	◇Examination in Japan																				

Scope of work (1)

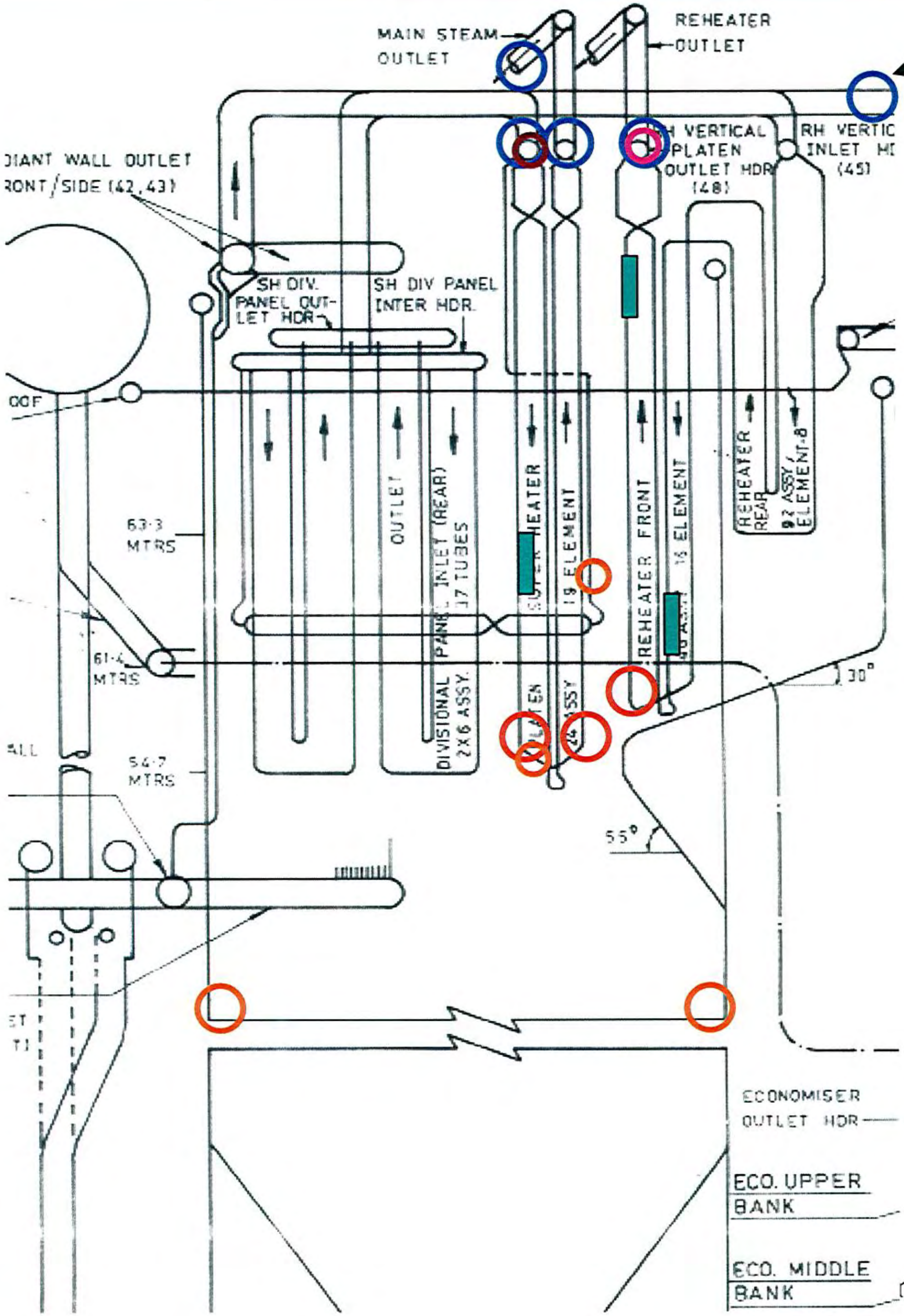
NO.	Parts	INSPECTION	Singrauli #6	Unchahar #2
1	WATER WALL	VT	･Mainly at burner level ･Errosion part	
2		THICKNESS MEASUREMENT	･20 points(5points each from 4corners)	
3	SUPER HEATER	VT	･Mainly Platen super heater	
4		THICKNESS MEASUREMENT	･50 points around soot blower	
5		SAMPLE TUBE INSPECTION *	1 tube with 1m length for Platen SH including weld joint portion	2 tubes with 1m length from Final SH, 1 tubes with 1m length from Platen SH including weld joint portion that is selected by steam oxide scale measurement result.
6		CREEP RUPTURE TEST*	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.
7		SUS SCALE DEPOSITION INSPECTION	･50 points of bottom bend portion of austenitic steel tubes	･29 ×3 points of bottom bend portion of austenitic steel tubes
8	REHEATER	VT	･Mainly around soot blower.	
9		SAMPLE TUBE INSPECTION *	2 tubes with 1m length for Final RH (one each from furnace inside and penthouse) including weld joint portion.	
10		CREEP RUPTURE TEST*	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to the one of the above sample tubes.	
11		SUS SCALE DEPOSITION INSPECTION	･50 points of bottom bend portion of austenitic steel tubes	

*: Examined in Japan

Scope of work (2)

NO.	Parts	INSPECTION	Singrauli #6	Unchahar #2
12	SUPER HEATER HEADER	VT	・Visual inspection in penthouse	
13		PT(DPT)	・4 portions at stub weld of Inlet header .	・4 portions at stub weld of Platten inlet header right side.
14		UT		・1ring of circumferential weld of Final outlet header right side with UT and TOFD identical to the replica portion
15		REPLICA INSPECTION	・1 point on 1ring of circumferential weld of left outlet header. ・1 point on base metal of left outlet header.	・1 point of circumferential weld potion of right side of Final outlet header.
16	DE SUPER HEATER PIPE	REPLICA INSPECTION	・2 points (one each from 1ring of circumferential weld right and left).	
17	REHEATER HEADER	VT	・Visual inspection in penthouse	
18		UT	・1ring of circumferential weld of outlet header with UT and TOFD identical to the replica portion	
19		REPLICA INSPECTION	・2 points (one each from circumferential weld of left and right of out let header.	・3 points of circumferential weld potion of right and left side outlet header.
20	MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	・2 points on a circumferential weld of left main steam pipe	・2 points on two circumferential welds of right main steam pipe
21	HOT RHEAT PIPE	REPLICA INSPECTION		・1 point on a circumferential weld of right High temperature reheat pipe.

Inspection points



Desuper heater

:Replica

:SUS scale

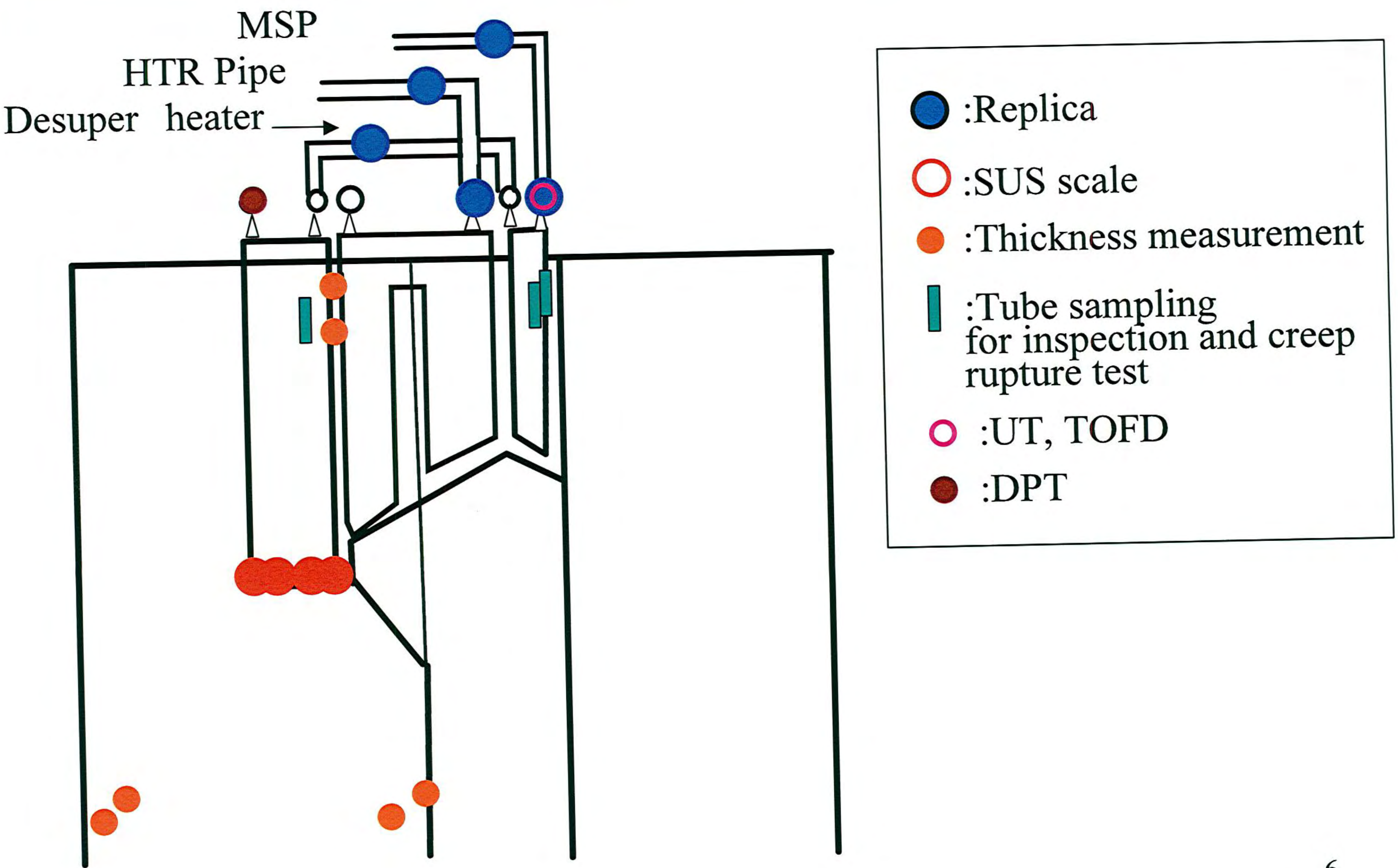
:Thickness measurement

:Tube sampling for inspection and creep rupture test

:UT, TOFD

:DPT

Inspection points (Unchahar #2)



Findings (1) (Singrauli #6)

Components	Inspection method	Findings
Water wall tube	Visual check	・Erosion of a number of tubes around short soot blower were found. ・No erosion at any other portions. ・No erosion and decease in thickness around burners.
	Thickness measurement of tubes	Thickness was measured at erosion regions around soot blowerrs near each 4 corner. Min. thickness was 3.7mm(2nd blower in forntwal first from right. f 51* 5.6mm, SA210 Gr.C
Platten SH	Visual check	・Attrition of binding tube #4 and #5 was found. (Min.2.8mm) ・Attrition of cooling spacer tubevwith front tube of #14 panel (Min.5.0mm) ・Disorder of arrangement at lower part of panel with distortion to adjacent panel. ・A number of disjointed slide spac
	Thickness measurement of tubes	・1:Outer tube of rear side portion at sootblower level〔24points〕⇒Min.6.3mm ϕ 63.5* 6.3mm SA213 TP347H ・2:Outer bottom tube 〔24points〕⇒Min.9.8mm ϕ 54.0* 9.5mm SA213 TP347H ・3:Attrition of coolin
	SUS scale deposition inspection	Nos. exceeding 10% fullness : 7 /50 (magnetized effect of material)
	Tube sampling for sample tube inspection (inspected in Japan).	#3-1(from leftside in penthouse)
	Creep rupture test (inspected in Japan)	

Findings (2) (Singrauli #6)

Components	Inspection method	Findings
Reheater	Visual check	・Disorder of arrangement at lower part of panel with distortion to adjacent panel.
	SUS scale deposition inspection	No exceeding 10% fullness
	Tube sampling for sample tube inspection (inspected in Japan).	#3-1(from leftside in penthouse) 1m including weld f 54*5.6, SA213 T22 #14-5(from rear side in furnace) (SA213T22 f 54*4.5-SA213T11 f 54*4.0)
	Creep rupture test (inspected in Japan) for 1 tube with 1m length.	
Super heater header	Visual check	・No appearance abnormarity in stubs and other weld portion.
	DPT	#2(1,4,7,12) Indication was found in #2-12 stub at tube side. Indication disaappeared after grindng off the tube in 1mm depth .
	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
De superheater pipe	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
Reheater header	Visual check	・No appearance abnormarity in stubs and other weld portion.
	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
	UT	・ No detection of flaw beyond H-detection line. ・ 4 detected flaw under H-detection line.
	TOFD	・ A number of flaw considered as satle blow holes and slag inclusions were detected. ・ No considerable crack detected.
Main steam pipe (near the stop valve weld joint)	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.

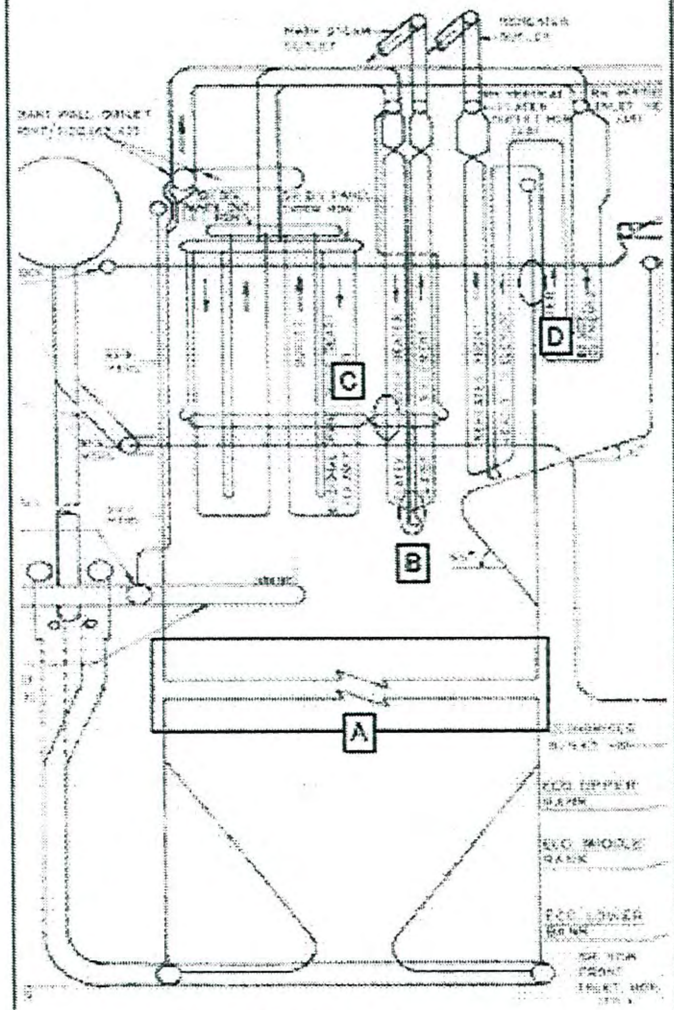
Findings (3) (Unchahar #2)

Components	INSPECTION	Unchahar #2 Brief comment
WATER WALL	VT	Erosion of a number of tubes around short soot blower were found. Erosion of corner tubes at soot blower level.(Thickness measurement 28points (Min.4.2mm)
	THICKNESS MEASUREMENT	Eroded tubes around short soot blower were meareured .(69points measured) Min 5.3mm (2nd short blower rear wall #1 form left)
SUPER HEATER	VT	Disorder of arrangement at lower part of panel with disjointed slide spacers. Slight erosion of rear tubes at the highest level of short soot blower.
	THICKNESS MEASUREMENT	Rear tubes at the highest level of short soot blower.(29points, Min.9.8mm) 2nd tubes from rear tubes at the highest level of short soot blower.(3points, Min.10.0mm) Rear tubes at the second highest level of short soot blower.(29points, Min.9.8mm)
	SAMPLE TUBE INSPECTION *	1 sample tube from Platen-SH in furnace (#3panel- 8th tube from rear) 2 sample tubes from Final-SH in furnace (#1-3rd tube from rear, #119-3rd tube from rear)
	CREEP RUPTURE TEST*	1 sample tube from Platen-SH in furnace (#3panel- 8th tube from rear), 1 sample tubes from Final-SH in furnace (#119-3rd tube from rear)
	SUS SCALE DEPOSITION INSPECTION	3 tubes with 15% fullness and 2 tubes with 10% fullness at front bend portion. 1 tube with 15% fullness and the others with less than 10%.
REHEATER	VT	No abnormality with panel ar r angement Slight erosion of tubes at the highest level of short soot blower.

Findings (4) (Unchahar #2)

Components	INSPECTION	Unchahar #2 Brief comment
SUPER HEATER HEADER	VT	No appearance abnormality in stubs and other weld portion.
	PT(DPT)	3 small circular indication patterns by ark strike at 4th tube from front.
	UT	No detection of flaw which echo exceeds L-line by UT. Continuous indication with fine flaws detected at 80mm depth from surface by TOFD.
	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
DE SUPER HEATER PIPE	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
REHEATER HEADER	VT	No appearance abnormality in stubs and other weld portion.
	REPLICA INSPECTION	No crack in Base metal, HAZ (Heat Affected Zone) and weld metal. Abnormal microstructure observed in base metal region of right-hand weld of header, which is considered to be the effect of ark during welding. More detail microstructural observation.
MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
HOT RHEAT PIPE	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo. Some deposit metal by welding attached to base metal near the weld ring.

Visual Inspection (Singrauli #6)

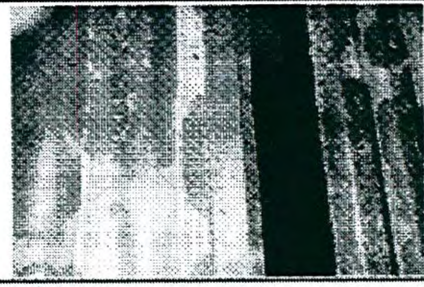


Finding portion

A: Erosion of water wall around short soot blower

- Erosion of a number of tubes around short soot blower.
(Thickness measurement conducted)

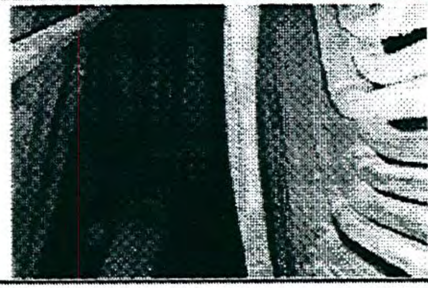
[Min. measured value]
Min. 3.7mm (2nd blower in forntwal first from right).



B: Platen-SH Attrition of binding tube #4 and #5 was found.(Min.2.8mm)

- Attrition of binding tube #4 and #5

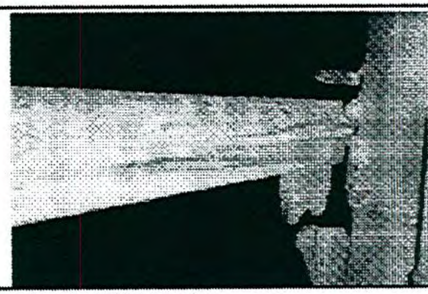
[Min. measured value]
Min.2.8mm φ63.5* 6.5mm SA213 TP347H



C: Attrition of cooling spacer tube with front tube of #14 panel.

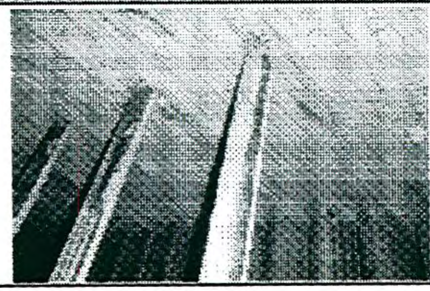
- Attrition of a cooling spacer tube with front tube of #14 panel.
(Thickness measurement conducted)

[Min. measured value]
Min.5.0mm

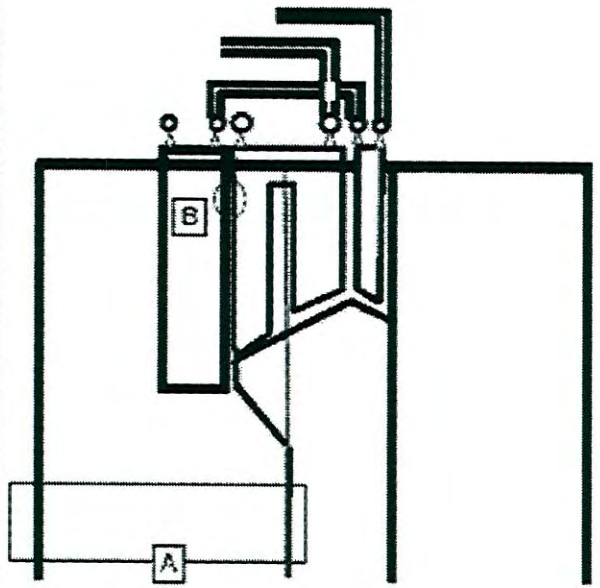


D: Erosion of screen tubes near the ceiling between front RH panel and rear RH panel.

- Erosion of screen tubes at front side near the ceiling were found at left side of boiler.
(Thickness measurement not conducted)



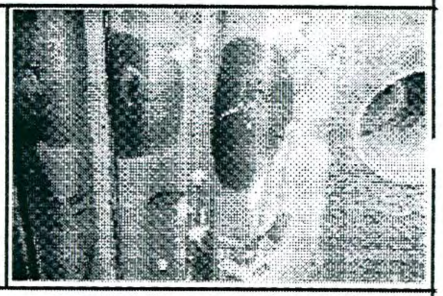
Visual inspection (Unchahar #2)



Potion noted

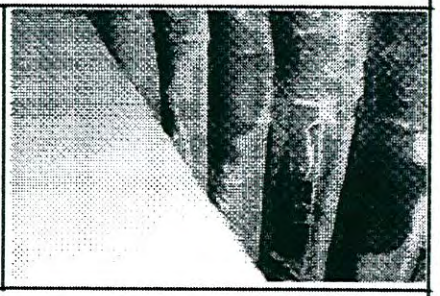
A: Erosion of water wall tube around short soot blowers.

Erosion of a number of tubes around short soot blower.
(Thickness measurement conducted)
Min. 5.3mm (1st tube from left in rear wall at 2nd blower)



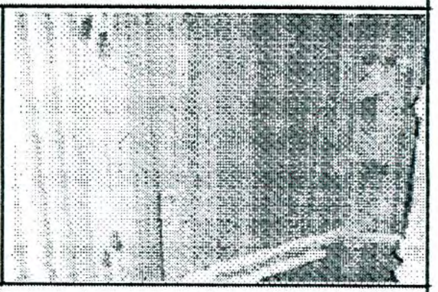
A: Erosion of water wall tubes around burners.

Erosion of several tubes around burners.
(Thickness measurement conducted)
Min. 4.7mm



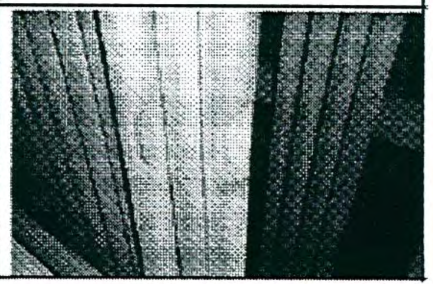
A: Erosion of water wall tubes near the corners.

Erosion of several tubes near the corners at short soot blower level.
(Thickness measurement conducted)
Min. 4.2mm



B: Erosion of Platen SH rear side tubes at the highest level of soot blower.

Slight erosion of rear side tubes at the highest level of soot blower.
(Thickness measurement conducted)
Min. 9.8mm



Thickness (Unchahar #2)

Thickness measurement of tubes

Tube	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (℃)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA-210, GR.A1	63.5	6.3	175.8	404	86.8	6.1	4.2	Erosion around short soot blower
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Highest soot blower level
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Second highest soot blower level
Platten SH (ELE 2)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	10.0	Highest soot blower level

O.D.:Outer Diameter
t:Thickness

tsr = PD/(2S+P)+0.005D

Creep life calculation of header and pipe based on disigned condition

Header and Pipe	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (℃)	Allowable Stress S (MPa)	tsr (mm)	Hoop stress (MPa)	Estimated Life(h) calculated by creep rupture data
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Re-Heater outlet header	SA 335 P-22	558.8	45	44.1	555	45.4	25.0	23.8	9.19E+06
LTSH outlet header	SA 335 P12	323.9	40	167.6	450	101.0	24.7	60.0	4.81E+08
Links to DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
Links from DESH	SA 335 P12	406.4	45	167.6	427	102.8	30.5	67.6	2.25E+09
Platen SH inlet header	SA 335 P12	323.9	40	167.6	427	102.8	24.3	60.0	4.30E+09
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Links to Final SH	SA 335 P-22	406.4	70	163.4	534	58.2	47.0	35.4	8.49E+06
SH Finish inlet header	SA 335 P-22	406.4	65	163.4	534	58.2	47.0	39.0	5.54E+06
SH Finish outlet header	SA 335 P-22	457.2	100	160.6	555	45.4	63.8	25.0	7.76E+06
Main Steam Pipe	SA 335 P-22	355.6	50.3	160.5	540	54.4	42.8	44.6	1.98E+06
Hot Reheat Pipe	SA 335 P-22	508	28	37.6	540	54.4	16.4	30.9	9.91E+06

tsr = PD /(2S?+2kP)+a (?=1, a=0)

k	Temperature(℃)						
	≦350	480	510	535	565	590	620
Feritic steel	0.4	0.4	0.5	0.7	0.7	0.7	0.7

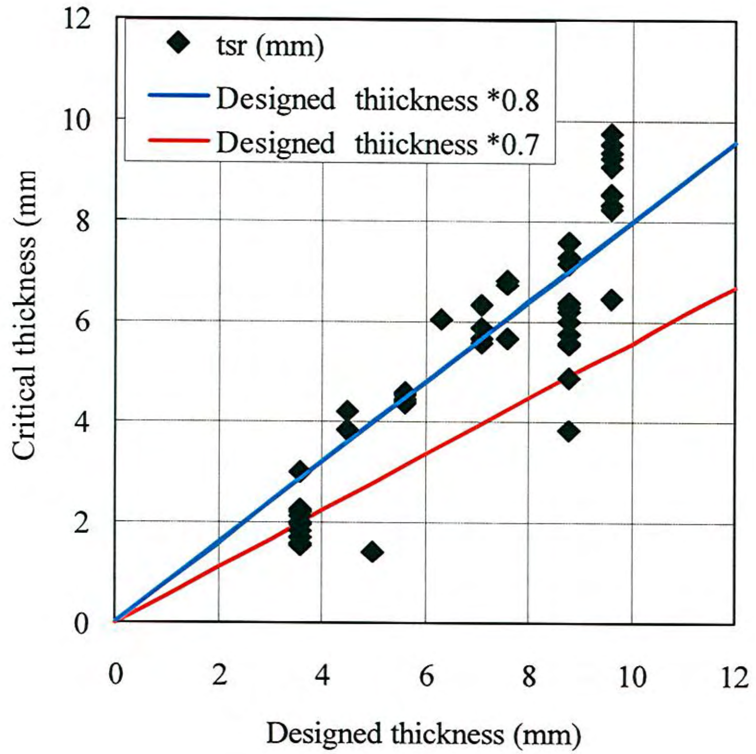
Thickness criterion (Unchahar #2)

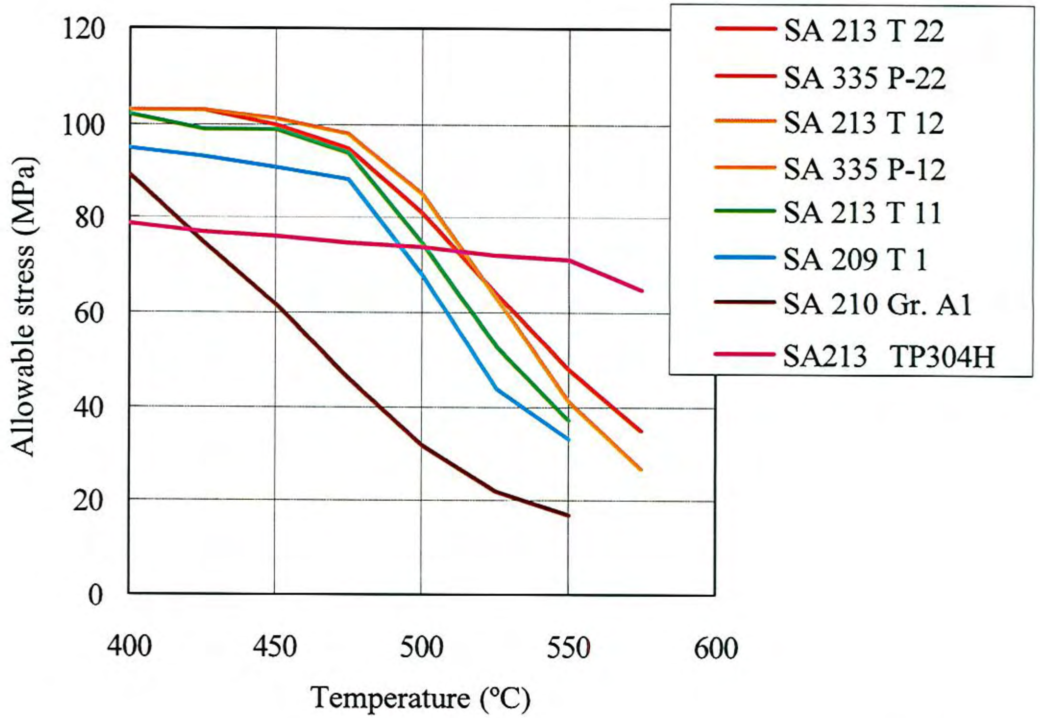
Thickness measurement of tubes

Tube	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (°C)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA-210, GR.A1	63.5	6.3	175.8	404	86.8	6.1	4.2	Erosion around short soot blower
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Highest soot blower level
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Second highest soot blower level
Platten SH (ELE 2)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	10.0	Highest soot blower level

O.D.:Outer Diameter
t:Thickness

tsr = PD/(2S+P)+0.005D





Caluculated designed creep life (Unchahar #2)

Creep life calculation of header and pipe based on disigned condition

Header and Pipe	Material	Designed				Allowable Stress S (MPa)	tsr (mm)	Hoop stress (MPa)	Estimated Life(h) calculated by creep rupture data
		O.D. D(mm)	t (mm)	Pressure P (kg/cm2)	Temperature (°C)				
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Re-Heater outlet header	SA 335 P-22	558.8	45	44.1	555	45.4	25.0	23.8	9.19E+06
LTSH outlet header	SA 335 P12	323.9	40	167.6	450	101.0	24.7	60.0	4.81E+08
Links to DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
Links from DESH	SA 335 P12	406.4	45	167.6	427	102.8	30.5	67.6	2.25E+09
Platen SH inlet header	SA 335 P12	323.9	40	167.6	427	102.8	24.3	60.0	4.30E+09
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Links to Final SH	SA 335 P-22	406.4	70	163.4	534	58.2	47.0	35.4	8.49E+06
SH Finish inlet header	SA 335 P-22	406.4	65	163.4	534	58.2	47.0	39.0	5.54E+06
SH Finish outlet header	SA 335 P-22	457.2	100	160.6	555	45.4	63.8	25.0	7.76E+06
Main Steam Pipe	SA 335 P-22	355.6	50.3	160.5	540	54.4	42.8	44.6	1.98E+06
Hot Reheat Pipe	SA 335 P-22	508	28	37.6	540	54.4	16.4	30.9	9.91E+06

tsr = PD /(2S?+2kP)+a (?=1, a=0)

k	Temperature(°C)						
	≦350	480	510	535	565	590	620
Feritic steel	0.4	0.4	0.5	0.7	0.7	0.7	0.7

Japanese Boiler RLA Guidline (1)

To extend periodical inspection interval 2 year to 4year after 100,000 hours operation.

(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

Japanese Boiler RLA Guidline (2)

(3) Method to assess the remaining life

- More than one method used as shown in table below

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

○ : applicable, −: not applicable

(4) Effective (countable) remaining life

- 1/ 2 of remaining life evaluated by above methods

Japanese Boiler Inspection (Water wall, Furnace tube)

Water wall tube / Furnace tube

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	General appearance	Burn out, distortion, swelling, ash cut, steam cut etc.	Periodic inspection (every 2years)
	General appearance building scaffolding by the burner level		Periodic inspection (every 4years)
	General appearance building scaffolding by the top of furnace at the necessary interval set.		Setting necessary interval.
VT(Endoscopy)	Water tube inside	Corrosion	Setting necessary interval.
Chemical analysis of deposit	Outside deposit	Corrosion	Periodic inspection (every 2years)
PT	Representative weld portion of fin edge	Creep-fatigue	In case of elongation of periodic inspection interval (max. 2years).
	Representative attached metal weld portion	Creep-fatigue	After 80,000 hours operation, depending on necessity
Thickness measurement	Fixed points of tube. Representative portion of ash cut and steam cut with no countermeasure	Thinning with aging. Ash cut and steam cut.	Continuous measurement depending on boiler structure and type. Erosion countermeasure necessary, in case of elongation of periodic inspection interval (max. 2years). .
Sampling tube examination	Water wall tube in high heat load portion	Scale deposit	Setting necessary interval.
Residual life assessment	Water wall tube in high heat load portion	Creep	Judge from operation and design condition, depending on necessity.

Japanese Boiler Inspection (SH, RH, Eco tube)

SH, RH, Eco tubes

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	General appearance	Leak, crack, corrosion, erosion	Periodic inspection (every 2years)
Chemical analysis of deposit	Outside deposit	High temperature corrosion	Depending on necessity
Thickness measurement	Representative points of SH, RH, Eco tubes with no countermeasures for erosion.	erosion	Periodic inspection (every 2years)
	High temperature corrosion portion and portion that tends to decrease in thickness	High temperature corrosion	Continuous measurement at constant points.
	Around soot blower	Ash cut and steam cut	Periodic inspection (every 2years)
	Attrition at cross over of tubes		Setting necessary interval.
PT	Representative weld portion of fin edge	Creep fatigue	In case of elongation of periodic inspection interval (max. 2years).
	Representative dissimilar weld portion with no use of Inconel weld metal.	Creep fatigue and creep	Setting necessary interval.
	Representative attached metal weld portion	Creep fatigue	After 80,000 hours operation, depending on necessity
Sampling tube examination	Austenitic steel tube (Austenitic steal used in steam temperature 540℃ or more and metal temperature 620℃ or more).	SUS scale deposition	In case of elongation of periodic inspection interval (max. 2years).
?-ray inspection etc.	Bottom bend potion of austenitic steel tube	SUS scale deposition	Depending on necessity
Residual life assessment	Low alloy steel used in steam temperature 540℃ or more.	Creep	Judge from operation and design condition, depending on necessity.

Japanese Boiler Inspection (Steam drum, water drum)

Steam drum, Water drum

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	・Drum inside with water steam separator equipments detached.	Deposit	Periodic inspection (every 2years)*
		Corrosion	
		Erosion	
Chemical analysis		Deposit	
DPT	・Inner weld line ・Inner corner of stub ・Support and hanging lug	Low cycle fatigue	
MT	・External seam and girth weld line ・Inner weld line of stub	Low cycle fatigue	After 80,000 hours operation

*If the weld of stub inside is smooth finished, periodic inspection every 4years

Desuper

Inspection measure	Portion	Deterioration factors	Inspection interval
Overhaul VT	Nozzle, Mixing chamber	Thermal fatigue, abrasion	Setting necessary interval.

Japanese Boiler Inspection (Header (1))

Header (Water wall header, Evaporator header, Economizer header, SH header, RH header)

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	General appearance	Erosion	Periodic inspection
		Corrosion	
		Cracking	
		Leak from weld part	
VT (Endoscope)	Ligament of Furnace header, Economizer header, SH header and RH header inside (including drain and bent tube portion).	Low cycle fatigue	Include in the periodic inspection plan systematically
	Inside of Furnace header, SH header and RH header inside	Corrosion by deteriorated water condition and dead drain during outage	
	Bottom inside of Furnace headers, Economizer headers	Deposition of sludge and initiation of corrosion fatigue crack	
	Final SH header and Final RH header	Exfoliation of steam oxide scale of header inside	
	Representative 2 or more headers inside	Low cycle fatigue Erosion	Periodic inspection (every 4years)
Chemical analysis of deposit		Deposition	
	Bottom inside of Furnace headers, Economizer headers	Deposition of sludge and initiation of corrosion fatigue crack	Include in the periodic inspection plan systematically
VT, Dimension measurement of corrosion	Stub outside of Economizer header	Low temperature corrosion	
Thickness measurement	Stub tubes of Final SH header and Final RH header	Thinning by high temperature corrosion	

Japanese Boiler Inspection (Header (2))

Header (Water wall header, Evaporator header, Economizer header, SH header, RH header)

Inspection measure	Portion	Deterioration factors	Inspection interval
DPT (MPI)	Representative stubs with no flexible structure and no rounding of weld end toe	Low cycle fatigue	Periodic inspection (every 2years)
	Stub weld of furnace headers, SH headers and RH headers.	Low cycle fatigue	Include in the periodic inspection plan systematically
	Support metal weld of furnace headers, SH headers and RH headers.	Low cycle fatigue	
	Representative header stub weld	Low cycle fatigue	After 80,000 hours operation (Precise
MPI	Representative header girth weld and seam weld	Creep	
Remaining life assessment	Most damaged header or pipe beyond 450°C among furnace headers among SH headers or main steam pipe among RH headers or hot reheat pipe.	Creep	To extend periodical inspection interval 2 year to 4year after 100,000 hours operation
	High temperature Header and pipe	Creep	Include in the periodic inspection plan systematically, taking into consideration of operation hours, start and stop times and designed life.

Japanese Boiler Inspection (Example (1))

Components	Inspected portion	degradation factor	Inspection method	Quantity	Note
Drum	Drum and stub	Corrosion loss, pitching	VT、DPT	1set	
	Stub, longitudinal and circumferential weld	Thermal fatigue crack	VT、DPT	1set	
Furnace	Water wall tube	Erosion thinning	VT、UT	2,000points(*1)	Thickness measurement Risidual life asessment
		High temperature corrosion loss	Sampling tube examionation (tube dimention, hardness, microstructure, adhearing scale volume)	4tubes	Tube sampling Risidual life asessment
	Welding portion of tube with attached metal	Thermal fatigue crack	VT、DPT	200points*(1)	
Furnace header	Headr inside	Scale deposition	VT (Fiber scope)	10 headers	
	Circumferntial weld	Thermal fatigue crack	VT, MPI, Replica	3points	Risidual life asessment
	Stub, Stub weld portion	Thermal fatigue crack	VT, DPT	360points(*1)	
SH	Tube	High temperature corrosion loss	VT、UT	300points(*1)	Thickness measurement Risidual life asessment
		Creep	Sampling tube examionation (tube dimention, hardness, microstructure, adhearing scale volume, creep rupture test)	1 tube	Tube sampling Risidual life asessment
		SUS scale deposit	Induction method	1200 points (*1)	
	Disimilar weld	Creep fatigue crack	VT, DPT	40points (*1)	
	Welding portion of tube with attached metal	Thermal fatigue crack	VT、DPT	60points (*1)	
SH header	Headr inside	Scale deposition	VT (Fiber scope)	3 headers	
	Circumferntial weld	Thermal fatigue crack	VT, MPI, Replica	3points	Risidual life asessment
	Stub, Stub weld portion	Thermal fatigue crack	VT, DPT	60points (*1)	

Japanese Boiler Inspection (Example (2))

Components	Inspected portion	degradation factor	Inspection method	Quantity	Note
RH	Tube	High temperature corrosion loss	VT、UT	3000points (*1)	Thickness measurement Risidual life asessment
		Creep	Sampling tube examionation (tube dimention, hardness, microstructure, adhearing scale volume, creep rupture test)	1tube	Tube sampling Risidual life asessment
	Disimilar weld	Creep fatigue crack	VT, DPT	40points (*1)	
	Welding portion of tube with attached metal	Thermal fatigue crack	VT、DPT	80points (*1)	
RH header	Headr inside	Scale deposition	VT (Fiber scope)	1header	
	Circumferntial weld	Thermal fatigue crack	VT, MPI, Replica	3points	Risidual life asessment
	Stub, Stub weld portion	Thermal fatigue crack	VT, DPT	680points (*1)	
Economizer	Tube	Erosion thinning Corrosion loss	VT、UT	100points (*1)	Thickness measurement Risidual life asessment
Economizer header	Headr inside	Scale deposition	VT (Fiber scope)	1header	
	Stub, stub weld	Thermal fatigue crack	VT DPT	40points (*1)	
Main pipe					
Main steam pipe	Longitudinal and circumferential weld	Creep, Creep fatigue	VT, MPI, Replica	3points	Risidual life asessment
Hot reheat pipe	Longitudinal and circumferential weld	Creep, Creep fatigue	VT, MPI, Replica	3points	Risidual life asessment
Boiler circulation pump	Casing, liner	Corrosion/attrition, thermal fatigue crack	VT、PT、MT	1pump	
	Motor coil (pump in water)	Degradation of electrical insulation	Electrical resistivity measurement	1pump	
Air heater	Element	Corrosion/attrition	VT, Weight measurement, Pack pressure measurement	4sector	Risidual life asessment

※1: Quantity is 60% of capacity 700MW (Suoer crytical boiler)

The Study
on
Enhancing Efficiency of Operating
Thermal Power Plants in NTPC-India

Boiler Remaining Life Assessment Inspection Report

JICA Study Team (Kyusyu Electric Power Co.,Inc.)
Kyudensangyo Co.,Inc

January 2010

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Table of content II -2 〔Unchahar #2〕

Inspection at Singrauli #6

Boiler residual life assessment was carried out as one of the activities to improve the efficiency of coal-fired thermal power plants in NTPC-India and transfer to counterpart the technology.
Boiler residual life assessment results are reported as follows.

1. Unit for evaluation

Singrauli Super Thermal Power Station #6 unit

2. Operation condition

(1) Cumulative operation hours: 172,000 hours

(2) Cumulative start and stop times: 309 times

3. Summary of residual life assessment results

The highest creep life consumption ratio among evaluated pipes and headers were 80% at Main Steam Pipe-Left (Circumferential weld, intrados) with the evaluated residual life 21,000 hours and 70% at Main Steam Pipe-Left (Circumferential weld, extrados) with the evaluated residual life 37,000 hours accompanied by microstructural degradation, though no direct creep damage was observed such as creep void and creep strain. The evaluated residual life for the other components was 105,000 hours or more.

It is recommended that the residual life assessment for Main Steam Pipe be carried out again before reaching the evaluated residual life.

Residual life assessment results by microstructural comparison method

Components	Location	Max. creep life consumption ratio (%)	Min. Evaluated residual life (h)	Evaluated region
Platen SH Outlet Header-Left	Circumferential weld at left side	38	140,000	Fine grain HAZ
De-Super heater-Left	Circumferential weld	45	100,000	Coarse grain HAZ
De-Super heater-Right	Circumferential weld	45	100,000	Coarse grain HAZ
RH Outlet Header-Left	Circumferential weld at left side	20	340,000	Coarse grain HAZ
RH Outlet Header-Right	Circumferential weld at right side	6	1,300,000	Base Metal
Main Steam Pipe-Left	Circumferential weld,extrados	70	37,000	Base Metal
Main Steam Pipe-Left	Circumferential weld,intrados	80	21,000	Fine grain HAZ

4. Summary of the other inspection results

(1) Visual inspection

- As results of visual inspection of boiler inside and penthouse, the decrease in thickness by erosion for Water wall tubes around short soot blower and the decrease in thickness by attrition of Platen SH binding tubes and cooling spacer tube in Platen SH were observed.
- Disorder of panel arrangement with distortion was observed at lower part of in Platen SH and RH.
- No appearance abnormality was observed in stubs and the other weld portions for headers in penthouse.

(2) Thickness measurement

- As a result of thickness measurement for Water wall tubes at erosion area around short soot blowers near each 4 corner (71points in total), the measured thickness for a number of tubes (min. 3.7mm) was less than tsr (thickness required) 5.5mm calculated with designed OD, pressure and allowable stress at the designed temperature.
- As a result of thickness measurement for mainly for outer tubes of rear side portion at soot blower level and outer bottom tubes of Platen SH tube (50points in total), no measured thickness value was found to be below the designed value.

(3) OD measurement

- As a result of OD measurement of Platen-SH outlet header-left, De-Super heater (left&right), RH outlet header (left&right) and Main Steam Pipe-left, the increase in measured OD to designed value was less than 1% for each component, indicating no remarkable creep strain

(4) SUS scale deposition inspection

- As a result of SUS scale deposition inspection for mainly outermost tubes of Platen-SH and RH 50 points for each, 5 portions were 15% fullness, 3 portions were 10% fullness and the others were less than 10% fullness of SUS scale deposition, indicating no remarkable SUS scale deposition.

(5) Dye penetrant inspection

- As a result of Dye penetrant inspection 4 stub weld portions of #5 panel from left of Platen SH inlet, a linear indication was found in tube side, which had disappeared after grinding off 1mm depth from surface.

(6) UT inspection

- As a result of UT inspection for RH outlet header-Right, no flaw echo judged as a crack was detected.

(7) TOFD inspection

- As a result of TOFD inspection at the location identical to UT inspection in RH outlet header-Right, no flaw echo judged as a crack was detected, although a number of flaw echoes from subtle blow holes and slag inclusions by welding were detected.

5. Components for residual life assessment and inspection

Components for residual life assessment and the other inspections are shown in Table I -1 and Table I -2 respectively.

Location and pictures for each inspection are shown in Fig. I -1 and Photo I -1～3 respectively.

Table I -1 Components for residual life assessment

Component	Location	Material		Designed				
				O.D.	t	Temperature	Pressure	
		ASME	JIS	(mm)	(mm)	(°C)	(MPa)	(kg/cm^2)
Platen SH Outlet Header-Left	circumferential weld at left side	SA335P12	STPA22	508.0	80.0	540	17.46	178.0
De-Suerheater-Left	Circumferential weld	SA335P12	STPA22	508.0	70.0	406	18.51	188.7
De-Suerheater-Right	Circumferential weld	SA335P12	STPA22					
RH Outlet Header-Left	Circumferential weld at left side	SA335P22	STPA24	558.8	50.0	540	4.26	43.5
RH Outlet Header-Right	Circumferential weld at right side	SA335P22	STPA24					
Main Steam Pipe-Left	Circumferential weld, extrados sid	SA335P22	STPA24	520.0	85.0	540	17.46	178.0
Main Steam Pipe-Left	Circumferential weld, intrados side	SA335P22	STPA24					

Table I -2 Components for the other inspections

Components	Inspection method
Water wall tube	Visual inspection
	Thickness measurement of tubes
Platten SH tube	Visual inspection
	Thickness measurement of tubes
	SUS scale deposition inspection
	Tube sampling for sample tube inspection
	Creep rupture test
Reheater tube	Visual inspection
	SUS scale deposition inspection
	Tube sampling for sample tube inspection (inspected in Japan).
	Creep rupture test for 1 tube with 1m length.
Super heater header	Visual inspection
	DPT
	Replica inspection
De-Superheater pipe	Replica inspection
Reheater header	Visual inspection
	Replica inspection
	UT
	TOFD
Main steam pipe (near the stop valve weld joint)	Replica inspection

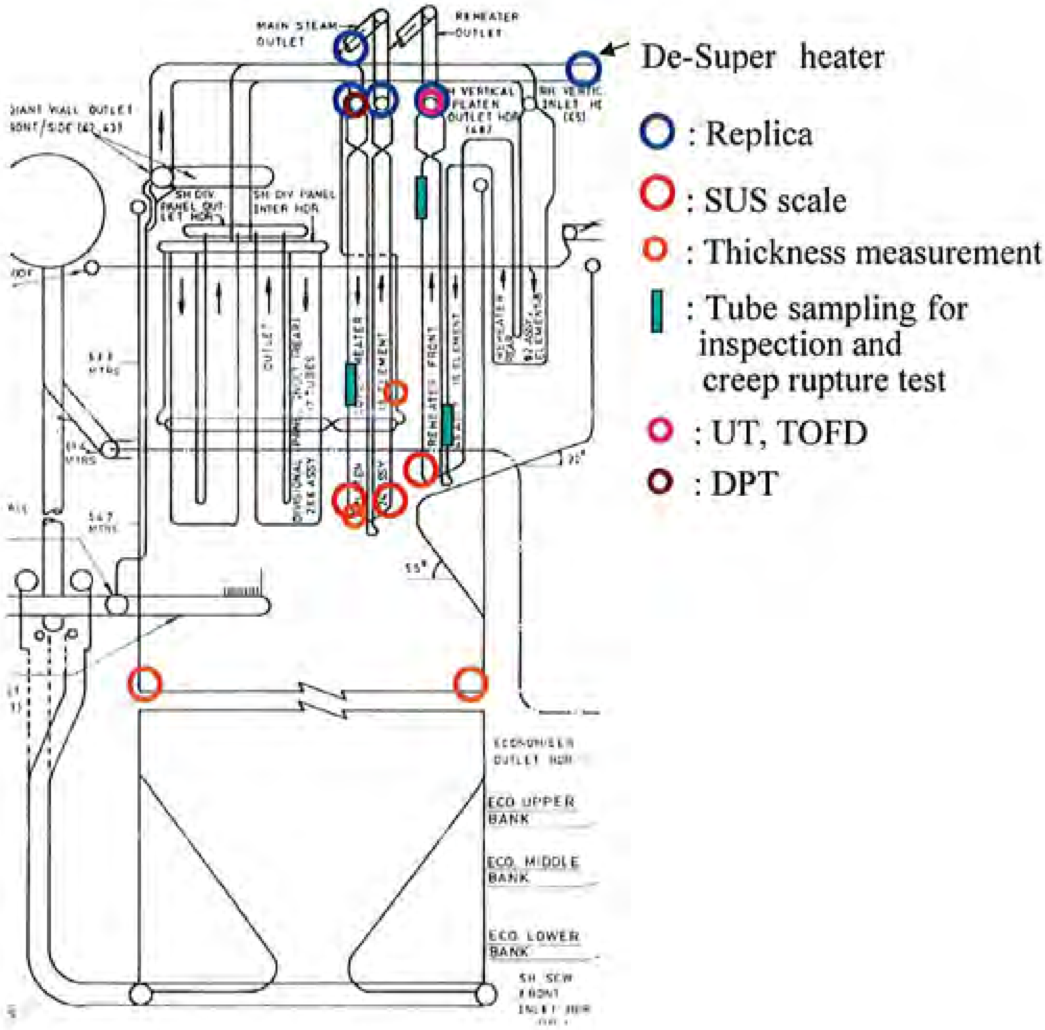


Fig. Ⅰ-1 Location for each inspection

6. Items for residual life assessment

Items for residual life assessment by microstructural comparison method are shown in Table I -3.

Table I -3 Items for residual life assessment

Components	Location	Material	Area	Microstructure	Carbide precipitation	Creep void grade	Average diameter of grainboundary precipitates	Average volume fraction of grainboundary precipitates	Precipitates free band width along grainboundary
Platen SH Outlet Header-Left	circumferential weld at left side	SA335P12	Base metal	O	O			O	
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				
De-Suerheater-Left	Circumferential weld	SA335P12	Base metal	O	O			O	
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				
De-Suerheater-Right	Circumferential weld	SA335P12	Base metal	O	O			O	
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				
RH Outlet Header-Left	Circumferential weld at left side	SA335P22	Base metal	O	O		O	O	O
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				
RH Outlet Header-Right	Circumferential weld at right side	SA335P22	Base metal	O	O		O	O	O
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				
Main Steam Pipe-Left	Circumferential weld,extrados	SA335P22	Base metal	O	O		O	O	O
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				
Main Steam Pipe-Left	Circumferential weld,intrados	SA335P22	Base metal	O	O		O	O	O
			Intercritical zone	O					
			Fine grain HAZ	O	O		O	O	
			Coarse grain HAZ	O	O	O			
			Weld metal	O	O				

(1) Microstructure evaluation

The existence of crack and microstructural degradation was inspected by optical microscope observation.

(Observed region)

Base metal, Intercritical zone, Fine grain HAZ, Coarse grain HAZ, Weld metal

(Observed magnification)

×500(2 views), ×1000(4 views) for each region

(2) Carbide precipitation evaluation

Morphology and distribution of precipitates were inspected by TEM (Transmission Electron Microscope) observation.

(Observed region)

Base metal, Intercritical zone, Fine grain HAZ, Coarse grain HAZ, Weld metal

(Observed magnification)

Main steam pipe ; ×1000 (2 views), ×5000(3 views), ×10000(2 views)

Other components ; ×2000 (2 views), ×10000(4 views)

(3) Creep void grade evaluation

The existence of micro crack and creep void was inspected by SEM (Scanning Electron Microscope) observation.

(Observed region)

Fine grain HAZ, Coarse grain HAZ, Weld metal (Evaluation was focused on Coarse grain HAZ).

(Observed magnification)

×500, ×2000 for each region (3 views for each)

(4) Quantitative evaluation of average diameter and volume fraction of grain boundary precipitates

Average diameter and volume fraction of grain boundary precipitates were evaluated quantitatively by SEM observation.

(Observed region)

Base metal, Fine grain HAZ

(Observed magnification)

Base metal ; ×3000, Fine grain HAZ ; ×4000 (6 views for each)

(5) Quantitative evaluation of precipitates free band width along grain boundary

Precipitates free band width along grain boundary were evaluated quantitatively by TEM observation.

(Observed region)

Base metal

(Observed magnification)

Base metal ; ×2000 (10 points evaluated in 6views)

7. Results of each observation and quantitative evaluation

7-1 Replica・extracted replica observation

(1) Platen SH Outlet Header-Left (Base metal at left side (SA335P12)

(Microstructure observation)

The results of microstructure observation are shown in Photo I -4-1.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal and intercritical zone.

(Grain boundary precipitates observation)

The results of grain boundary precipitates observation are shown in Photo I -4-10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation)

The results of precipitates distribution observation are shown in Photo I -4-13.

The summary of observation results is shown in Table I -6.

- Precipitates free zone along grain boundary and attenuated plate-shaped precipitates were observed in base metal.

(2) Platen SH Outlet Header-Left (circumferential weld at left side (SA335P12)

(Microstructure observation)

The results of microstructure observation are shown in Photo I -4-2～6.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal and intercritical zone and fine grain HAZ.
- Rod-shaped precipitates were observed in ferrite grain of base metal.

(Creep void observation)

The results of creep void observation are shown in Photo I -4- 7～9.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates observation are shown in Photo I -4-11～12.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation)

The results of precipitates distribution observation are shown in Photo I -4-14～17.

The summary of observation results is shown in Table I -6.

- Precipitates free zone along grain boundary and attenuated plate-shaped precipitates were observed in base metal.
- Disintegration of bainite structure was observed in base metal.

(3) De-Suerheater-Left (circumferential weld (SA335P12))

<u>(Microstructure observation)</u>

The results of microstructure observation are shown in Photo I -5-1～5.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal, intercritical zone, fine grain HAZ and coarse grain HAZ.
- Coarse granular precipitates were observed in coarse grain HAZ.

<u>(Creep void observation)</u>

The results of creep void observation are shown in Photo I -5-6～8.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

<u>(Grain boundary precipitates observation)</u>

The results of grain boundary precipitates observation are shown in Photo I -5-9～10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

<u>(Precipitates distribution observation)</u>

The results of precipitates distribution observation are shown in Photo I -5-11～14.

The summary of observation results is shown in Table I -6.

- Attenuated plate-shaped precipitates were observed in base metal.
- Fine precipitates had disappeared in fine grain HAZ.

(4) De-Suerheater-Right (circumferential weld (SA335P12))

<u>(Microstructure observation)</u>

The results of microstructure observation are shown in Photo I -6-1～5.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal, intercritical zone, fine grain HAZ and coarse grain HAZ.
- Coarse granular precipitates were observed in coarse grain HAZ.

<u>(Creep void observation)</u>

The results of creep void observation are shown in Photo I -6-6～8.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

<u>(Grain boundary precipitates observation)</u>

The results of grain boundary precipitates observation are shown in Photo I -6-9～10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

<u>(Precipitates distribution observation)</u>

The results of precipitates distribution observation are shown in Photo I -6-11～14.

The summary of observation results is shown in Table I -6.

- Attenuated plate-shaped precipitates were observed in base metal.
- Fine precipitates had disappeared in weld metal.

(5) RH Outlet Header-Left (circumferential weld at left side (SA335P22))

(Microstructure observation)

The results of microstructure observation are shown in Photo I -7-1～5.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal, intercritical zone, fine grain HAZ and coarse grain HAZ.

(Creep void observation)

The results of creep void observation are shown in Photo I -7-6～8.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates observation are shown in Photo I -7-9～10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation)

The results of precipitates distribution observation are shown in Photo I -7-11～14.

The summary of observation results is shown in Table I -6.

- No remarkable degradation of precipitates distribution was observed.

(6) RH Outlet Header-Right (circumferential weld at right side (SA335P22))

(Microstructure observation)

The results of microstructure observation are shown in Photo I -8-1～5.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal, intercritical zone and fine grain HAZ.
- Precipitates free zone along grain boundary was observed in base metal.

(Creep void observation)

The results of creep void observation are shown in Photo I -8-6～8.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates observation are shown in Photo I -8-9～10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation)

The results of precipitates distribution observation are shown in Photo I -8-11～14.

The summary of observation results is shown in Table I -6.

- Precipitates free zone along grain boundary was observed in base metal.
- No remarkable degradation of precipitates distribution was observed.
- Fine precipitates had disappeared in fine grain HAZ, coarse grain HAZ and weld metal.

(7) Main Steam Pipe-Left (Circumferential weld, extrados (SA335P22))

(Microstructure observation)

The results of microstructure observation are shown in Photo I -9-1～5.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal, intercritical zone, fine grain HAZ and coarse grain HAZ.
- Precipitates free zone along grain boundary was observed in base metal and intercritical zone.

(Creep void observation)

The results of creep void observation are shown in Photo I -9-6～8.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates observation are shown in Photo I -9-9～10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation)

The results of precipitates distribution observation are shown in Photo I -9-11～14.

The summary of observation results is shown in Table I -6.

- Precipitates free zone along grain boundary was observed in base metal.

(8) Main Steam Pipe-Left (Circumferential weld, intrados (SA335P22))

(Microstructure observation)

The results of microstructure observation are shown in Photo I -10-1～5.

The summary of observation results is shown in Table I -4.

- Precipitates at gain boundary were observed in base metal, intercritical zone and fine grain HAZ.
- Precipitates free zone along grain boundary was observed in base metal and intercritical zone.

(Creep void observation)

The results of creep void observation are shown in Photo I -10-6～8.

The summary of observation results is shown in Table I -5.

- No creep void was observed in fine grain HAZ, coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates observation are shown in Photo I -10-9～10.

- Precipitates on grain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation)

The results of precipitates distribution observation are shown in Photo I -10-11～14.

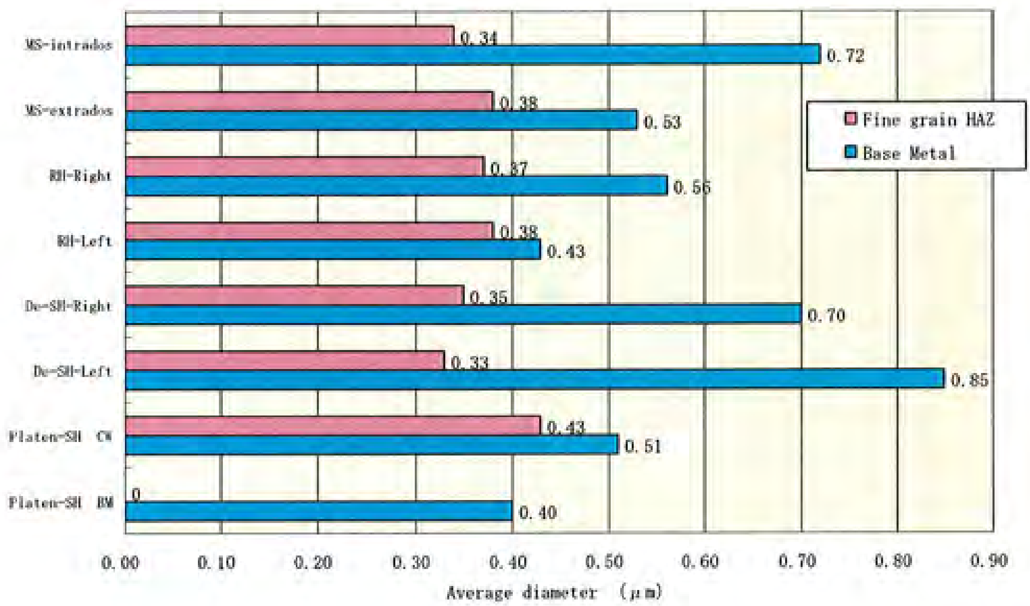
The summary of observation results is shown in Table I -6.

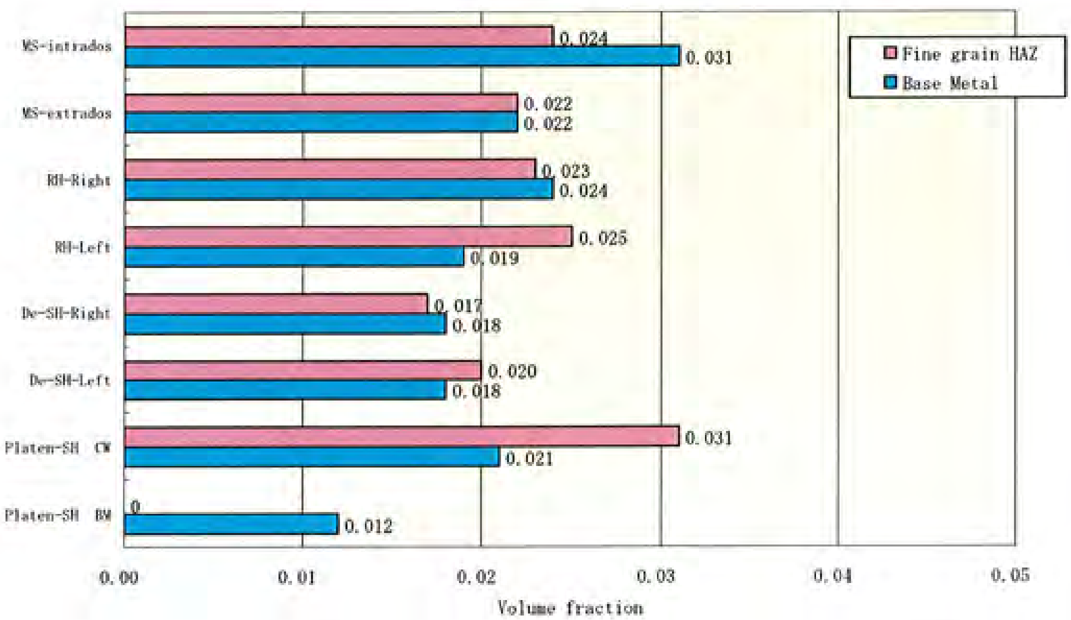
- Precipitates free zone along grain boundary was observed in base metal.
- Fine precipitates had disappeared in fine grain HAZ, coarse grain HAZ and weld metal.

7-2 Quantitative evaluation of grain boundary precipitates

The results of quantitative evaluation of grain boundary precipitates are shown in Table I -7.

- The Max. value of average diameter of grain boundary precipitates was 0.85 μm in base metal at De-Superheater-Left, 0.43 μm in fine grain HAZ at Platen-SH Outlet Header-Left circumferential weld.
- The max. value of volume fraction of grain boundary precipitates was 0.031 in base metal at Main Steam Pipe-Intrados, 0.031 in fine grain HAZ at Platen-SH Outlet Header-Left circumferential weld.



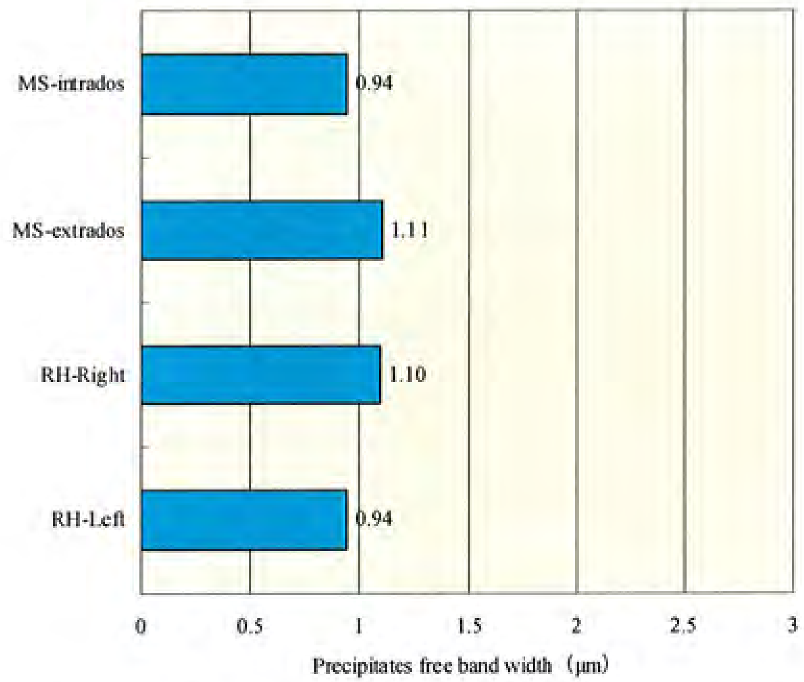


Quantitative evaluation of grain boundary precipitates〔extracted Table I -7〕

7-3 Quantitative evaluation of precipitates free band width along grain boundary

The results of quantitative evaluation of precipitates free band width along grain boundary are shown in Table I -8.

- The quantitative evaluation was focused on base metal of SA 335 P22.
- The Max. value of precipitates free band width along grain boundary was 1.11 μm at Main Steam Pipe-Extrados.



Precipitates free band width along grain boundary〔extracted Table I -8〕

8. Residual life assessment results

8-1 Operational condition of evaluated components

Operational condition of evaluated components are shown in Table I -9.

The evaluation stress σ was the hoop stress calculated with designed pressure, designed diameter D and thickness t of each component.

$$\sigma = P(D-t)/2t$$

where P : Designed pressure.

8-2 Evaluation results

Evaluation results of residual life assessment for each components by microstructural comparison method are shown in Evaluation Results I -1～7 and Table I -10. The summary of evaluation results are shown in Table I -11

- The high creep life consumption ratio was evaluated at Main Steam Pipe-Left with high evaluation stress portion.
- The creep life consumption ratio was 70% and the evaluated residual life was 37,000 hours at Main Steam Pipe-Left (Circumferential weld, extrados) with microstructural degradation that was observed as precipitates free zone along grain boundary in base metal.
- The creep life consumption ratio was 80% and the evaluated residual life was 21,000 hours at Main Steam Pipe-Left (Circumferential weld, intrados) with microstructural degradation that was observed as disappearance of fine needlelike precipitates.
- For the other components, the highest creep life consumption ratio was 45% and the evaluated residual life was 100,000 hours at De-Superheater (Left&Right).
- It is recommended that the residual life assessment for Main Steam Pipe is carried out again before reaching the evaluated residual life.

Table I -11 Summary of residual life evaluation results

Components	Location	Max. creep life consumption ratio (%)	Min. Evaluated residual life (h)	Evaluated region
Platen SH Outlet Header-Left	Circumferential weld at left side	38	140,000	Fine grain HAZ
De-Superheater-Left	Circumferential weld	45	100,000	Coarse grain HAZ
De-Superheater-Right	Circumferential weld	45	100,000	Coarse grain HAZ
RH Outlet Header-Left	Circumferential weld at left side	20	340,000	Coarse grain HAZ
RH Outlet Header-Right	Circumferential weld at right side	6	1,300,000	Base Metal
Main Steam Pipe-Left	Circumferential weld,extrados	70	37,000	Base Metal
Main Steam Pipe-Left	Circumferential weld,intrados	80	21,000	Fine grain HAZ

9. The other inspection results

9-1 Visual inspection, Thickness measurement

Visual inspection results for boiler inside are shown in Table I -12

(Erosion of water wall around short soot blower)

- Erosion by soot blower was observed at a number of Water wall tubes around short soot blower.
- The thickness measurement was carried out at the representative eroded portion (2nd short soot blower level) as shown in Table I -13∼16.
- Min.thickness was 3.7mm at a front wall tube around #1 short soot blower from right, that was less than tsr (thickness required) 5.5mm calculated with designed OD, pressure and allowable stress at the designed temperature.

Erosion of front wall tube
〔extracted from Table I -12〕

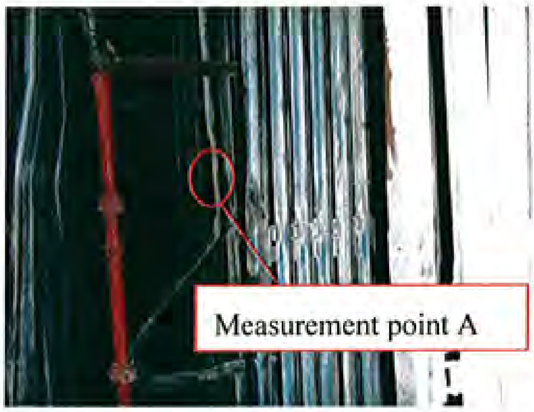
(Attrition of Platen-SH binding tube #4 and #5

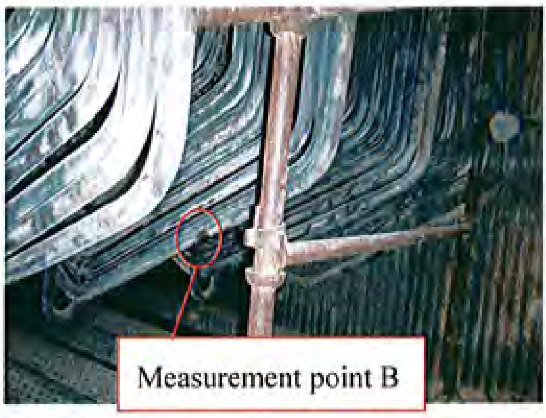
- Attrition of binding tube #4 and #5 with each other was found.
- The thickness measurement results are shown in Table I -17.
- Min.thickness was 2.8mm, that was far less than the designed value 6.5mm.

Attrition of binding tube [extracted from Table I -12]

(Thickness measurement of Platen-SH)

- Thickness was measured mainly for outer tubes of rear side portion at soot blower level and outer bottom tubes as shown in Table I -18.
- Min.thickness at soot blower level (measurement point A) was 6.3mm, that was not less than the designed value 6.3mm.
- Min.thickness at outer bottom tubes (measurement point B) was 9.8mm, that was larger than the designed value 9.5mm.





Thickness measurement portion of Platen-SH [extracted Table I -18]

(Attrition of cooling spacer tube with Platen-SH front tube of #14 panel)

- Attrition of a cooling spacer tube with Platen-SH front tube of #14 panel.
- The thickness measurement results are shown in Table I -17.
- Min.thickness was 5.0mm.

Attrition of cooling spacer tube〔extracted Table I -12〕

(Erosion of screen tubes near the ceiling between front RH panel and rear RH panel)

- Erosion of screen tubes at front side near the ceiling was found at left side of boiler.

Erosion of rear wall screen tubes〔extracted Table I -12〕

9-2 OD measurement results

OD measurement results of residual life evaluated portion are shown in Table I -19～22.

- The increase in measured average OD to designed value was less than 1% for each portion, indicating no remarkable creep strain.

Table I -23 OD measurement results of each portion
(Increase in measured average OD to designed value)

Components	Location	Material	(Averaged measured value-Designed OD) /Designed OD(%)
Platen SH Outlet Header-Left	Circumferential weld at left side	SA335P12	0.10
De-Superheater-Left	Circumferential weld	SA335P12	0.94
De-Superheater-Right	Circumferential weld	SA335P12	0.55
RH Outlet Header-Left	Circumferential weld at left side	SA335P22	0.37
RH Outlet Header-Right	Circumferential weld at right side	SA335P22	0.52
Main Steam Pipe-Left	Circumferential weld,extrados	SA335P22	0.08
Main Steam Pipe-Left	Circumferential weld,intrados	SA335P22	

9-3 SUS scale deposition inspection

Applied equipment and inspection condition are shown in Table I -24.

SUS scale deposition inspection were carried out at outer most tube bend portion and binding tube bottom bend portion of Platen-SH and RH as shown in Fig. I -2.

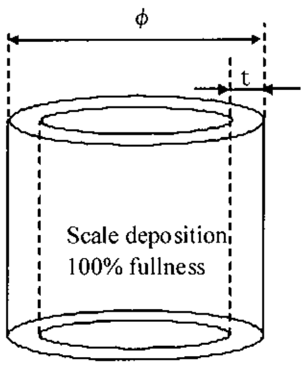
Table I -24 Applied equipment and inspection condition

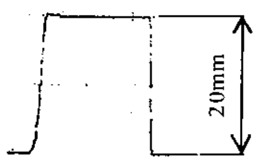
DETECTOR	MAKER・TYPE	UNI-ELECTRONICS,Inc. ・SSD－1
DETECTOR	I.D.№	34A3382(64SCA02101)
DETECTOR	CHECK DATE・PERSON	2009 June 5th ・Shinichi Aizawa
DETECTOR	VAIDITY DATE	2010 June 4th
RECORDER	MAKER・TYPE	HIOKI E. E. CORPORATION ・8205-10
RECORDER	I.D.No.	041213164(64SCZ05102)
RECORDER	CHECK DATE・PERSON	2009 May 28th ・Shinichi Aizawa
RECORDER	VAIDITY DATE	2010 May 27th ・Shinichi Aizawa

INSPECTION METHOD	Magnetized scale deposition inspection of tube inside with scale detector
INSPECTION METHOD	Refer to next page
SENSITIVITY LEVEL	The sensitivity is adjusted at 20mm in amplitude of signal with the probe touching right to the reference test piece filled with the white magnetic particle 100% fullness.
SCANNING SPEED	Approx. 0.3m/sec
RECORDING RANGE	1V/cm
RECORDING SPEED	2.5mm/sec
REFERENCE TEST PIECE	Platen SH outer most tube bend portion : ϕ 54.0× t 9.5 (I.D. No. : 50-21-1) Platen SH binding tube bottom bend portion : ϕ 47.6× t 6.3 (I.D. No : 40-14-1) RH outer most tube bend portion : ϕ 54.0× t 4.0 (I.D. No : 50-19-1) RH binding tube bottom bend portion : ϕ 54.0× t 4.0 (I.D. No : 50-19

REMARKS

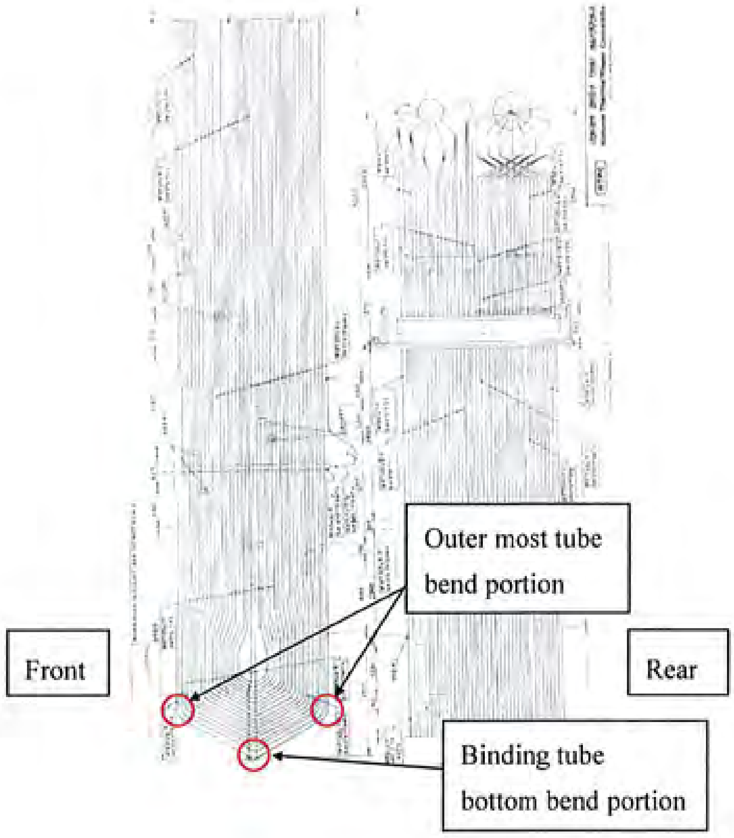
Shape of reference test piece and wave form



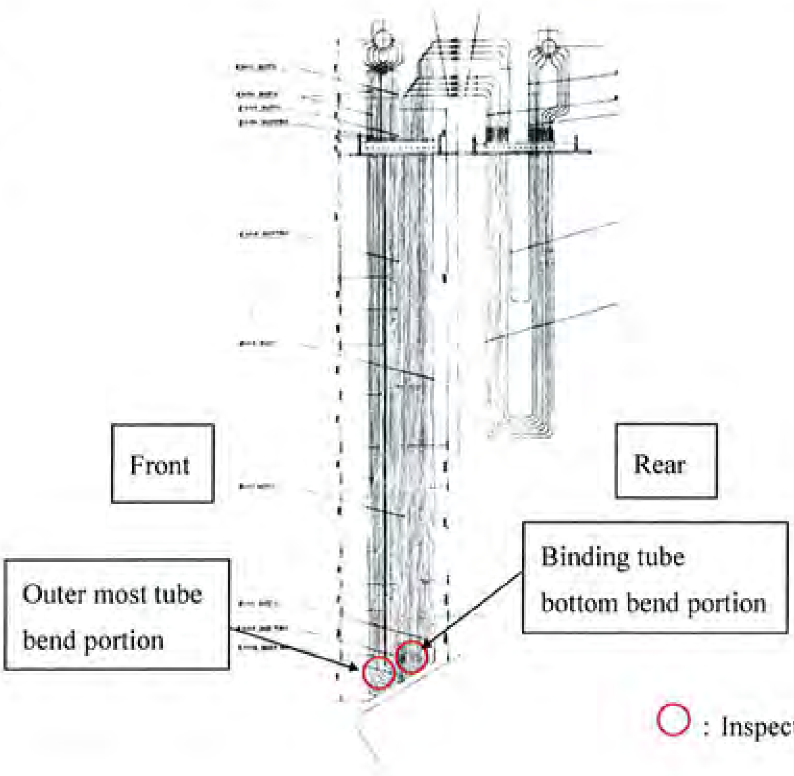


Wave form
by reference test piece

Platen-SH



RH



○ : Inspected point

Fig. I -2 Inspection location

SUS scale deposition inspection results are shown in Table I -25.

- 15% fullness of SUS scale deposition was detected at 4 outermost tubes of Platen-SH and 1 outermost tube of RH.
- 10% % fullness of SUS scale deposition was detected at 3 outermost tubes of Platen-SH.
- The others were less than 10% fullness of SUS scale deposition.

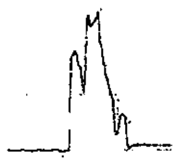
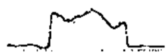
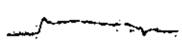
Table I -25 SUS scale deposition inspection results

Platen SH (outermost tube)				RH (outermost tube)	
Front		Rear		Front	
Panel No.	Fullness (%)	Panel No.	Fullness (%)	Panel No.	Fullness (%)
14	15	6	15	3	15
20	10	13	10		
21	15	18	10		
		21	15		

〔Remarks〕

The signal by magnetization of tube material with heat was recognized at front side outermost tubes in Platen-SH except #1,2,5,7～11 panel from left and at rear side tubes in Platen-SH except #7～11 from left.

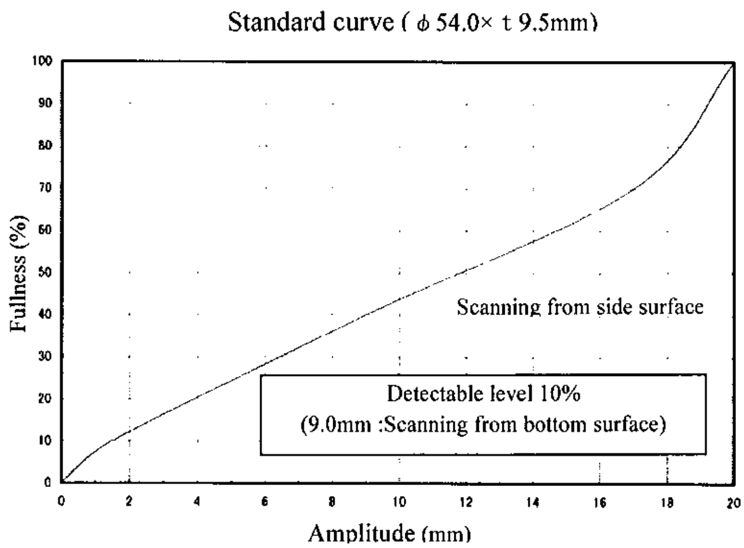
The representative deposition signal for this inspection is shown in Fig. I -3. The standard curve used is shown in Fig. I -4.

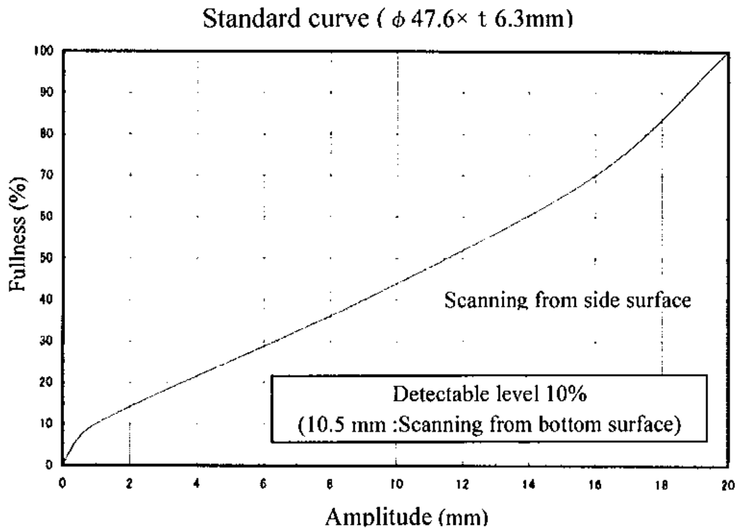
	Scanning from bottom surface	Scanning from side surface
Platen SH outermost tube front bend portion #14 panel Fullness 15%		
	Scanning from bottom surface	Scanning from side surface
Platen SH binding tube bottom bend portion #18 panel Fullness 0%		
	Scanning from bottom surface	Scanning from side surface
RH outermost tube front bend portion # 3 panel Fullness 15%		
	Scanning from bottom surface	Scanning from side surface
RH binding tube bottom bend portion #5 panel- a Fullness 0%		

Note) "a" indicates front tube in RH binding tubes,

Fig. I -3 The representative deposition signal

Fig. I -3 Representative deposition signal for this inspection





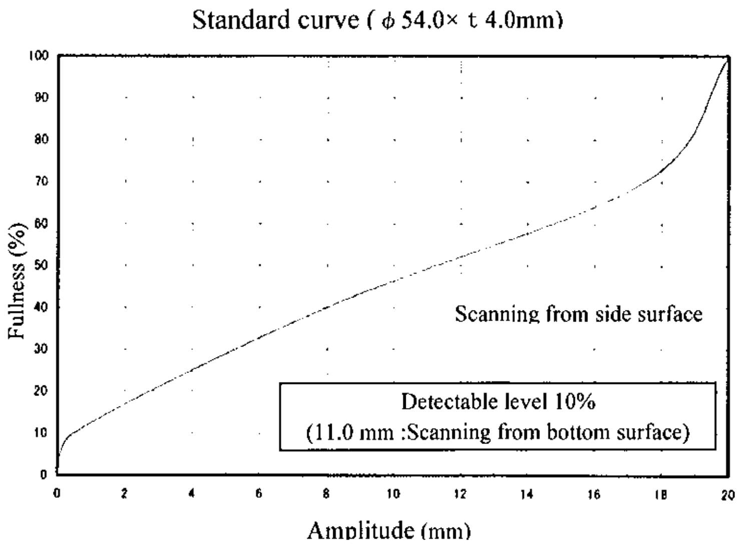


Fig. I -4 Standard curve used for evaluation

9-4 DPT

Applied material and inspection condition are shown in Table I -26.

Inspected location of DPT is shown in Fig. I -5.

DPT inspection were carried out at 4 stub weld portions of #5 panel from left in Platen SH inlet header front side.

Table I -26. Applied material and inspection condition

APPLIED MATERIAL

APPLIED MATERIAL	PENETRANT	BRAND	Eishin Kagaku Co., Ltd.
		MAKER	R-1A (NT)
	REMOVER	BRAND	Eishin Kagaku Co., Ltd.
		MAKER	R-1S (NT)
	DEVELOPER	BRAND	Eishin Kagaku Co., Ltd.
		MAKER	R-1M (NT)

EXAMINATION CONDITION

EXAMINATION METHOD	Liquid penetrant with removability for solvents - Drying development method
TIME TO EXAMINATION	at periodic inspection
TEMPERATURE OF EXAMINATION SURFACE	Normal temperature (10～50℃)
EXAMINATION SURFACE CONDITION	As weld
PRE-TREATMENT	■Rinse with solvents □Others ( )
PENETRATION METHOD	■Spray □Brush painting □Dipping □Others ( )
PENETRATION TIME	10 minutes
REMOVING OF EXTRA PENETRANT	■Wipe out with wes (using solvent) □Others ( )
DEVELOPMENT METHOD	■Spray □Brush painting □Dipping □Others ( )
DEVELOPMENT TIME	10 minutes
ILLUMINANCE OF EXAMINATION SURFACE／ILLUMINANCE OF ENVIRONMENT	500Lux or more

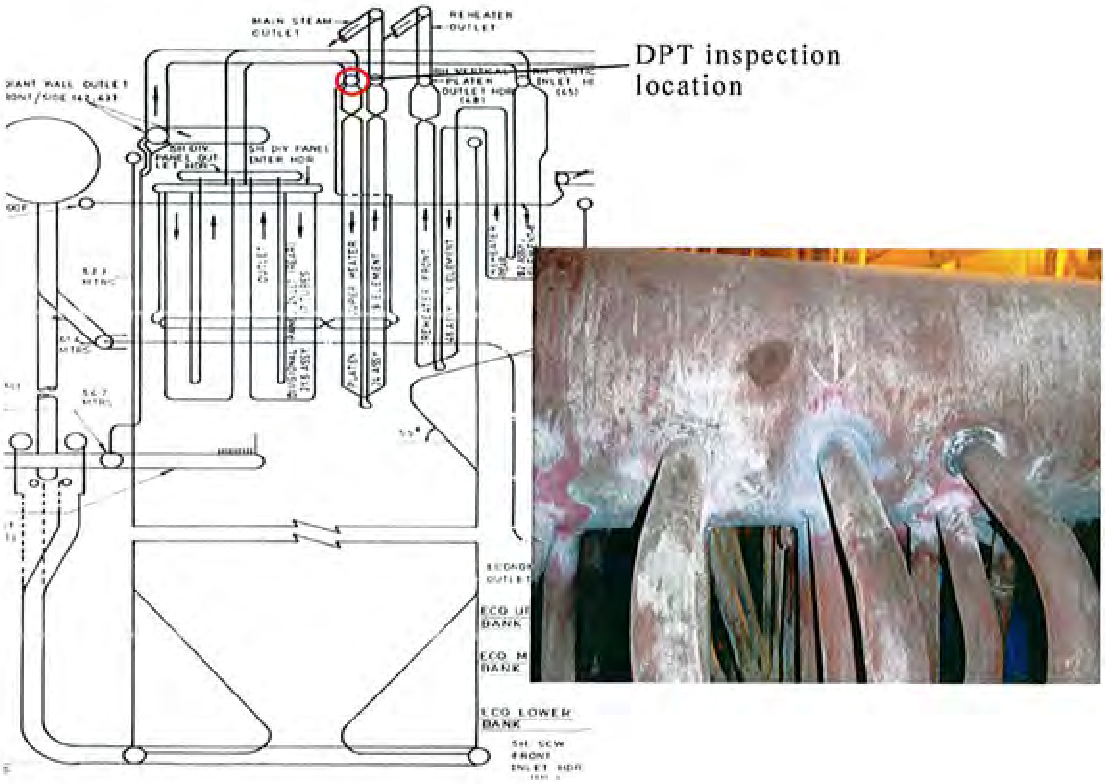


Fig. I -5 DPT inspection location

An indication with 2mm in length was found in 3rd stub weld portion from front. The indication disappeared after grinding off the tube 1mm in depth.

Before grinding off

After grinding off

9-5 UT

Applied equipment and inspection condition are shown in Table I -27.

Inspected location of UT is shown in Fig. I -6.

UT inspection was carried out at circumferential weld of left RH outlet header.

Table I -27 Applied equipment and inspection condition

APPLIED EQUIPMENT AND MATERIAL

FLAW DETECTOR	MAKER・TYPE	GE INSPECTION TECHNOLOGIES ・ USM35X		
	SERIAL No.(I.D.№)	994a(61UAA06110)		
	AMPLITUDE LINEARITY	within ±3%		
	TIME SCALE LINEARITY	within ±1%		
	MARGIN OF DETECTION SENSITIVITY	40dB or more		
	CHECK DATE・PERSON	2008 November 20th ・ Hidekazu Ishihara(UT-2)		
	VAIDITY DATE	2009 November 19th		
PROBE	TYPE	angle beam probe		
	DESIGNATION	2C14×14A70		
	MAKER	KGK		
	SERIAL No.	XA7424		
	DEAD ZONE	18mm		
	STB ANGLE OF REFRACTION	70 degree		
	ACCESIBLE LIMIT DISTANCE	17mm		
	FAR SURFACE RESOLUTION	7mm		
	CHECK DATE・PERSON	2009 August 26th Ishizaki (UT-2)		
	VAIDITY DATE	2010 February 25th		

EXAMINATION CONDITION

EXAMINATION METHOD	Single angle beam probe technique
TIME TO EXAMINATION	at periodic inspection
SURFACE CONDITION	Grinded surface
COUPLANT	Sonicoat
SPECIFIED SENSITIVITY	RB-41 №2 ϕ 3.0mm side cylindrical hole: H-line
SENSITIVITY CORRECTION	Non
DISREGARD LEVEL	Regarded as flaw that echo hight is over DAC(H-line)
ACCEPTANCE CRITERIA	Flaw length with t/3 or less
REFERENCE BLOCK OR CALIBRATION BLOCK	RB-41 №2
ANGLE OF REFRACTION IN TEST OBJECT	ANGLE OF REFRACTION : — CALCULATION METHOD : ☐ Ratio of sound velocity of STB ☐ V path technique

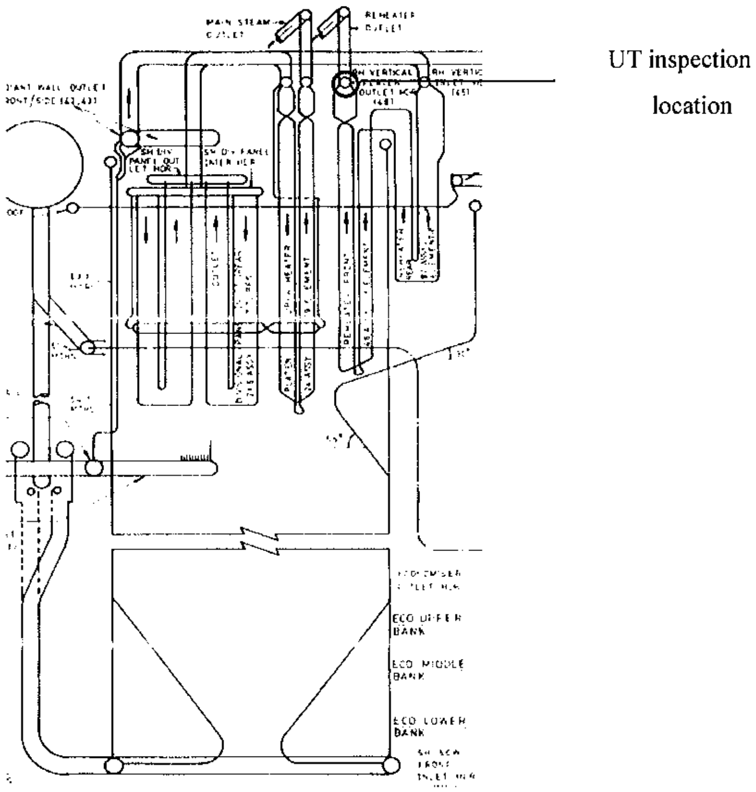


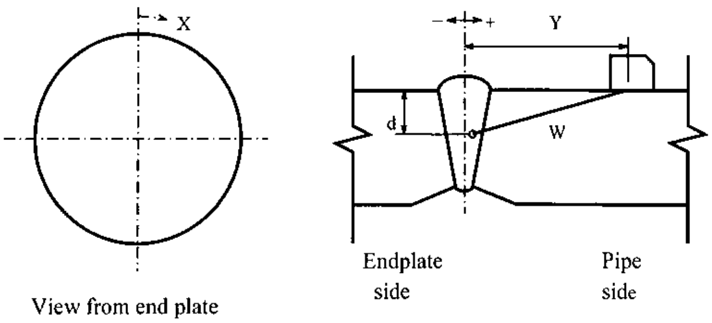
Fig. I -6 Inspected location of UT

UT detection results are shown in Table I -28.

No flaw echo exceeded criteria was detected, although 4 flaws exceeded L-line were detected as shown in Table I -28. In Table I -28, symbols are described in the figure shown below.

Table I -28 Detected flaw list

Flaw №	X	Y	W	d	k	Region of echo height	l
1	582	93	104.6	37.5	-4.7	II	10
2	820	122	129.2	46.3	1.4	III	34
3	^{0}940	51	26.8^{k}	9.6	26	II	6
4	1110	101	101.3	36.3	6.4	II	8



9-6 TOFD

Applied equipment and inspection condition are shown in Table I -29.

Table I -29 Applied equipment and inspection condition

APPLIED EQUIPMENT AND MATERIAL

FLAW DETECTOR	MAKER・TYPE	OLYMPUS NDT μ-Tomoscan
	SERIAL No.(I.D.№)	23918-15(71UAA96105)
PROBE	DESIGNATION	5MHz、 φ 1/4inch
	WEDGES	60°
	MAKER	GE INSPECTION TECHNOLOGIES
	SERIAL No.	00CP4M,00B25K

EXAMINATION CONDITION

EXAMINATION METHOD	TOFD technique
TIME TO EXAMINATION	at periodic inspection
SURFACE CONDITION	Grinded surface
COUPLANT	Sonicoat
SPECIFIED SENSITIVITY	φ 4.8mm side cylindrical hole ((d=40mm):80%+6dB
SENSITIVITY CORRECTION	Non
DISREGARD LEVEL	――――――

TOFD inspection was carried out at the location identical to UT inspection.

The range of X : 300～600mm and 900～1200mm in circumferential direction was not detectable because of the interference of attached objects.

TOFD detection results are shown in Fig. I -7～10.

No flaw echo judged as a crack was detected, although a number of flaw echoes from subtle blow holes and slag inclusions by welding were detected.

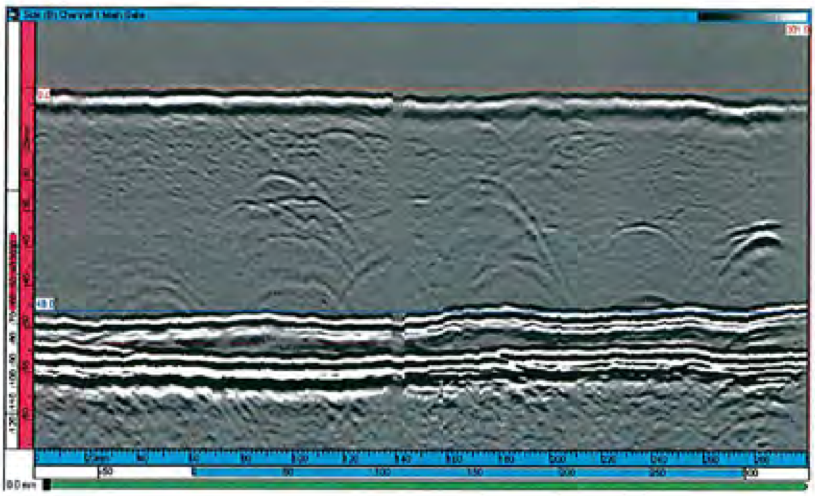


Fig. I -7 X=0～300mm TOFD detection results

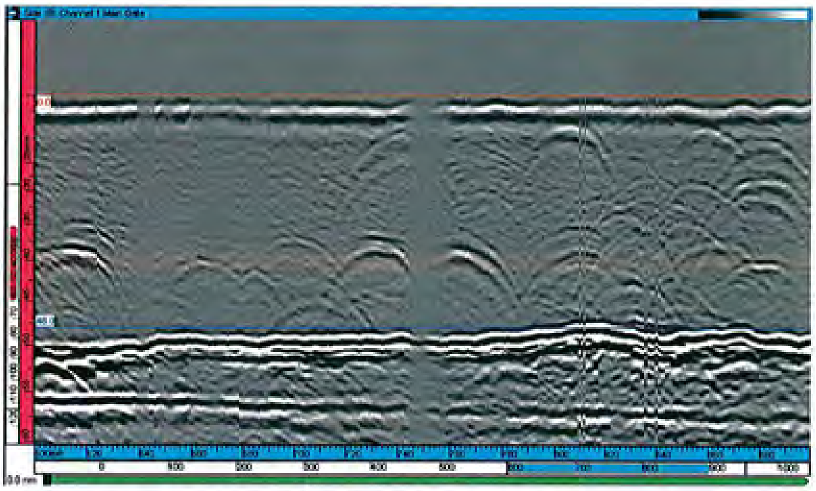


Fig. I -8 X=600～900mm TOFD detection results

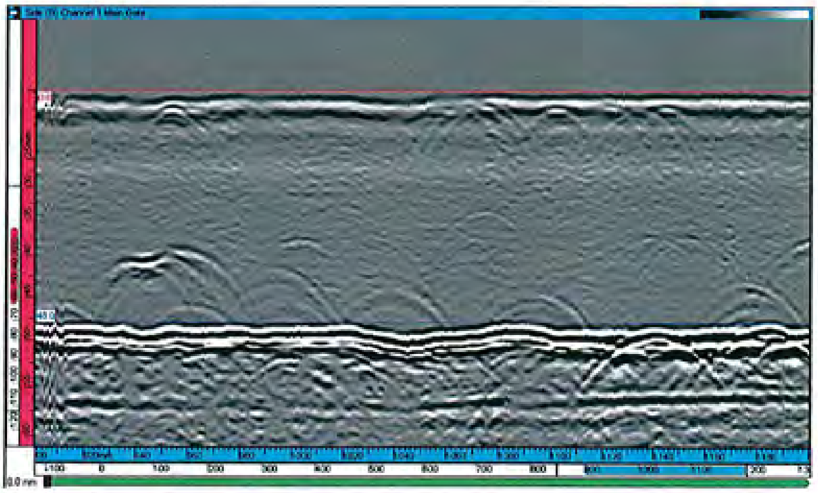


Fig. I -9 X=1200～1500mm TOFD detection results

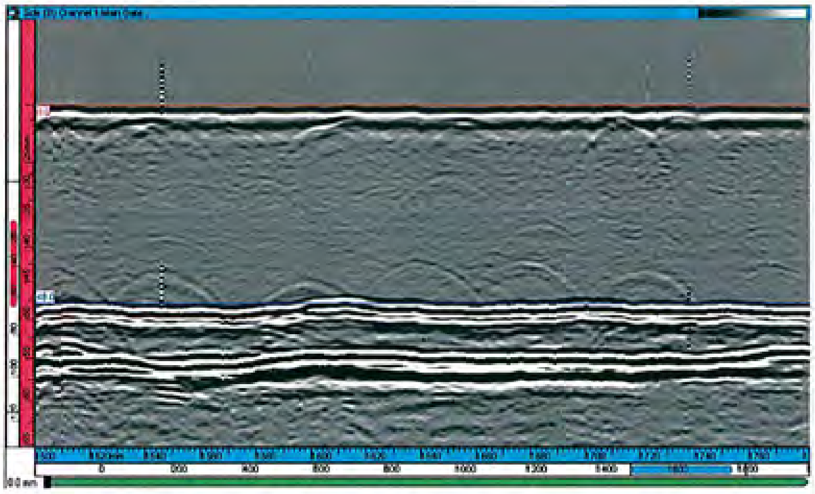
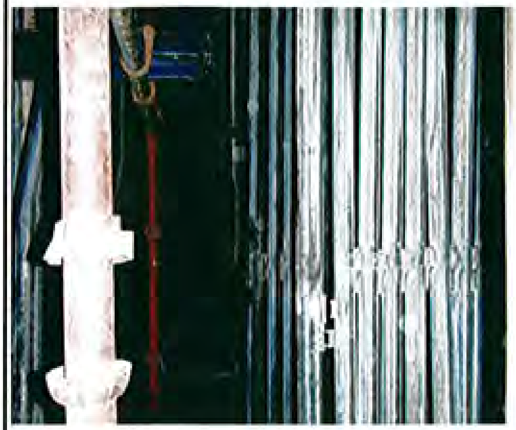


Fig. I -10　X=1500～1780mm TOFD detection

Water wall around short soot blower

・Visual inspection ・Thickness measurement

Platen SH at soot blower level

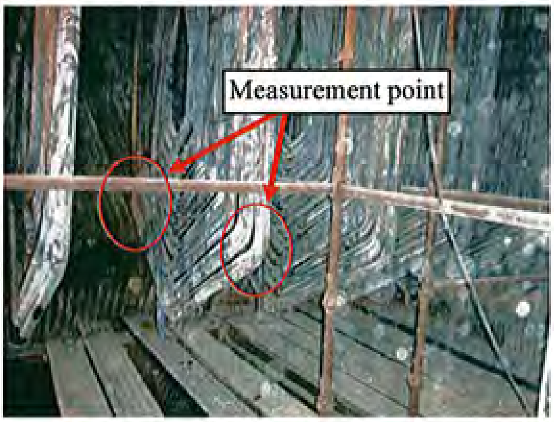


・Visual inspection ・Thickness measurement

Platen SH tube sampling location

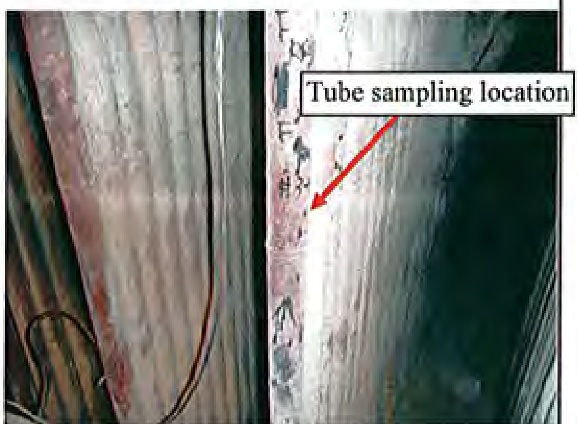
・Sample tube inspection
・Creep rupture test

Platen SH SUS scale mesurement point



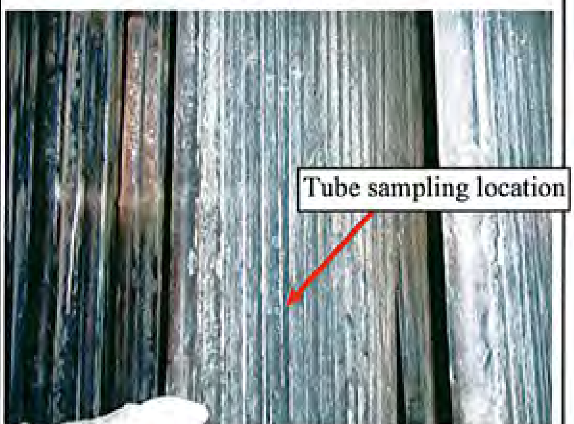
・SUS scale deposition inspection

RH(in penthouse) tube sampling location



・Sample tube inspection
・Creep rupture test

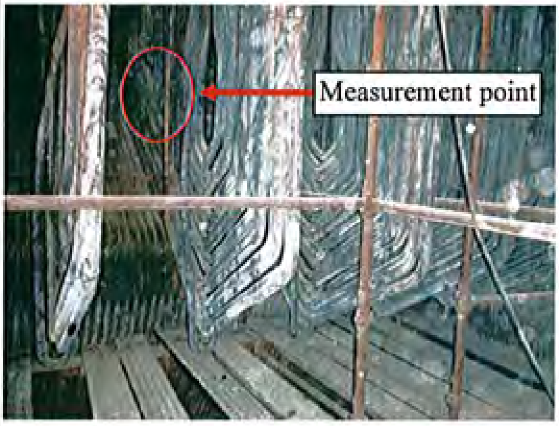
RH(in furnace) tube sampling location



・Sample tube inspection
・Creep rupture test

Photo I -1 Inspection location

RH SUS scale mesurement point

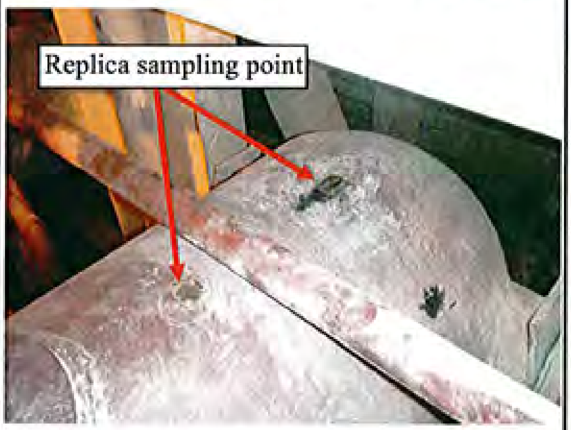


・SUS scale deposition inspection

Platen SH Inlet Header

・DPT

Platen SH Outlet Header(Boiler left side)

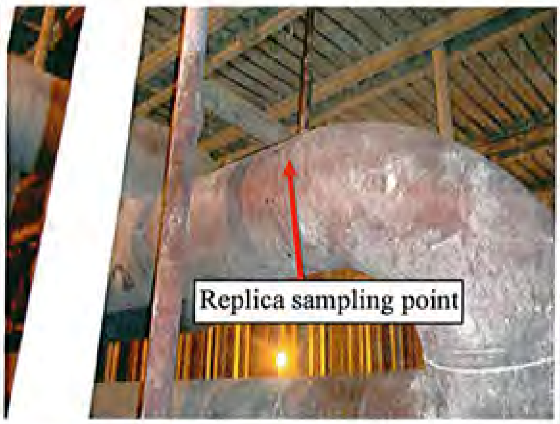


・Replica inspection ・OD measurement

De-superheater(Boiler left side)

・Replica inspection ・OD measurement

De-superheater(Boiler right side



・Replica inspection ・OD measurement

RH Outlet header(Boiler left side

・Replica inspection ・OD measurement

Photo I -2 Inspection location

RH Outlet header(Boiler right side)

・Replica inspection ・OD measurement
・UT ・TOFD

Main Steam Pipe-Left (extrados)

・Replica inspection ・OD measurement

Main Steam Pipe-Left (intrados)

・Replica inspection ・OD measurement

Photo I -3 Inspection location

Table I -4 Microstructure observation resuluts

Components	Location		Observed region	OM (Optical microscope observation) Microstructural features: Precipitation at gain boundary	Precipitates free zone along grain boundary	Granular precipitates in ferrite grain	Rod-shaped precipitates in ferrite grain	Granular precipitates	Coarse granular precipitates
Platen SH outlet header (SA 335 P12)	Left outlet header	Base metal	Base metal	Appeared	Not appeared	No precipitation	Not appeared		
Platen SH outlet header (SA 335 P12)	Left outlet header	Circumferential weld	Base metal	Appeared	Not appeared	No precipitation	Not appeared		
Platen SH outlet header (SA 335 P12)	Left outlet header	Circumferential weld	Intercritical zone	Appeared				Appeared	Not appeared
Platen SH outlet header (SA 335 P12)	Left outlet header	Circumferential weld	Fine grain HAZ	Appeared					Not appeared
Platen SH outlet header (SA 335 P12)	Left outlet header	Circumferential weld	Coarse grain HAZ	Not appeared					Not appeared
Platen SH outlet header (SA 335 P12)	Left outlet header	Circumferential weld	Weld metal					Appeared	
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Base metal	Appeared	Not appeared	No precipitation	Not appeared		
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Intercritical zone	Appeared				Appeared	Not appeared
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Fine grain HAZ	Appeared					Not appeared
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Coarse grain HAZ	Appeared					Appeared
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Weld metal					Appeared	
De-Superheater pipe (SA 335 P12)	Right de superheater	Circumferential weld	Base metal	Appeared	Not appeared	No precipitation	Not appeared		
De-Superheater pipe (SA 335 P12)	Right de superheater	Circumferential weld	Intercritical zone	Appeared				Appeared	Not appeared
De-Superheater pipe (SA 335 P12)	Right de superheater	Circumferential weld	Fine grain HAZ	Appeared					Not appeared
De-Superheater pipe (SA 335 P12)	Right de superheater	Circumferential weld	Coarse grain HAZ	Not appeared					Appeared
De-Superheater pipe (SA 335 P12)	Right de superheater	Circumferential weld	Weld metal					Appeared	
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Base metal	Appeared	Not appeared				
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Intercritical zone	Appeared	Not appeared				
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Fine grain HAZ	Appeared					
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Coarse grain HAZ	Appeared					
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Weld metal						
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Base metal	Appeared	Appeared				
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Intercritical zone	Appeared	Not appeared				
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Fine grain HAZ	Appeared					
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Coarse grain HAZ	Not appeared					
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Weld metal						
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) extrados side	Base metal	Appeared	Appeared				
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) extrados side	Intercritical zone	Appeared	Appeared				
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) extrados side	Fine grain HAZ	Appeared					
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) extrados side	Coarse grain HAZ	Appeared					
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) extrados side	Weld metal						
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Appeared				
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Intercritical zone	Appeared	Appeared				
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Fine grain HAZ	Appeared					
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Coarse grain HAZ	Not appeared					
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Weld metal						
View nos. for each area				×500 (2 views) ×1000 (4 views)					

Table I -5 Creep void observation results

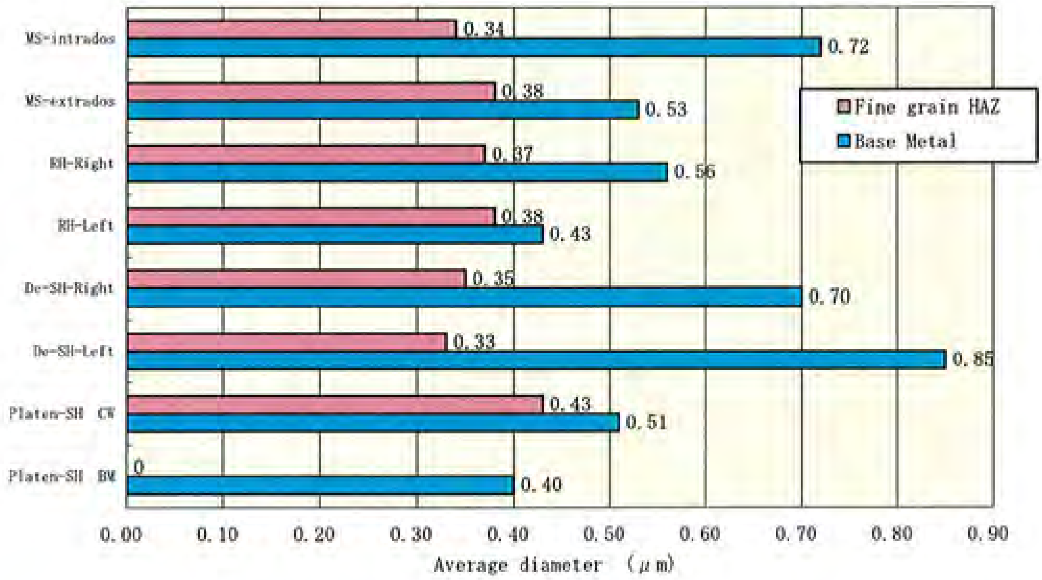
Components	Location		Observed region	SEM (Scanning Electron Microscope observation) Ceep void damage
Platen SH outlet header	Left outlet header	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
De-Superheater pipe	Left de superheat	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
	Right de superhea	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
Reheater outlet header	Left	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
	Right	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
Main steam pipe	Left	Circumferential weld (near the stop valve) extrados side	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
		Circumferential weld (near the stop valve) extrados side	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
View nos. for each area				×500 (3 views) ×2000 (3 views)

Table I -6 Precipitates distribution observation results

Components	Location		Observed region	TEM (Transmission Electron Microscope observation)							
				Precipitates features							
				Precipitates free zone along grain boundary	Featherlike precipitates	Fine needlelike and granular precipitates	Needlelike precipitates	Fine needlelike and granular precipitates in bainite grain	Bainite structure disintegration	Attenuated plate-shaped precipitates	Rod-shaped precipitates, spherodized precipitates
Platen SH outlet header (SA 335 P12)	Left outlet header	Base metal	Base metal	Appeared		Remaining in ferrite grain			Disintegrated	Appeared	
		Circumferential weld	Base metal	Not appeared		Remaining in ferrite grain			Disintegrated	Not appeared	
			Fine grain HAZ			Remaining				Not appeared	Coexist
			Coarse grain HAZ			Remaining					Coexist
			Weld metal			Remaining					
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Base metal	Not appeared		Remaining in ferrite grain			Normal structure	Appeared	
			Fine grain HAZ			Disappeared				Not appeared	Coexist
			Coarse grain HAZ			Remaining					Coexist
			Weld metal			Remaining					
	Right de superheater	Circumferential weld	Base metal	Not appeared		Remaining in ferrite grain			Normal structure	Not appeared	
			Fine grain HAZ			Remaining				Not appeared	Coexist
			Coarse grain HAZ			Remaining					Coexist
			Weld metal			Disappeared					
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Base metal	Not appeared	Remained		No decrease in ferrite grain	Remaining			
			Fine grain HAZ				Remaining				
			Coarse grain HAZ			Remaining					
			Weld metal			Remaining					
	Right	Circumferential weld	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Disappeared				
			Coarse grain HAZ			Disappeared					
			Weld metal			Disappeared					
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) extrados side	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Remaining				
			Coarse grain HAZ			Remained					
			Weld metal			Remained					
		Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Disappeared				
			Coarse grain HAZ			Disappeared					
			Weld metal			Disappeared					
View nos. for each area				×2000 (2 views), ×10000 (4 views)							

Table Ⅰ-7 Quantitative evaluation of grain boundary precipitates

Component	Evaluated location	Material	Average diameter (μm)		Volume fraction	
			Base Metal	Fine grain HAZ	Base Metal	Fine grain HAZ
Platen-SH OutletHeader-Left	Base metal at left side	SA335P12	0.40	—	0.012	—
	Circumferential weld at left side	SA335P12	0.51	0.43	0.021	0.031
De-Suerheater-Left	Circumferential weld	SA335P12	0.85	0.33	0.018	0.020
De-Suerheater-Right	Circumferential weld	SA335P12	0.70	0.35	0.018	0.017
RH Outlet Header-Left	Circumferential weld at left side	SA335P22	0.43	0.38	0.019	0.025
RH Outlet Header-Right	Circumferential weld at right side	SA335P22	0.56	0.37	0.024	0.023
Main Steam Pipe-Left	Circumferential weld,extrados	SA335P22	0.53	0.38	0.022	0.022
Main Steam Pipe-Left	Circumferential weld,intrados	SA335P22	0.72	0.34	0.031	0.024



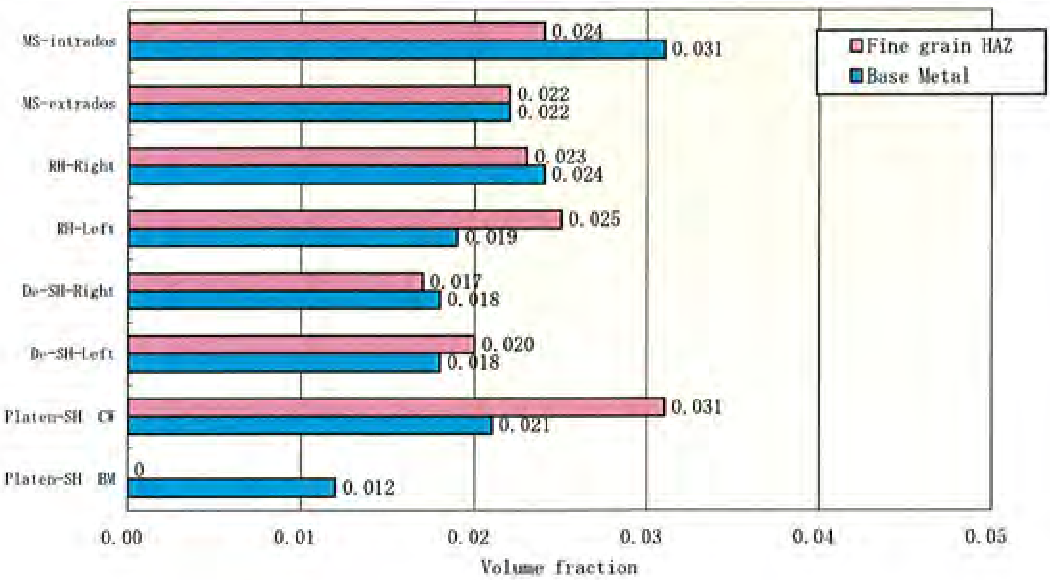


Table I -8 Precipitates free band width along grain boundary

Component	Evaluated location	Material	Precipitates free band width (μm) ※1
			Base Metal
RH Outlet Header-Left	Circumferential weld at left side	SA335P22	0.94
RH Outlet Header-Right	Circumferential weld at right side	SA335P22	1.10
Main Steam Pipe-Left	Circumferential weld,extrados	SA335P22	1.11
Main Steam Pipe-Left	Circumferential weld,intrados	SA335P22	0.94

※1 : Average value of 10 measured points

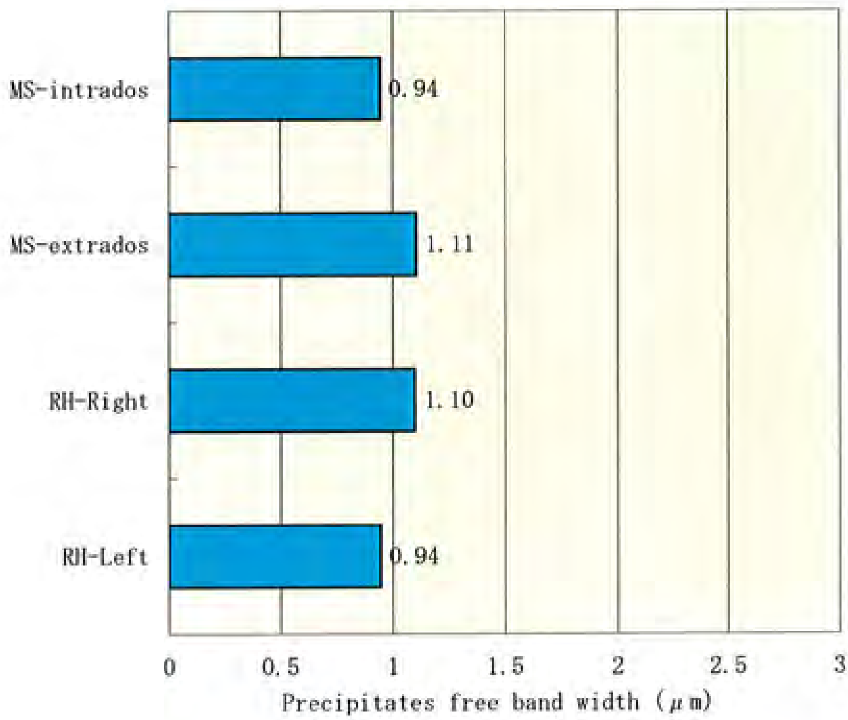


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Table I -9 Operational condition of evaluated components(Singrauli

Component	Location	Material		Designed					Hoop Stress	
		ASME	JIS	O.D. (mm)	t (mm)	Temperature (℃)	Pressure (MPa)	Pressure (kg/cm^2)	(MPa)	(kg/mm^2)
Platen SH Outlet Header-Left	circumferential weld at left side	SA335P12	STPA22	508.0	80.0	540	17.46	178.0	46.69	4.76
De-Suerheater-Left	Circumferential weld	SA335P12	STPA22	508.0	70.0	406	18.51	188.7	57.89	5.90
De-Suerheater-Right	Circumferential weld	SA335P12	STPA22							
RH Outlet Header-Left	Circumferential weld at left side	SA335P22	STPA24	558.8	50.0	540	4.26	43.5	21.68	2.21
RH Outlet Header-Right	Circumferential weld at right side	SA335P22	STPA24							
Main Steam Pipe-Left	Circumferential weld, extrados side	SA335P22	STPA24	520.0	85.0	540	17.46	178.0	44.67	4.55
Main Steam Pipe-Left	Circumferential weld, intrados side	SA335P22	STPA24							

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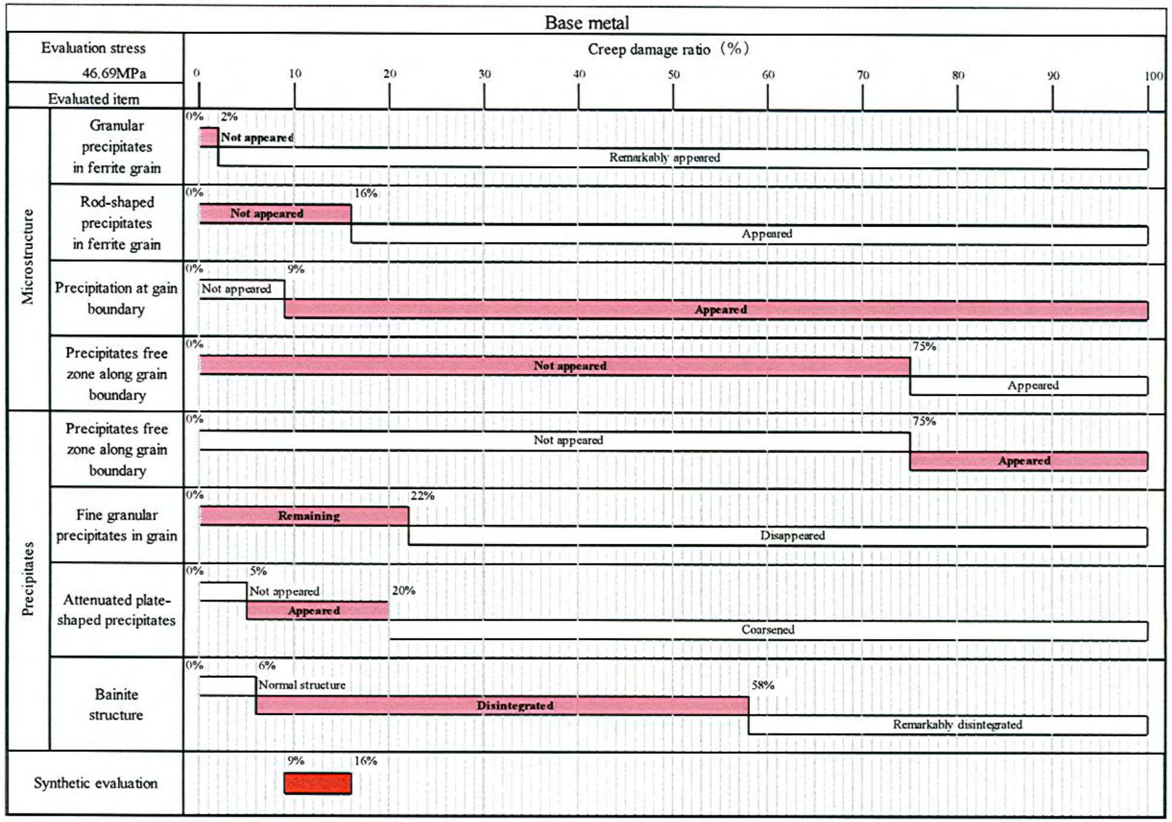
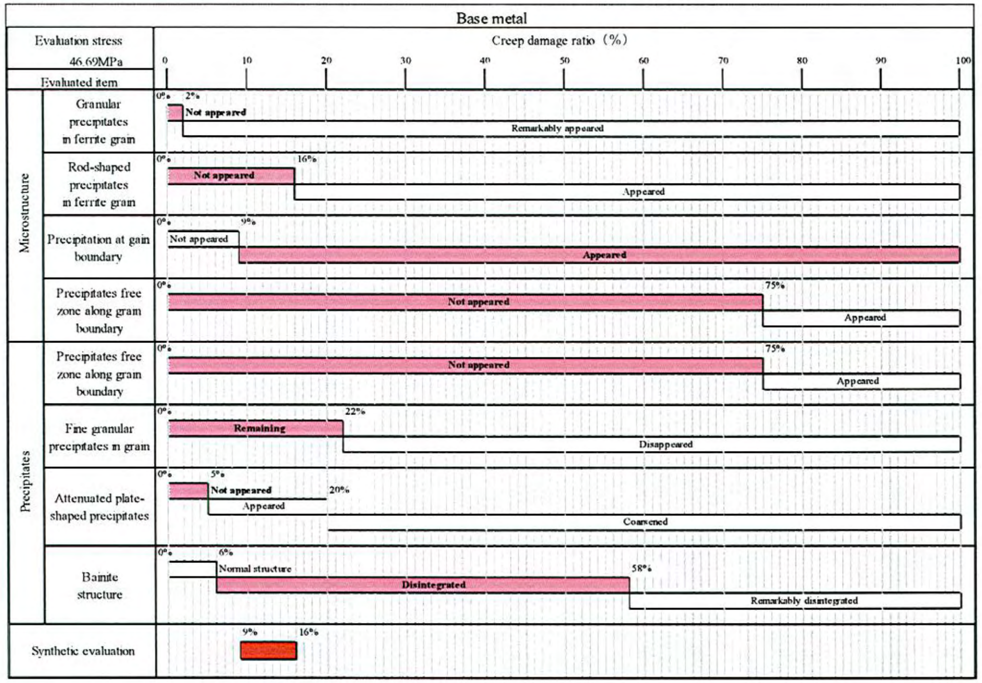
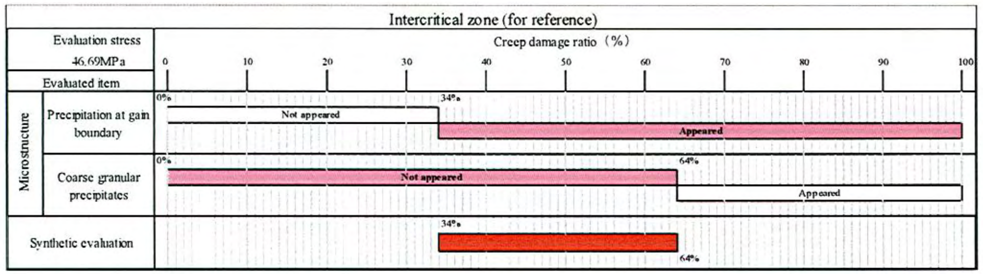
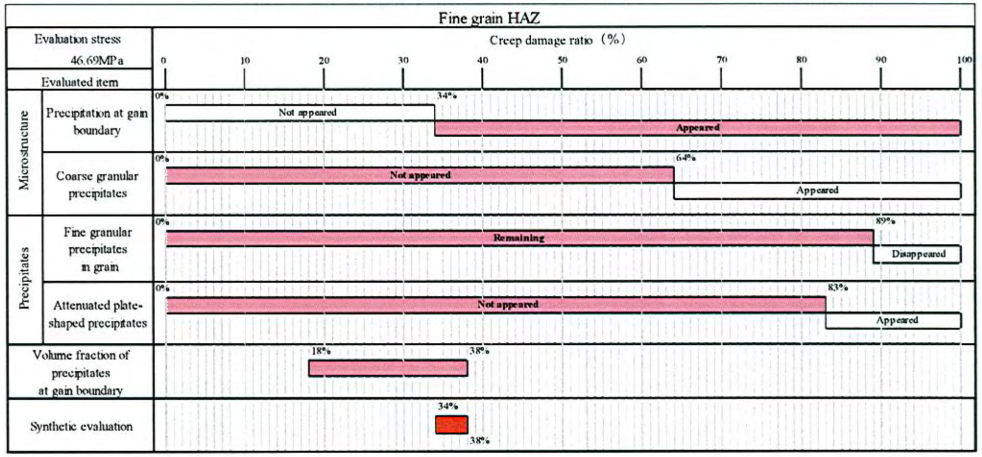
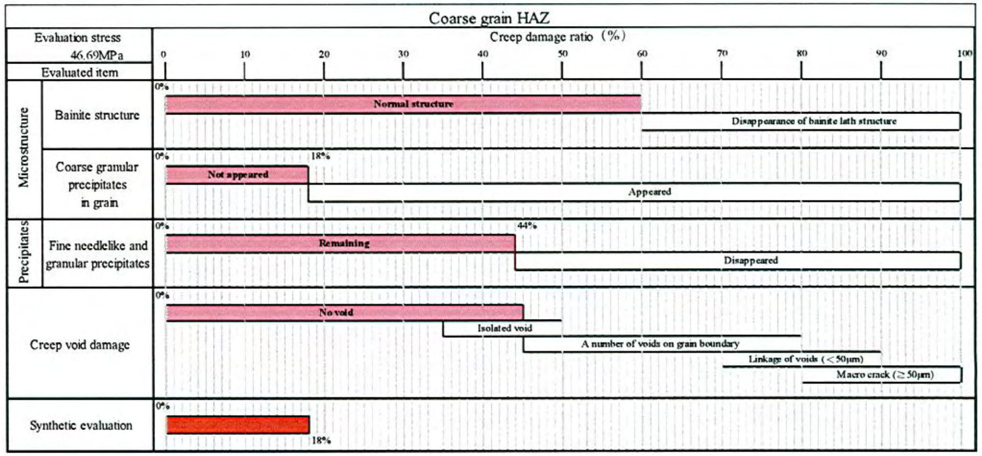


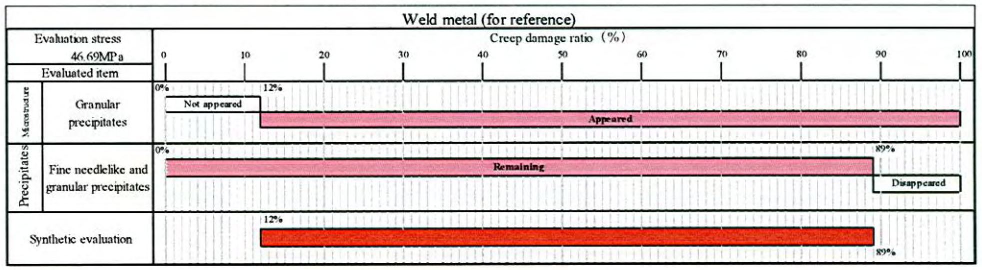
Evaluation Results I —1-1　Platen SH Outlet Header-Left　Base metal at left side





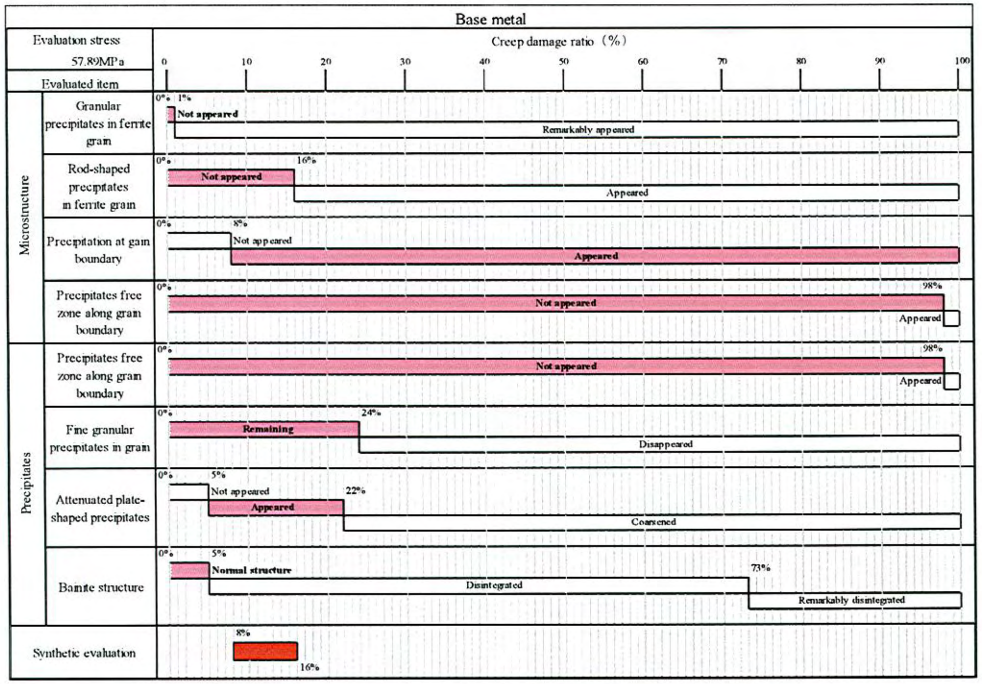


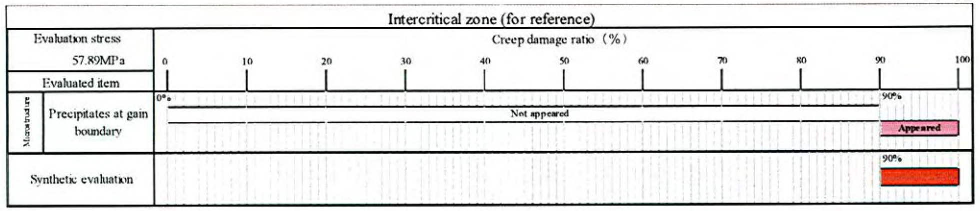


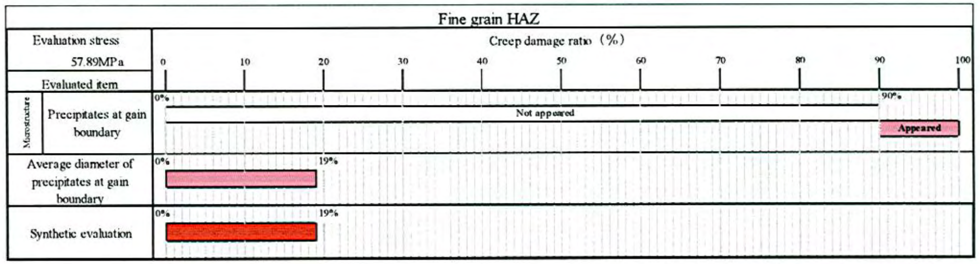


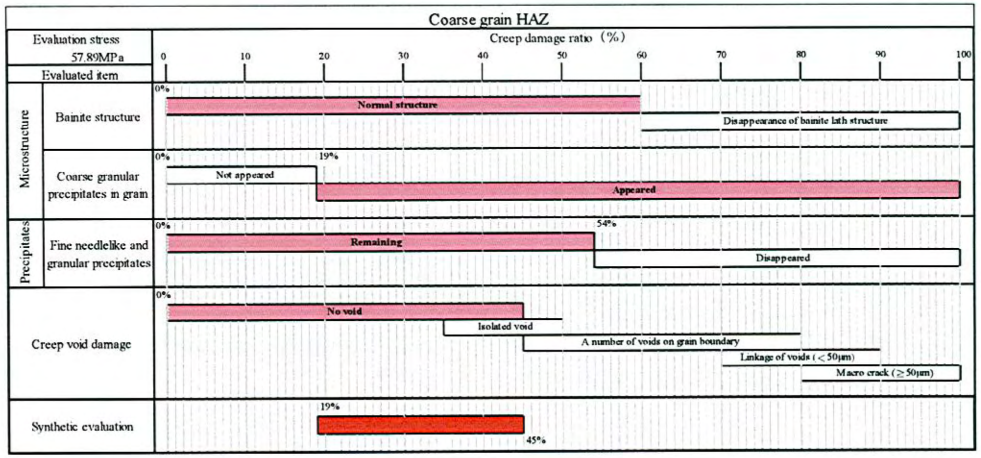
Evaluation Results I —1-2 Platen SH Outlet Header-Left circumferential weld at left side

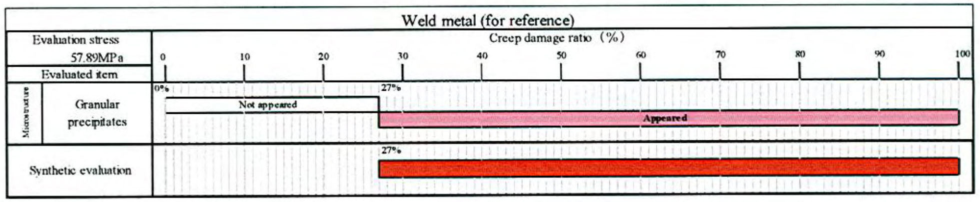
06











Evaluation Results I −2 De-Suerheater-Left Circumferential weld

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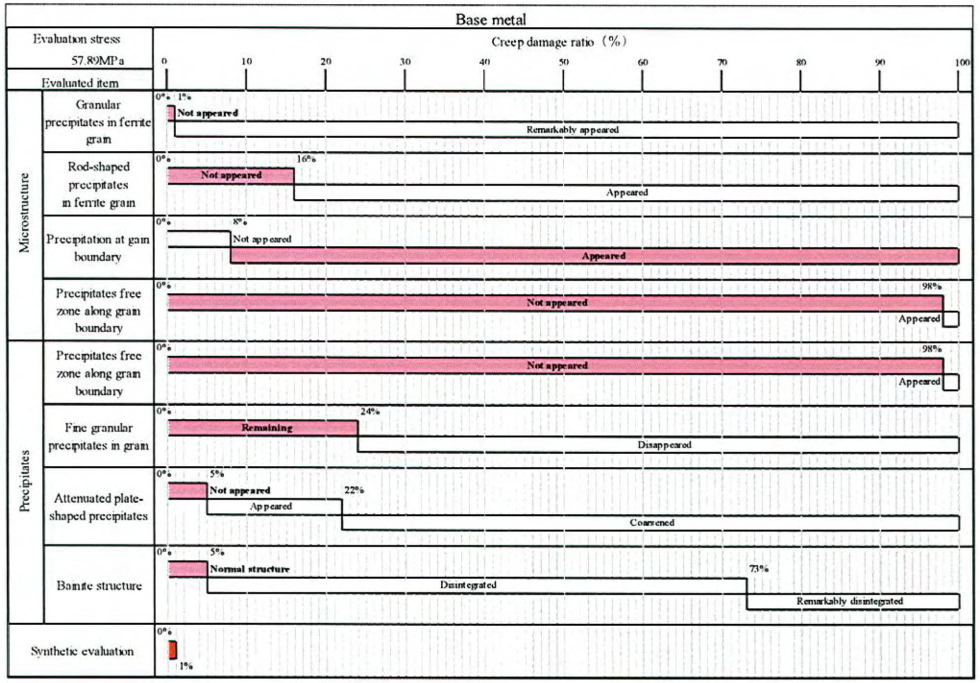
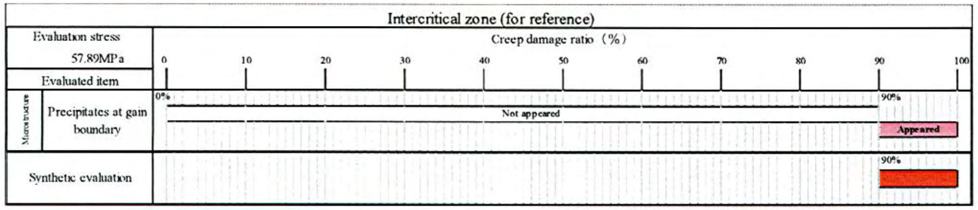
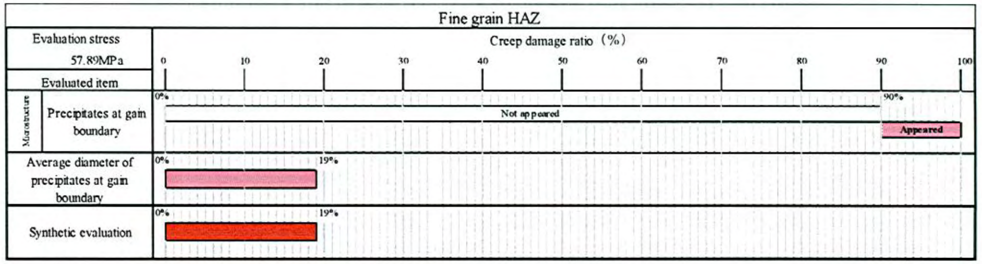
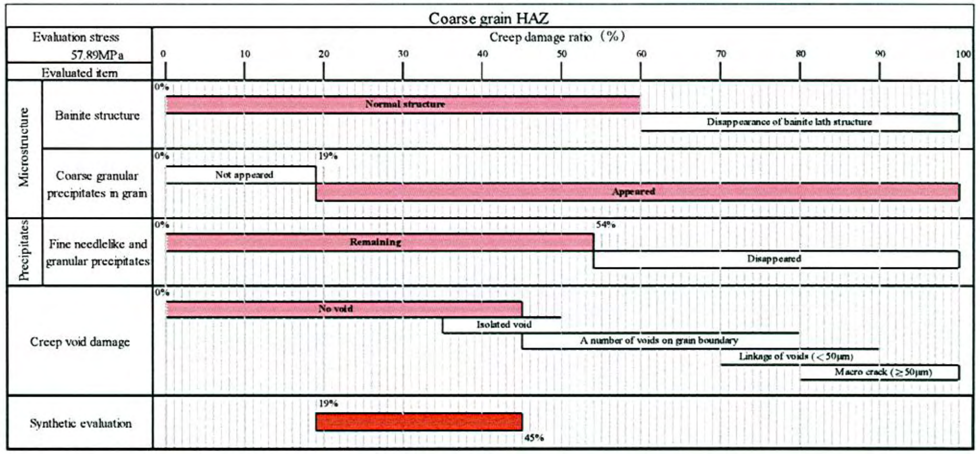
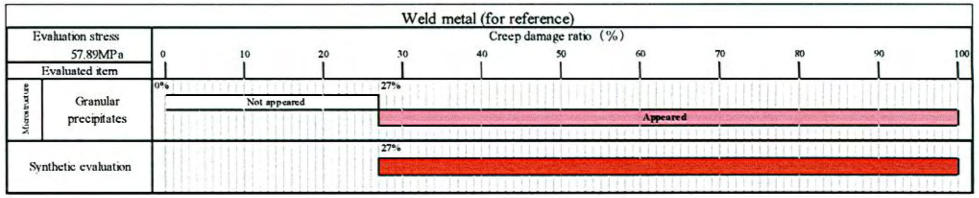




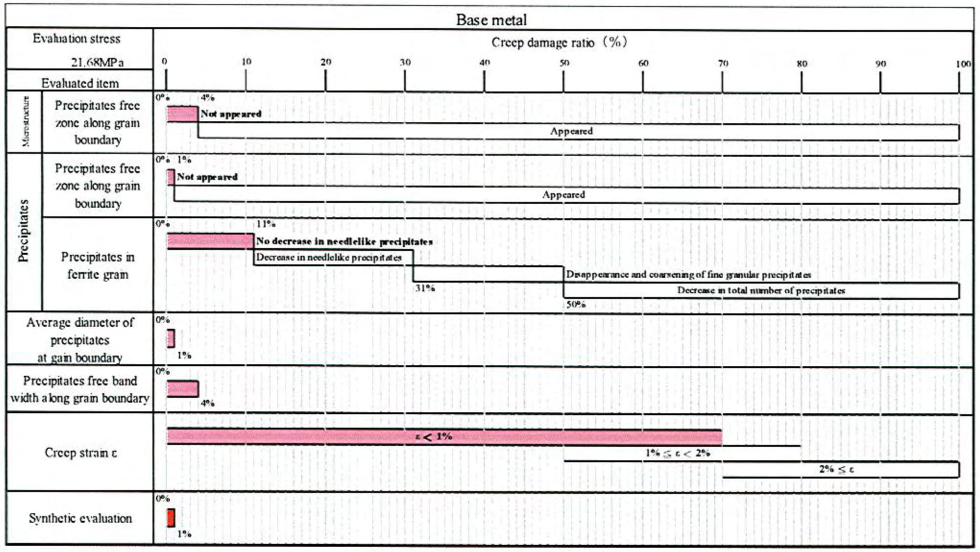


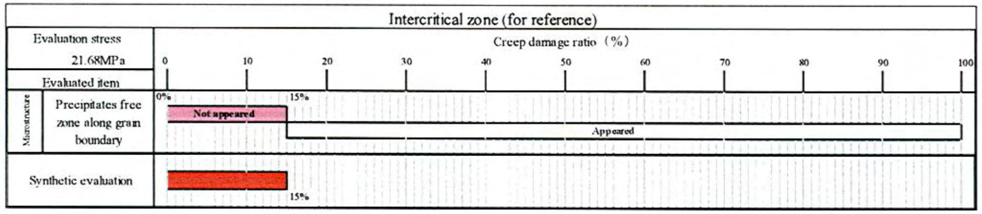


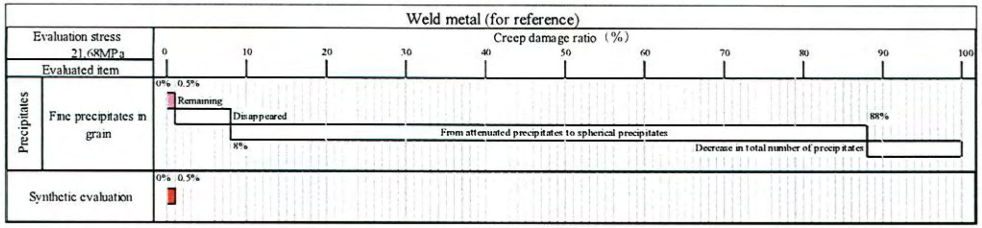


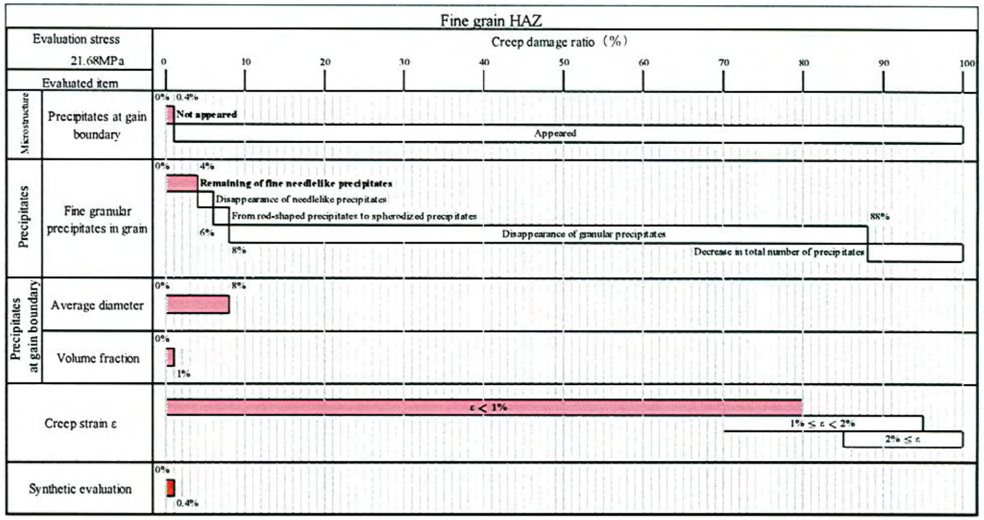
Evaluation Results I －3　De-Suerheater-Right　Circumferential weld

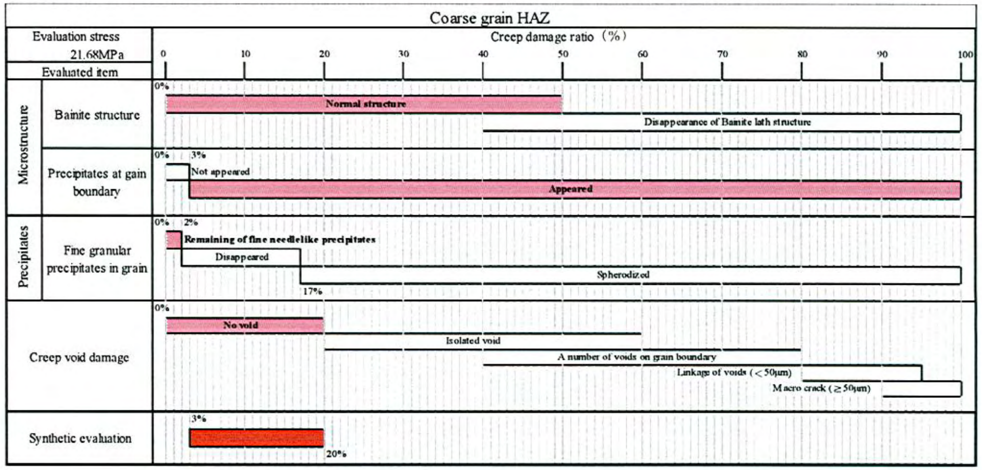
26





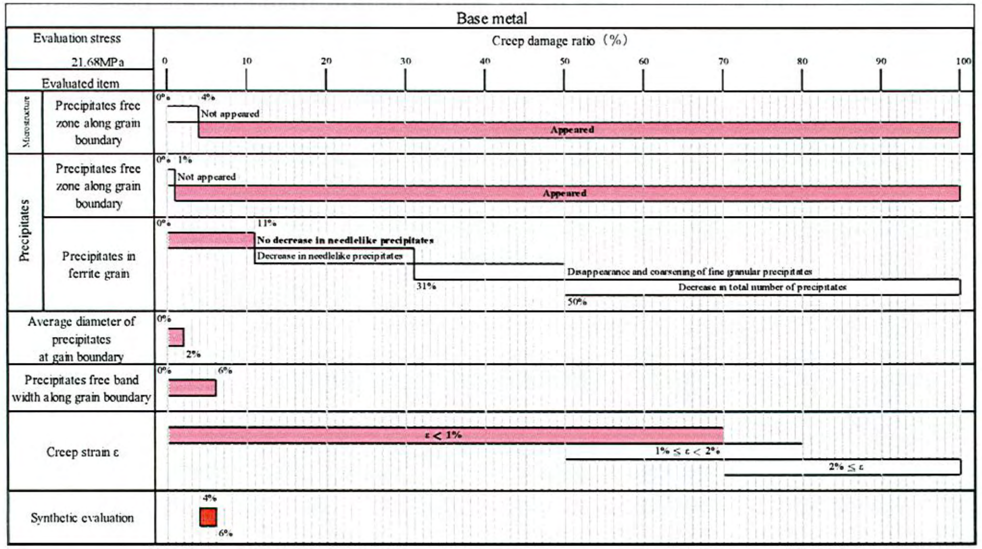


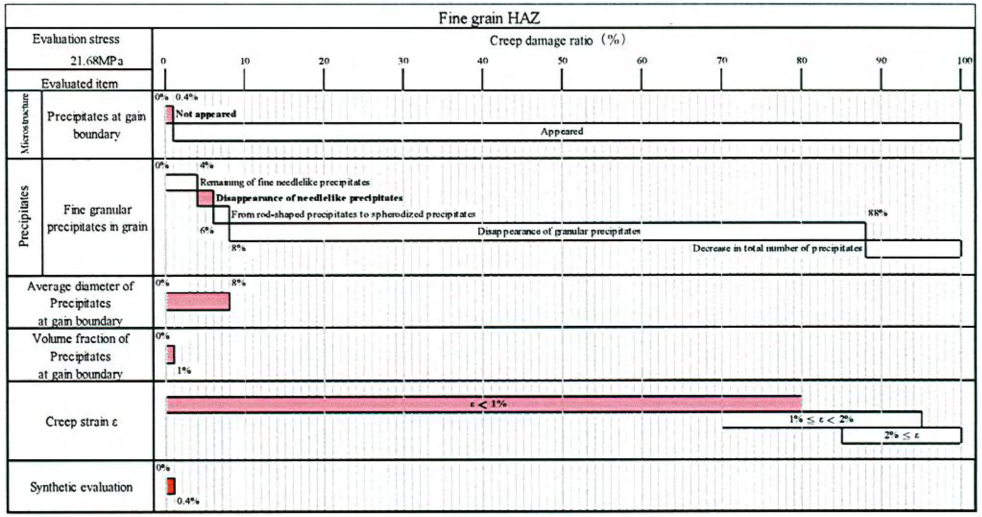


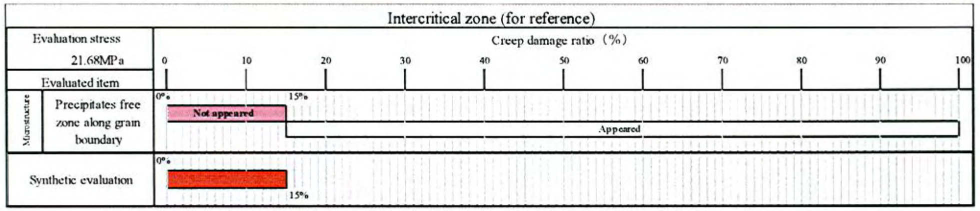


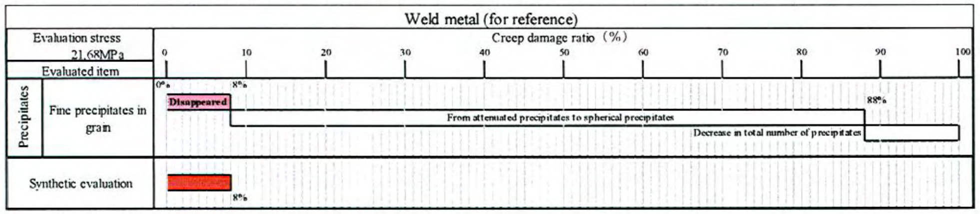
Evaluation Results I −4 RH Outlet Header-Left Circumferential weld at left side

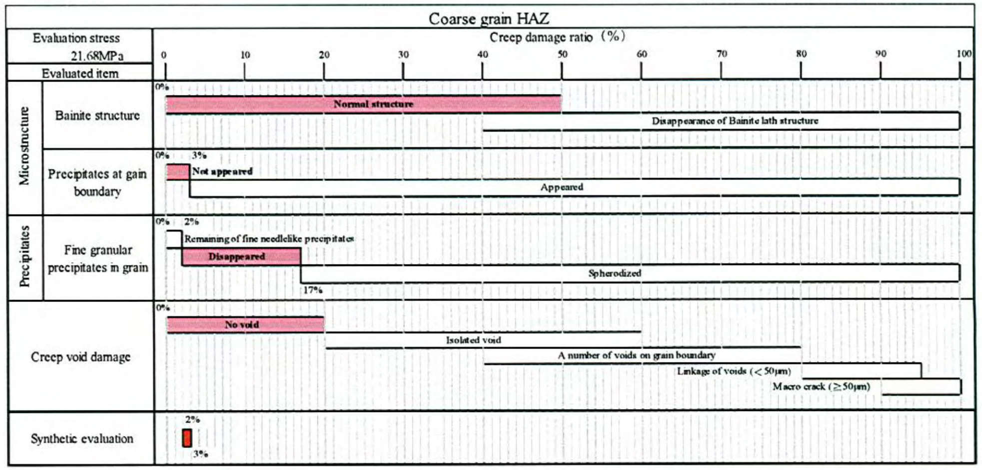
86





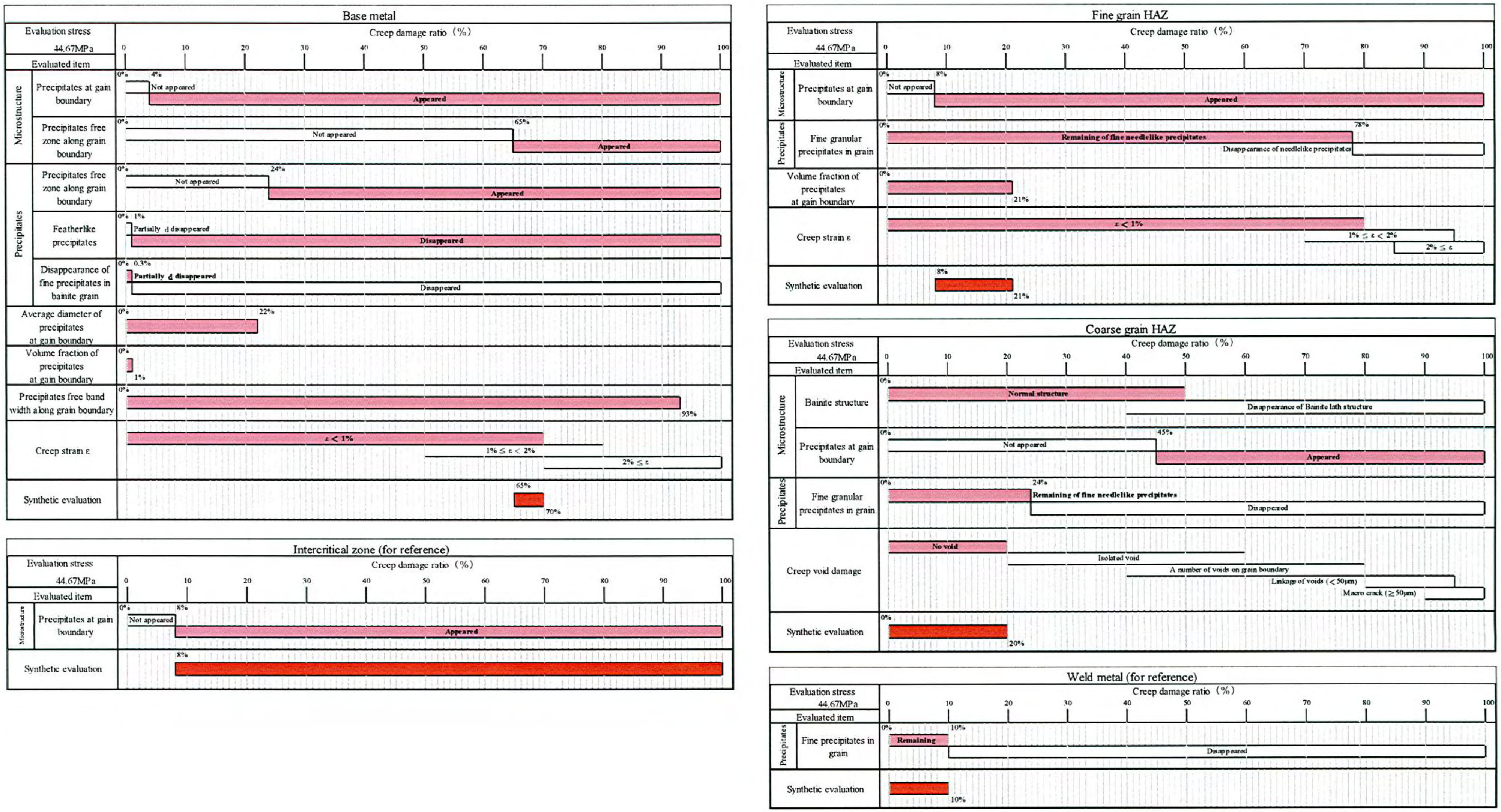






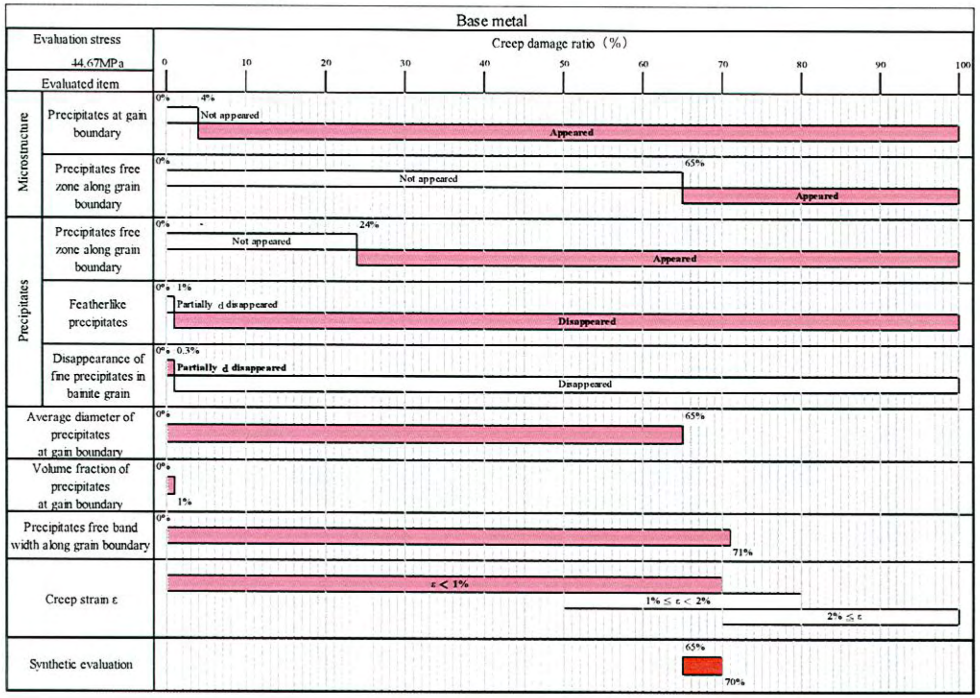
Evaluation Results I -5 RH Outlet Header-Right Circumferential weld at right side

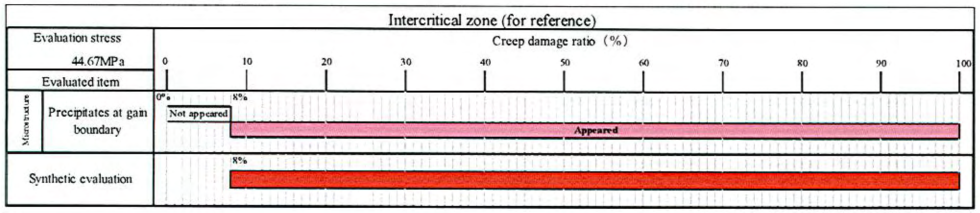
66

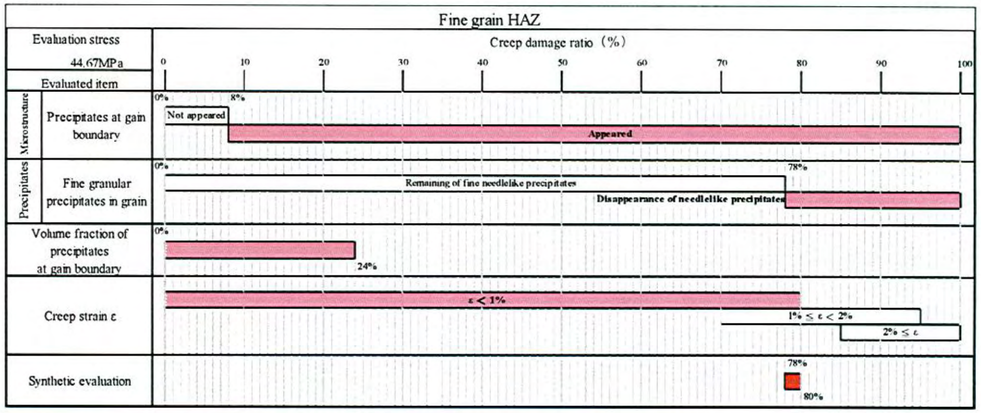


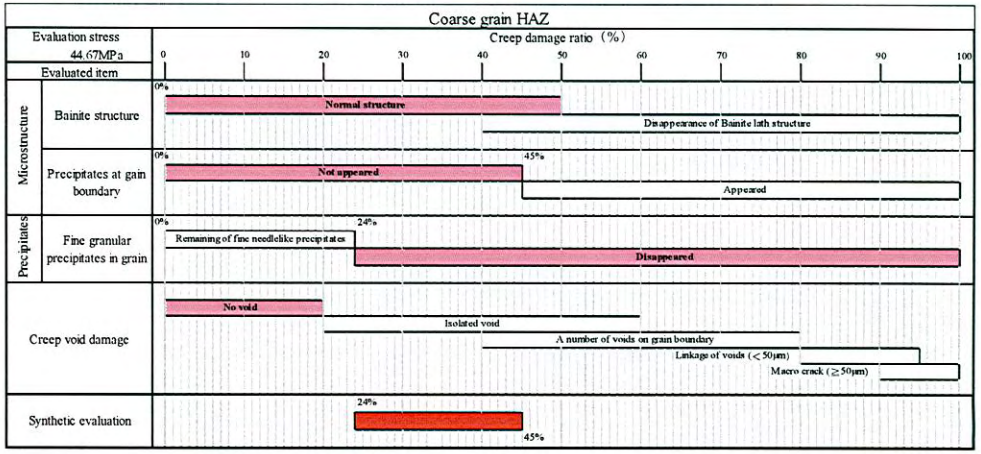
Evaluation Results I —6 Main Steam Pipe-Left Circumferential weld, extrados

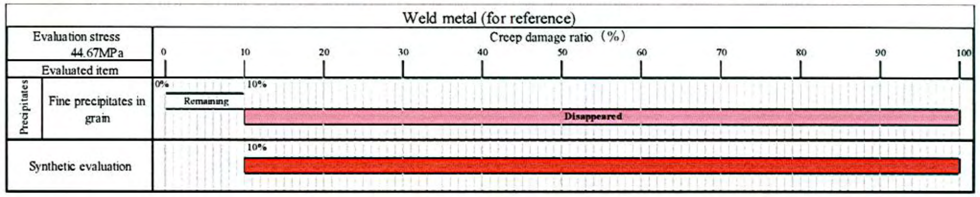
56











Evaluation Results I −7 Main Steam Pipe-Left Circumferential weld, intrados

Table Ⅰ-10 Residual life assessment results

Components	Location	Material	Region	Evaluation results		
				Creep life consumption ratio (%)	Residual life (hr)	Evaluated residual life (h)
Platen-SH OutletHeader-Left	Base Metal at left side	SA 335 P12	Base Metal	9 ～ 16	903,000 ～ 1,739,000	140,000
	circumferential weld at left side		Base Metal	9 ～ 16	903,000 ～ 1,739,000	
			Fine grain HAZ	34 ～ 38	281,000 ～ 334,000	
			Coarse grain HAZ	0 ～ 18	784,000 <	
De-Suerheater-Left	Circumferential weld	SA 335 P12	Base Metal	8 ～ 16	903,000 ～ 1,978,000	100,000
			Fine grain HAZ	0 ～ 19	733,000 <	
			Coarse grain HAZ	19 ～ 45	210,000 ～ 733,000	
De-Suerheater-Right	Circumferential weld	SA 335 P12	Base Metal	0 ～ 1	17,028,000 <	100,000
			Fine grain HAZ	0 ～ 19	733,000 <	
			Coarse grain HAZ	19 ～ 45	210,000 ～ 733,000	
RH Outlet Header-Left	Circumferential weld at left side	SA 335 P22	Base Metal	0 ～ 1	17,028,000 <	340,000
			Fine grain HAZ	0 ～ 0.4	42,828,000 <	
			Coarse grain HAZ	3 ～ 20	688,000 ～ 5,561,000	
RH Outlet Header-Right	Circumferential weld at right side	SA 335 P22	Base Metal	4 ～ 6	2,695,000 ～ 4,128,000	1,300,000
			Fine grain HAZ	0 ～ 0.4	42,828,000 <	
			Coarse grain HAZ	2 ～ 3	5,561,000 ～ 8,428,000	
Main Steam Pipe-Left	Circumferential weld,extrados	SA 335 P22	Base Metal	65 ～ 70	74,000 ～ 93,000	37,000
			Fine grain HAZ	8 ～ 21	647,000 ～ 1,978,000	
			Coarse grain HAZ	0 ～ 20	688,000 <	
Main Steam Pipe-Left	Circumferential weld,intrados	SA 335 P22	Base Metal	65 ～ 70	74,000 ～ 93,000	21,000
			Fine grain HAZ	78 ～ 80	43,000 ～ 49,000	
			Coarse grain HAZ	24 ～ 45	210,000 ～ 545,000	

※1 : Residual life was evaluated with microstructural comparison method of KYUSHYU ELECTRIC POWER CO., INC. RESEARCH LABORATORY.
※2 : Residual life= (Cumulative operation hours／Creep life consumption ratio) ×100－Cumulative operation hours.
※3 : Evaluated residual life is half of residual life based on Japanese guideline of boiler residual life asessment.
Evaluated residual life=Residual life／2

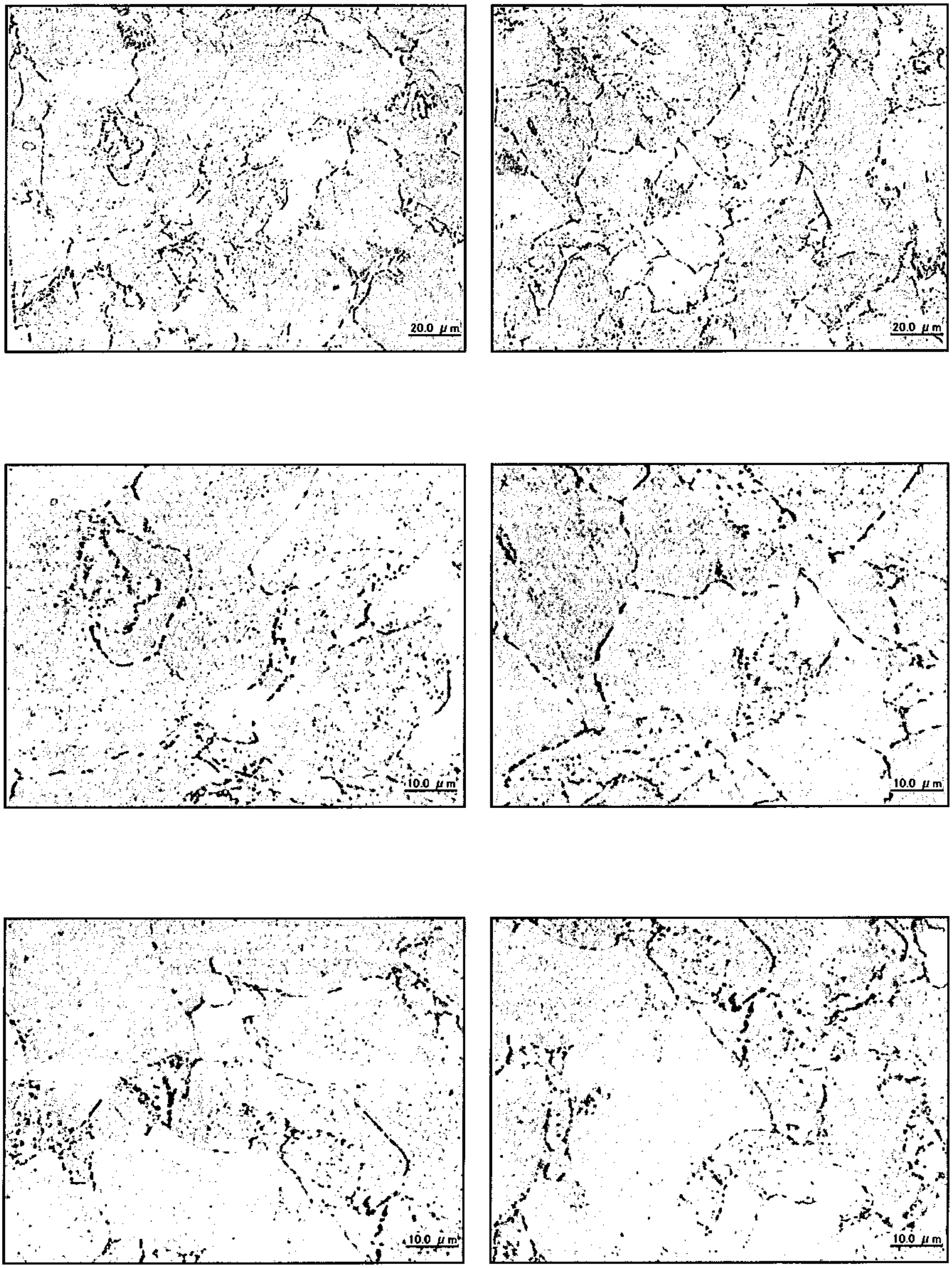


Photo I -4-1 Microstructure observation
Platen SH Outlet Header-Left (Base metal at left side : Base metal)

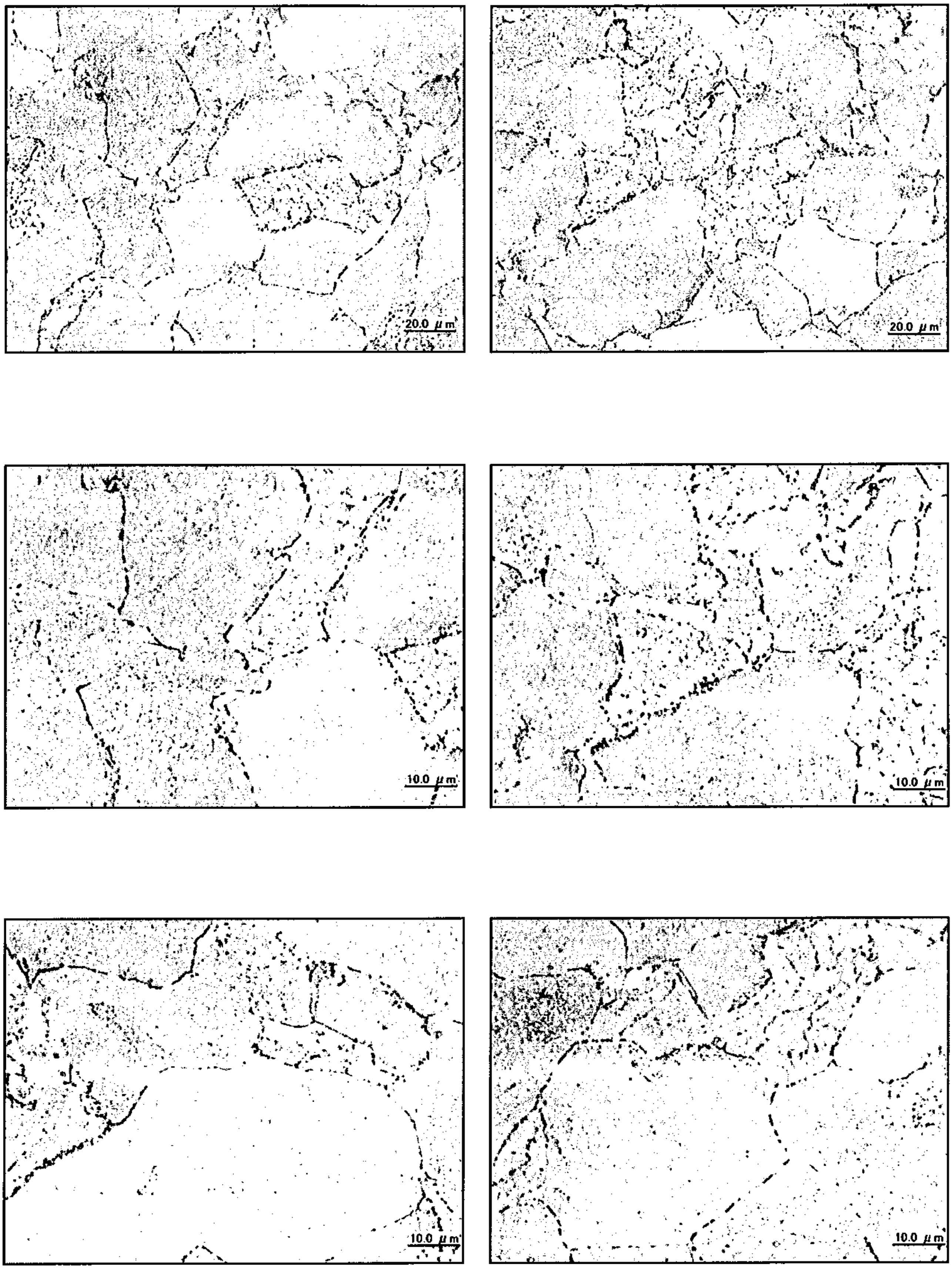


Photo I -4-2 Microstructure observation
Platen SH Outlet Header-Left (Circumferential weld at left side : Base metal)

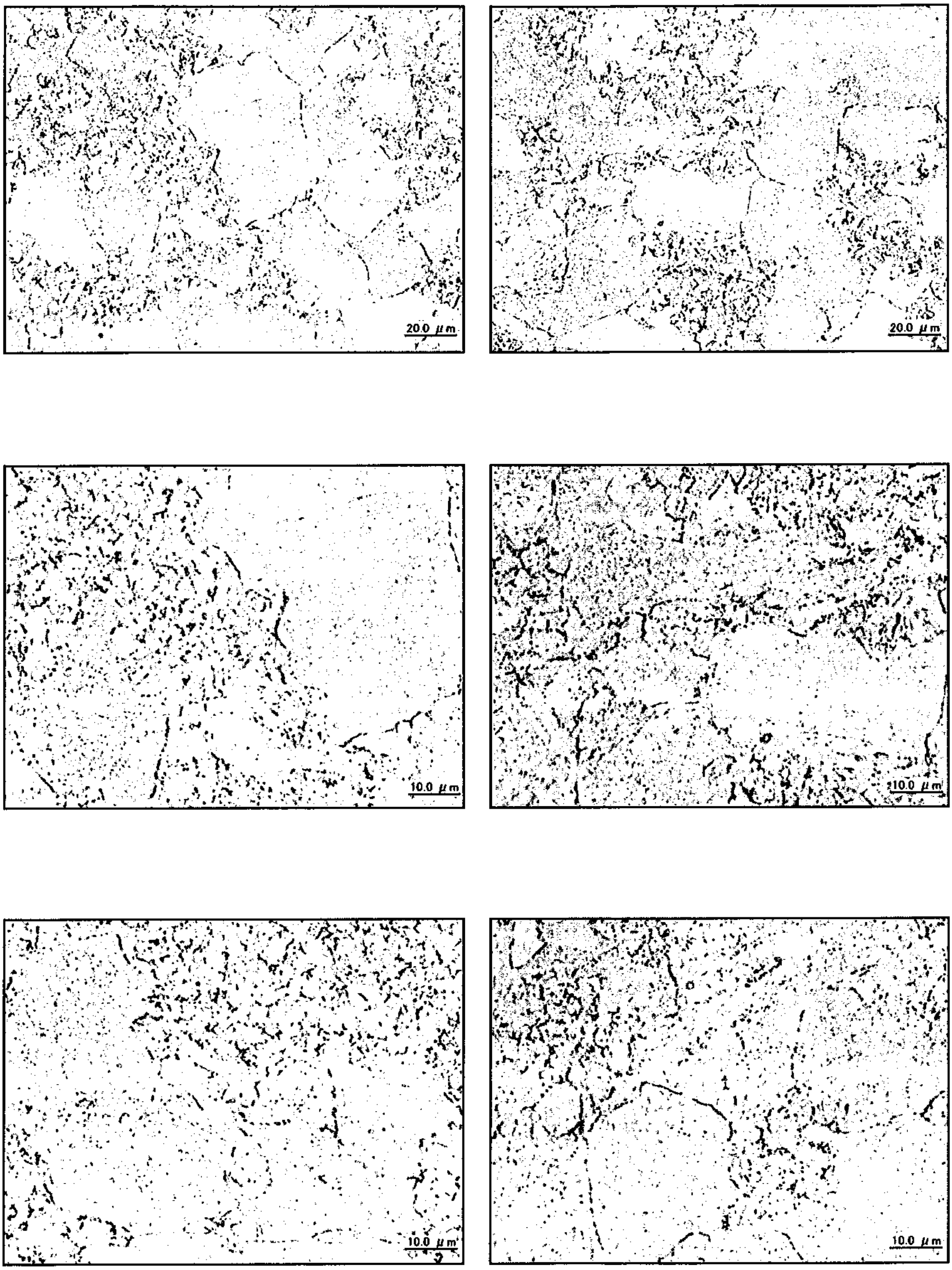


Photo I -4-3 Microstructure observation
Platen SH Outlet Header-Left (Circumferential weld at left side : Intercritical zone)

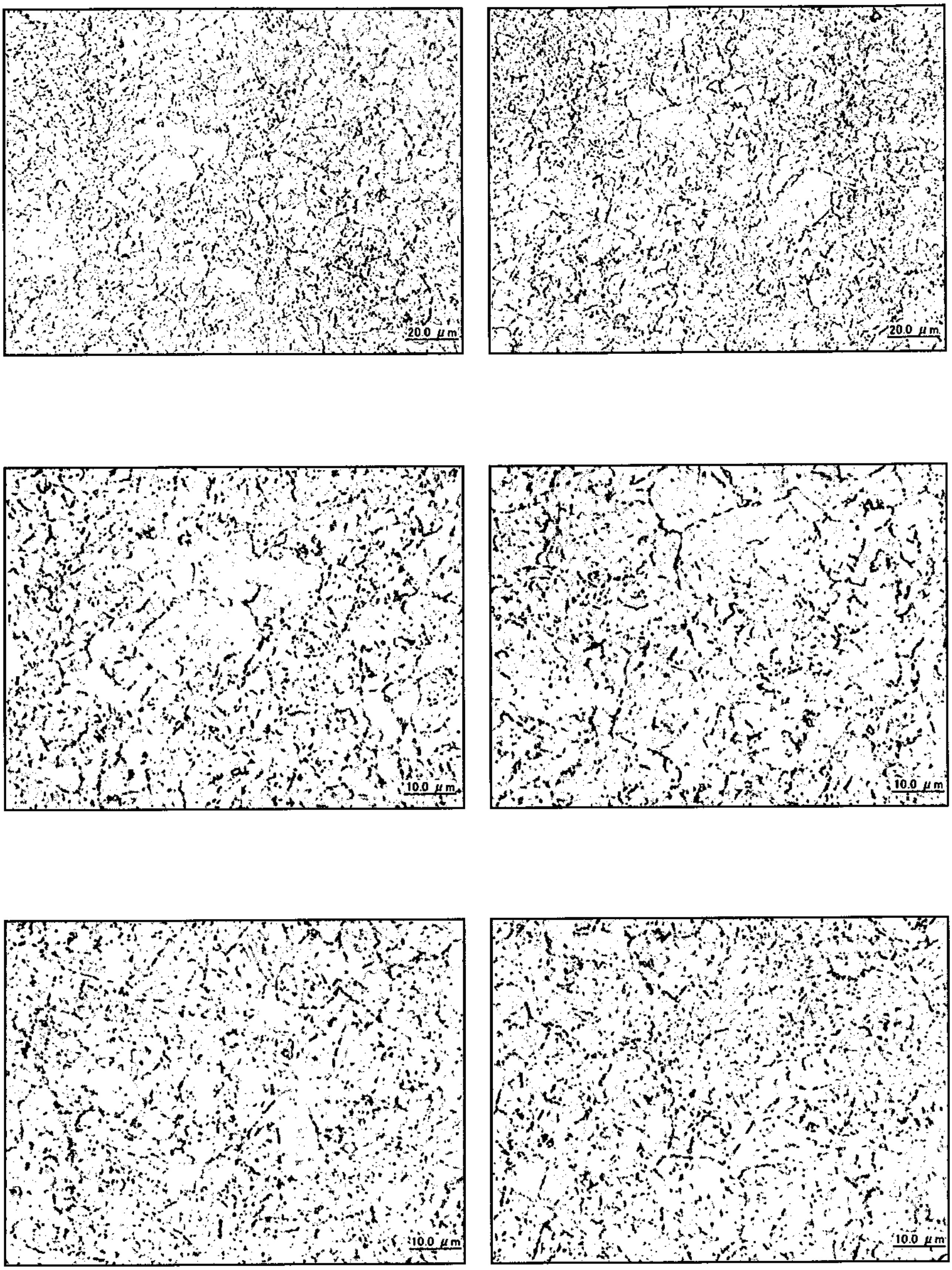


Photo I -4-4 Microstructure observation
Platen SH Outlet Header-Left (Circumferential weld at left side : Fine grain HAZ)

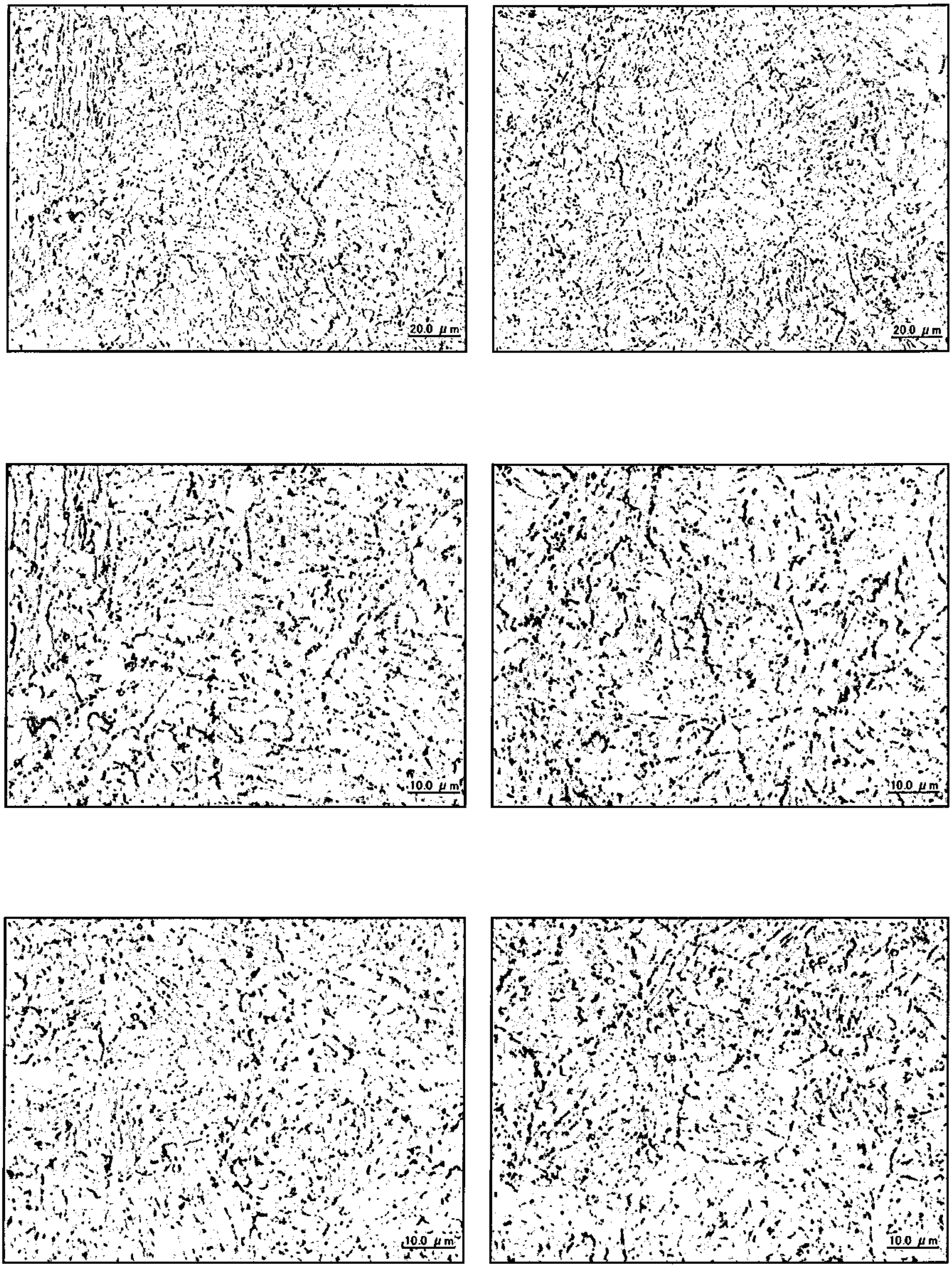


Photo I -4-5 Microstructure observation
Platen SH Outlet Header-Left (Circumferential weld at left side : Coarse grain HAZ)

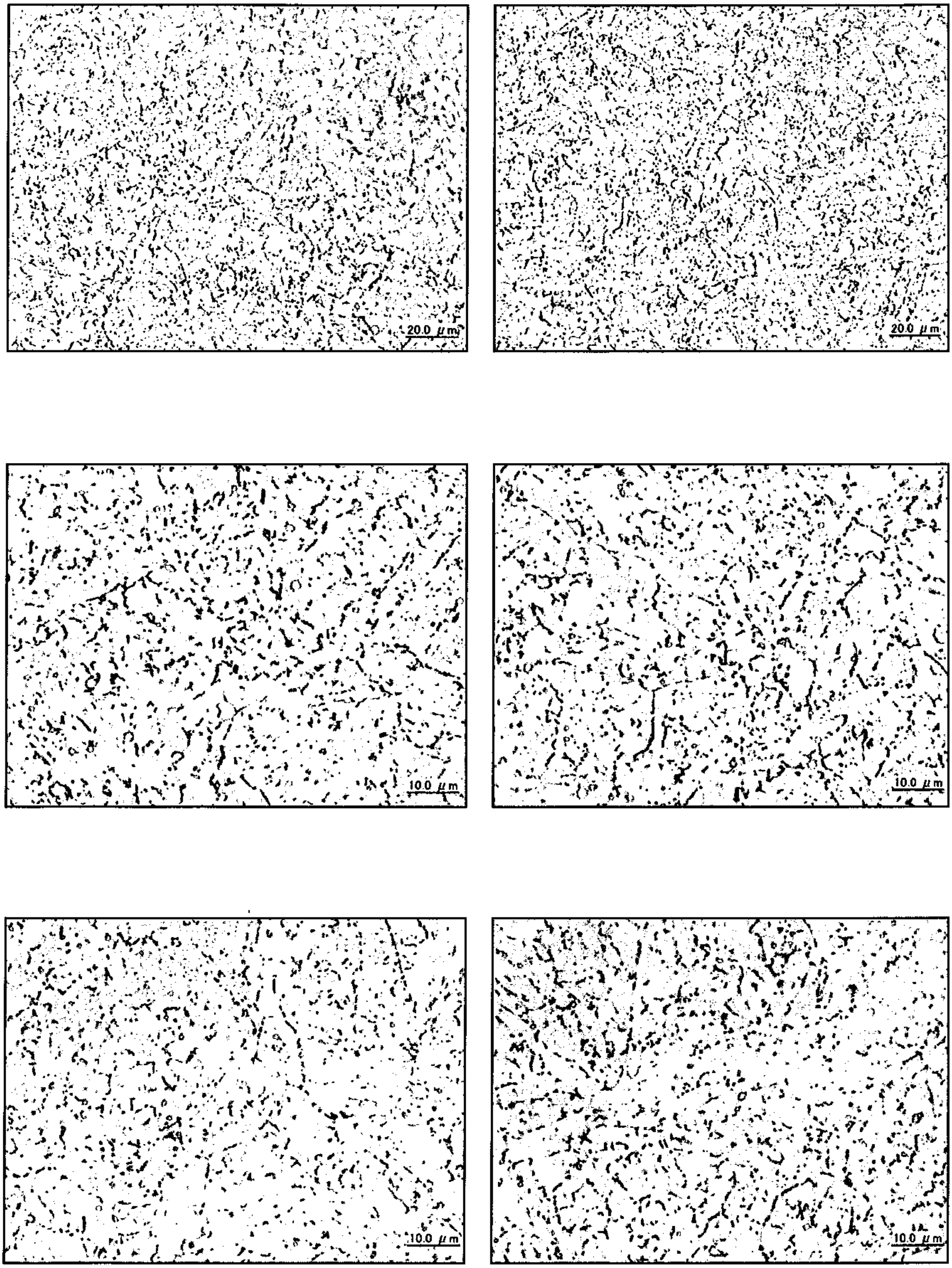


Photo I -4-6　Microstructure observation
Platen SH Outlet Header-Left (Circumferential weld at left side : Weld metal)

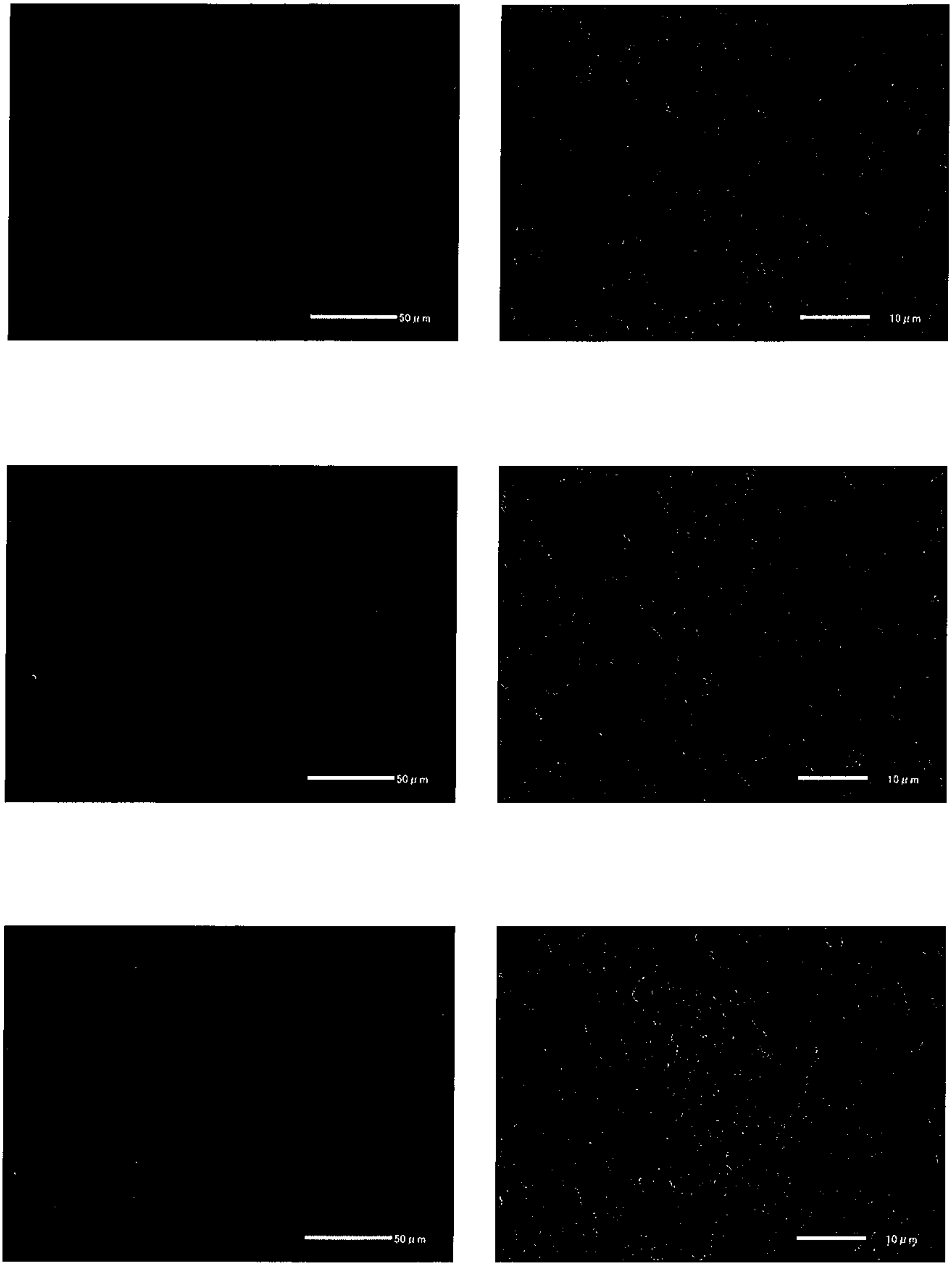


Photo I -4-7 SEM(Scanning electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Fine grain HAZ)

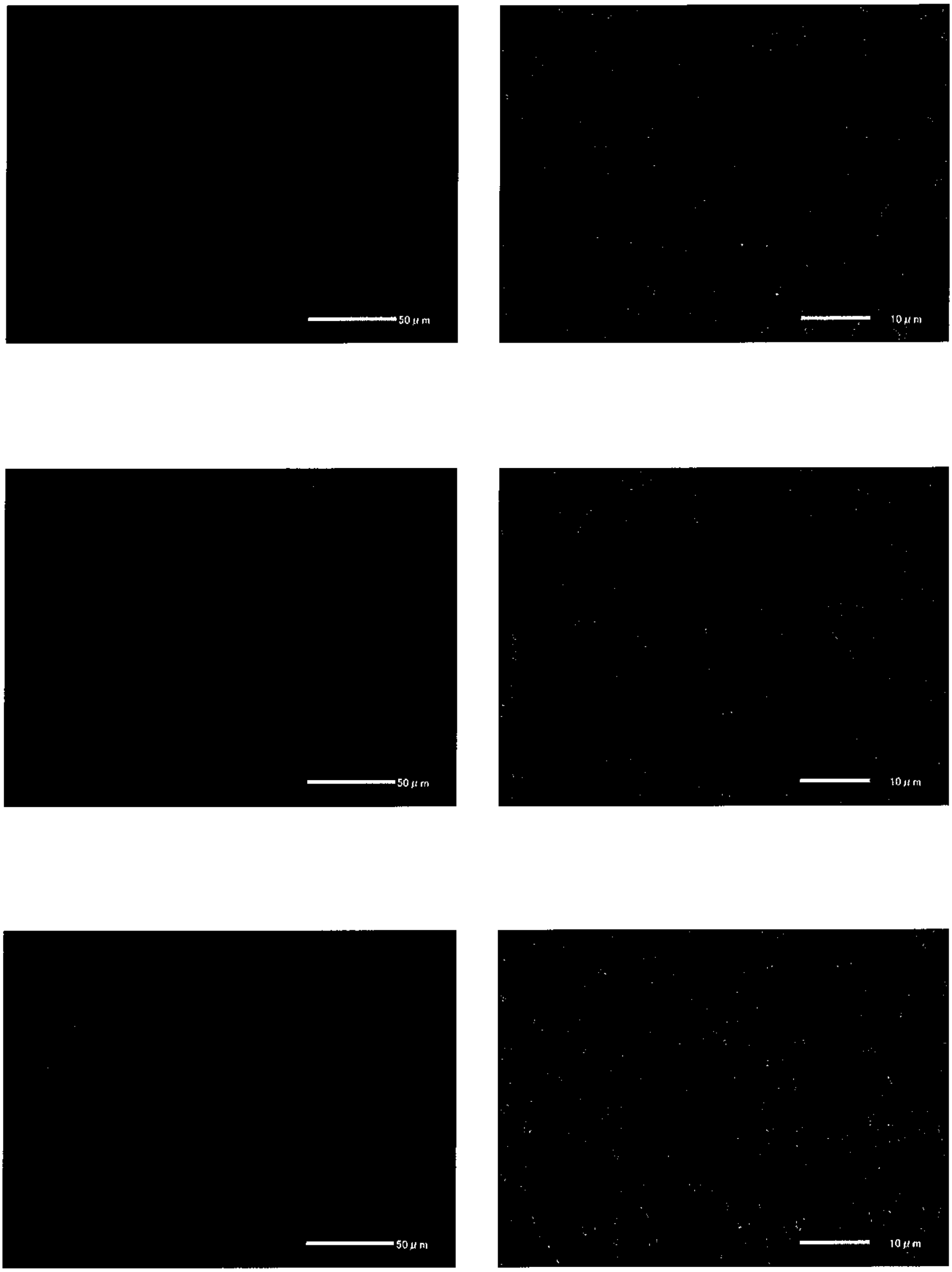


Photo I -4-8 SEM(Scanning electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Coarse grain HAZ)

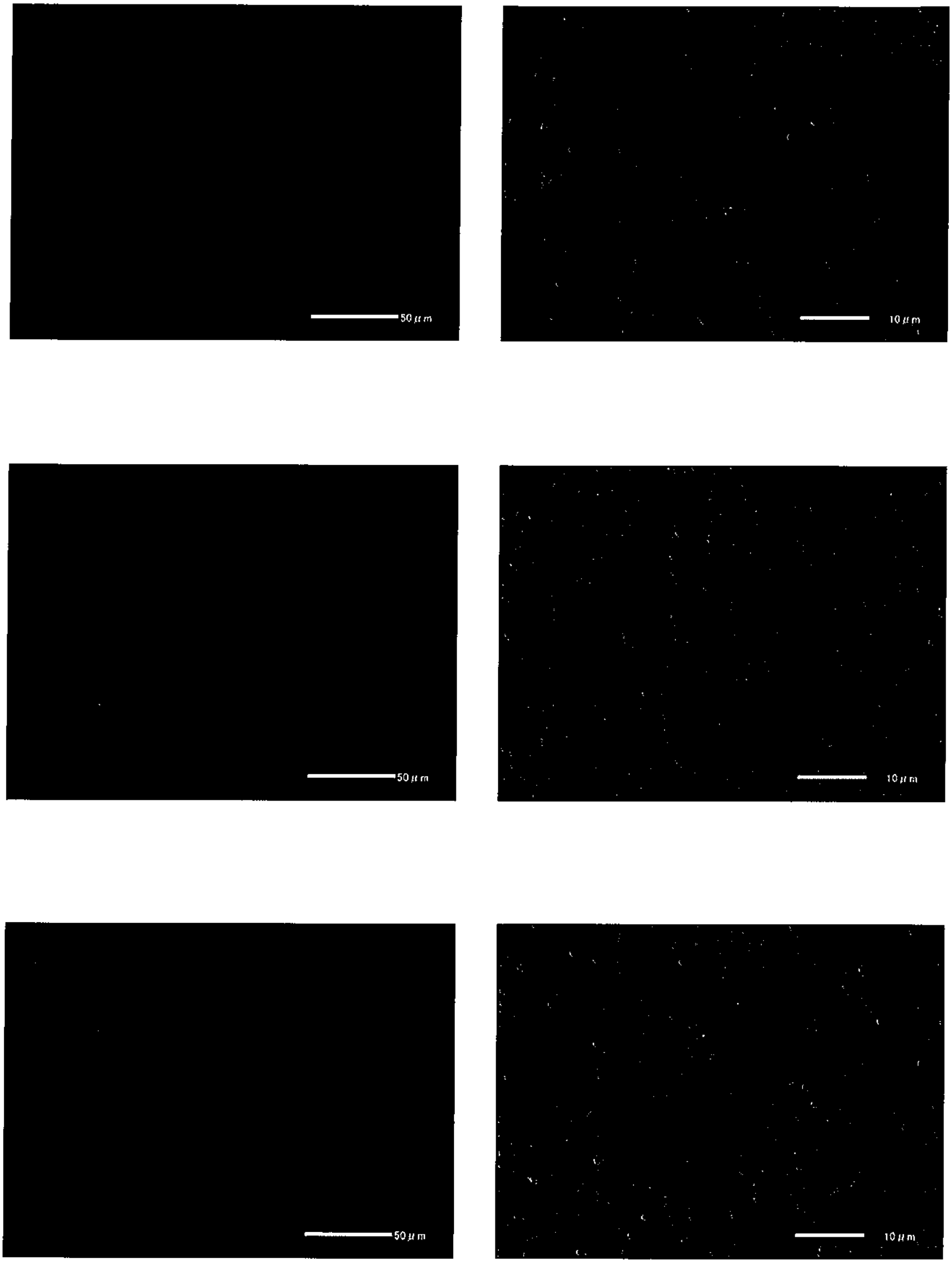


Photo I -4-9 SEM(Scanning electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Weld metal)

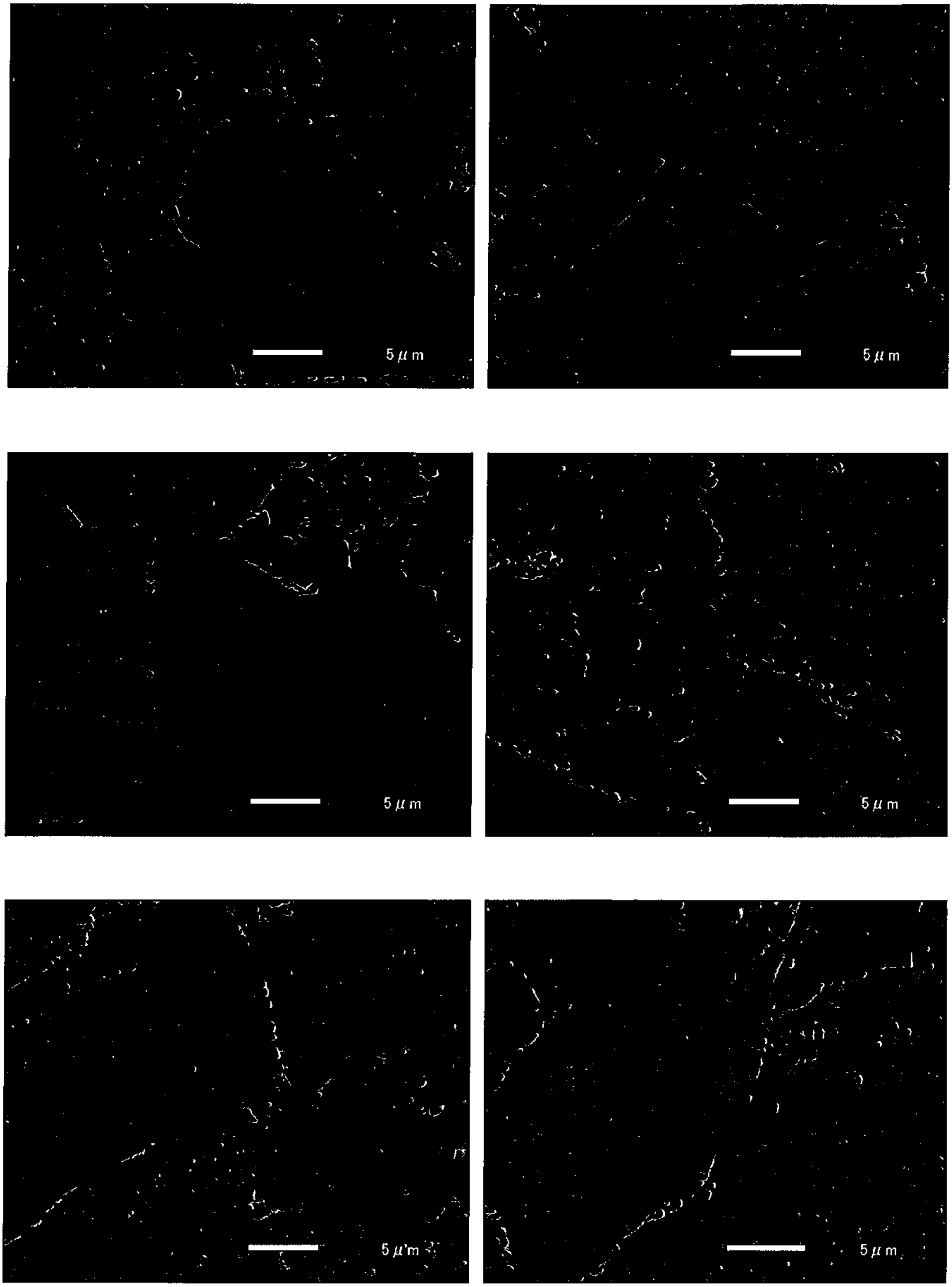


Photo I -4-10 Precipitates along grain boundary by SEM observation
Platen SH Outlet Header-Left(Base metal at left side : Base metal)

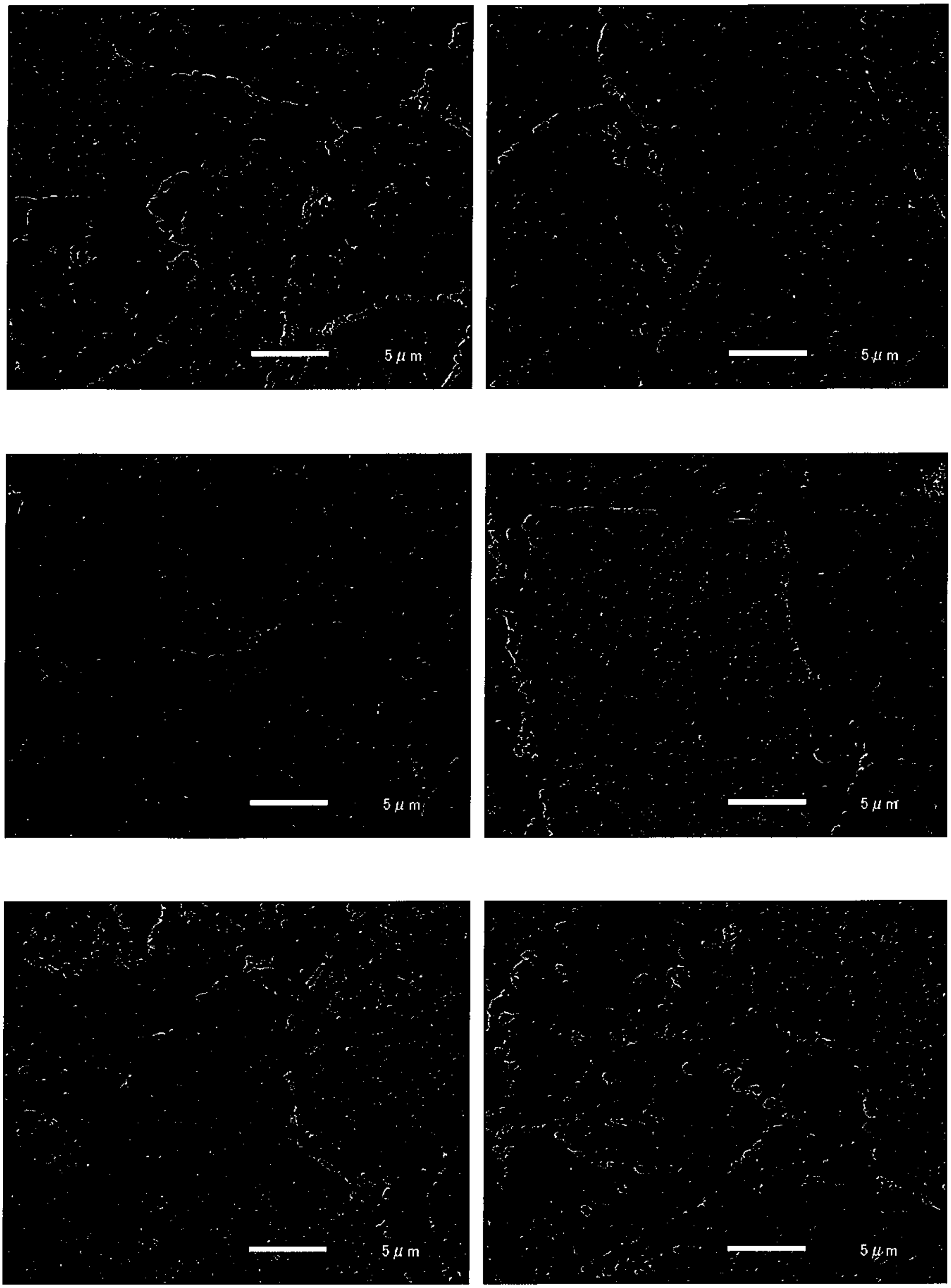


Photo I -4-11 Precipitates along grain boundary by SEM observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Base metal)

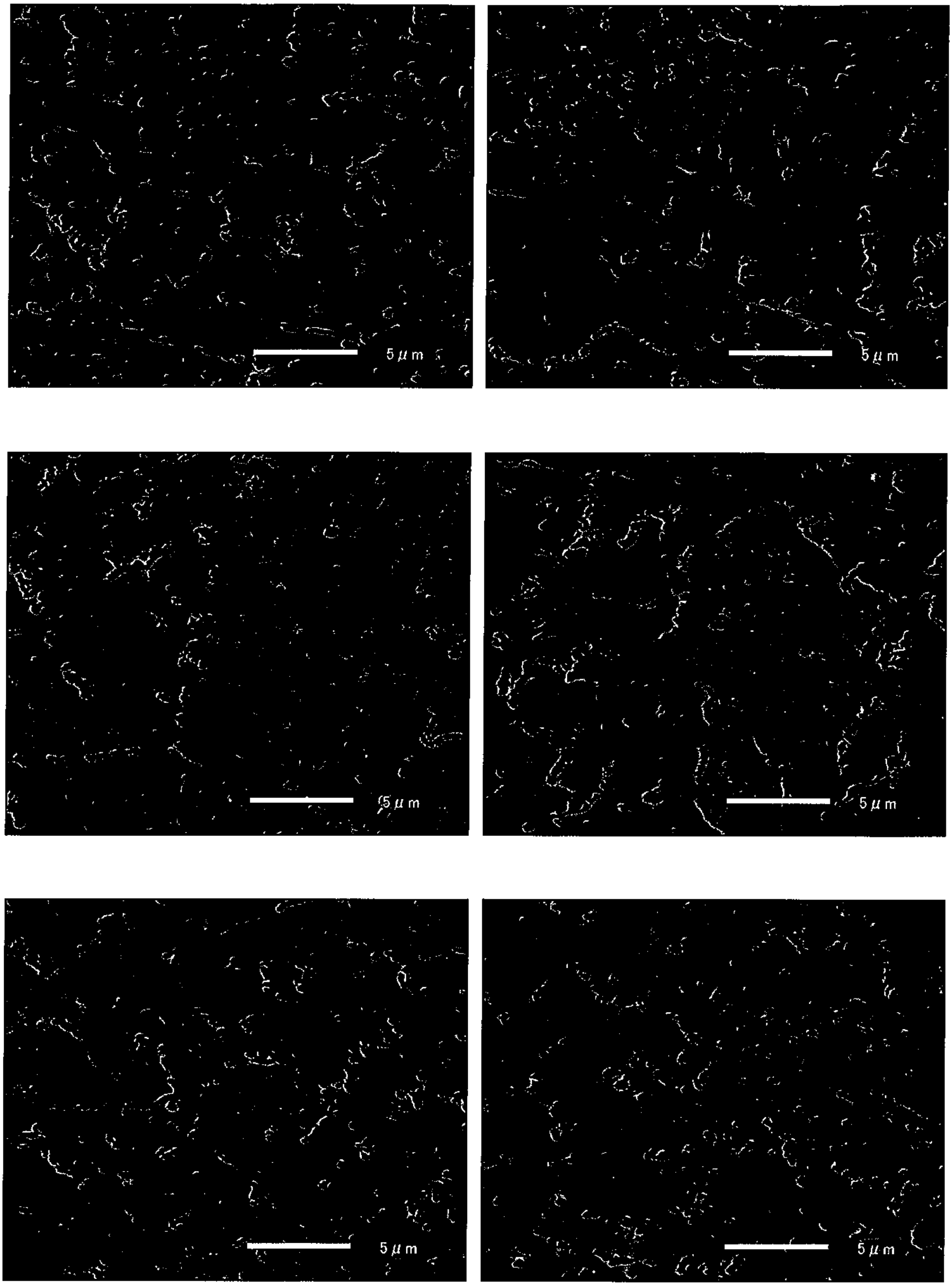


Photo I-4-12 Precipitates along grain boundary by SEM observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Fine grain HAZ)

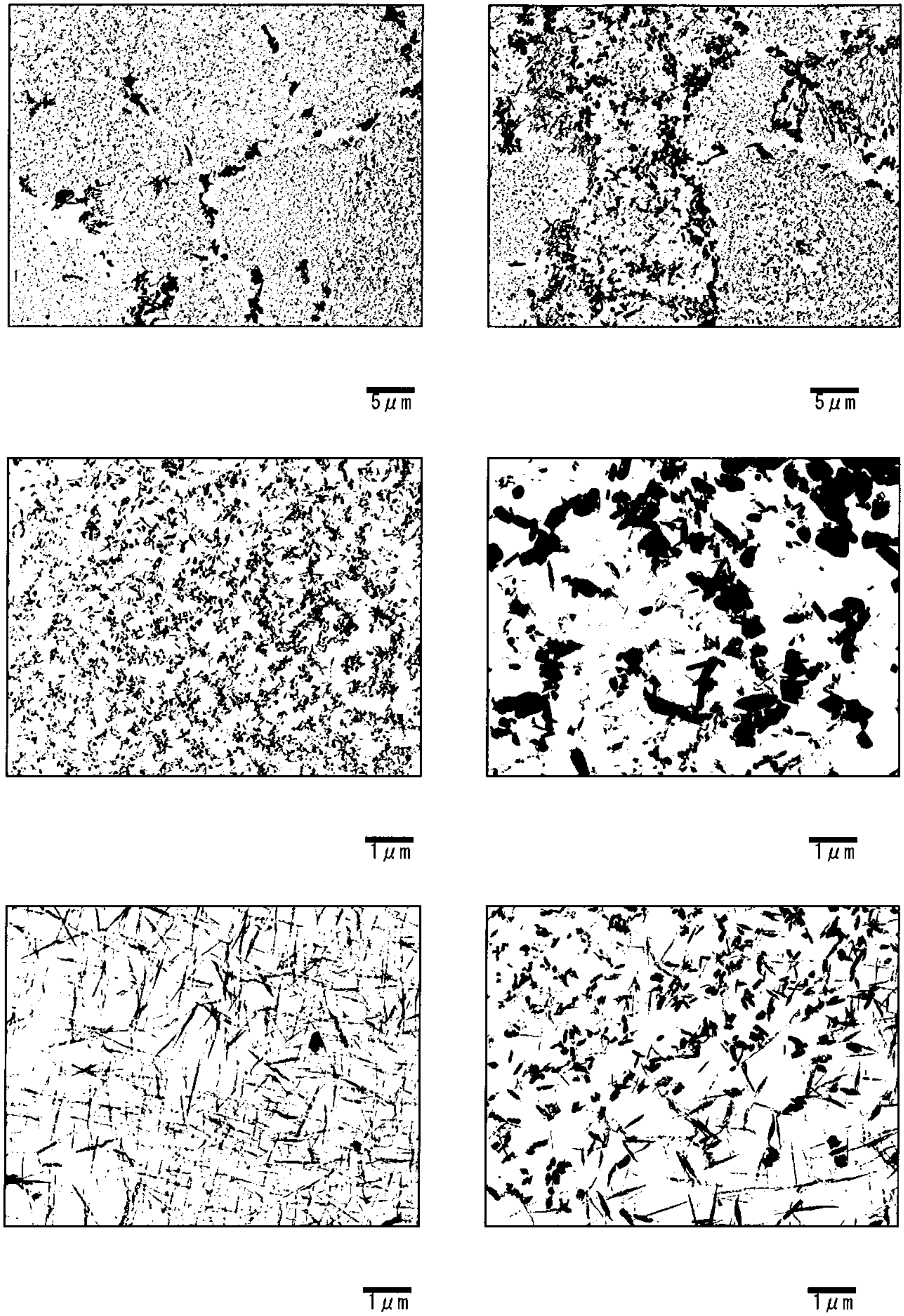


Photo I -4-13 Precipitates by TEM (Transmission electron microscope) observation
Platen SH Outlet Header-Left(Base metal at left side : Base metal)

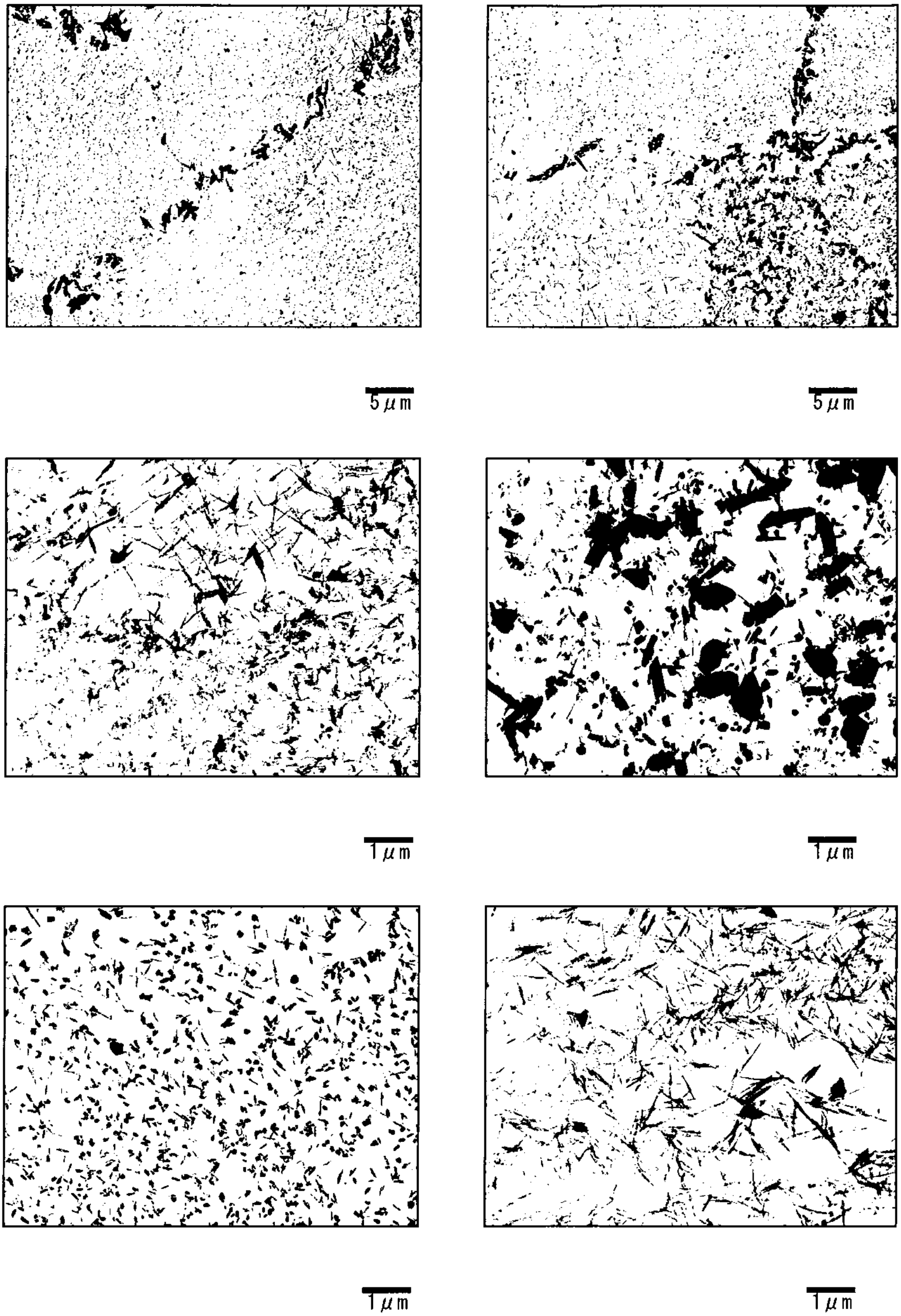


Photo I -4-14 Precipitates by TEM (Transmission electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Base metal)

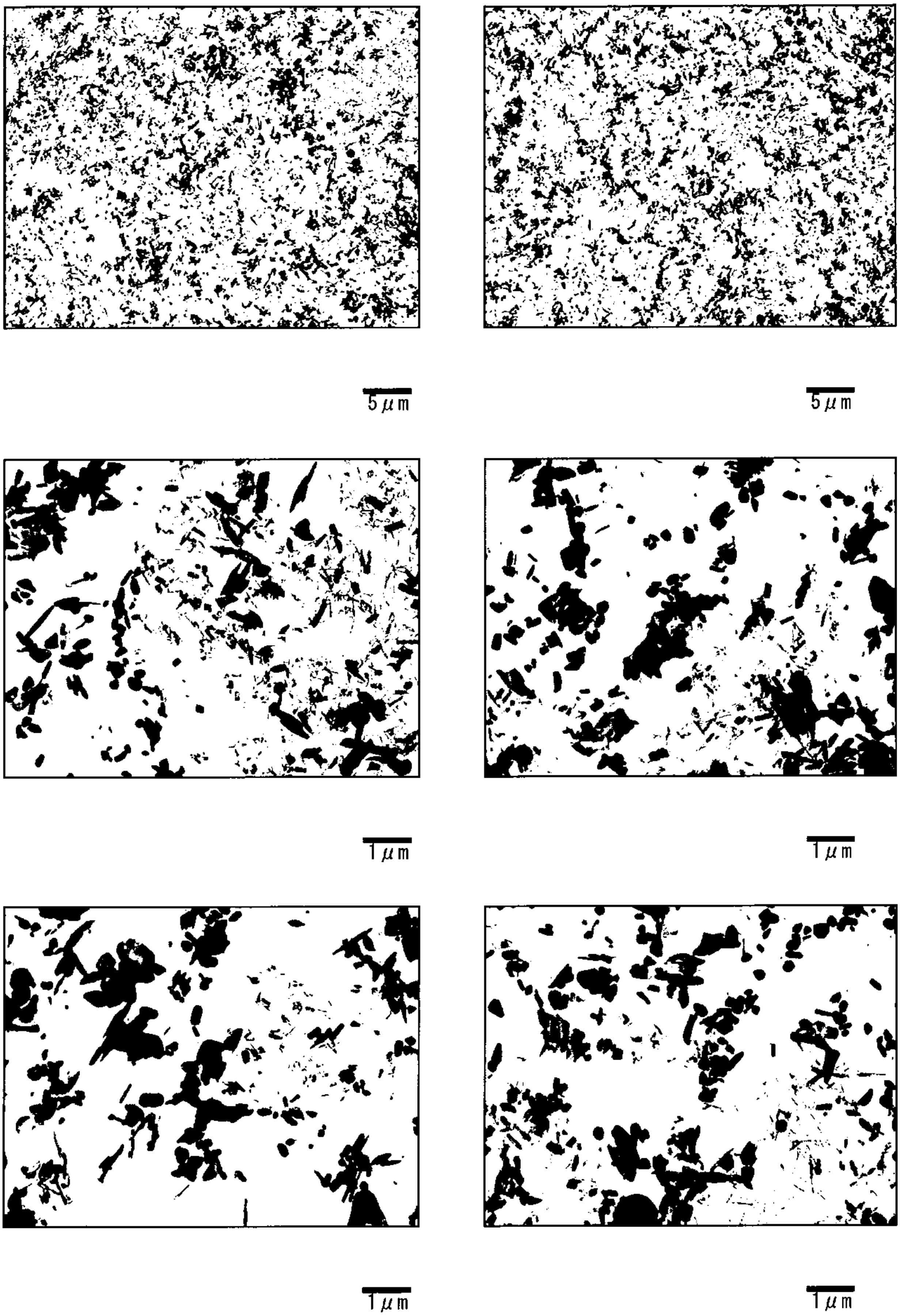


Photo I -4-15 Precipitates by TEM (Transmission electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Fine grain HAZ)

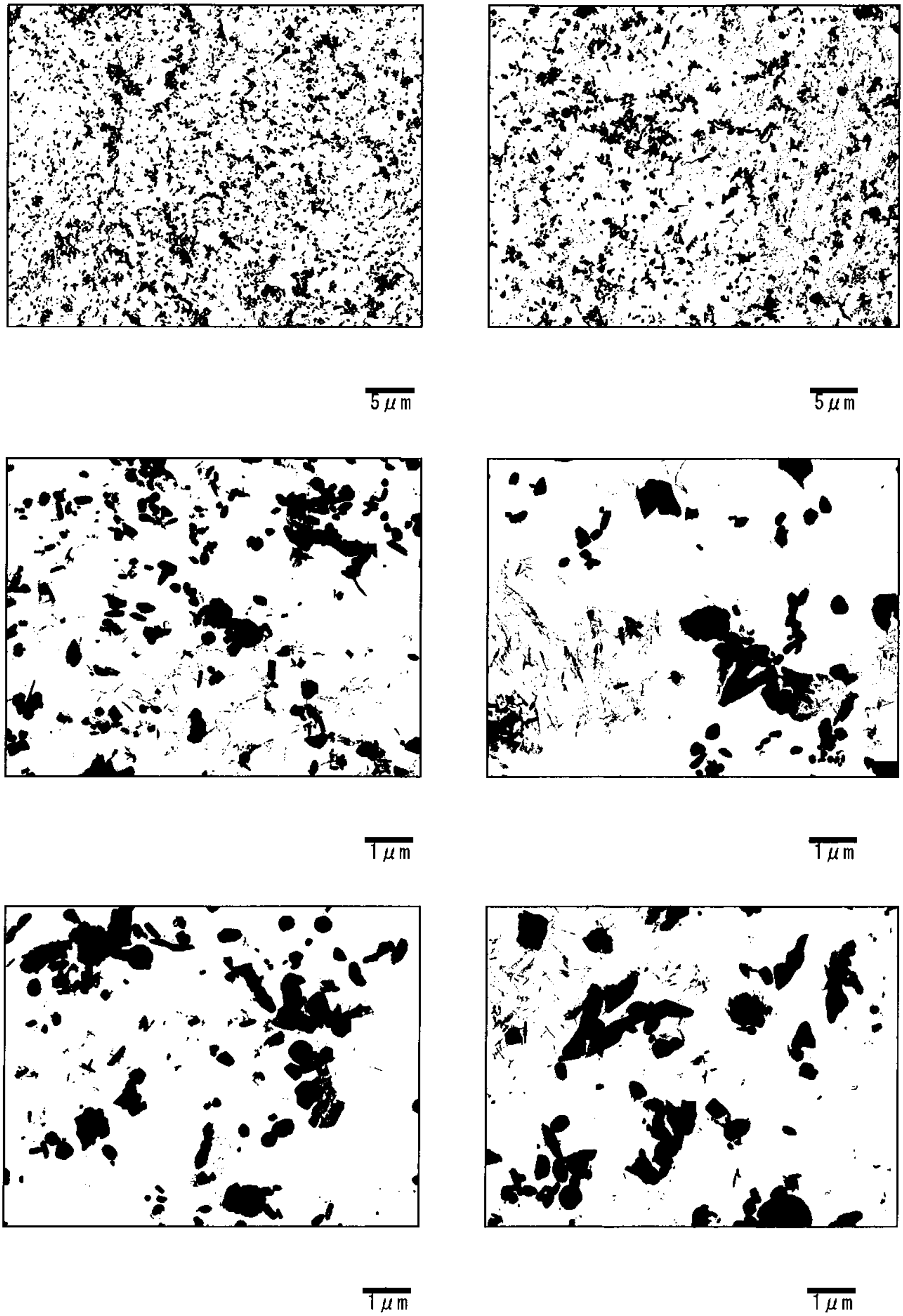


Photo I -4-16 Precipitates by TEM (Transmission electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Coarse grain HAZ)

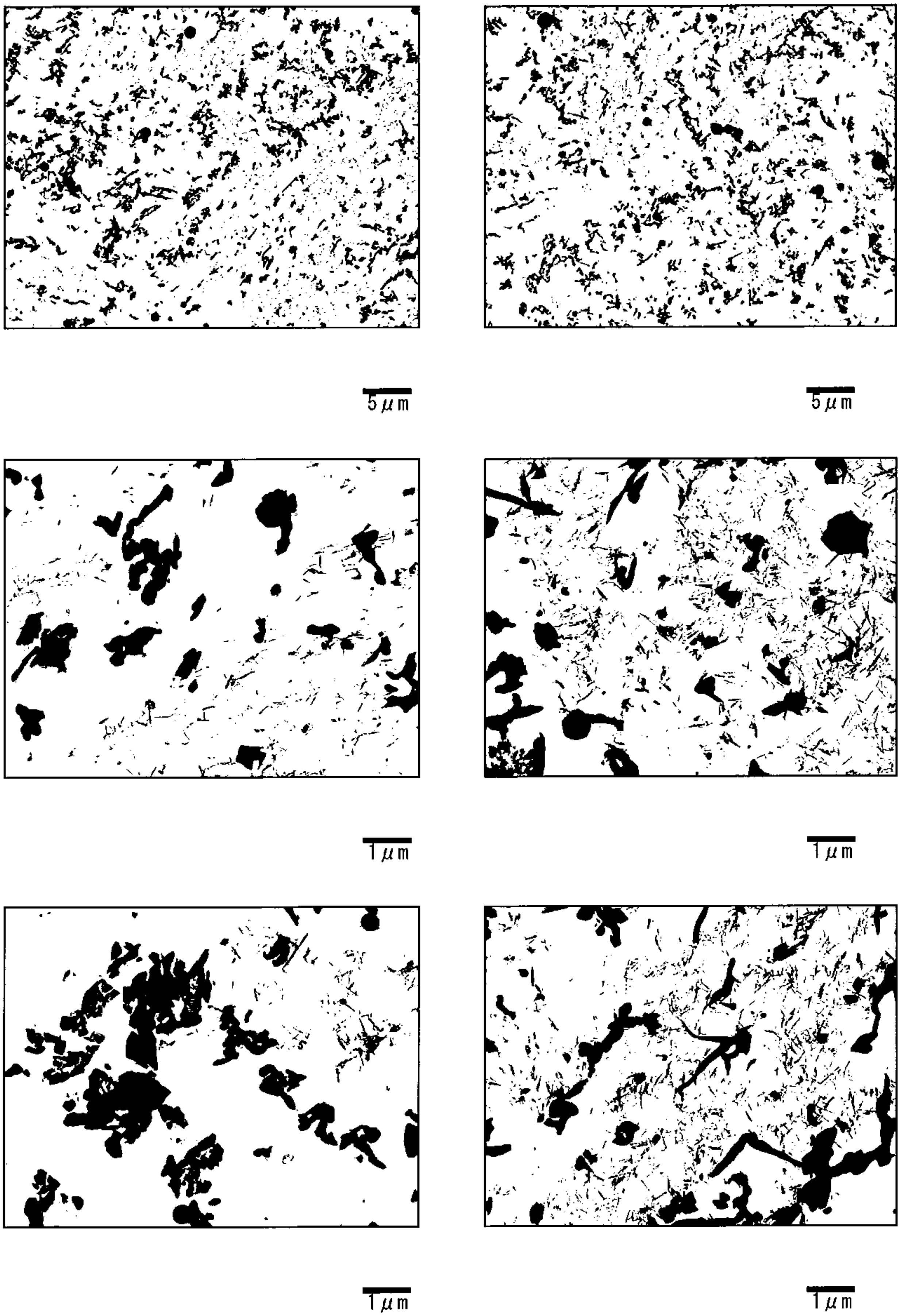


Photo I-4-17 Precipitates by TEM (Transmission electron microscope) observation
Platen SH Outlet Header-Left(Circumferential weld at left side : Weld metal)

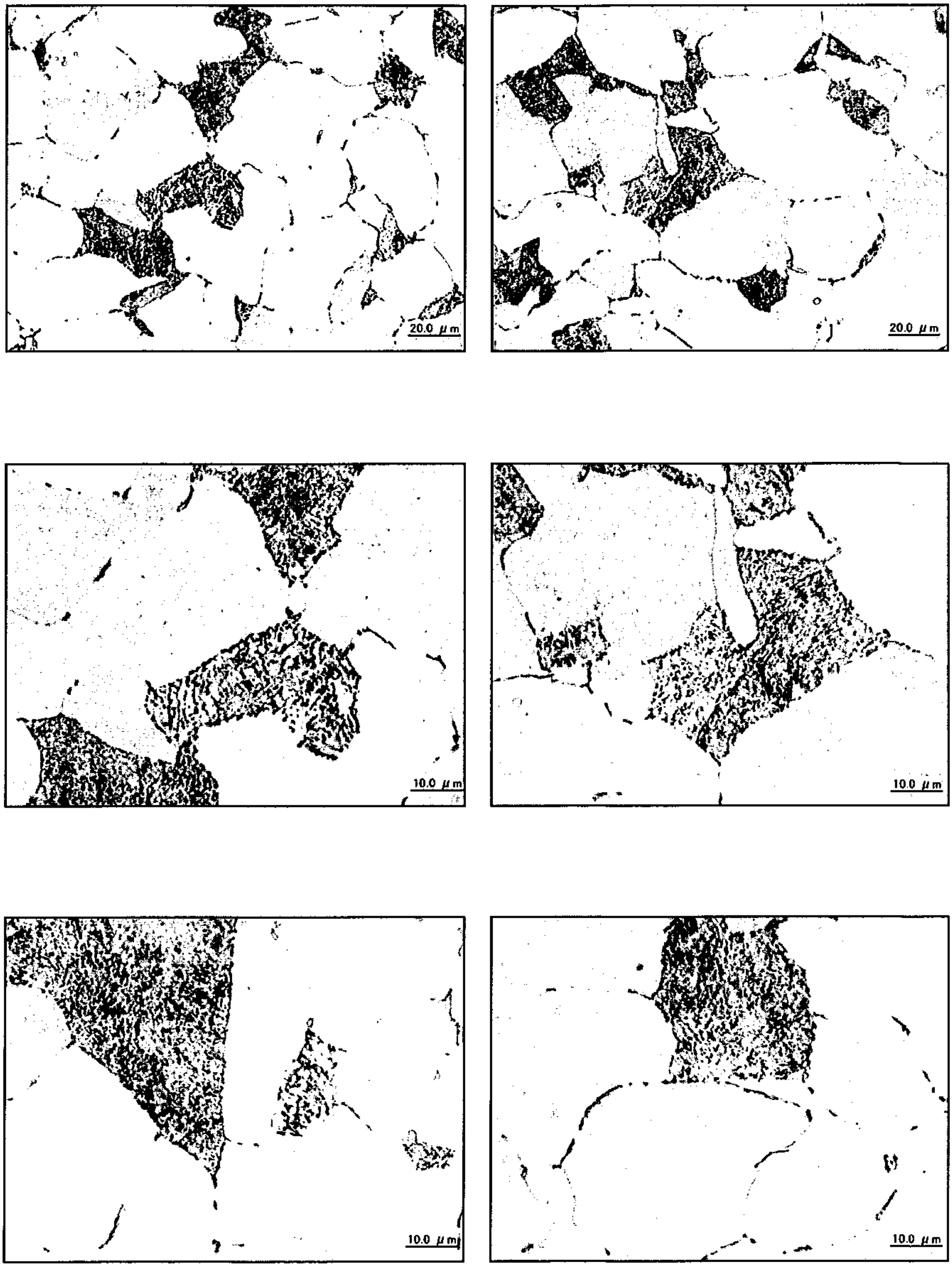


Photo I -5-1 Microstructure observation
De-Superheater-Left (Circumferential weld : Base metal)

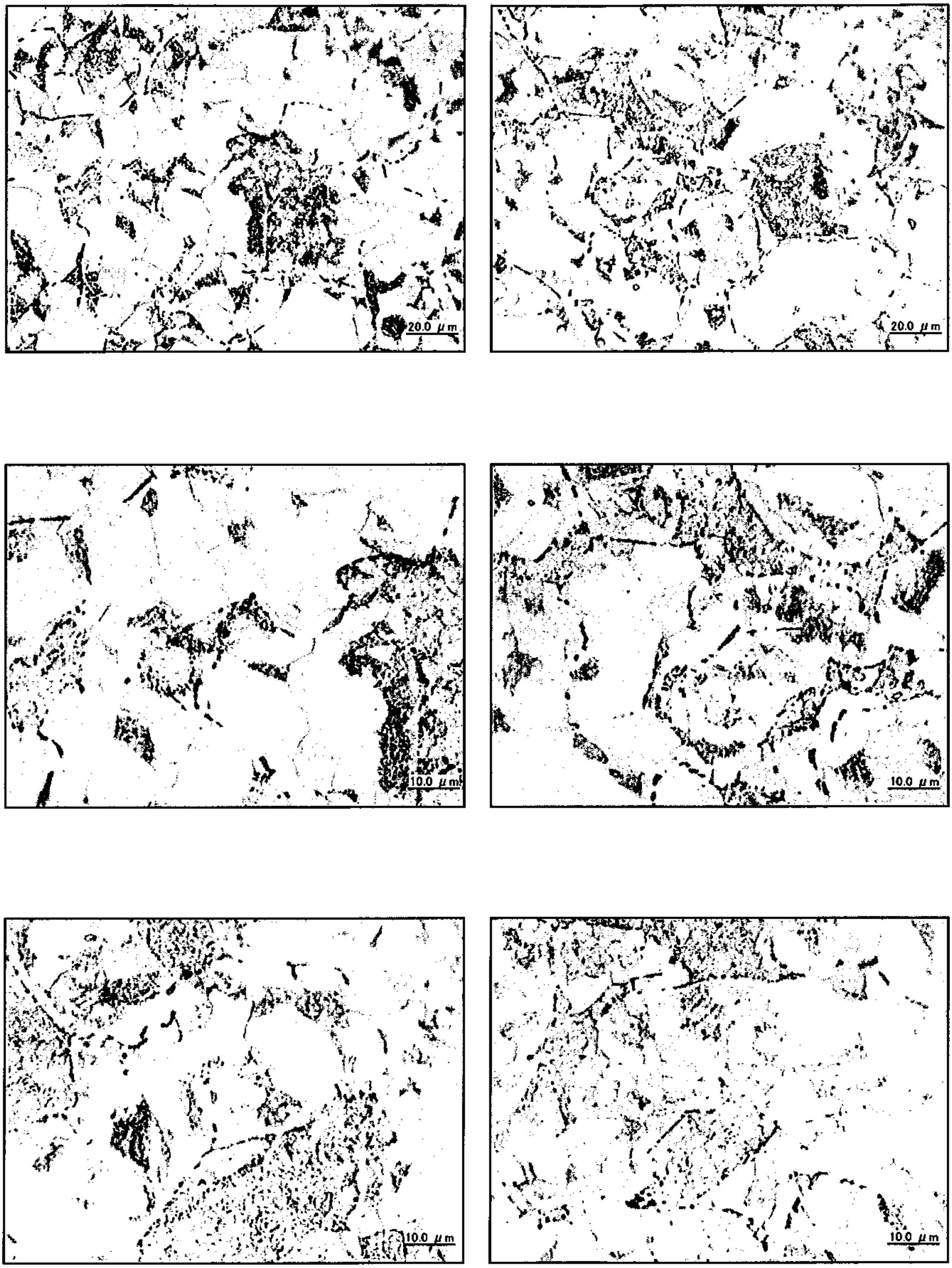


Photo I -5-2 Microstructure observation
De-Superheater-Left (Circumferential weld : Intercritical zone)

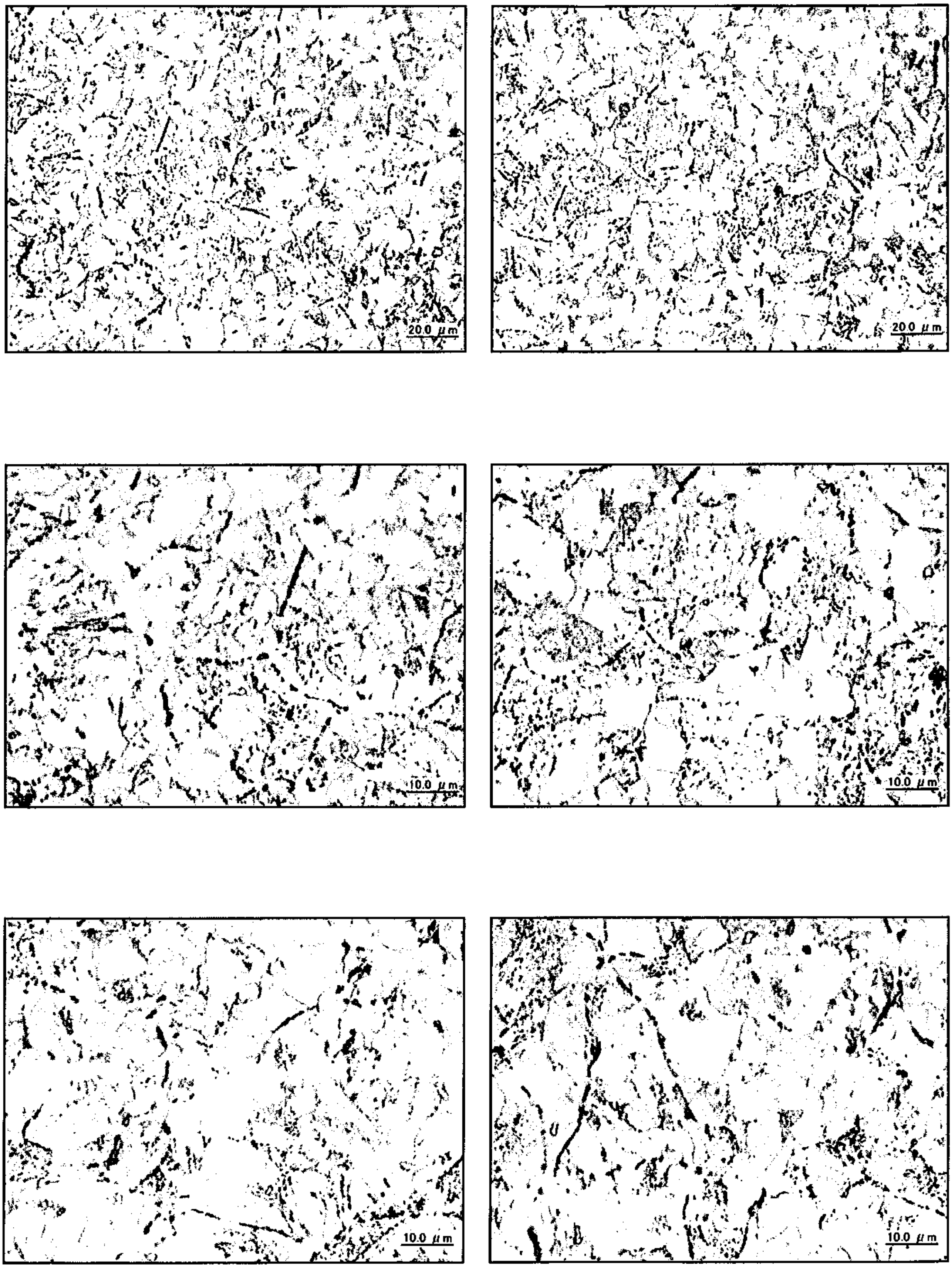


Photo I -5-3 Microstructure observation
De-Superheater-Left (Circumferential weld : Fine grain HAZ)

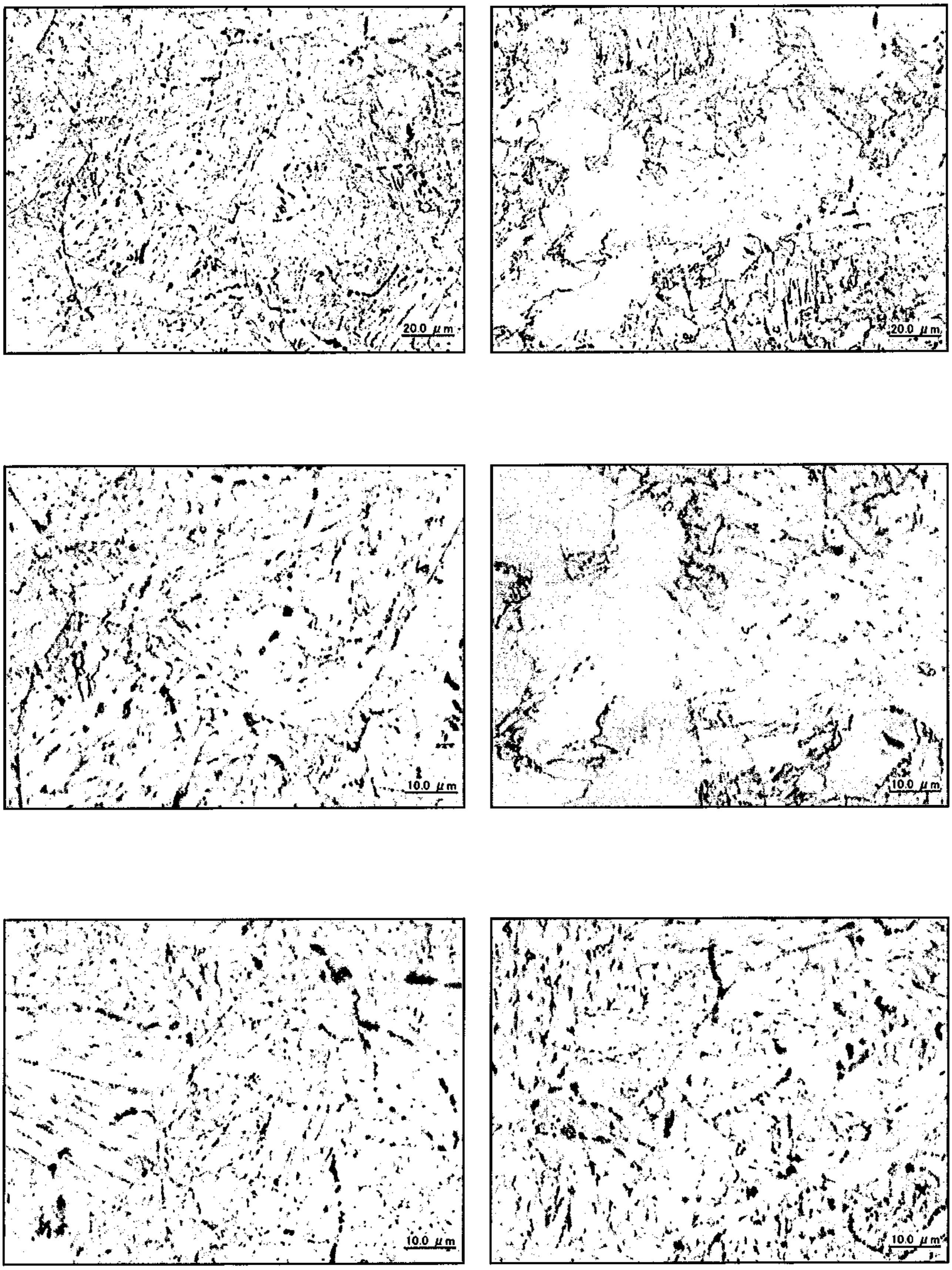


Photo I -5-4 Microstructure observation
De-Superheater-Left (Circumferential weld : Coarse grain HAZ)

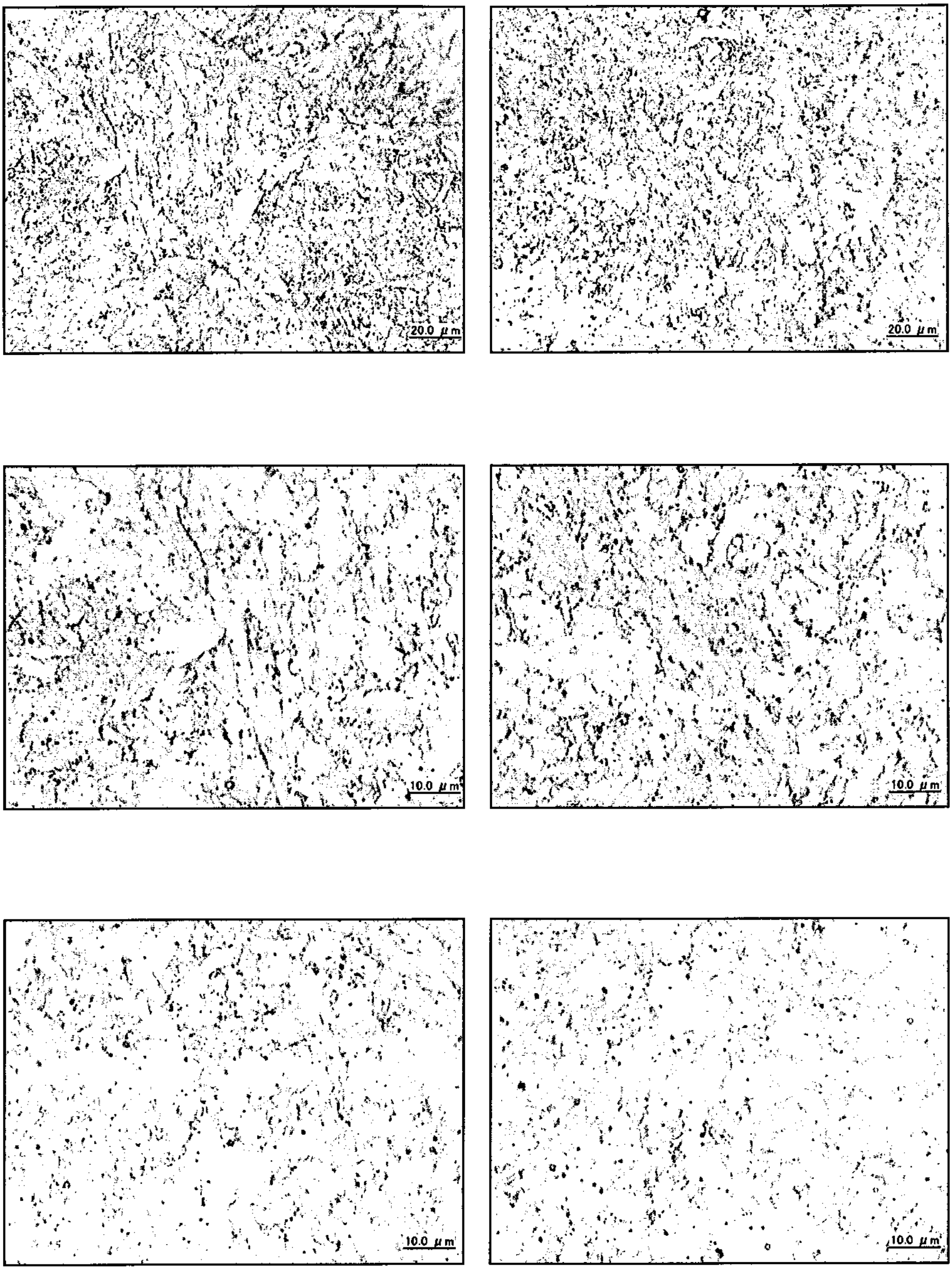


Photo I -5-5 Microstructure observation
De-Superheater-Left (Circumferential weld : Weld metal)

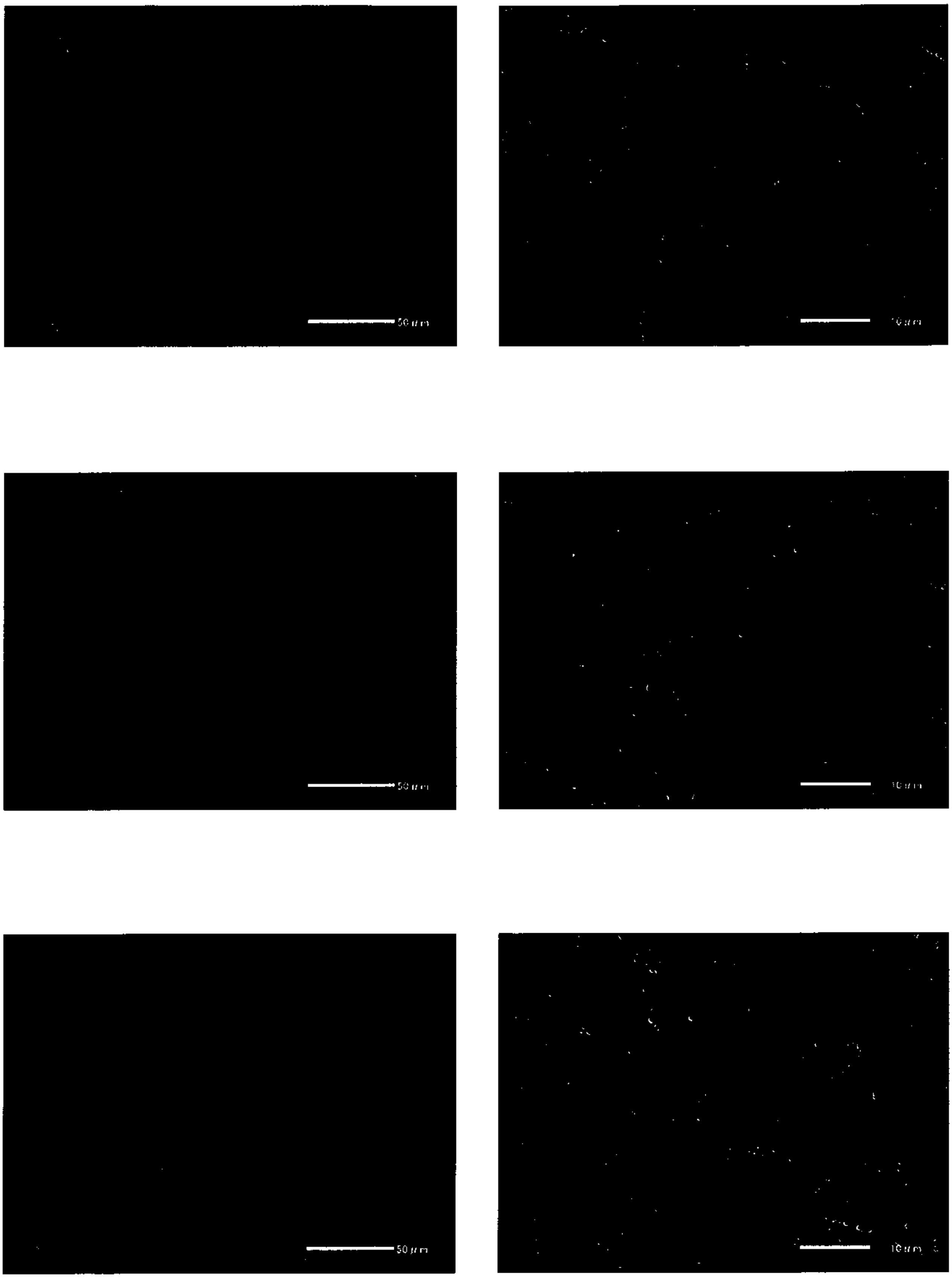


Photo I -5-6 SEM(Scanning electron microscope) observation
De-Superheater-Left(Circumferential weld : Fine grain HAZ)

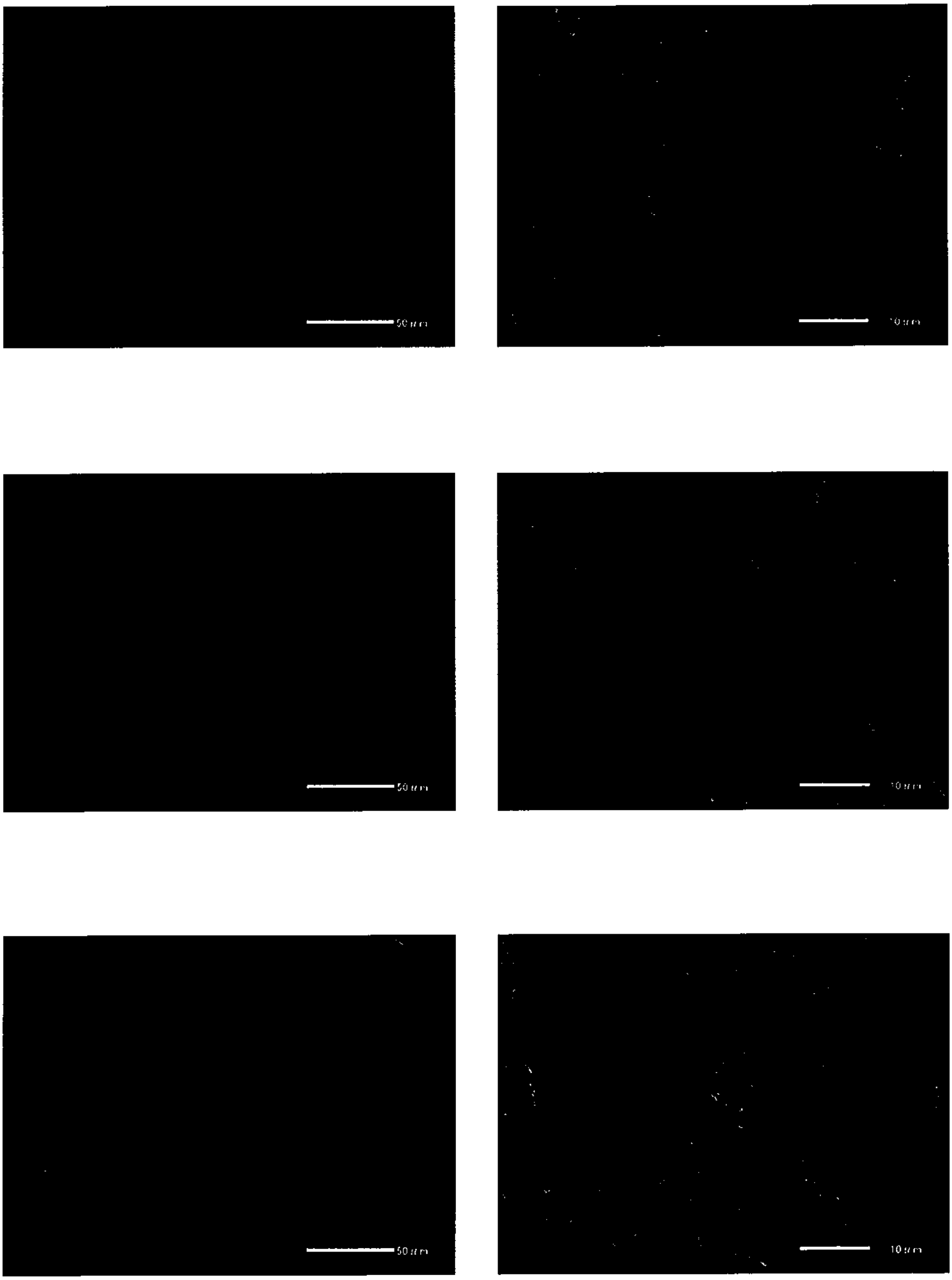


Photo I -5-7 SEM(Scanning electron microscope) observation
De-Superheater-Left(Circumferential weld : Coarse grain HAZ)

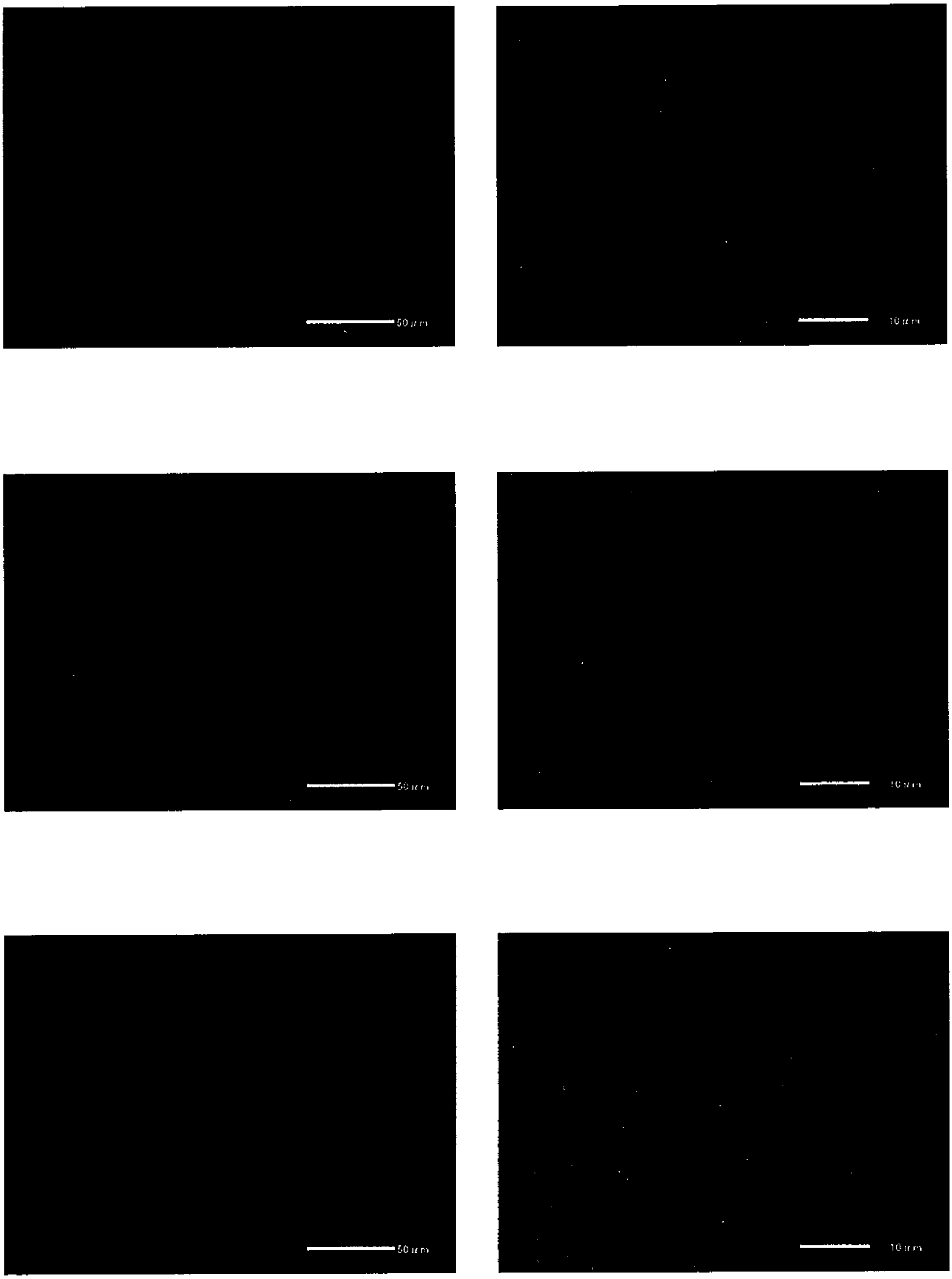


Photo I -5-8 SEM(Scanning electron microscope) observation
De-Superheater-Left(Circumferential weld : Weld metal)

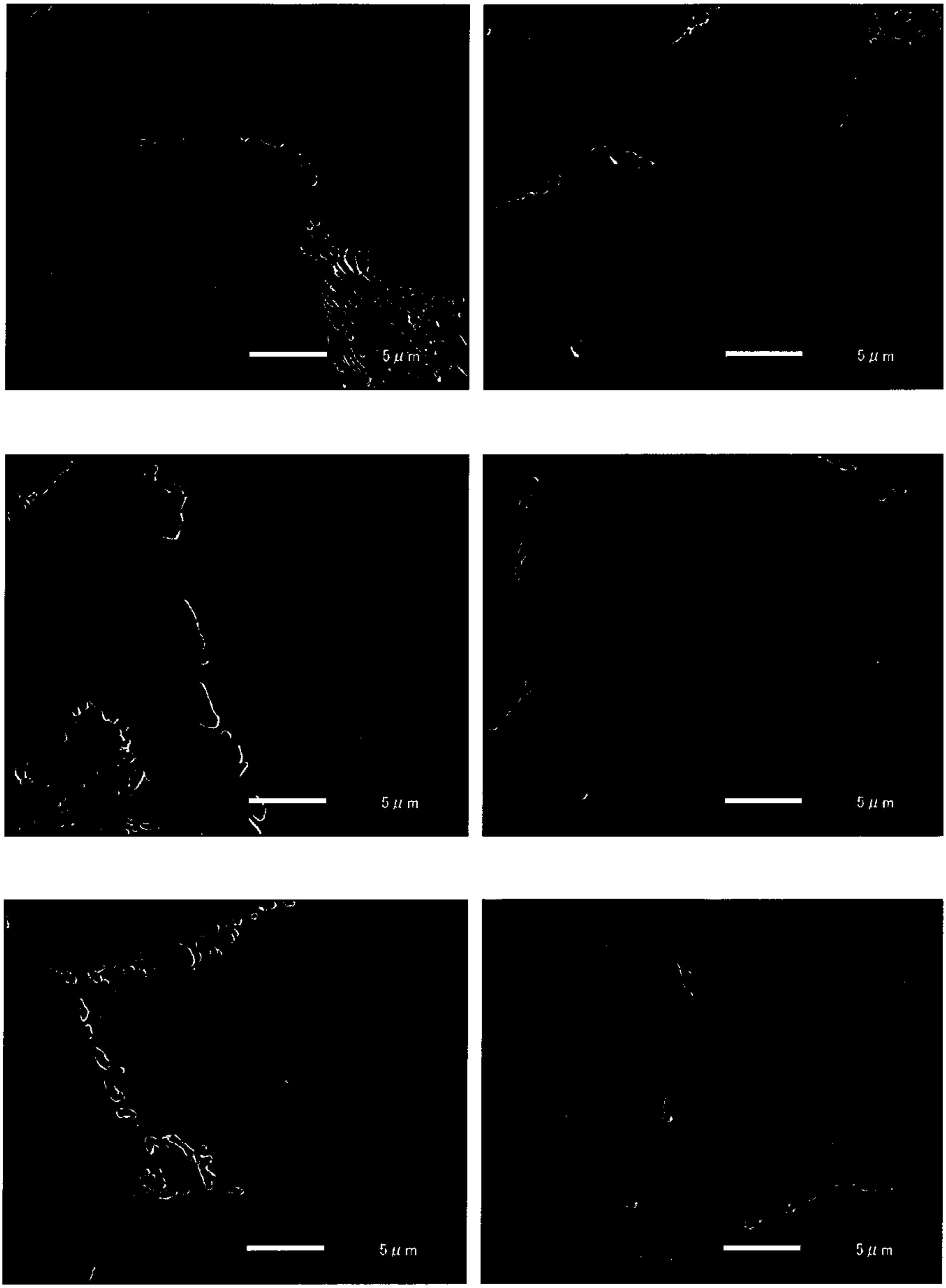


Photo I -5-9 Precipitates along grain boundary by SEM observation
De-Superheater-Left (Circumferential weld : Base metal)

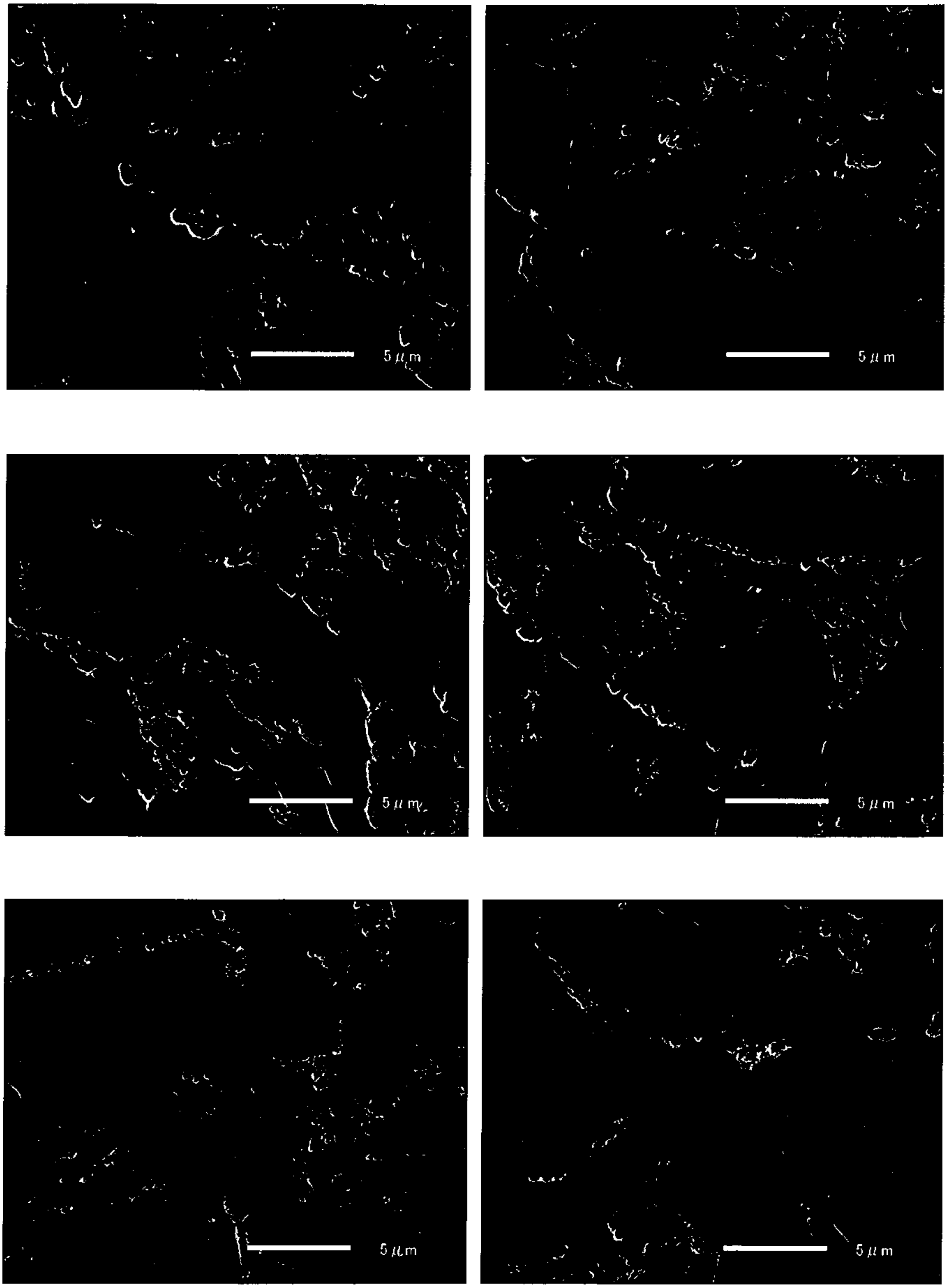


Photo I -5-10 Precipitates along grain boundary by SEM observation
De-Superheater-Left (Circumferential weld : Fine grain HAZ)

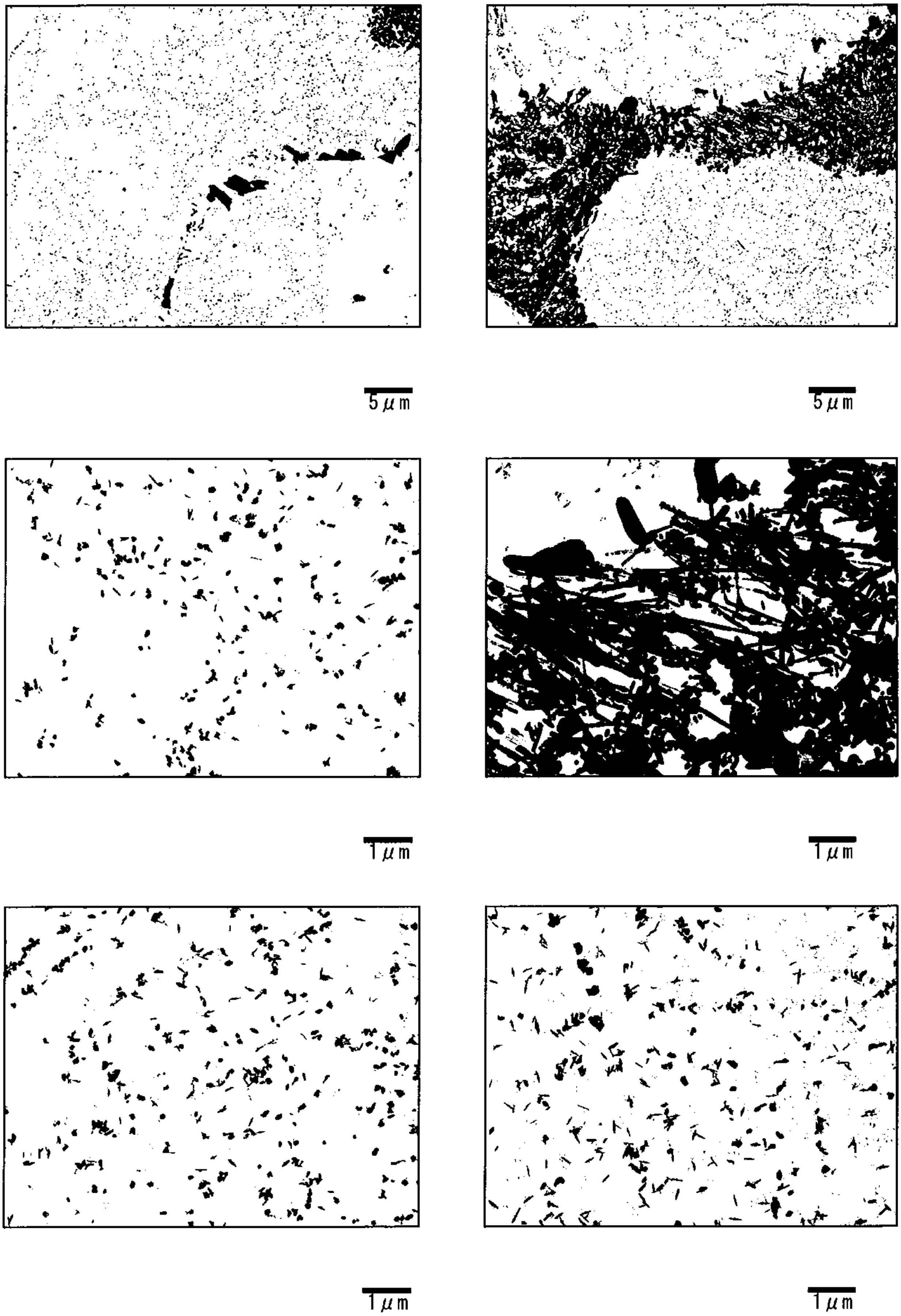


Photo I -5-11 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Left (Circumferential weld : Base metal)

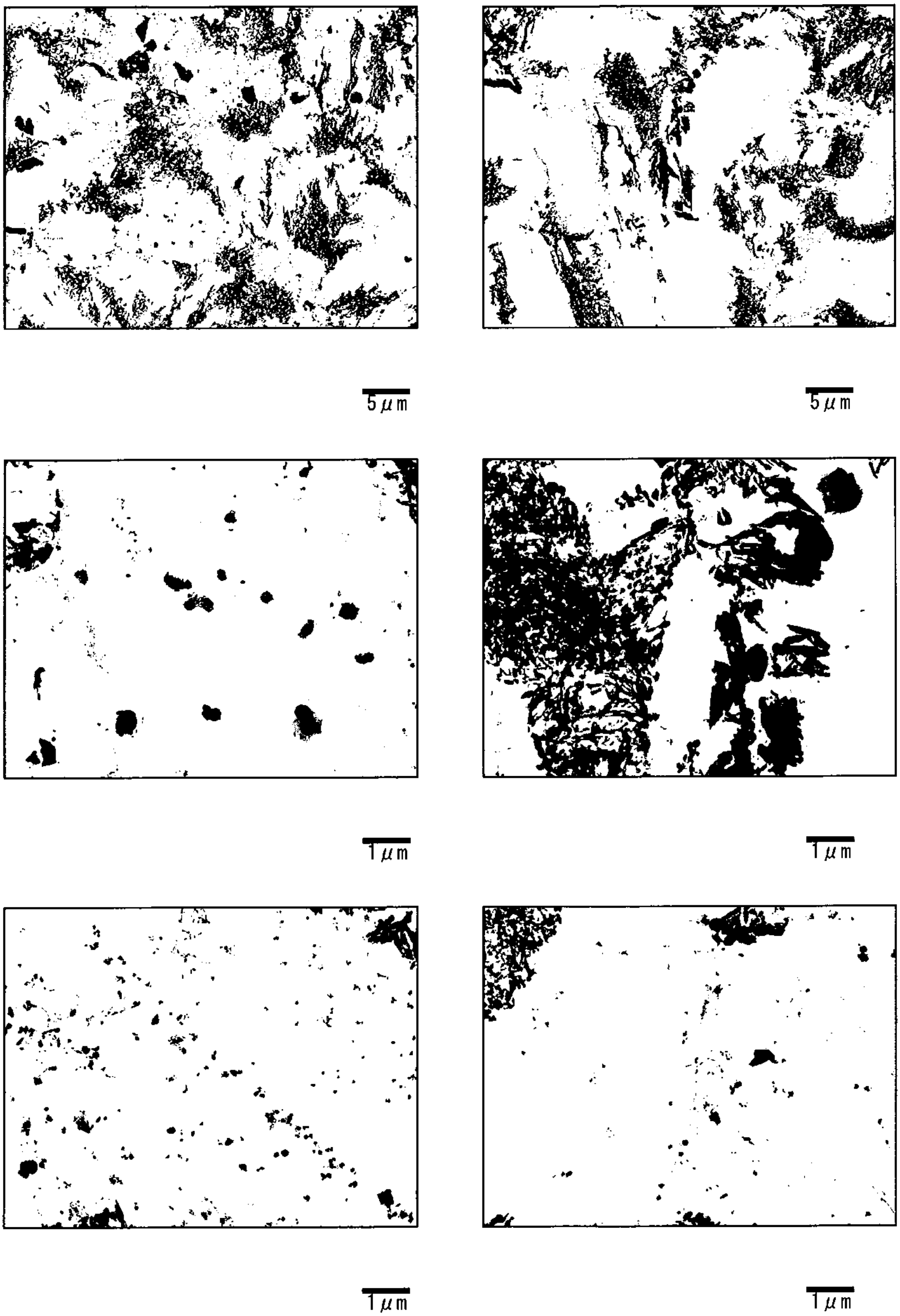


Photo I -5-12 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Left (Circumferential weld : Fine grain HAZ)

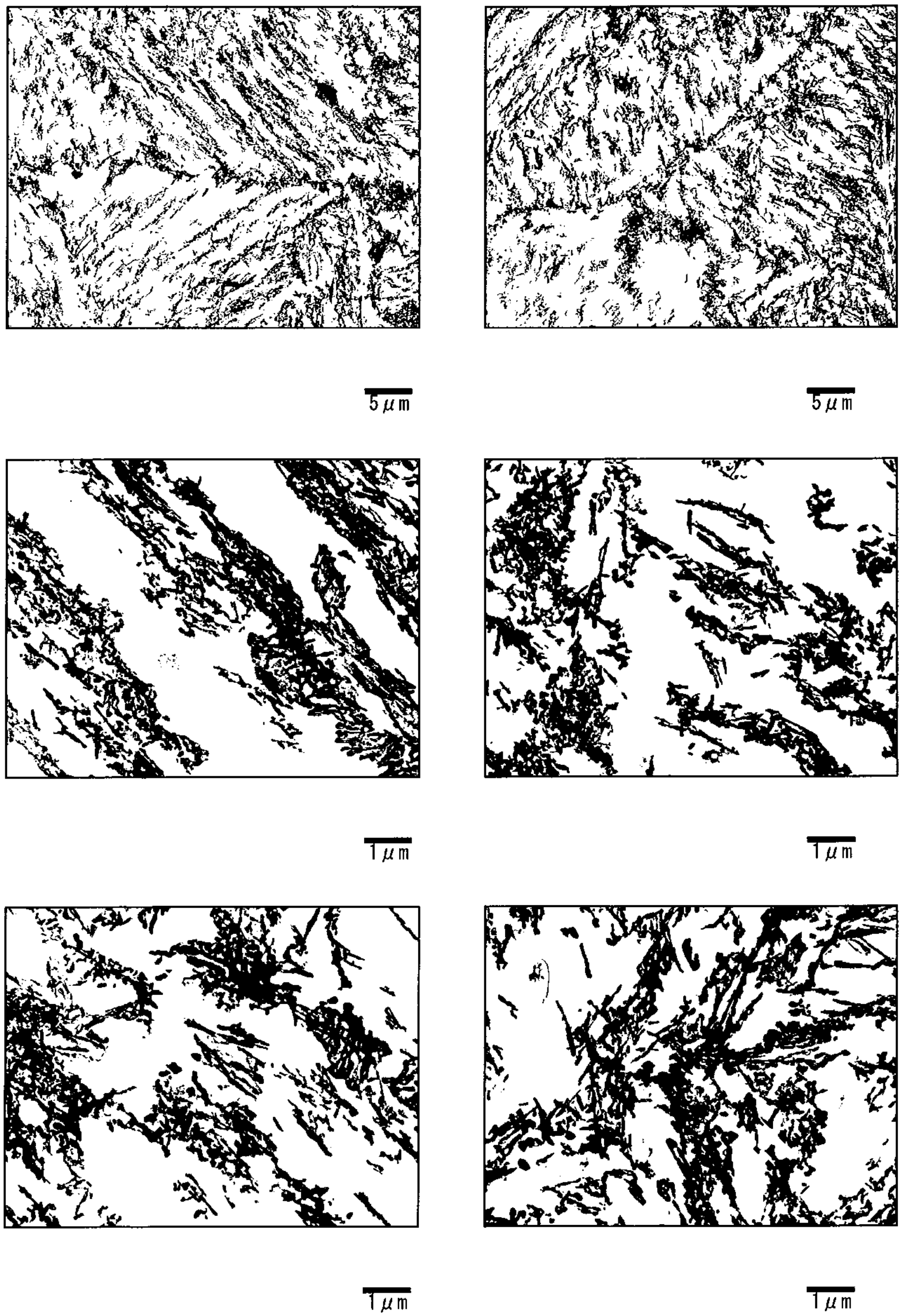


Photo I -5-13 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Left(Circumferential weld : Coarse grain HAZ)

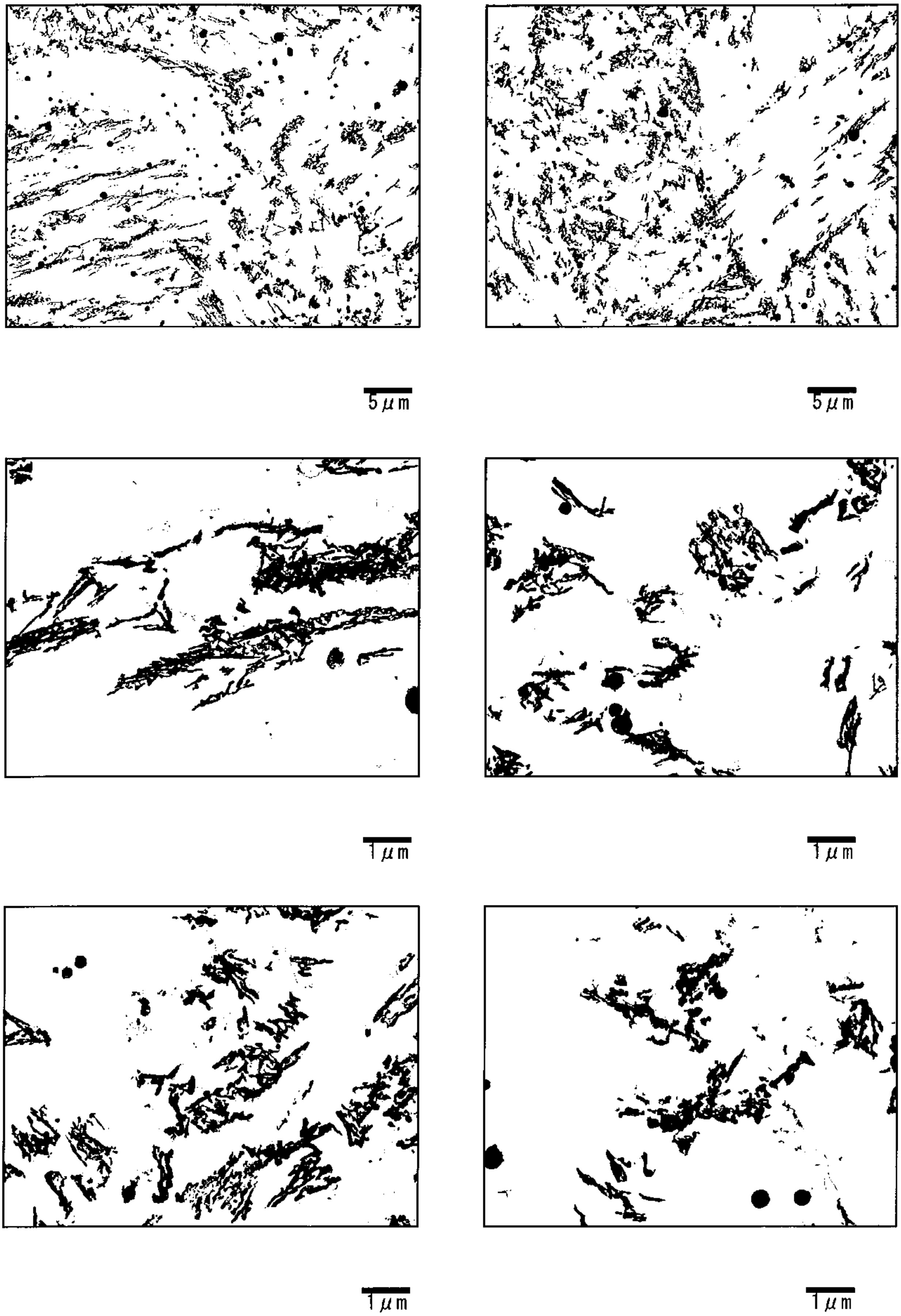


Photo I-5-14 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Left (Circumferential weld : Weld metal)

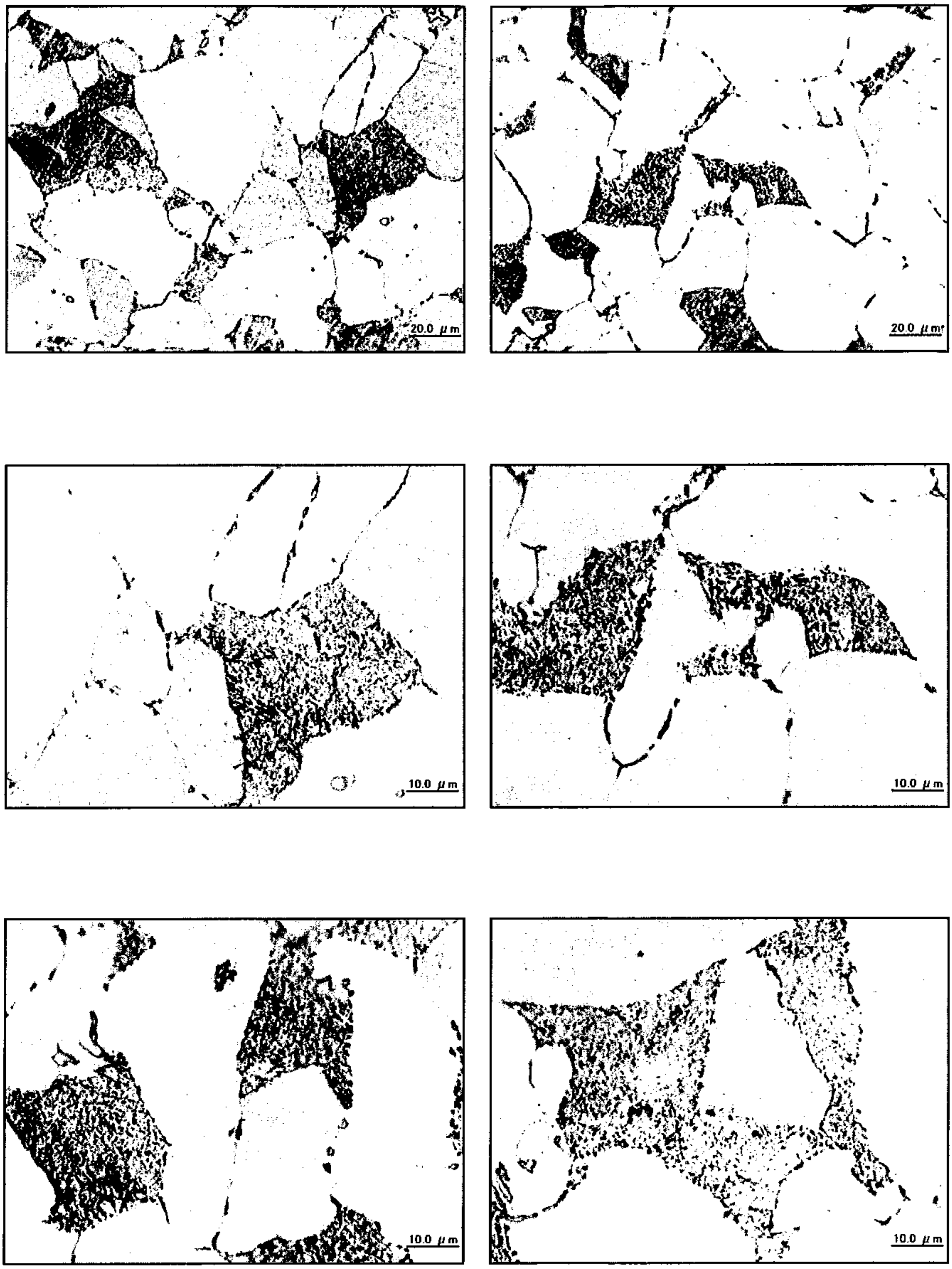


Photo I -6-1 Microstructure observation
De-Superheater-Right (Circumferential weld : Base metal)

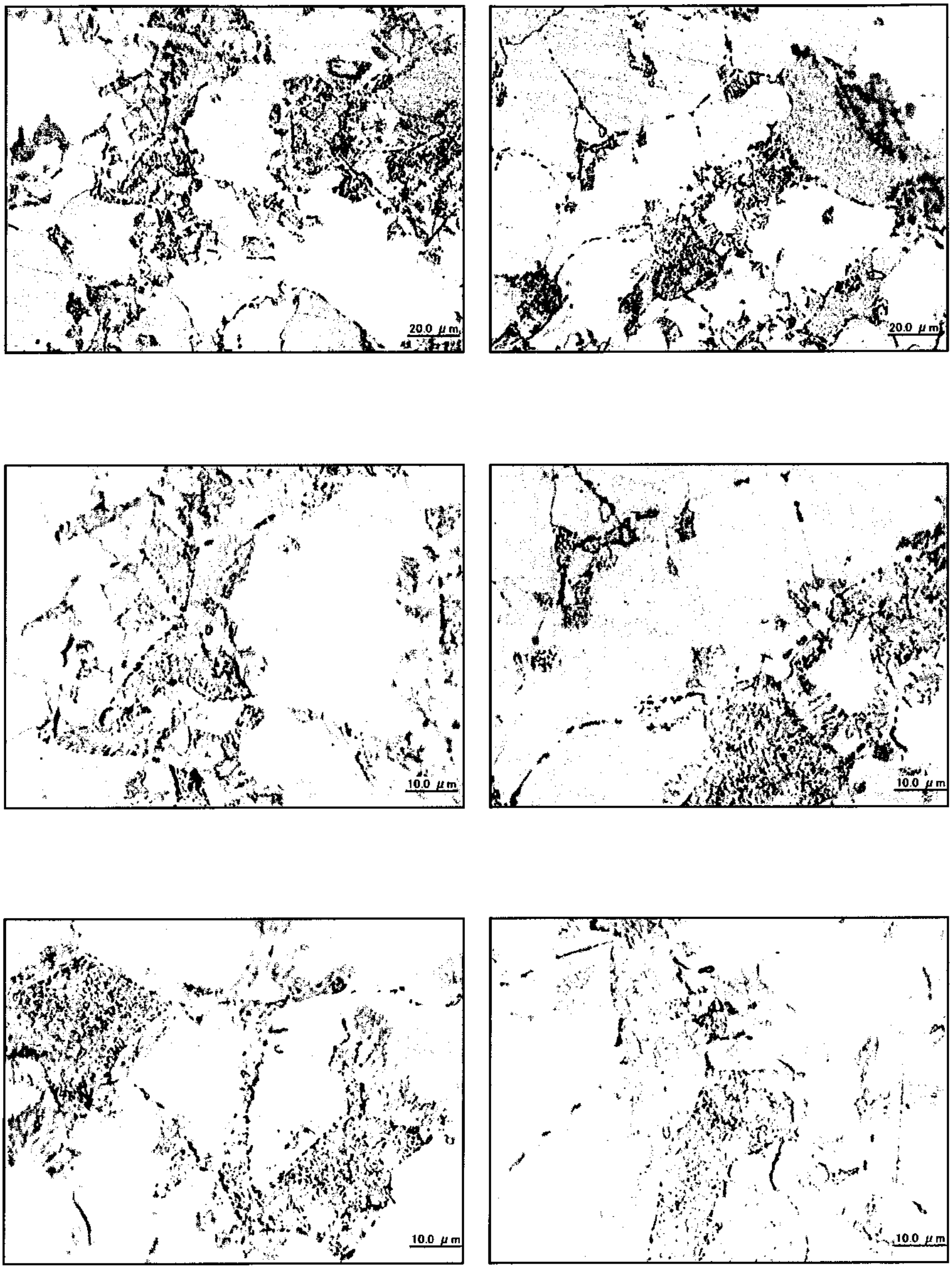


Photo I-6-2 Microstructure observation
De-Superheater-Right (Circumferential weld : Intercritical zone)

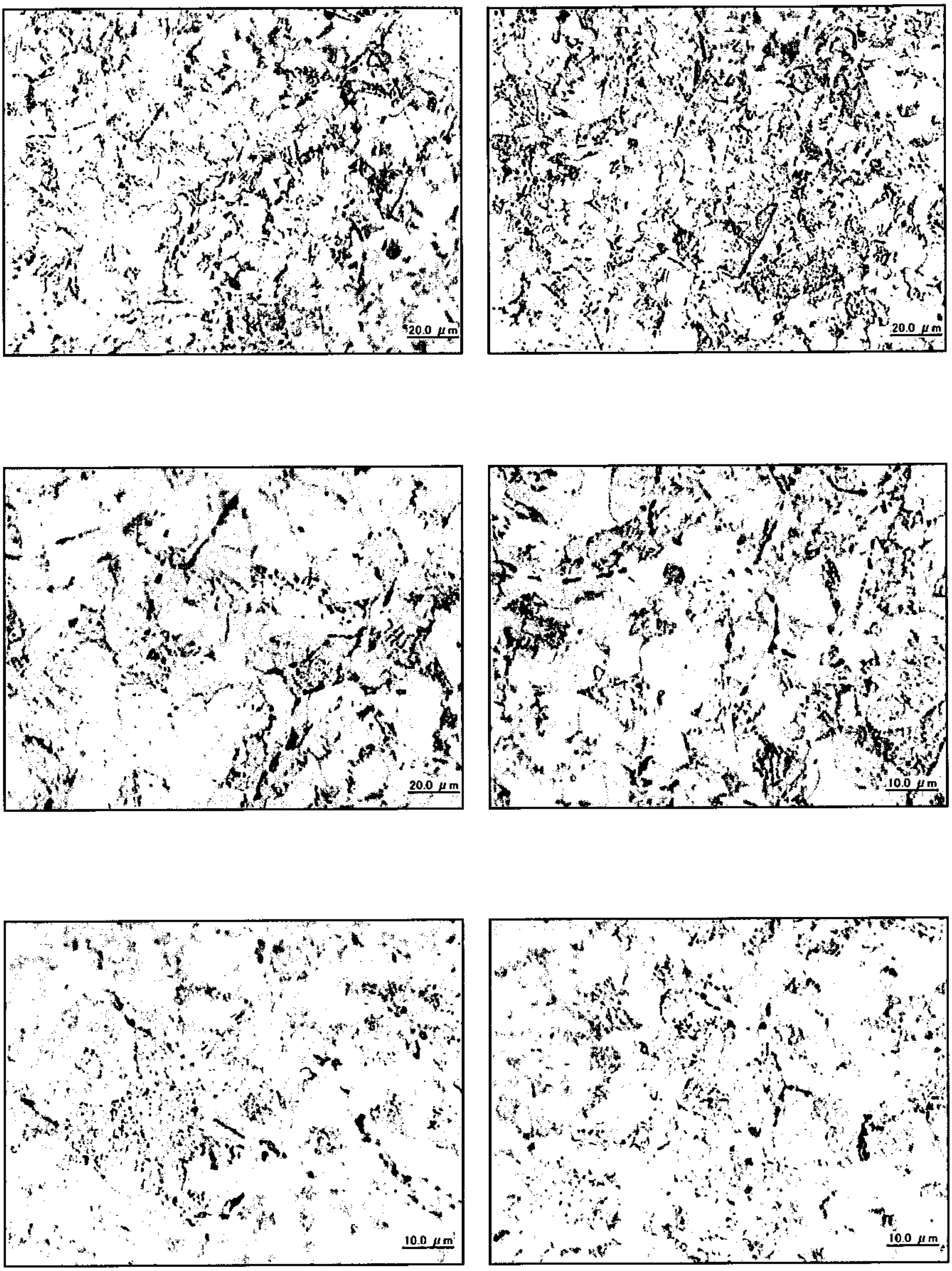


Photo I -6-3 Microstructure observation
De-Superheater-Right (Circumferential weld : Fine grain HAZ)

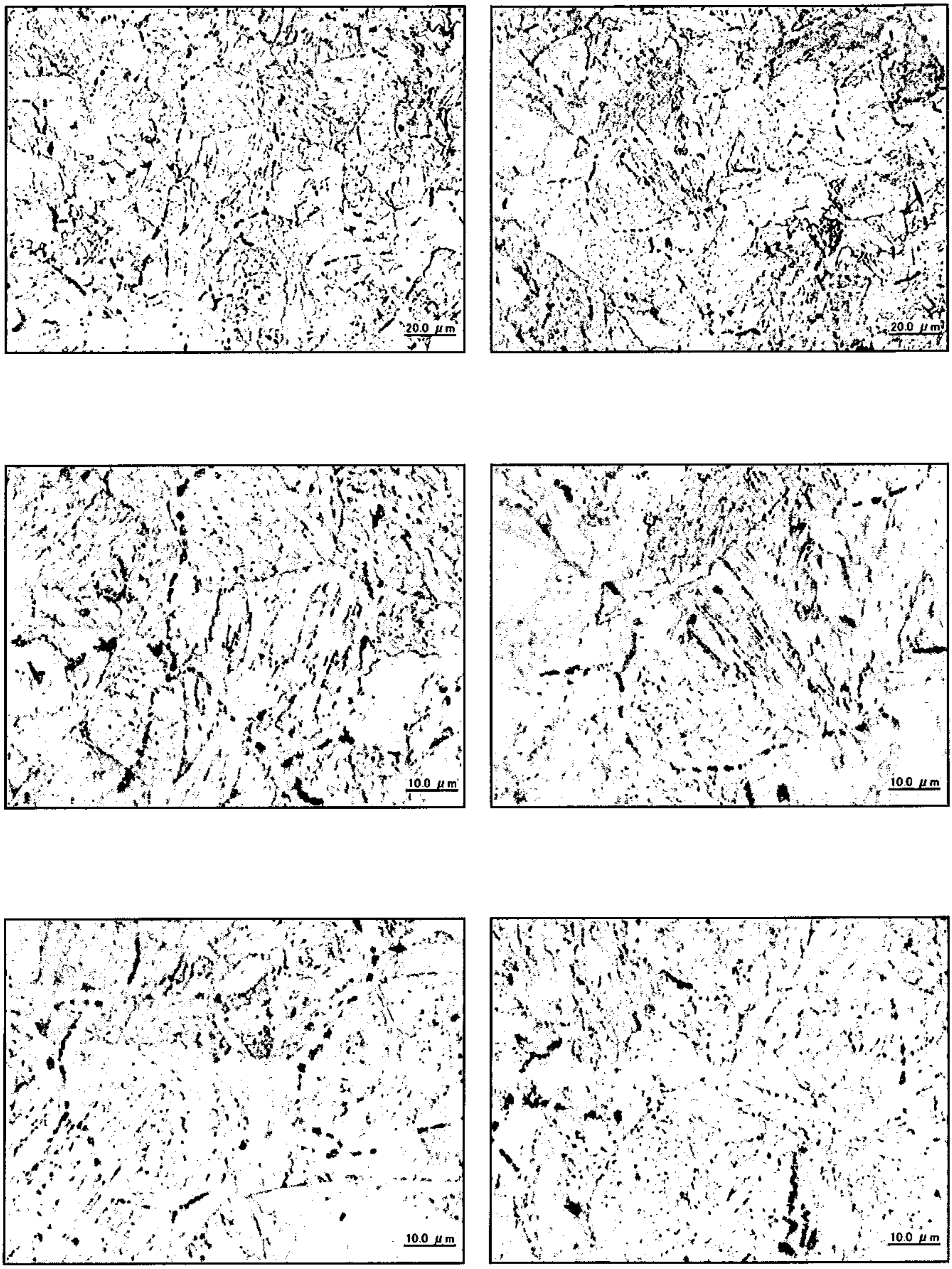


Photo I -6-4 Microstructure observation
De-Superheater-Right (Circumferential weld : Coarse grain HAZ)

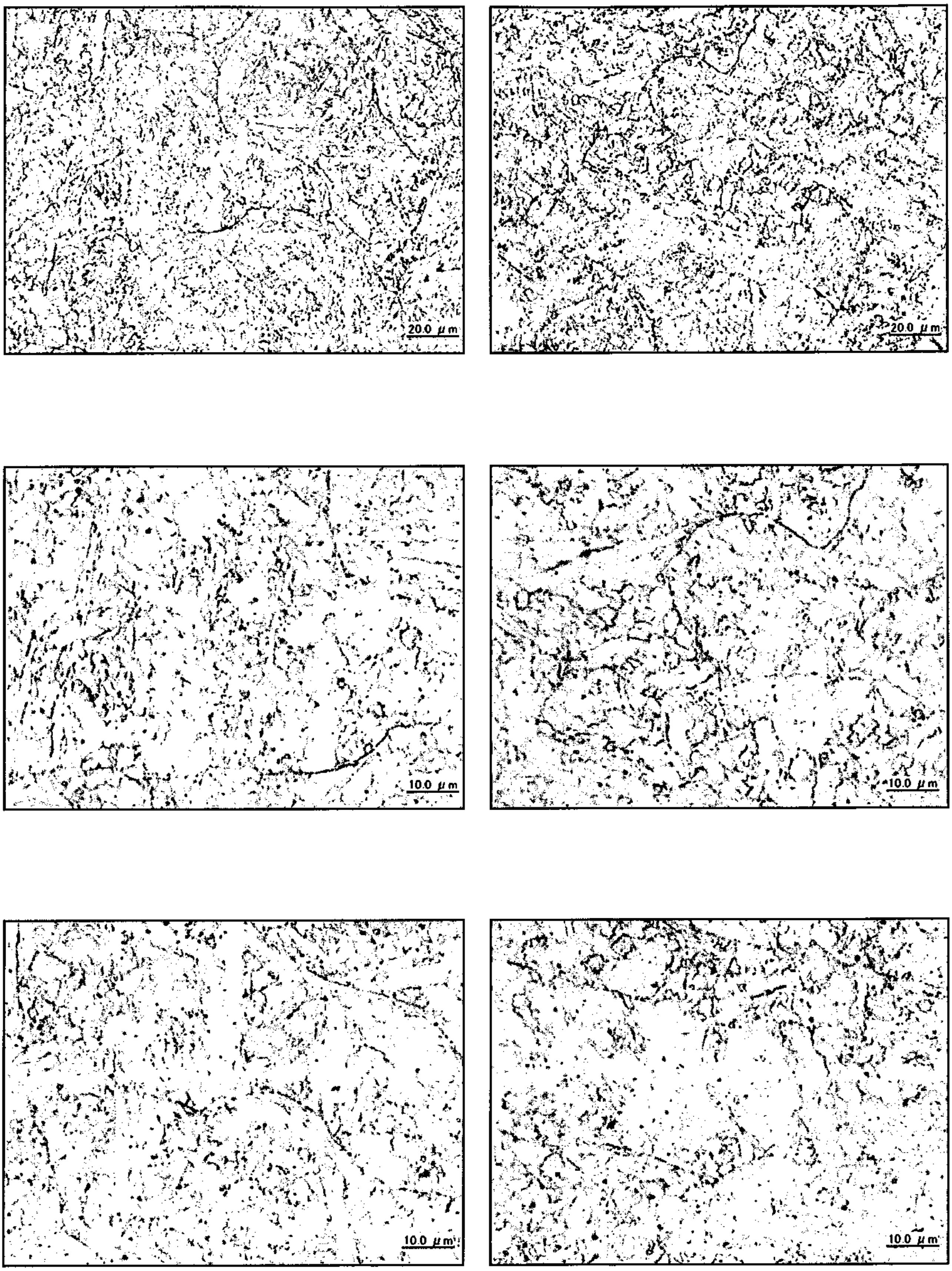


Photo I -6-5 Microstructure observation
De-Superheater-Right (Circumferential weld : Weld metal)

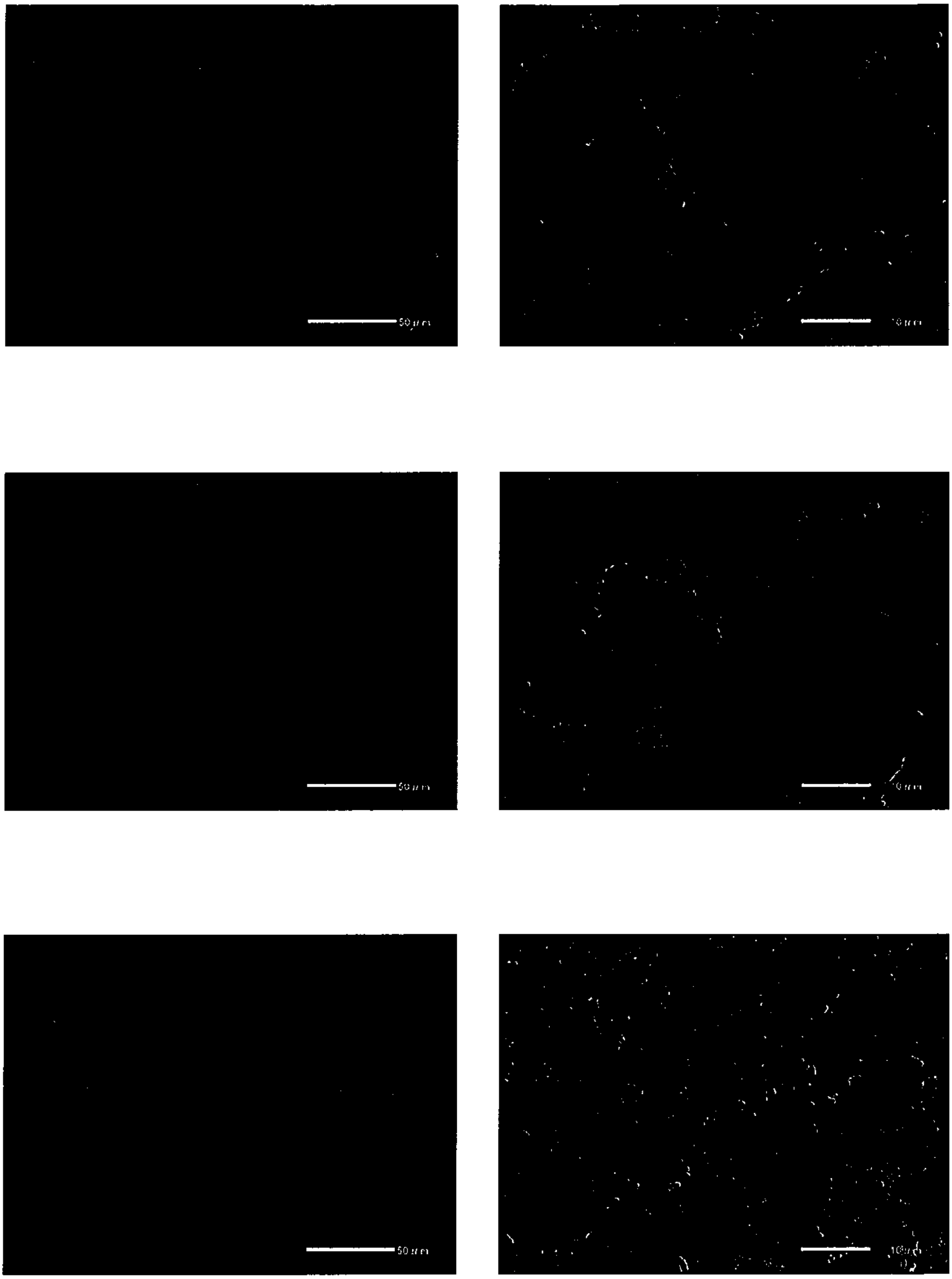


Photo I -6-6 SEM(Scanning electron microscope) observation
De-Superheater-Right(Circumferential weld : Fine grain HAZ)

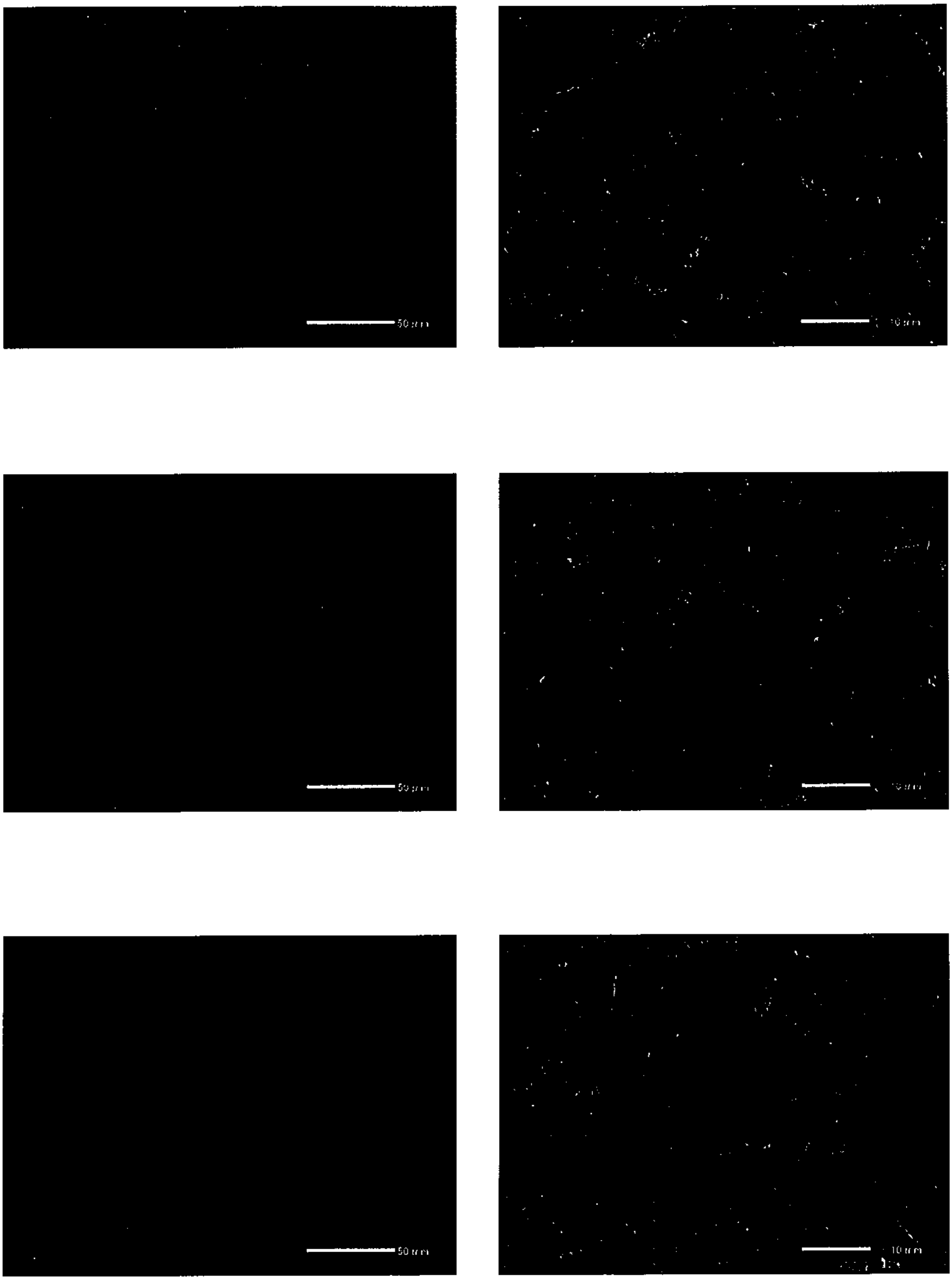
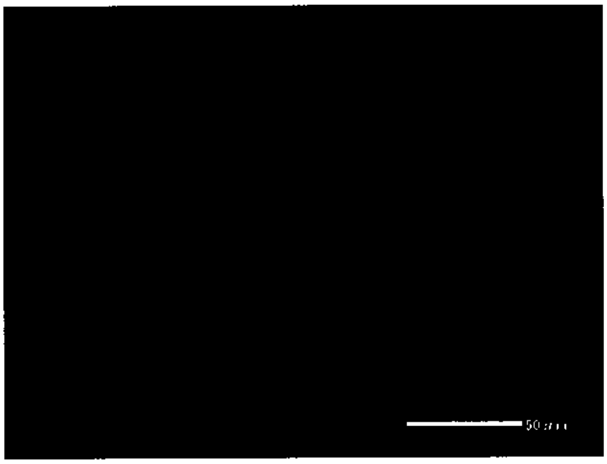
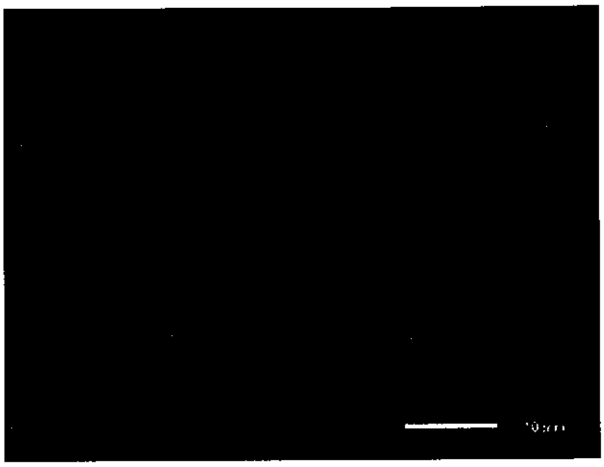
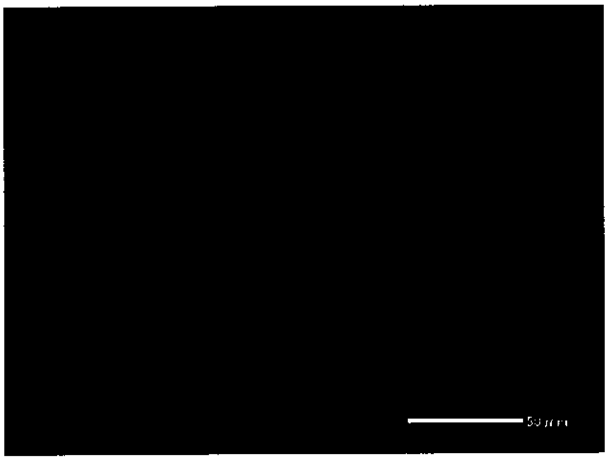
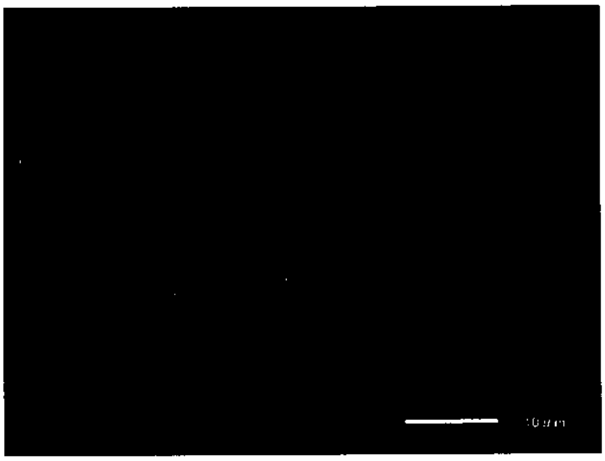


Photo I -6-7 SEM(Scanning electron microscope) observation
De-Superheater-Right(Circumferential weld : Coarse grain HAZ)

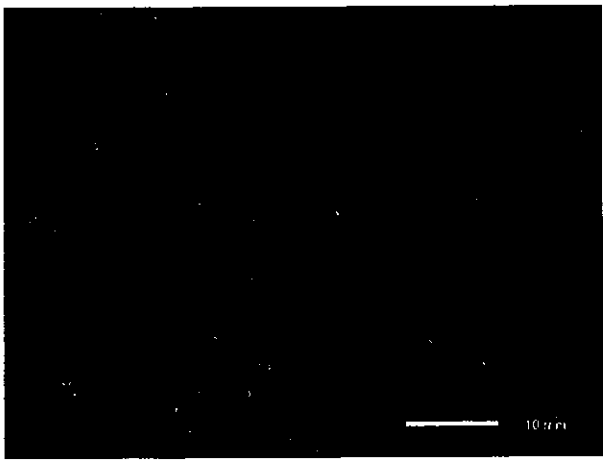


Photo I -6-8 SEM(Scanning electron microscope) observation
De-Superheater-Right(Circumferential weld : Weld metal)

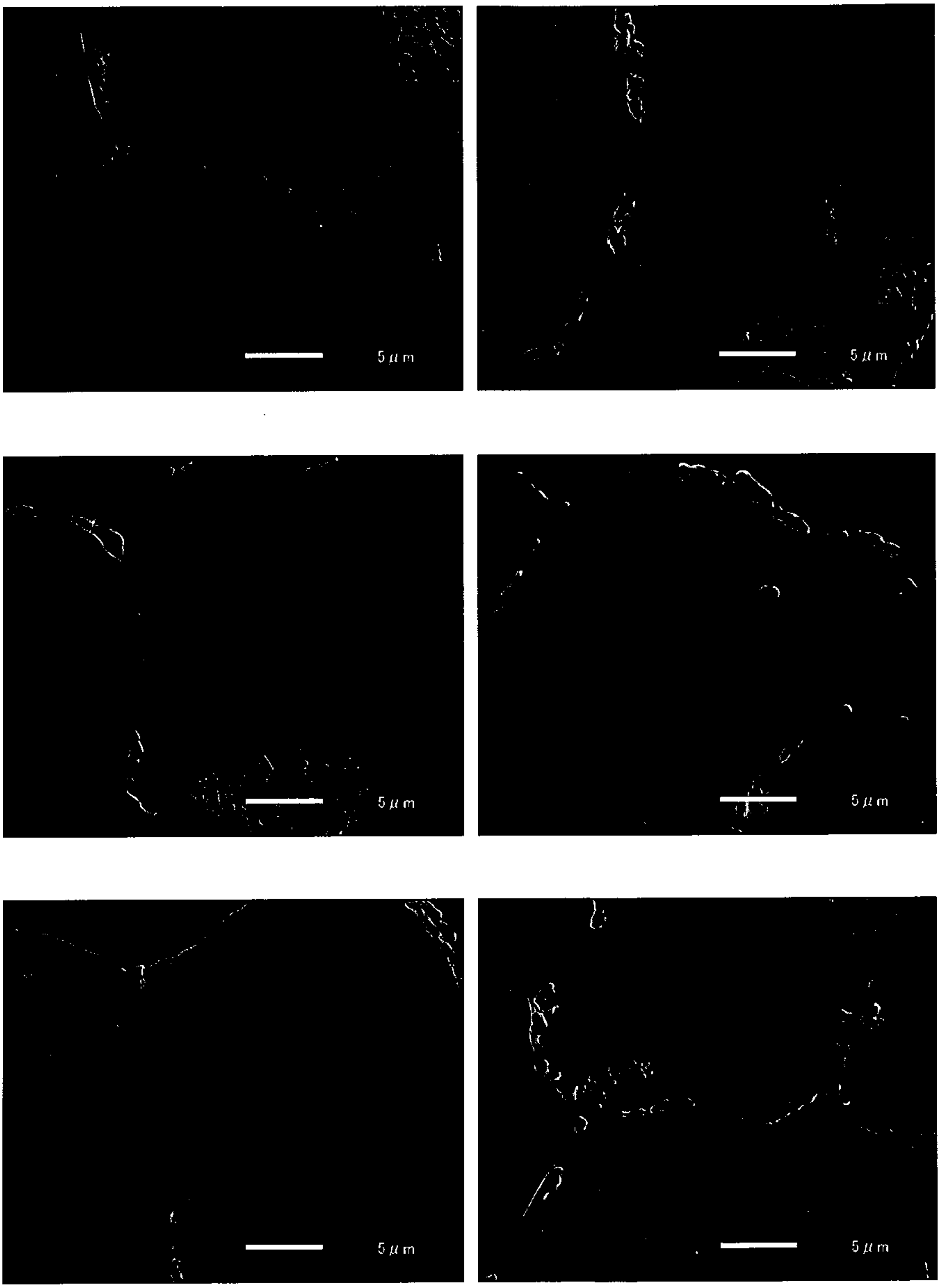


Photo I -6-9 Precipitates along grain boundary by SEM observation
De-Superheater-Right(Circumferential weld : Base metal)

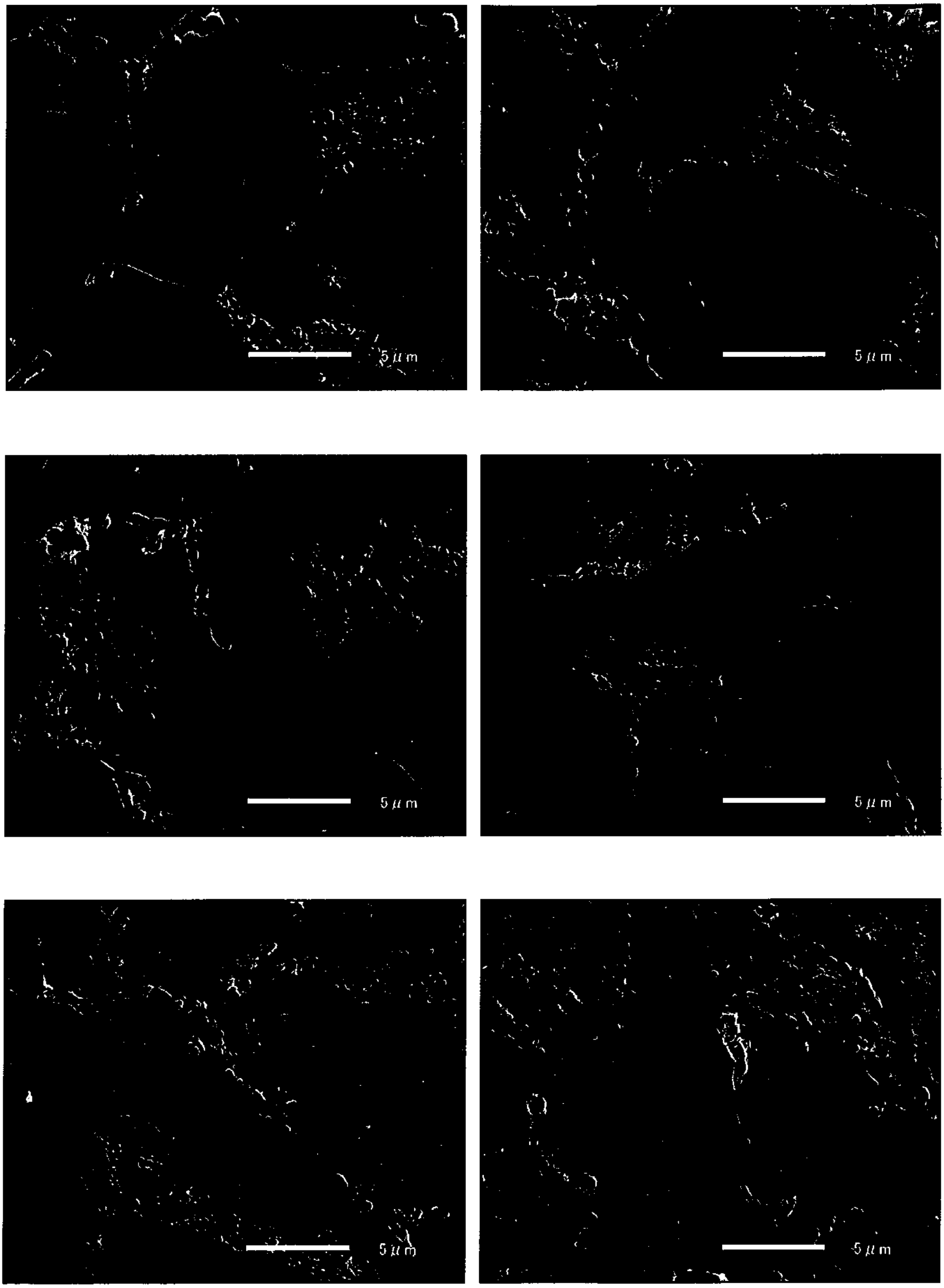


Photo I-6-10 Precipitates along grain boundary by SEM observation
De-Superheater-Right (Circumferential weld : Fine grain HAZ)

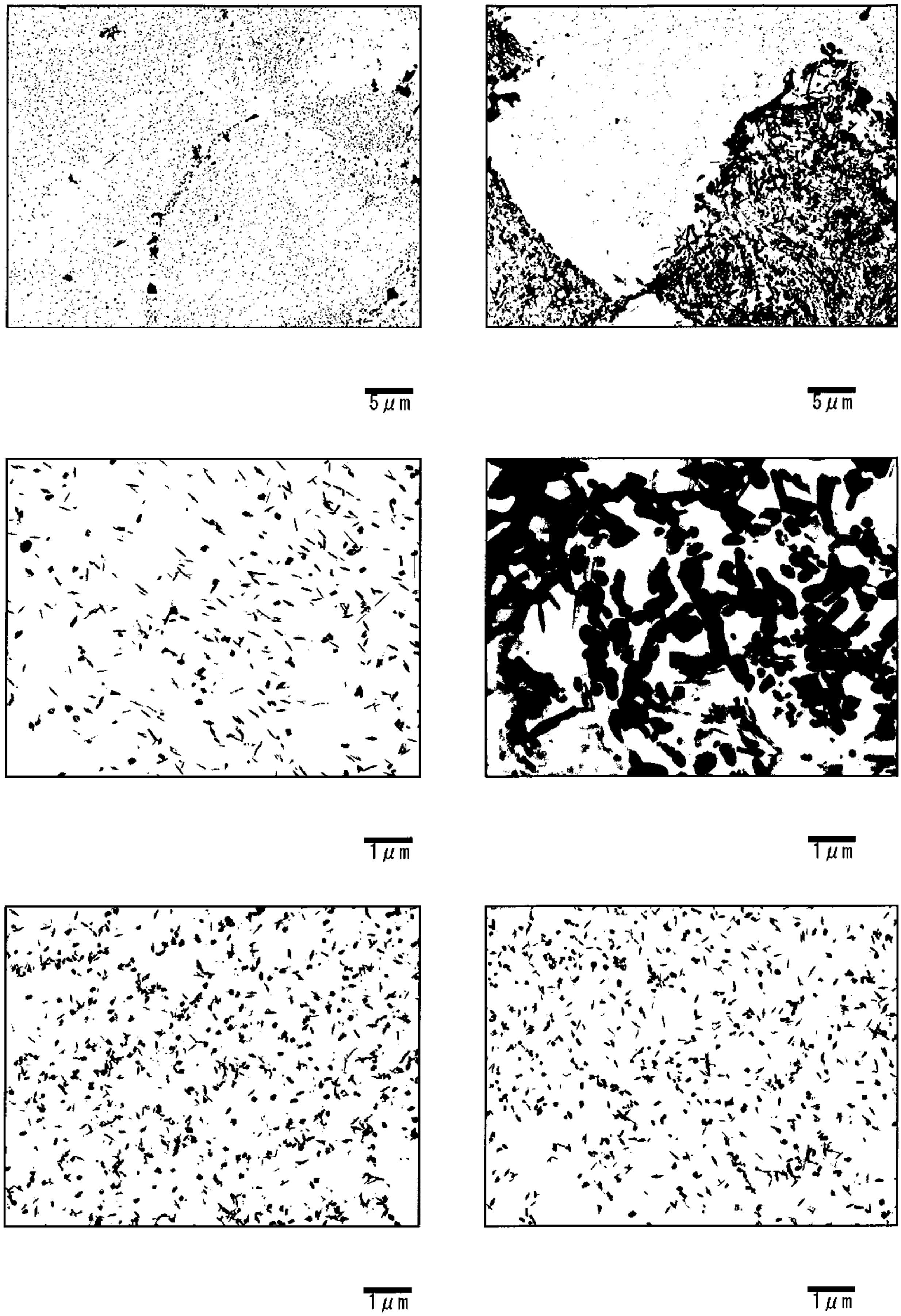


Photo I -6-11 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Right (Circumferential weld : Base metal)

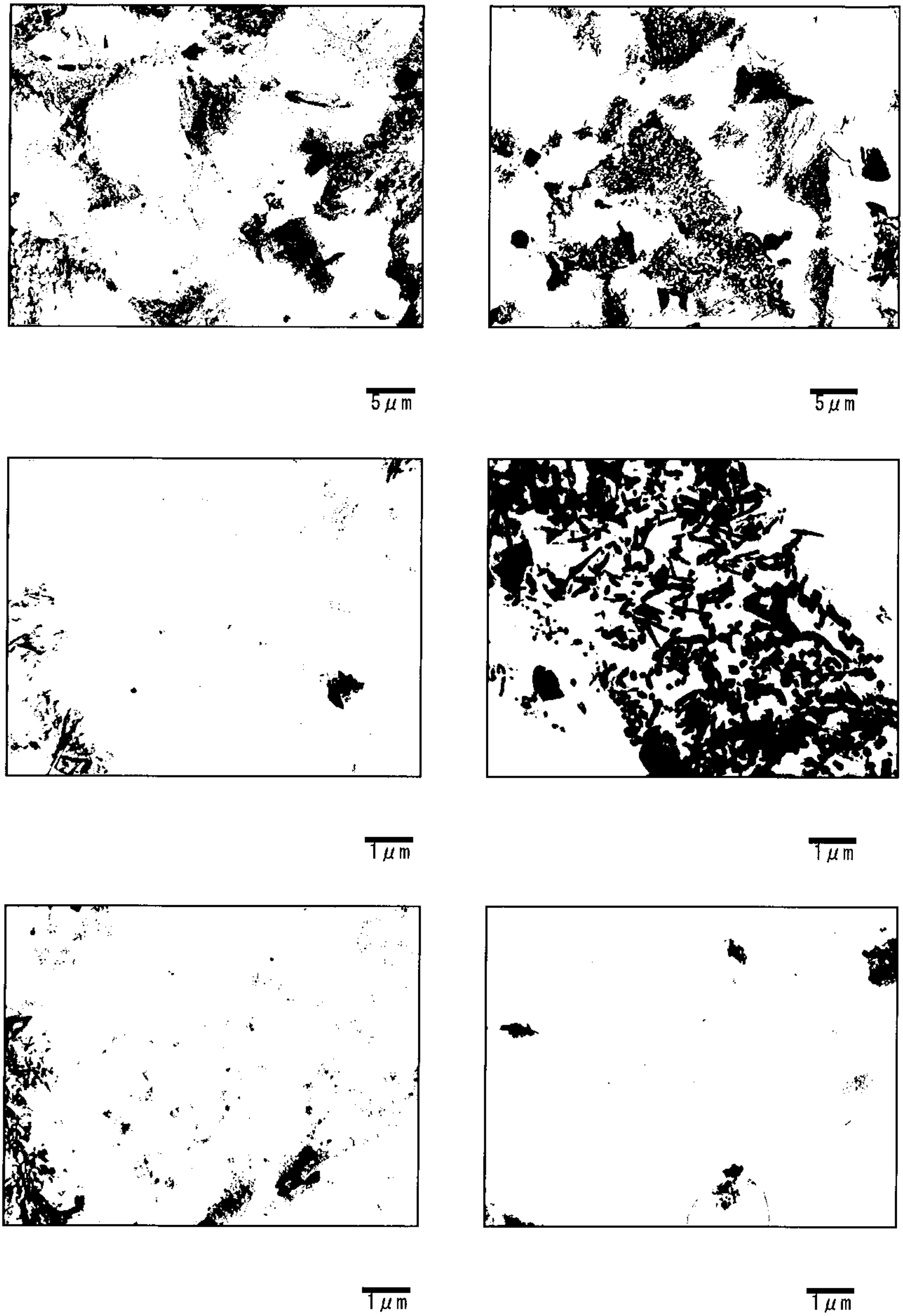


Photo I -6-12 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Right(Circumferential weld : Fine grain HAZ)

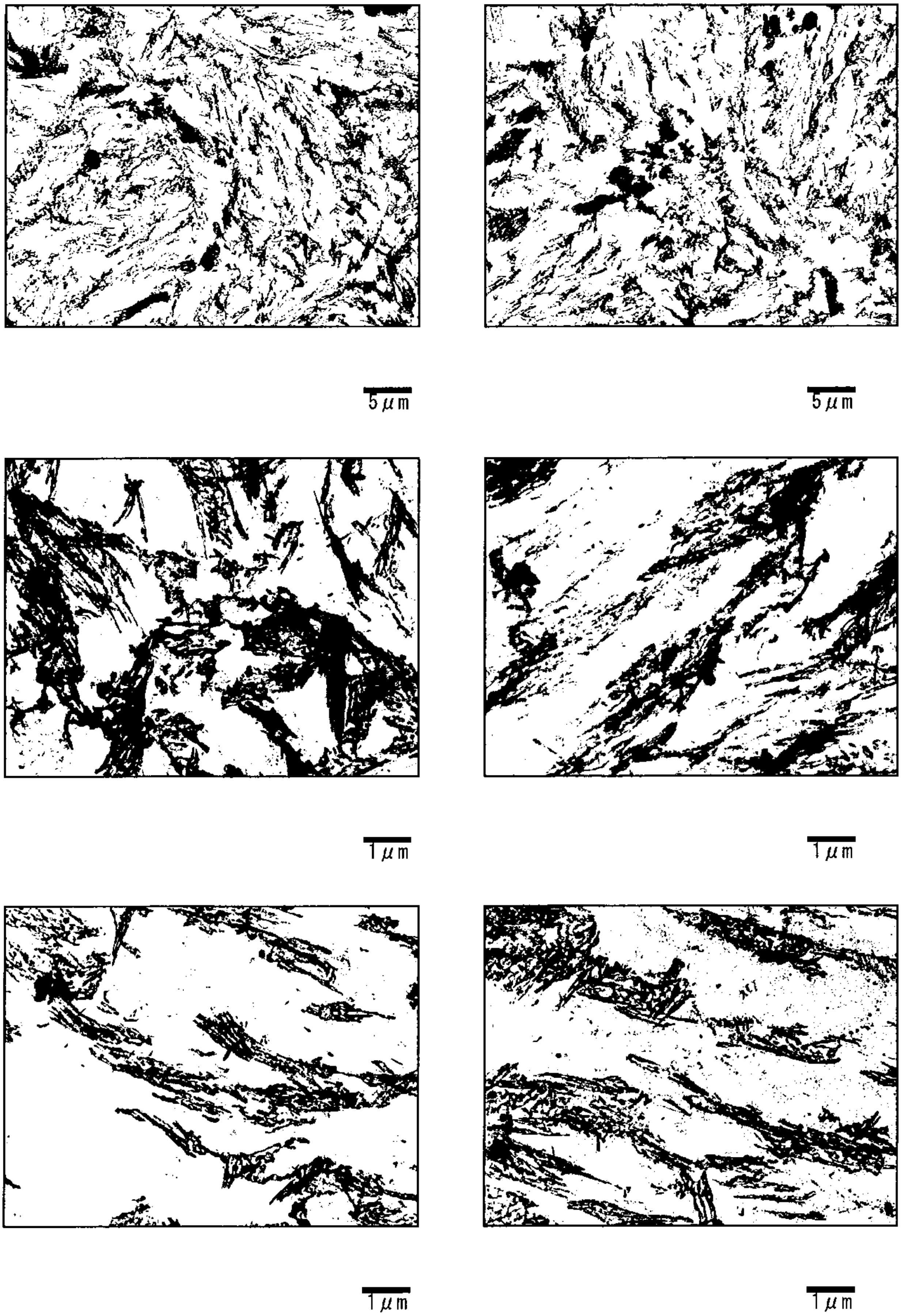


Photo I -6-13 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Right(Circumferential weld : Coarse grain HAZ)

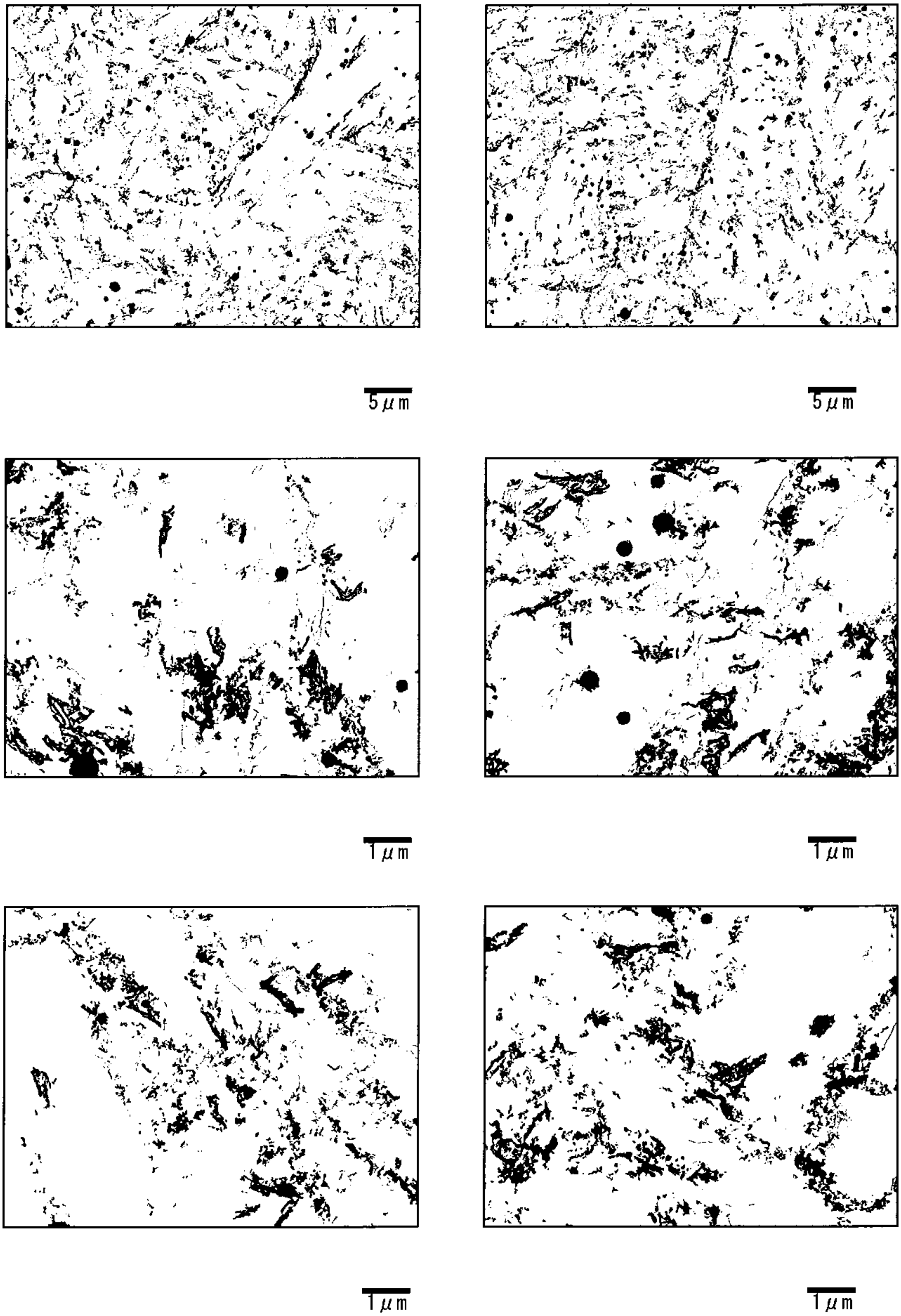


Photo I -6-14 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Right (Circumferential weld : Weld metal)

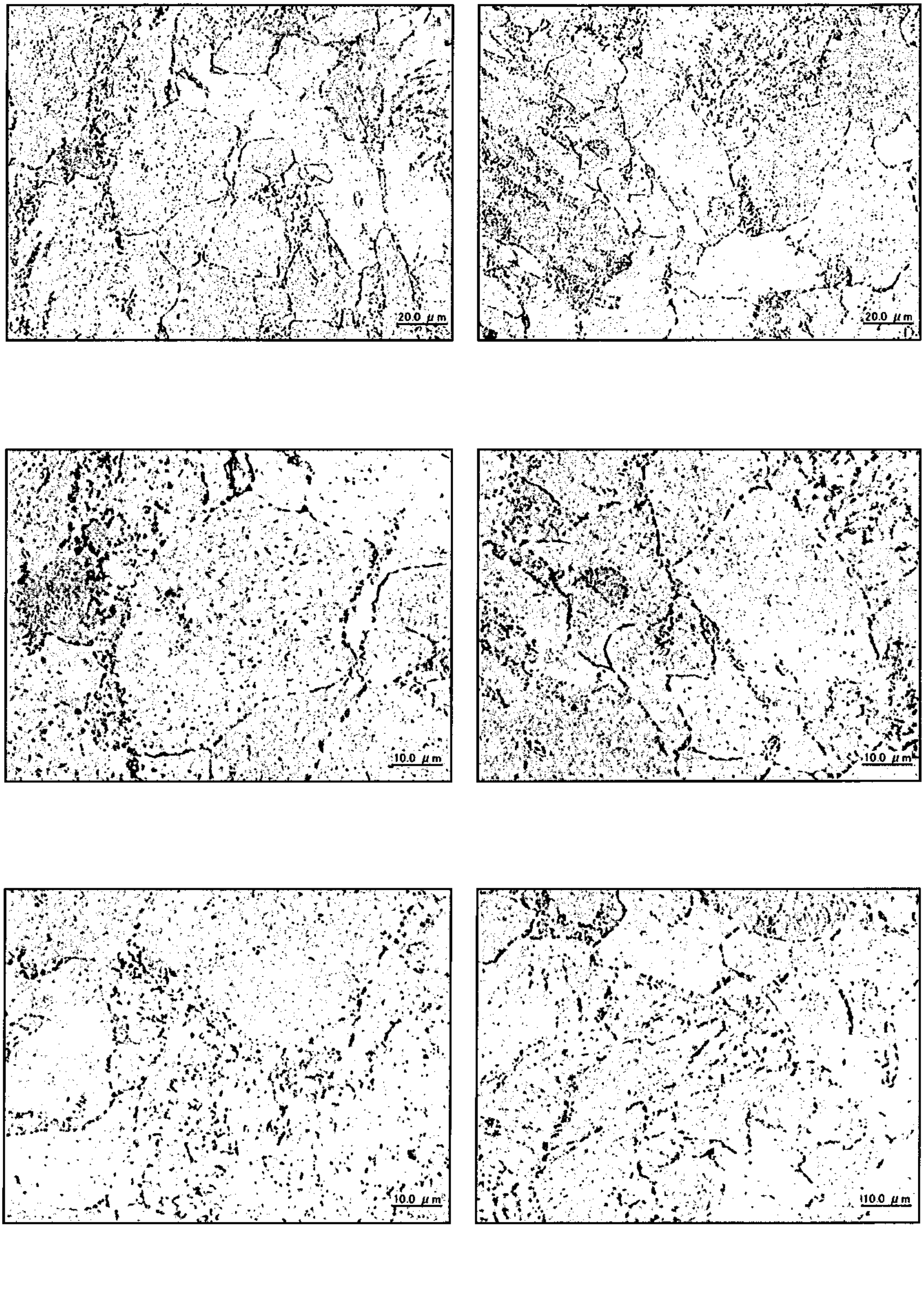


Photo I -7-1 Microstructure observation
RH Outlet Header-Left (Circumferential weld at left side : Base metal)

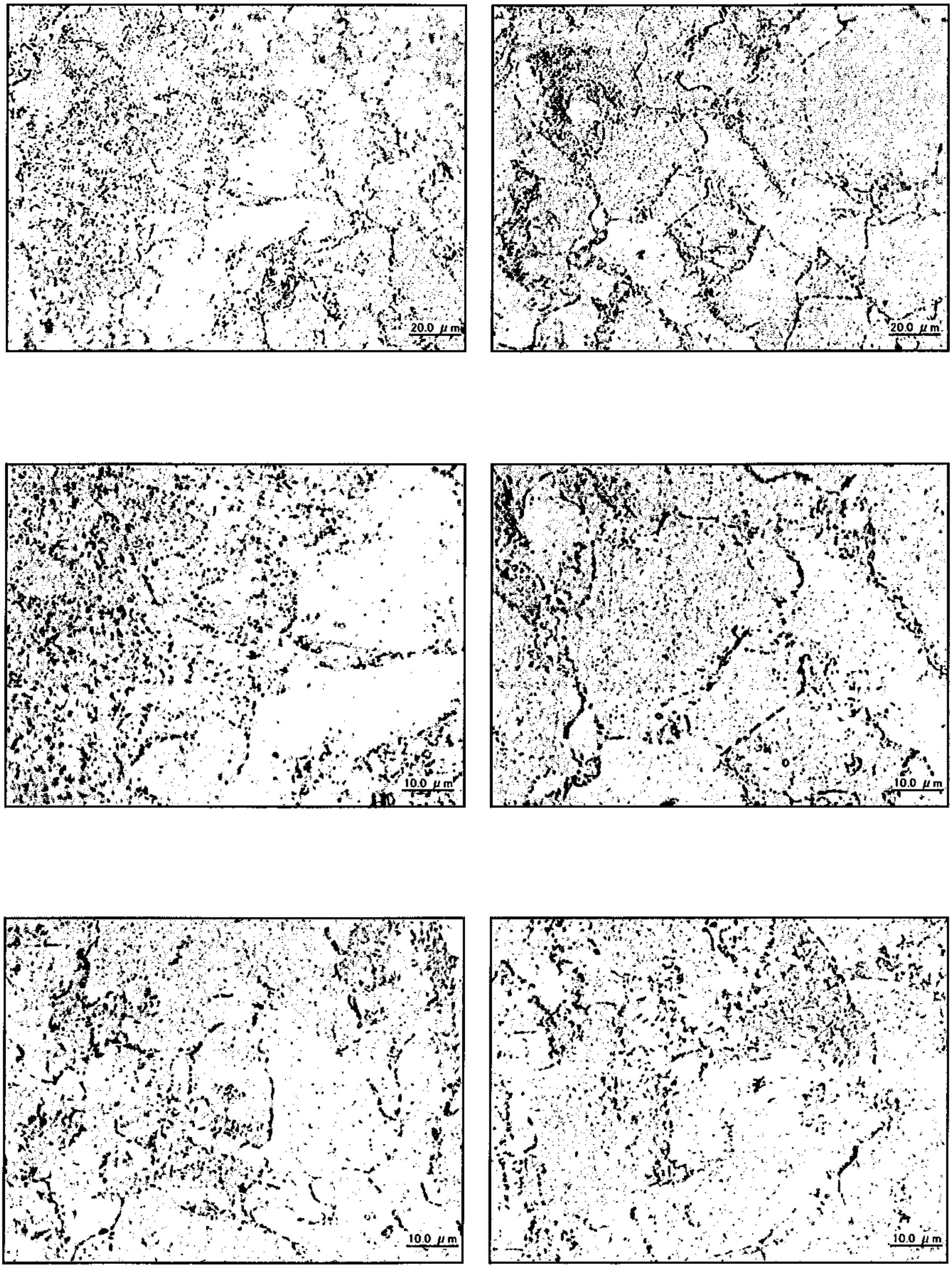


Photo I -7-2 Microstructure observation
RH Outlet Header-Left (Circumferential weld at left side : Intercritical zone)

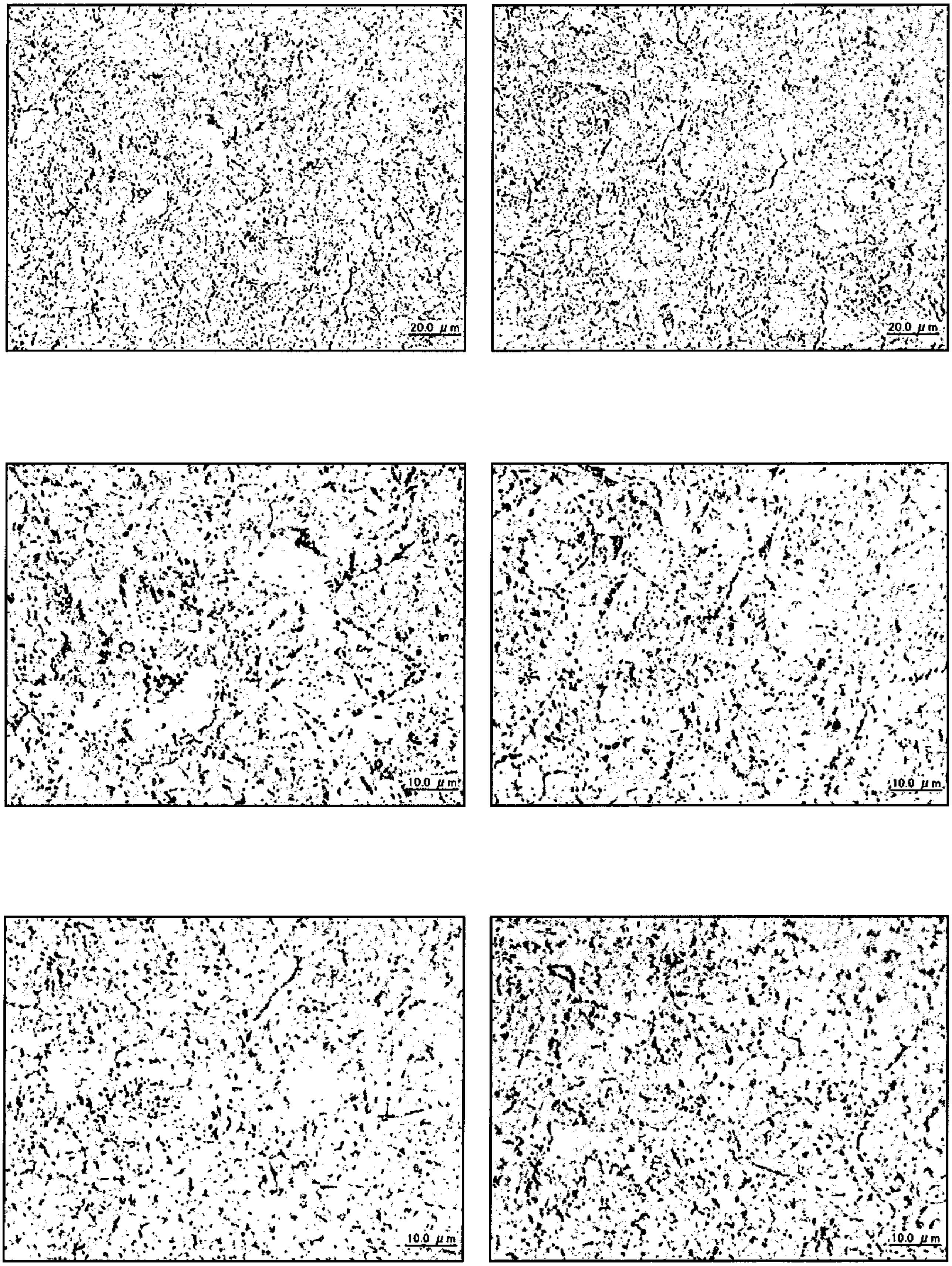


Photo I -7-3 Microstructure observation
RH Outlet Header-Left (Circumferential weld at left side : Fine grain HAZ)

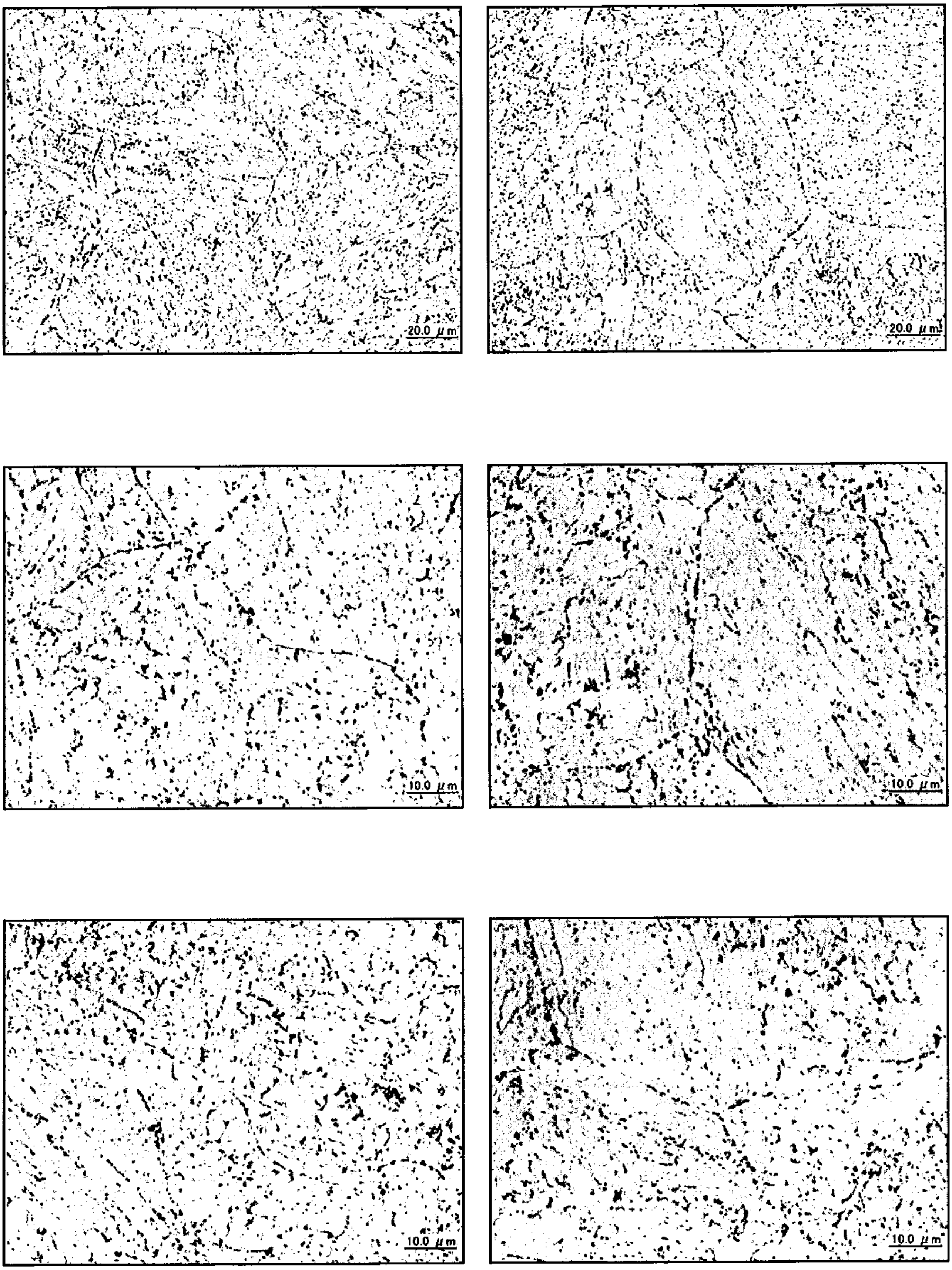


Photo I-7-4 Microstructure observation
RH Outlet Header-Left (Circumferential weld at left side : Coarse grain HAZ)

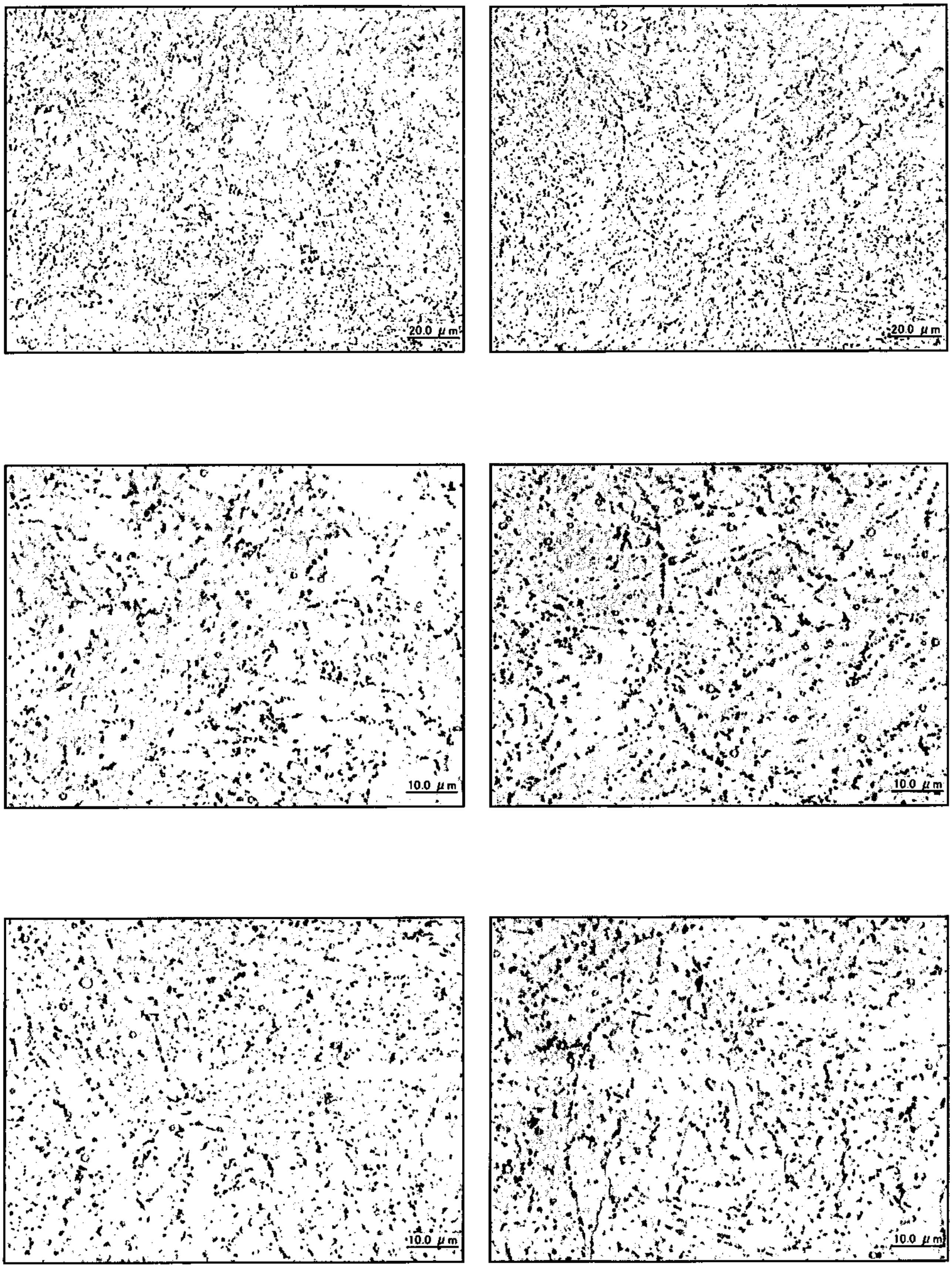


Photo I -7-5 Microstructure observation

RH Outlet Header-Left (Circumferential weld at left side : Weld metal)

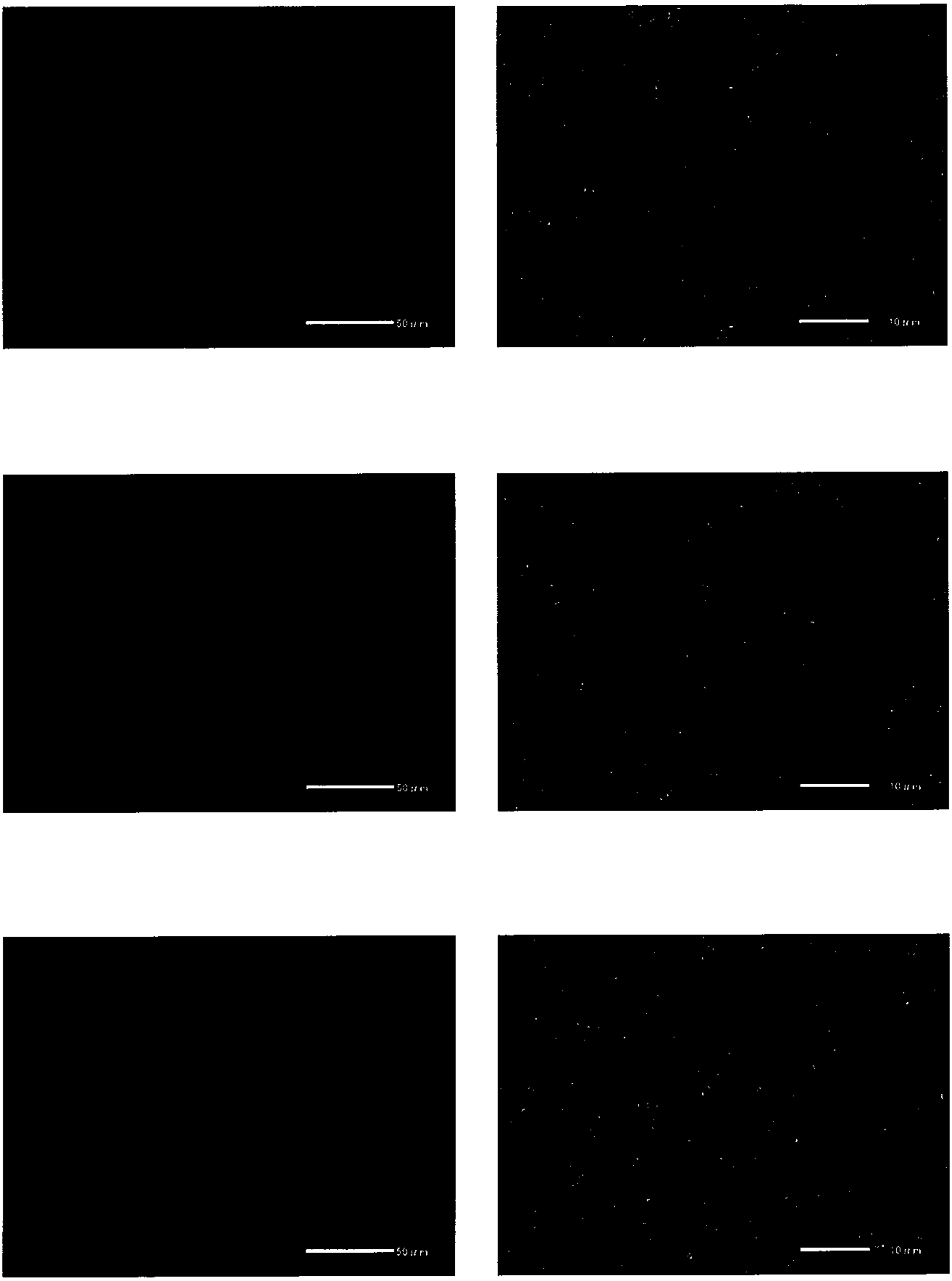
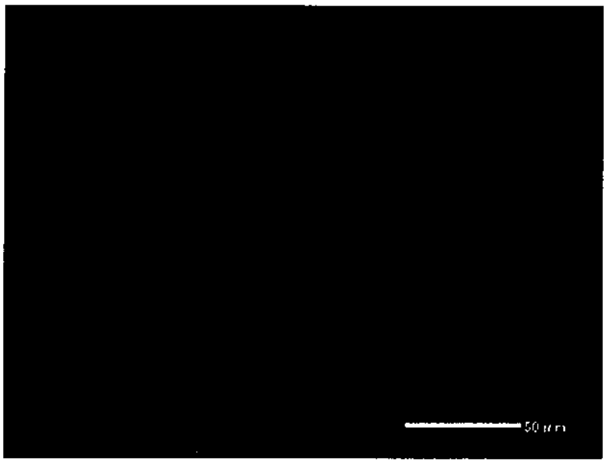
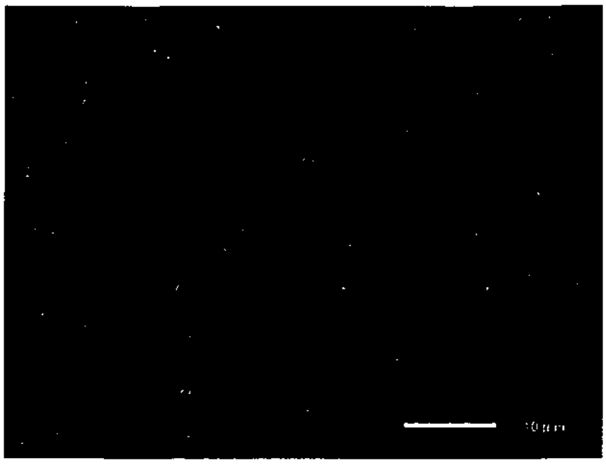
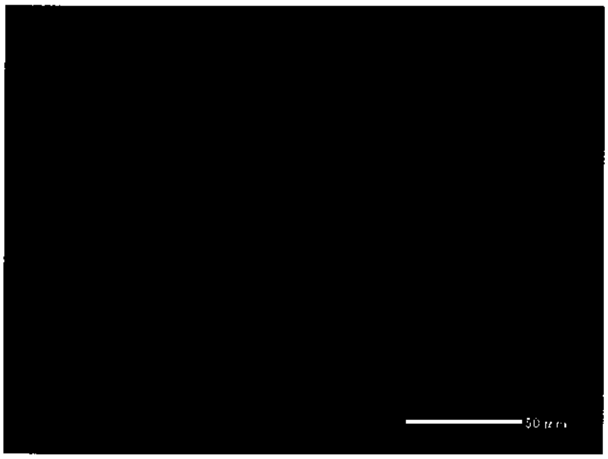
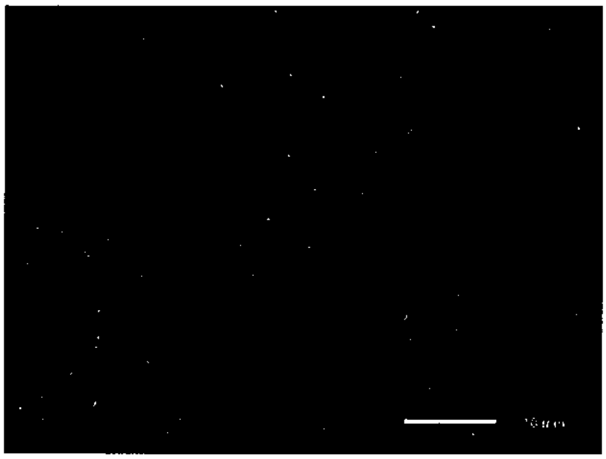


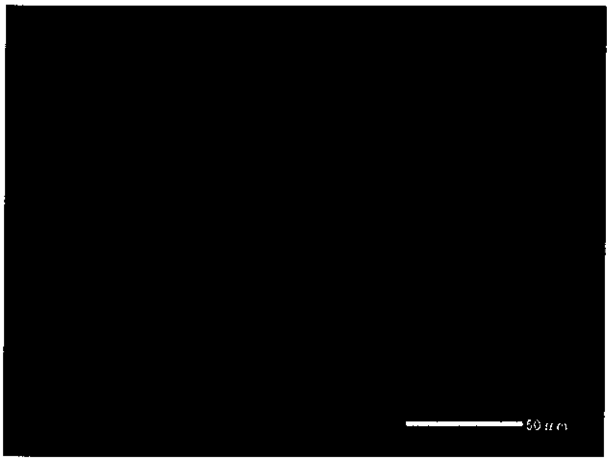
Photo I -7-6 SEM(Scanning electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Fine grain HAZ)











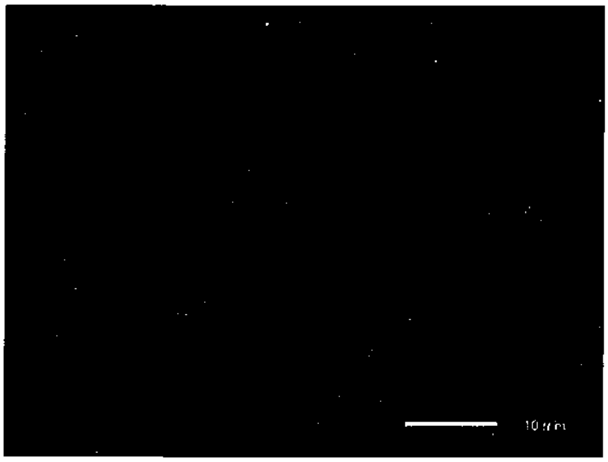


Photo I-7-7 SEM(Scanning electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Coarse grain HAZ)

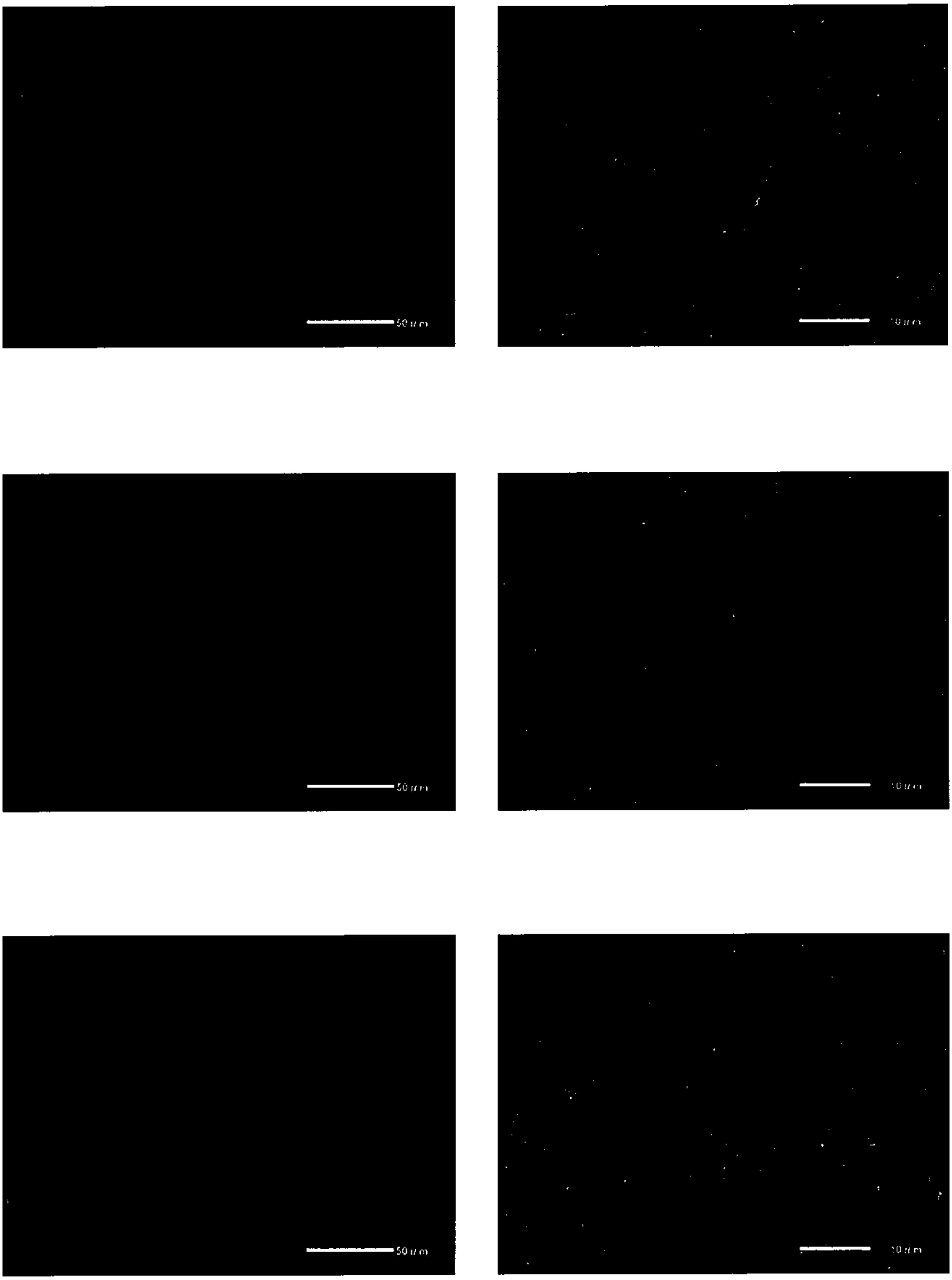


Photo I -7-8 SEM(Scanning electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Weld metal)

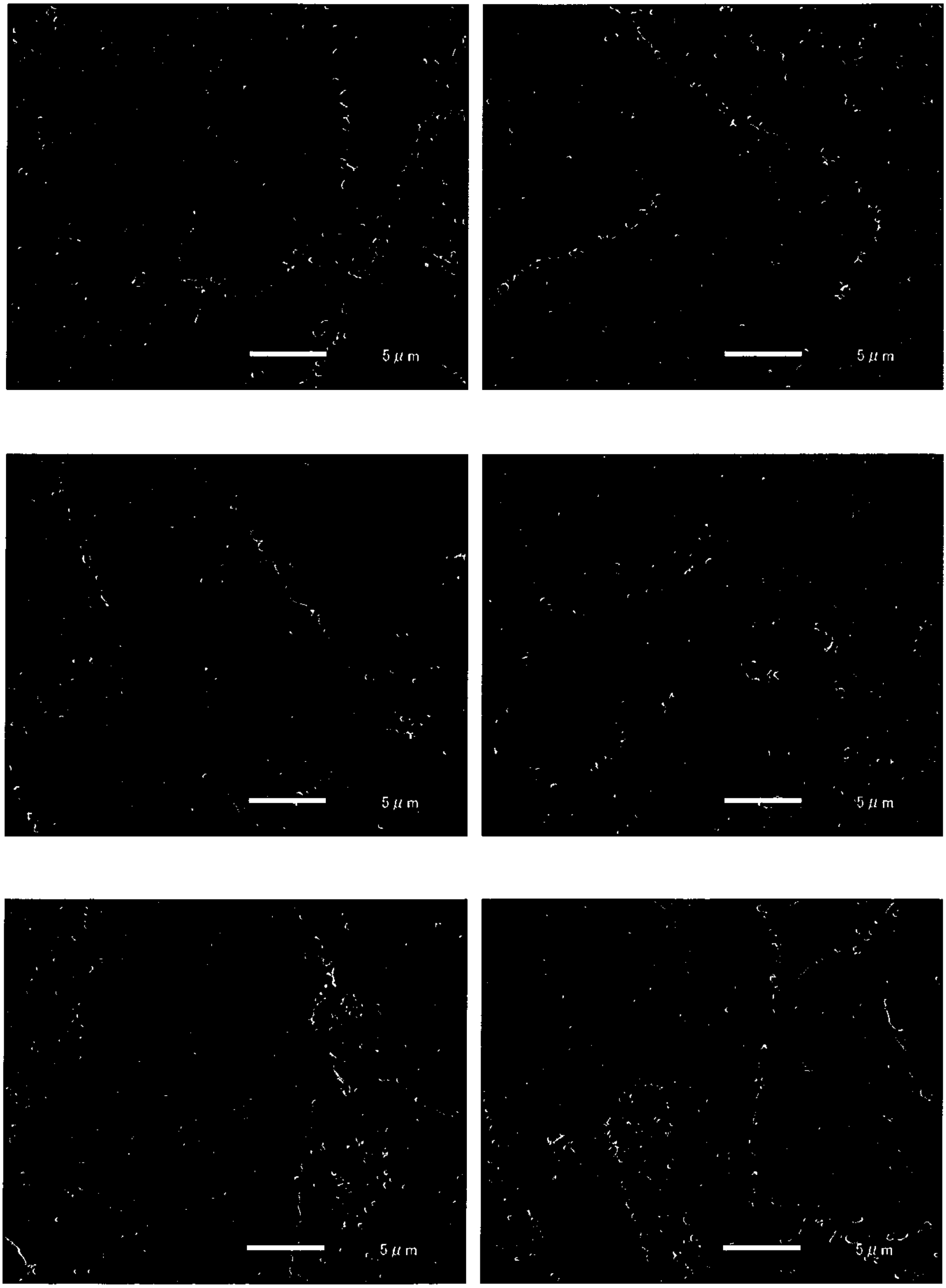


Photo I -7-9 Precipitates along grain boundary by SEM observation
RH Outlet Header-Left(Circumferential weld at left side : Base metal)

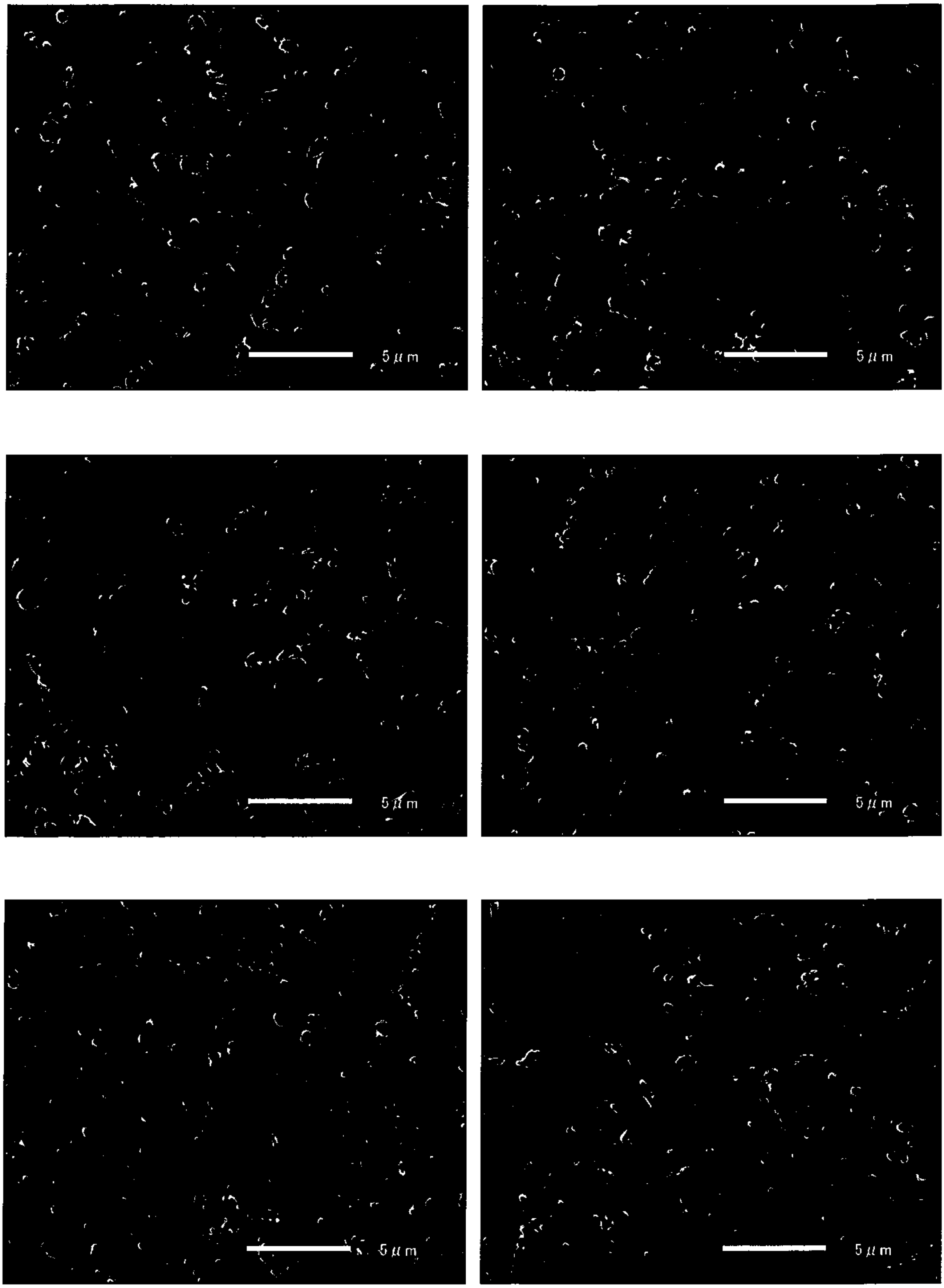


Photo I-7-10 Precipitates along grain boundary by SEM observation
RH Outlet Header-Left(Circumferential weld at left side : Fine grain HAZ)

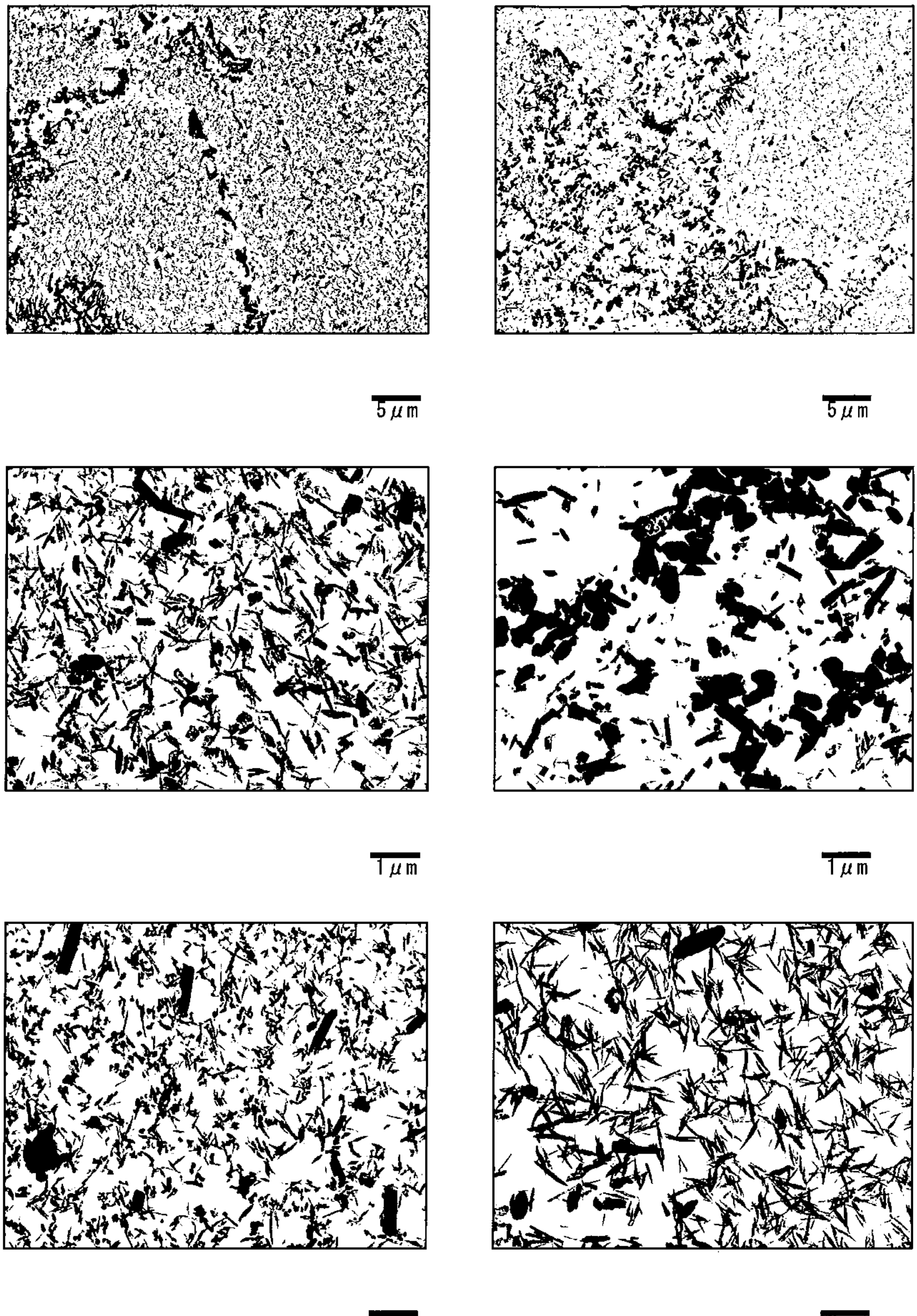


Photo I -7-11 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Base metal)

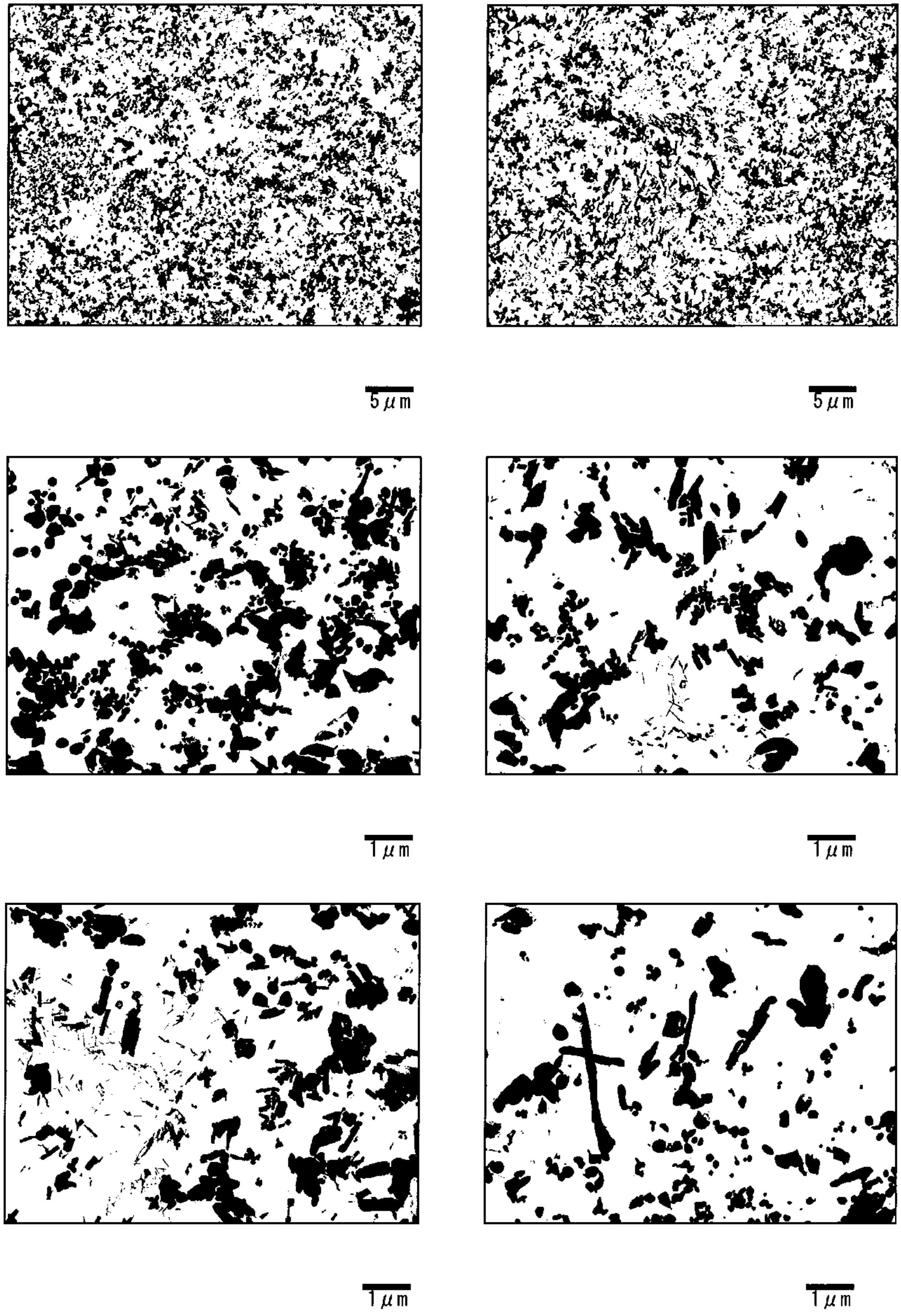


Photo I-7-12 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Fine grain HAZ)

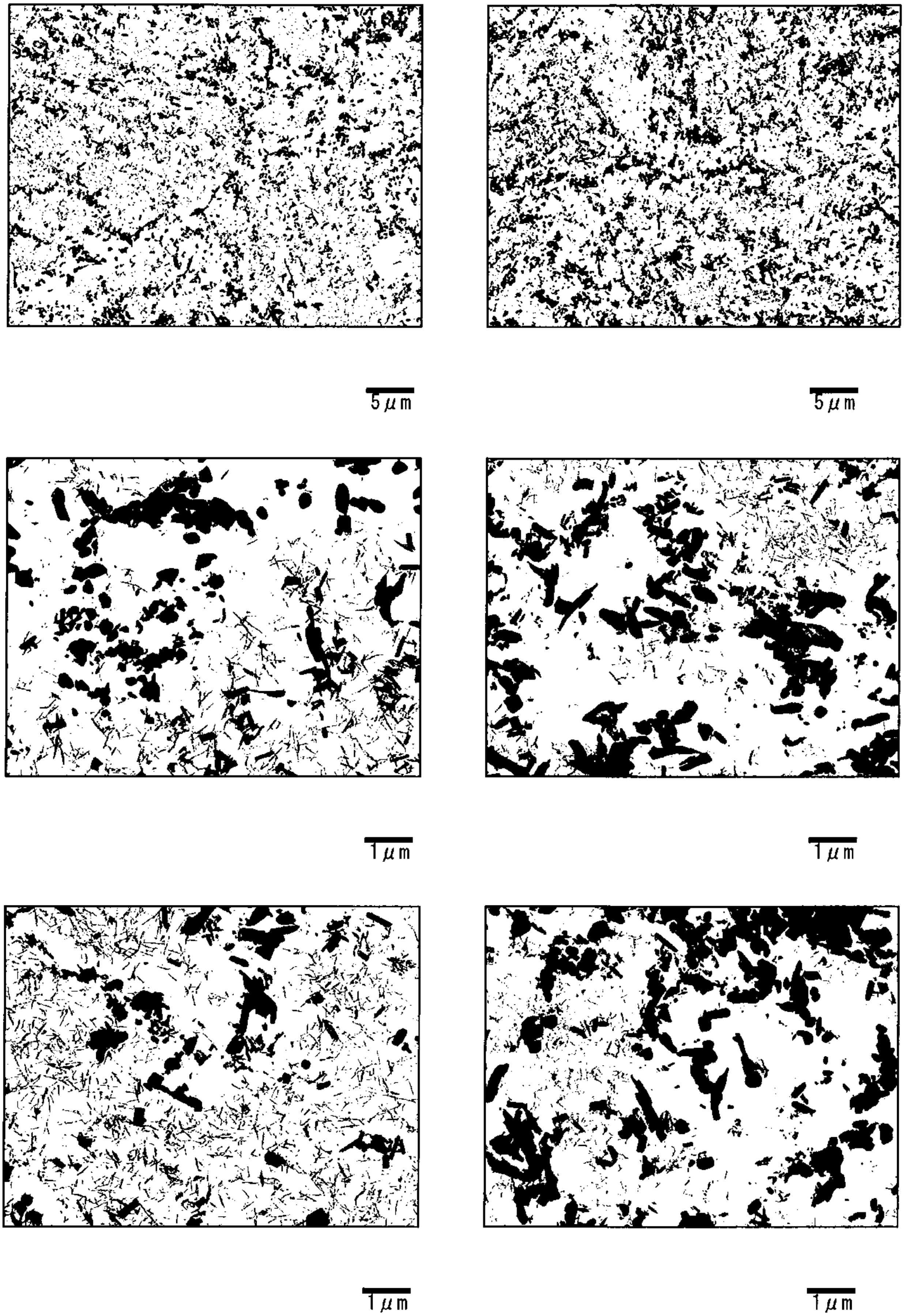


Photo I-7-13 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Coarse grain HAZ)

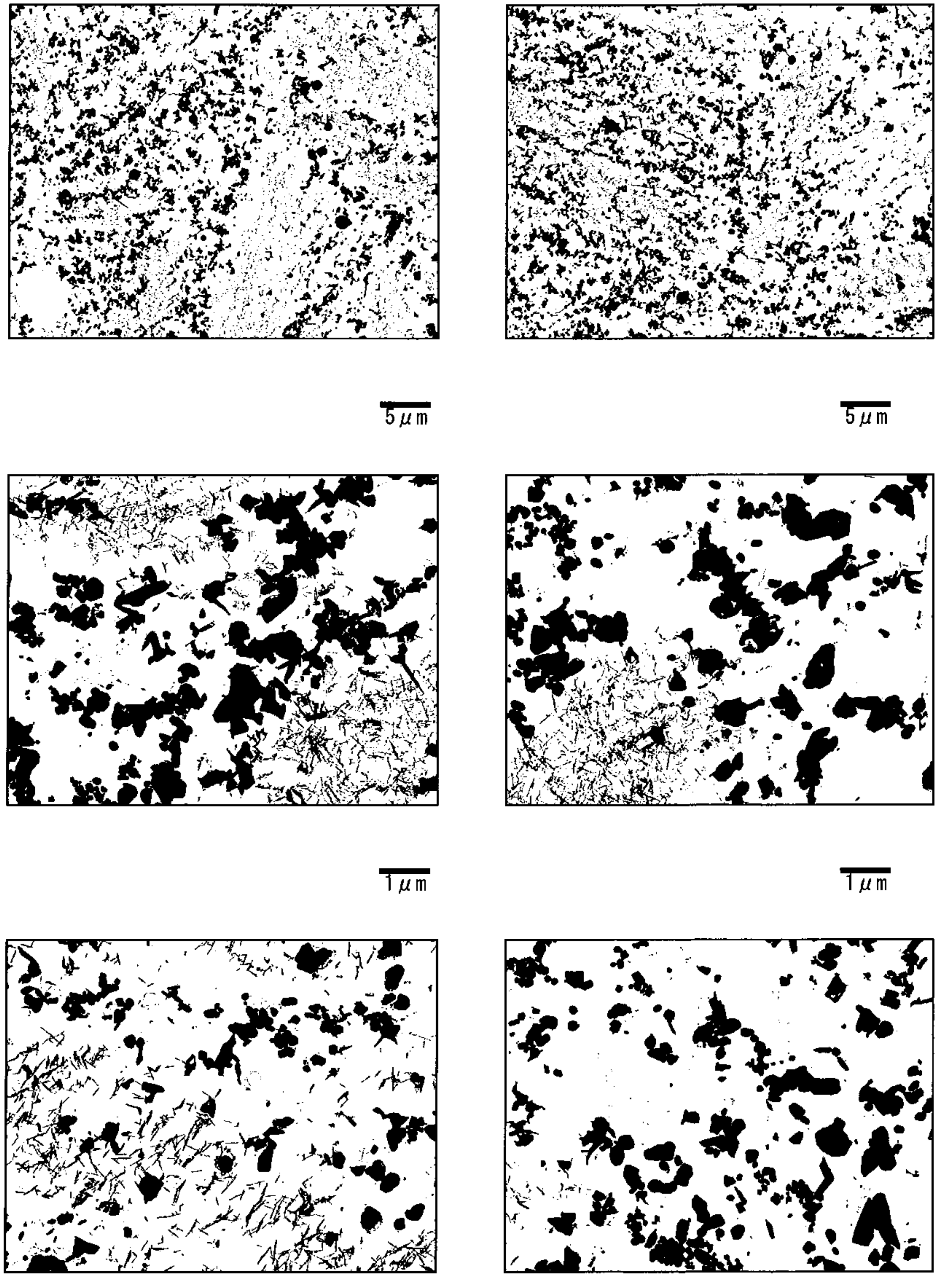


Photo I -7-14 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Left(Circumferential weld at left side : Weld metal)

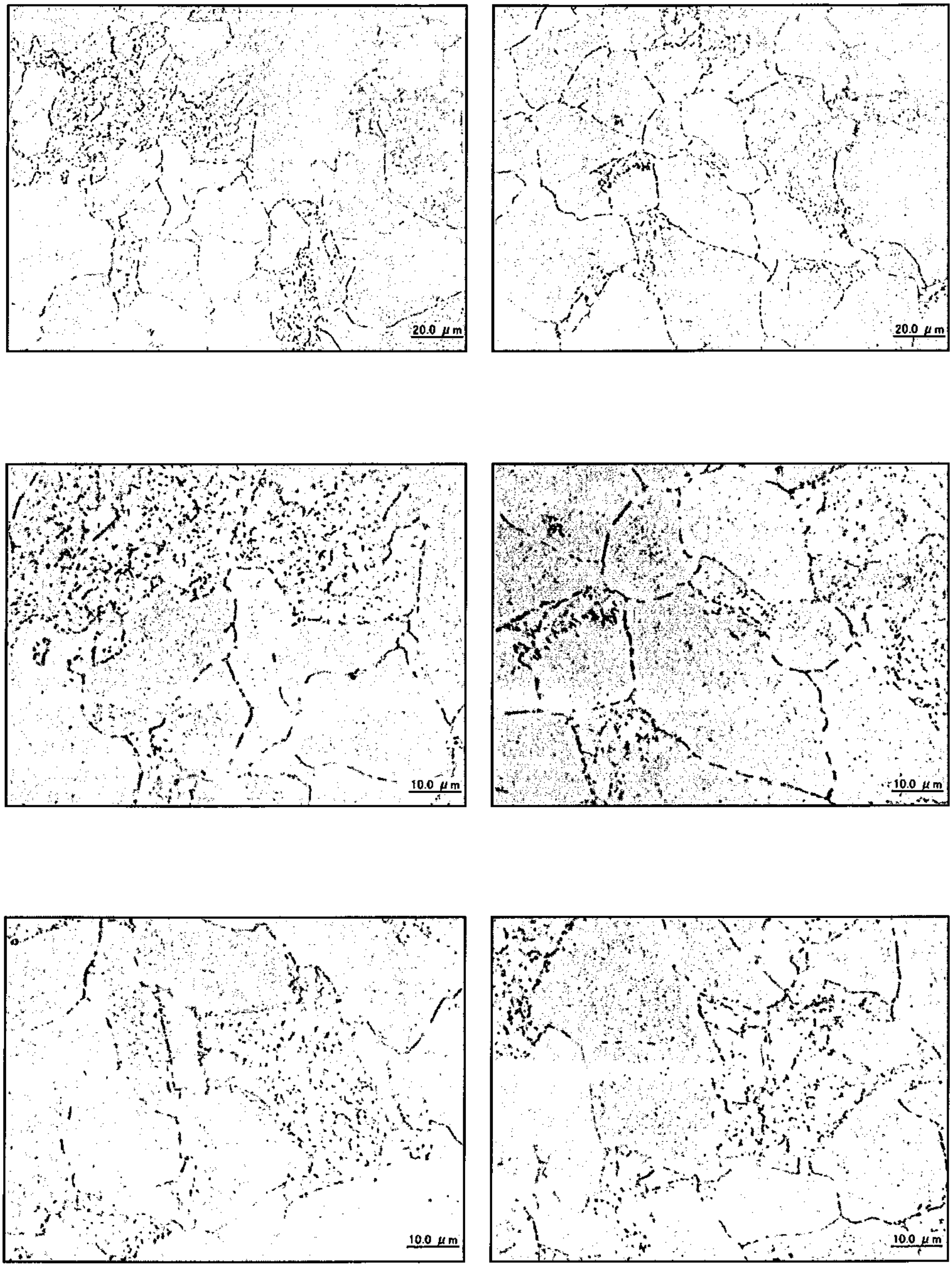


Photo I -8-1 Microstructure observation
RH Outlet Header-Right (Circumferential weld at right side : Base metal)

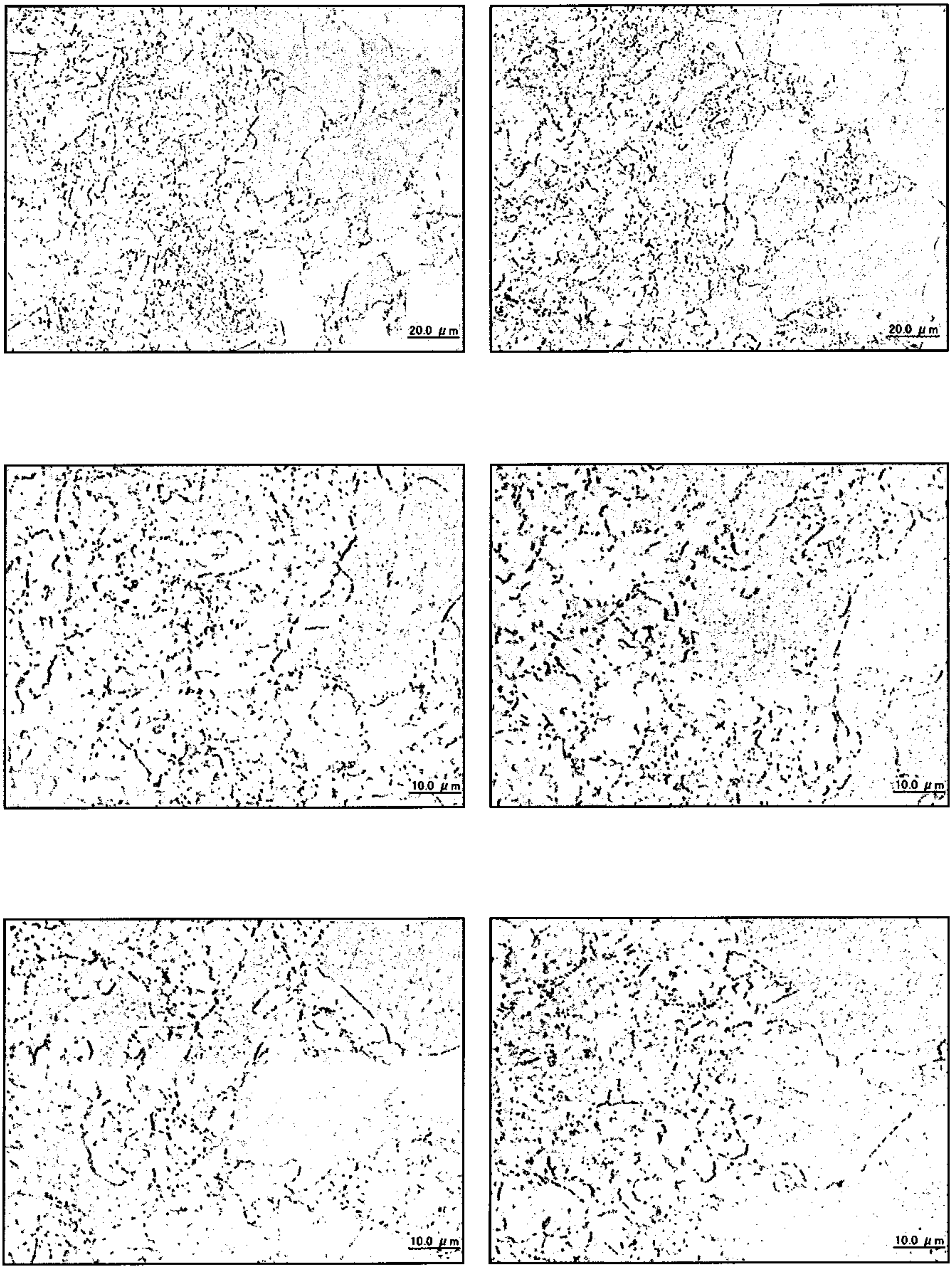


Photo I-8-2 Microstructure observation
RH Outlet Header-Right (Circumferential weld at right side : Intercritical zone)

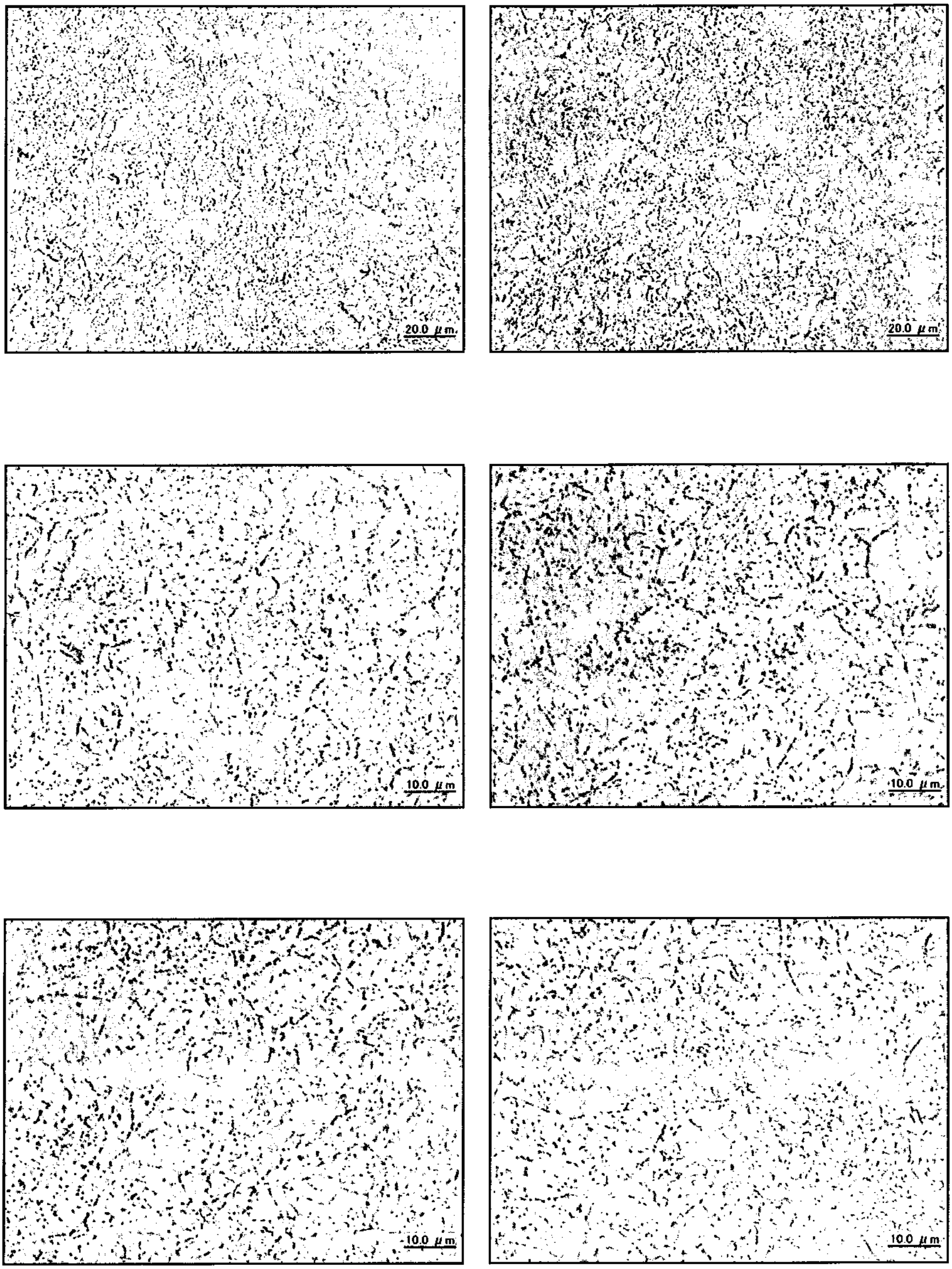


Photo I -8-3 Microstructure observation
RH Outlet Header-Right (Circumferential weld at right side : Fine grain HAZ)

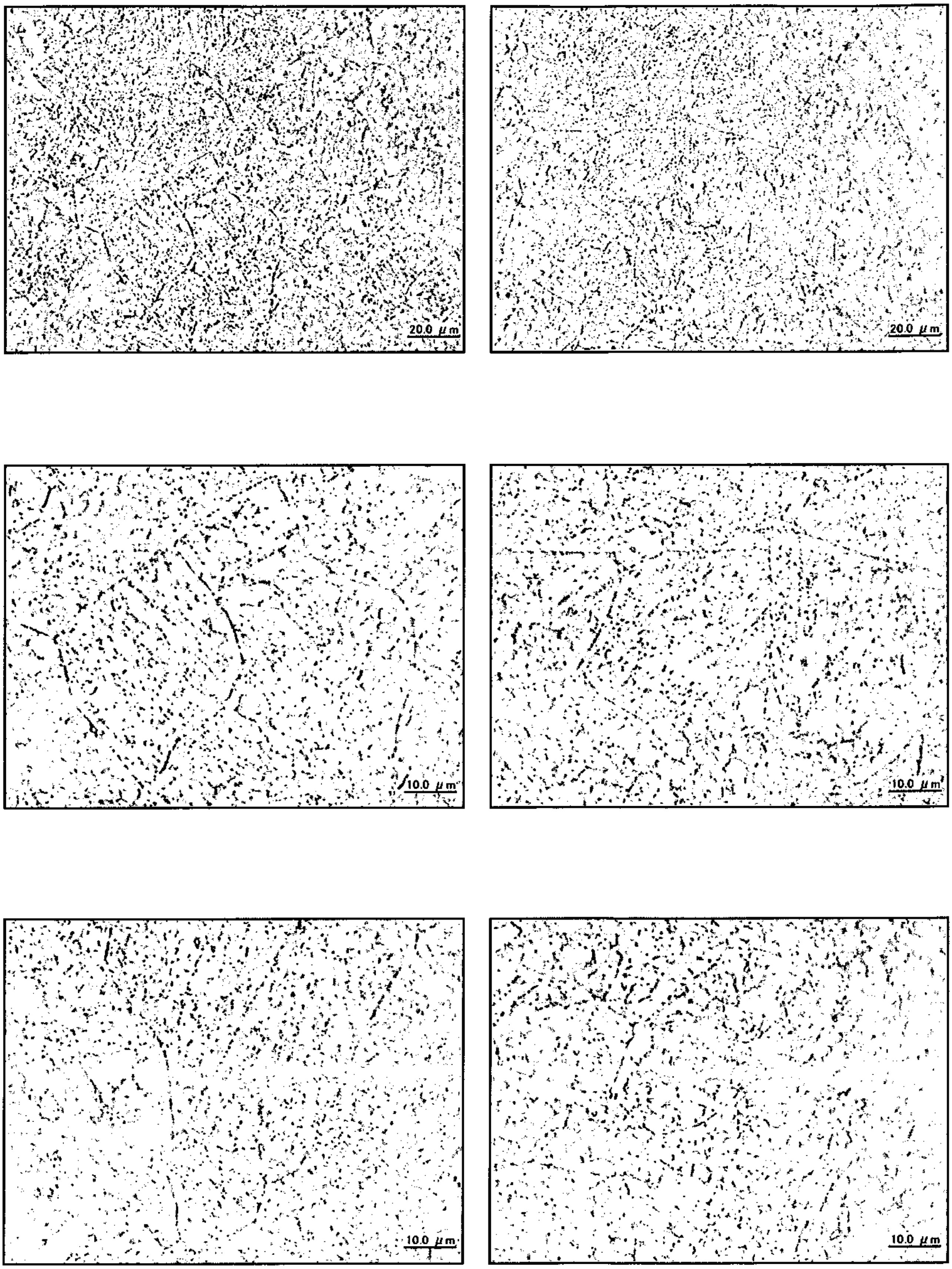


Photo I -8-4 Microstructure observation
RH Outlet Header-Right (Circumferential weld at right side : Coarse grain HAZ)

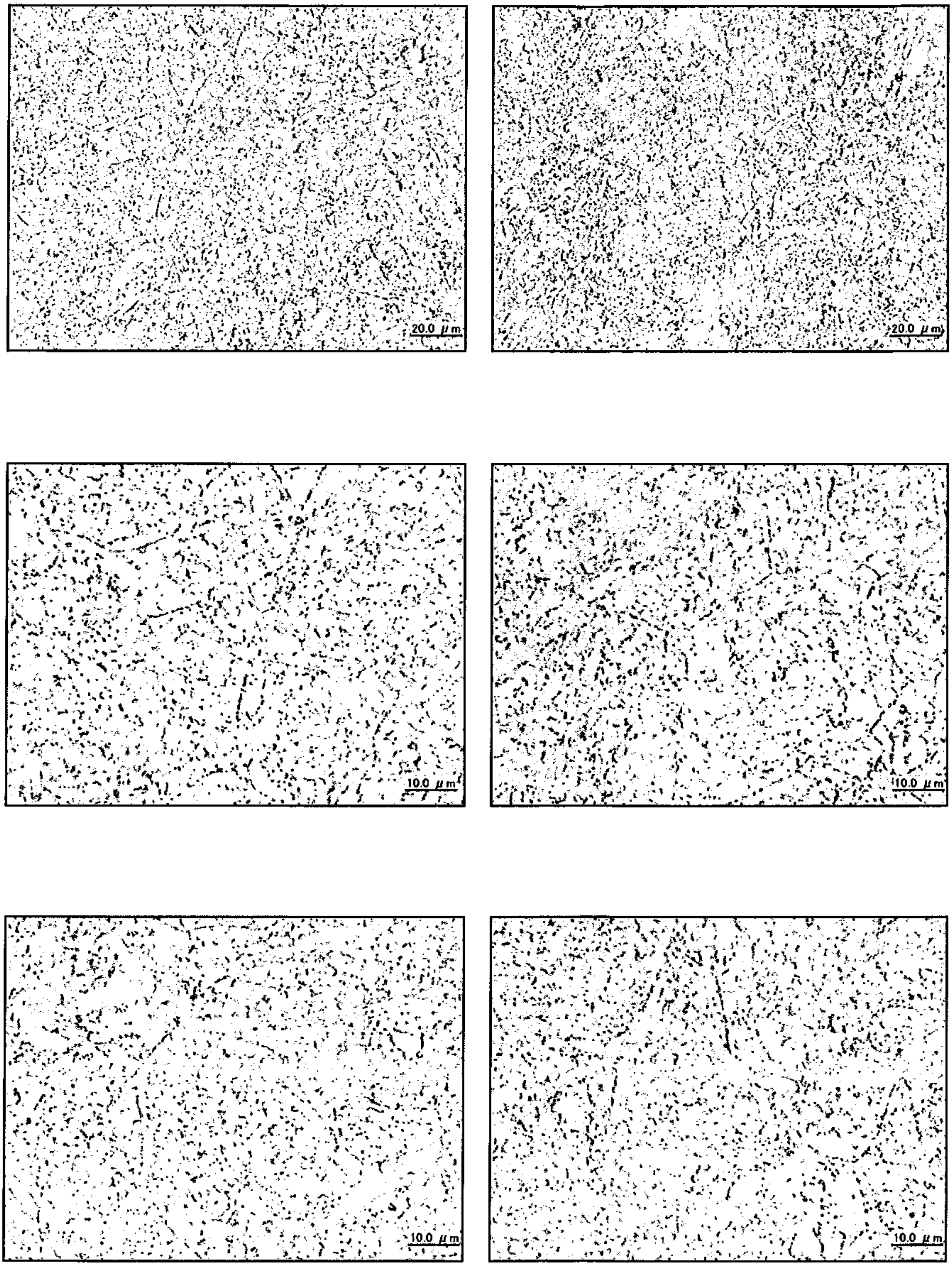
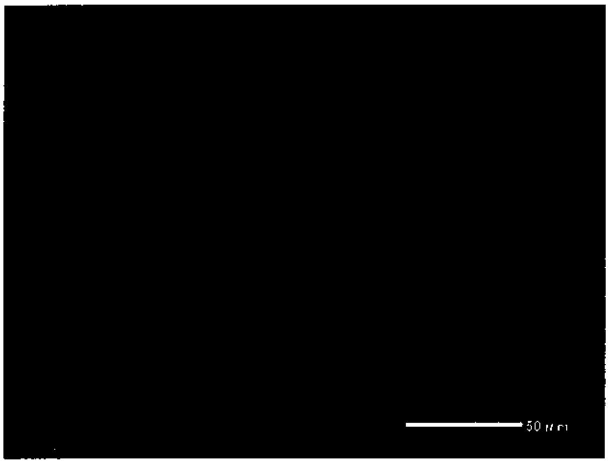
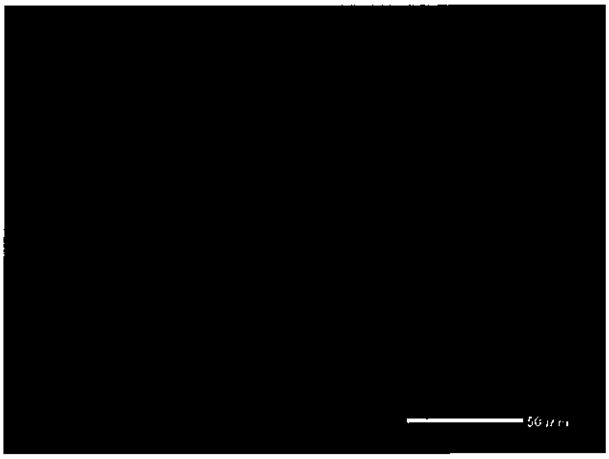
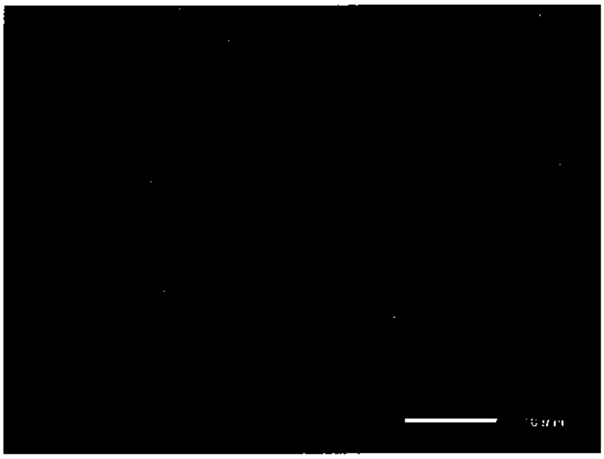


Photo I -8-5 Microstructure observation
RH Outlet Header-Right (Circumferential weld at right side : Weld metal)







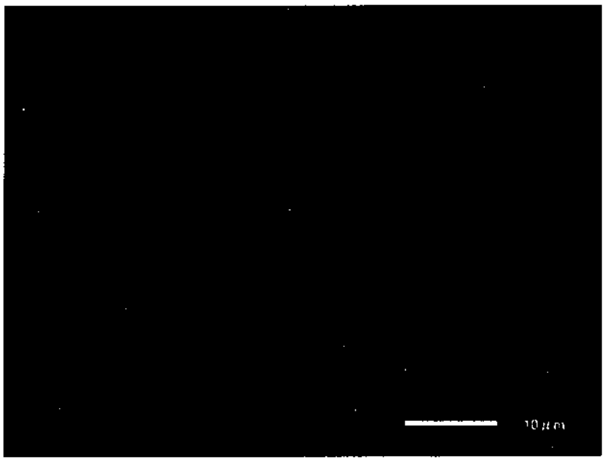


Photo I -8-6 SEM(Scanning electron microscope) observation
RH Outlet Header-Right(Circumferential weld at right side : Fine grain HAZ)

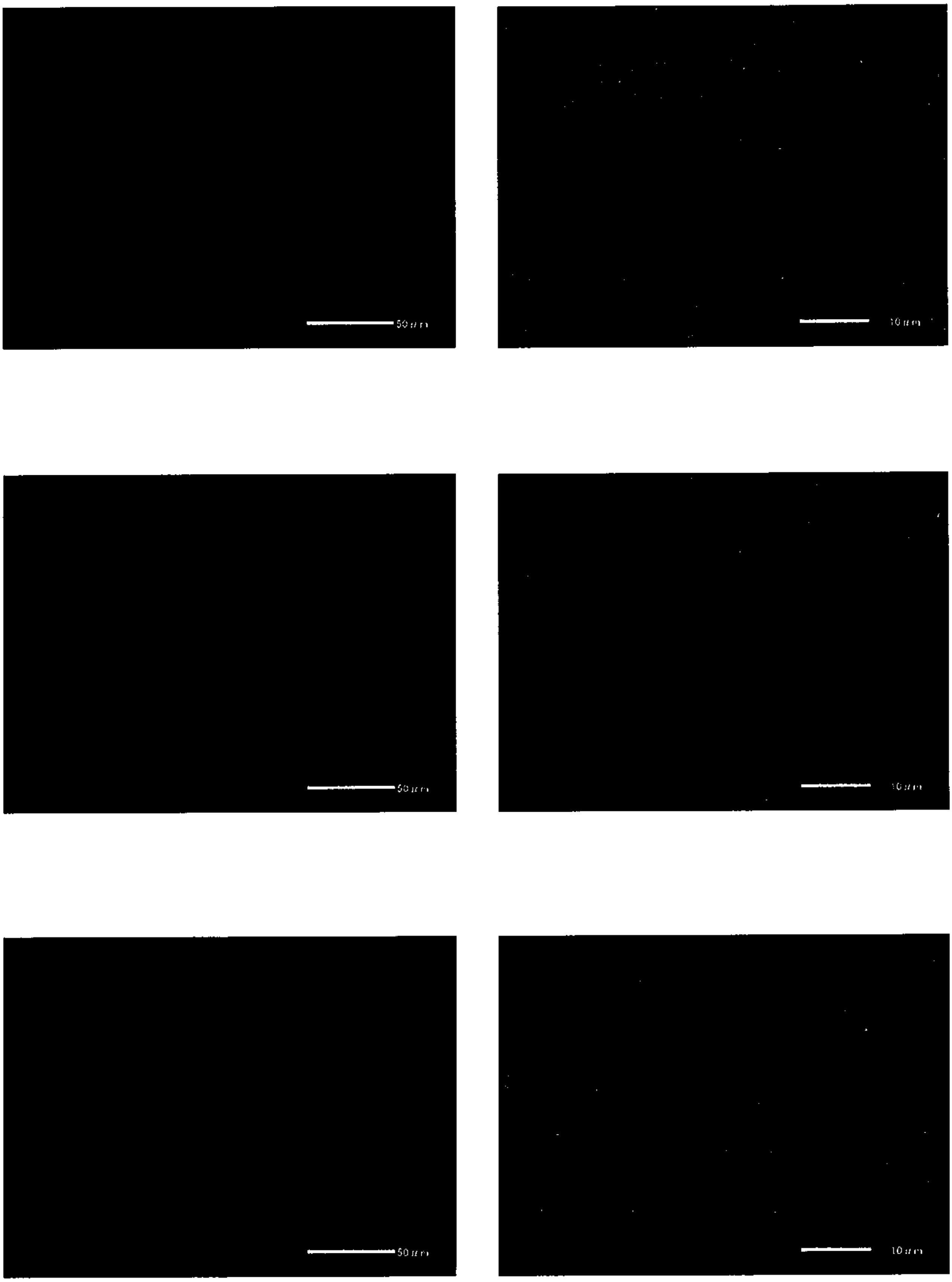
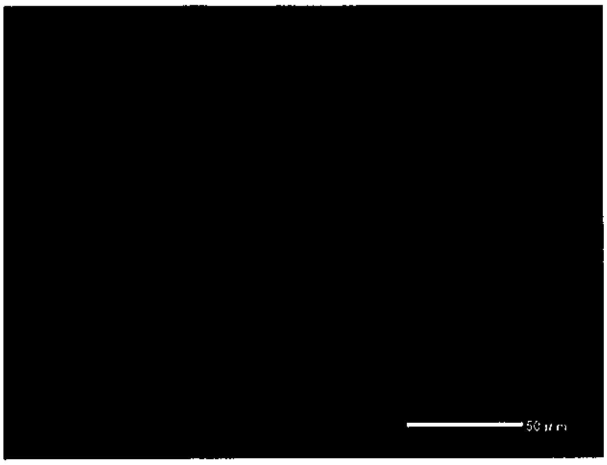
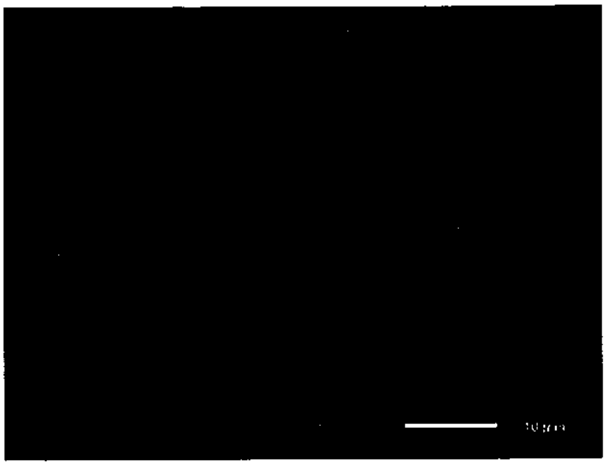
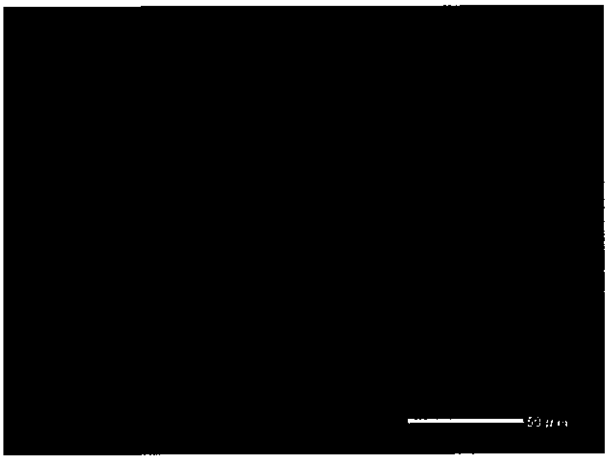
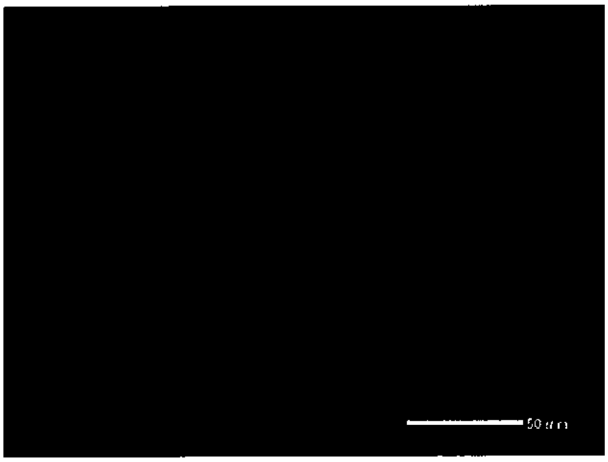


Photo I -8-7 SEM(Scanning electron microscope) observation
RH Outlet Header-Right(Circumferential weld at right side : Coarse grain HAZ)









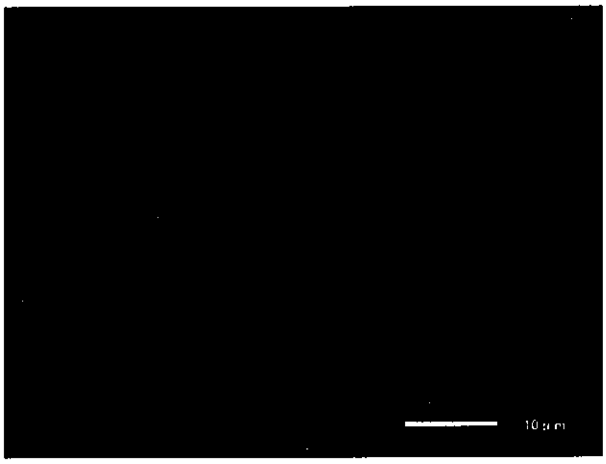


Photo I -8-8 SEM(Scanning electron microscope) observation
RH Outlet Header-Right(Circumferential weld at right side : Weld metal)

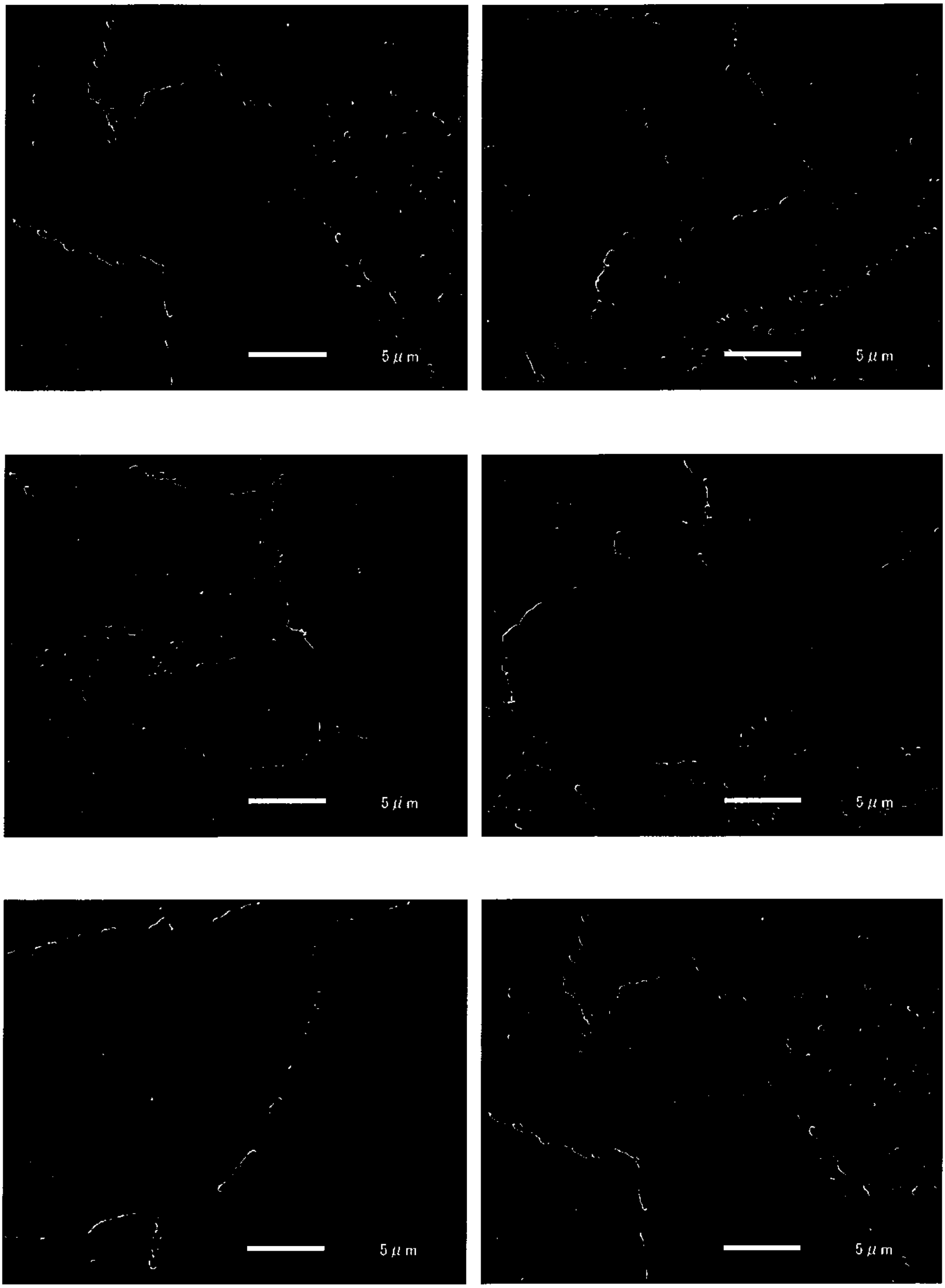


Photo I-8-9 Precipitates along grain boundary by SEM observation
RH Outlet Header-Right (Circumferential weld at right side : Base metal)

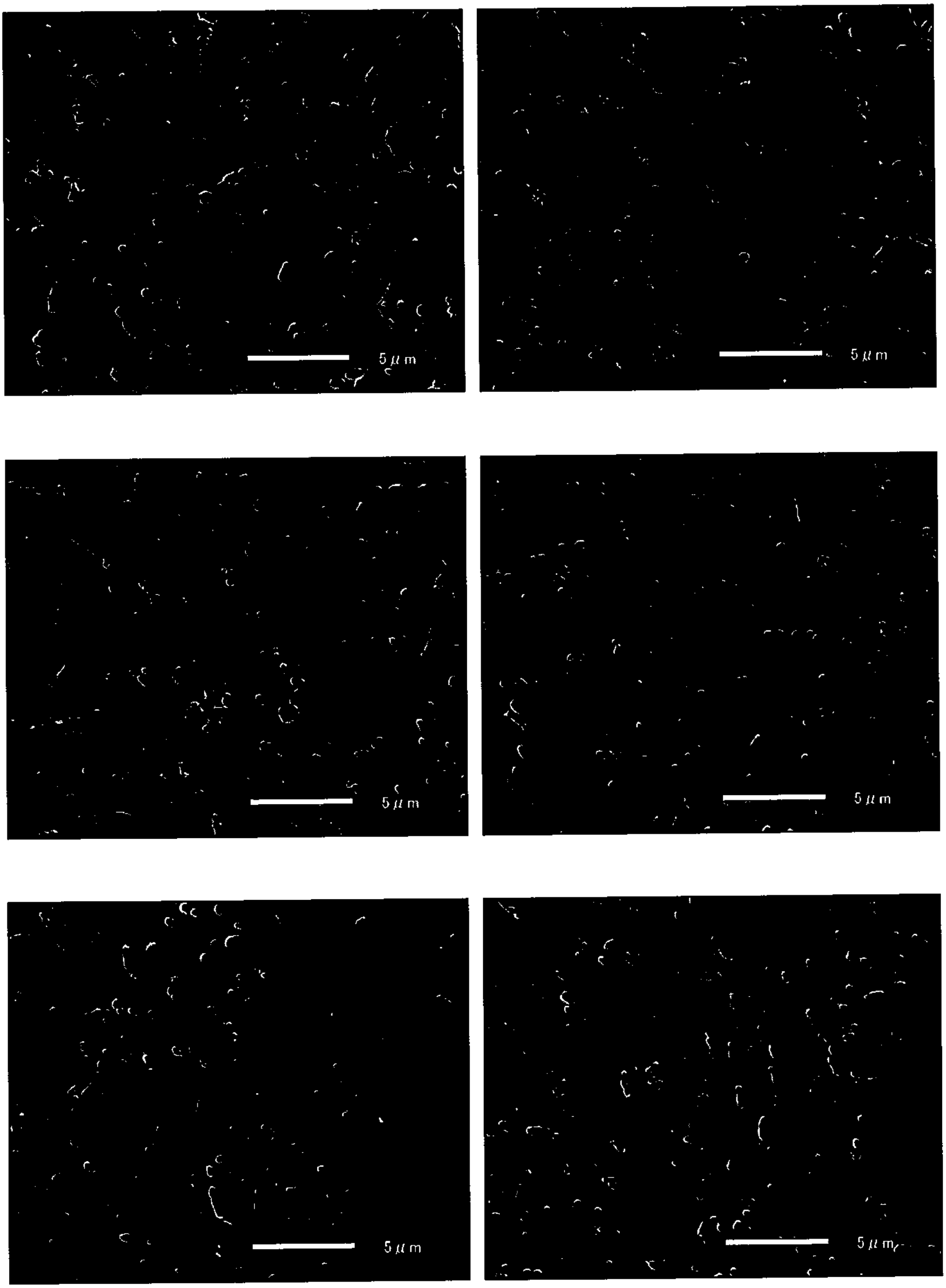


Photo I -8-10 Precipitates along grain boundary by SEM observation
RH Outlet Header-Right (Circumferential weld at right side : Fine grain HAZ)

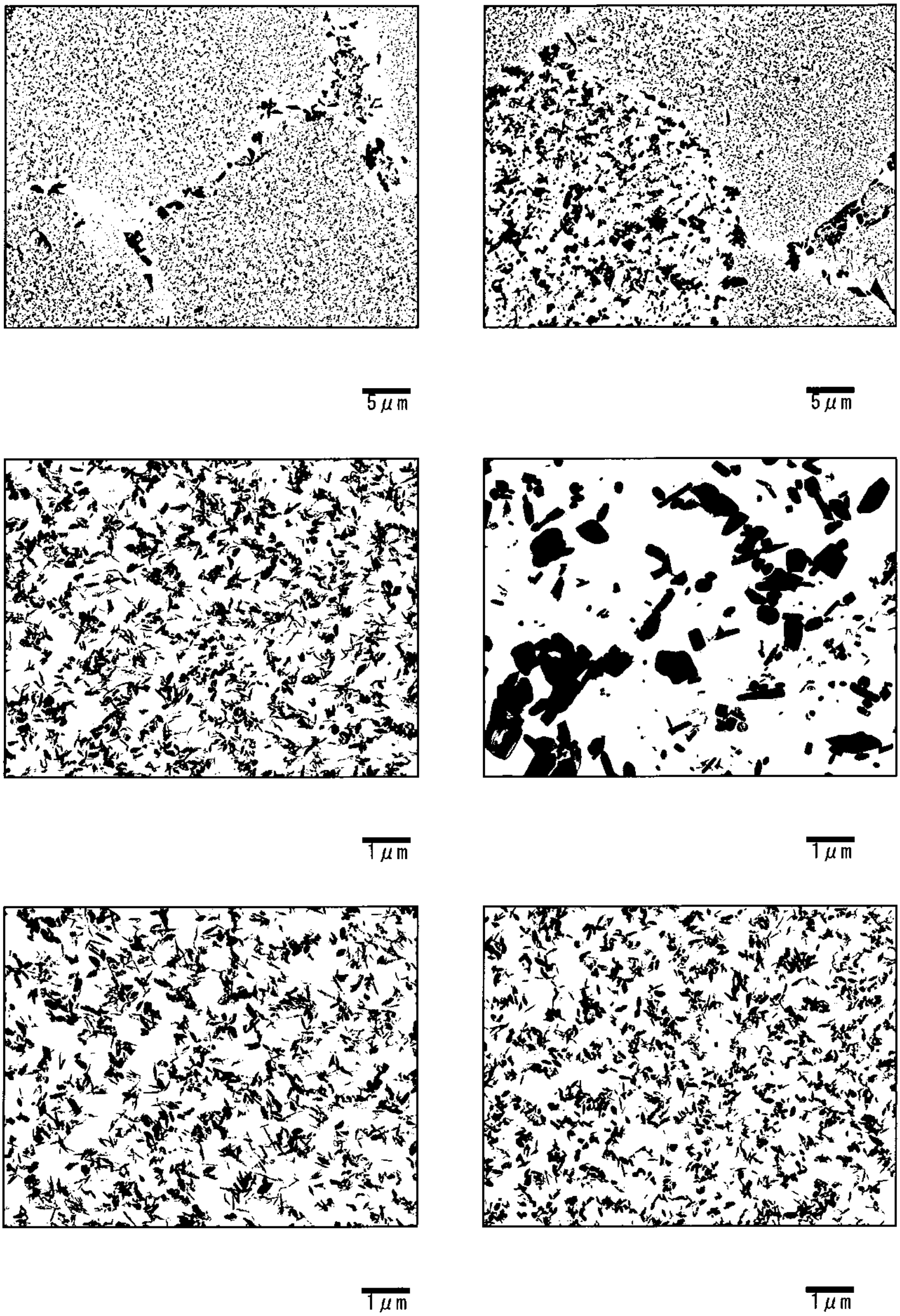


Photo I -8-11 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Right(Circumferential weld at right side : Base metal)

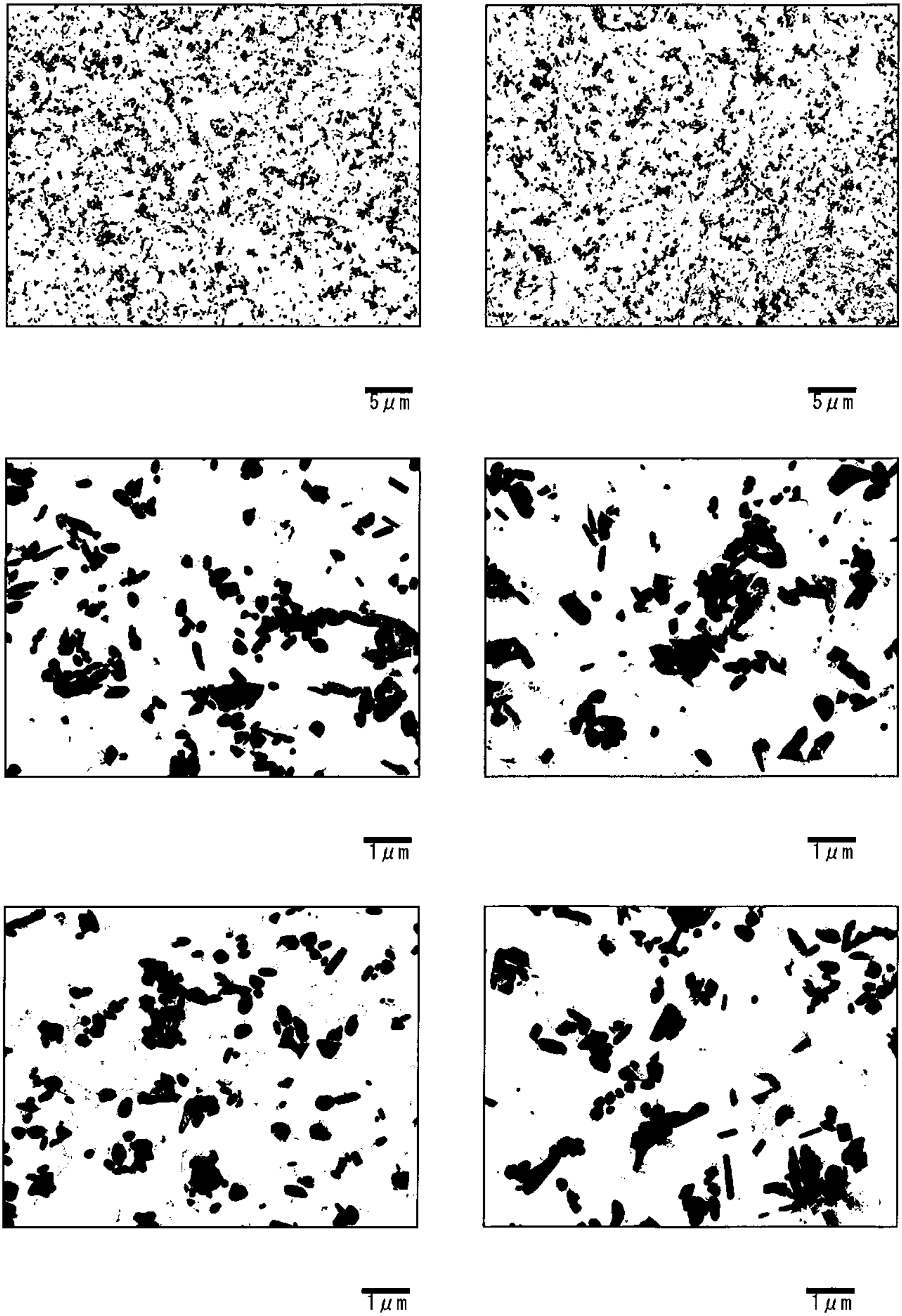


Photo I -8-12 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Right (Circumferential weld at right side : Fine grain HAZ)

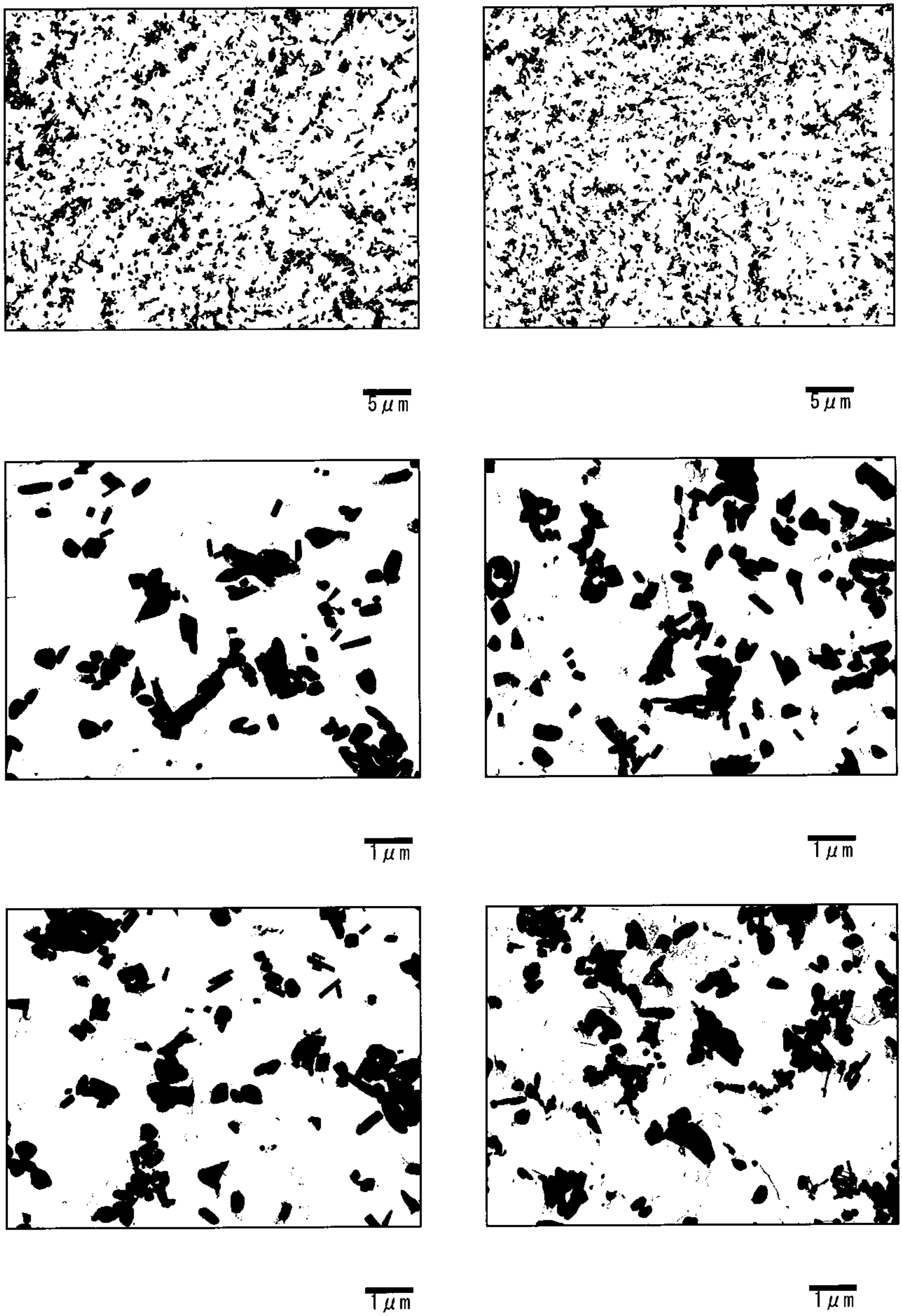


Photo I-8-13 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Right(Circumferential weld at right side : Coarse grain HAZ)

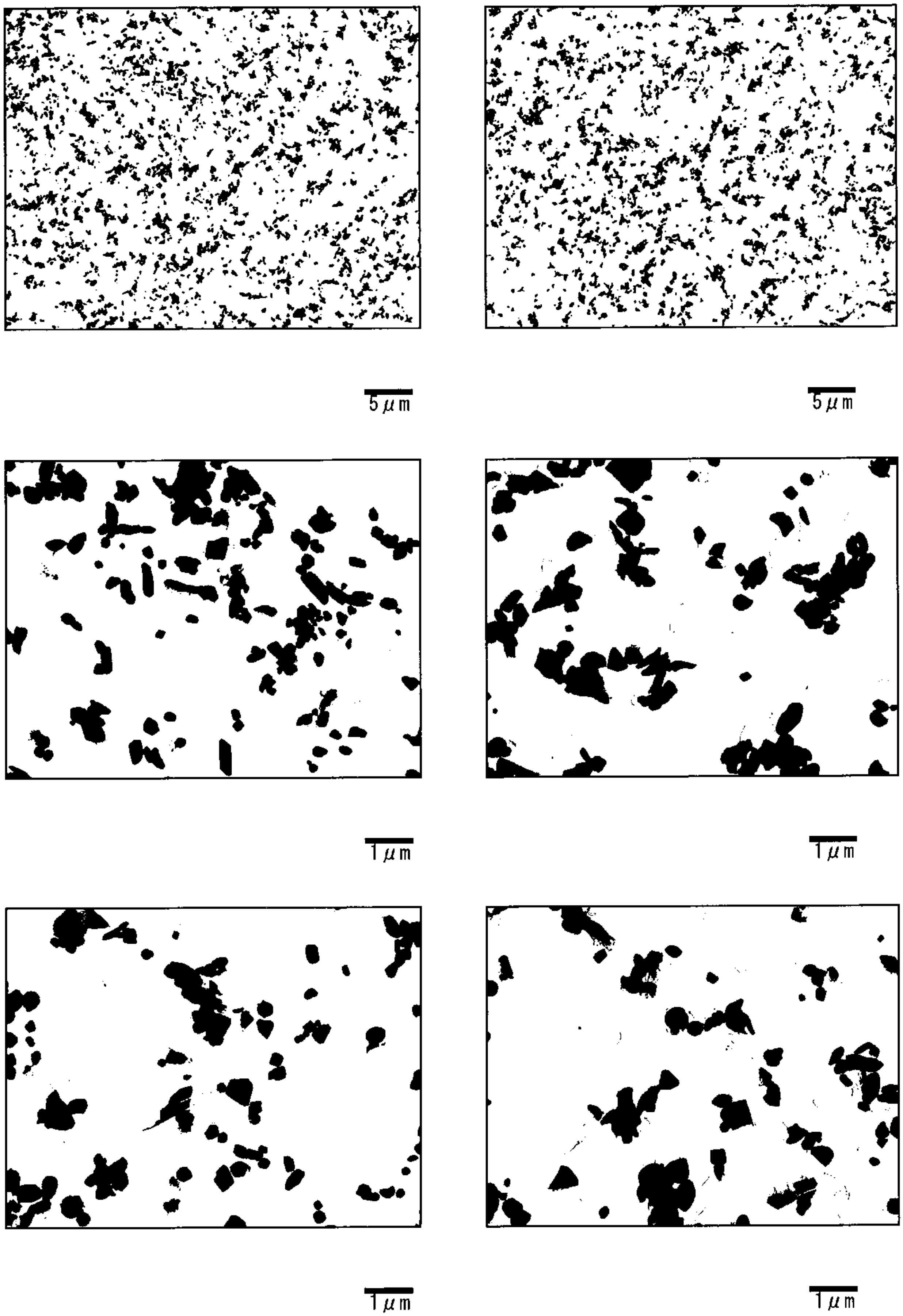


Photo I-8-14 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header-Right (Circumferential weld at right side : Weld metal)

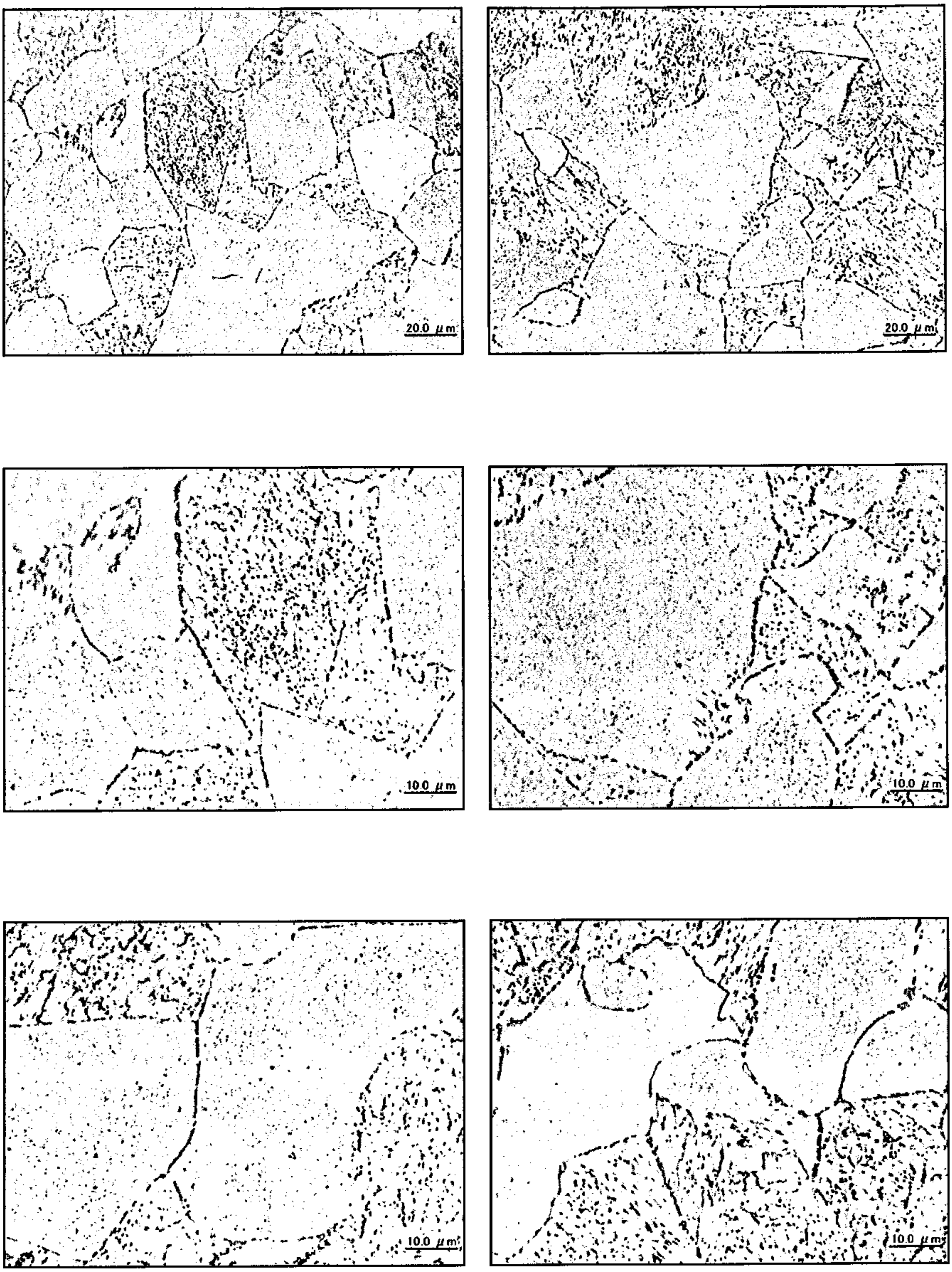


Photo I -9-1 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, extrados : Base metal)

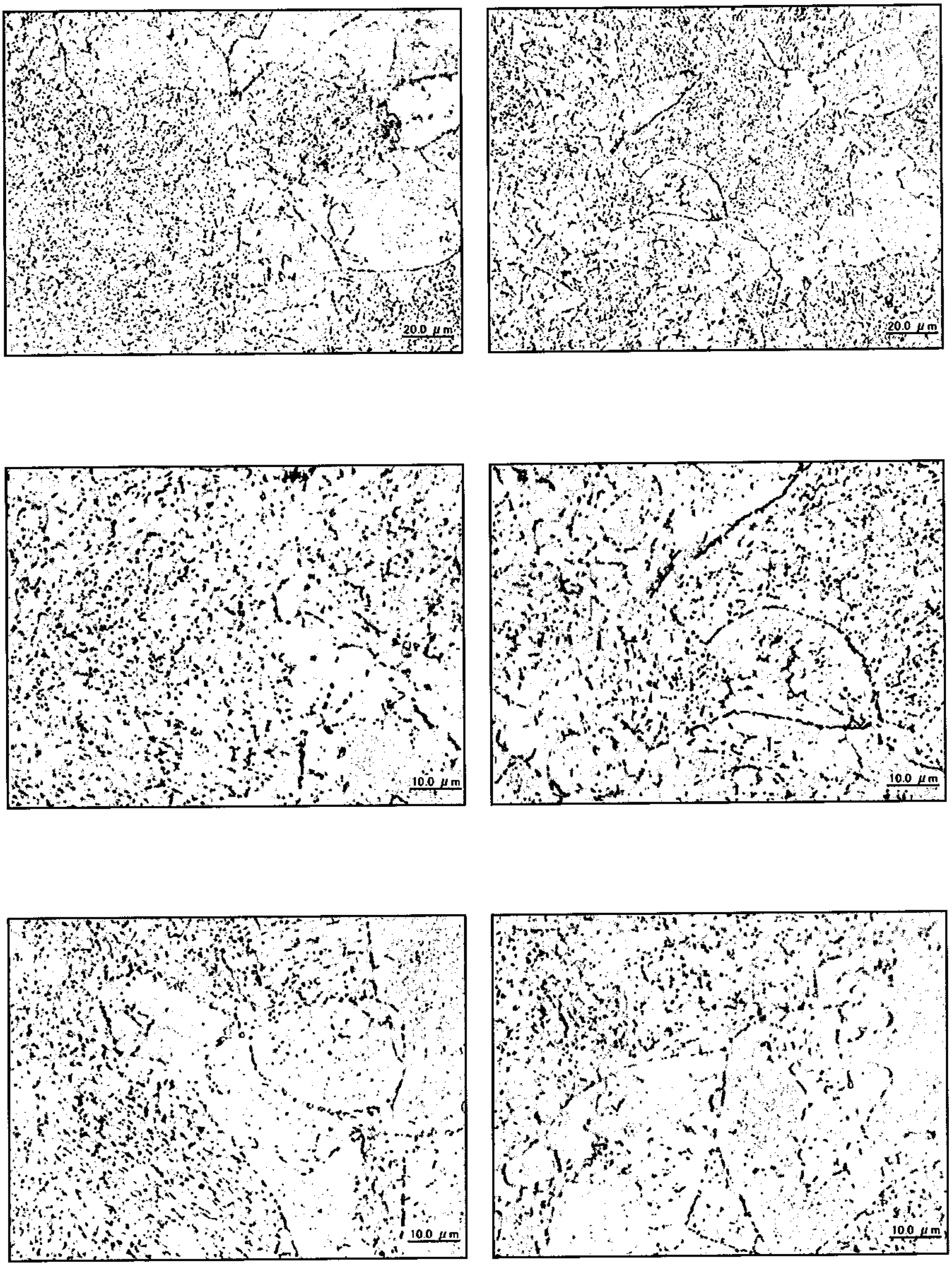


Photo I -9-2 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, extrados : Intercritical zone)

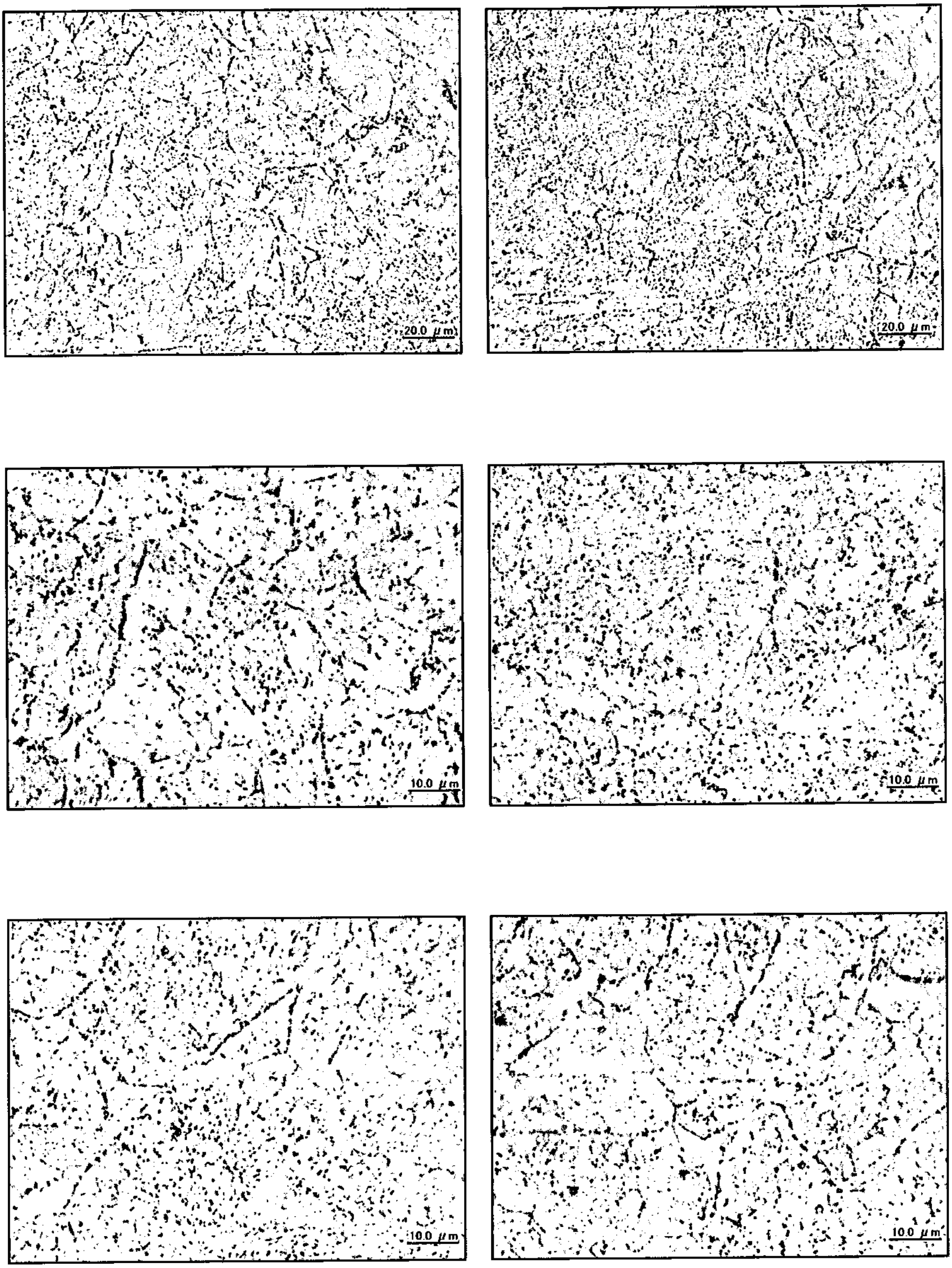


Photo I -9-3 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, extrados : Fine grain HAZ)

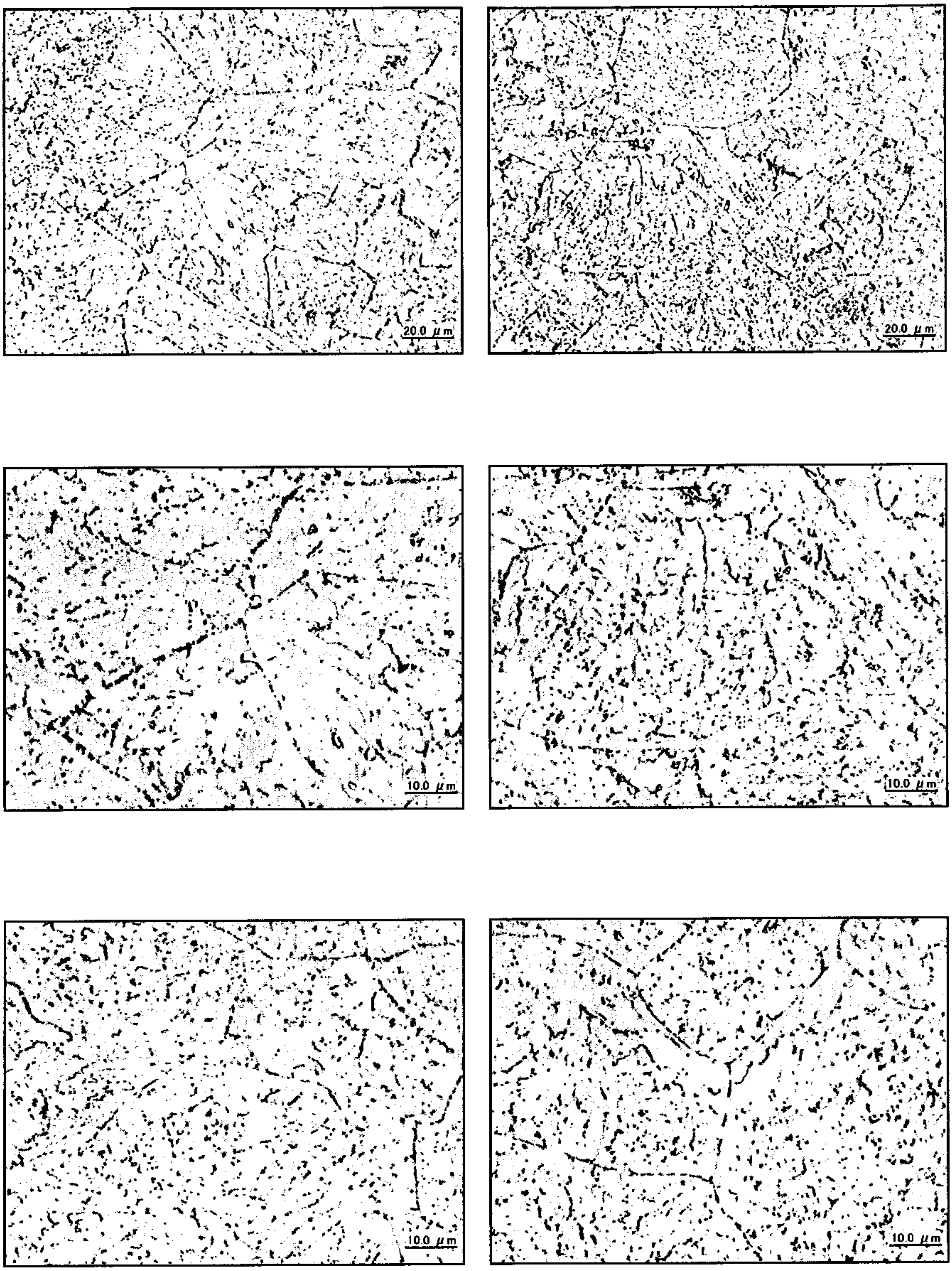


Photo I -9-4 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, extrados : Coarse grain HAZ)

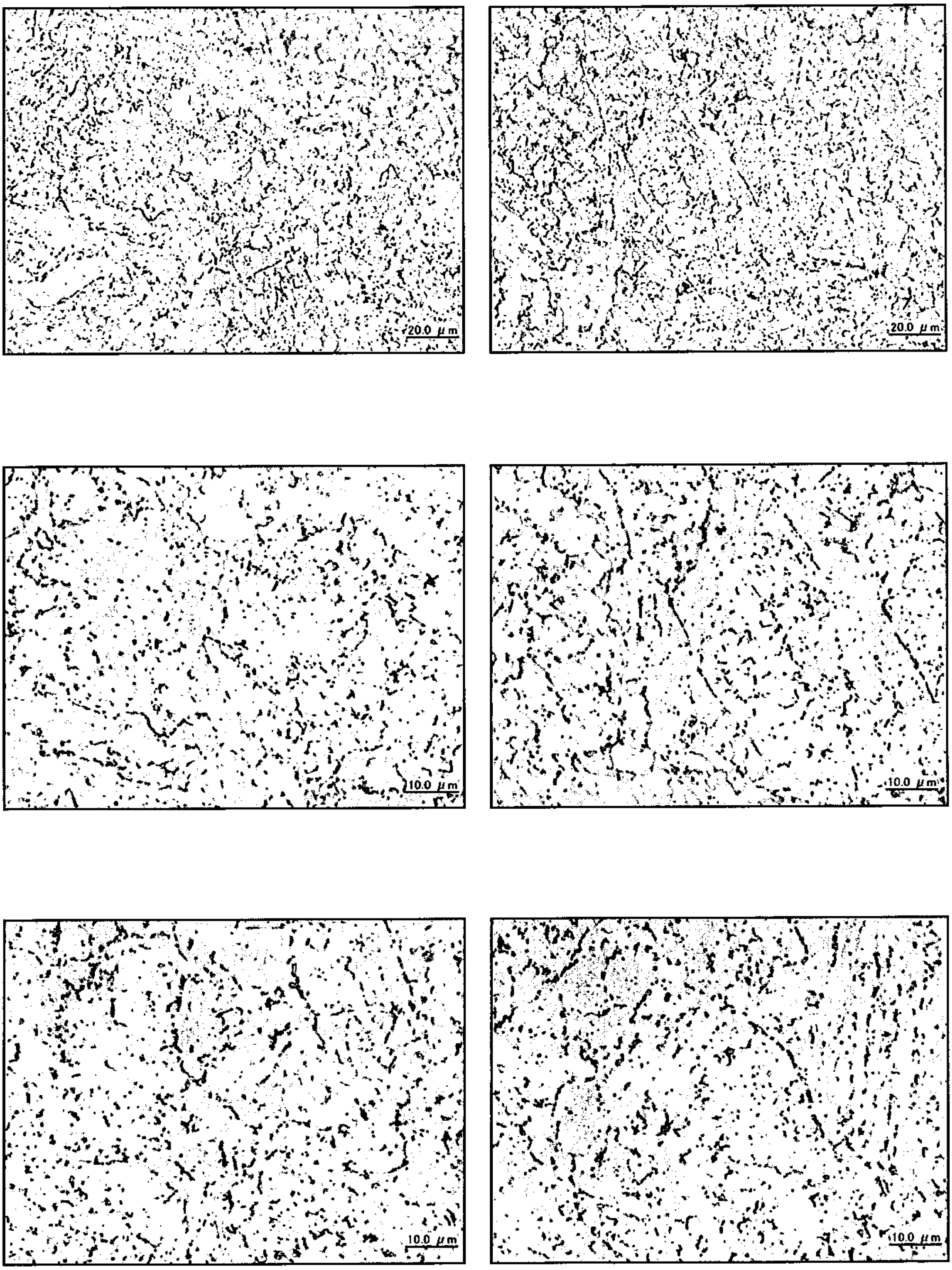


Photo I -9-5 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, extrados : Weld metal)

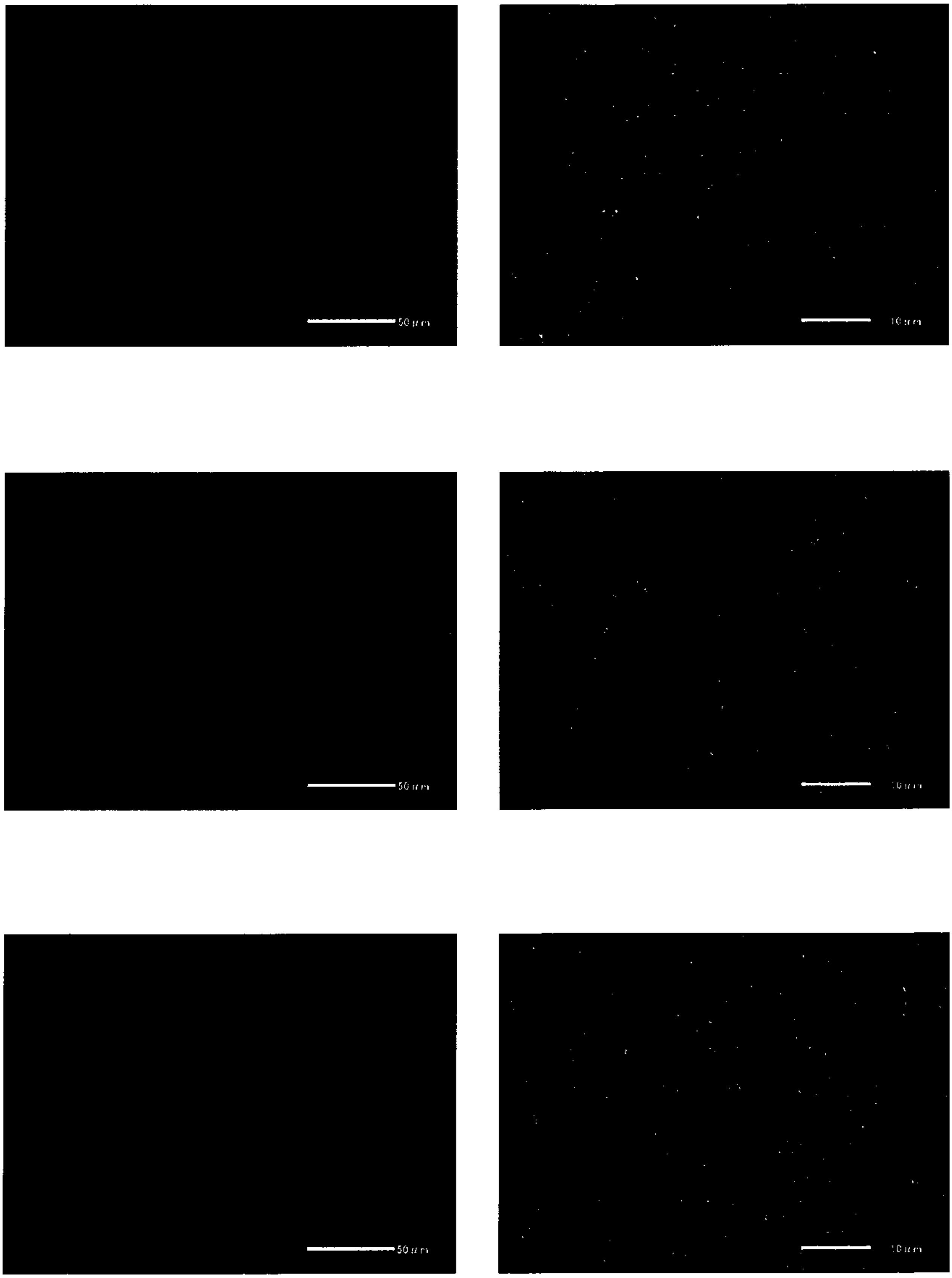


Photo I -9-6 SEM(Scanning electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, extrados : Fine grain HAZ)

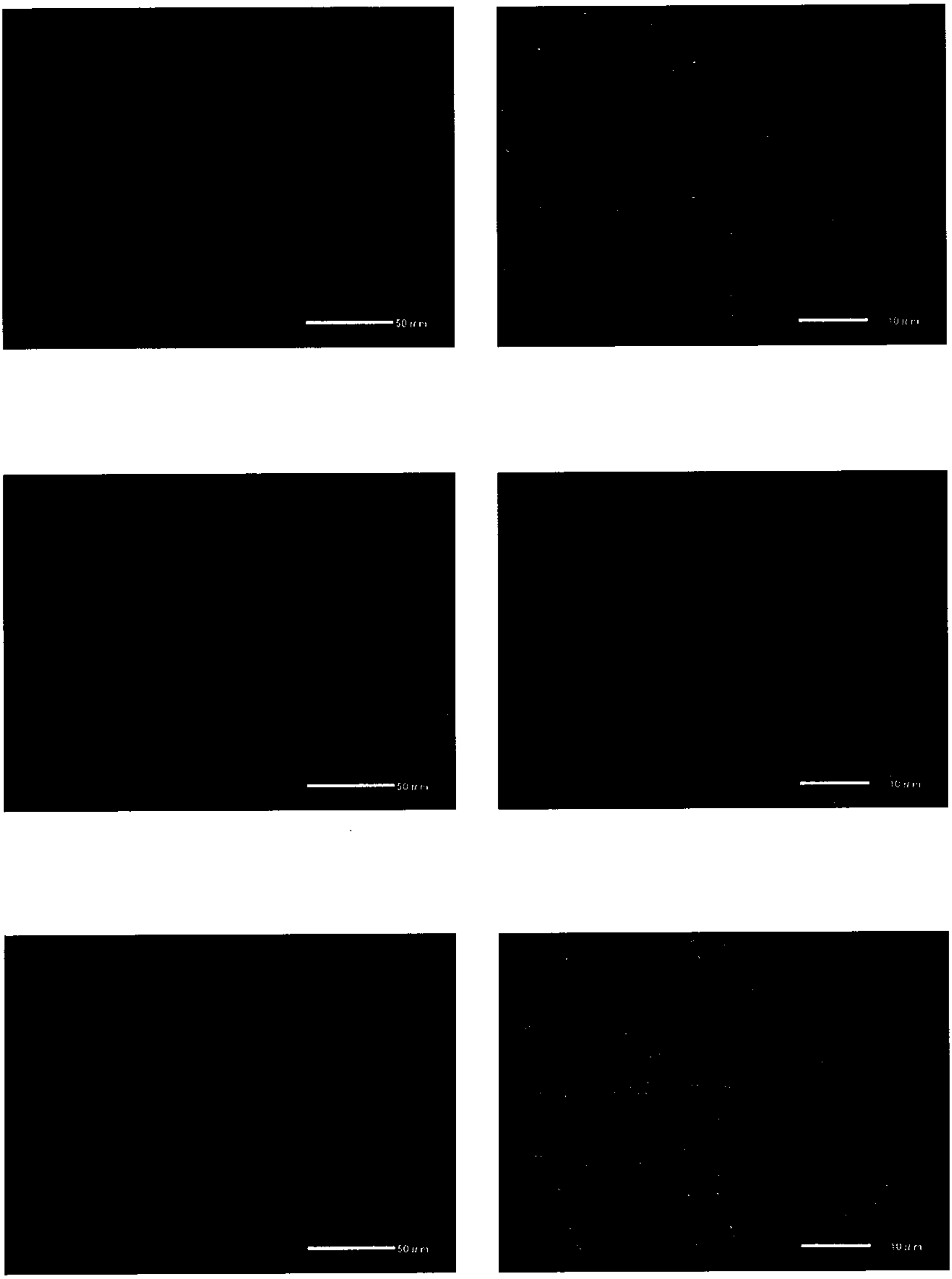
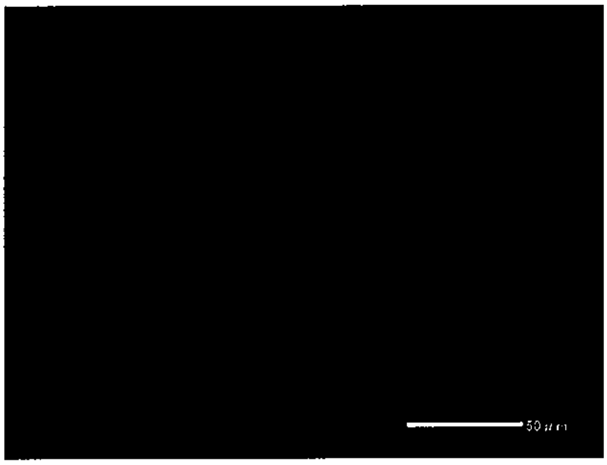
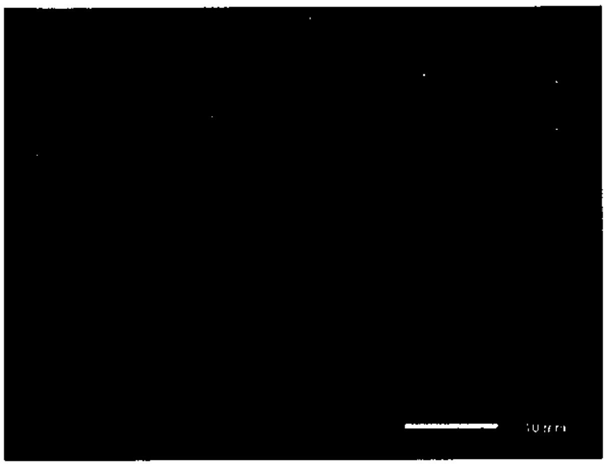
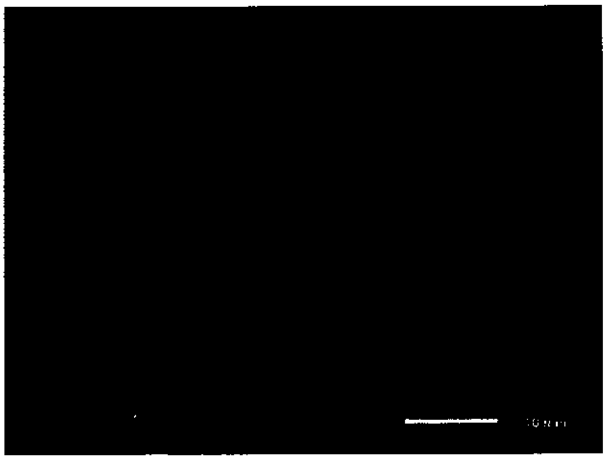
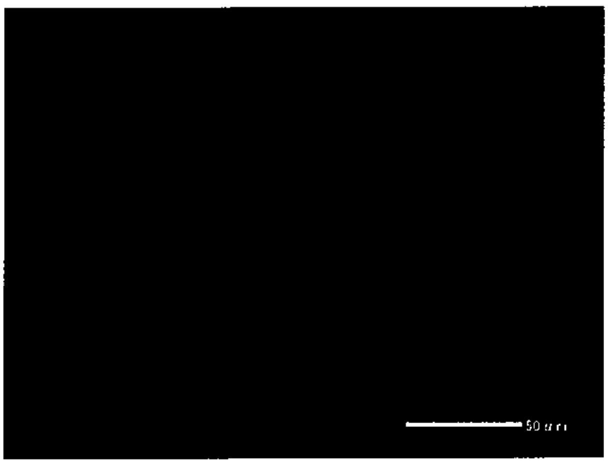


Photo I -9-7 SEM(Scanning electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, extrados : Coarse grain HAZ)









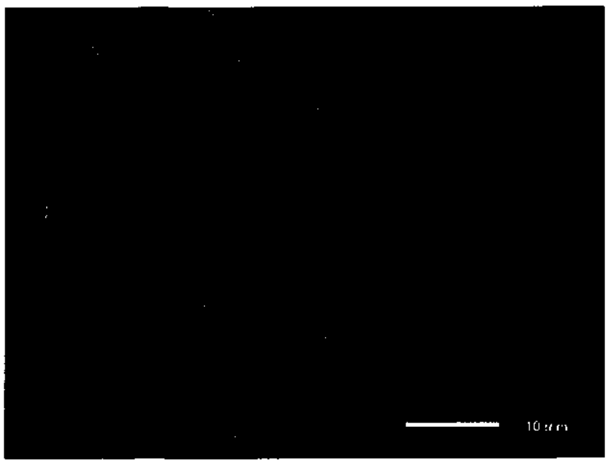


Photo I -9-8 SEM(Scanning electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, extrados : Weld metal)

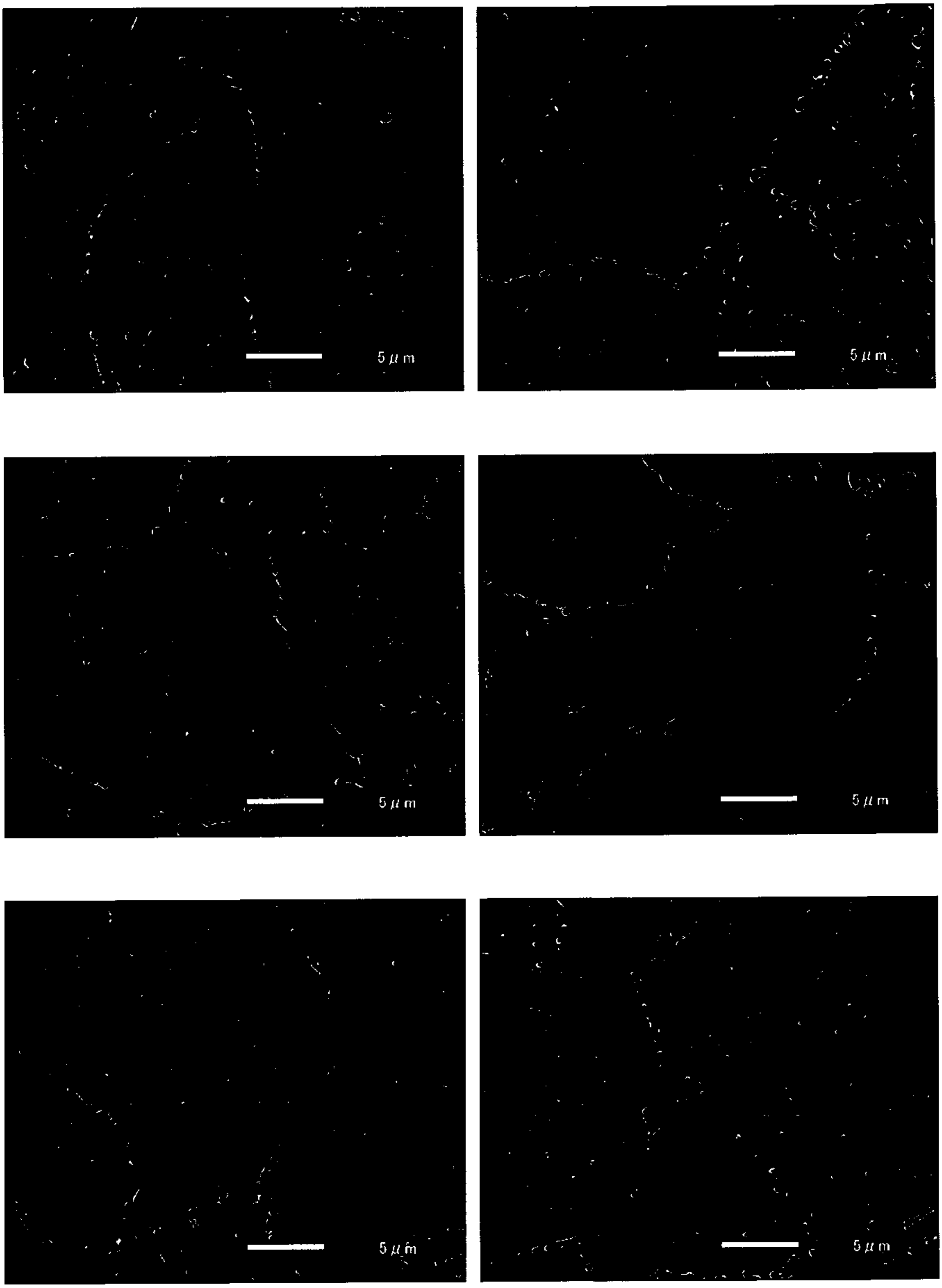


Photo I-9-9 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Left (Circumferential weld, extrados : Base metal)

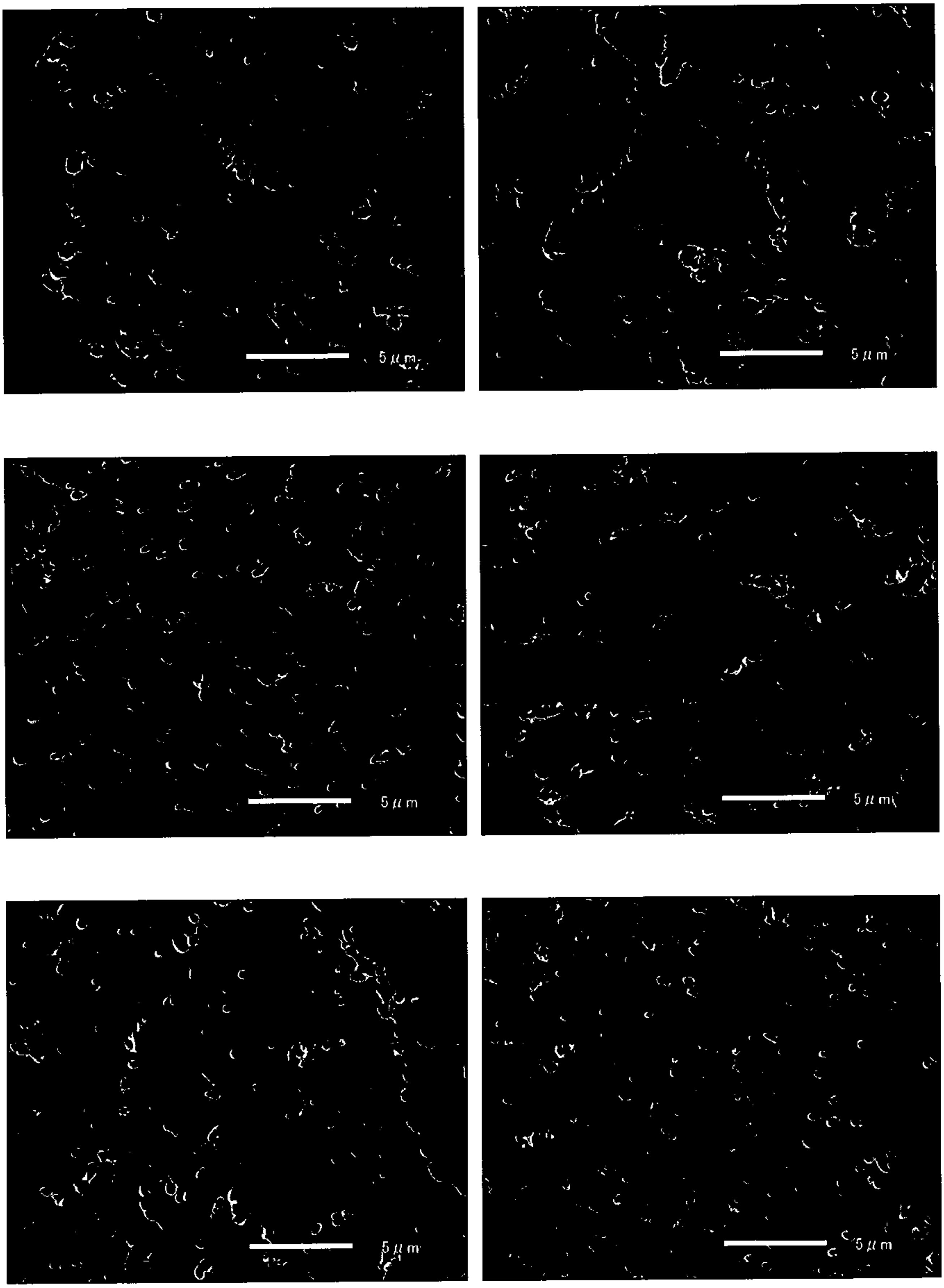


Photo I -9-10 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Left (Circumferential weld, extrados : Fine grain HAZ)

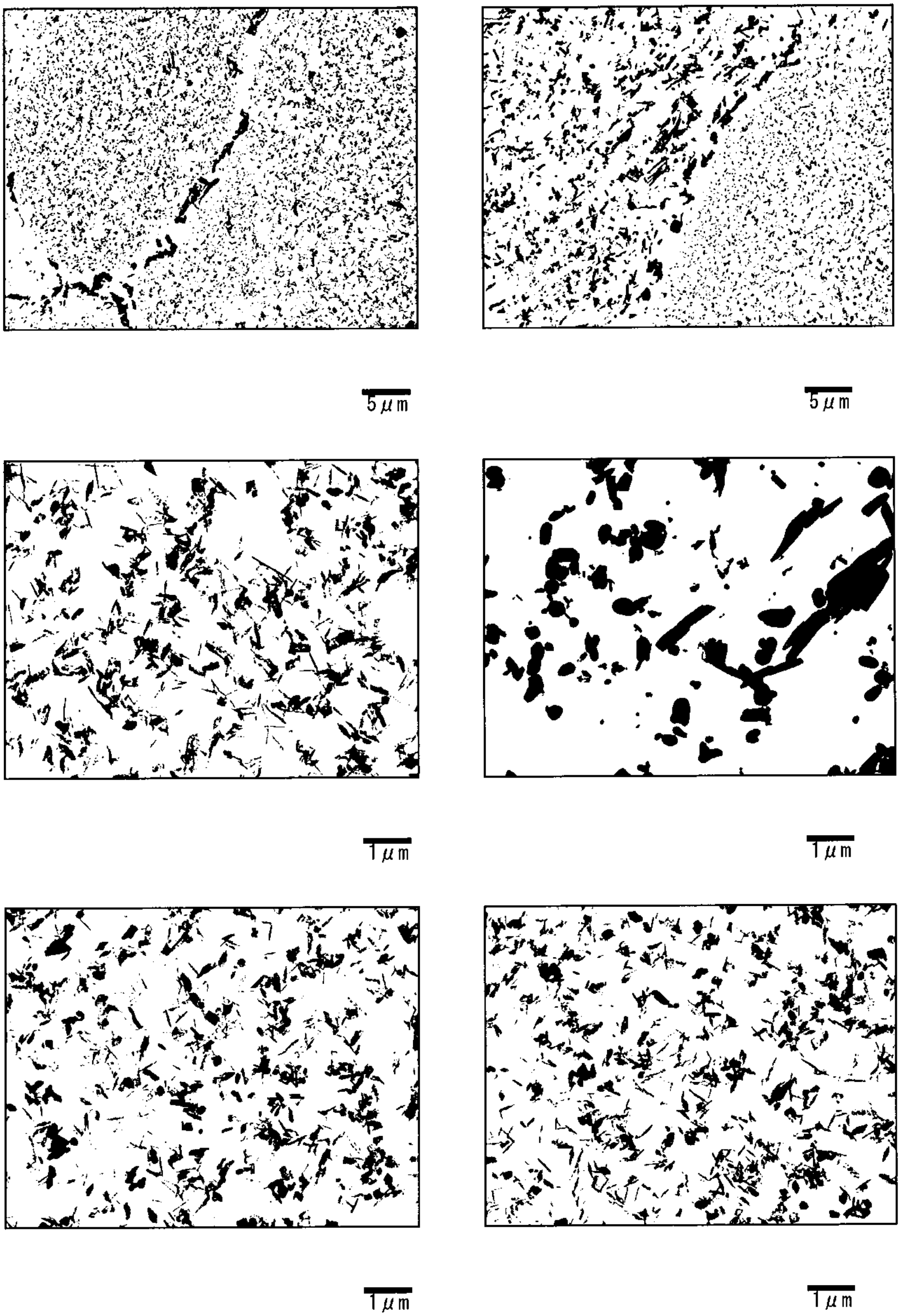


Photo I -9-11 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left (Circumferential weld, extrados : Base metal)

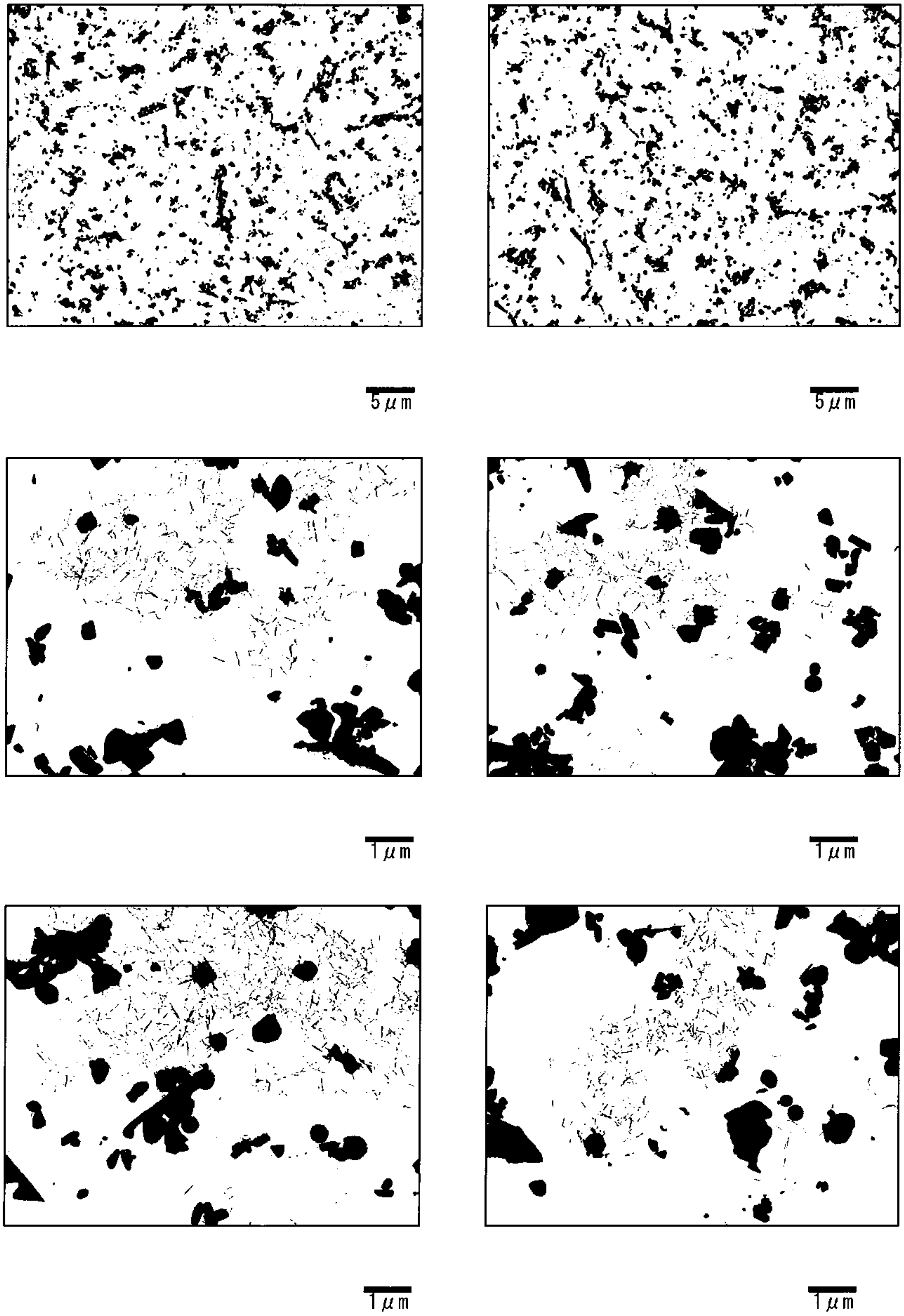


Photo I -9-12 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, extrados : Fine grain HAZ)

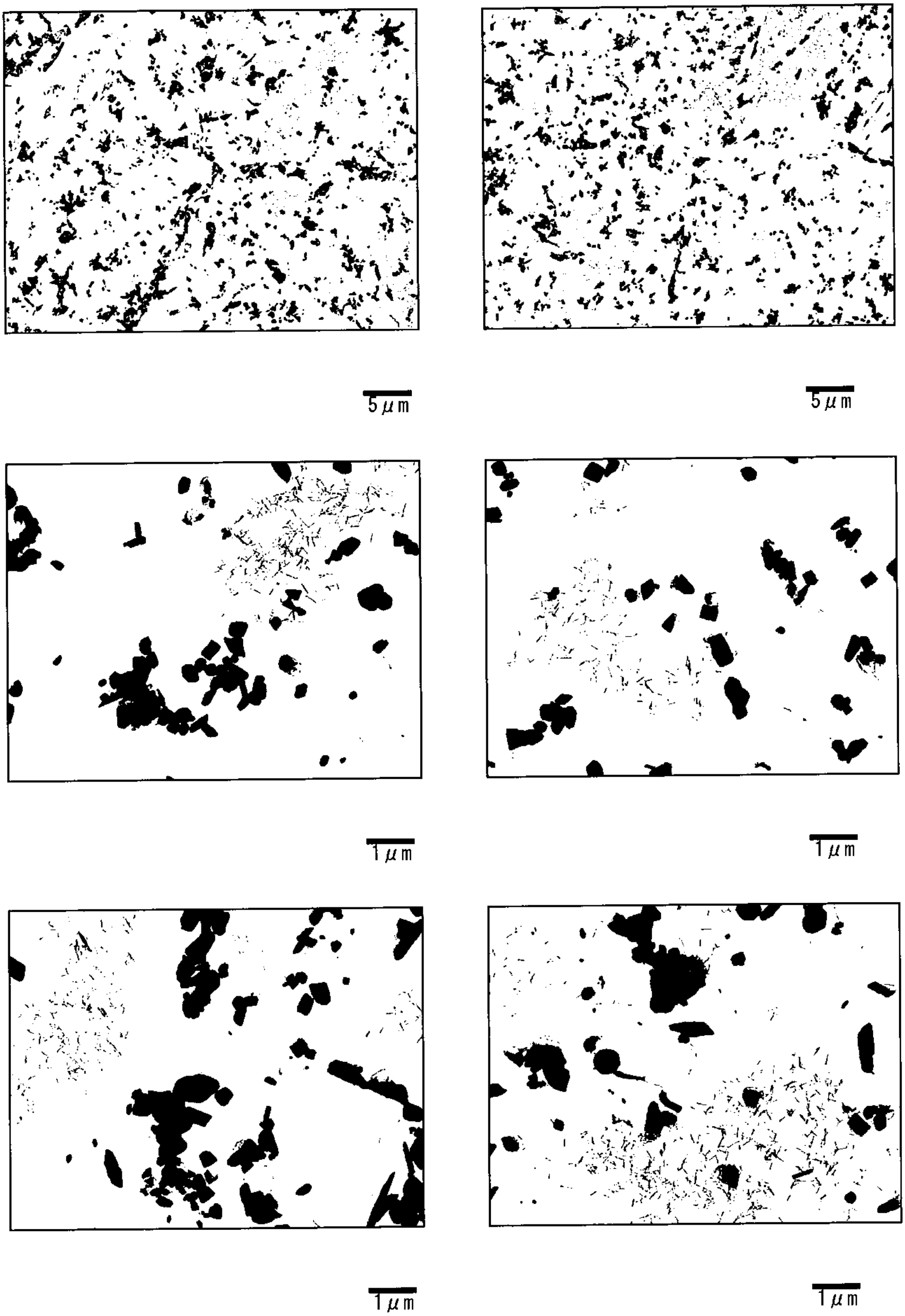


Photo I -9-13 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, extrados : Coarse grain HAZ)

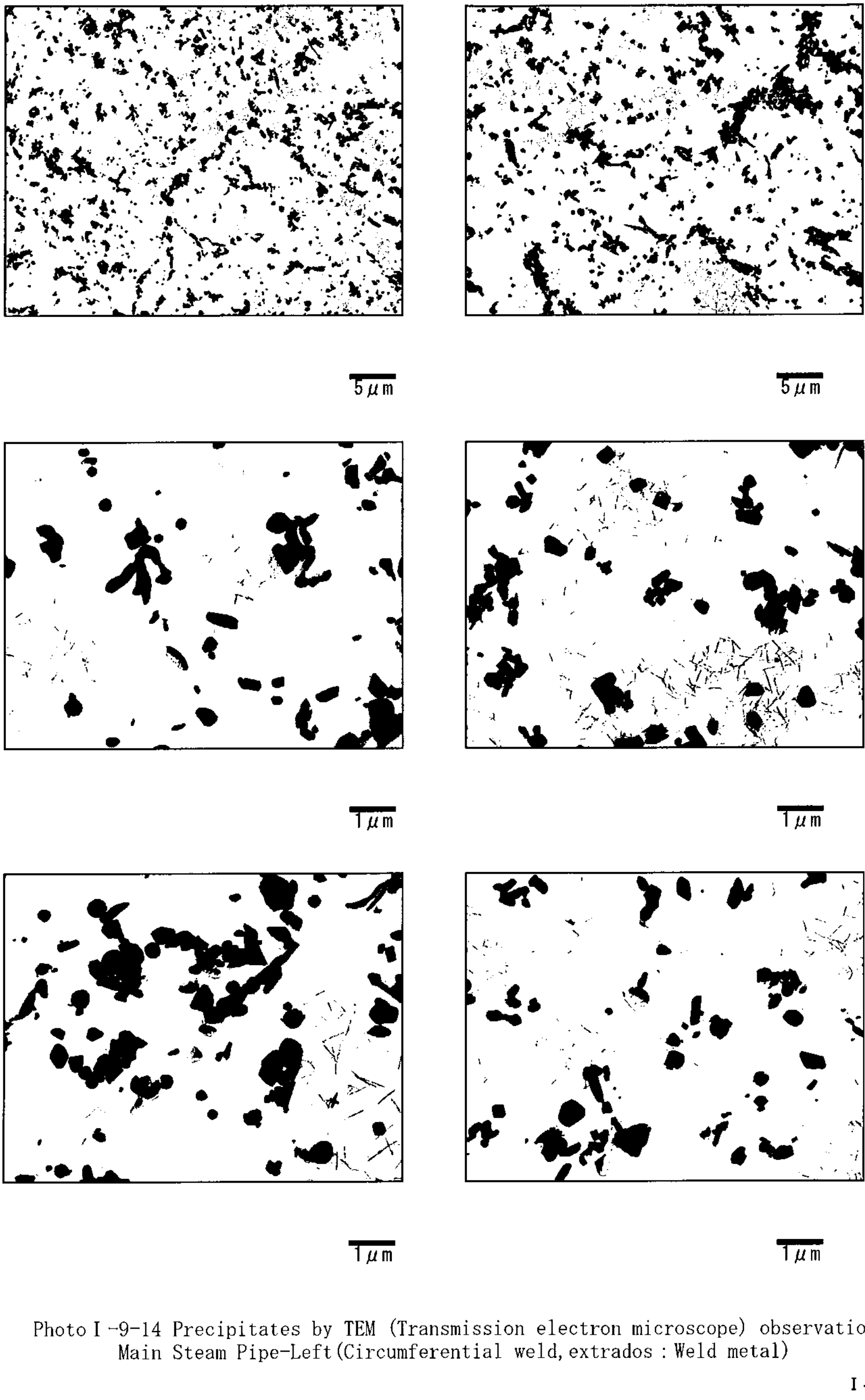


Photo I-9-14 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left (Circumferential weld, extrados : Weld metal)

Photo I-10-1 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, intrados : Base metal)

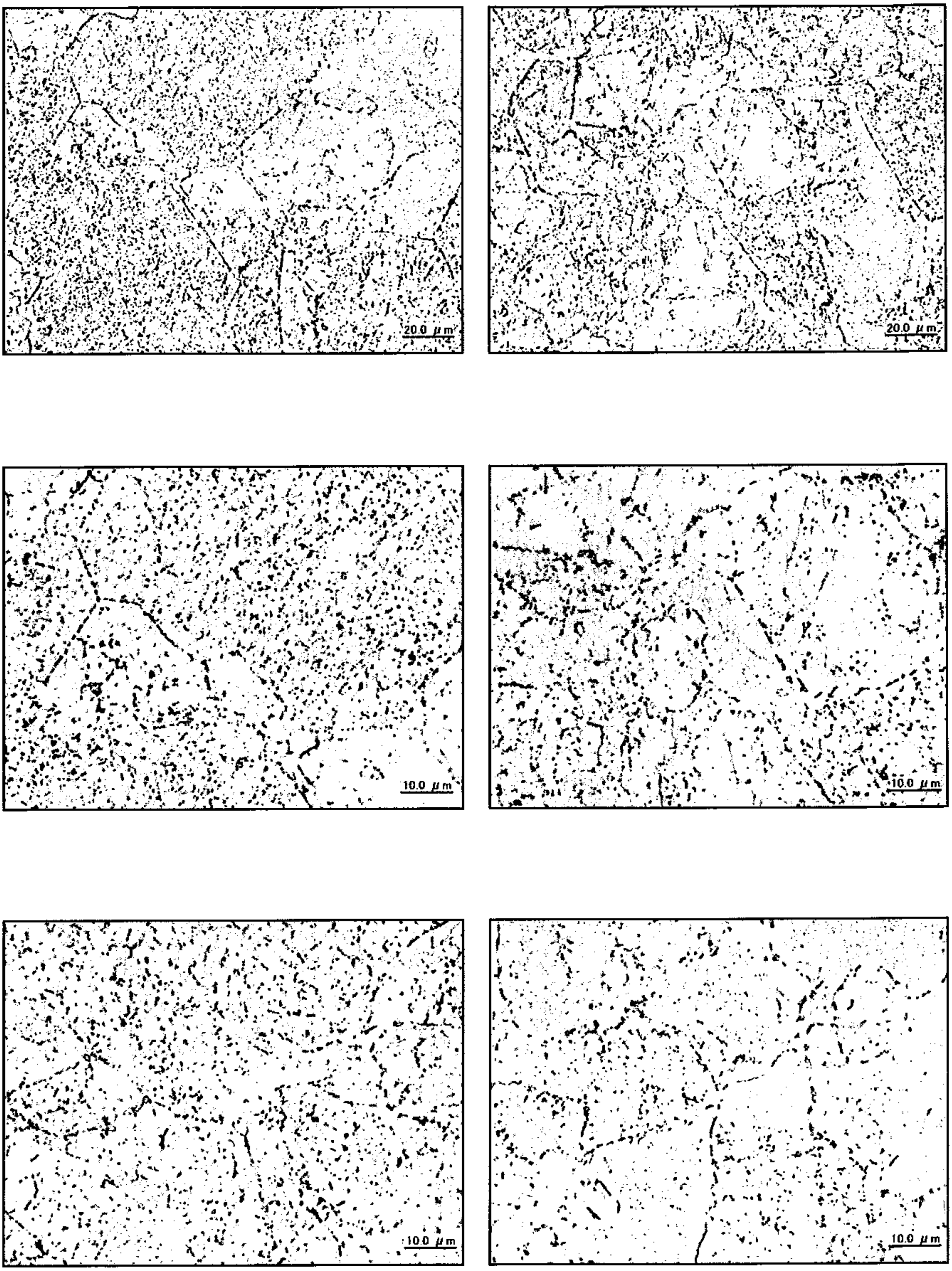


Photo I -10-2 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, intrados : Intercritical zone)

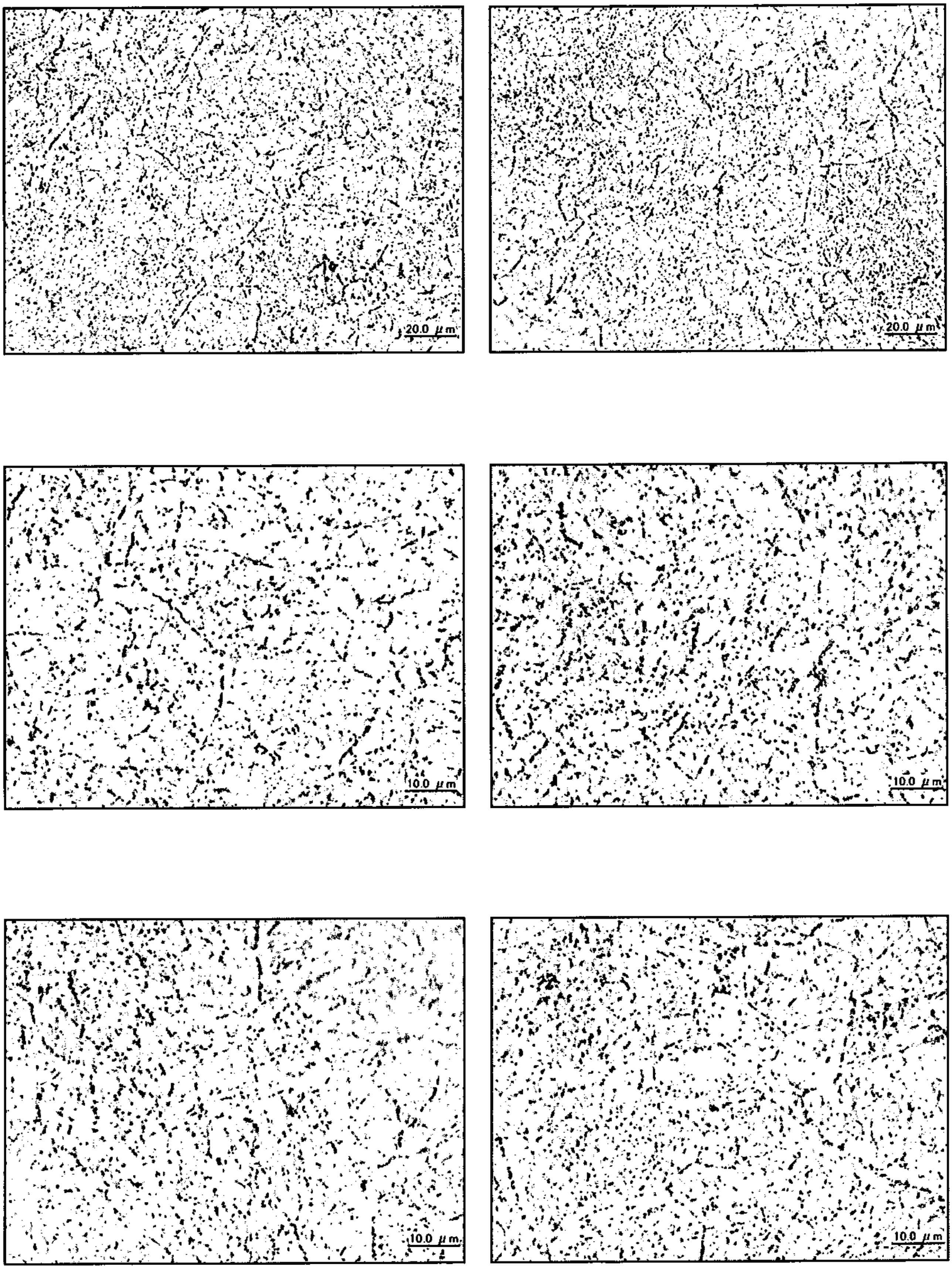


Photo I -10-3 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, intrados : Fine grain HAZ)

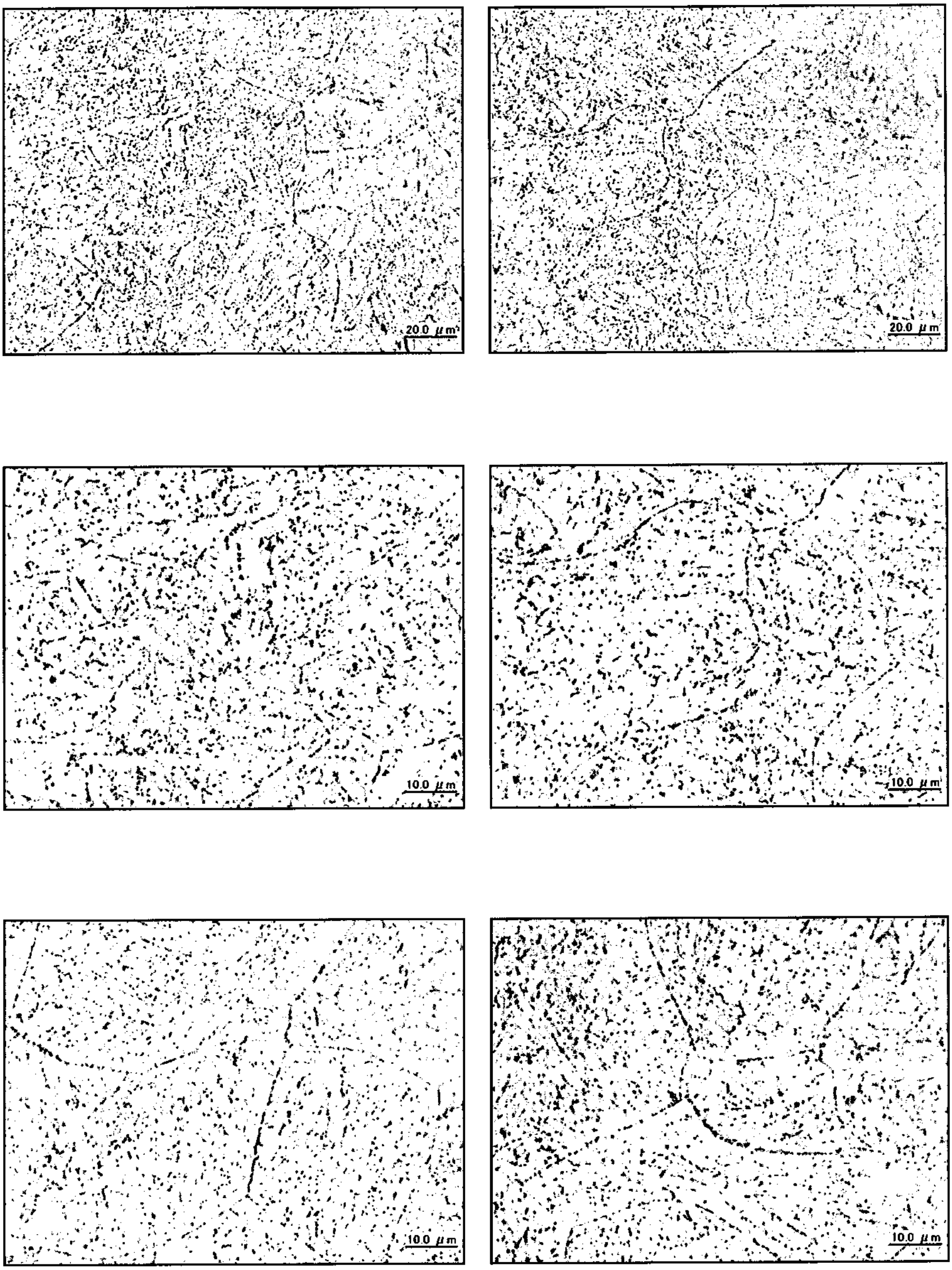


Photo I -10-4 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, intrados : Coarse grain HAZ)

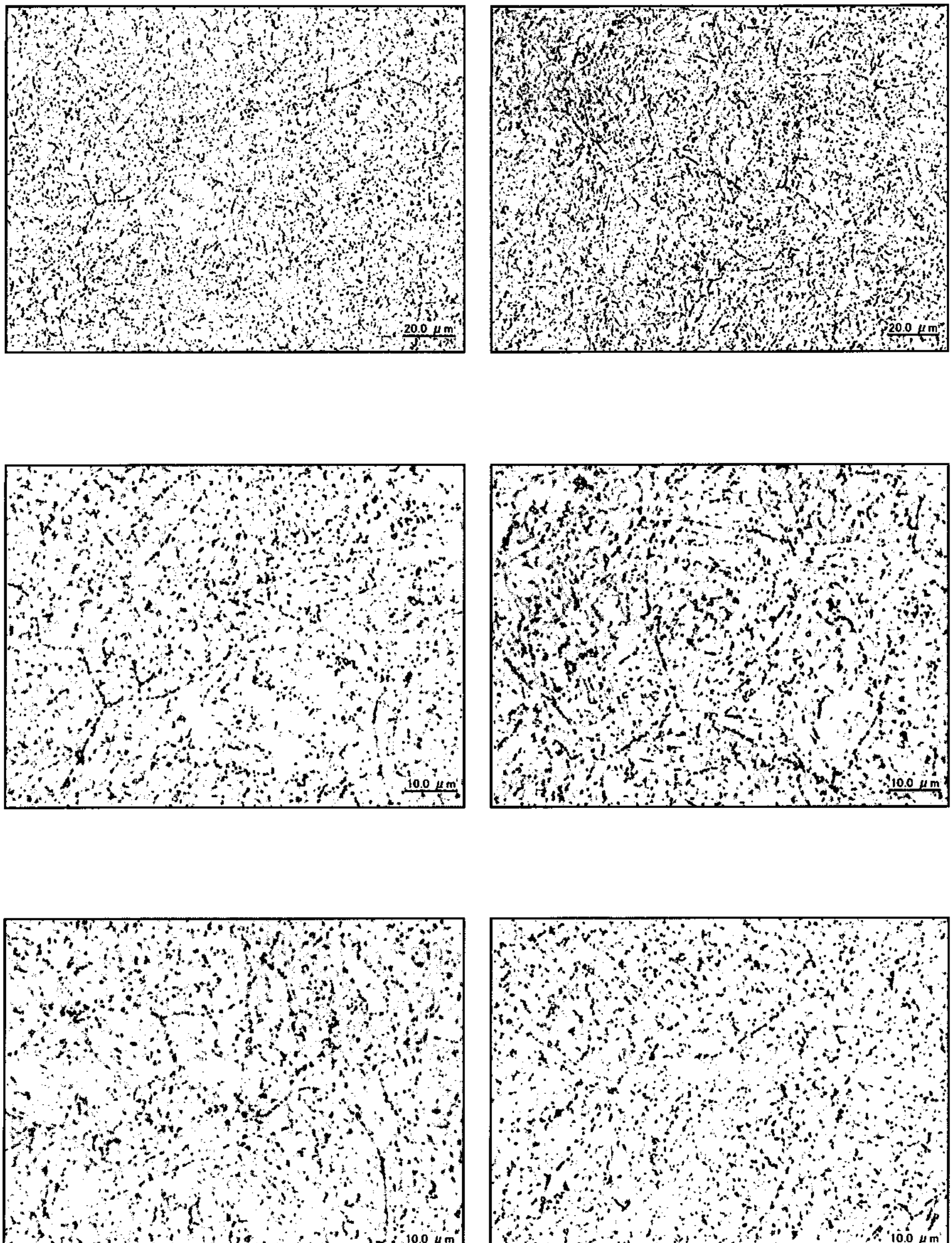
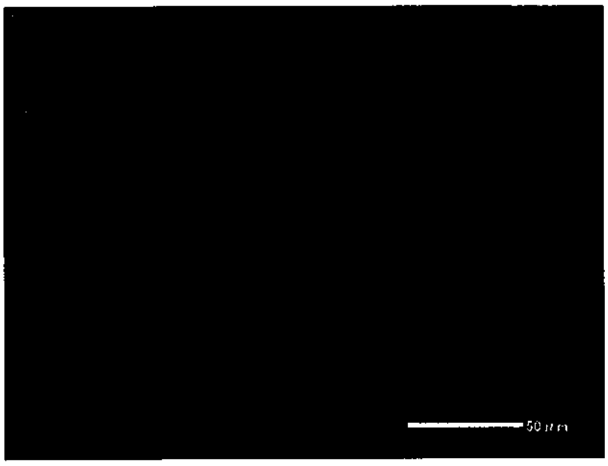
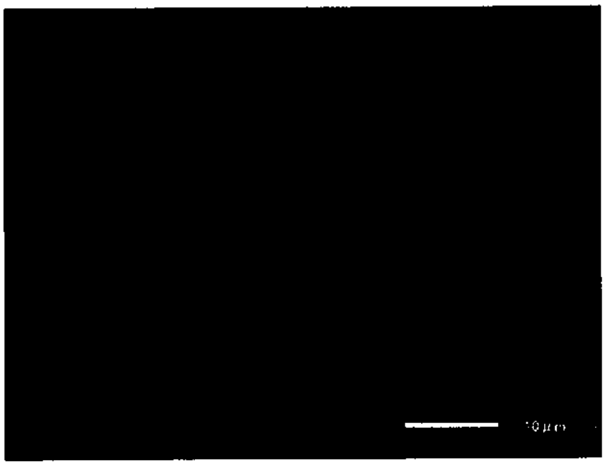
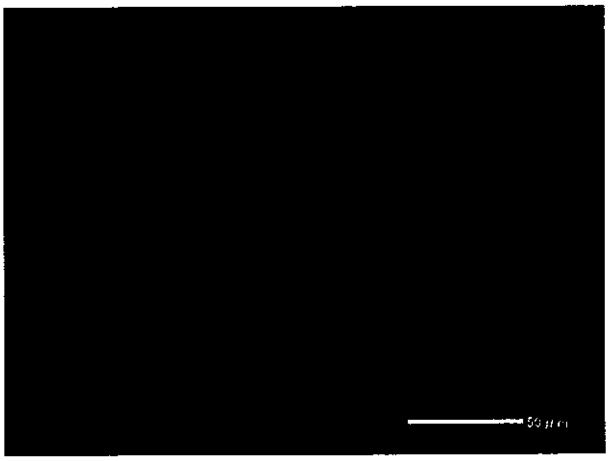
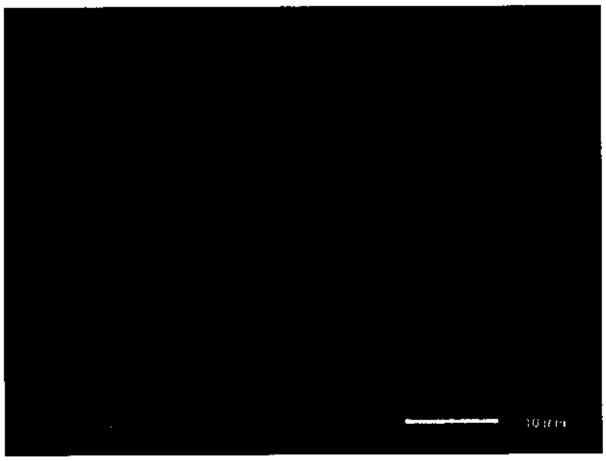


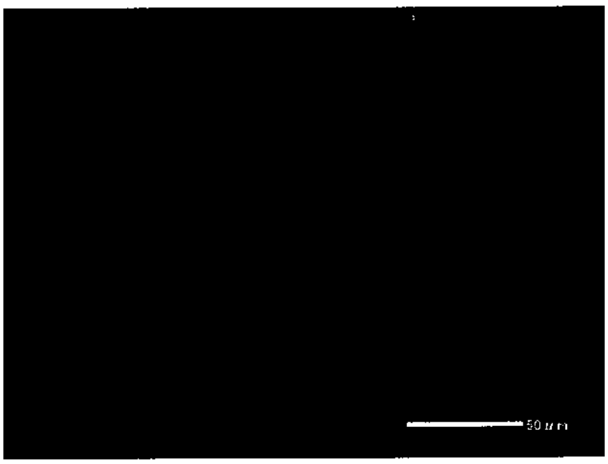
Photo I -10-5 Microstructure observation
Main Steam Pipe-Left (Circumferential weld, intrados : Weld metal)











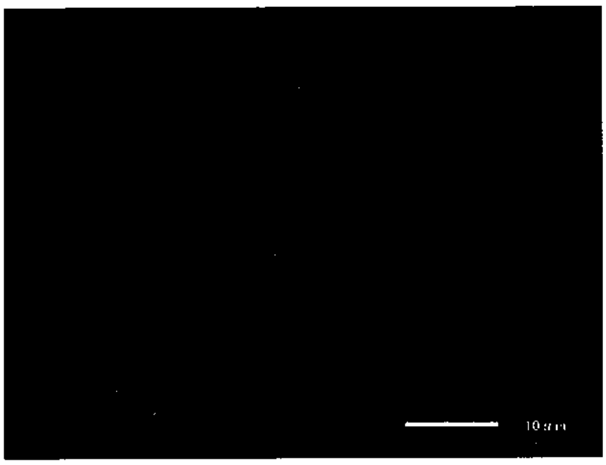


Photo I -10-6 SEM(Scanning electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, intrados : Fine grain HAZ)

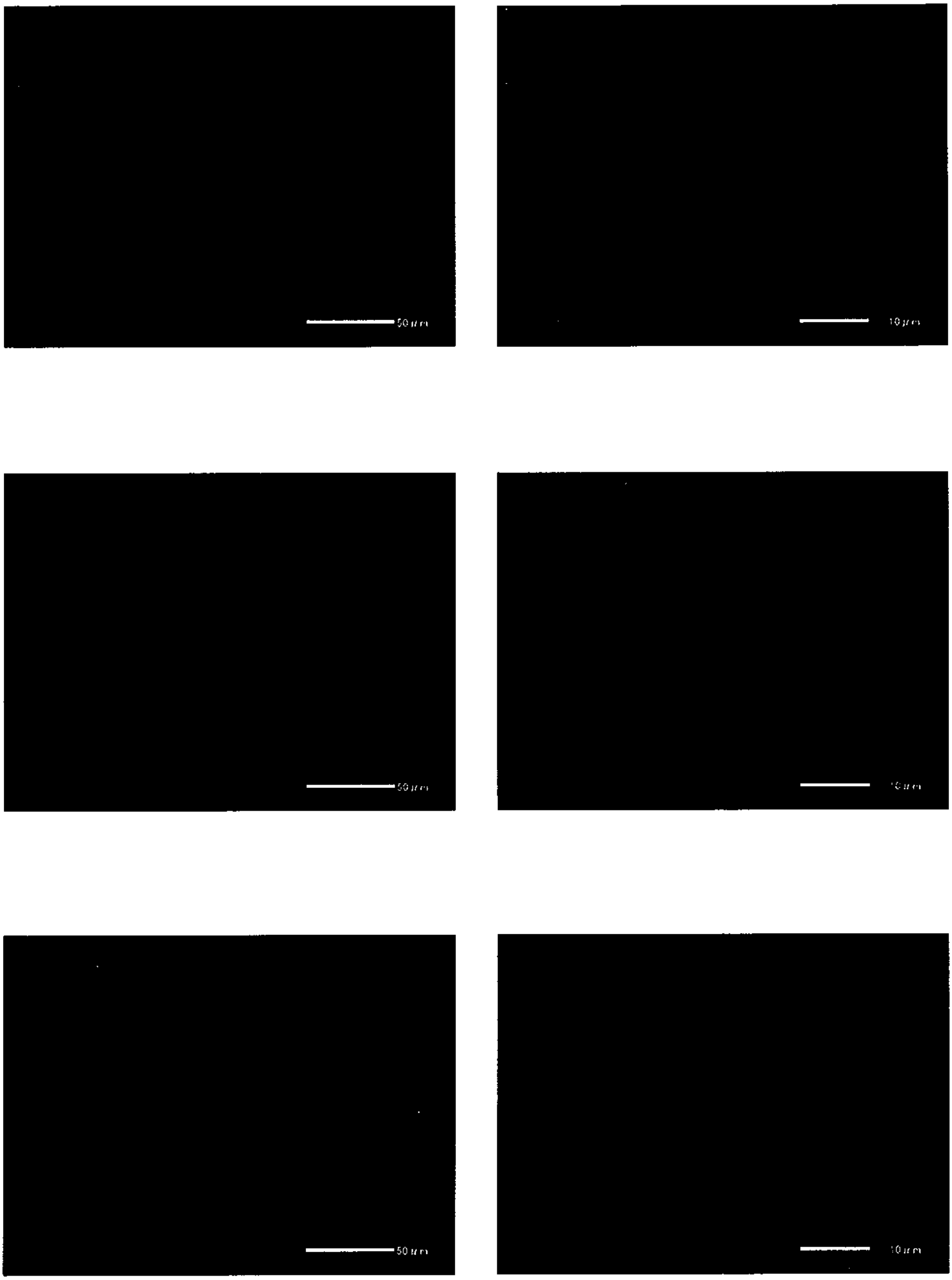


Photo I-10-7 SEM(Scanning electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, intrados : Coarse grain HAZ)

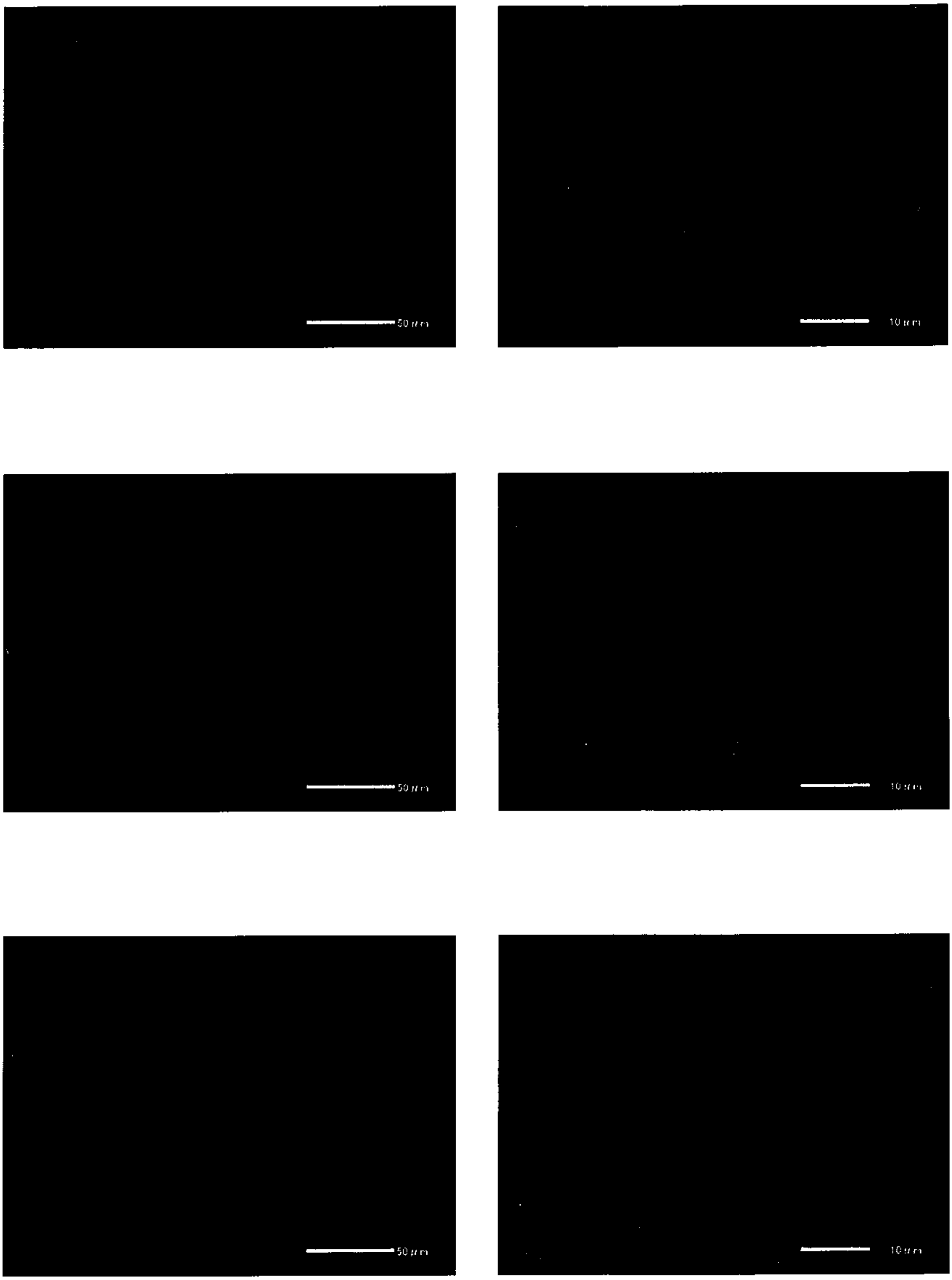


Photo I -10-8 SEM(Scanning electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, intrados : Weld metal)

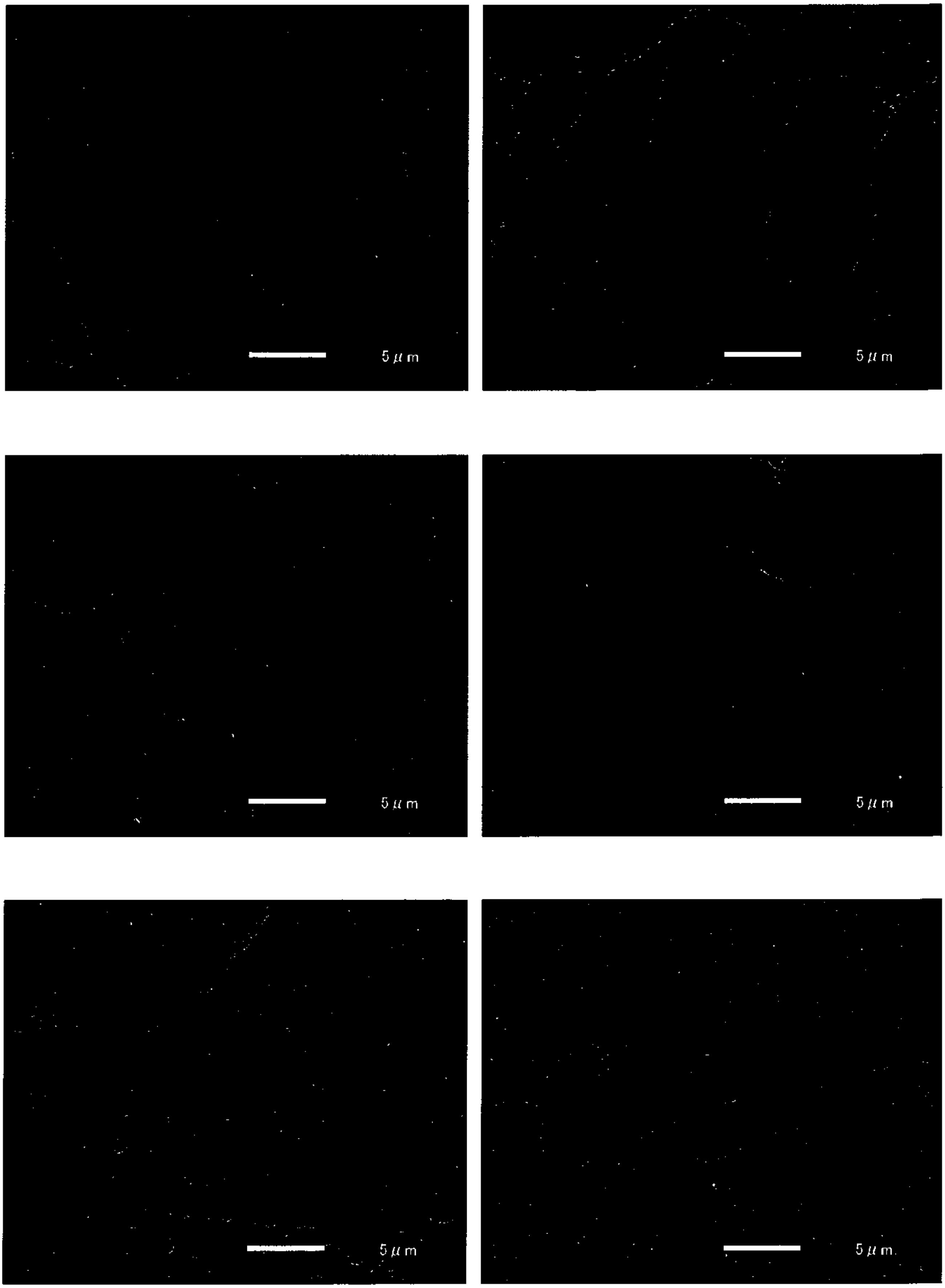


Photo I -10-9 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Left (Circumferential weld, intrados : Base metal)

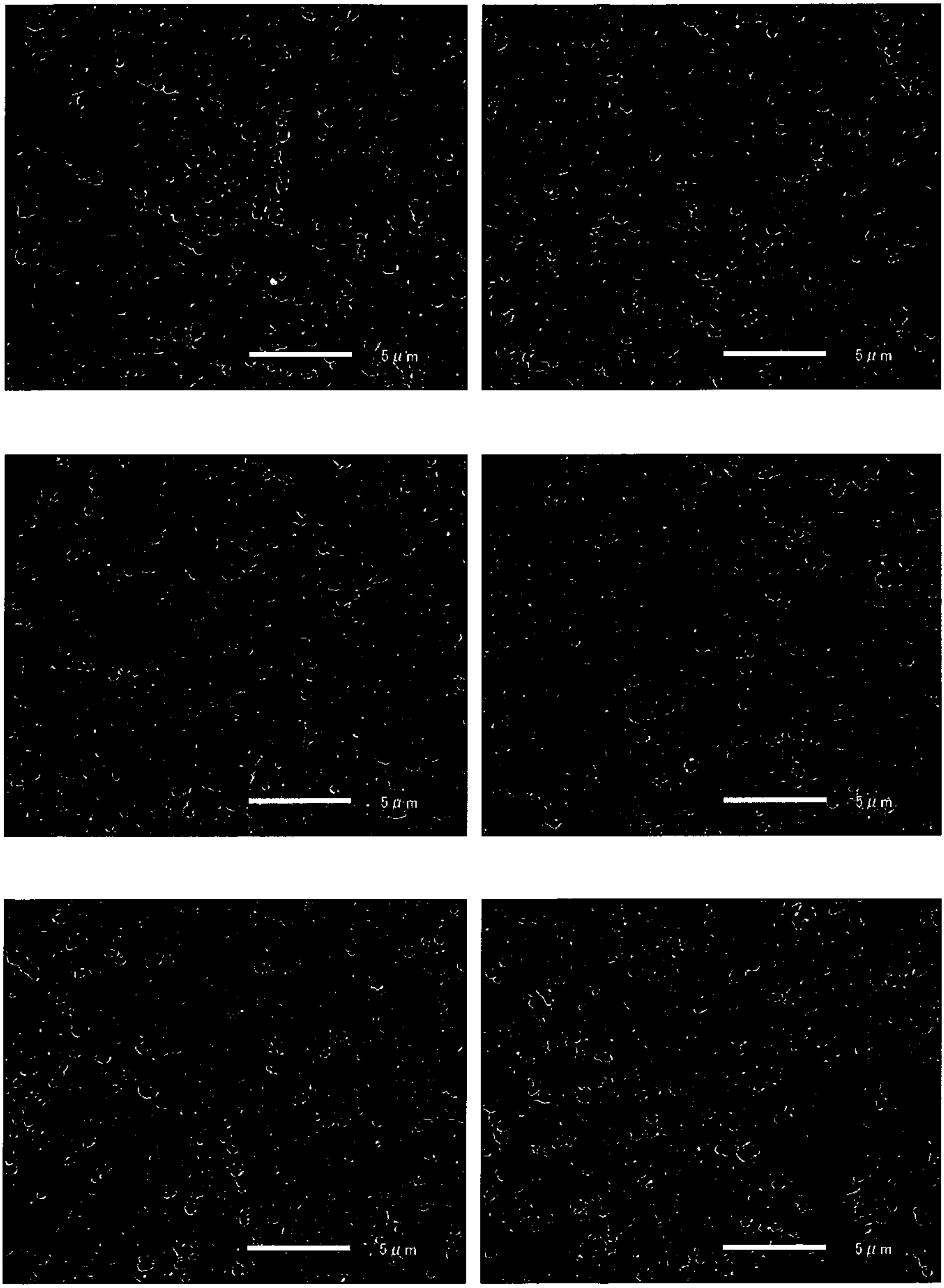


Photo I -10-10 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Left (Circumferential weld, intrados : Fine grain HAZ)

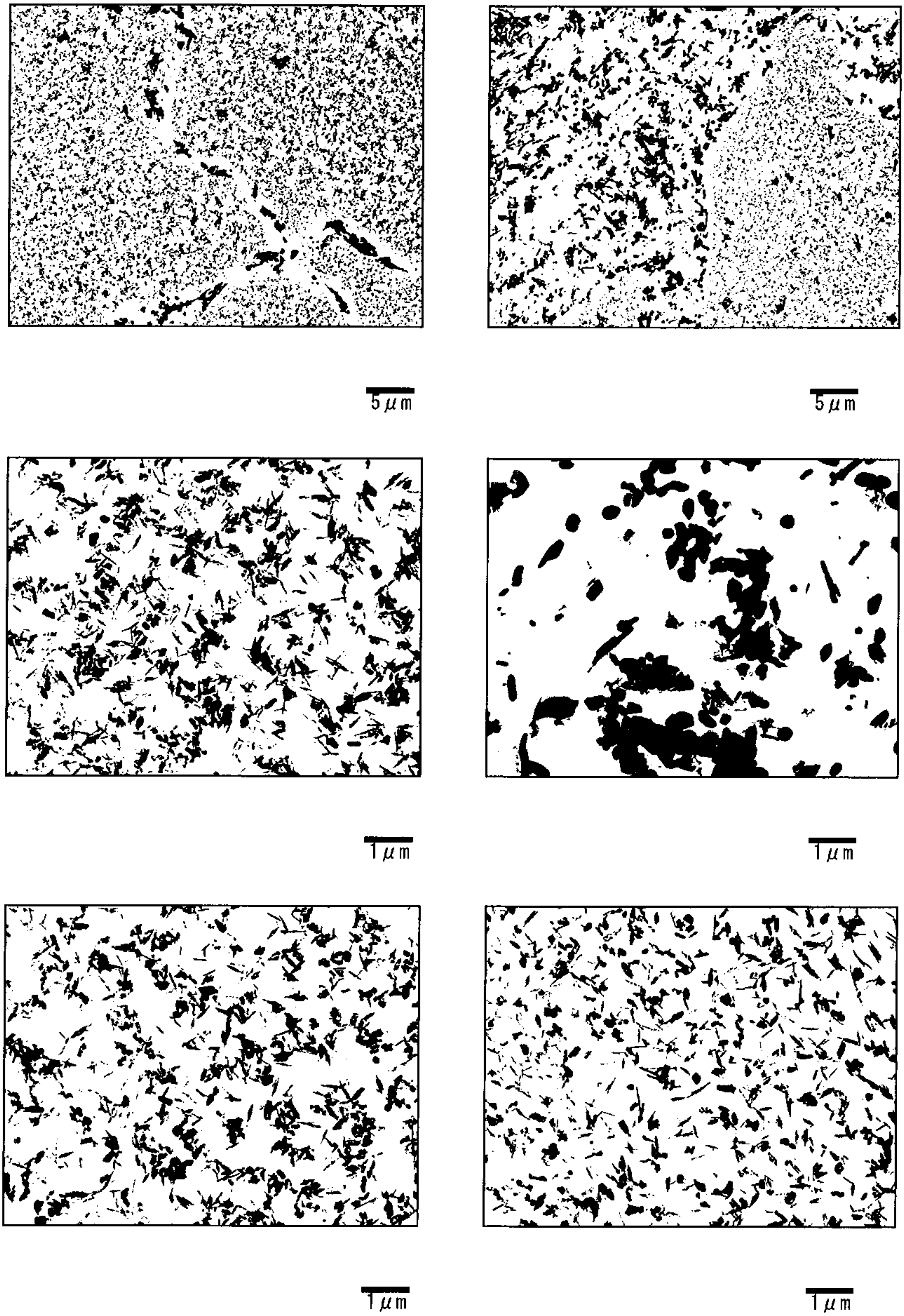


Photo I -10-11 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left(Circumferential weld, intrados : Base metal)

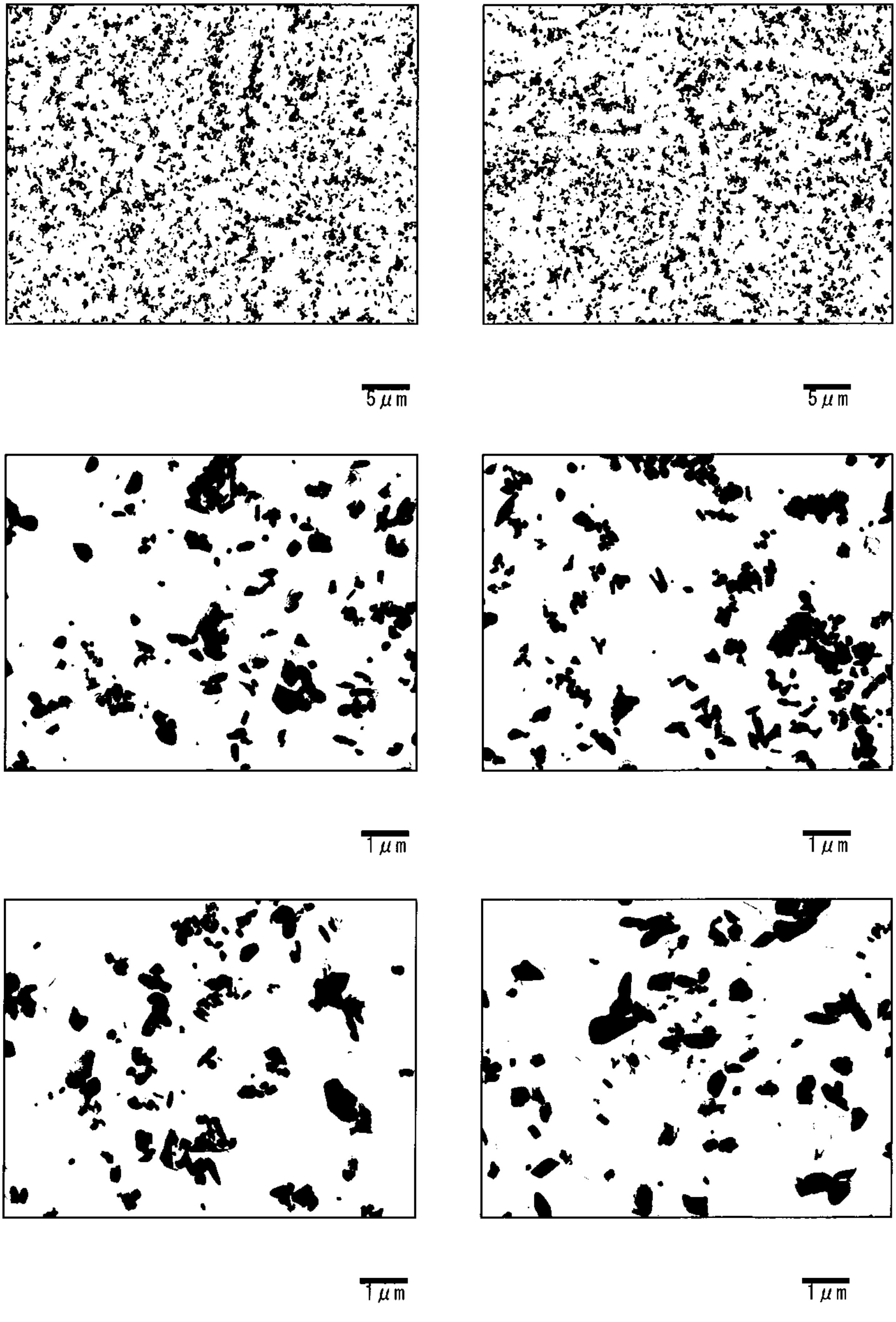


Photo I -10-12 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left (Circumferential weld, intrados : Fine grain HAZ)

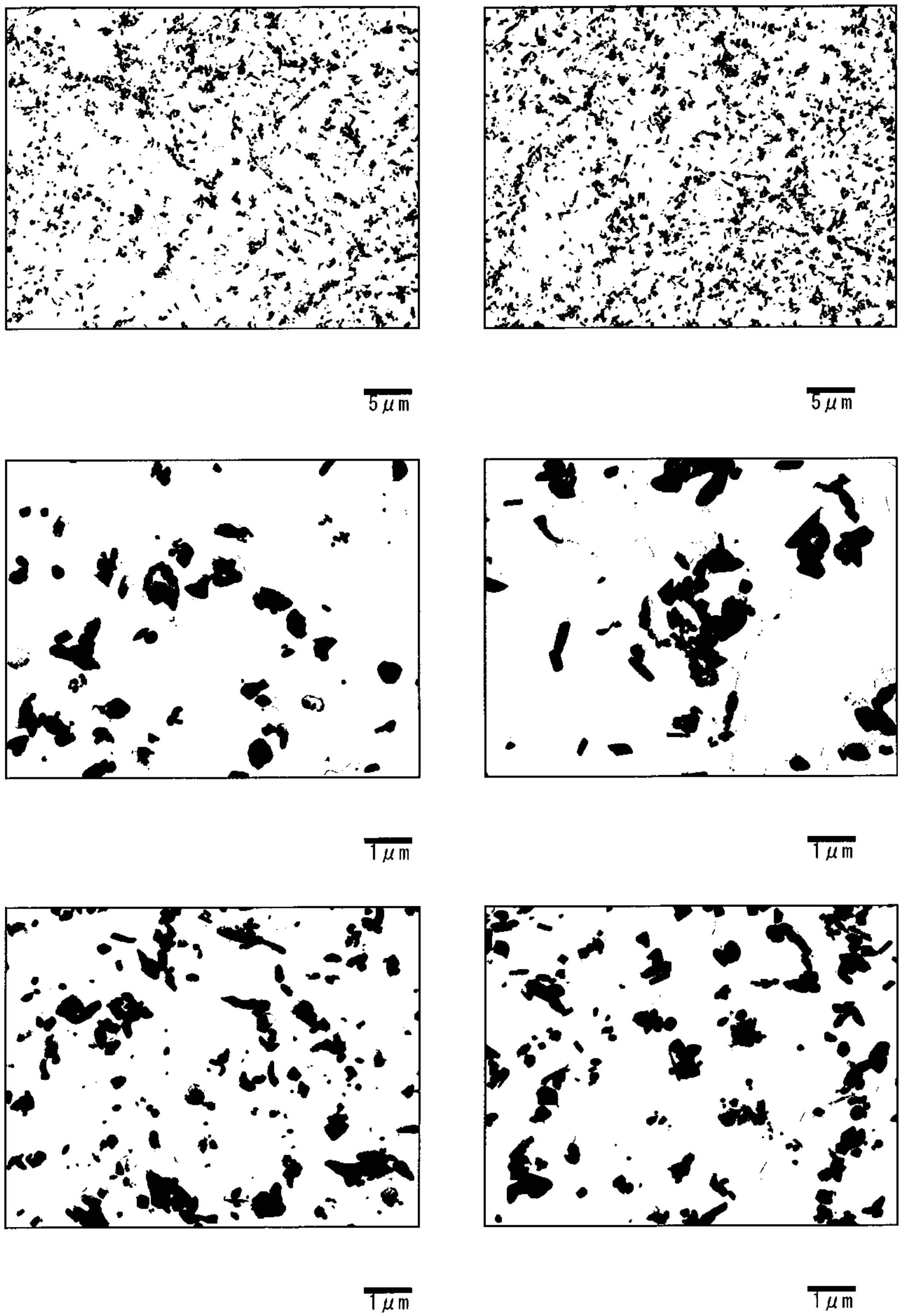


Photo I-10-13 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left (Circumferential weld, intrados : Coarse grain HAZ)

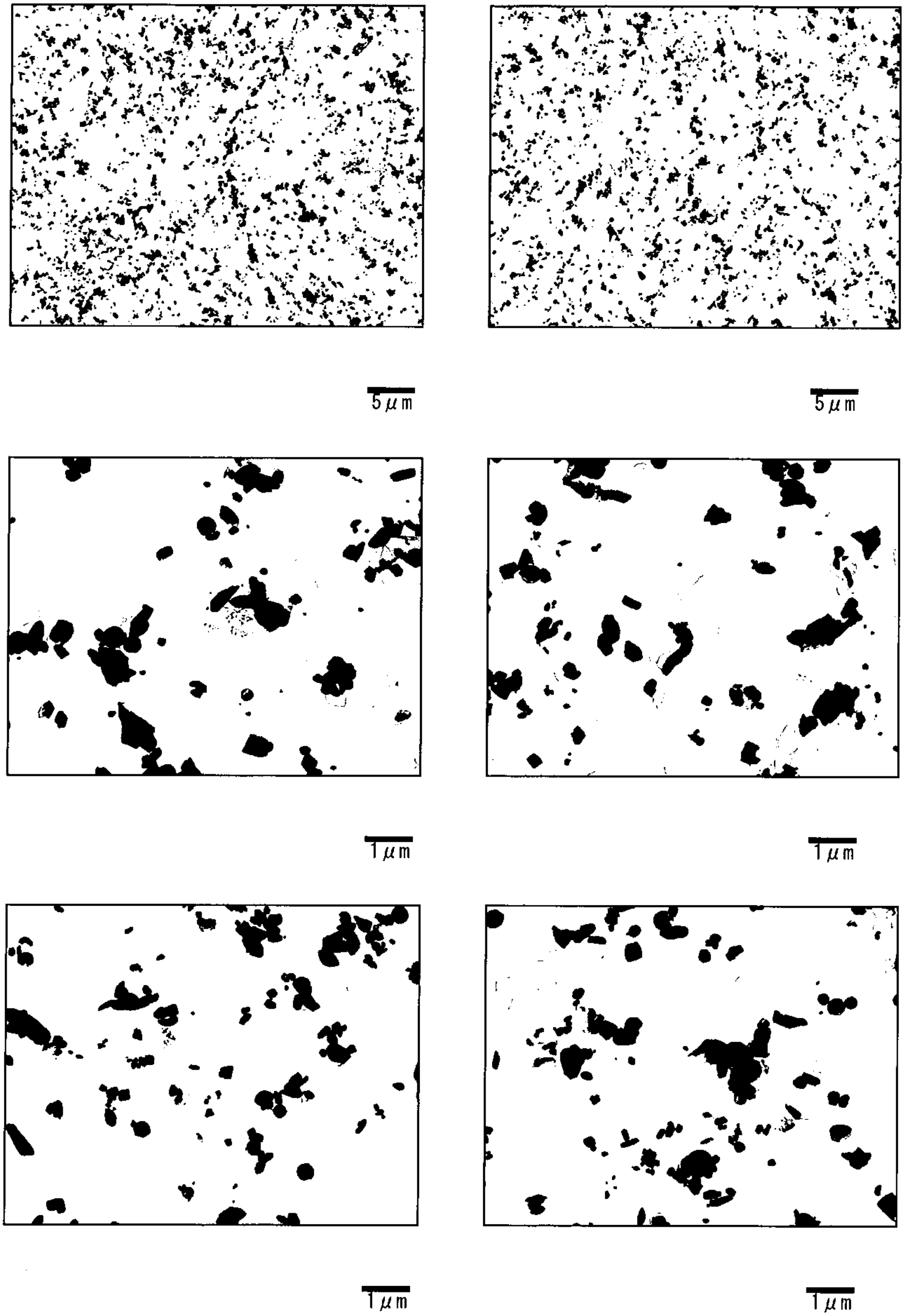


Photo I -10-14 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Left (Circumferential weld, intrados : Weld metal)

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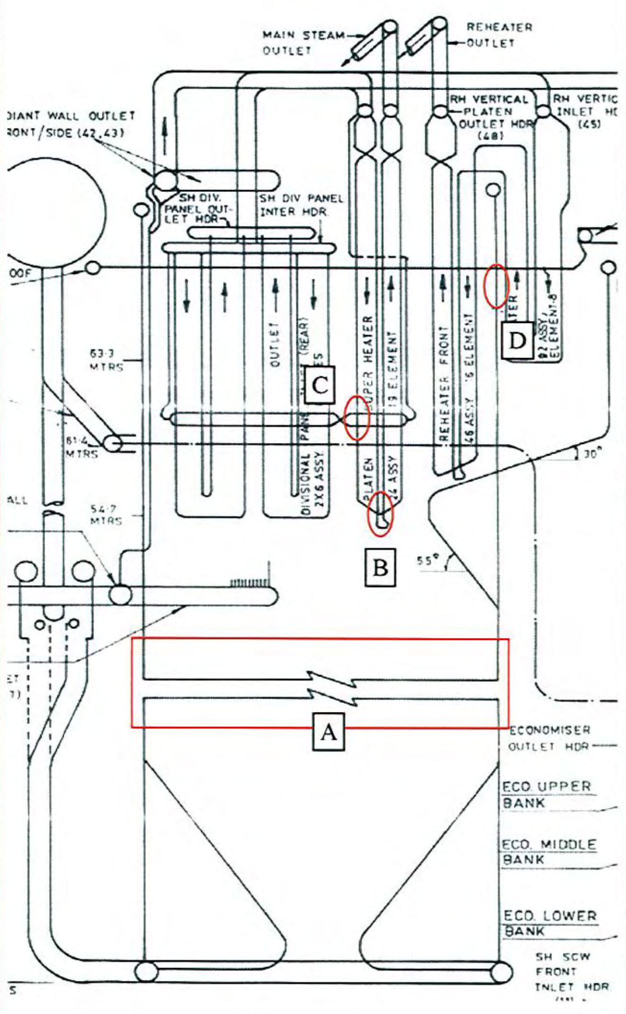
Table I -12 Singrauli #6 Boiler findings by visual inspection



Finding portion

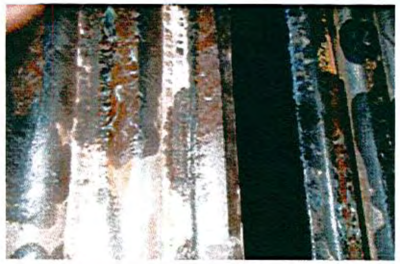
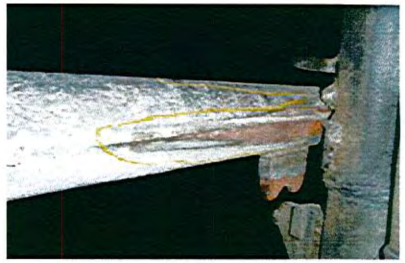
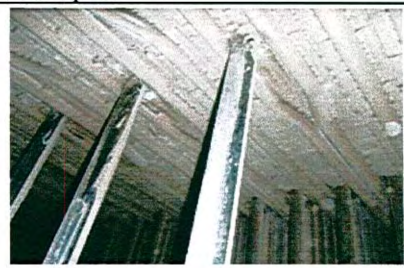
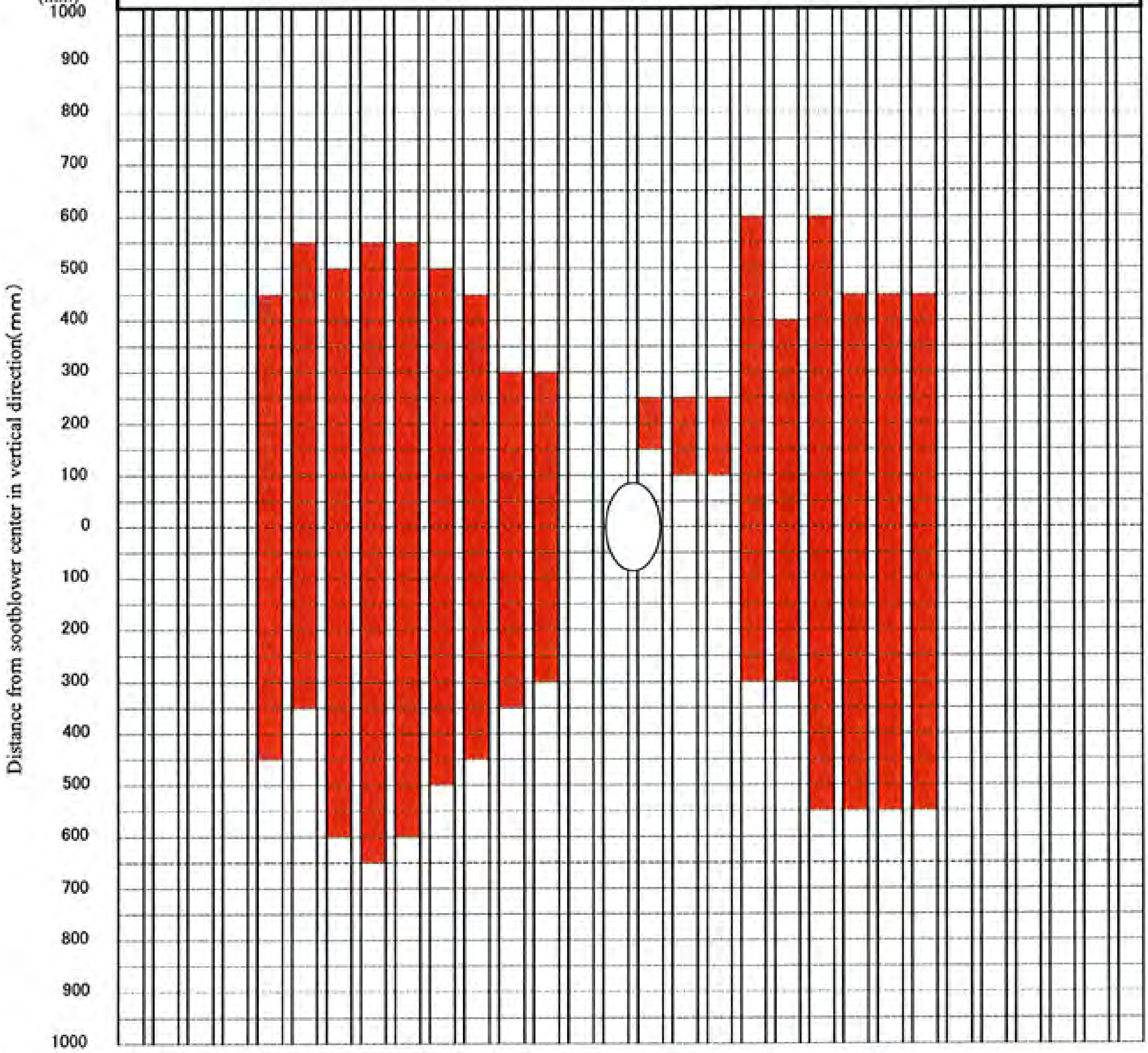
A: Erosion of water wall around short soot blowe	
・Erosion of a number of tubes around short soot blowe (Thickness measurement conducted) 〔Min. measured value〕 Min. 3.7mm (2nd blower in forntwal first from right	
B: Platen-SH Attrition of binding tube #4 and #5 (Min.2.8mm)	
・Attrition of binding tube #4 and #5 with each othe 〔Min. measured value〕 Min.2.8mm φ63.5* 6.5mm SA213 TP347H (Normal portion: 6.5mm)	
C: Attrition of cooling spacer tube with front tube of #14 pane	
・Attrition of a cooling spacer tube with front tube of #14 pane (Thickness measurement conducted) 〔Min. measured value〕 Min.5.0mm	
D: Erosion of screen tubes near the ceiling between front RH panel and rear RH pane	
・Erosion of screen tubes at front side near the ceiling were found at left side of boiler. (Thickness measurement not conducted)	

Table I -13 (Singrauli) WATER WALL Front wall Thickness Measurement Results

Tube number from sootblower center veiwed from furnace inside

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Min. value in thin portion (mm)					5.3	5.4	4.9	4.5	4.4	3.7	4.1	5.2	3.8			4.3	4.9	5.3	4.0	5.4	4.2	4.2	4.3	4.4						



Tube specification: SA210Gr.C φ51.0×t5.6(tsr5.5mm)

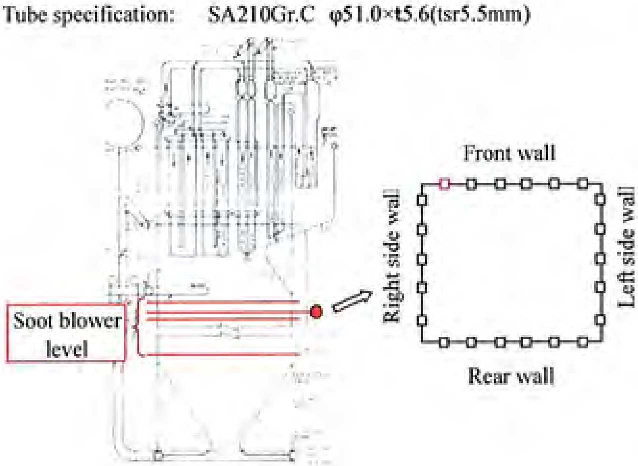
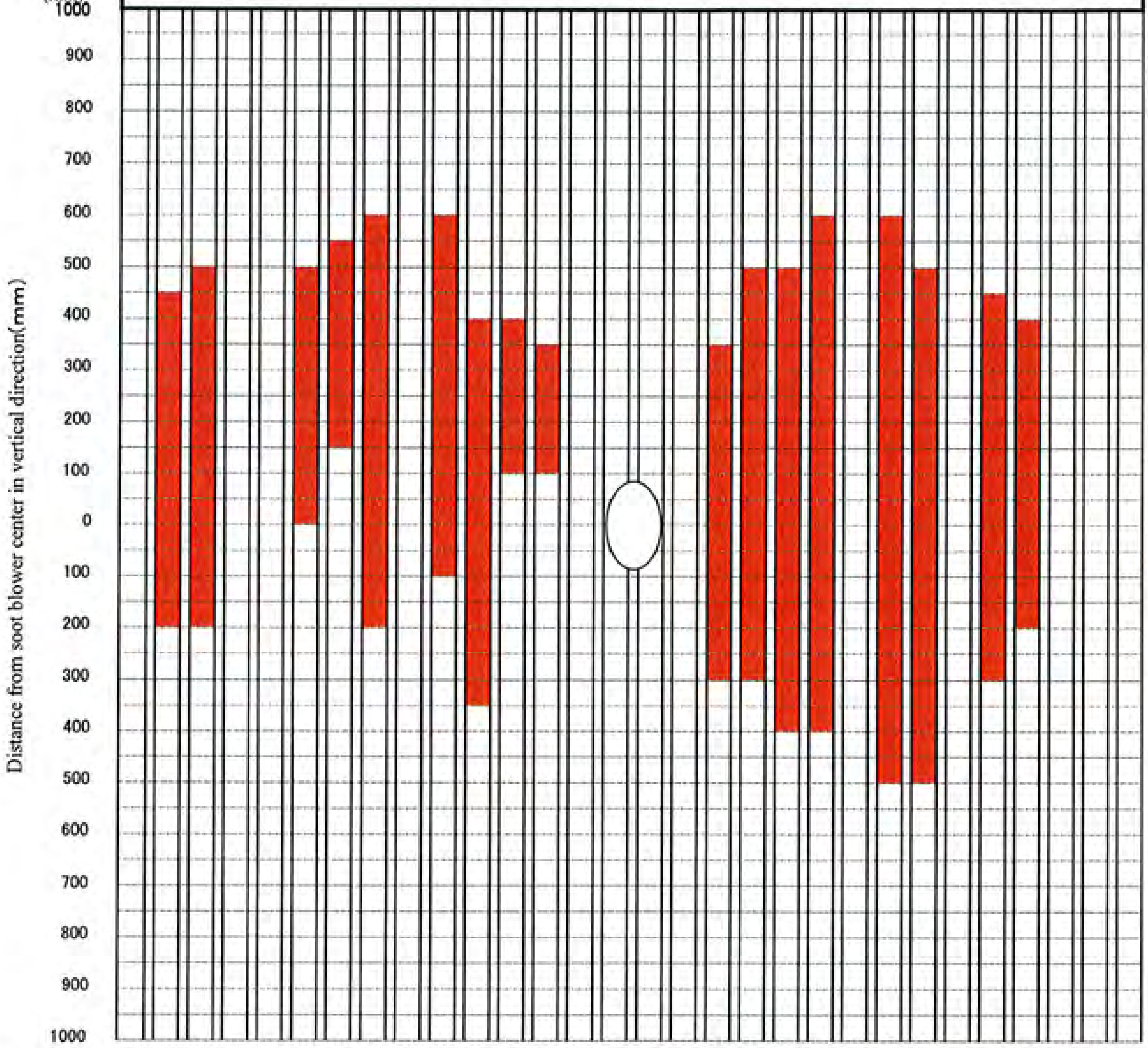


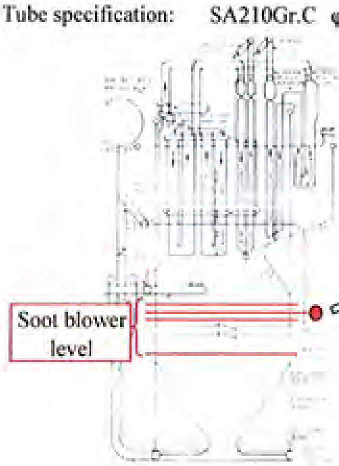
Table I -14 (Singrauli) WATER WALL Rear wall Thickness Measurement Results

Tube number from soot blower center veiwed from furnace inside

Tube number	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Min. value in thin portion (mm)		5.1	5.8			5.7	5.4	5.0		4.9	5.6	5.5	5.4					5.2	4.3	4.3	4.6		4.3	3.9		4.9	5.1			



Tube specification: SA210Gr.C φ51.0×t5.6(tsr5.5mm)



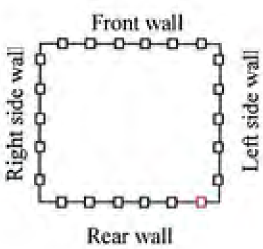
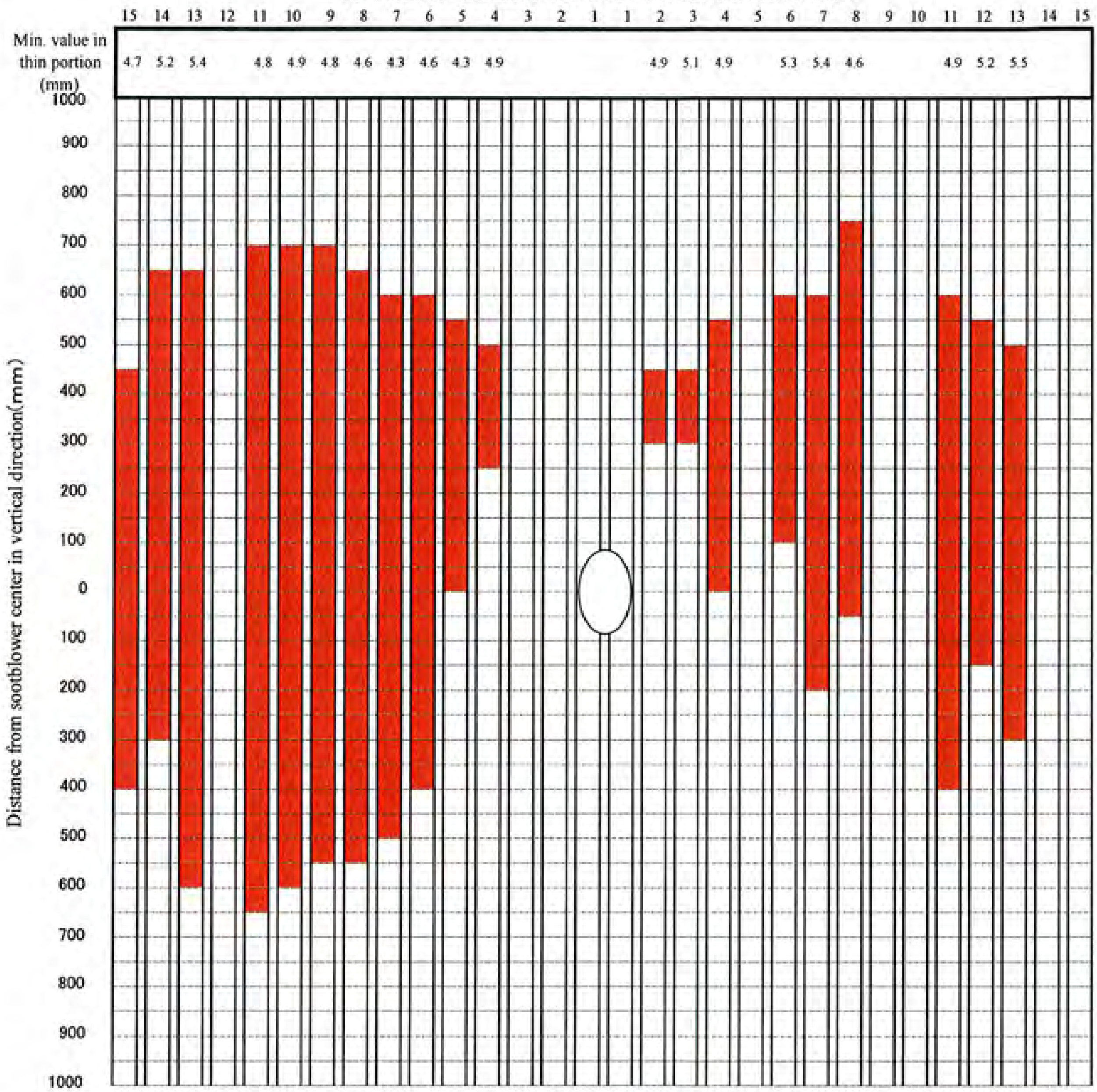


Table Ⅰ-15 (Singrauli) WATER WALL Left side wall Thickness Measurement Results



Tube specification: SA210Gr.C φ51.0×t5.6(tsr5.5mm)

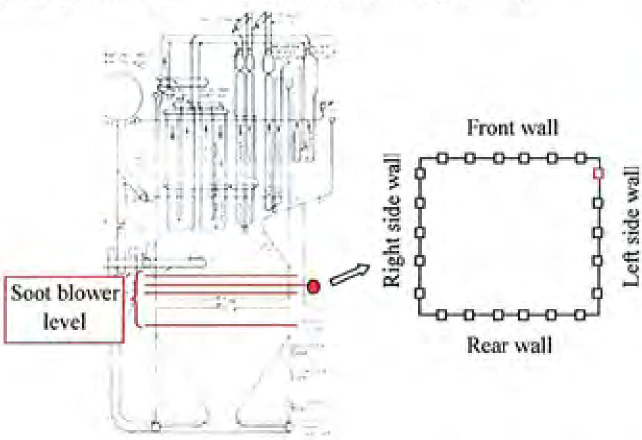
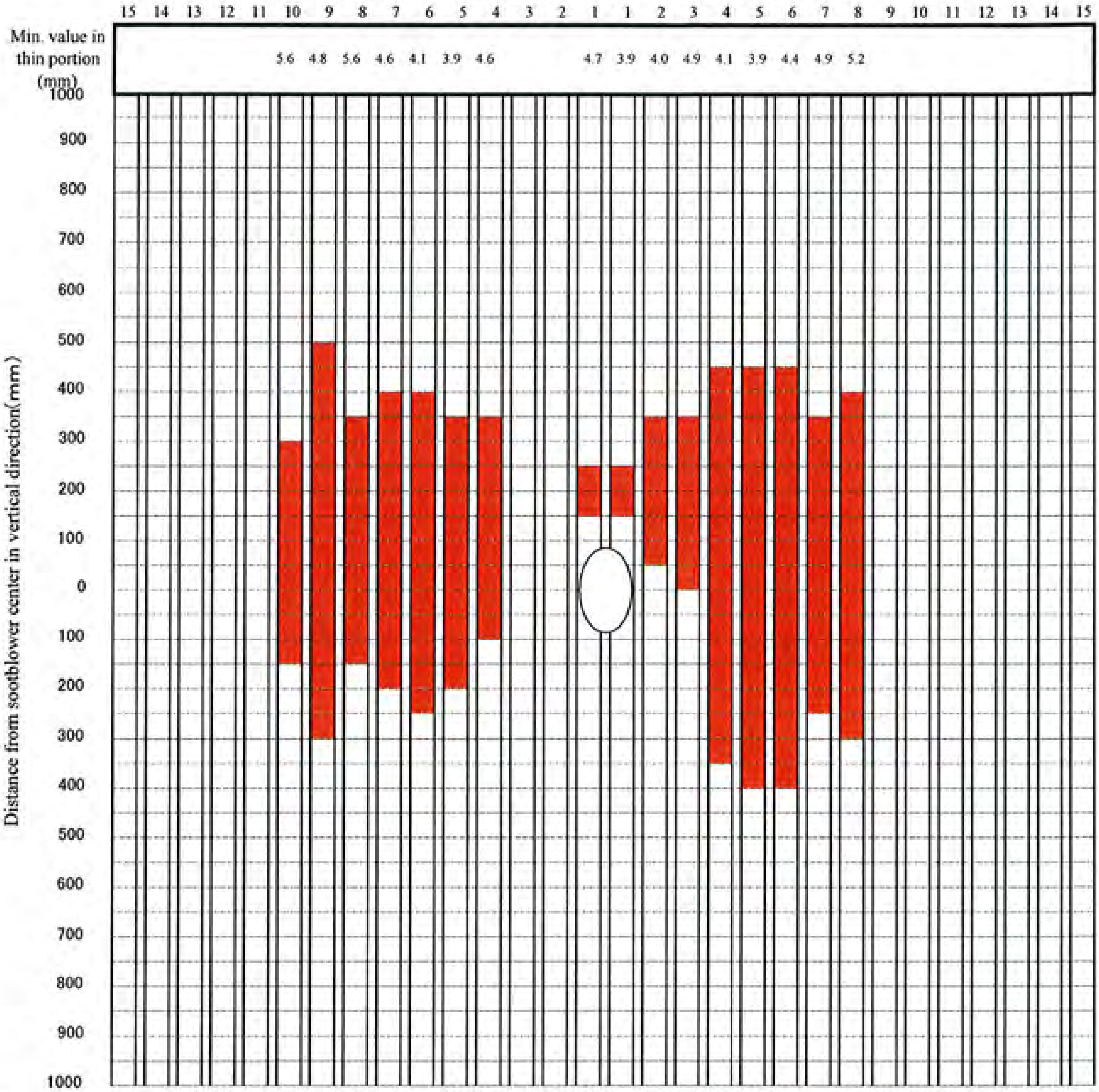


Table Ⅰ-16 (Singrauli)WATER WALL Rightt side wall Thickness Measurement Results



Tube specification: SA210Gr.C φ51.0×t5.6(tsr5.5mm)

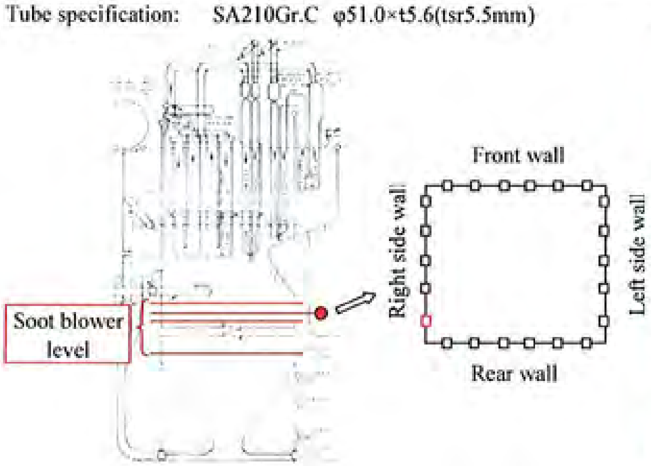
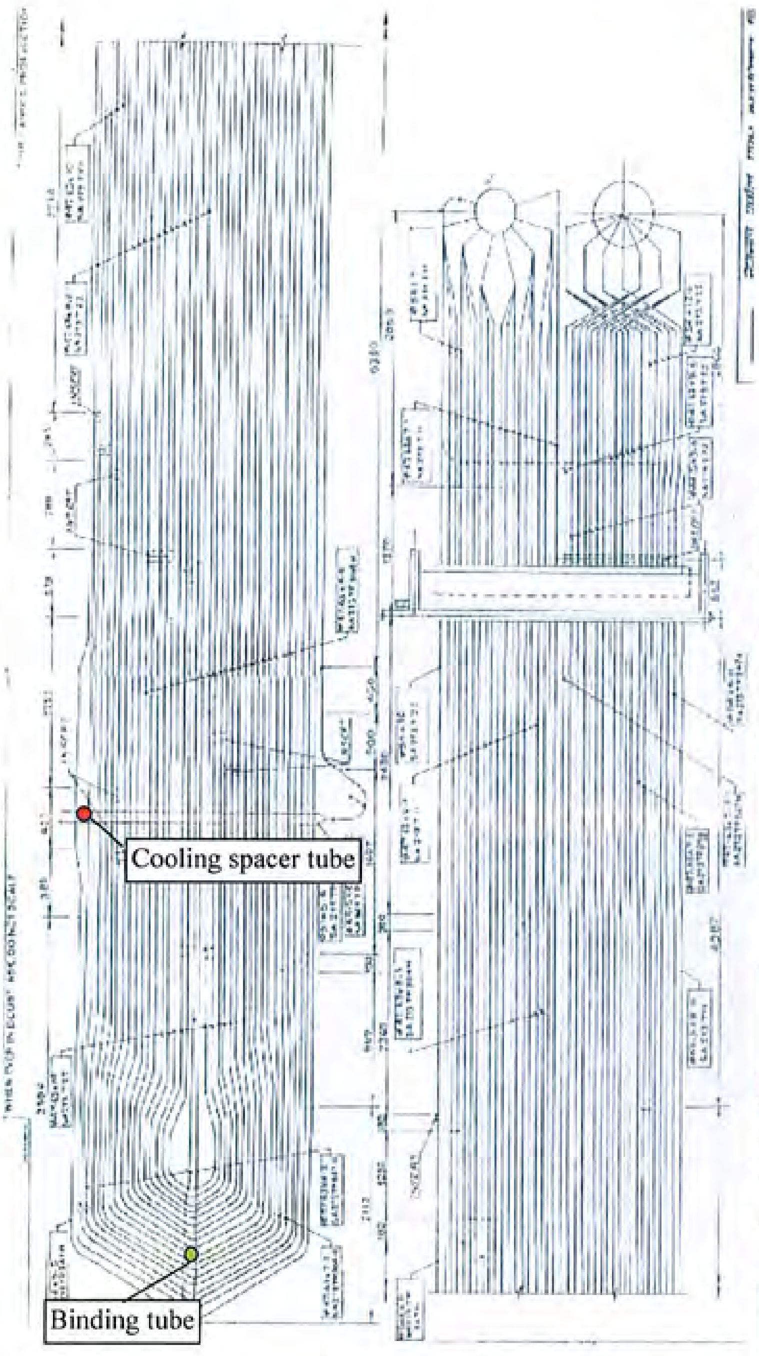


Table Ⅰ-17 (Singrauli) Platen SH Thickness Measurement Results

Binding tube: SA213TP347H φ47.63×t6.3
Cooling spacer tube:



Binding tube

Panel No. (From left)	Thin point	Normal point
4R	2.8	6.5
5L	3.3	6.6

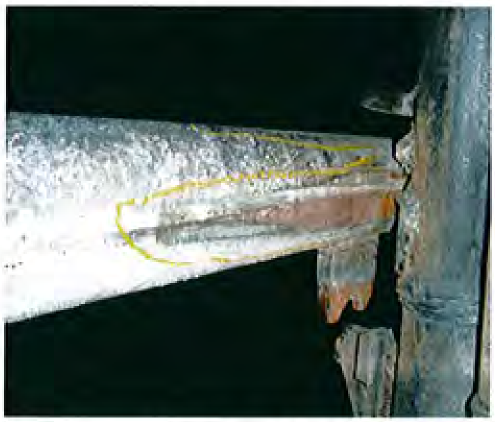
(unit: mm)

Cooling spacer tube

Attrition point with front tube of #14	5.0

(unit: mm)

Thining portion of binding tube



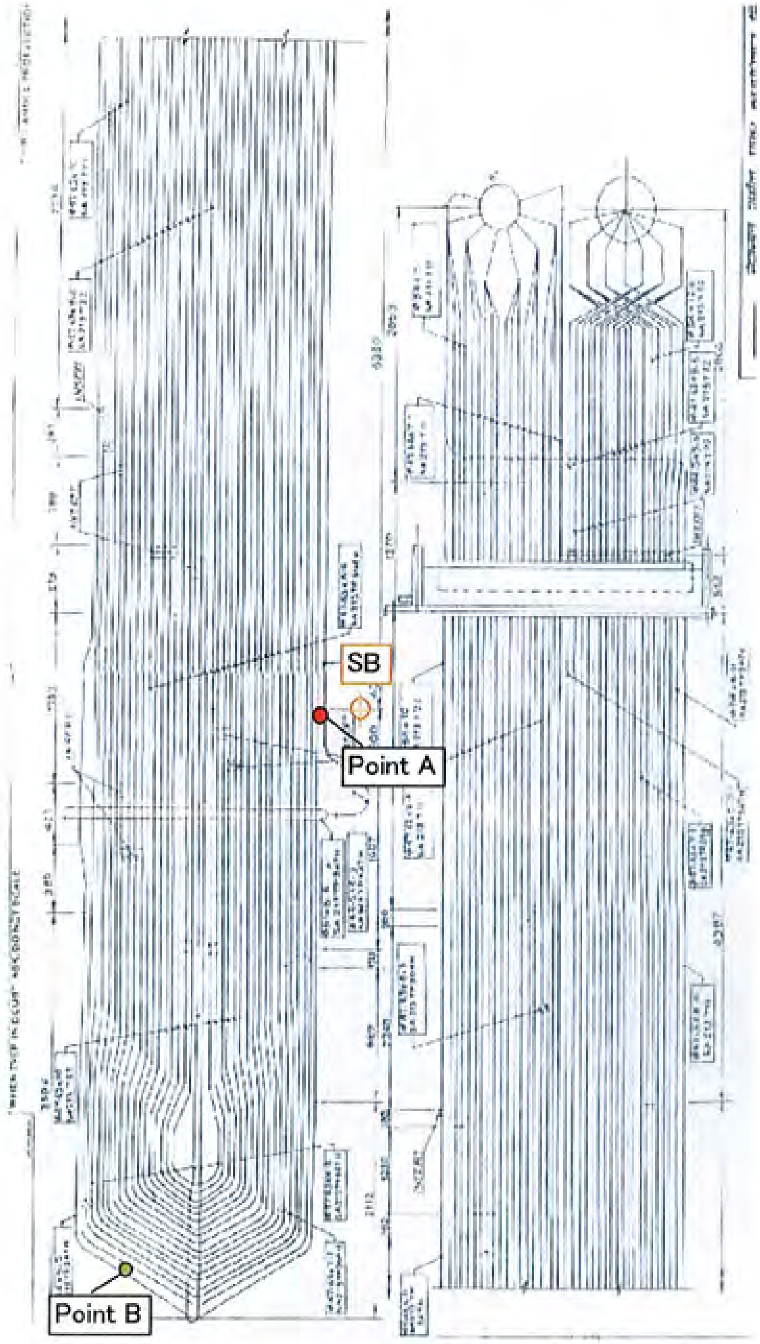
Thining portion of cooling spacer tube

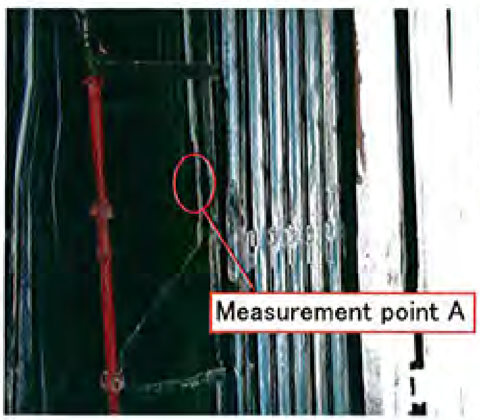
Table Ⅰ-18 (Singrauli) Platen SH Thickness Measurement Results

Tube specification Point A: SA213TP347H φ63.5×t6.3
Point B: SA213TP347H φ54.0×t9.5

Panel No. (From left)	Point A ●	Point B ●
1	6.5	10.2
2	6.6	10.0
3	6.5	10.0
4	6.6	10.3
5	6.6	10.0
6	6.5	10.4
7	6.8	10.4
8	6.5	10.4
9	6.7	10.5
10	6.5	10.1
11	6.7	10.5
12	6.3	9.8
13	6.4	10.2
14	7.2	10.0
15	6.3	10.0
16	6.4	10.2
17	6.4	10.1
18	6.9	10.4
19	6.6	9.9
20	6.5	10.1
21	7.1	10.0
22	6.4	10.0
23	6.5	10.3
24	6.5	10.1

(unit: mm)





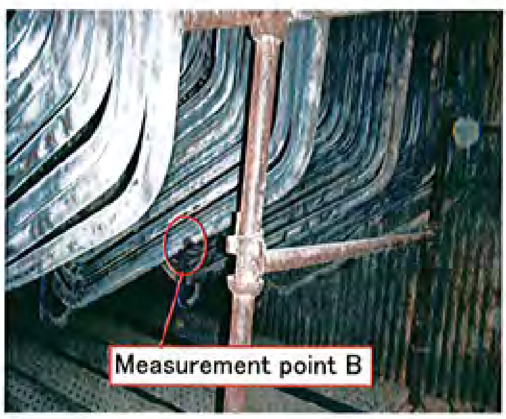
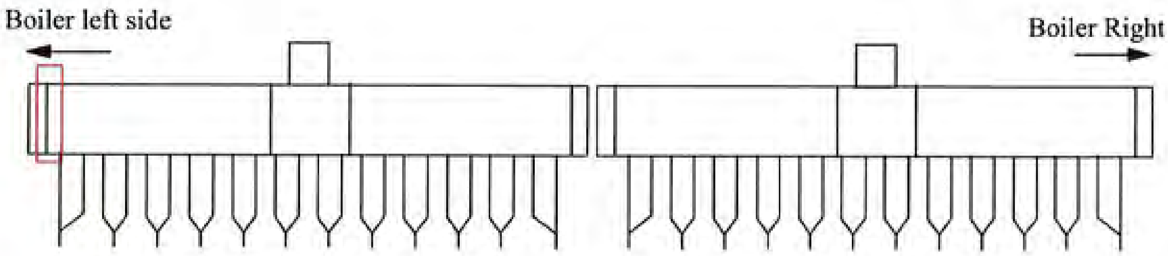
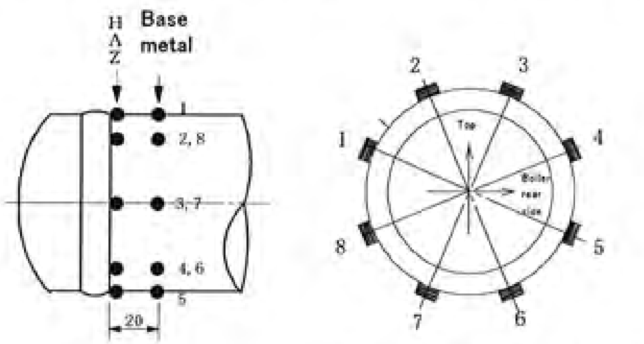


Table I -19 (Singrauli) PLATEN-SH Outlet Header Outside Diameter Measurement Results

Components	Material	Designed OD	Position	Region	Measured value (mm)				Averaged (mm)	(Averaged measured value-Designed OD) /Designed OD(%)
					1⇔5	2⇔6	3⇔7	4⇔8		
PLATEN SH Outlet Header	SA335 P-12	508.0mm	(Header side)	Base metal	508.03	508.36	508.75	508.95	508.52	+0.10
				HAZ	506.82	508.35	507.85	508.42	507.86	-0.03

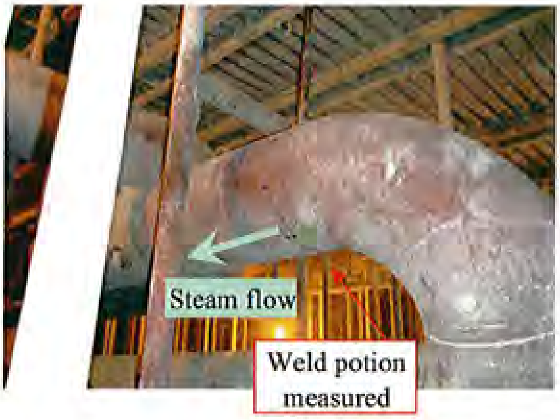




View from boiler right side

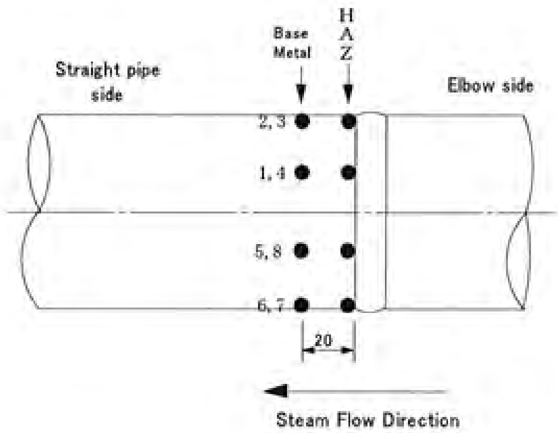
Table I -20 (Singrauli) De-Superheater Pipe Outside Diameter Measurement Results

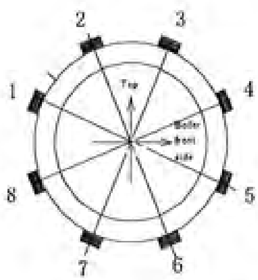
Components	Material	Designed OD	Position	Region	Measured value (mm)				Averaged (mm)	(Averaged measured value-Designed OD) /Designed OD(%)
					1⇔5	2⇔6	3⇔7	4⇔8		
De-Superheater Pipe (Right)	SA335 P-12	508.0mm	Downstream side (Straight pipe side)	Base metal	513.22	513.21	512.02	512.72	512.79	+0.94
				HAZ	511.85	512.35	511.80	511.60	511.90	+0.77
De-Superheater Pipe (Left)	SA335 P-12	508.0mm	Downstream side (Straight pipe side)	Base metal	509.87	511.60	511.41	510.32	510.80	+0.55
				HAZ	509.17	511.25	511.37	510.06	510.46	+0.48



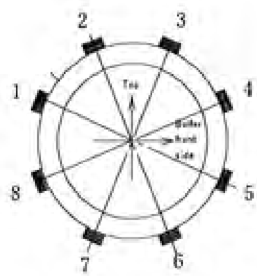
Measurement point of right De-superheater pipe

Measurement point of left De-superheater pipe





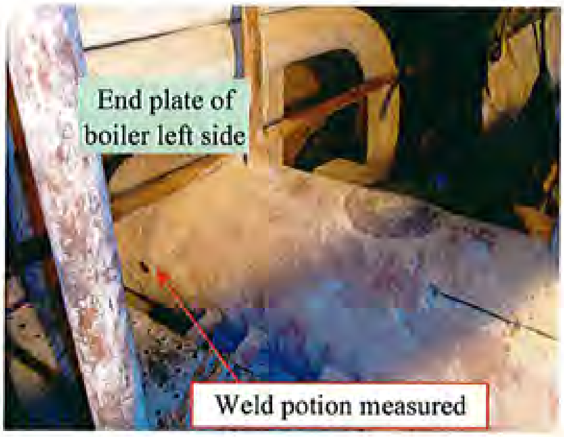
Right side: View from downstream



Left side: View from upstream

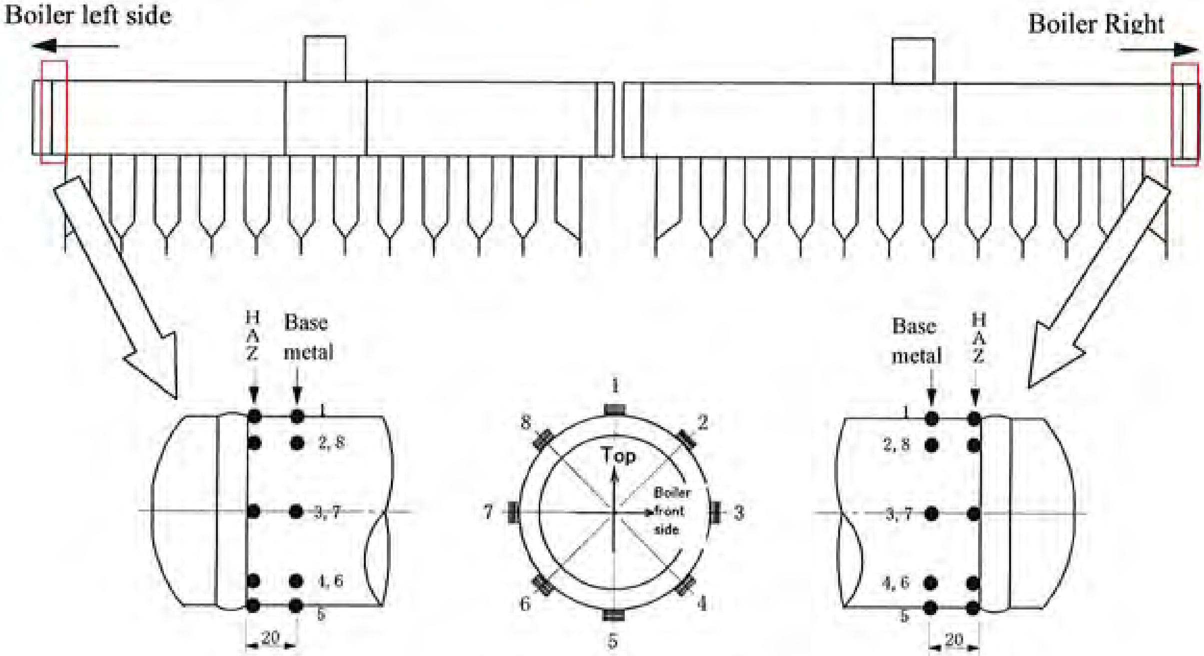
Table I -21 (Singrauli) Re-Heater Outlet Header Outside Diameter Measurement Results

Components	Material	Designed OD	Position	Region	Measured value (mm)				Averaged (mm)	(Averaged measured value-Designed OD) /Designed OD(%)
					1⇔5	2⇔6	3⇔7	4⇔8		
Re-Heater Outlet Header(Right)	SA335 P-22	558.8mm	(Header side)	Base metal	561.16	561.31	562.16	562.16	561.70	+0.52
				HAZ	560.33	561.16	562.05	561.88	561.36	+0.46
Re-Heater Outlet Header(Left)	SA335 P-22	558.8mm	(Header side)	Base metal	560.40	560.68	561.21	561.10	560.85	+0.37
				HAZ	559.47	560.64	560.55	561.00	560.42	+0.29



Measurement point of left RH outlet header

Measurement point of right RH outlet header

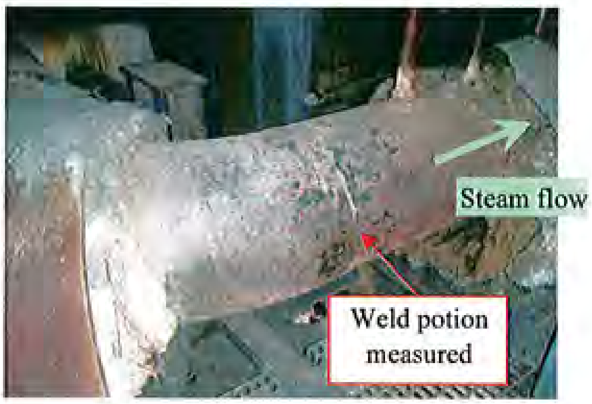


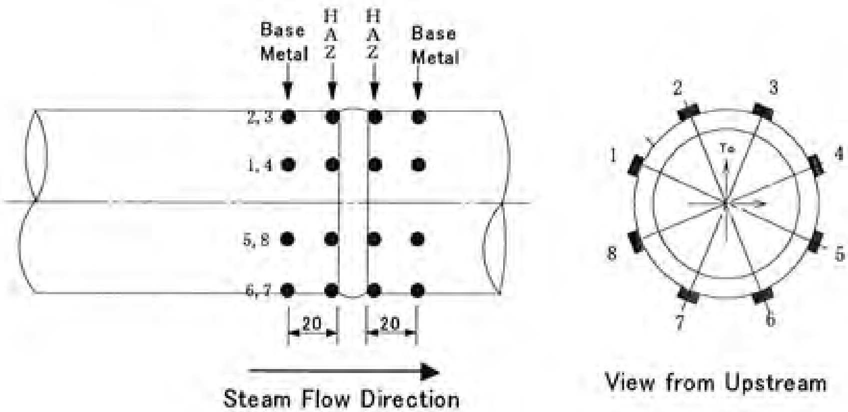
View from boiler left side

Table I -22 (Singrauli) Main Steam Pipe Outside Diameter Measurement Results

Components	Material	Designed OD	Position	Region	Measured value (mm)				Averaged (mm)	(Averaged measured value-Designed OD) /Designed OD(%)
					1⇔5	2⇔6	3⇔7	4⇔8		
MSP	SA335 P-22	520.0mm	Upstream side (Elbow side)	Base metal	521.45	525.17	527.46	531.70	526.45	+1.24*
				HAZ	520.20	520.80	522.38	521.84	521.31	+0.25*
			Downstream side (Straight pipe	Base metal	520.15	520.19	520.58	520.79	520.43	+0.08
				HAZ	520.15	520.52	519.92	520.61	520.30	+0.06

*: Upstream side value is reference because of elbow side.





Sample tube inspection 〔Singrauli #6〕

Sample tube inspection and creep rupture test were carried out as one of the boiler residual life assessment items for Singrauli Super Thermal Power Station #6 unit. The results are reported as follows.

1. Unit for evaluation

Singrauli Super Thermal Power Station #6 unit

2. Sample tube for inspection

- Platen-SH tube
- RH tube (Penthouse portion, Furnace portion)

3. Operation condition

(1) Cumulative operation hours:	172,000	hours
(2) Cumulative start and stop times:	309	times

4. Summary of inspection results

(1) As a result of tube appearance observation after acid cleaning, traces of corrosion at outside surface and slightly rough condition at inside surface were observed for each sample tube.

(2) As a result of tube dimension measurement, OD of RH tubes in penthouse and in furnace was less than designed value, the thickness of RH tubes in penthouse was less than designed value.

(3) As a result of steam oxide scale examination, steam oxide scale was adhering evenly by cross sectional observation for RH tube in penthouse and in furnace, unevenly for Platen-SH tube.
Average thickness of steam oxide scale mainly consisting of Fe and O was remarkably larger in RH tube (in penthouse) than in Platen-SH tube and RH tube (in furnace).

(4) As a result of hardness measurement, the hardness values were stable in circumferential direction,though measured values were out of the normal value of virgin material by Japanese steel manufacturer.

(5) As a result of creep rupture test, the evaluated residual life of Platen-SH tube was 290,000 hours for base metal, 150,000hours for weld joint at equivalent temperature 553℃ estimated by comparison with the average creep rupture data of NIMS.
The evaluated residual life of RH tube in furnace was 670,000 hours for base metal and 610,000 hours for weld joint at equivalent temperature 551℃ estimated by comparison with the average creep rupture data of NIMS.
Each portion has enough evaluated residual life at present, with the min. evaluated residual life of 150,000 hours for weld joint portion of Platen-SH tube.

(6) As a result of microstructure comparison method, the evaluated residual life was 82,000 hours for RH tube (in furnace), 520,000 hours for RH tube (in penthouse) and 1,300,000 hours for Platen-SH tube.

5. Sample tube specification

Sample tube specification is shown in Table I -30.

Table I -30 Sample tube specification

Sample	Material	Designed OD×t(mm)	Designed Temperature(℃)	Designed Pressure (MPa)
Platen-SH #12-3	SA213T11※	φ47.63×t8.6	Not available	17.46
	SA213T11	φ47.63×t10.0	Not available	
RH #3-1 (in penthouse)	SA213T22※	φ54.0×t5.6	540	5.27
	SA213T22	φ54.0×t5.6	540	
RH #14-5 (in furnace)	SA213T22	φ54.0×t4.5	Not available	5.27
	SA213T11※	φ54.0×t4.0	Not available	

※ : Chemical composition analysis was conducted as shown below.
The material of Platen-SH#12-3 appeared to be SA213T11 by chemical composition analysis, though the material specification was supposed to be SA213T22 for Platen-SH#12-3 according to the drawing.

Chemical composition analysis results by spark discharge optical emission analysis (wt%)

Sample tube	C	Si	Mn	P	S	Cr	Mo
Platen-SH#12-3	0.10	0.53	0.38	0.026	0.012	1.14	0.46
RH #3-1 (in penthouse)	0.10	0.28	0.45	0.013	0.008	2.20	0.95
RH #14-5 (in furnace)	0.10	0.67	0.41	0.006	0.008	1.30	0.58
SA213T11 (JIS-STBA23)	≦0.15	0.50～1.00	0.30～0.60	≦0.030	≦0.030	1.00～1.50	0.45～0.65
SA213T22 (JIS-STBA24)	≦0.15	≦0.50	0.30～0.60	≦0.030	≦0.030	1.90～2.60	0.87～1.13

2/2

6. Inspection item and inspected portion

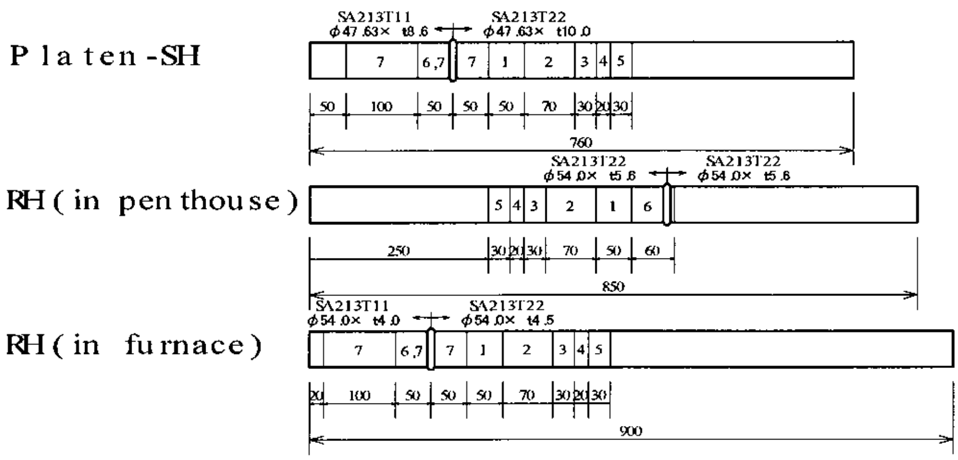
Inspection item and inspected portion are shown in Table I -31.

Table I -31 Inspection item

Sample tube	Inspection item						
	1	2	3	4	5	6	7
	Outer surface appearance	Internal surface appearance	Tube dimension・Hardness	Metallography	Scale analysis	RLA by microstructure degradation	Creep rupture test
Platen-SH	○	○	○	○	○	○	○
RH(in penthouse)	○	○	○	○	○	○	–
RH(in furnace)	○	○	○	○	○	○	○

Sample tube appearance and sampling location are shown in Photo I -11.

Sampling portion for each inspection item is shown in Fig I -11.



1: Outer surface appearance 2: Internal surface appearance 3: Tube dimension・Hardness 4: Metallography

5: Scale thickness, EPMA analysis, 6: RLA by microstructural comparison method 7: Creep rupture test

Fig I -11 Sampling portion for each inspection item

7. **Inspection results**

(1) Tube appearance

a. Tube appearance from outside (Photo I -12)

- Hard oxide scale was adhering for each sample tube outer surface, with light brown color in Platen-SH tube, red brown color in RH tube (penthouse) and dark brown color in RH tube (furnace).
- Traces of corrosion were observed in each sample tube outside surface after acid cleaning.

b. Tube appearances of sample tubes from inside after removal of steam oxide scale (Photo I -13～18)

(Platen SH tube)

- Internal surface of both front and rear side were covered with gray and red color steam oxide scale.
- Slight rough internal surface was observed after acid cleaning.

(RH tube （in penthouse, furnace）)

- Internal surface of both front and rear side were covered with gray color steam oxide scale with scale exfoliation partially observed on rear side.
- Slightly rough internal surface was observed after acid cleaning.

(2) Tube dimension measurement (Table I -32, Fig I -12)

a. OD measurement

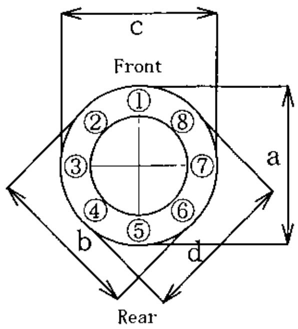
OD of RH tubes in penthouse and furnace were measured to be less than designed values.

b. Thickness measurement

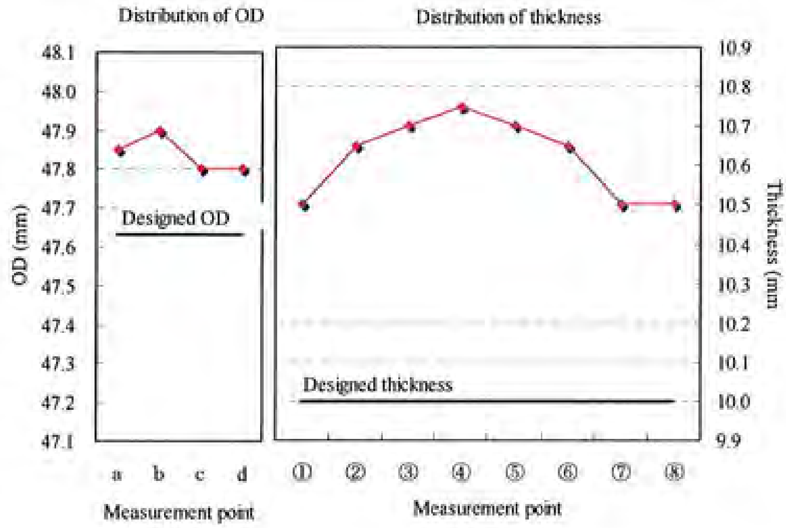
Thickness of RH tubes in penthouse was measured to be less than designed values.

Table I -32　Tube dimension measurement results

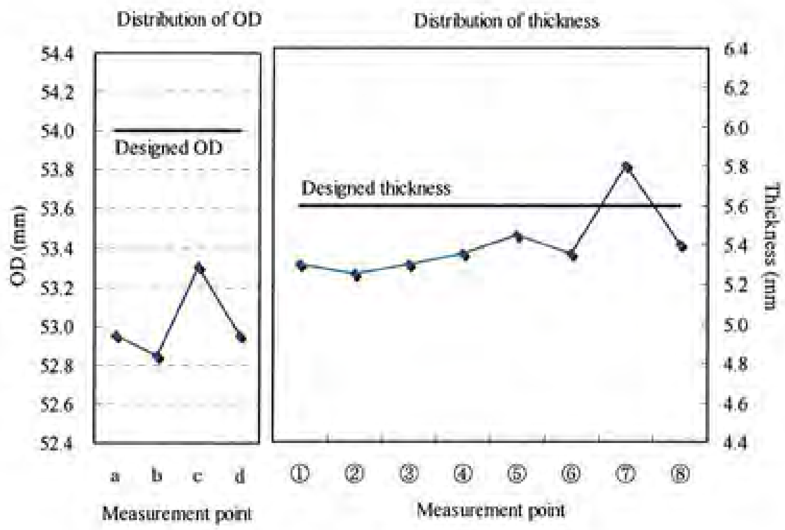
Sample tube	Specification	OD (mm)			Thickness (mm)							
		Direction	OD	ID	①	②	③	④	⑤	⑥	⑦	⑧
Platen-SH	Φ47.63×t10.0	a	47.85	26.60	10.50				10.70			
		b	47.90	26.60		10.65				10.65		
		c	47.80	26.60			10.70				10.50	
		d	47.80	26.60				10.75				10.50
RH(in penthouse)	Φ54.0×t5.6	a	52.95	42.25	5.30				5.45			
		b	52.85	42.25		5.25				5.35		
		c	53.30	42.15			5.30				5.80	
		d	52.95	42.15				5.35				5.40
RH(in furnace)	Φ54.0×t4.5	a	53.75	43.65	5.10				5.05			
		b	54.00	43.95		4.95				5.10		
		c	54.00	43.95			4.90				5.20	
		d	53.75	43.65				4.95				5.15



Platen-SH



RH(in penthouse)



RH(in furnace)

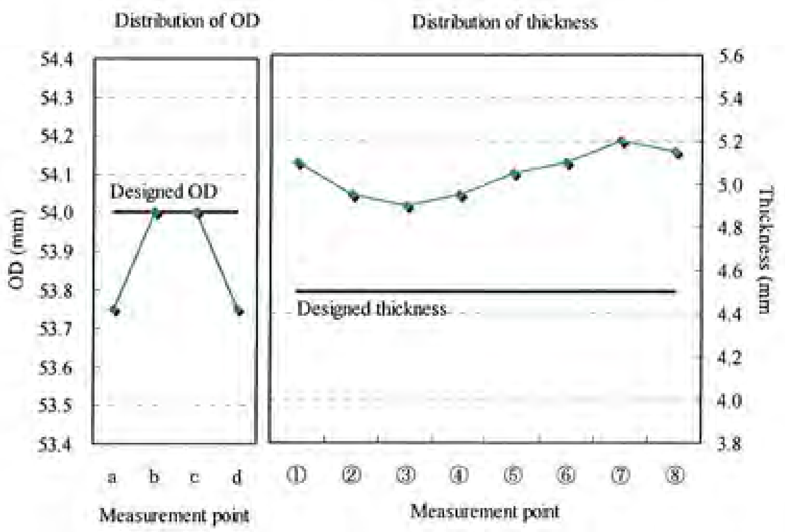


Fig I -12 Tube dimension measurement results

(3) Steam oxide scale adhesion on internal surface

a. Cross sectional observation of internal surface (Photo I -19)

(Platen SH tube)

- Steam oxide scale was adhering unevenly by cross sectional observation.
- Corrosion in metal surface was observed with rugged interface between steam oxide scale and metal.

(RH tube in penthouse)

- Steam oxide scale was adhering evenly by cross sectional observation with dual layer consisting of dense inner layer and slightly porous outer layer.

(RH tube in furnace)

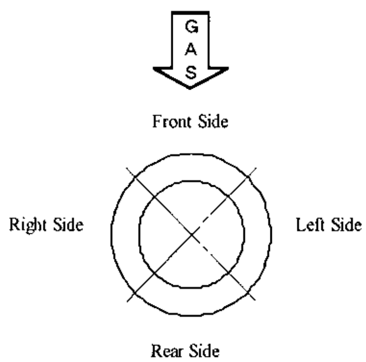
- Steam oxide scale was adhering evenly by cross sectional observation with the thicker scale on left and right side surfaces than the scale on front and rear side.

b. Thickness measurement of steam oxide scale on internal surface (Table I -33)

Average thickness of steam oxide scale was remarkably larger in RH tube (in penthouse) than in Platen-SH tube and RH tube (in furnace).

Table I -33 Steam oxide scale thickness measurement results

Sample tube	Position	Scale thickness (μ m)	
		Average among 90°range	Max. among 90° range
Platen-SH	Front Side	89.2	109.8
	Right Side	85.3	102.4
	Rear Side	74.7	96.8
	Left Side	82.8	125.0
RH (in penthouse)	Front Side	439.6	475.7
	Right Side	447.9	479.0
	Rear Side	381.4	453.0
	Left Side	458.0	476.0
RH (in furnace)	Front Side	32.9	41.9
	Right Side	68.9	96.8
	Rear Side	65.4	90.3
	Left Side	34.5	41.3



c. EPMA analysis of steam oxide scale on internal surface (Fig. I -13～24, Table I -34)

Mainly iron oxide scale was formed since Fe and O were remarkably detected.

- In Platen-SH tube, Fe, Cr and Mo were detected as tube material elements and O, P, Ca, Zn as the other detected elements.
- In RH tube (in penthouse), Fe, Cr and Mo were detected as tube material elements, and O as the other detected element.
- In RH tube (in furnace), Fe, Cr and Mo were detected as tube material elements, and O, P, Na, Mn as the other detected element.

Table I -34 Elements detected by EPMA analysis

Sample tube	Position	Element													
		O	S	P	N	Na	Si	Ca	Mn	Fe	Ti	Cr	Ni	Zn	Mo
Platen-SH	Front Side	■		■				■		■		■		■	■
	Right Side	■		■				■		■		■		■	■
	Rear Side	■		■				■		■		■		■	■
	Left Side	■		■				■		■		■		■	■
RH (in penthouse)	Front Side	■								■		■			■
	Right Side	■								■		■			■
	Rear Side	■								■		■			■
	Left Side	■								■		■			■
RH (in furnace)	Front Side	■								■		■			■
	Right Side	■								■		■			■
	Rear Side	■		■		■			■	■		■			■
	Left Side	■								■		■			■

■ : Elements detected clearly

(4) Hardness measurement (Fig. I -25～24, Table I -35)

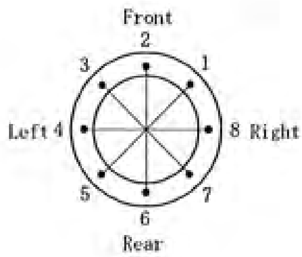
- The hardness of RH tube (in penthouse, SA213T22) was lower than the normal value of virgin material by Japanese steel manufacturer.
- The hardness of Platen-SH tube (SA213T11) and RH tube (in furnace, SA213T11) were higher than the normal value of virgin material by Japanese steel manufacturer.

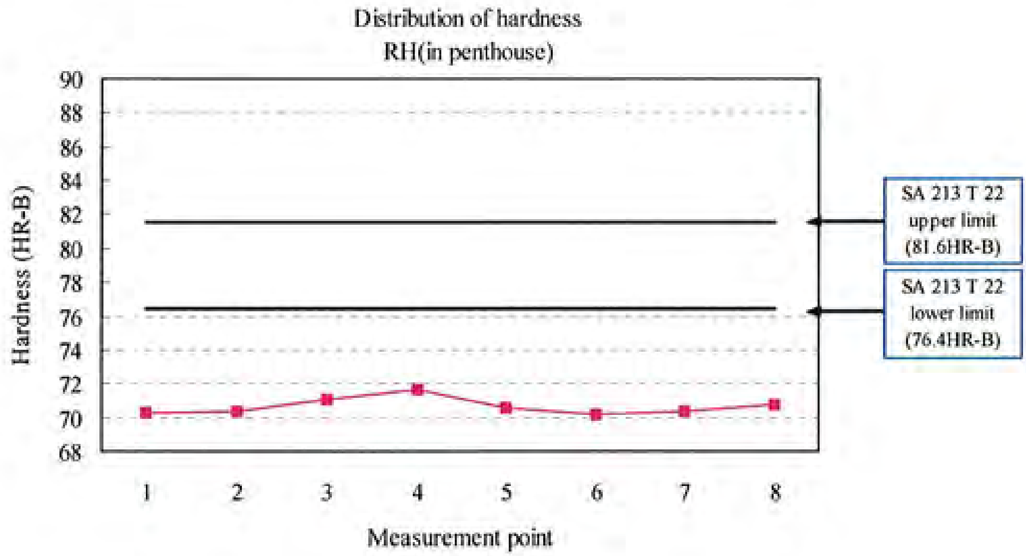
Table I -35 Hardness measurement results

(unit:HR-B)

Sample tube	Marterial	1	2	3	4	5	6	7	8
Platen-SH	SA 213 T 11	88	88	86	86	87	87	88	87
RH (in penthouse)	SA 213 T 22	70	70	71	72	71	70	70	71
RH (in furnace)	SA 213 T 11	81	82	83	82	82	82	83	82

Hardness value of vigin material by fabricator : SA 213 T 22;76.4～81.6(HR-B)
SA 213 T 11;73.4～78.4(HR-B)





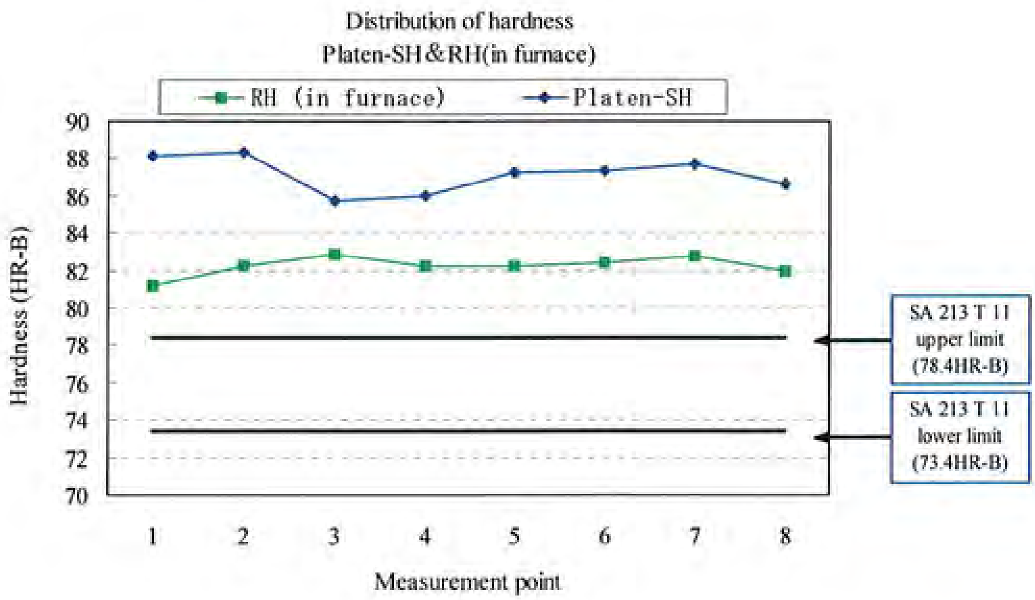


Fig I -25 Hardness measurement results

(5) Metallographic observation

Microstructure observation results at cross section of sample tube were shown in Photo I -20～25.

(Platen-SH tube (SA 213 T11))

- Microstructural degradation with disintegration of pearlite structure and precipitation in ferrite grain was not observed.

(RH tube in penthouse and furnace (SA 213 T11))

- Microstructural degradation with disintegration of pearlite structure was observed.

(6) Creep rupture test

a. Test condition

The creep test condition is shown in Table I -36. The shape of test specimens is shown in Fig. I -26

3 specimens were cut out from each of base metal portion and weld portion in Platen-SH tube and RH tube(in furnace) with a set of three test conditions for each portion.

As the shape of test specimens, ϕ 6mm round bar specimen was applied for Platen-SH tube and arc shaped specimen with the weld reinforcement left for RH thin-walled tube (in furnace) .

Table I -36 Creep test condition

Sample tube	Portion	Material	Test condition		Shape of specimen
			Tem. (℃)	Stress (MPa)	
Platen-SH	Base Metal	SA213T11	665	49.0	φ6mm round bar
			665	63.7	
			700	38.3	
	Weld Metal	SA213T11	665	49.0	
			665	63.7	
			700	38.3	
RH(in furnace)	Base Metal	SA213T11	665	44.1	Arc shaped
			665	58.8	
			700	27.9	
	Weld Metal	SA213T11	665	44.1	
			665	58.8	
			700	27.9	

ϕ 6mm round bar　　Ark shaped

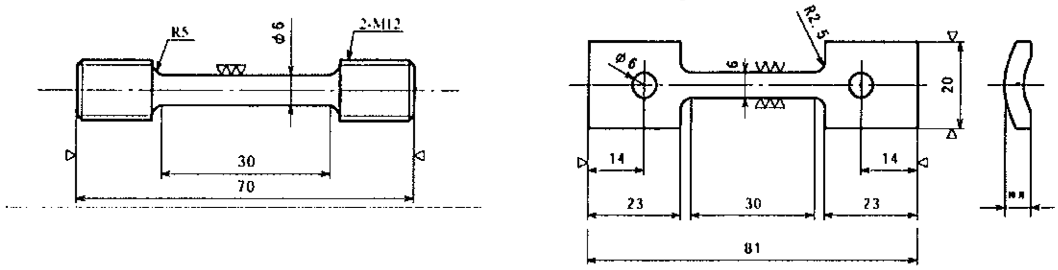
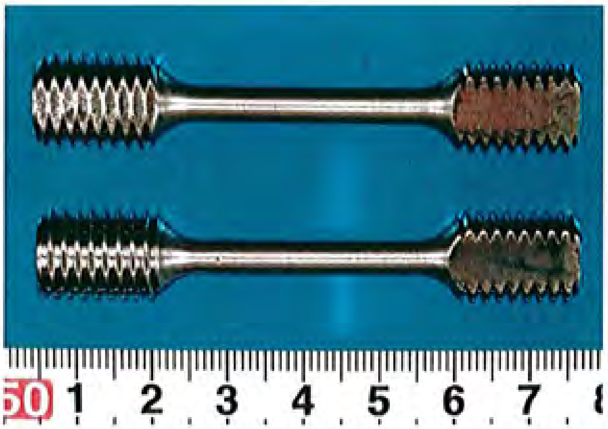


Fig I -26 Shape of creep rupture test specimens

Test specimens before and after creep rupture test in Platen-SH tube

Before machining ⇒

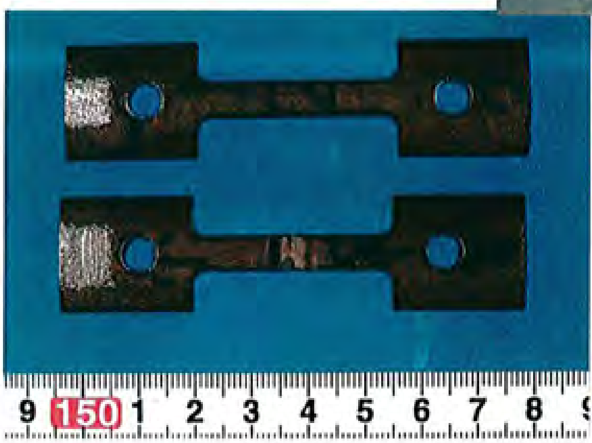


After machining ↑

After creep rupture test ↑

Test specimens before and after creep rupture test in RH tube (in furnace)

Before machining ⇒



After machining ↑

After creep rupture test ↑

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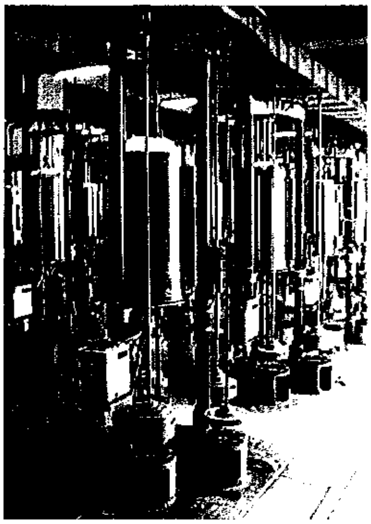
Creep rupture testing machine ⇒



b. Test results

Test result is shown in Table I -37-1. All specimens had ruptured for each test condition.

Table I -37-1 Creep rupture test results (Platen-SH)

Component		Material	Test condition Temp. T(℃)	Stress (MPa)	Rupture time t (h)	LMP* C=19.95	Fracture elongation (%)	Reduction of area (%)
Platen-SH	Base Metal	SA 213 T11	665	49.0	187.7	20,852	102	97
			665	63.7	48.7	20,302	87	94
			700	38.3	76.1	21,248	88	94
	Weld Metal	SA 213 T11	665	49.0	149.0	20,758	36	92
			665	63.7	39.0	20,212	44	92
			700	38.3	43.5	21,012	35	95

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

Table I -37-2 Creep rupture test results (RH in furnace)

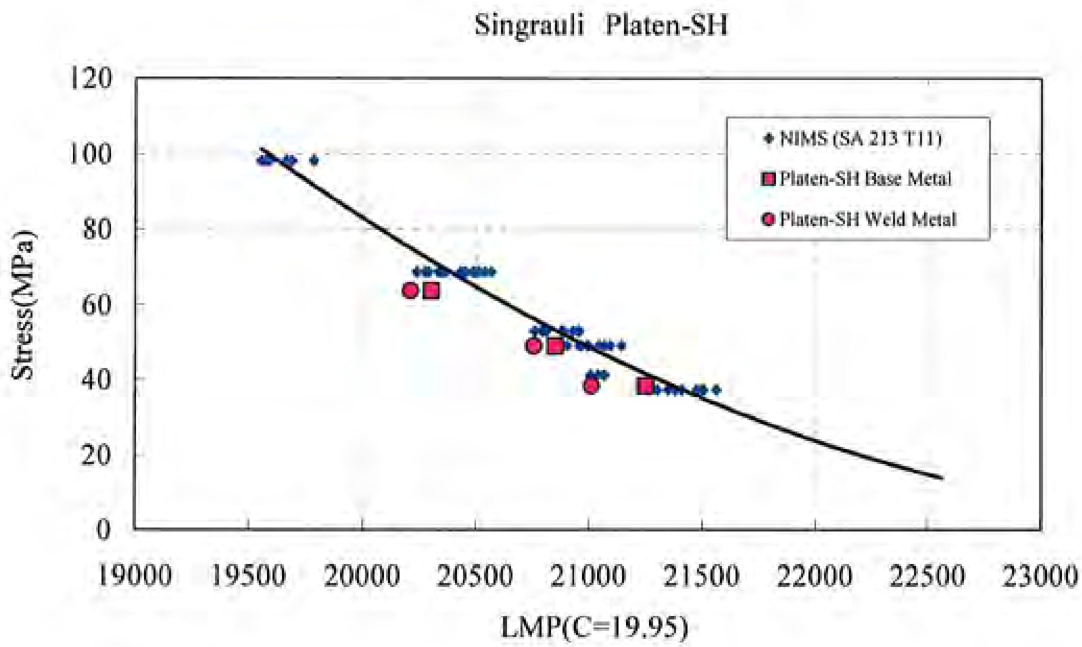
Component		Material	Test condition Temp. T(℃)	Stress (MPa)	Rupture time t (h)	LMP* C=17.52	Fracture elongation (%)	Reduction of area ** (%)
RH(in furnace)	Base Metal	SA 213 T11	665	44.1	457.0	18,933	53	57
			665	58.8	139.2	18,448	62	63
			700	27.9	319.4	19,488	39	55
	Weld Metal	SA 213 T11	665	44.1	310.9	18,776	20	52
			665	58.8	69.3	18,164	13	53
			700	27.9	296.8	19,457	16	56

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

** Reduction of area for RH tube is regarded as reference, because the value was evaluated by reduction of width of arc shaped specimen.

The comparison of the test results with the creep rupture data of virgin materials by NIMS (National Institute for Materials Science) is shown in Fig. I -27.

The test results for base metal and weld joint in Platen-SH tube indicate the lower creep rupture strength than NIMS data, and those in RH tube (in furnace) indicate almost same creep rupture strength as NIMS data.



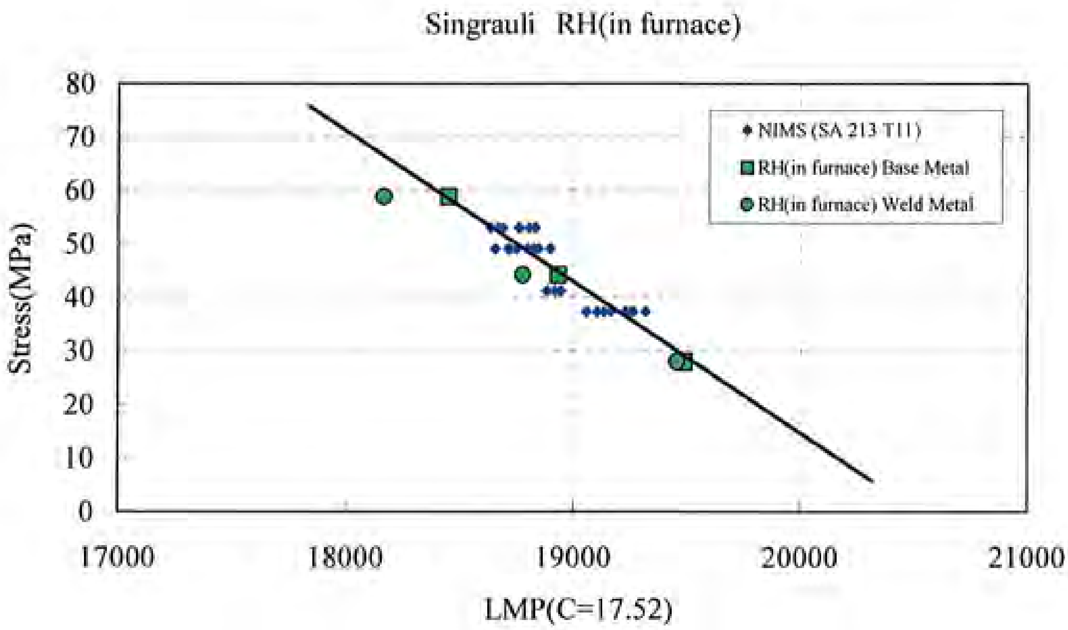


Fig I -27 The comparison of the test results with the creep rupture data of virgin materials by NIMS (National Institute for Materials science)

c. Residual life evaluation results

Residual life evaluation results of creep rupture test by parameter –method are shown in Table I -38.

The stress condition for the evaluation was calculated as the hoop stress with the measured OD, thickness of the test sample tube and the designed pressure. As for the temperature condition for the evaluation, two conditions were used for evaluation, those are the case of evaluation at the designed temperature and the other one at equivalent temperature estimated by comparison with the average creep rupture data of NIMS.

(Platen-SH tube)

The evaluated residual life (half of residual life evaluated by creep rupture test) of Platen-SH tube was 750,000 hours for base metal, 380,000 hours for weld joint portion at designed temperature 540℃of Platen-SH outlet header.

In case of evaluation at equivalent temperature 553℃, the evaluated residual life of Platen-SH tube was 290,000 hours for base metal, 150,000 hours for weld joint portion.

(RH tube in furnace)

The evaluated residual life (half of residual life evaluated by creep rupture test) of RH tube in furnace was 1,300,000 hours for base metal, 1,200,000 hours for weld joint portion at designed temperature 540℃ of RH outlet header.

In case of evaluation at equivalent temperature 551℃, the evaluated residual life of RH tube in furnace was 670,000 hours for base metal, 610,000 hours for weld joint portion.

Each portion has enough evaluated residual life at present, with the min. evaluated residual life of 150,000 hours for weld joint portion of Platen-SH tube.

Table I -38 Residual life evaluation results of creep rupture test by parameter –method

Parameter method (evaluated at designed temp.)								
Component		Material	Operation hours (h)	Hoop Stress (MPa)	Designed temp. (℃)	Residual life (h)	Creep life consumption ratio	Evaluated residual life (h)
Platen-SH	Base Metal	SA 213 T11	172,000	38.3	540(※1)	1,505,000	0.10	750,000
	Weld Metal	SA 213 T11	172,000	38.3	540(※1)	770,000	0.18	380,000
RH(in furnace)	Base Metal	SA 213 T11	172,000	27.9	540(※2)	2,783,000	0.06	1,300,000
	Weld Metal	SA 213 T11	172,000	27.9	540(※2)	2,549,000	0.06	1,200,000

Parameter method (evaluated at equivalent temp.)								
Component		Material	Operation hours (h)	Hoop Stress (MPa)	Equivalent temperature (℃)	Residual life (h)	Creep life consumption ratio	Evaluated residual life (h)
Platen-SH	Base Metal	SA 213 T11	172,000	38.3	553	598,000	0.22	290,000
	Weld Metal	SA 213 T11	172,000	38.3	553(※3)	309,000	0.36	150,000
RH(in furnace)	Base Metal	SA 213 T11	172,000	27.9	551	1,347,000	0.11	670,000
	Weld Metal	SA 213 T11	172,000	27.9	551(※3)	1,235,000	0.12	610,000

※1; Designed temp. at Platen-SH Outlet Header

※2; Designed temp. at RH Outlet Header

※3; Equivalent temperature evaluated at base metal

(7) Residual life assessment by microstructural comparison method

a. Platen-SH tube

(Microstructure observation)

The results of microstructure observation are shown in Photo I -26～30.

The summary of observation results is shown in Table I -39.

- Precipitates at gain boundary were observed in base metal, intercritical zone, fine grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates by SEM observation are shown in Photo I -31～32.

- Precipitates at gain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation of extracted replica)

The results of precipitates distribution observation by TEM observation are shown in Photo I -33～36.

The summary of observation results is shown in Table I -40.

- Fine needlelike precipitates had disappeared in base metal , fine grain HAZ, coarse grain HAZ and weld metal.
- Rod-shaped precipitates and attenuated plate-shaped precipitates were observed in fine grain HAZ.

b. RH tube (in penthouse)

(Microstructure observation)

The results of microstructure observation are shown in Photo I -37～41.

The summary of observation results is shown in Table I -39.

- Precipitates free zone along grain boundary was observed in base metal, intercritical zone and fine grain HAZ.
- Granular precipitates in grain were observed in each region..

(Grain boundary precipitates observation)

The results of grain boundary precipitates by SEM observation are shown in Photo I -42～43.

- Precipitates at gain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation of extracted replica)

The results of precipitates distribution observation by TEM observation are shown in Photo I -44～47.

The summary of observation results is shown in Table I -40.

- Precipitates free zone along grain boundary, rod-shaped precipitates and disintegration of pearlite structure were observed in base metal.
- Fine needlelike precipitates had disappeared in fine grain HAZ, coarse grain HAZ and weld metal.

c. RH tube (in furnace)

(Microstructure observation)

The results of microstructure observation are shown in Photo I -48～52.

The summary of observation results is shown in Table I -39.

- Precipitates at gain boundary were observed in base metal and fine grain HAZ.
- Granular precipitates in grain were observed in each region.
- Granular precipitates in grain were observed in each region.

(Grain boundary precipitates observation)

The results of grain boundary precipitates by SEM observation are shown in Photo I -53～54.

- Precipitates at gain boundary were observed in base metal and fine grain HAZ.

(Precipitates distribution observation of extracted replica)

The results of precipitates distribution observation by TEM observation are shown in Photo I -55～58.

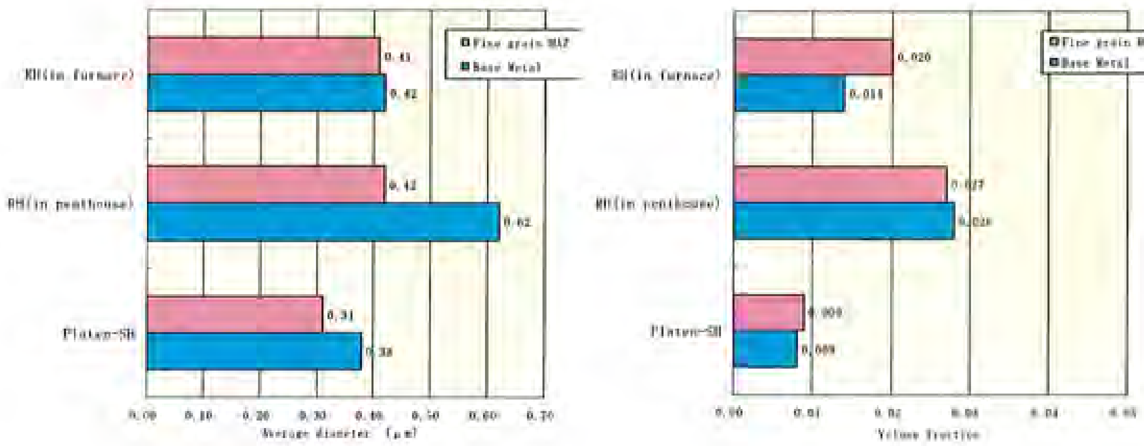
The summary of observation results is shown in Table I -40.

- Precipitates free zone along grain boundary was observed in base metal.
- Disintegration of pearlite like structure was observed in fine grain HAZ.
- Attenuated plate-shaped precipitates were observed in coarse grain HAZ.

d. Quantitative evaluation of grain boundary precipitates

The results of quantitative evaluation of grain boundary precipitates are shown in Table I -41.

- The max. value of average diameter of grain boundary precipitates was 0.62 μ m in base metal at RH tube(in penthouse), 0.42 μ m in fine grain HAZ at RH tube(in penthouse).
- The max. value of volume fraction of grain boundary precipitates was 0.028 in base metal at RH tube(in penthouse), 0.027 in fine grain HAZ at RH tube(in penthouse).



Quantitative evaluation of grain boundary precipitates〔extracted Table I -41〕

e. Quantitative evaluation of precipitates free band width along grain boundary

The results of quantitative evaluation of precipitates free band width along grain boundary are shown in Table I -42.

- The quantitative evaluation was focused on base metal of SA 213 T22 for RH tube (in penthouse).
- The precipitates free band width along grain boundary was 1.15 μ m.

f. Operational condition of residual life evaluation portion

Operational condition of evaluated components are shown in Table I -43.

The evaluation stress σ was the hoop stress calculated with designed pressure, designed diameter D and thickness t of each component.

$$\sigma = P(D-t) / 2t$$

where P : Designed pressure.

Table I -43 Operational condition of evaluated components

Component	Material	Operational condition				
		OD※1 mm	t※1 mm	Designed		Hoop Stress MPa
				Temperature※2 ℃	Pressure MPa	
Platen-SH	SA213T11	48.5	9.0	540	17.5	38.3
RH(in penthouse)	SA213T22	53.0	5.4	540	5.3	23.2
RH(in furnace)	SA213T11	53.9	5.1	540	5.3	25.2

※1 : Measured value

※2 : Designed temperature at Outlet Header

g. Residual life evaluation results by microstructure comparison method

Evaluation figures of residual life assessment for each components by microstructural comparison method are shown in Fig. I -28～30 and evaluation results are shown in Table I -44.

The highest creep life consumption ratio was evaluated at RH tube (in furnace) with 51% and evaluated residual creep life (half of residual life evaluated microstructure comparison method) was 82,000 hours.

Table I -44 Residual life evaluation results

Component	Material	Region	Residual life evaluation results		
			Creep life consumption ratio(%)	Residual life(Hr)	Evaluated residual life (Hr)
Platen-SH	SA213T11	Base Metal	1 ～ 2	8,428,000 ～ 17,028,000	1,300,000
		Fine grain HAZ	3 ～ 6	2,695,000 ～ 5,561,000	
		Coarse grain HAZ	0 ～ 1	17,028,000 <	
RH(in penthouse)	SA213T22	Base Metal	11 ～ 14	1,057,000 ～ 1,392,000	520,000
		Fine grain HAZ	9	1,739,000	
		Coarse grain HAZ	4 ～ 6	2,695,000 ～ 4,128,000	
RH(in furnace)	SA213T11	Base Metal	1 ～ 2	8,428,000 ～ 17,028,000	82,000
		Fine grain HAZ	3 ～ 4	4,128,000 ～ 5,561,000	
		Coarse grain HAZ	6 ～ 51	165,000 ～ 2,695,000	

Table I -39 Microstructure observation resuluts

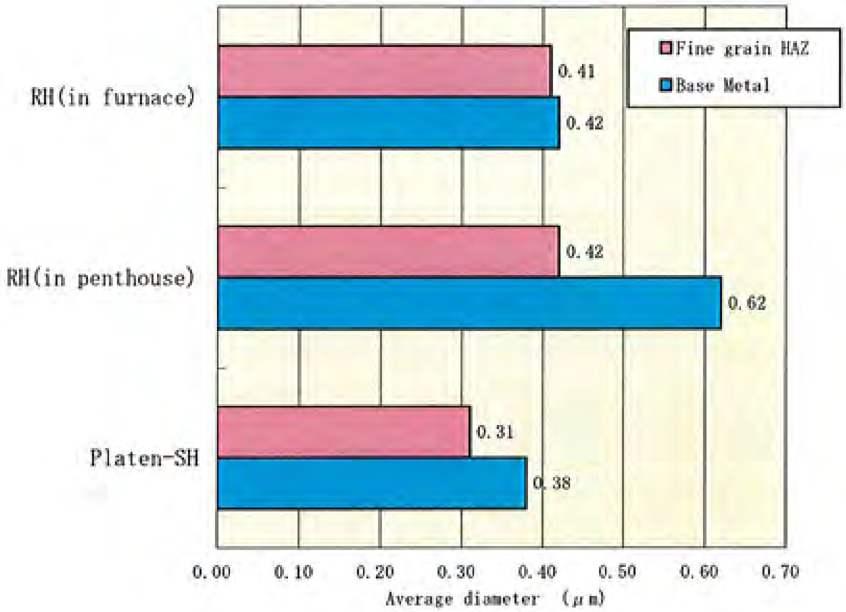
Components	Location		Observed area	OM (Optical microscope observation)						
				Microstructural features						
				Precipitation at gain boundary	Precipitates free zone along grain boundary	Precipitation in ferite grain		Pearlite structure	Subgrain boundary	Ferrite grain
						Granular precipitates	Rod-shaped precipitates			
Platen SH tube	#12-3 (SA 213 T11)	Circumferential weld	Base metal	Appeared	Not appeared	Appeared	Not appeared	Normal		
			Intercritical zone	Appeared		Appeared	Not appeared	Normal	Normal	
			Fine grain HAZ	Appeared		Appeared	Not appeared			
			Coarse grain HAZ	Not appeared		Not appeared				
			Weld metal	Appeared		Appeared				Appeared
Reheater tube	#3-1 from leftside in penthouse (SA 213 T22)	Circumferential weld	Base metal	Appeared	Appeared	Appeared	Not appeared	Disintegrated		
			Intercritical zone	Appeared		Appeared	Appeared			
			Fine grain HAZ	Appeared		Appeared	Appeared			
			Coarse grain HAZ	Not appeared		Appeared				
			Weld metal	Not appeared		Appeared				
	#14-5 from rearside in furnace (SA 213 T11)	Circumferential weld	Base metal	Appeared	Not appeared	Appeared	Not appeared	Normal		
			Intercritical zone	Not appeared		Appeared	Not appeared	Normal	Normal	
			Fine grain HAZ	Appeared		Appeared	Not appeared			
			Coarse grain HAZ	Not appeared		Appeared				
			Weld metal	Not appeared		Appeared				Appeared
View nos. for each area				×500 (2 views) ×1000 (4 views)						

Table I -40 Precipitates distribution observation results

Components	Location		Observed area	TEM (Transmission Electron Microscope observation)					
				Precipitates features					
				Precipitates free zone along grain boundary	Precipitation in ferite grain			Pearlite structure	Aggromerated precipitates structure
					Fine needlelike and granular	Rod-shaped precipitates	Atenuated plate-shaped precipitates		
Platen SH tube	#12-3 (SA 213 T11)	Circumferential weld	Base metal	Not appeared	Disappeared	Not appeared	Not appeared	Disintegrated	
			Fine grain HAZ		Disappeared	Appeared	Appeared	Normal	
			Coarse grain HAZ		Disappeared	Not appeared	Not appeared		Normal
			Weld metal		Disappeared				
Reheater tube	#3-1 from leftside in penthouse (SA 213 T22)	Circumferential weld	Base metal	Appeared	Remaining	Appeared	Not appeared	Remarkably disintegrated	
			Fine grain HAZ		Disappeared		Not appeared		
			Coarse grain HAZ		Disappeared		Disappeared		
			Weld metal		Disappeared				
	#14-5 from rearside in furnace (SA 213 T11)	Circumferential weld	Base metal	Appeared	Remaining	Not appeared	Not appeared	Normal	
			Fine grain HAZ		Remaining	Not appeared	Not appeared	Disintegrated	
			Coarse grain HAZ		Remaining	Not appeared	Appeared		Disintegrated
			Weld metal		Remaining				
View nos. for each area				×2000 (2 views) ×1000 (4 views)					

Table I -41 Quantitative evaluation of grain boundary precipitates

Component	Material	Average diameter (μm)		Volume fraction	
		Base Metal	Fine grain HAZ	Base Metal	Fine grain HAZ
Platen-SH	SA213T11	0.38	0.31	0.008	0.009
RH(in penthouse)	SA213T22	0.62	0.42	0.028	0.027
RH(in furnace)	SA213T11	0.42	0.41	0.014	0.020



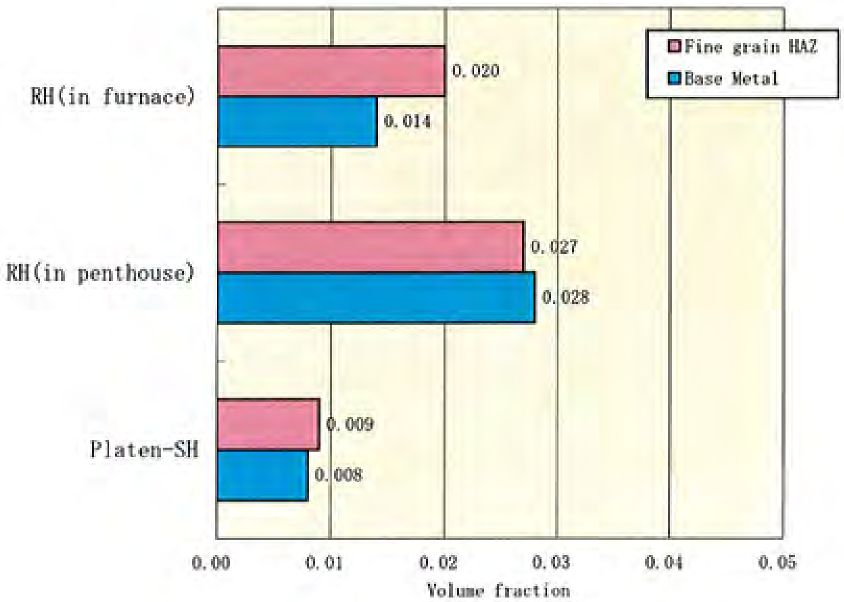


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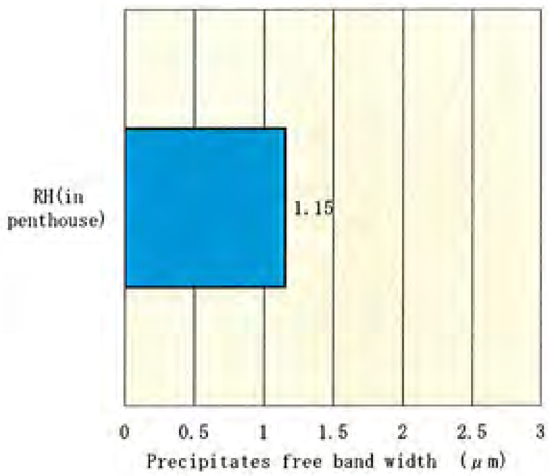
Table Ⅰ-42 Precipitates free band width along grain boundary

Sample tube	Material	Precipitates free band width (μm) ※1
		Base Metal
RH(in penthouse)	SA213T22	1.15

※1 : Average value of 10 measured points



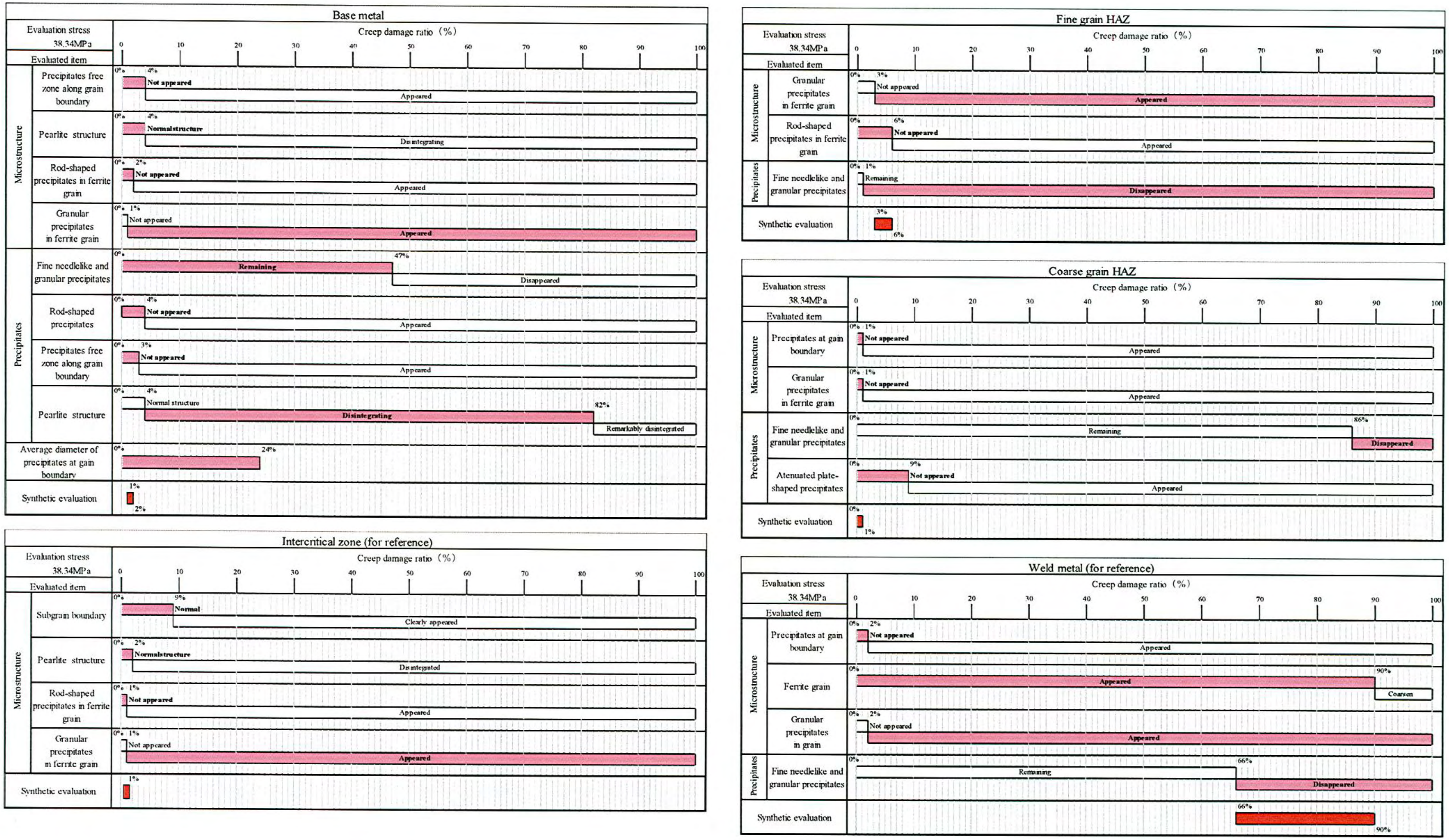


Fig I -28 Evaluation Results Platen SH

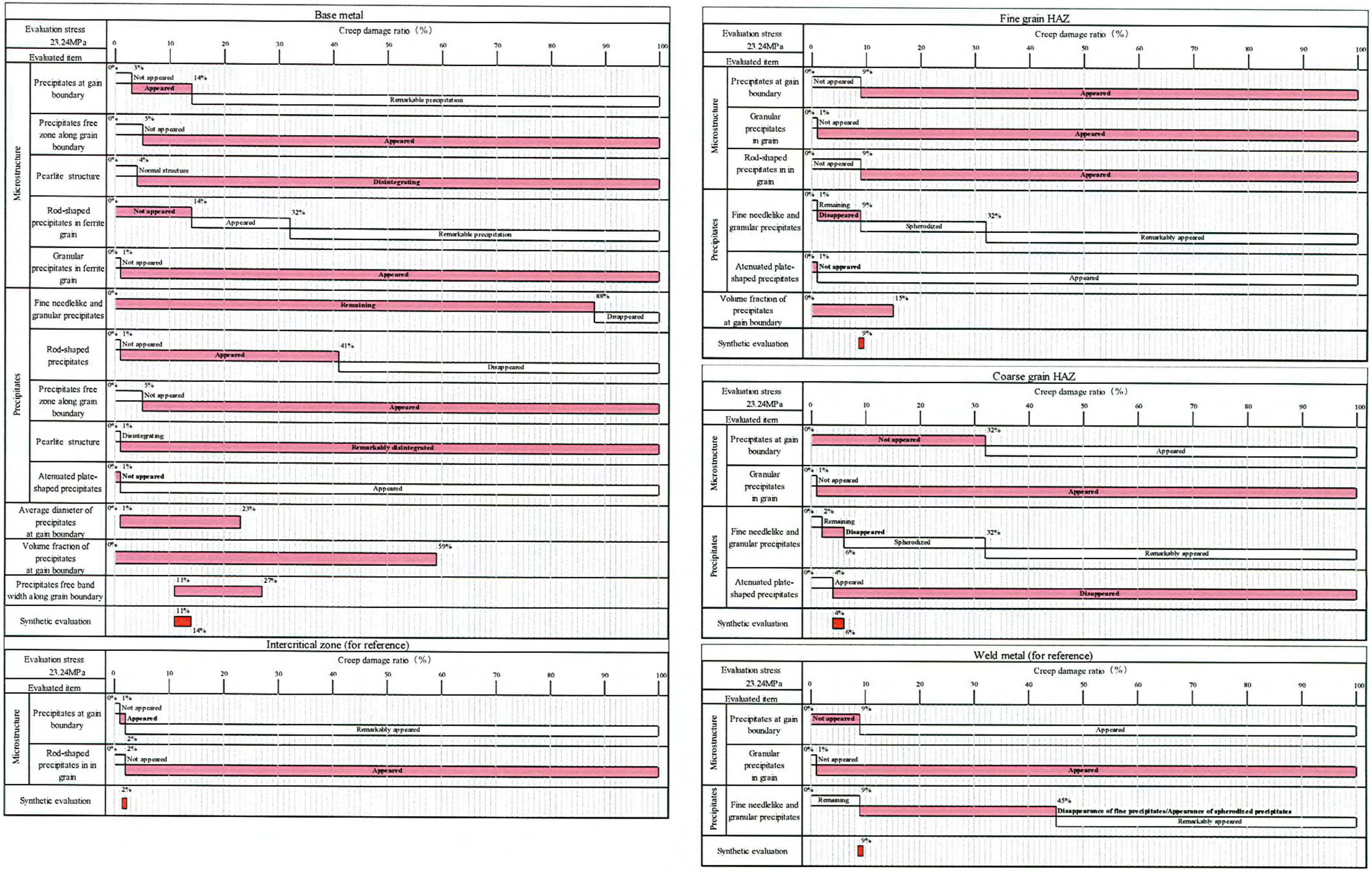


Fig I-29 Evaluation Results RH(in penthouse)