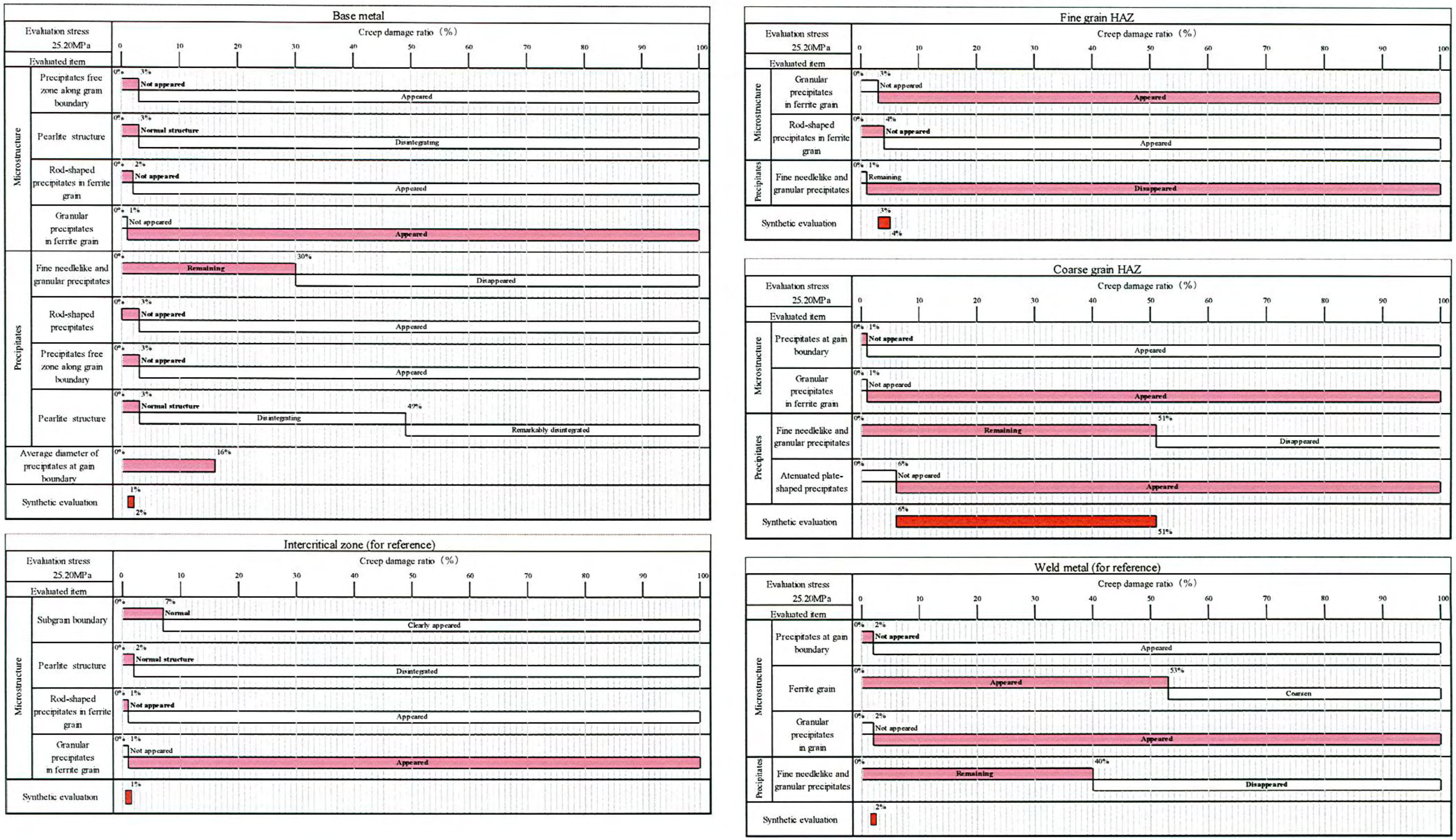
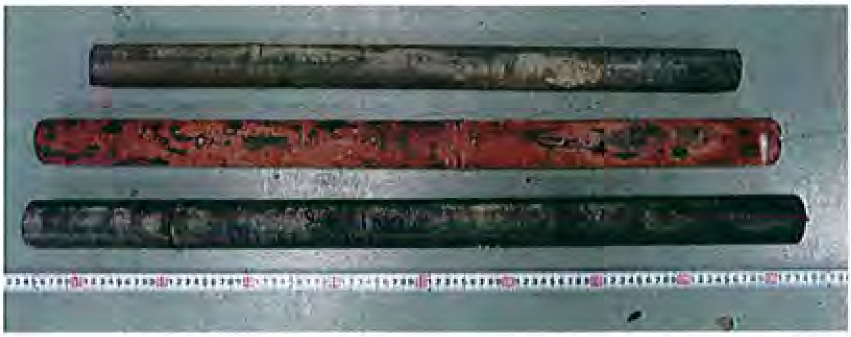


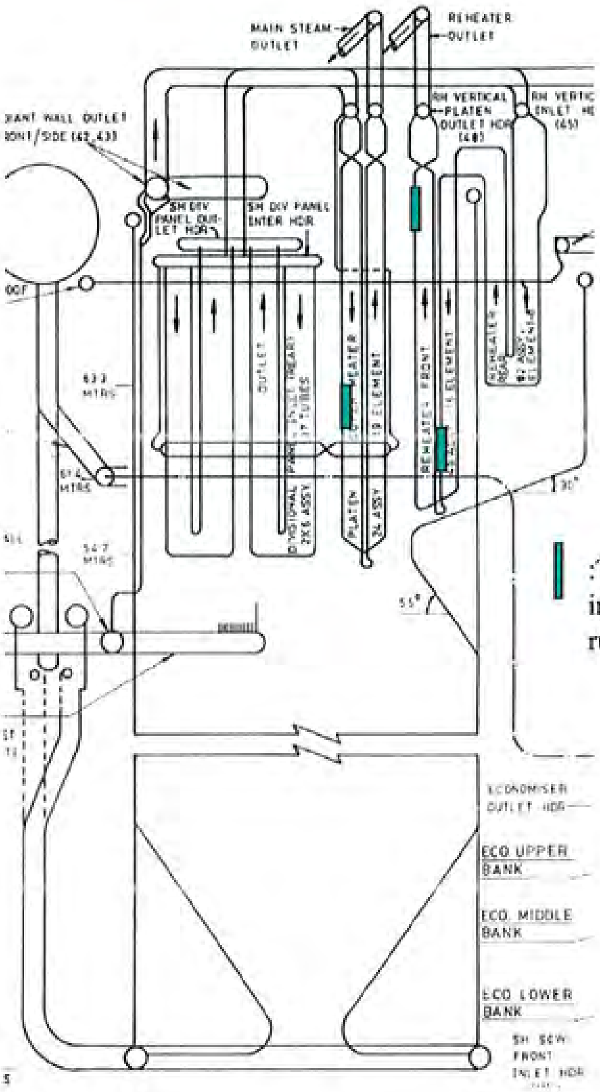
Fig I-30 Evaluation Results RH(in furnace)

Platen SH

RH(in penthouse)

RH(in furnace)





:Tube sampling for inspection and creep rupture test

Photo I -11 Tube sampling location

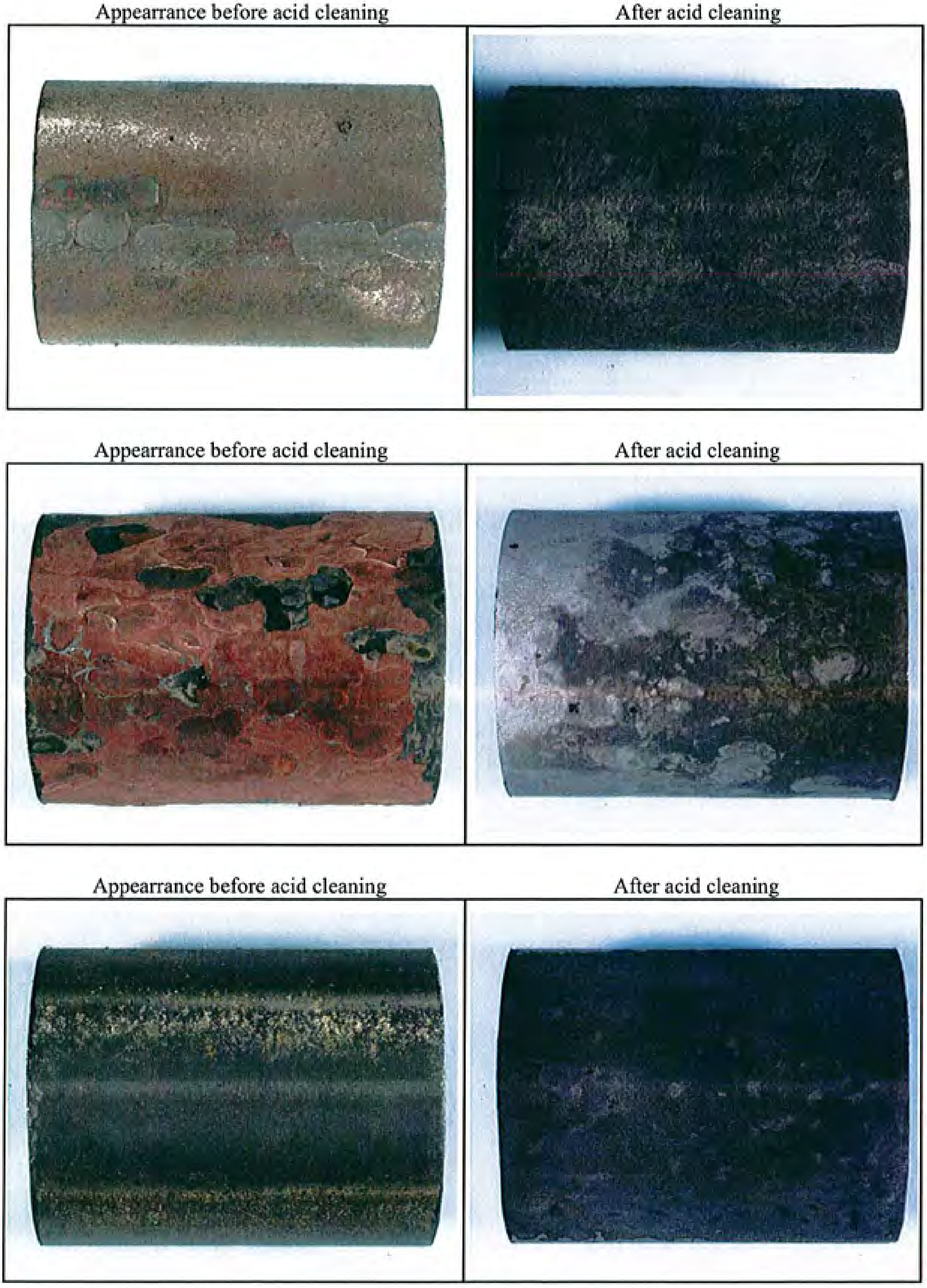


Photo I -12 Tube appearance from outside (boiler front side)

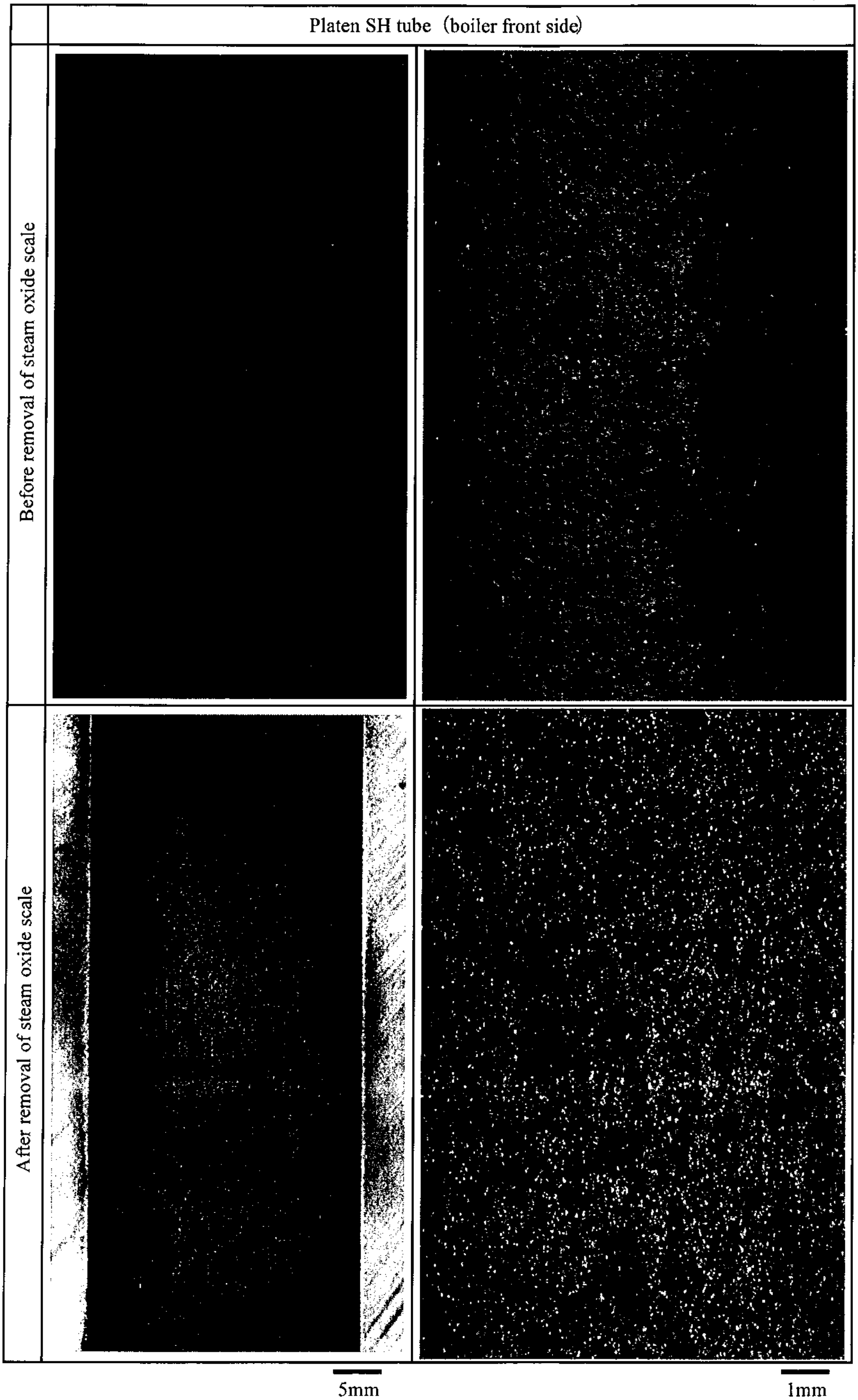


Photo I -13 Tube appearance from inside before and after removal of steam oxide scale
(Platen SH tube-boiler front side)

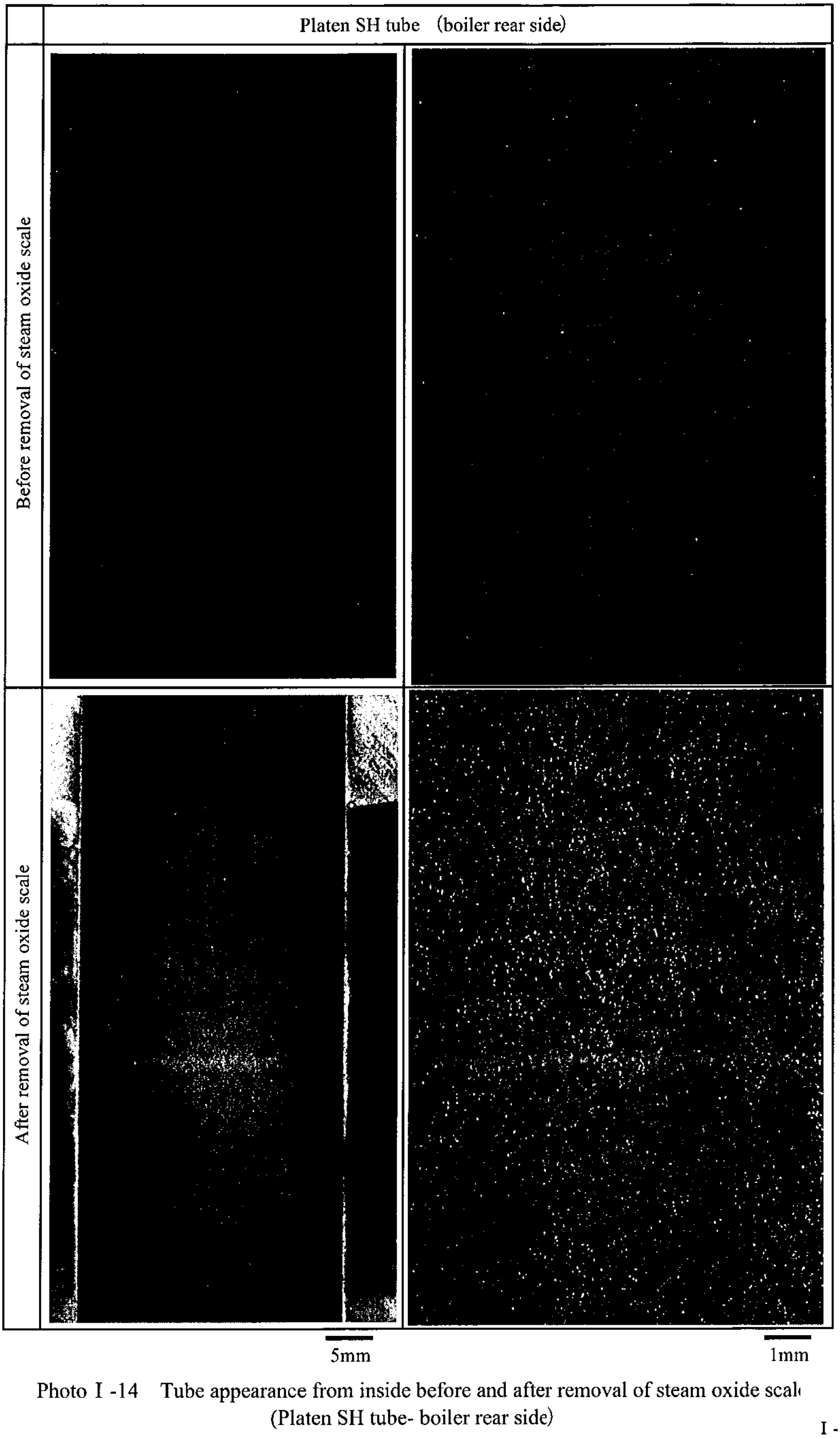


Photo I -14 Tube appearance from inside before and after removal of steam oxide scale
(Platen SH tube- boiler rear side)

RH tube in penthouse (boiler front side)

Before removal of steam oxide scale

After removal of steam oxide scale

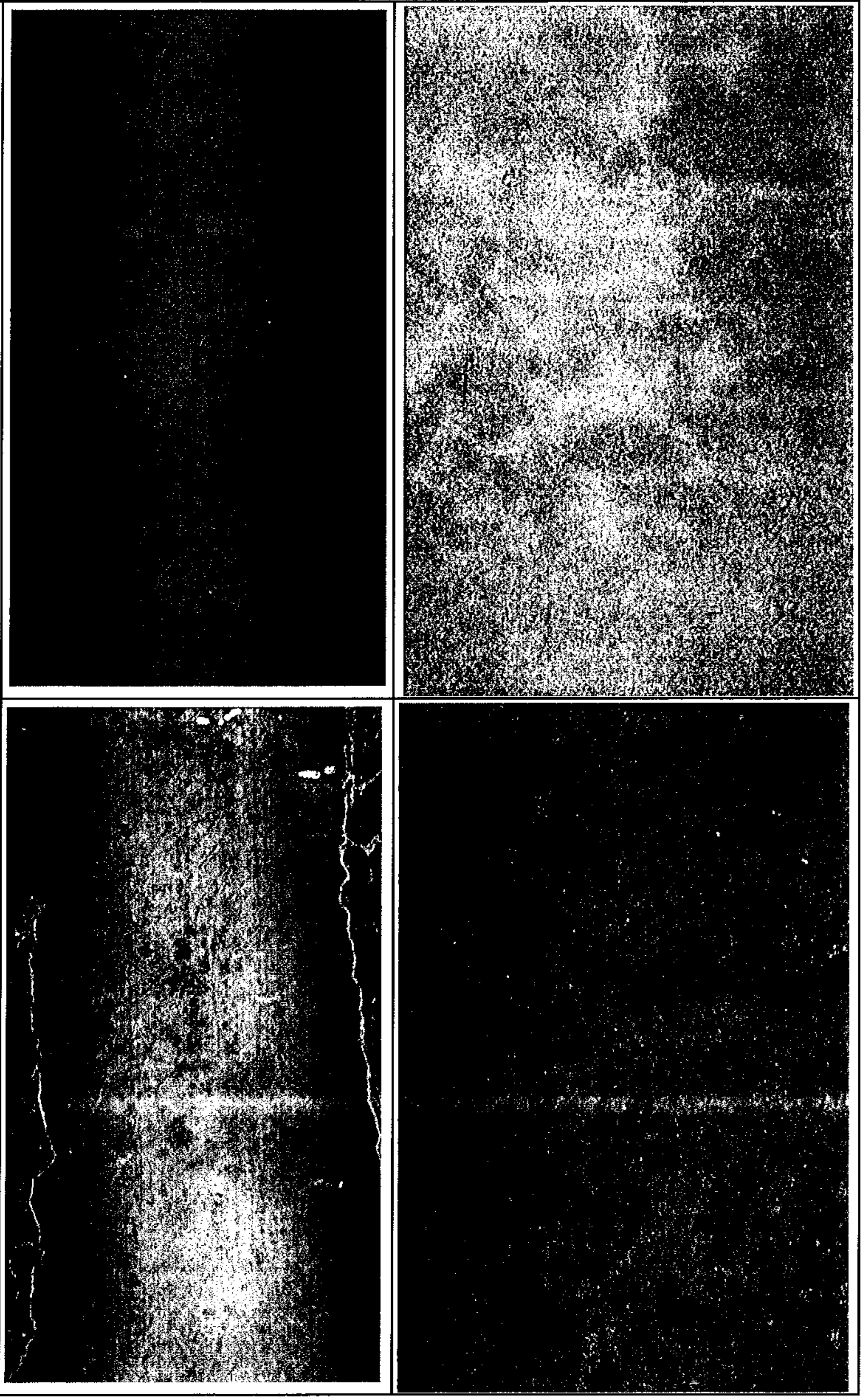


Photo I -15 Tube appearance from inside before and after removal of steam oxide scale
(RH tube in penthouse (boiler front side))

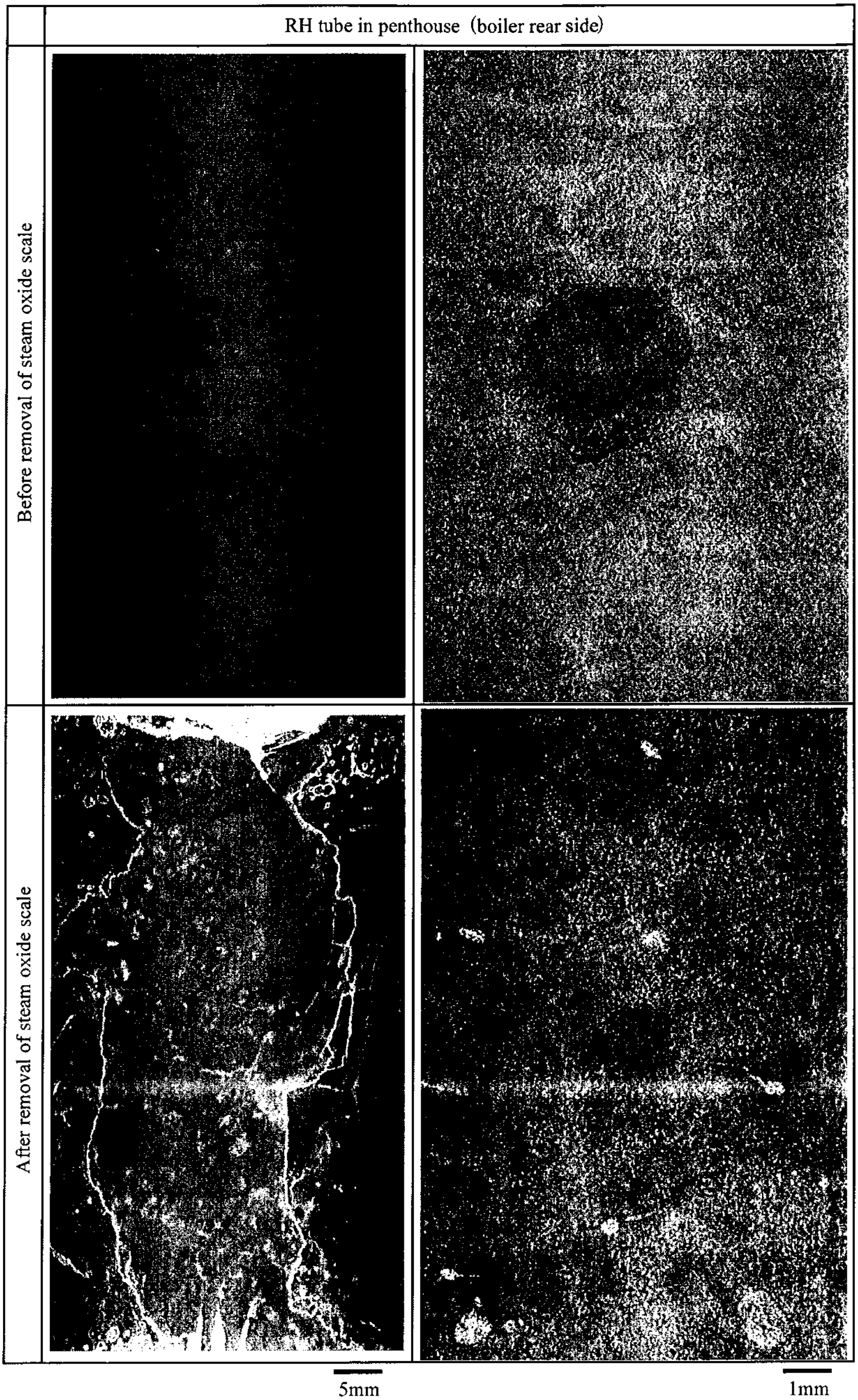


Photo I -16 Tube appearance from inside before and after removal of steam oxide scal
(RH tube in penthouse (boiler rear side))

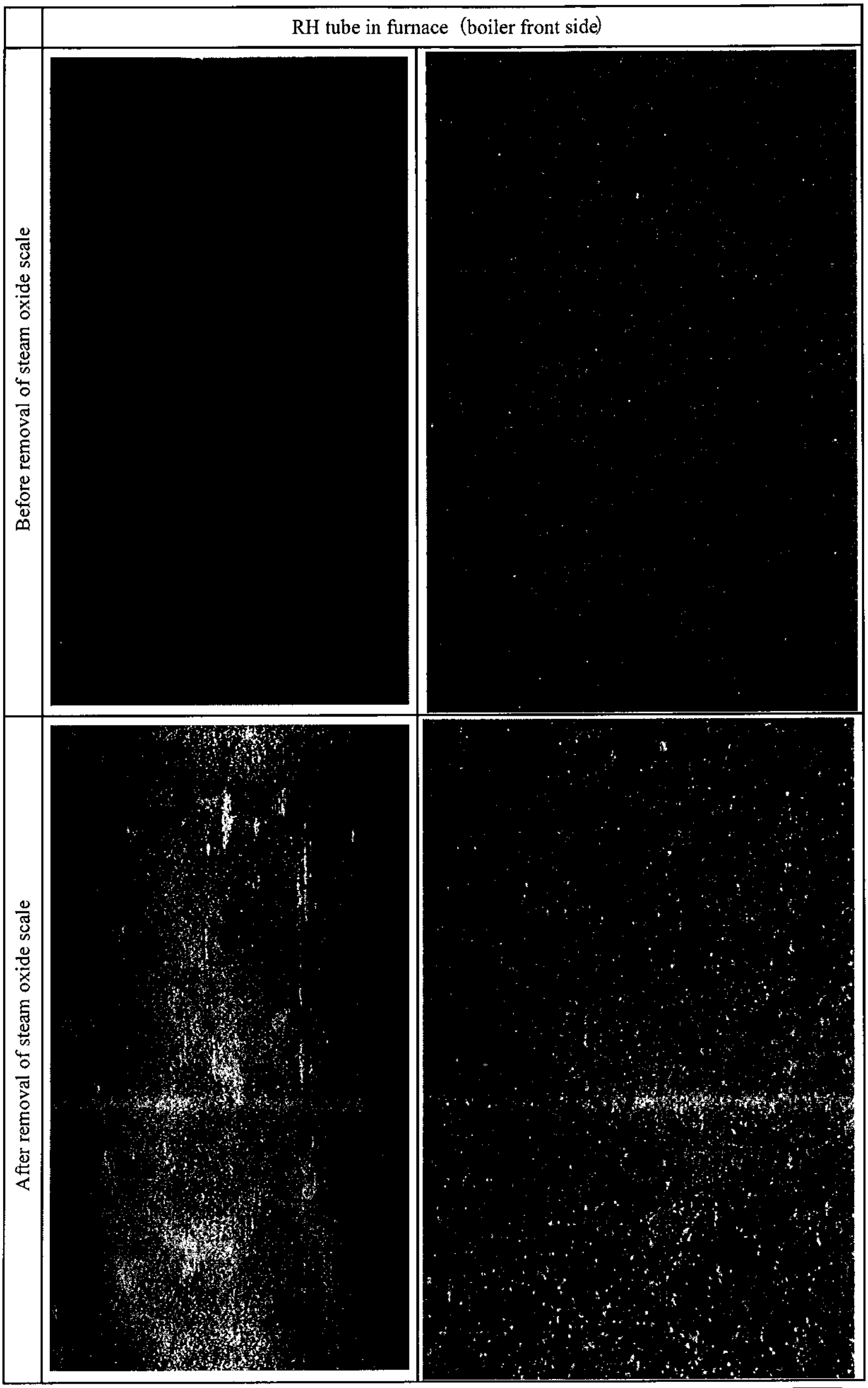


Photo I -17 Tube appearance from inside before and after removal of steam oxide scale
(RH tube in furnace (boiler front side))

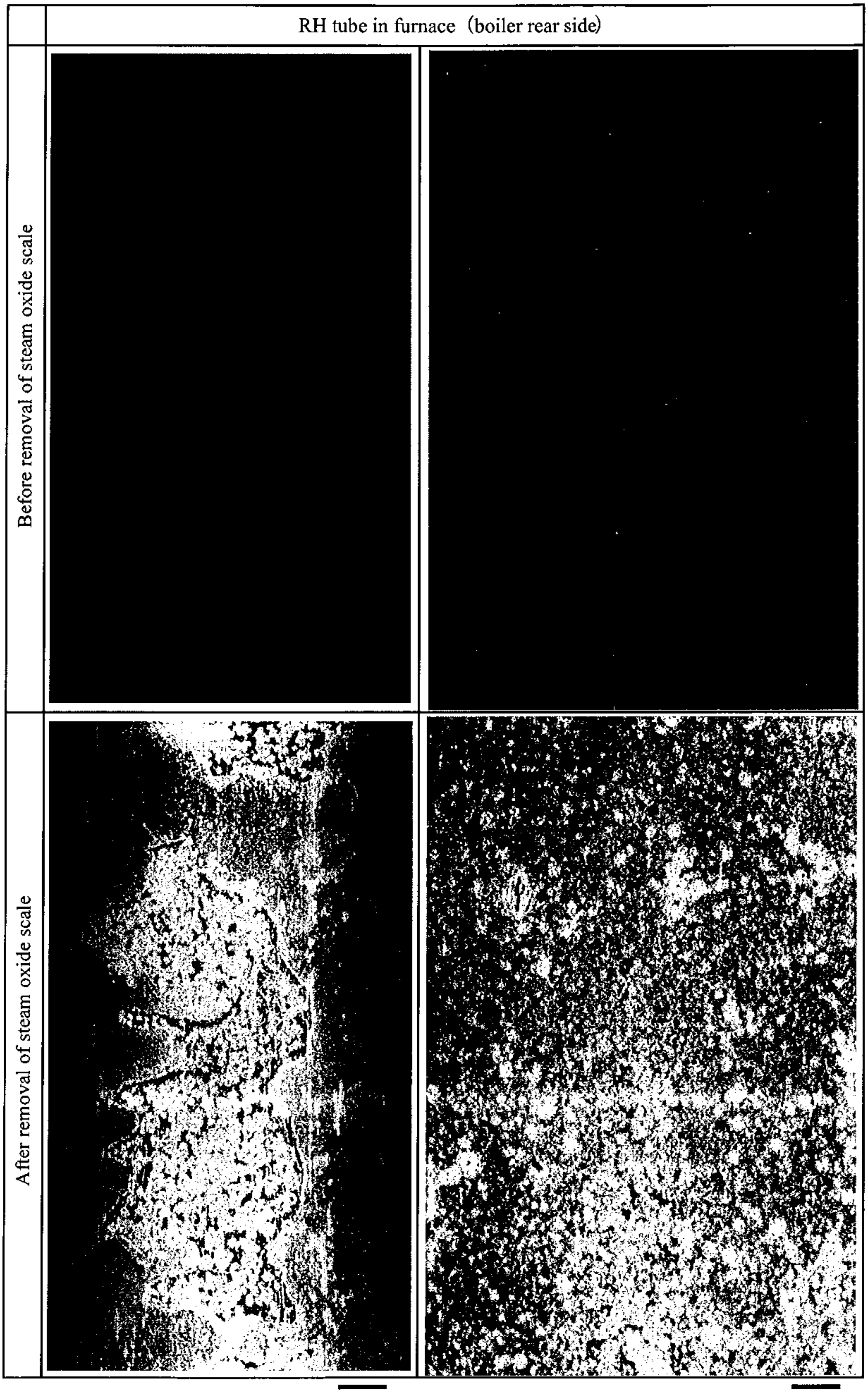


Photo I -18 Tube appearance from inside before and after removal of steam oxide scal
(RH tube in furnace (boiler rear side))

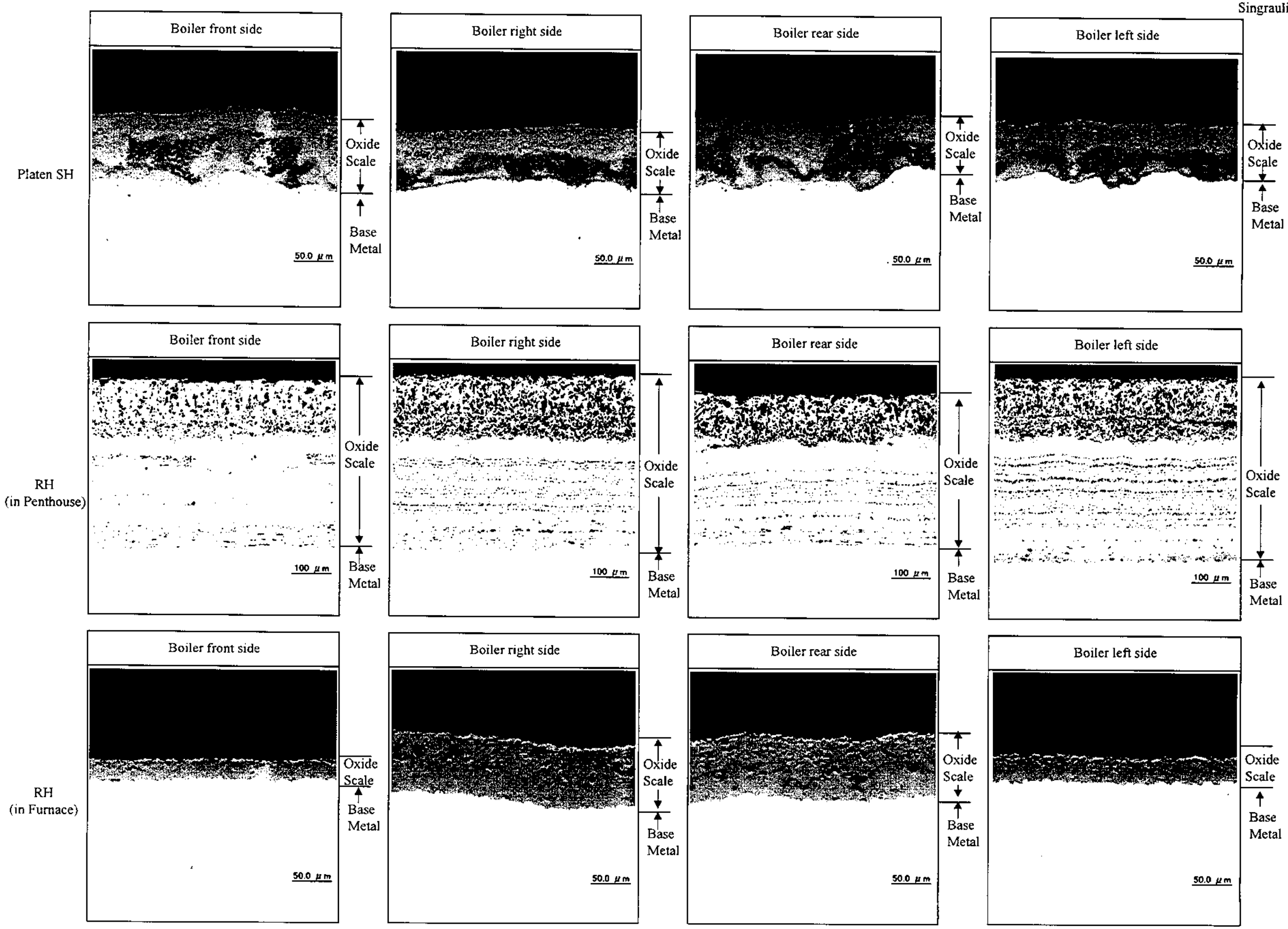
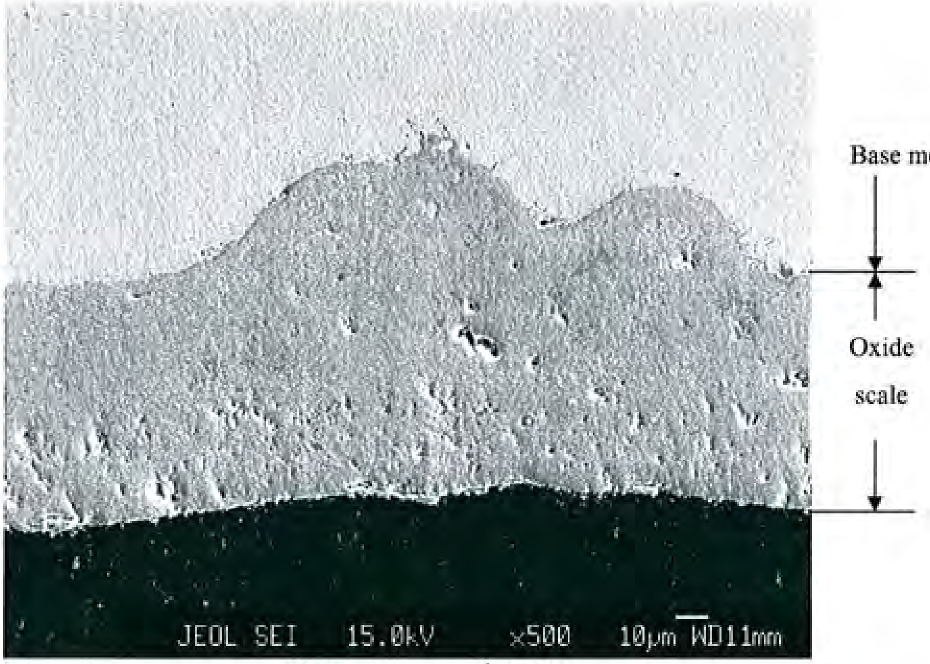


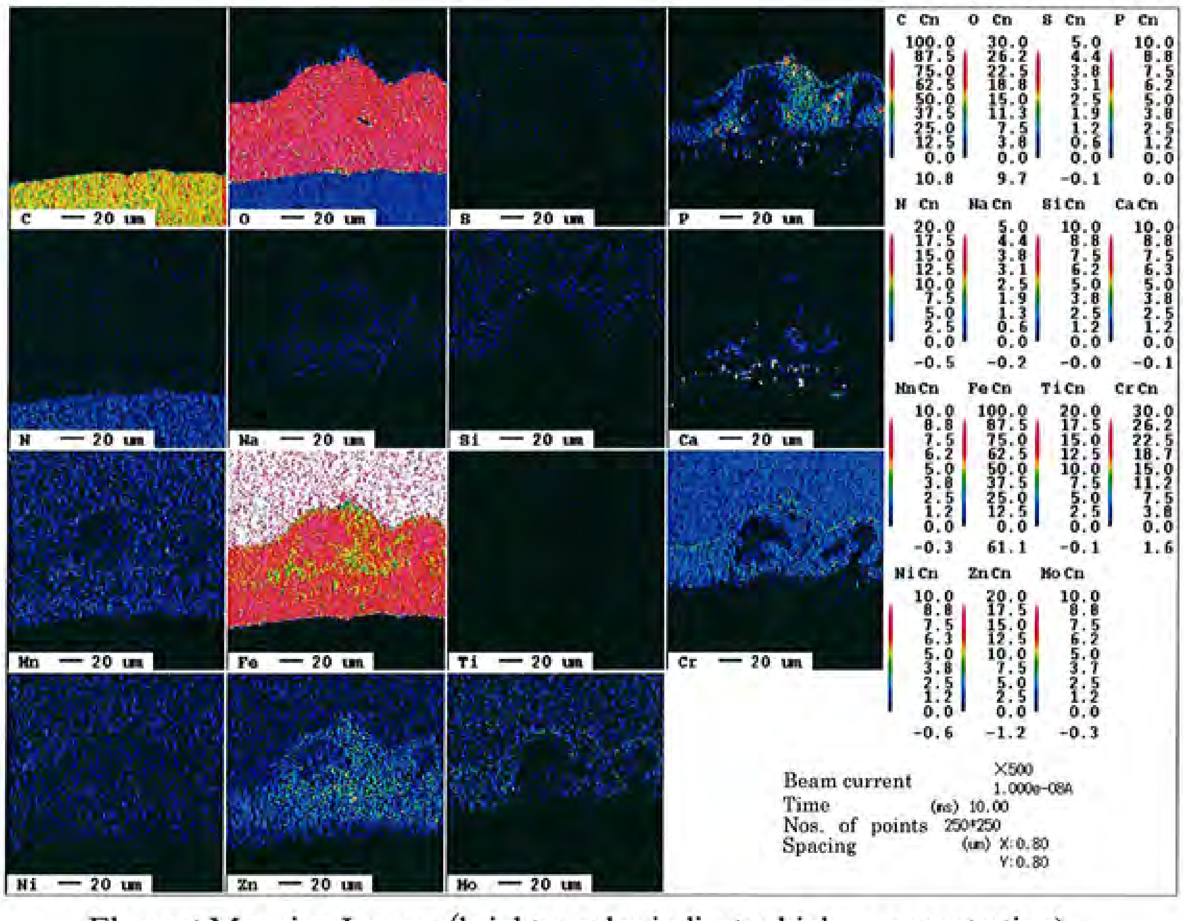
Photo I -19 Cross sectional observation of sample tube inside surface

Singrauli Platen-SH 【Front】



SEM Image (×500)

(Concentration/%)



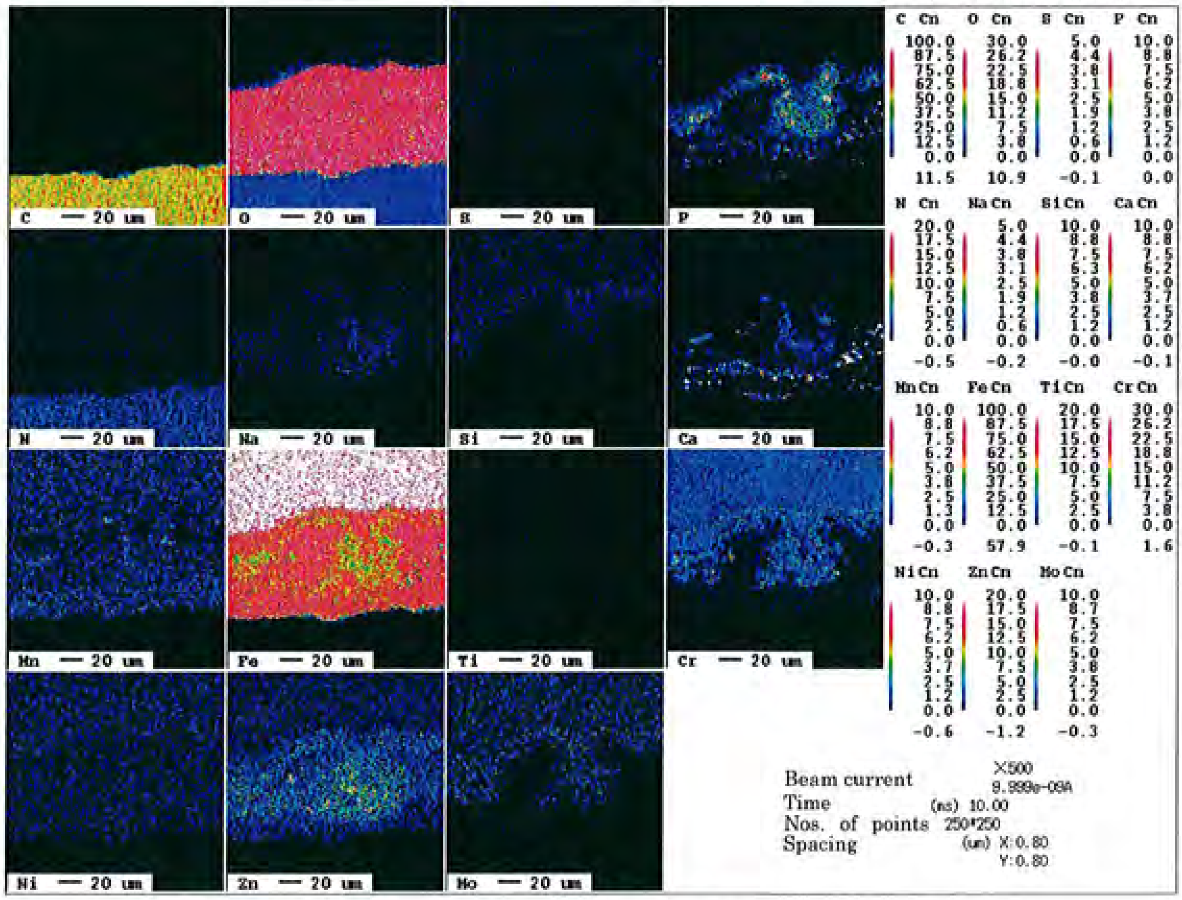
Element Mapping Image (brighter color indicates higher concentration)

Fig I -13. EPMA analysis results

Singrauli Platen-SH 【Right】

SEM Image (×500)

(Concentration/%)



Element Mapping Image (brighter color indicates higher concentration)

Fig I -14. EPMA analysis results

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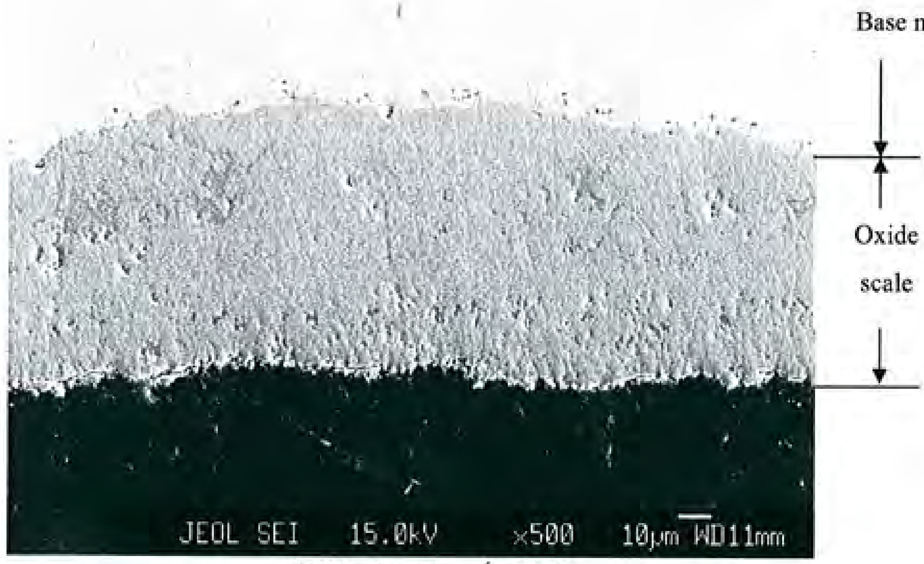
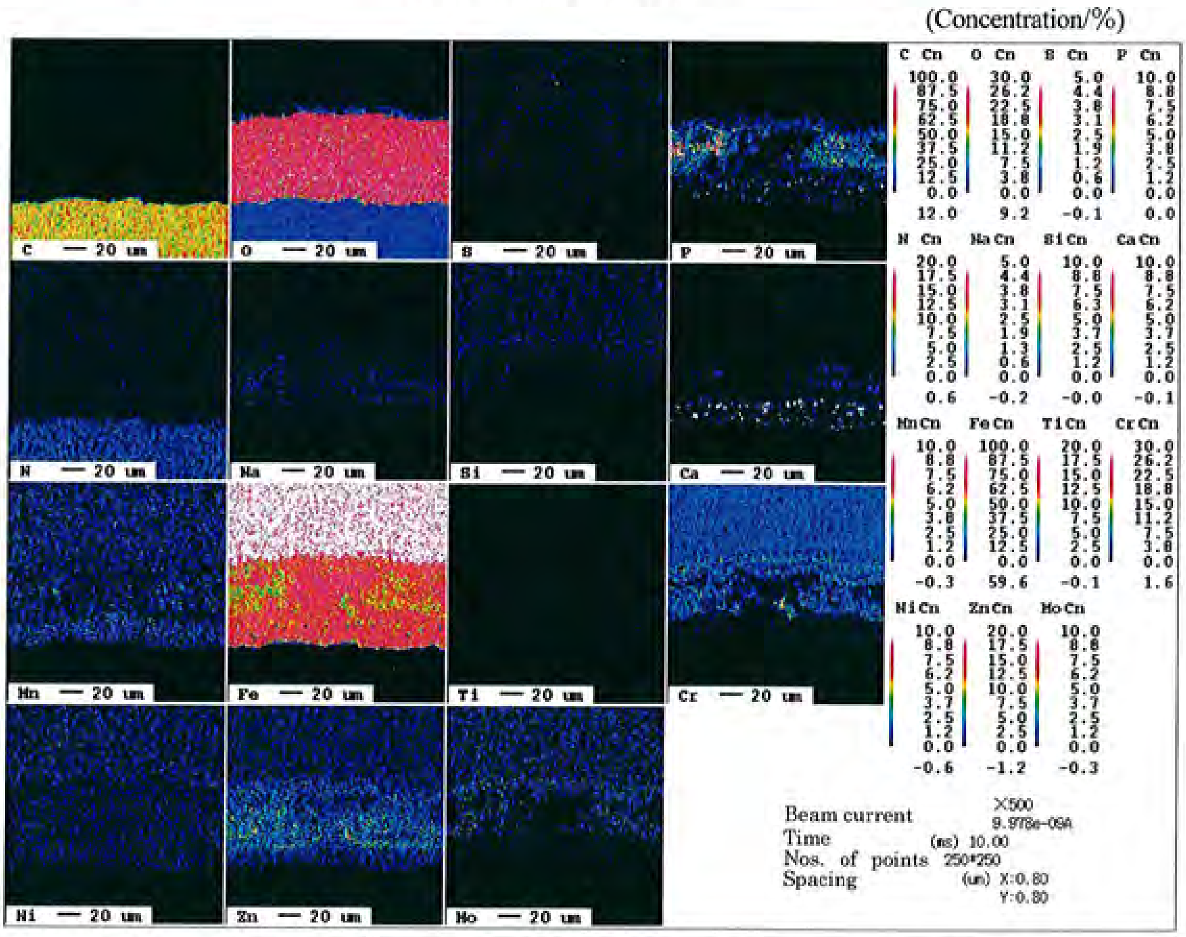
Singrauli Platen-SH 【Rear】



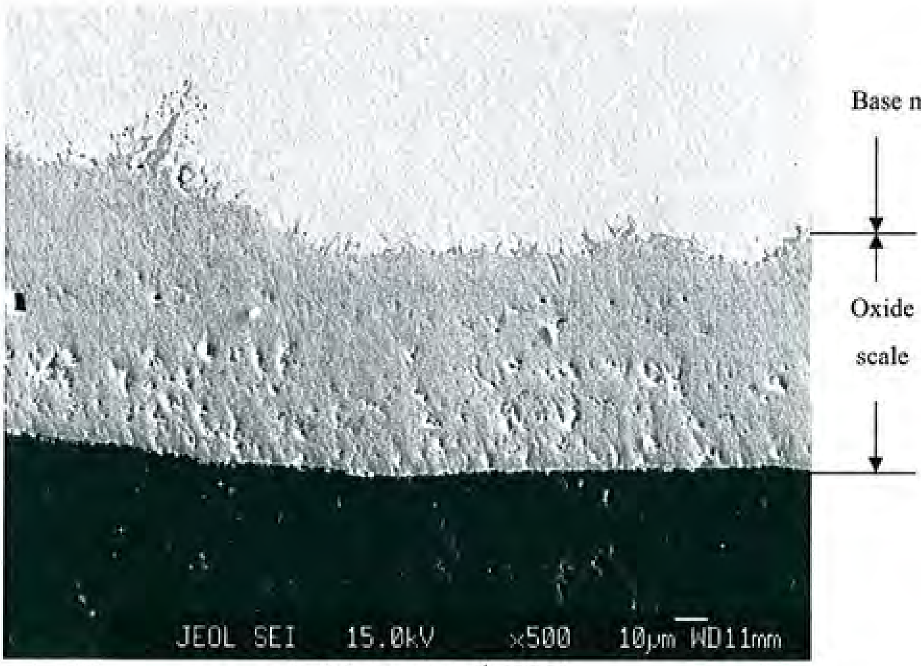
SEM Image (×500)



Element Mapping Image (brighter color indicates higher concentration)

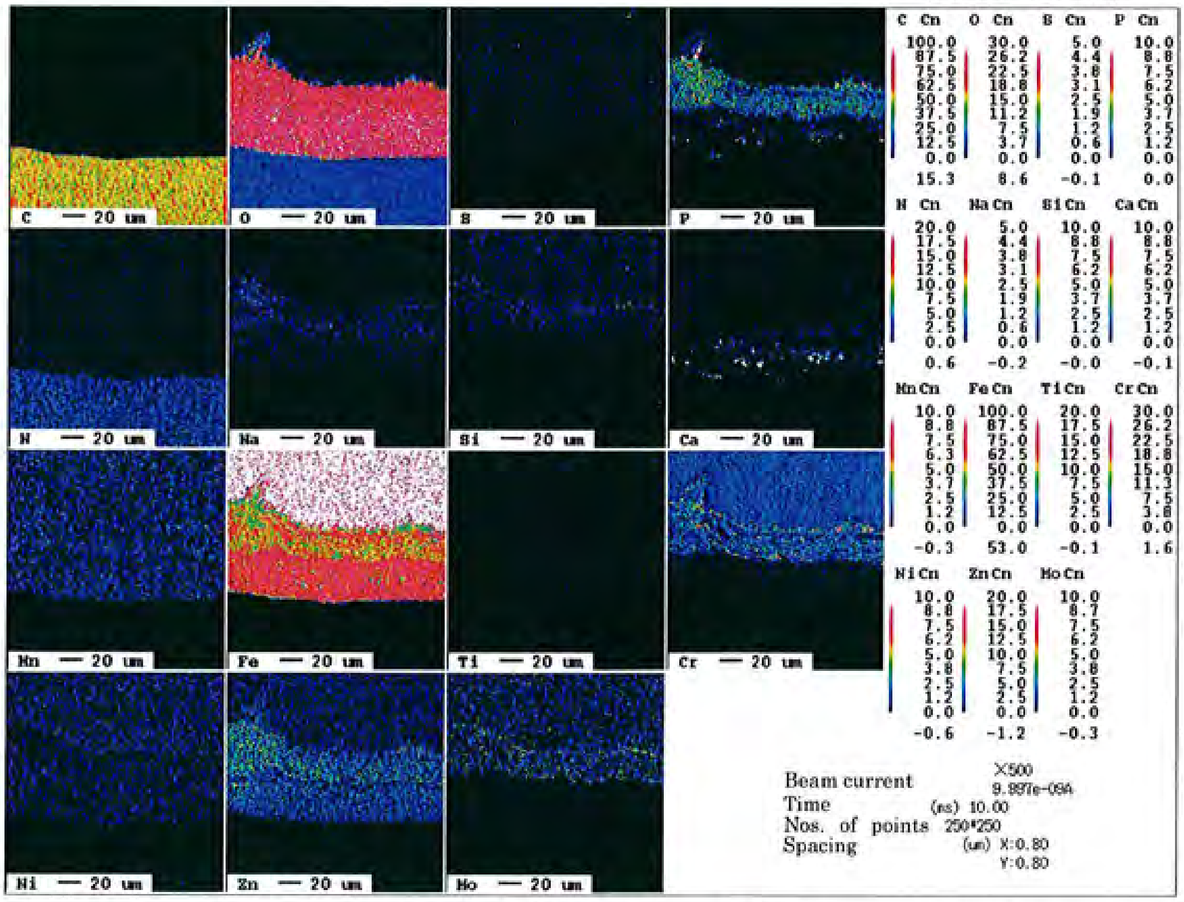
Fig I -15. E P M A analysis results

Singrauli Platen-SH 【Left】



SEM Image (×500)

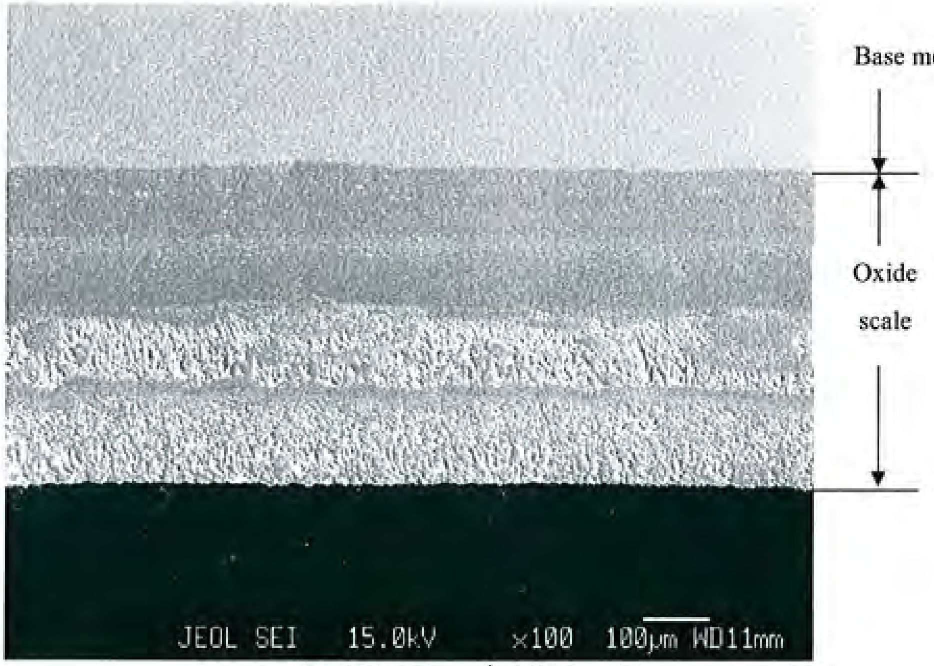
(Concentration/%)



Element Mapping Image (brighter color indicates higher concentration)

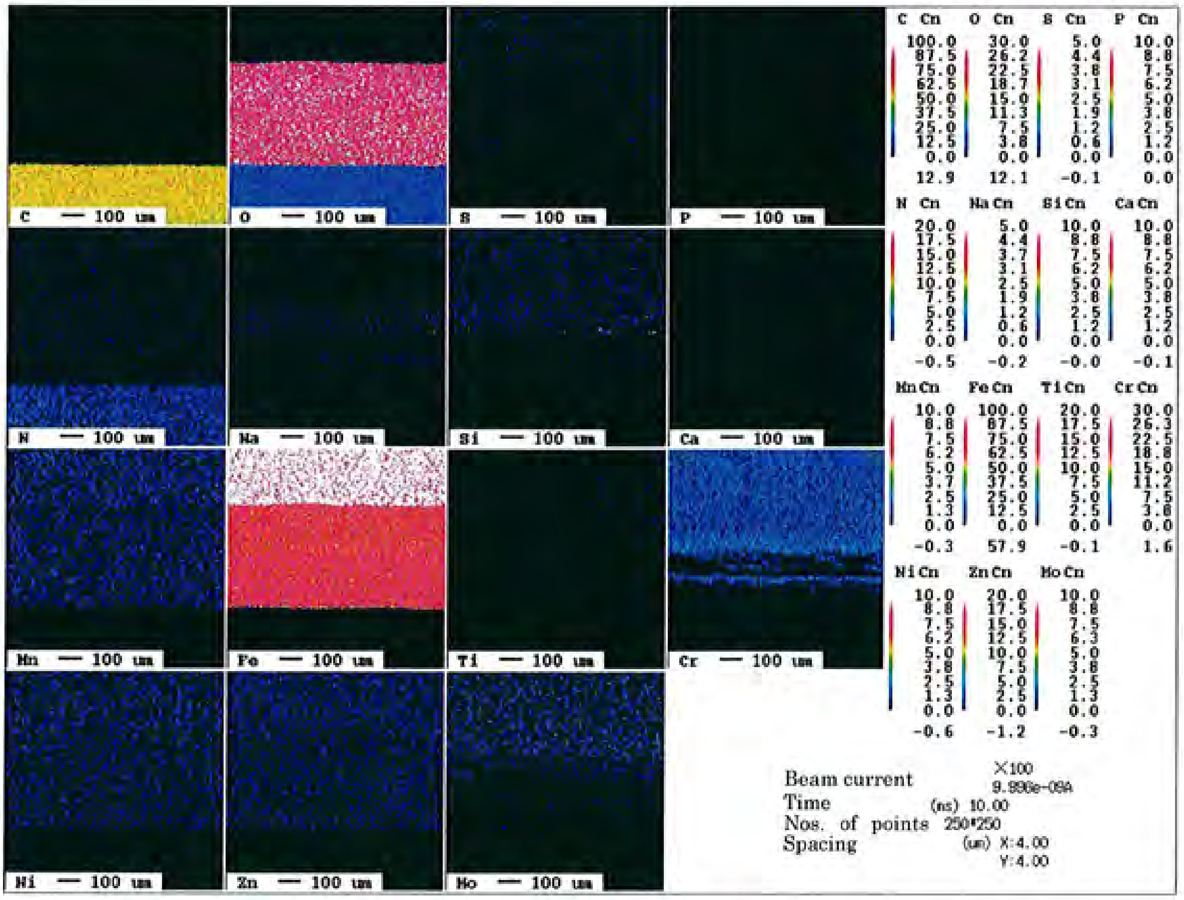
Fig I -16. EPMA analysis results

Singrauli RH(in penthouse) 【Front】



SEM Image (×100)

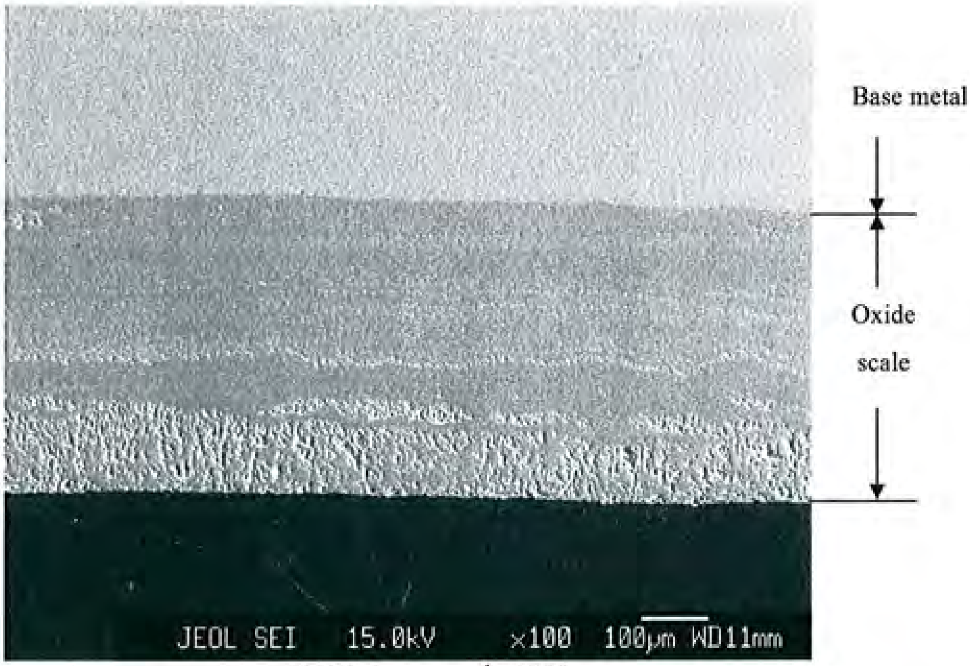
(Concentration/%)



Element Mapping Image (brighter color indicates higher concentration)

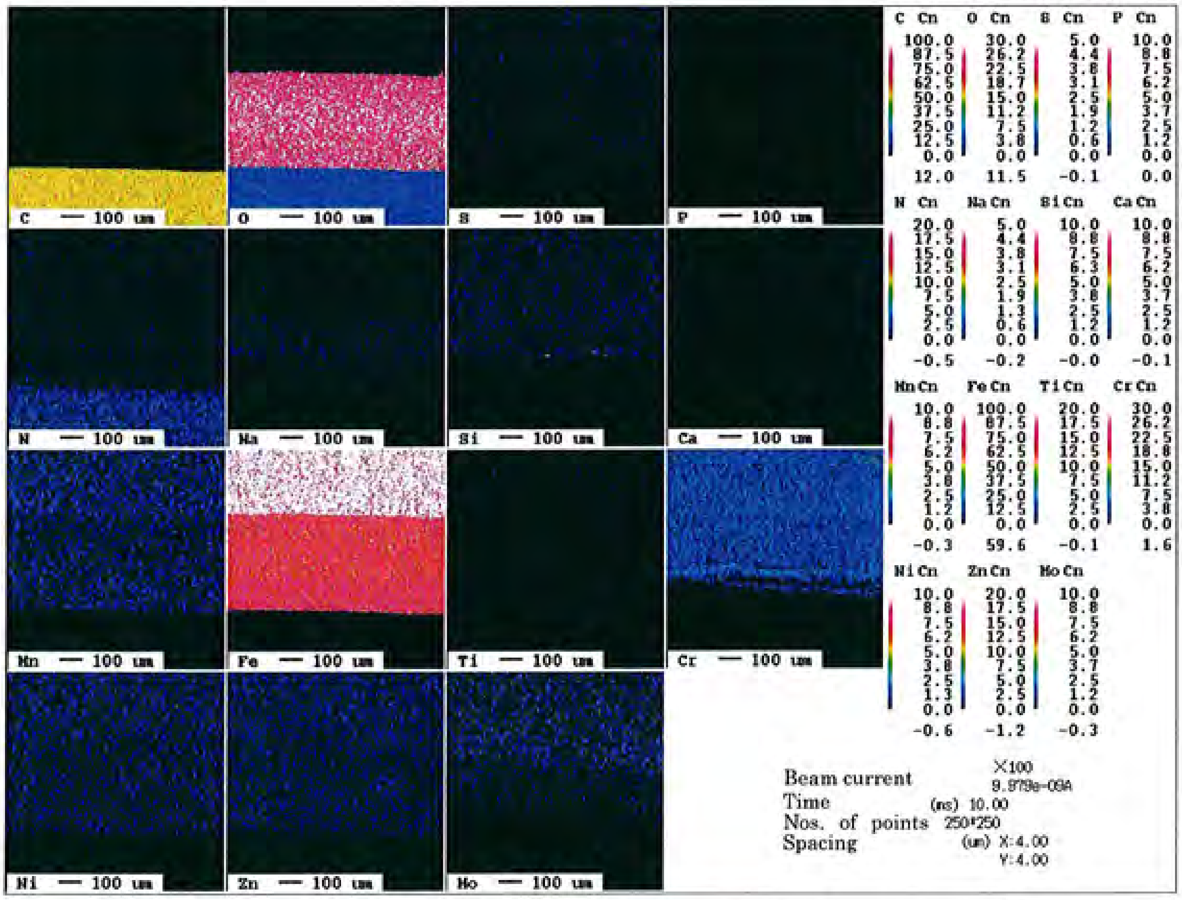
Fig I -17. E P M A analysis results

Singrauli RH(in penthouse) 【Right】



SEM Image (×100)

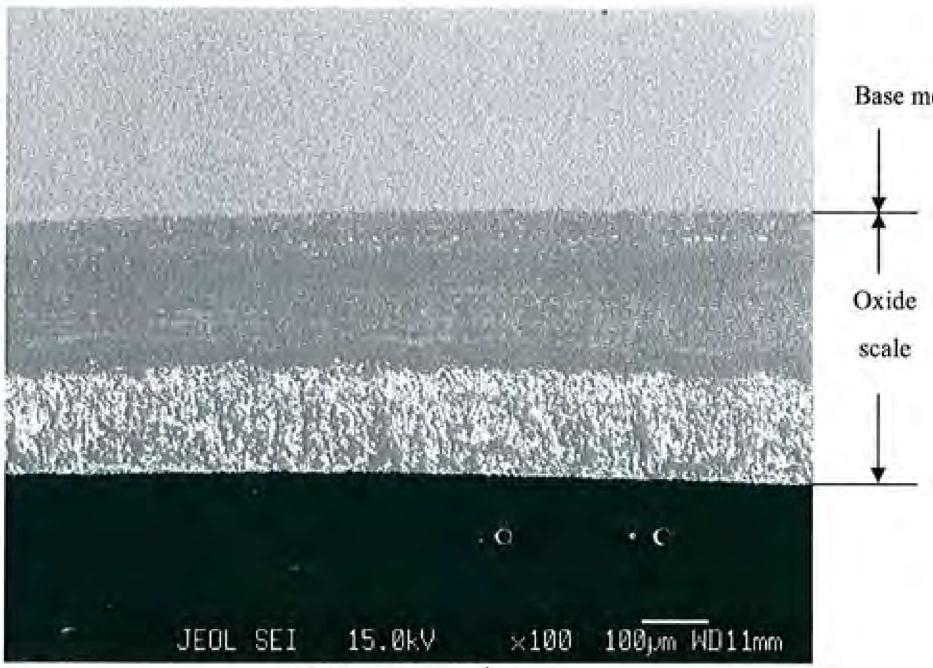
(Concentration/%)



Element Mapping Image (brighter color indicates higher concentration)

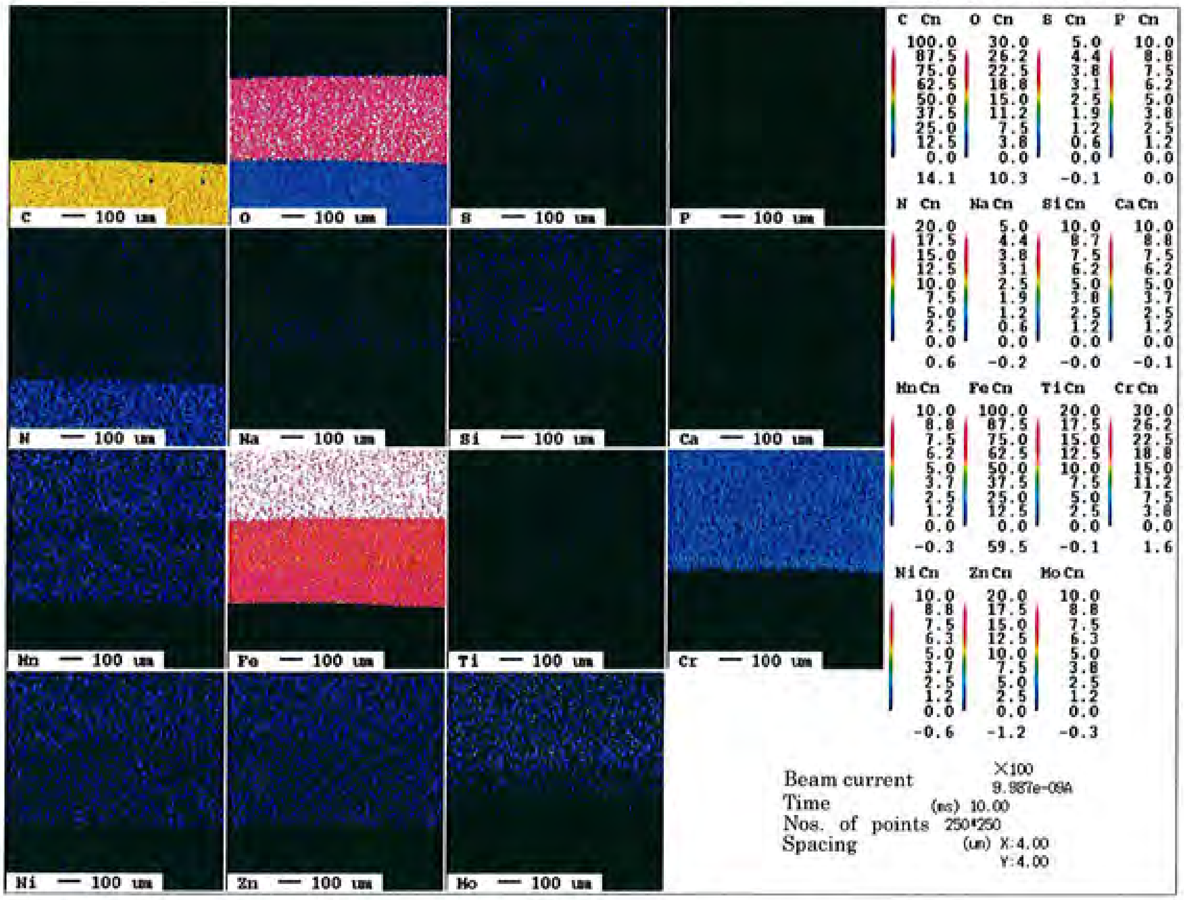
Fig I -18. EPMA analysis results

Singrauli RH(in penthouse) 【Rear】



SEM Image (×100)

(Concentration/%)



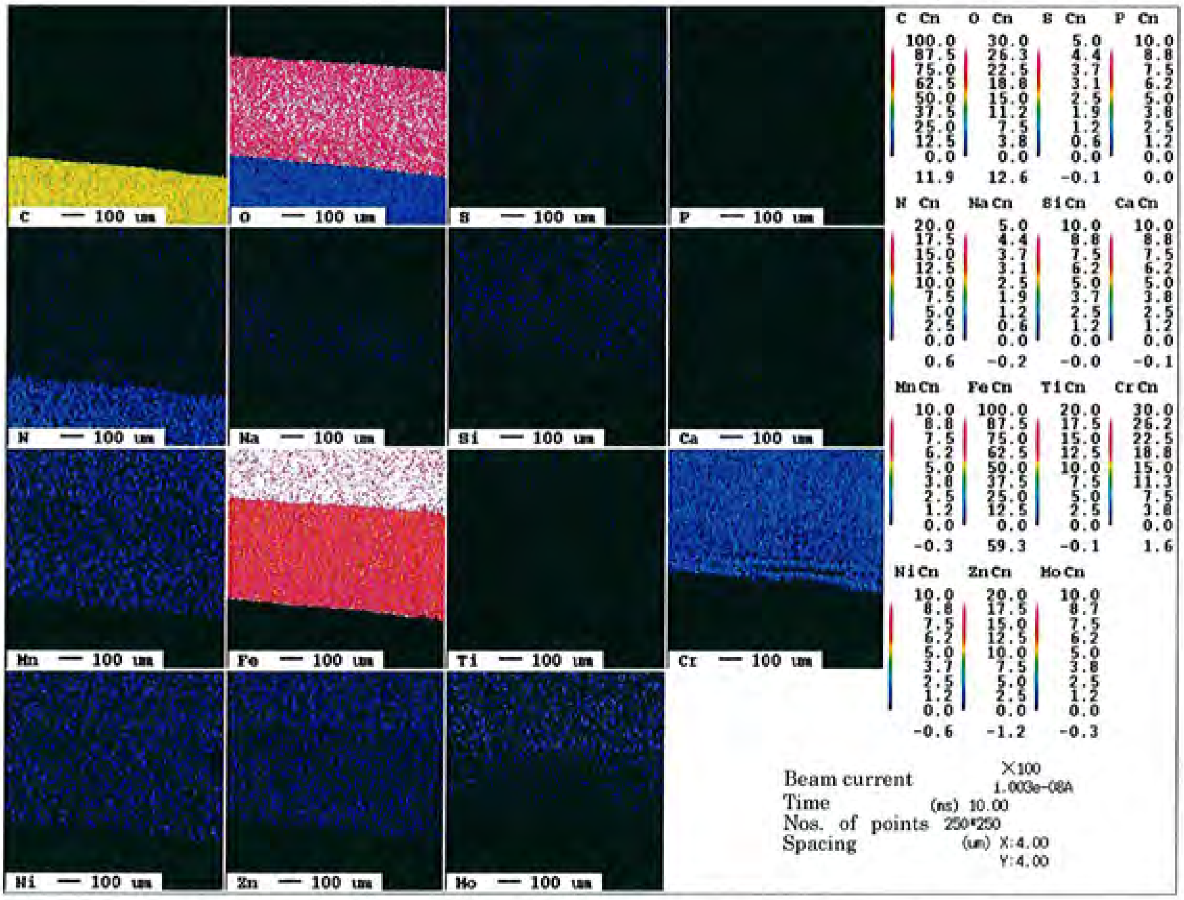
Element Mapping Image (brighter color indicates higher concentration)

Fig I -19. EPMA analysis results

Singrauli RH(in penthouse) 【Left】

SEM Image (×100)

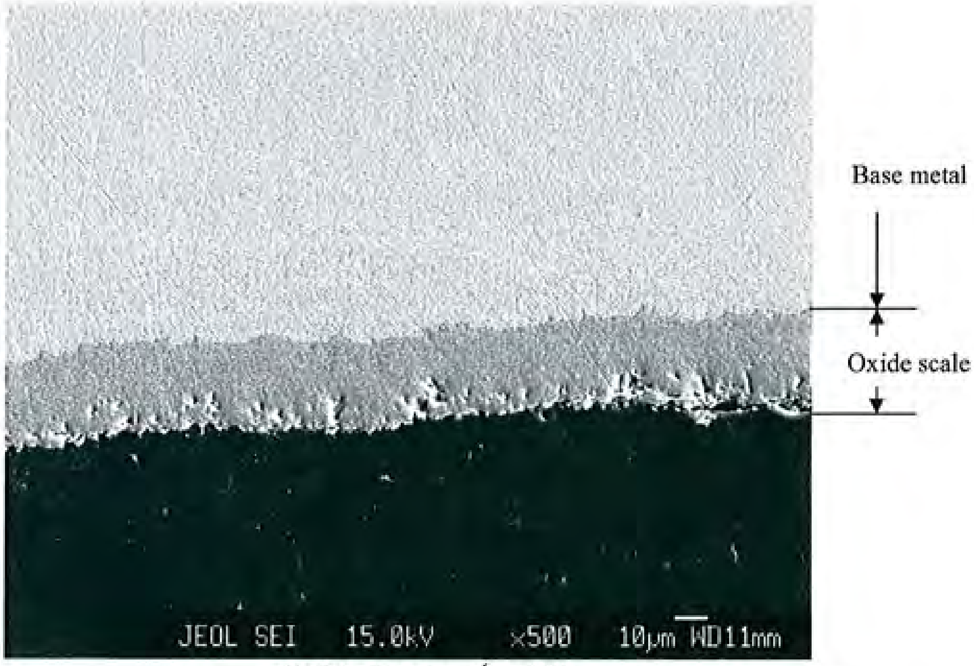
(Concentration/%)



Element Mapping Image (brighter color indicates higher concentration)

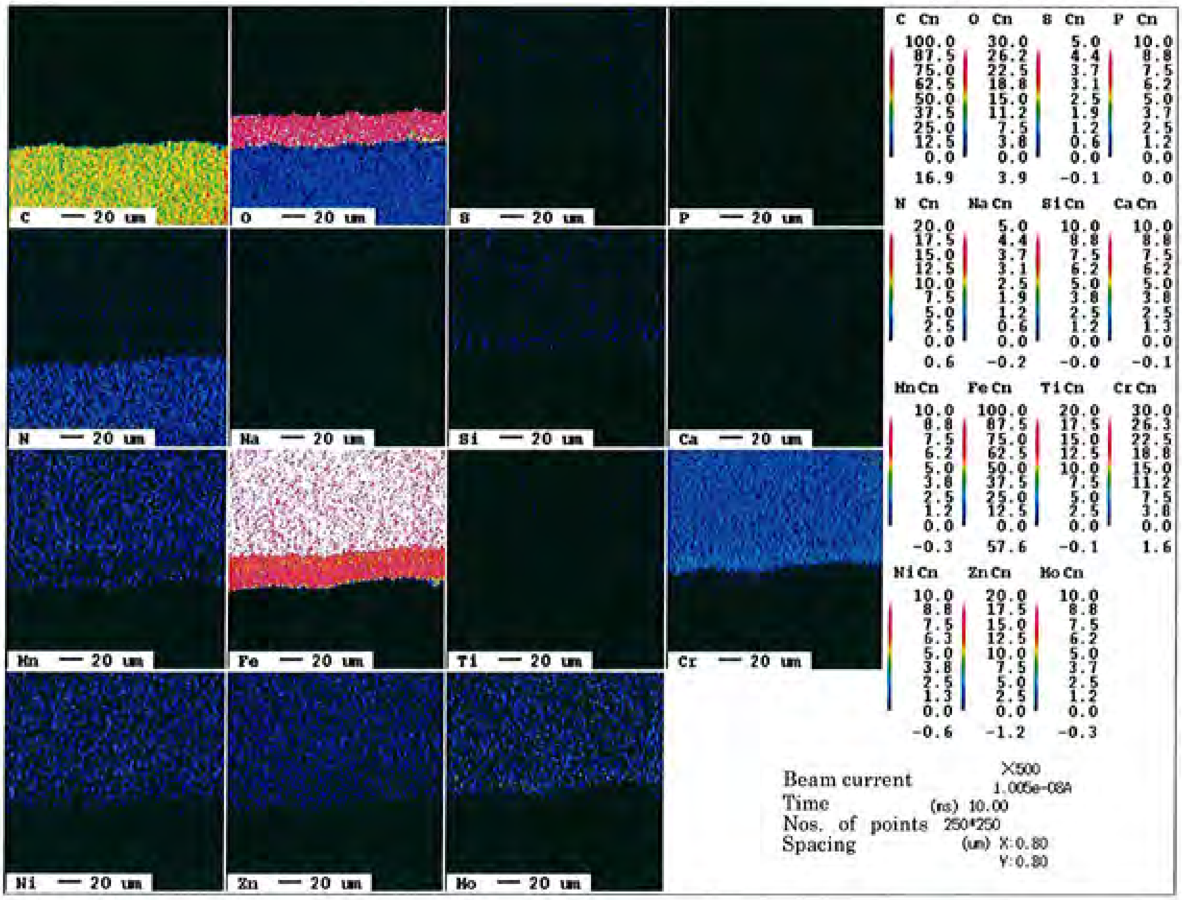
Fig I -20. EPMA analysis results

Singrauli RH(in furnace) 【Front】



SEM Image (×500)

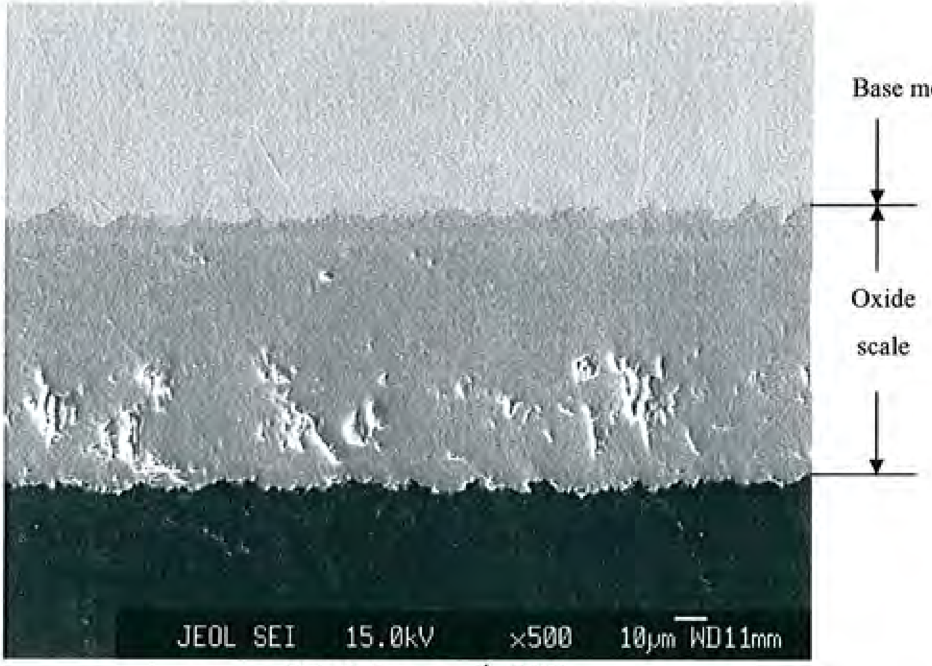
(Concentration/%)



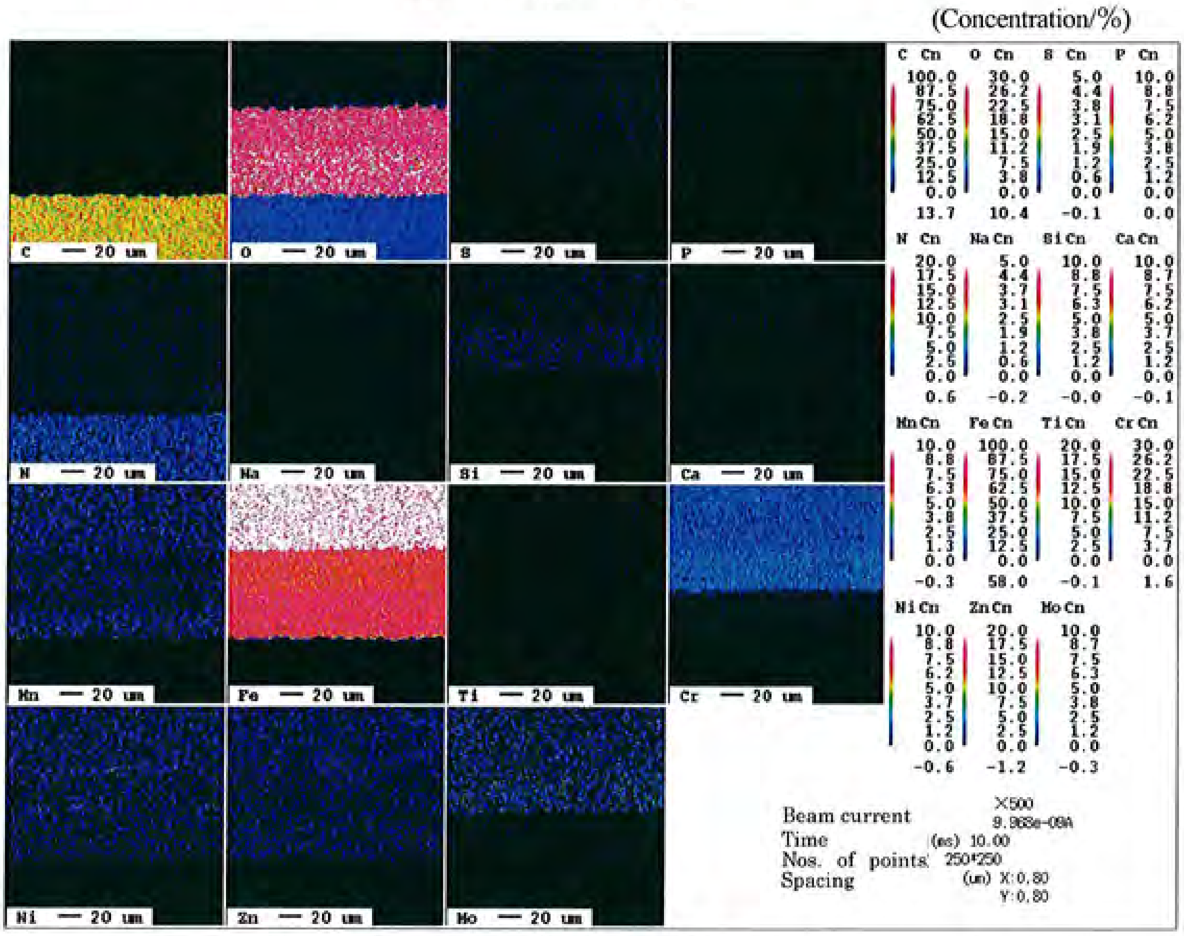
Element Mapping Image (brighter color indicates higher concentration)

Fig I -21. EPMA analysis results

Singrauli RH(in furnace) 【Right】



SEM Image（×500)

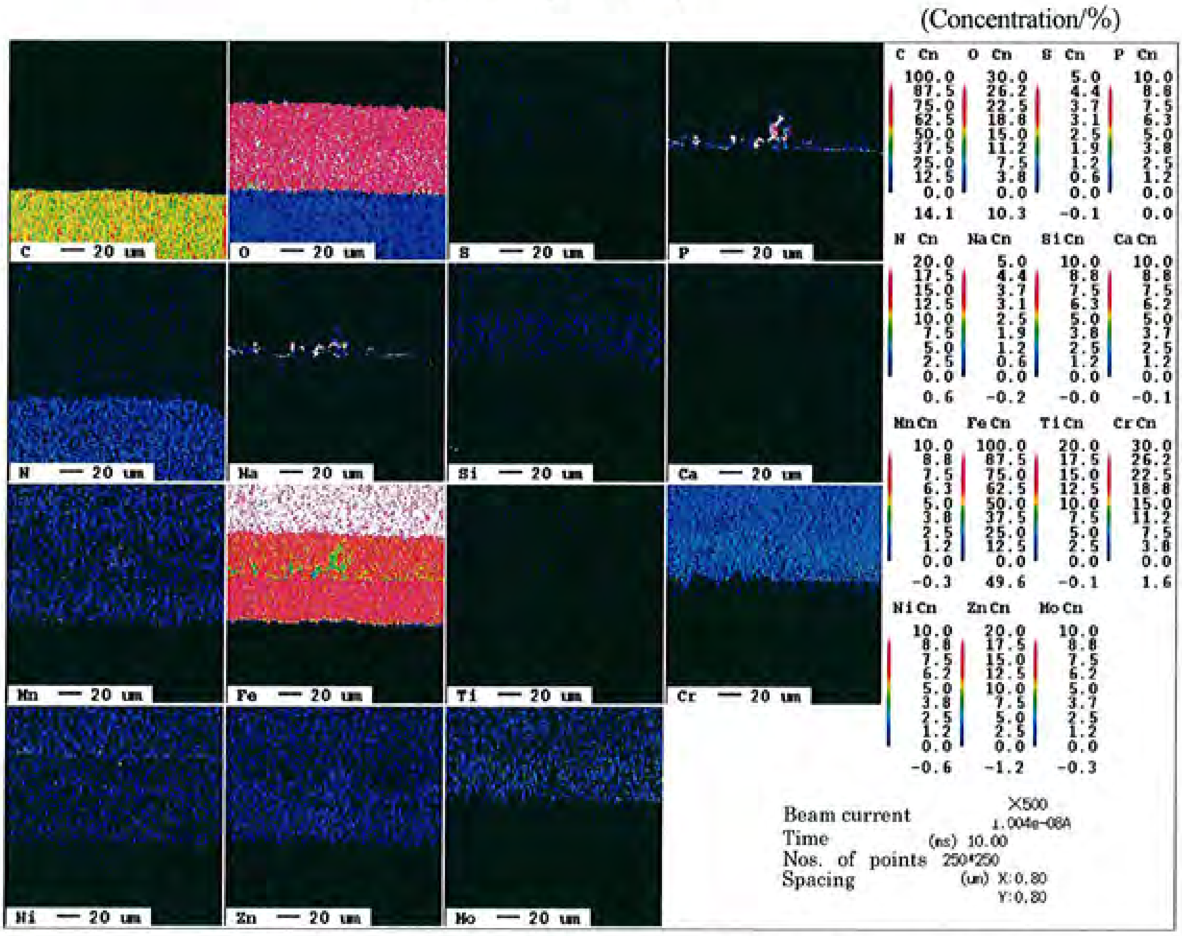


Element Mapping Image（brighter color indicates higher concentration)

Fig I -22. EPMA analysis results

Singrauli RH(in furnace) 【Rear】

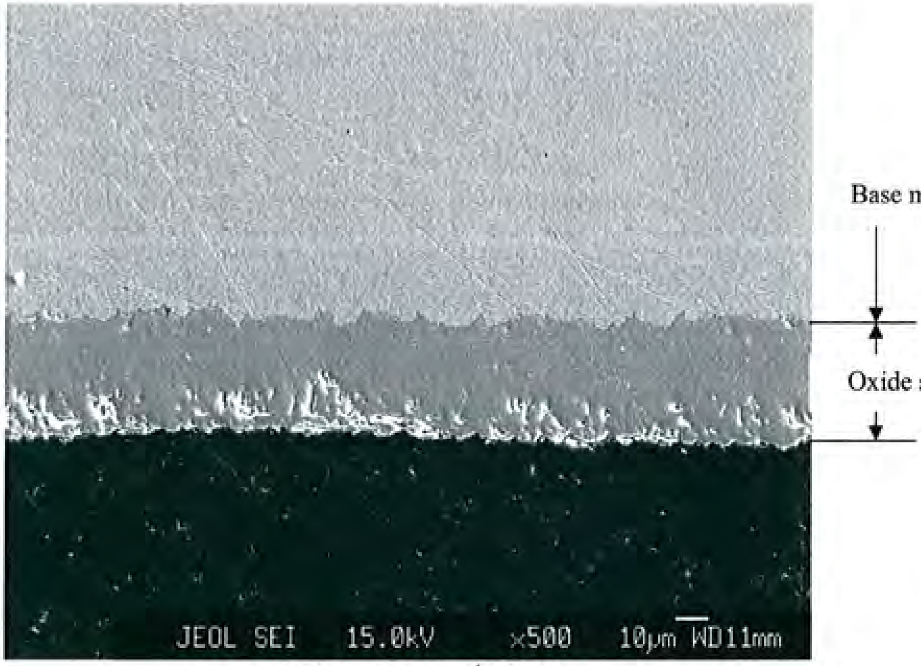
SEM Image (×500)



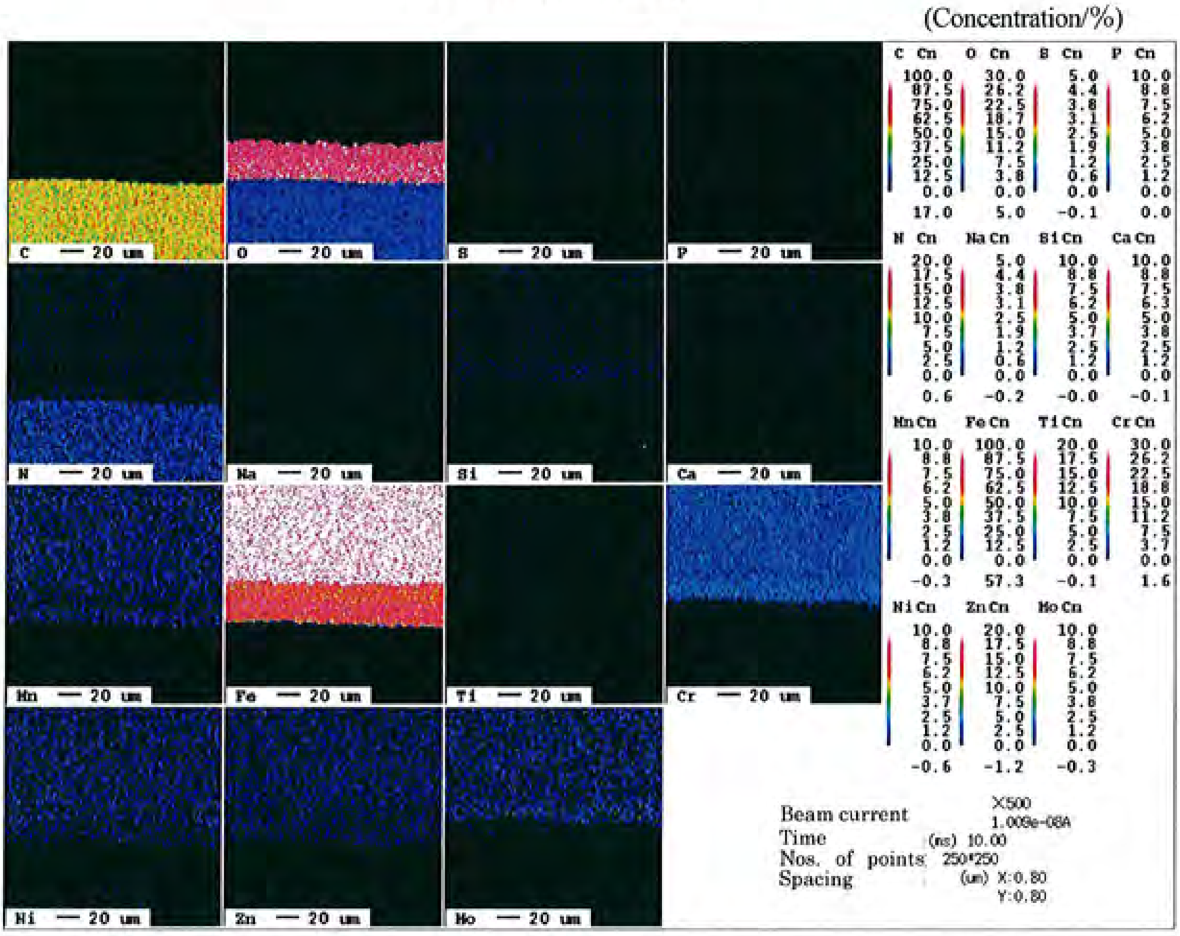
Element Mapping Image (brighter color indicates higher concentration)

Fig I -23. EPMA analysis results

Singrauli RH(in furnace) 【Left】

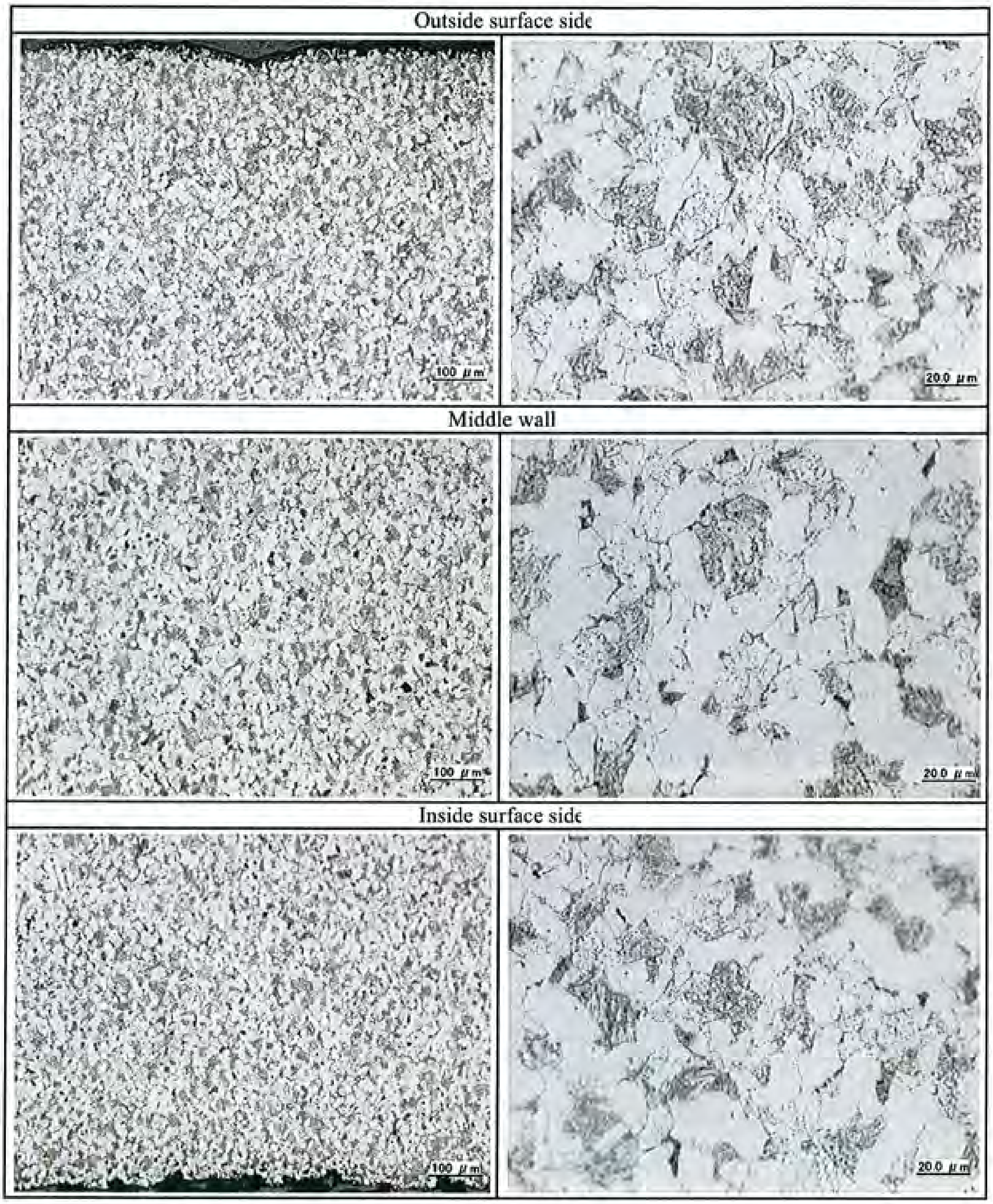


SEM Image (×500)



Element Mapping Image (brighter color indicates higher concentration)

Fig I -24. E P M A analysis results



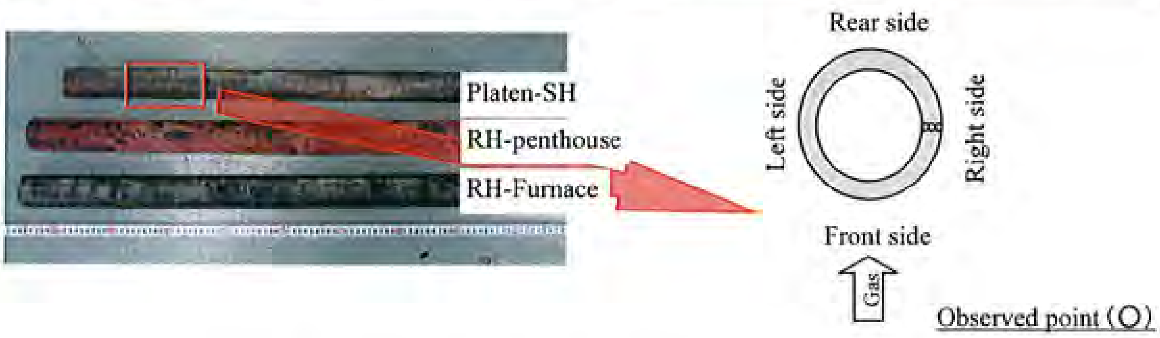
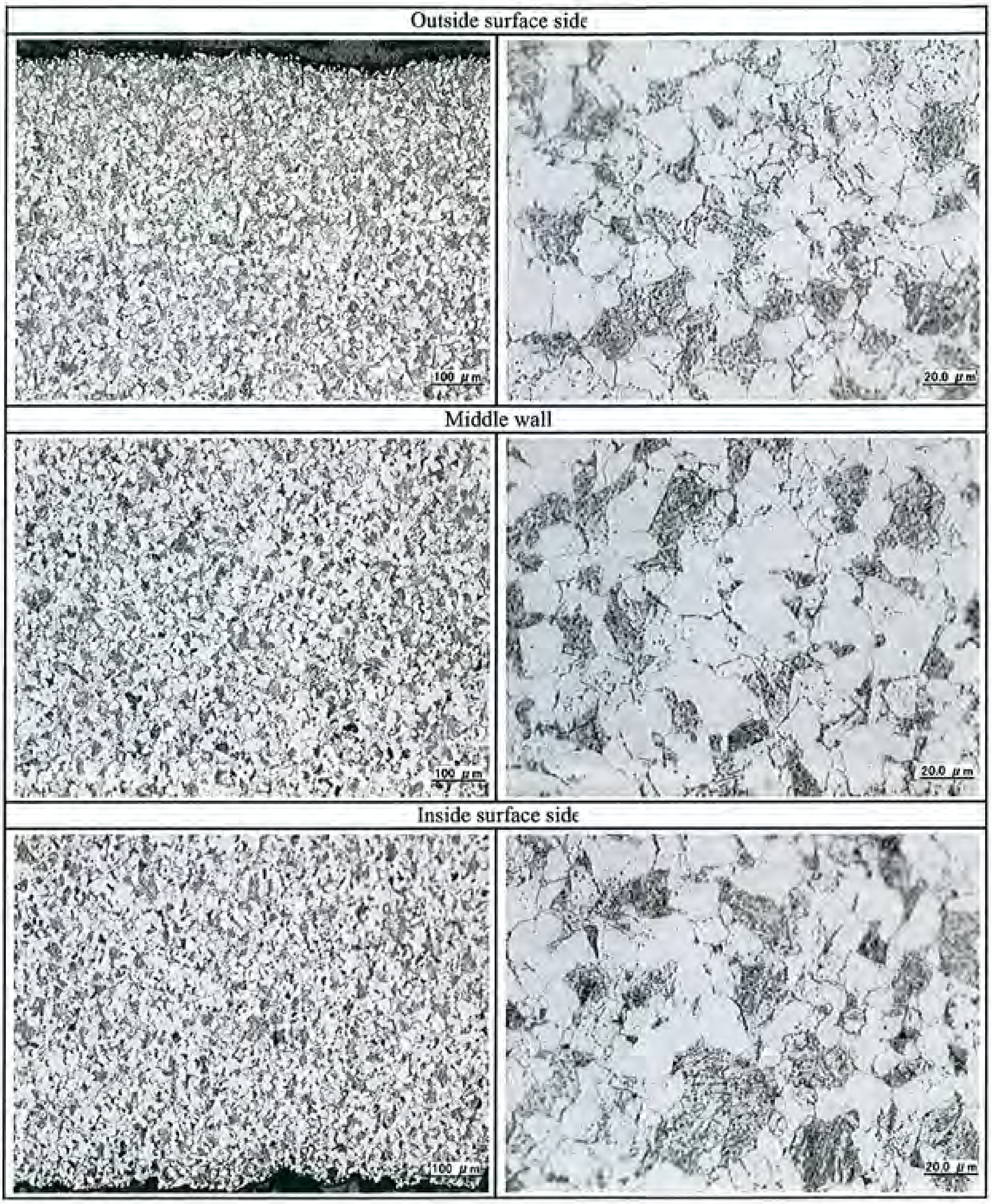


Photo I -20 Microstructure observation at cross section of sample tub
〔Platen-SH (right side, Base Metal)〕



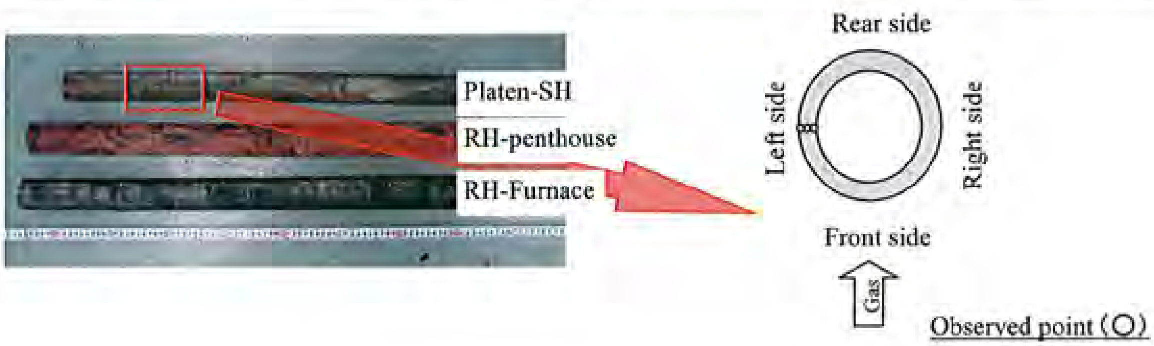
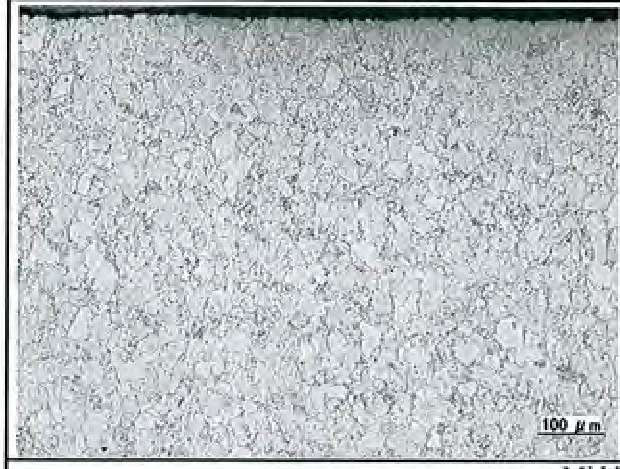
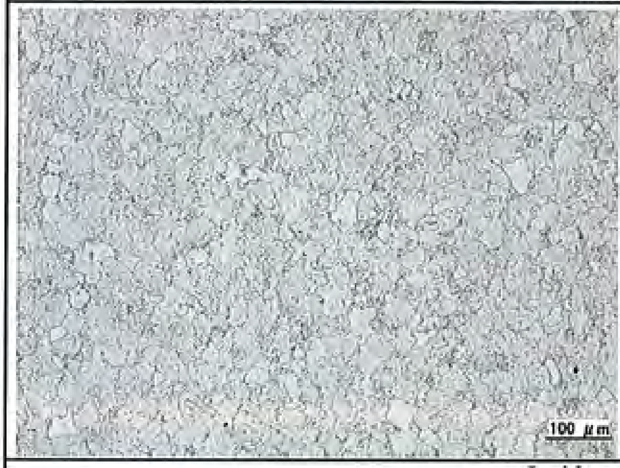


Photo I -21 Microstructure observation at cross section of sample tub
〔Platen-SH (left side, Base Metal)〕

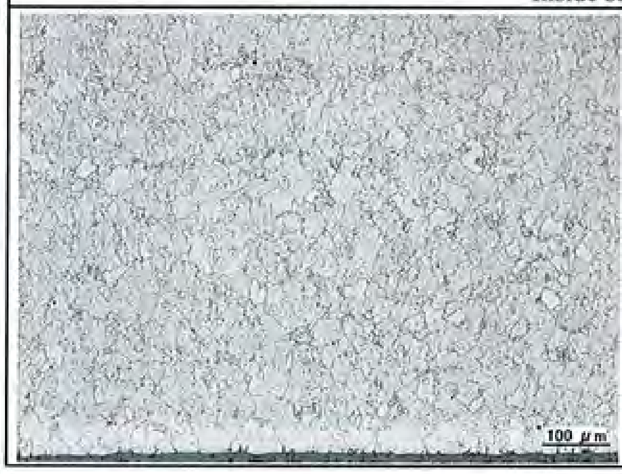
Outside surface side

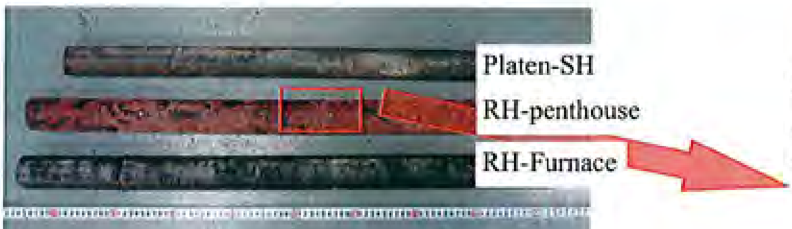


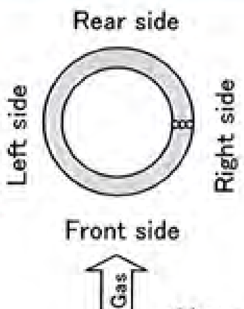
Middle wall



Inside surface side



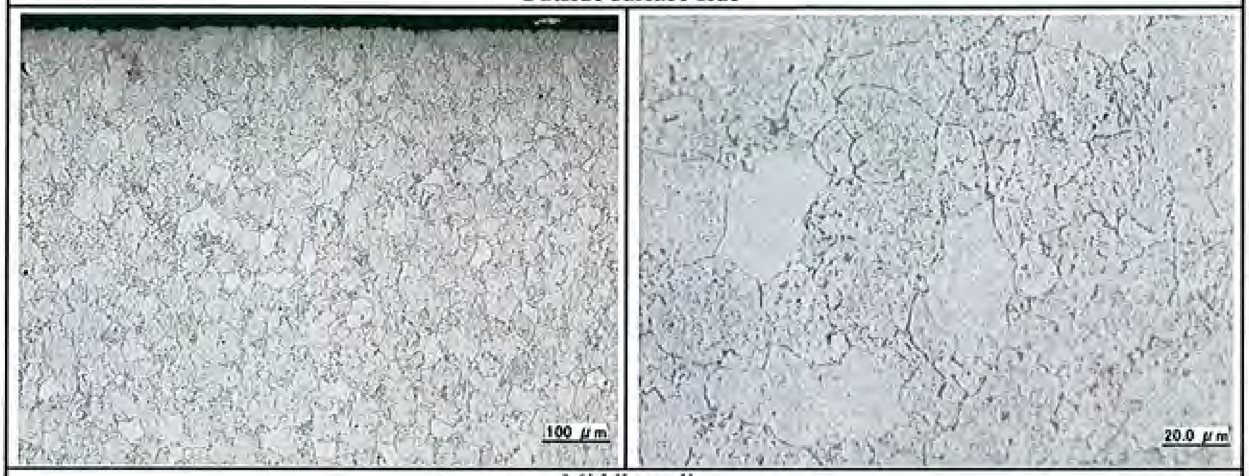




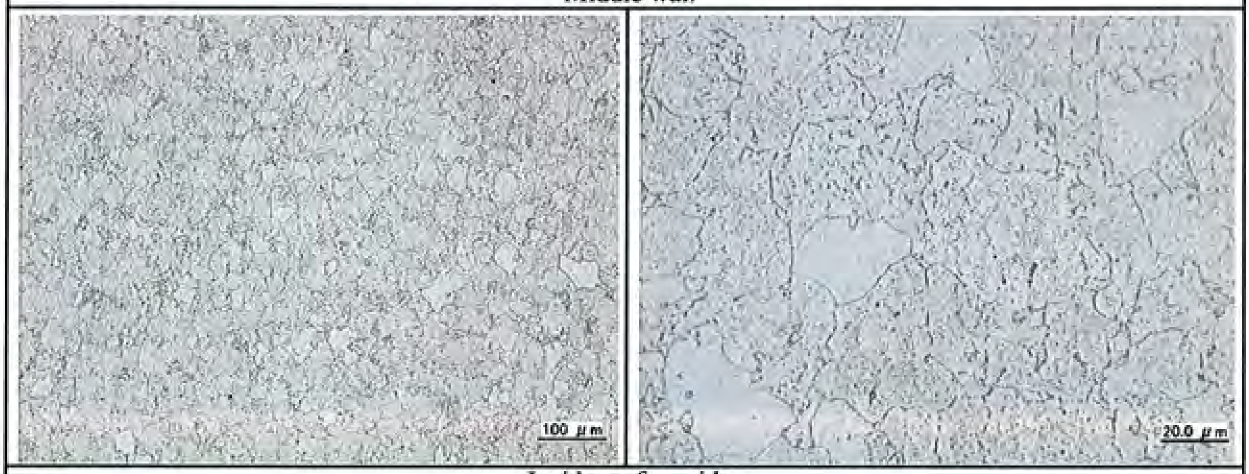
Observed point (O)

Photo I -22　Microstructure observation at cross section of sample tube
〔RH-Penthouse（right side, Base Metal）〕

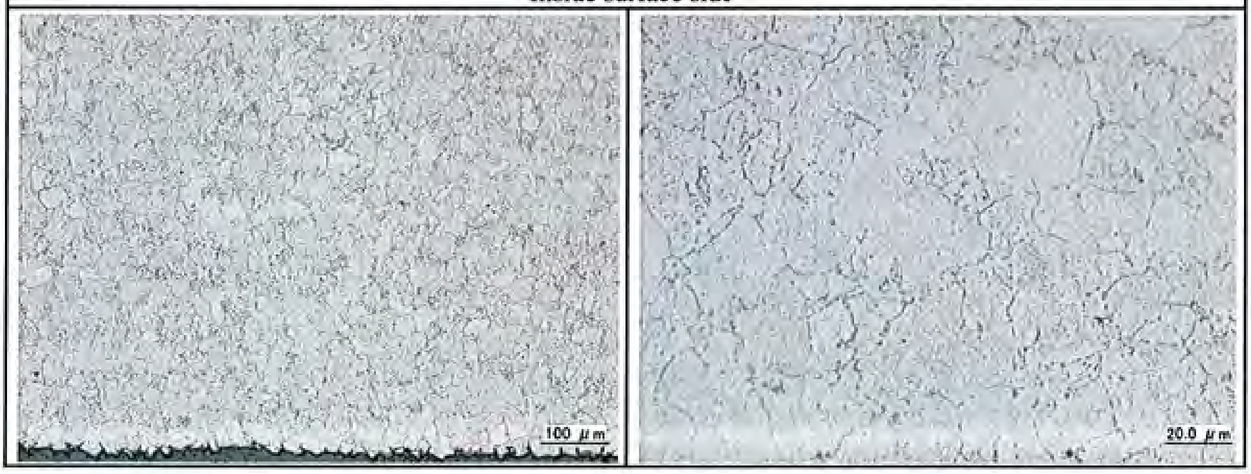
Outside surface side



Middle wall



Inside surface side



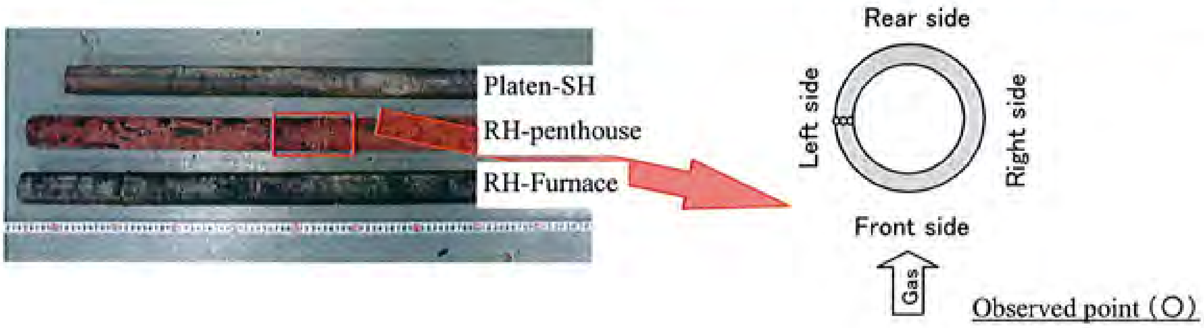
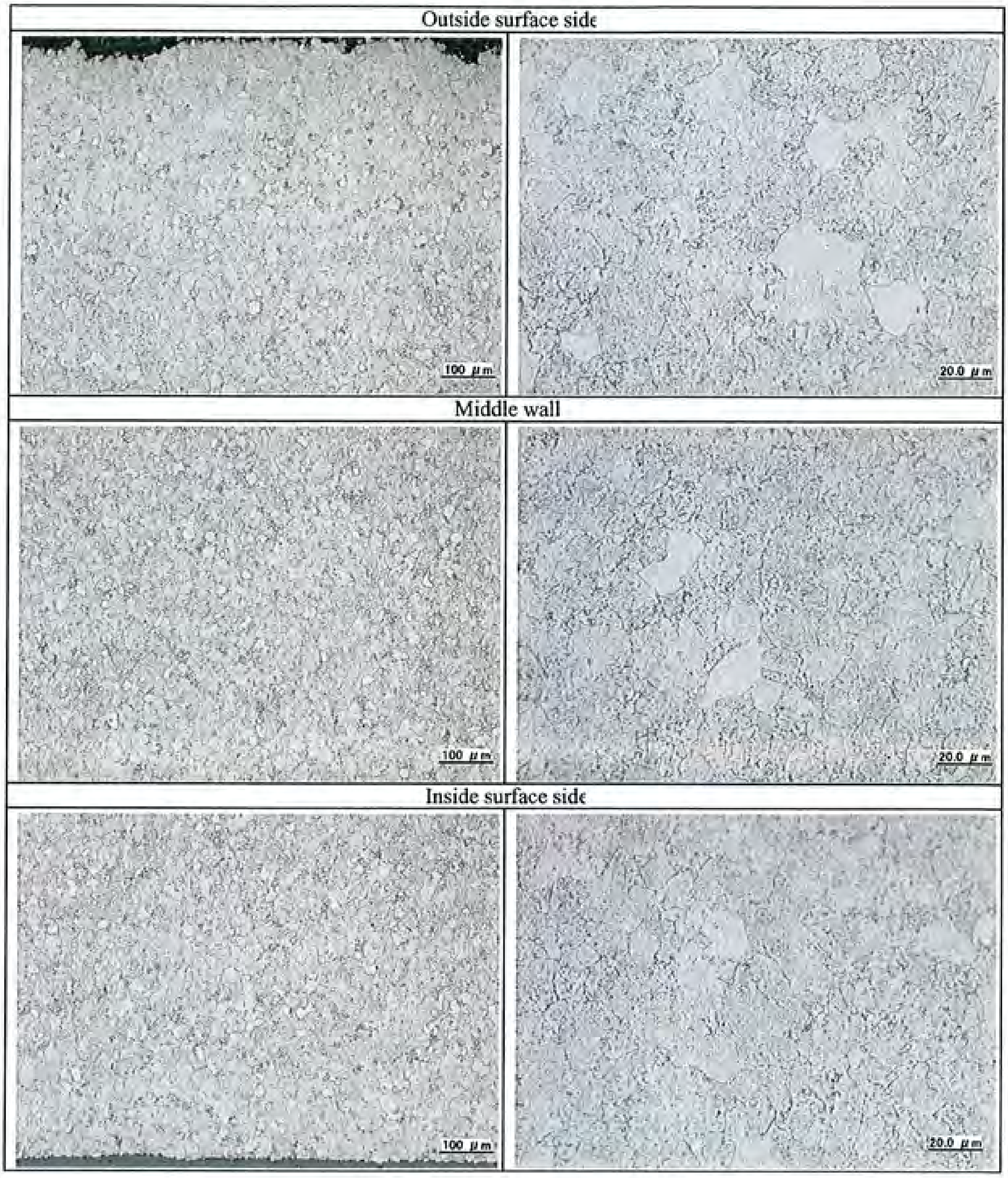


Photo Ⅰ-23 Microstructure observation at cross section of sample tube
〔RH-Penthouse（right side, Base Metal）〕



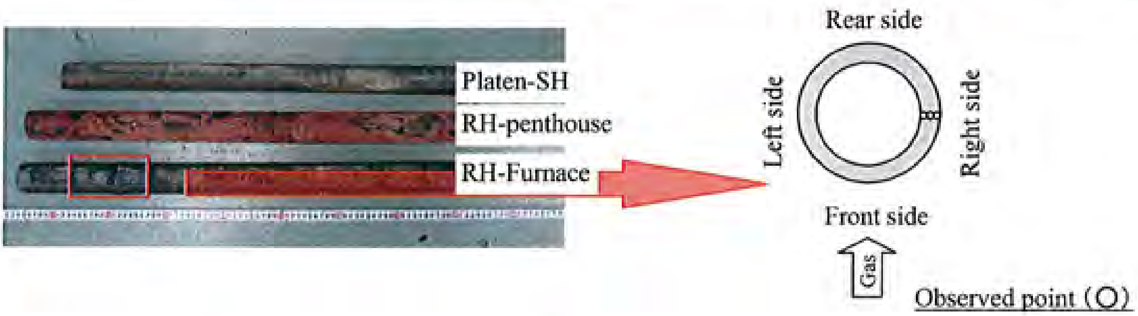


Photo I -24 Microstructure observation at cross section of sample tube
〔RH-Furnace (right side, Base Metal) 〕

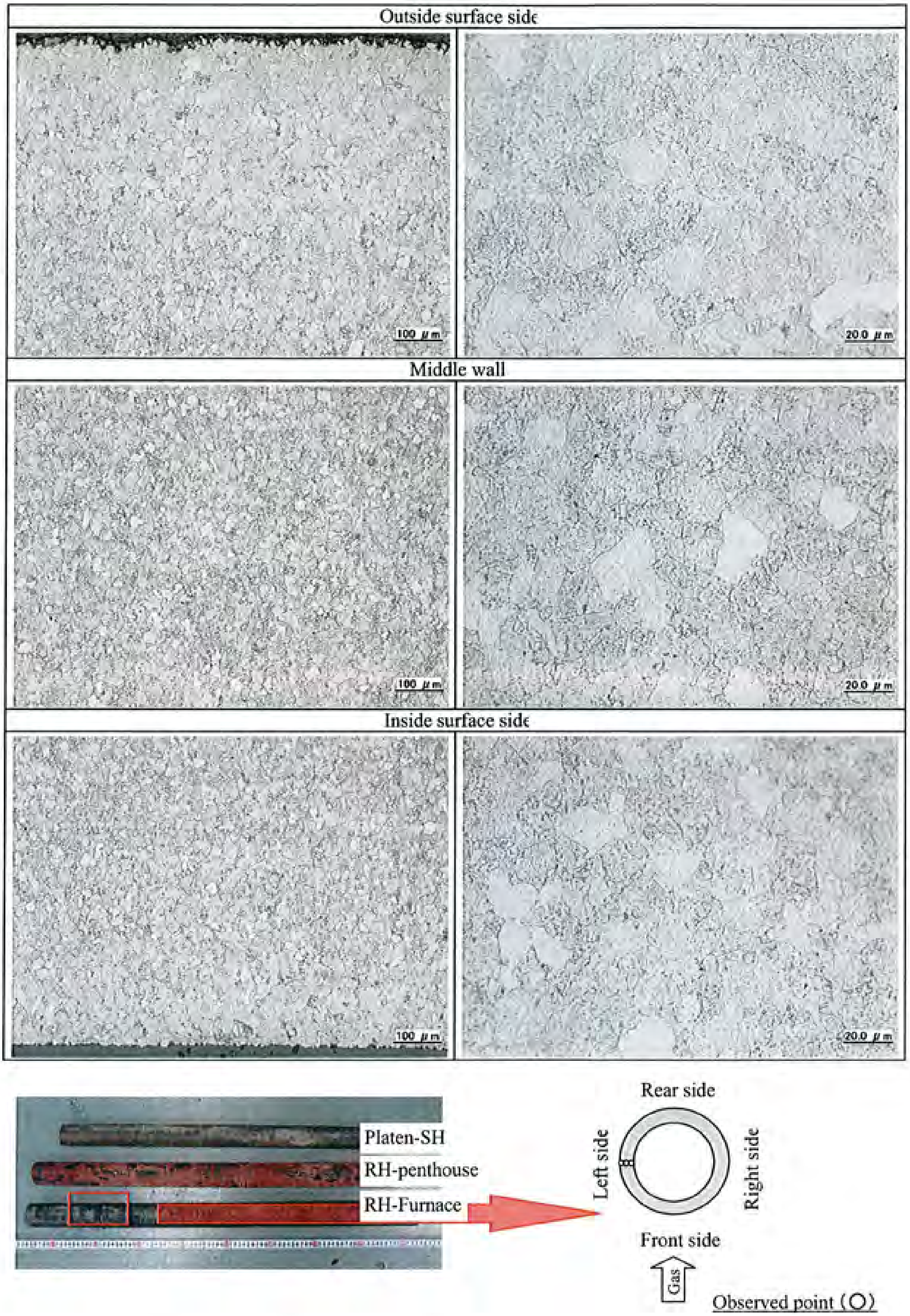
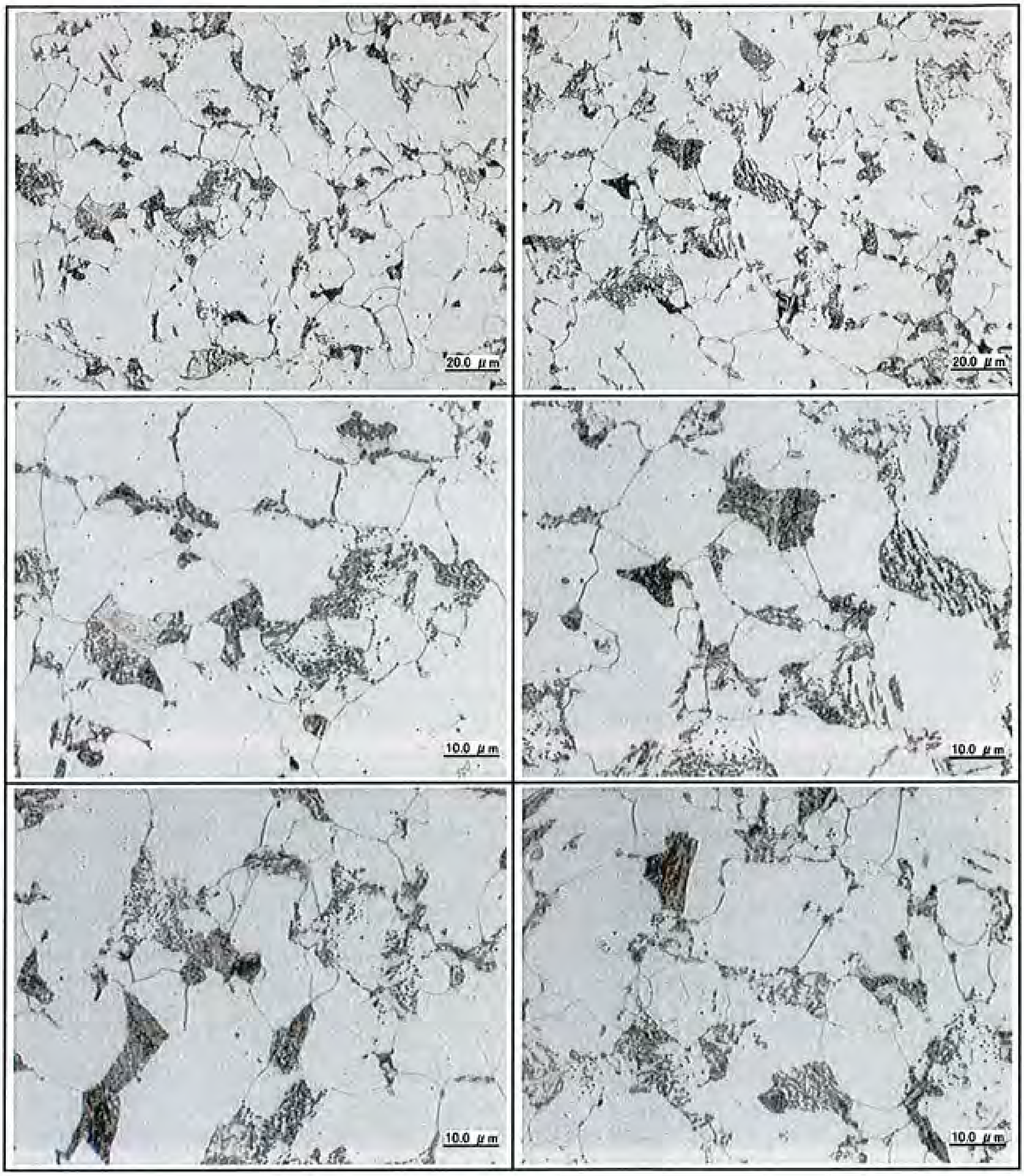
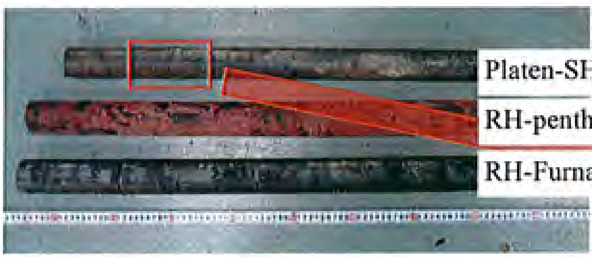


Photo I -25 Microstructure observation at cross section of sample tube
〔RH-Furnace (left side, Base Metal) 〕





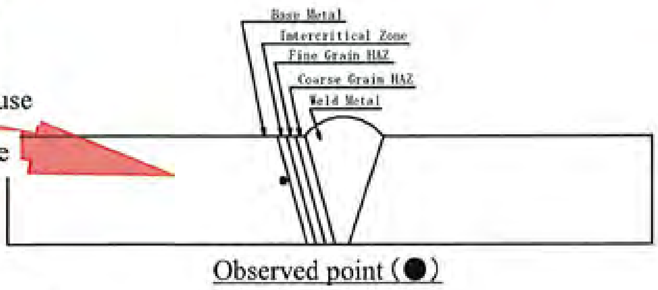
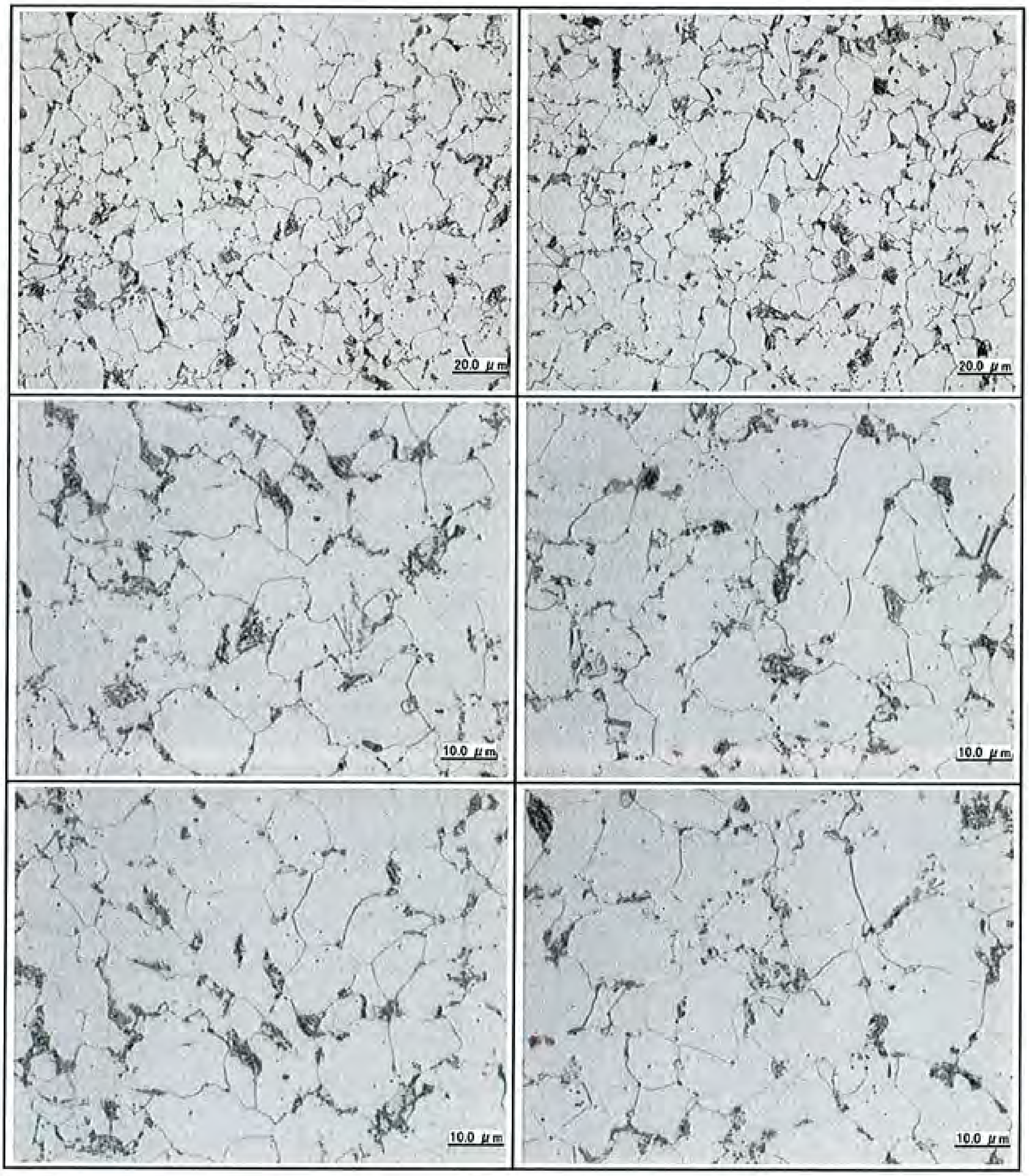


Photo I -26　Microstructure observation at cross section of sample tube
〔Platen-SH（Base Metal）〕



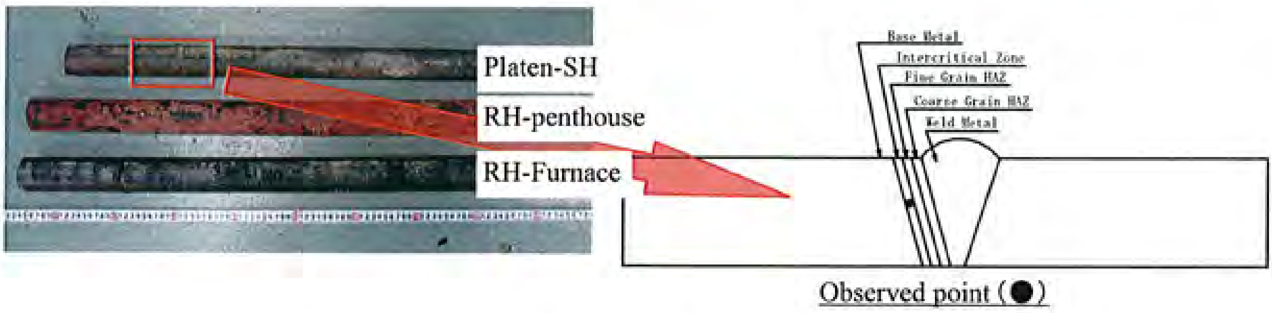
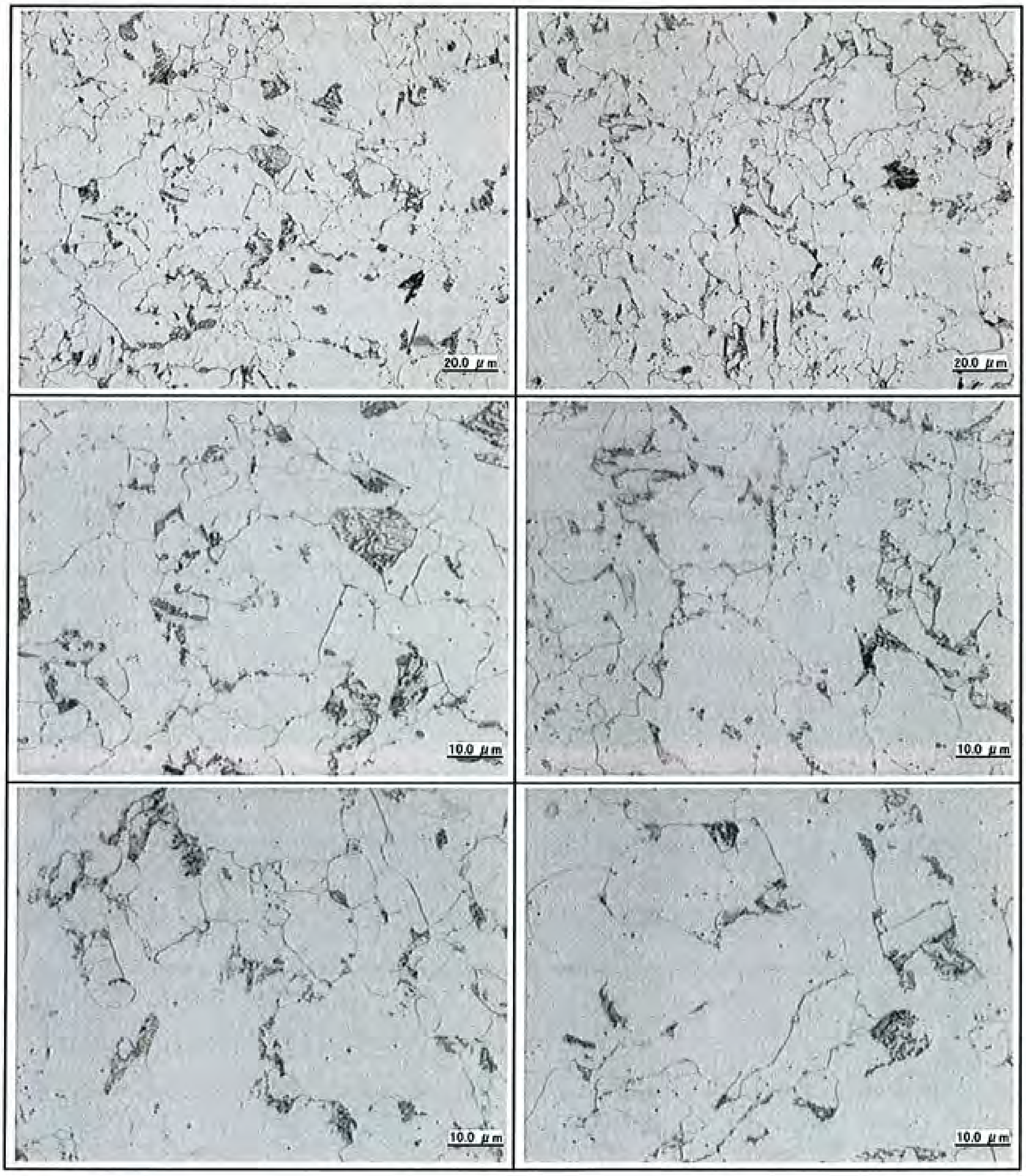


Photo I -27　Microstructure observation at cross section of sample tube
〔Platen-SH（Intercritical Zone）〕



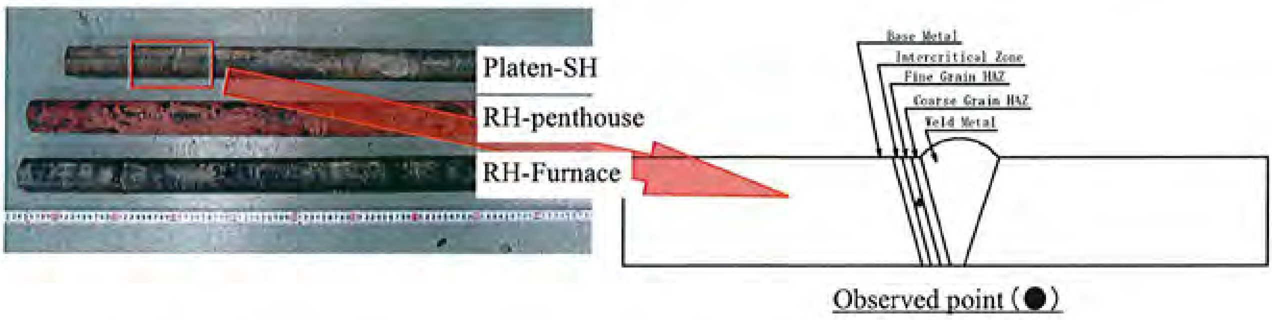
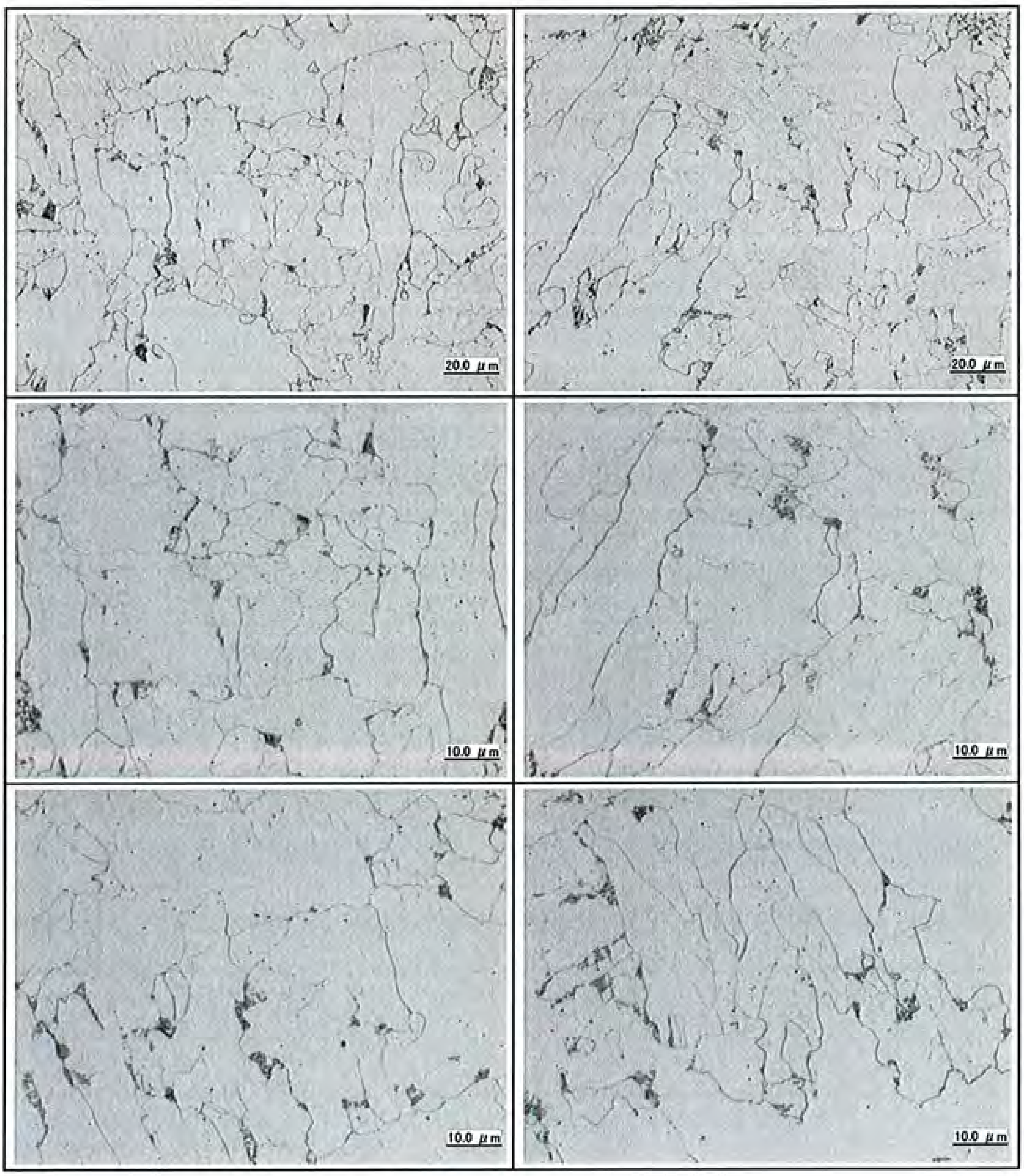


Photo Ⅰ-28 Microstructure observation at cross section of sample tube
〔Platen-SH（Fine Grain HAZ）〕



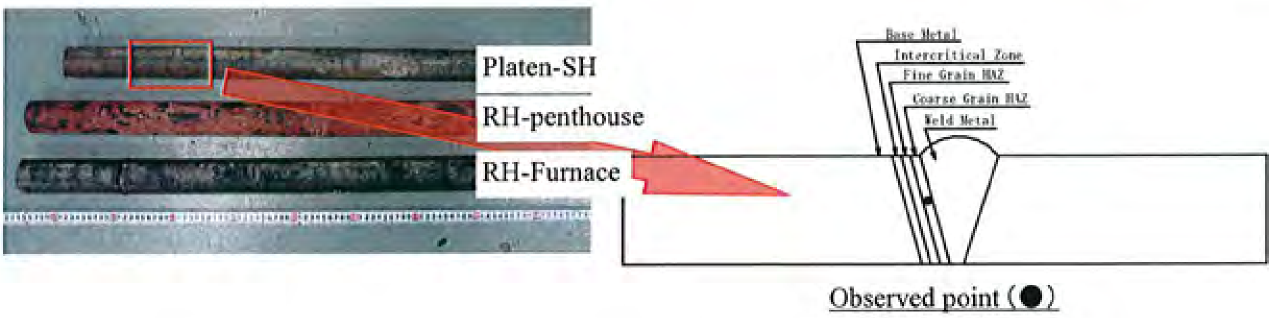
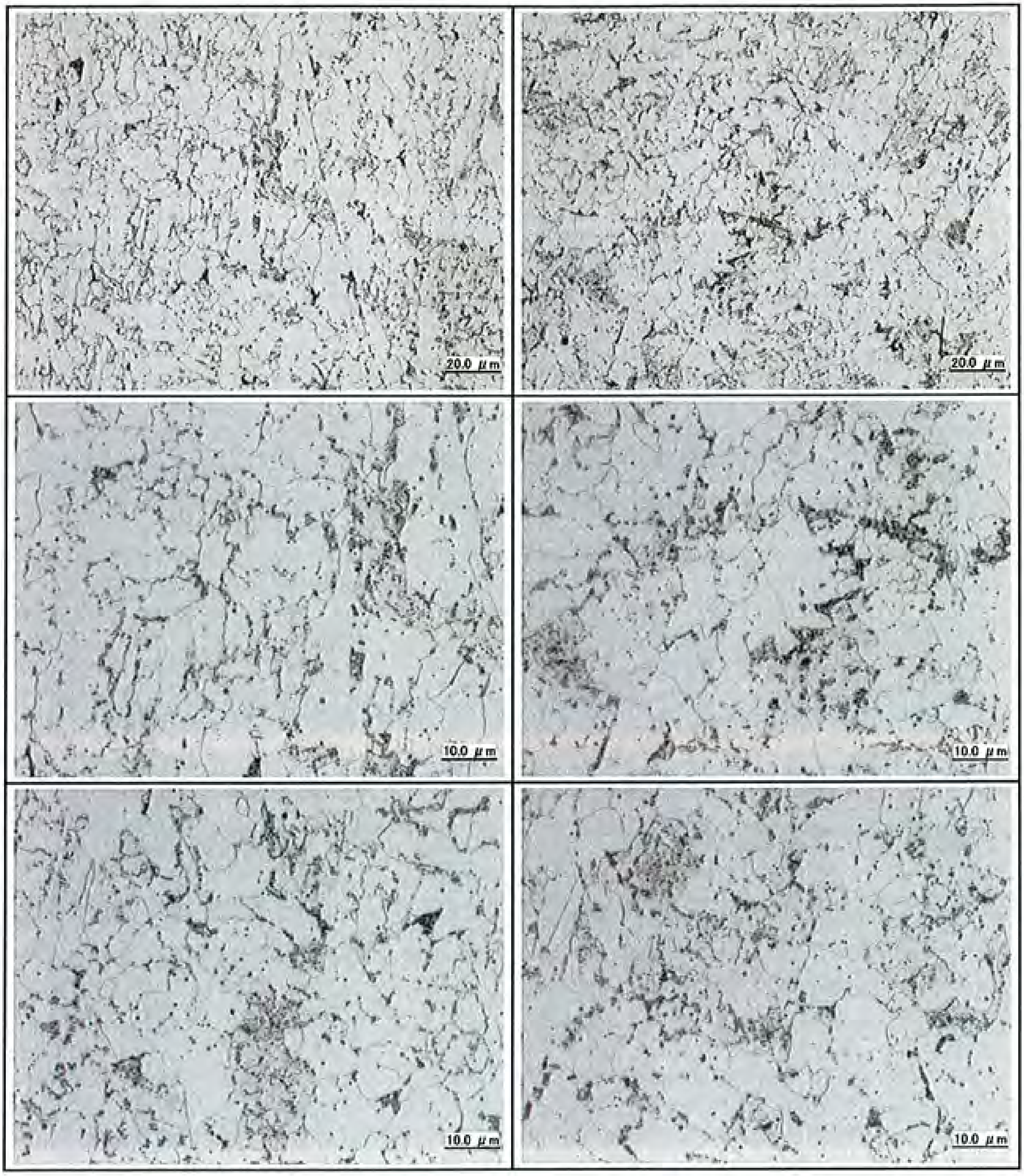


Photo I -29 Microstructure observation at cross section of sample tube
〔Platen-SH（Coarse Grain HAZ）〕



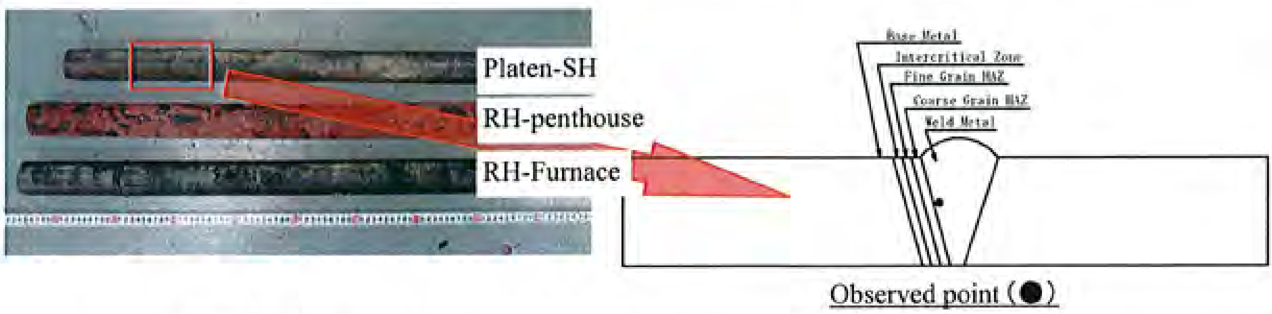
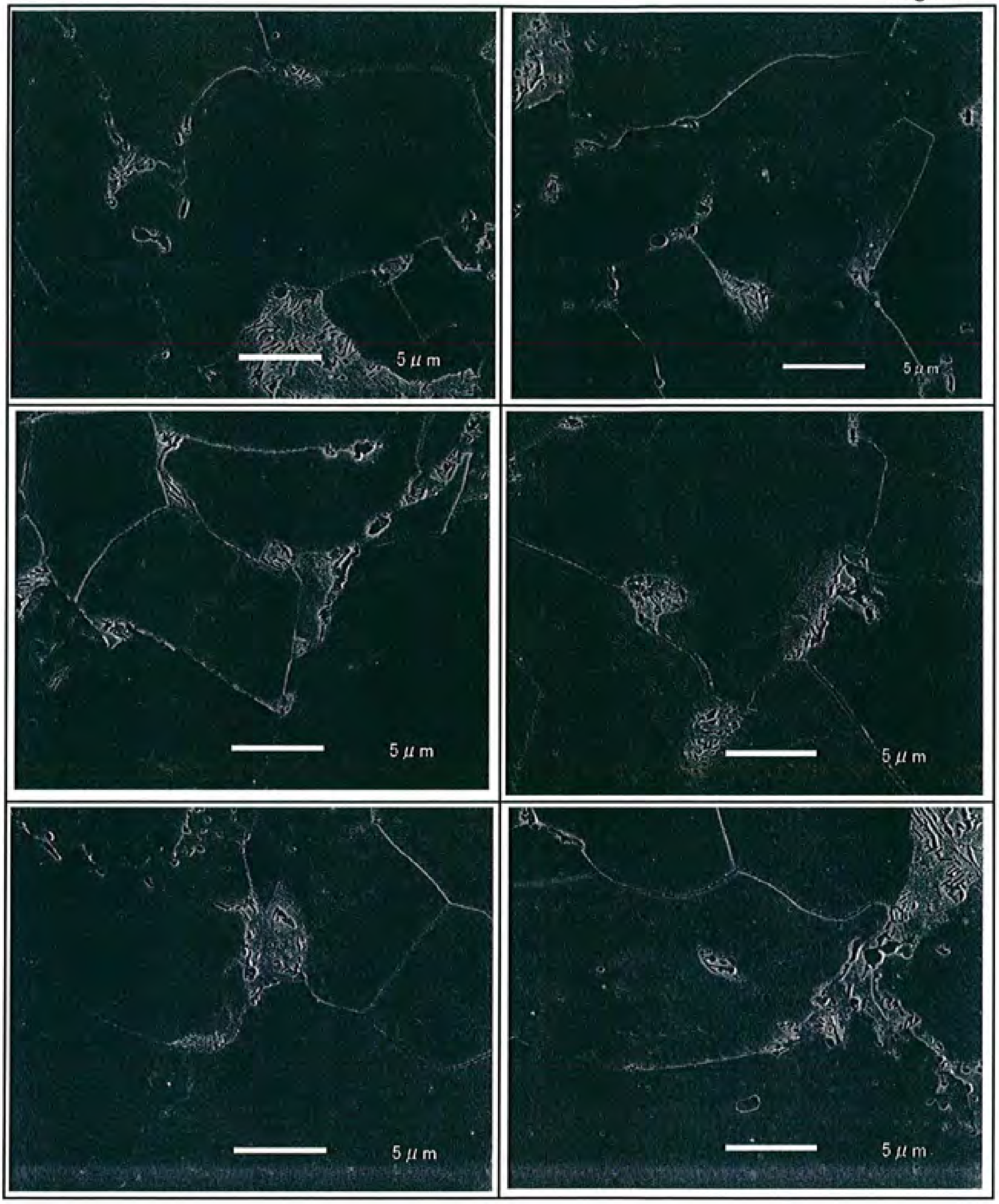


Photo Ⅰ-30 Microstructure observation at cross section of sample tube
〔Platen-SH（Weld Metal）〕



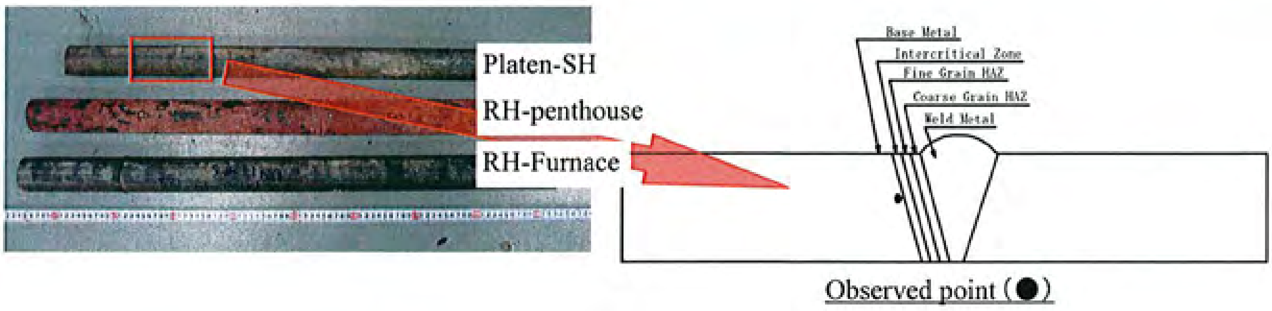
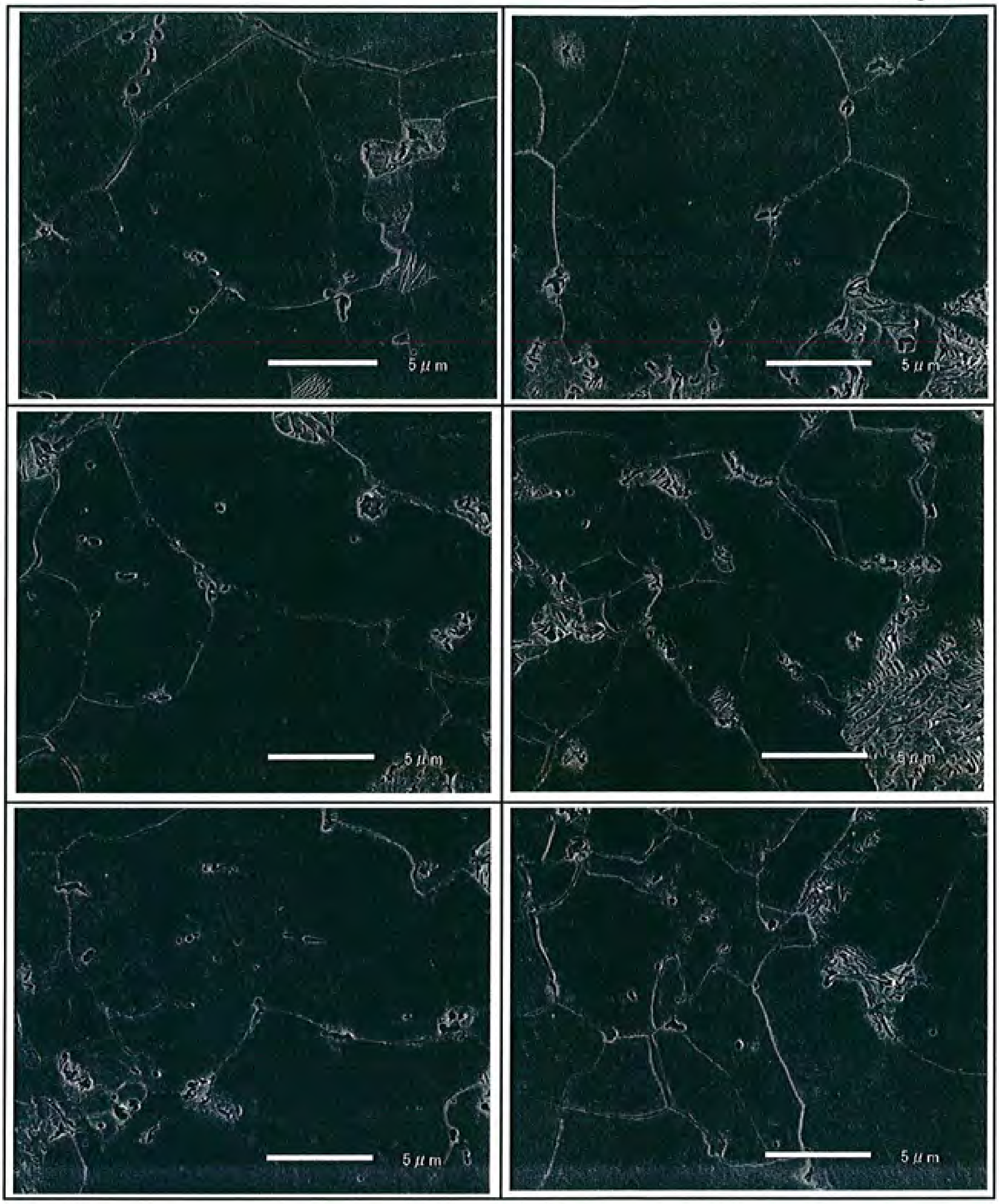


Photo I -31　Precipitates along grain boundary by SEM observatior
〔Platen-SH（Base Metal）〕



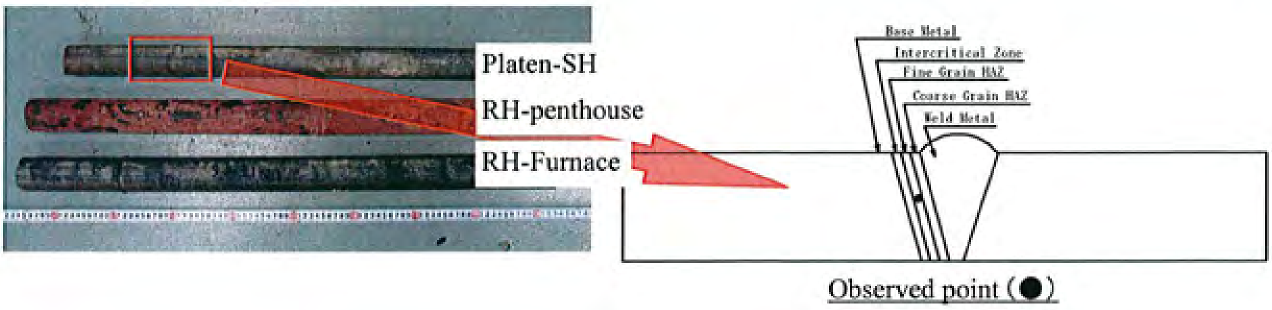
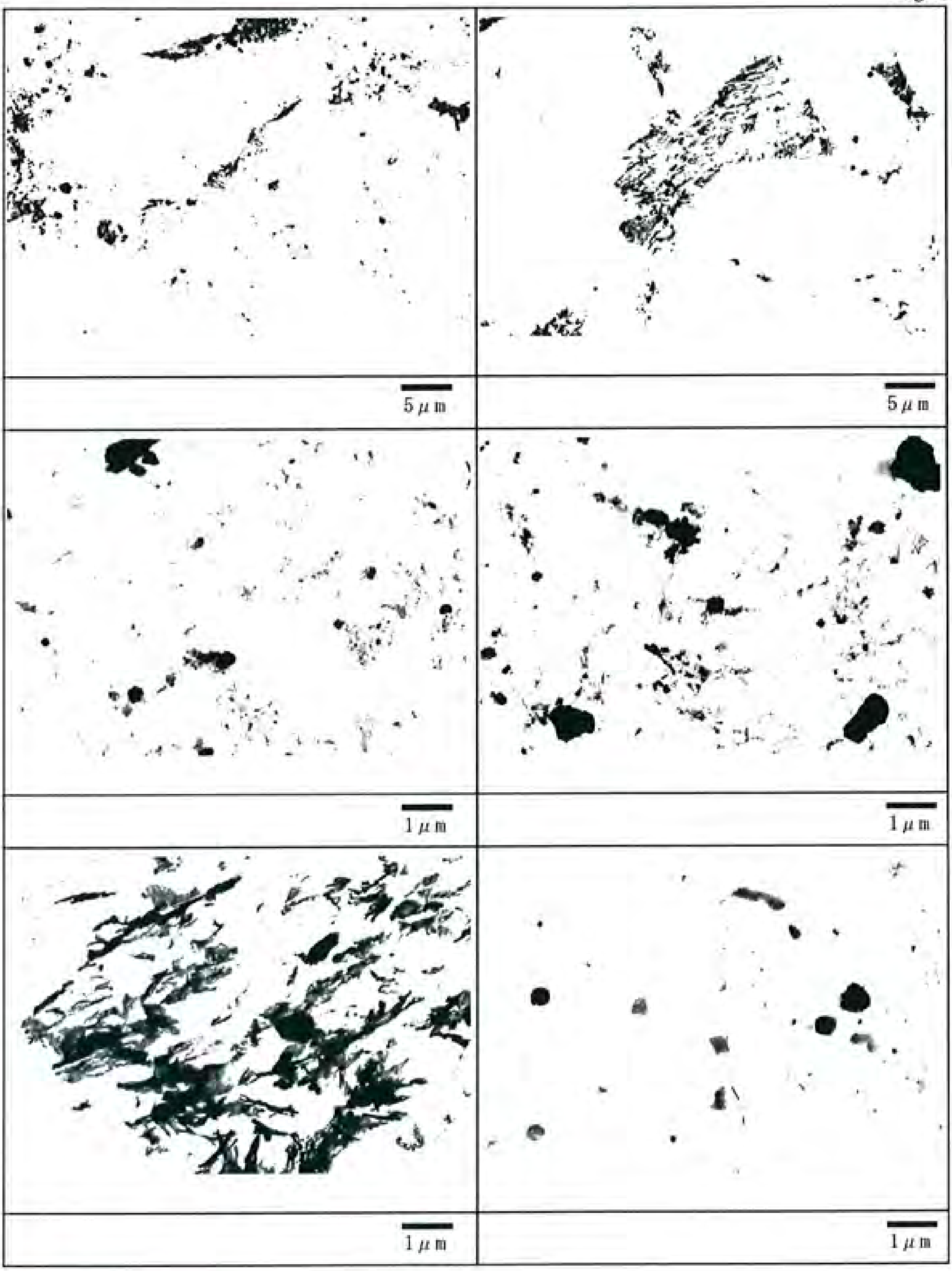


Photo I -32 Precipitates along grain boundary by SEM observatior
〔Platen-SH (Fine Grain HAZ) 〕



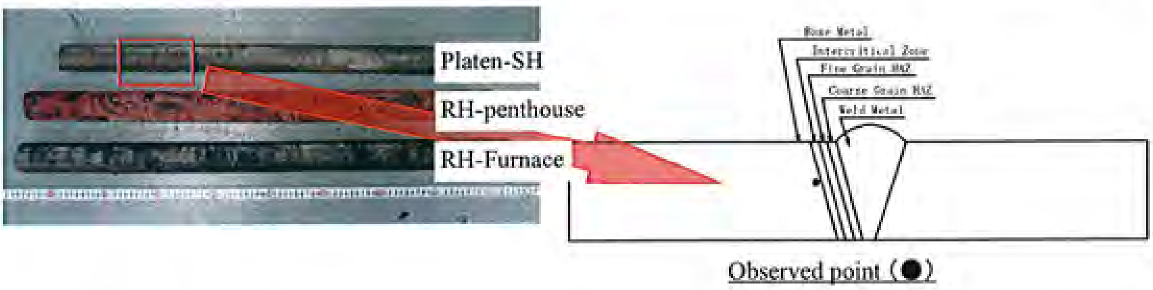
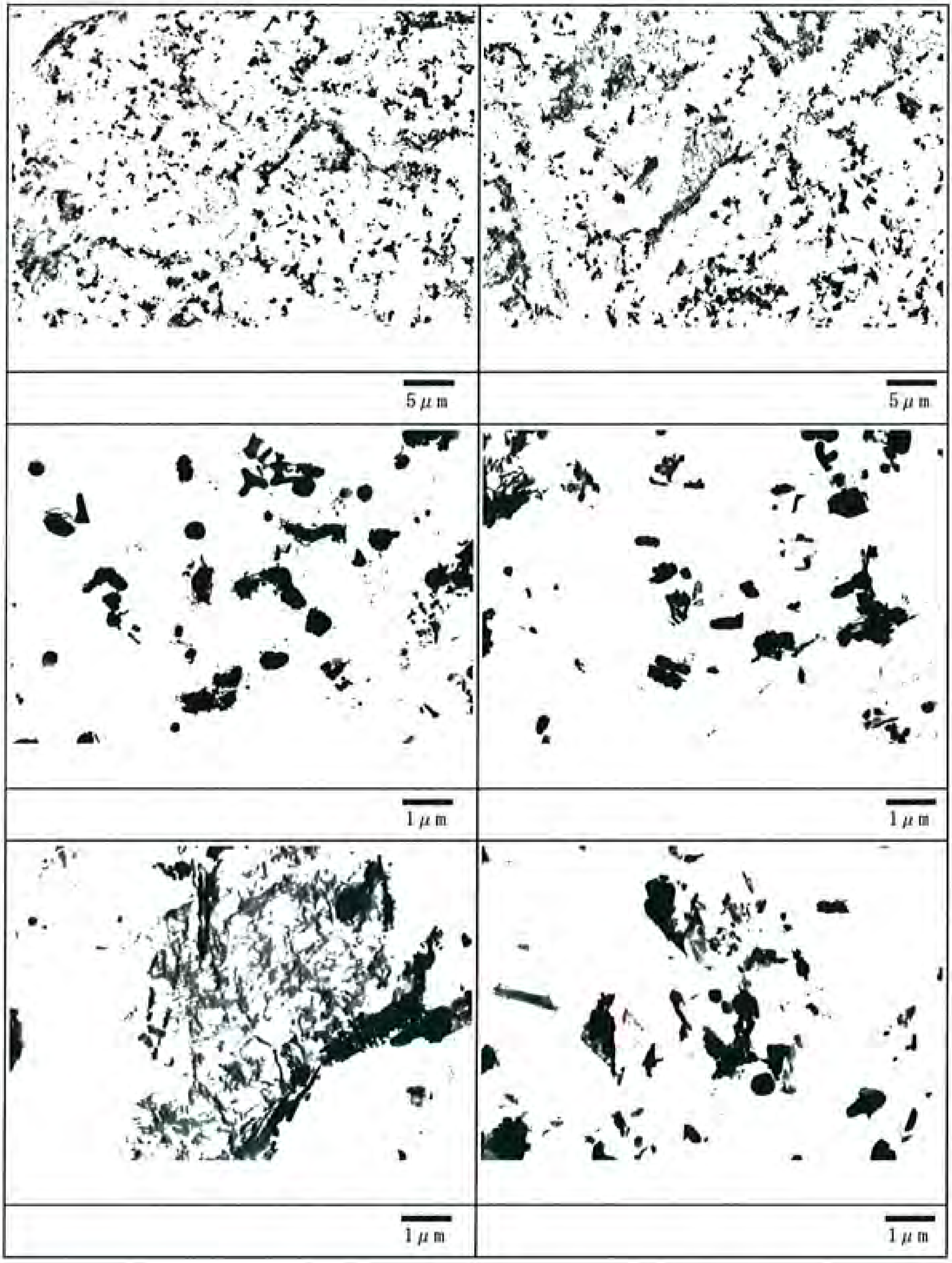


Photo I -33 Precipitates distribution by TEM observation〔Platen-SH (Base Metal)〕



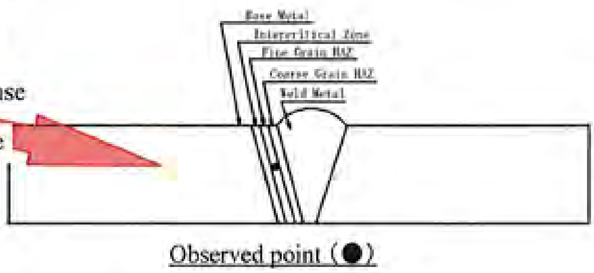
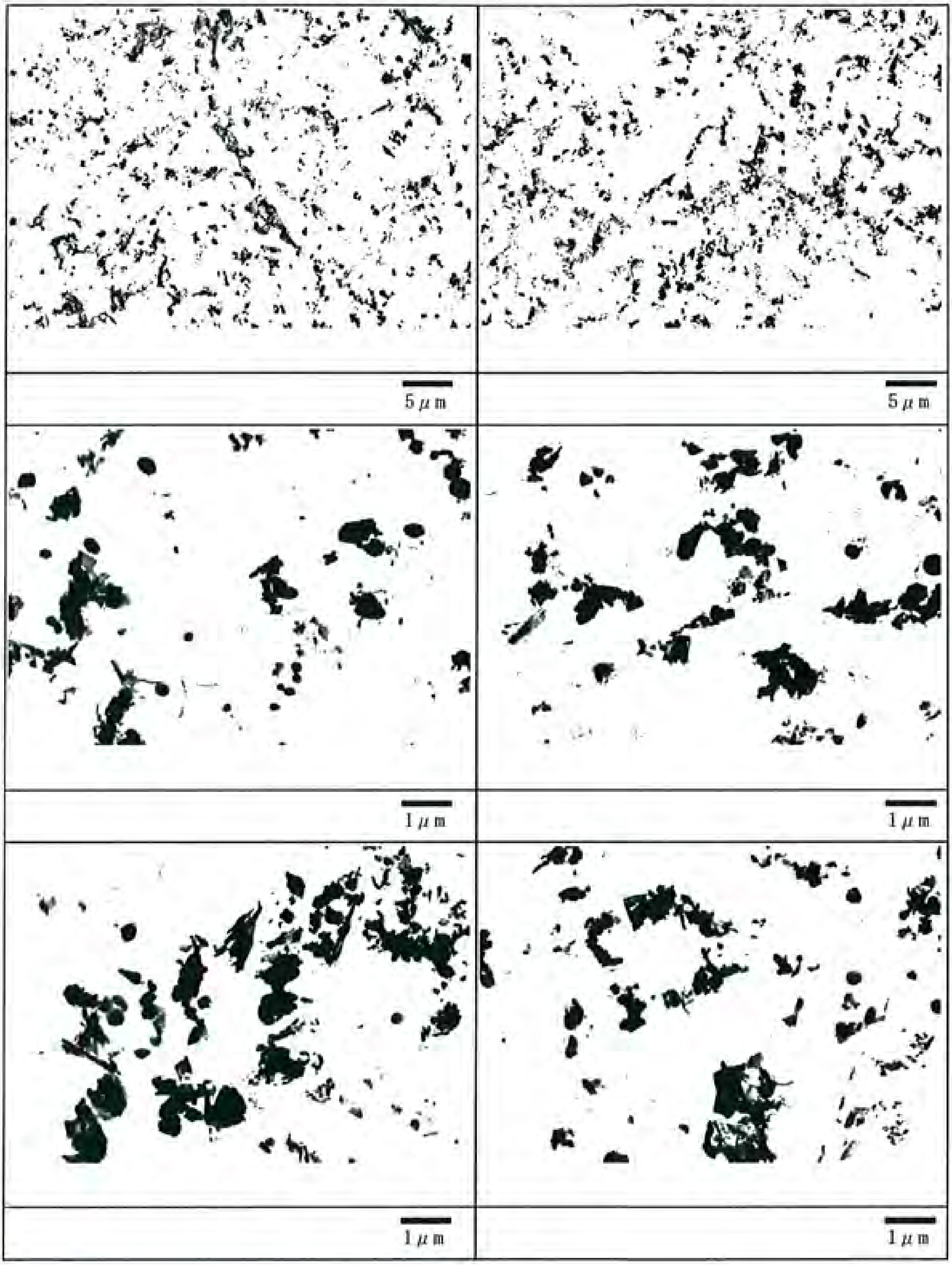


Photo Ⅰ-34 Precipitates distribution by TEM observation〔Platen-SH (Fine Grain HAZ) 〕



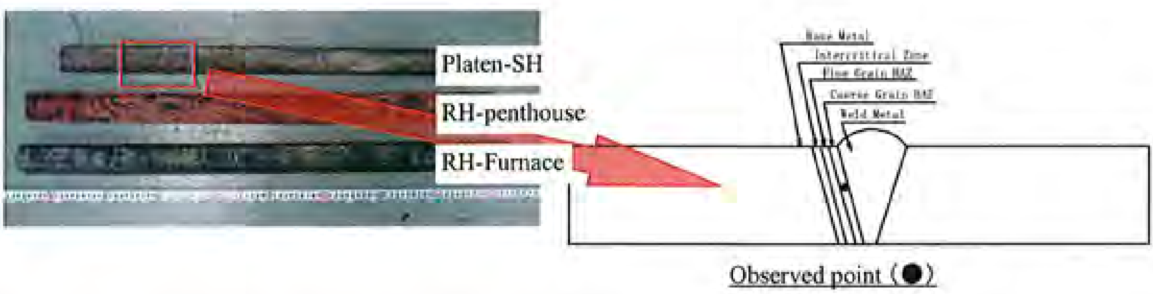


Photo I -35 Precipitates distribution by TEM observation〔Platen-SH (Coarse Grain HAZ) 〕

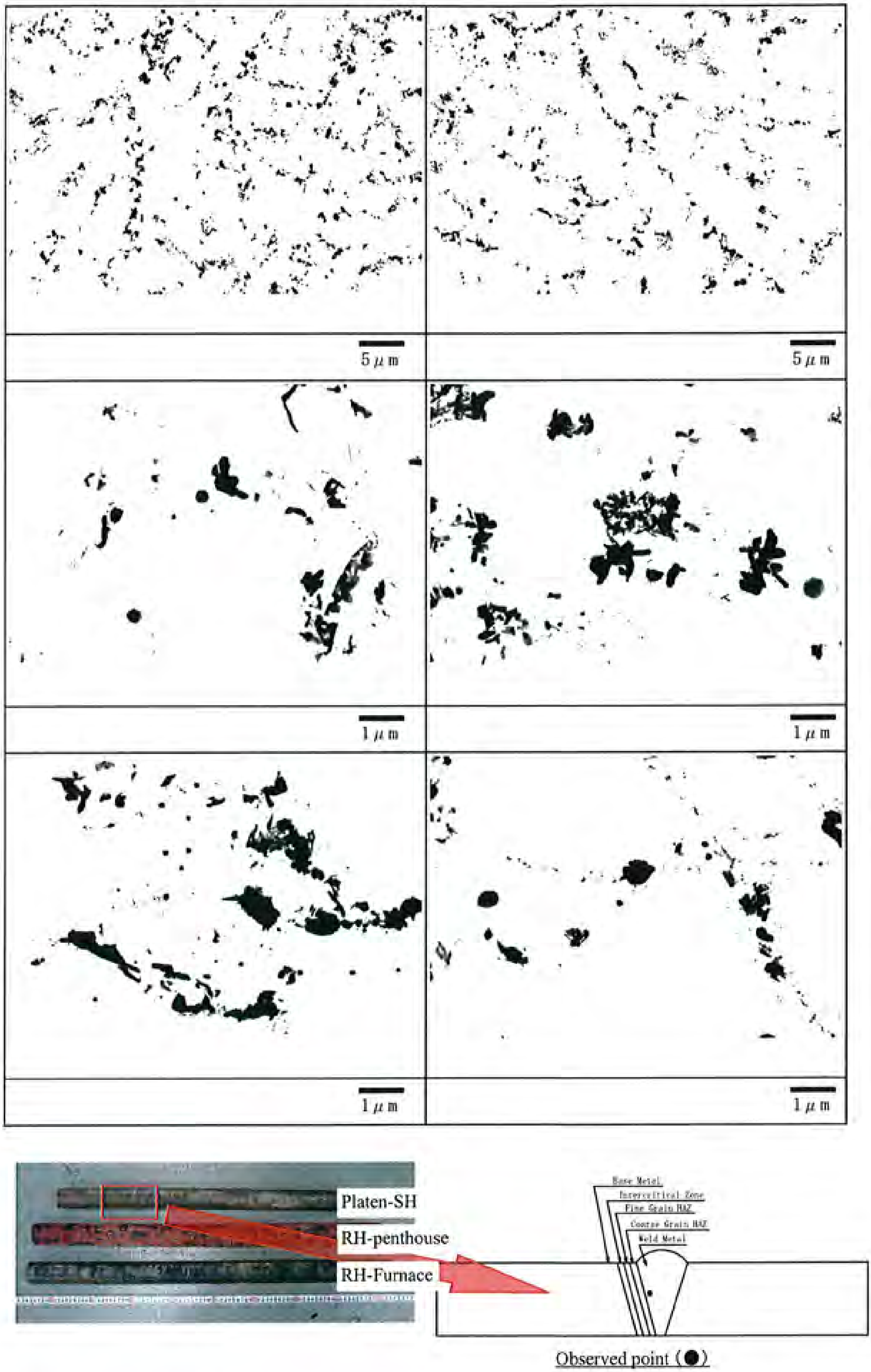


Photo I -36 Precipitates distribution by TEM observation〔Platen-SH (Weld Metal) 〕

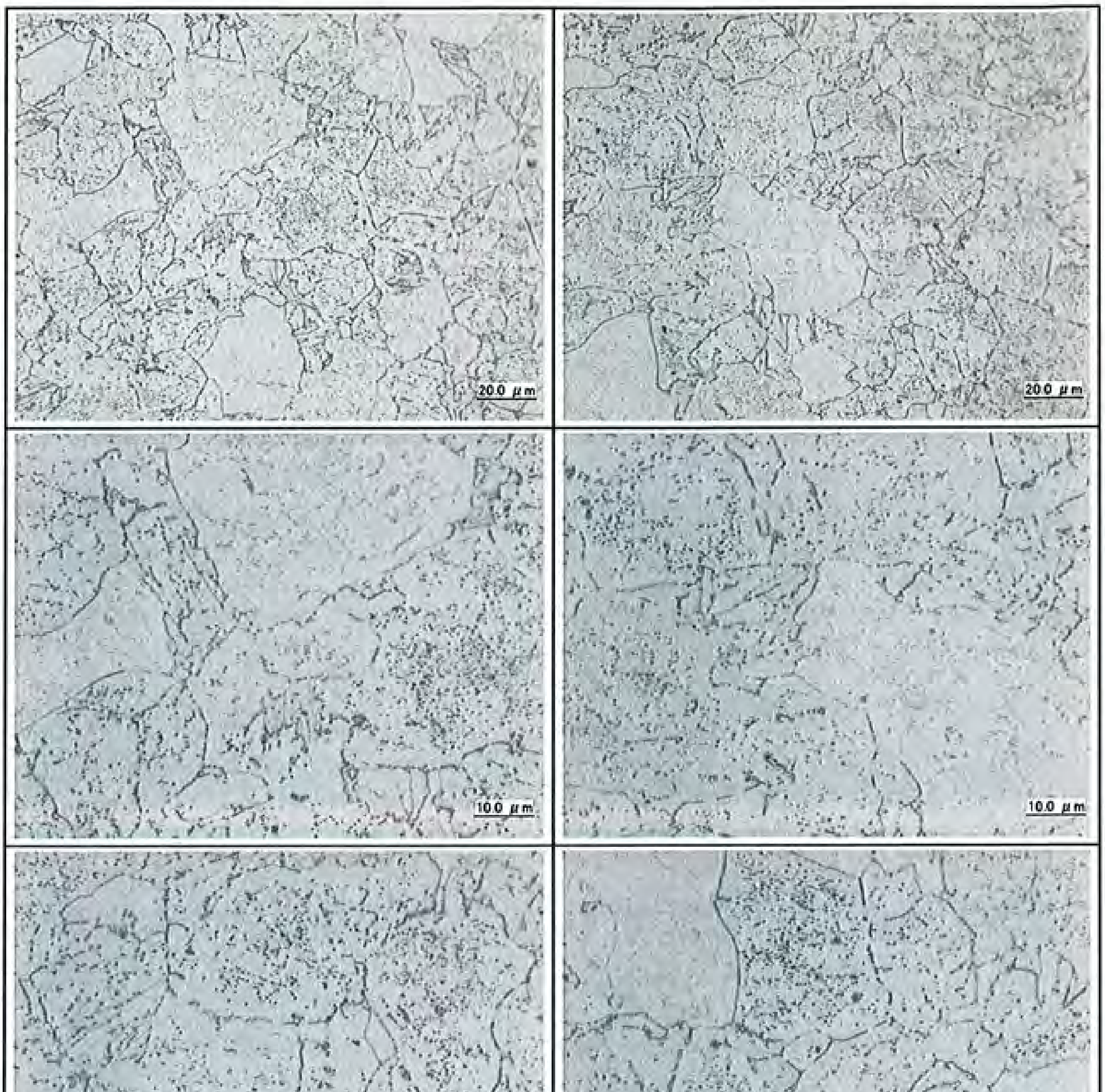
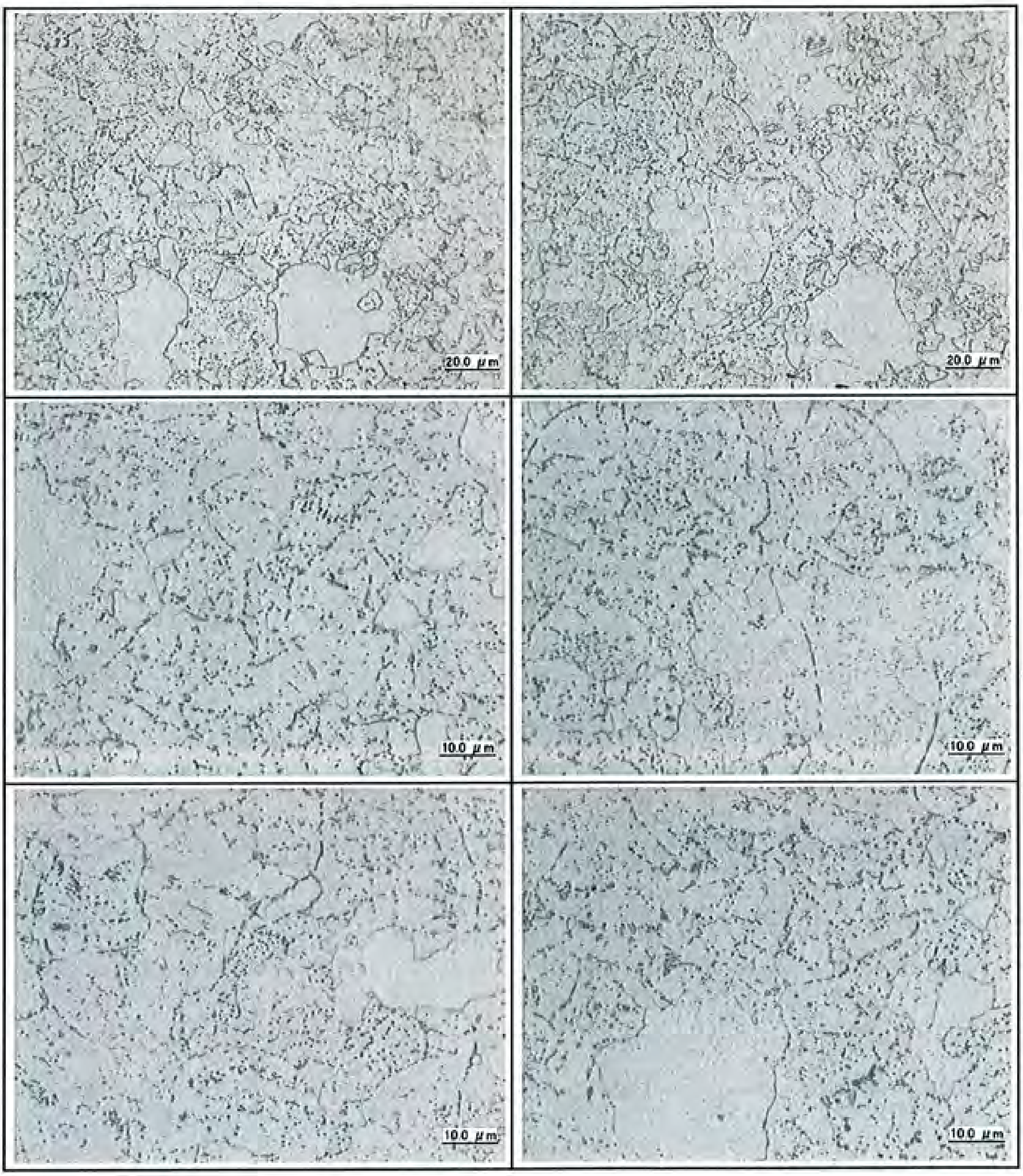


Photo I -37 Microstructure observation at cross section of sample tube
〔RH-Penthouse (Base Metal) 〕



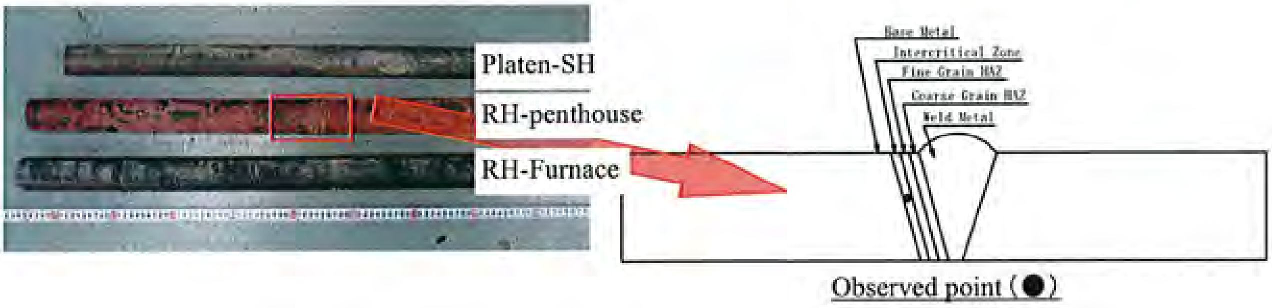
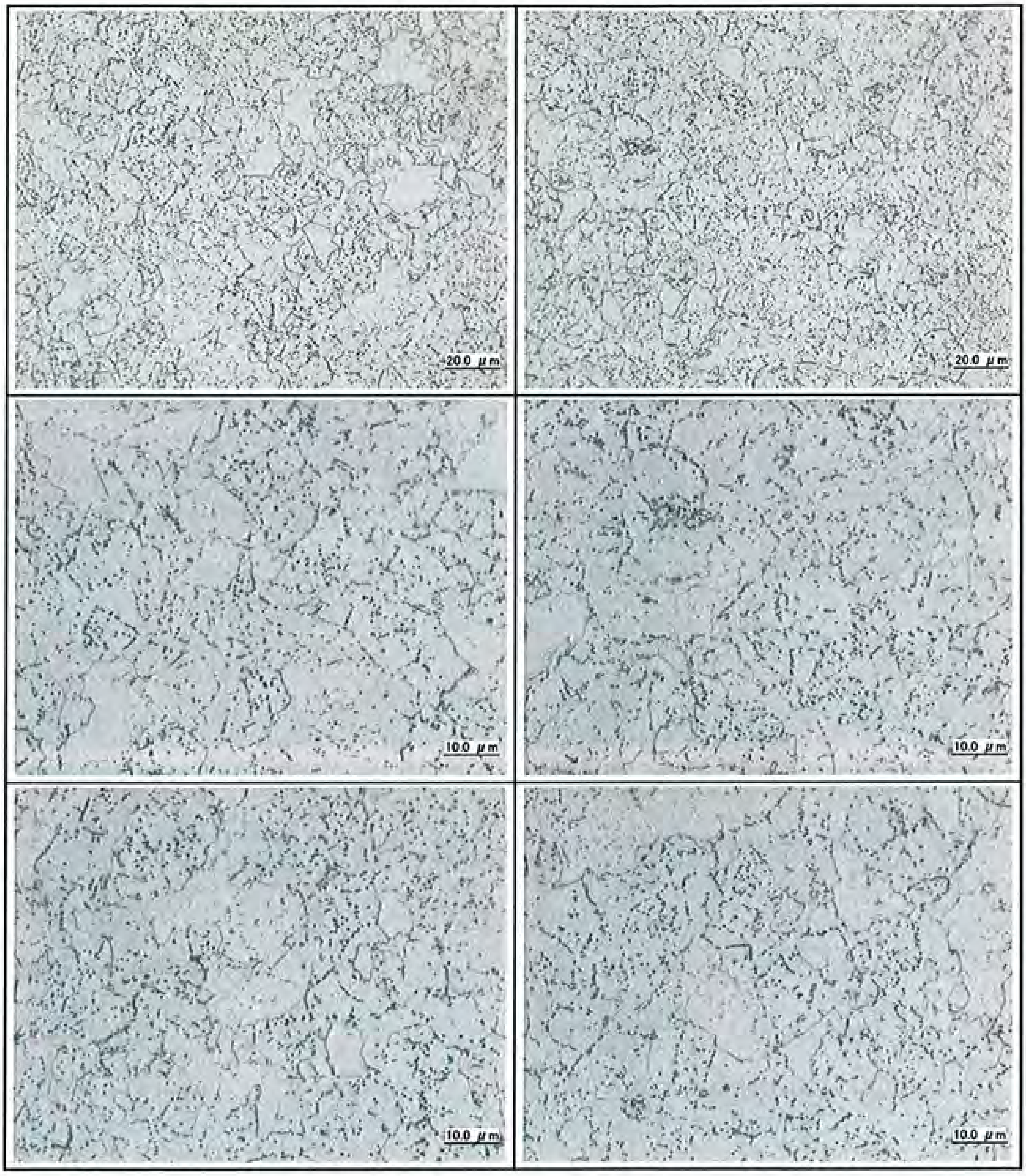


Photo I -38 Microstructure observation at cross section of sample tube
〔RH-Penthouse (Intercritical Zone) 〕



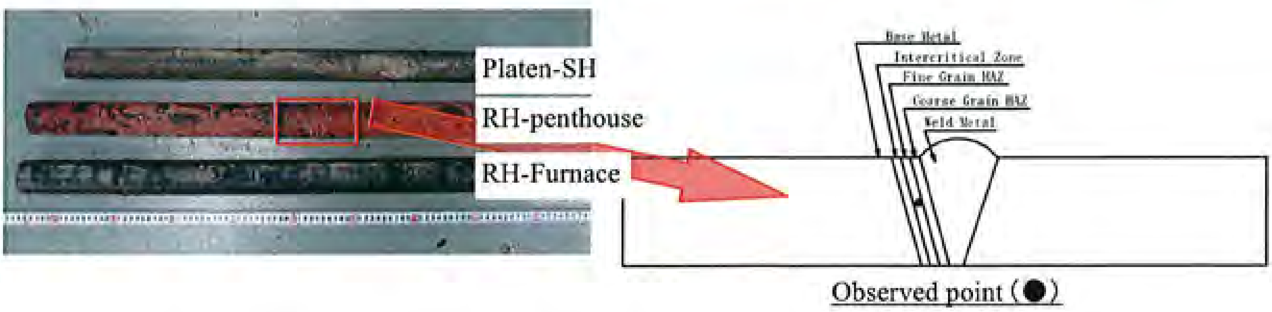


Photo I -39 Microstructure observation at cross section of sample tube
〔RH-Penthouse（Fine Grain HAZ）〕

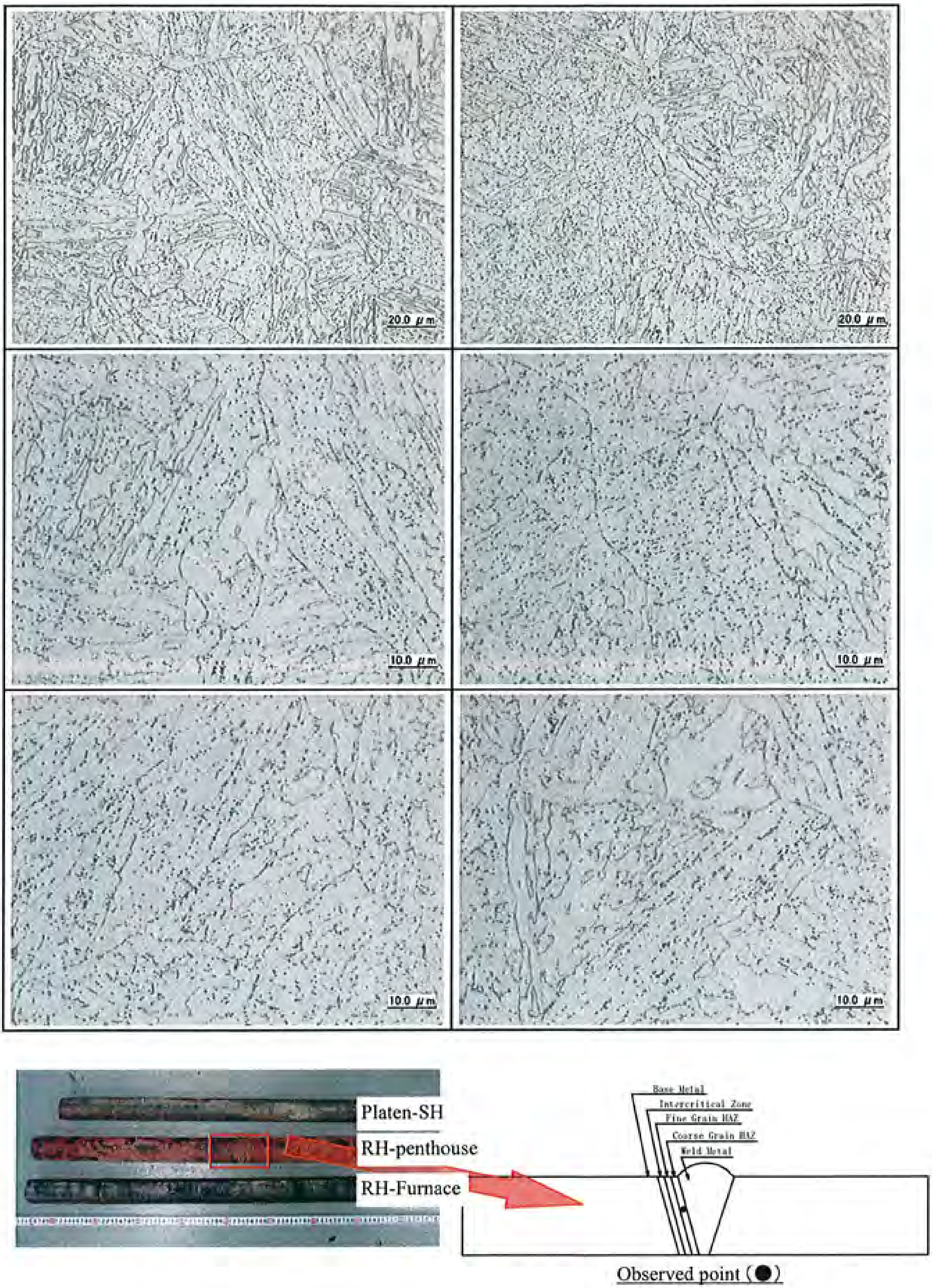
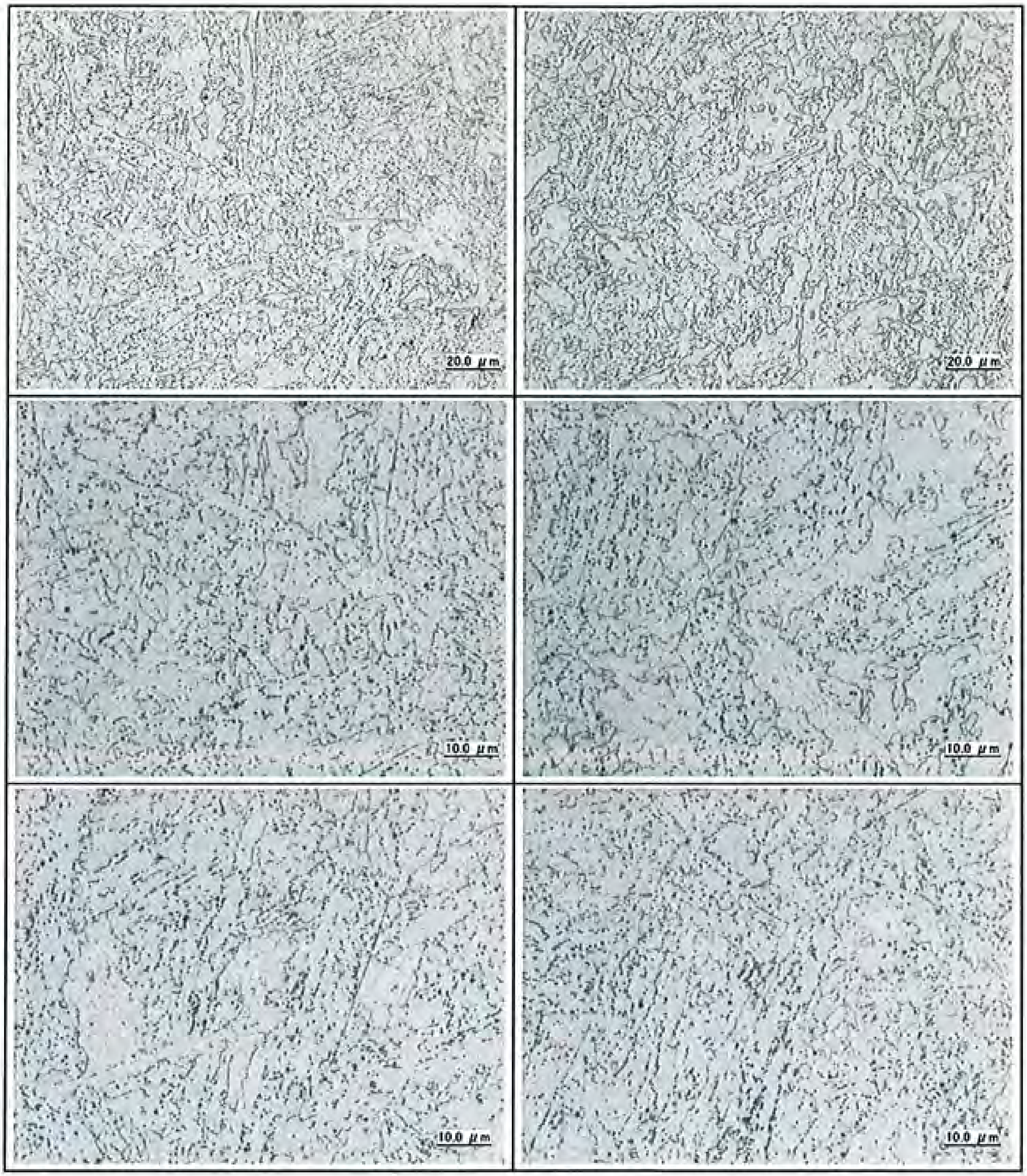


Photo I -40 Microstructure observation at cross section of sample tube
〔RH-Penthouse（Coarse Grain HAZ）〕



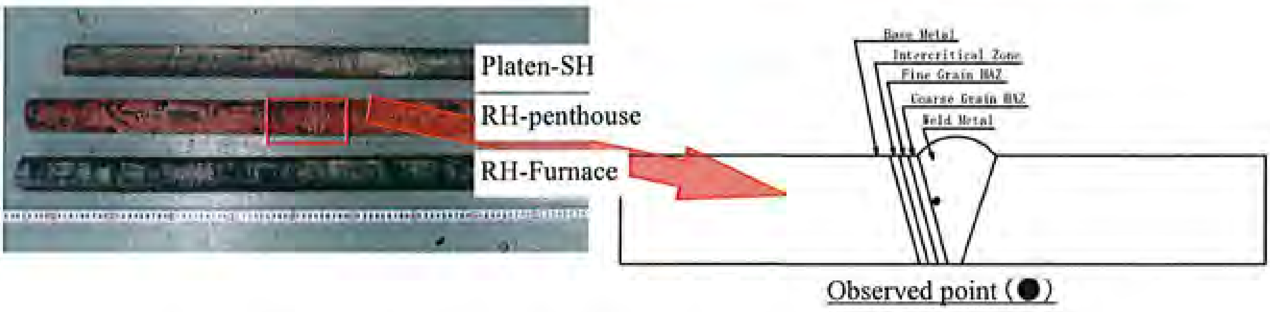
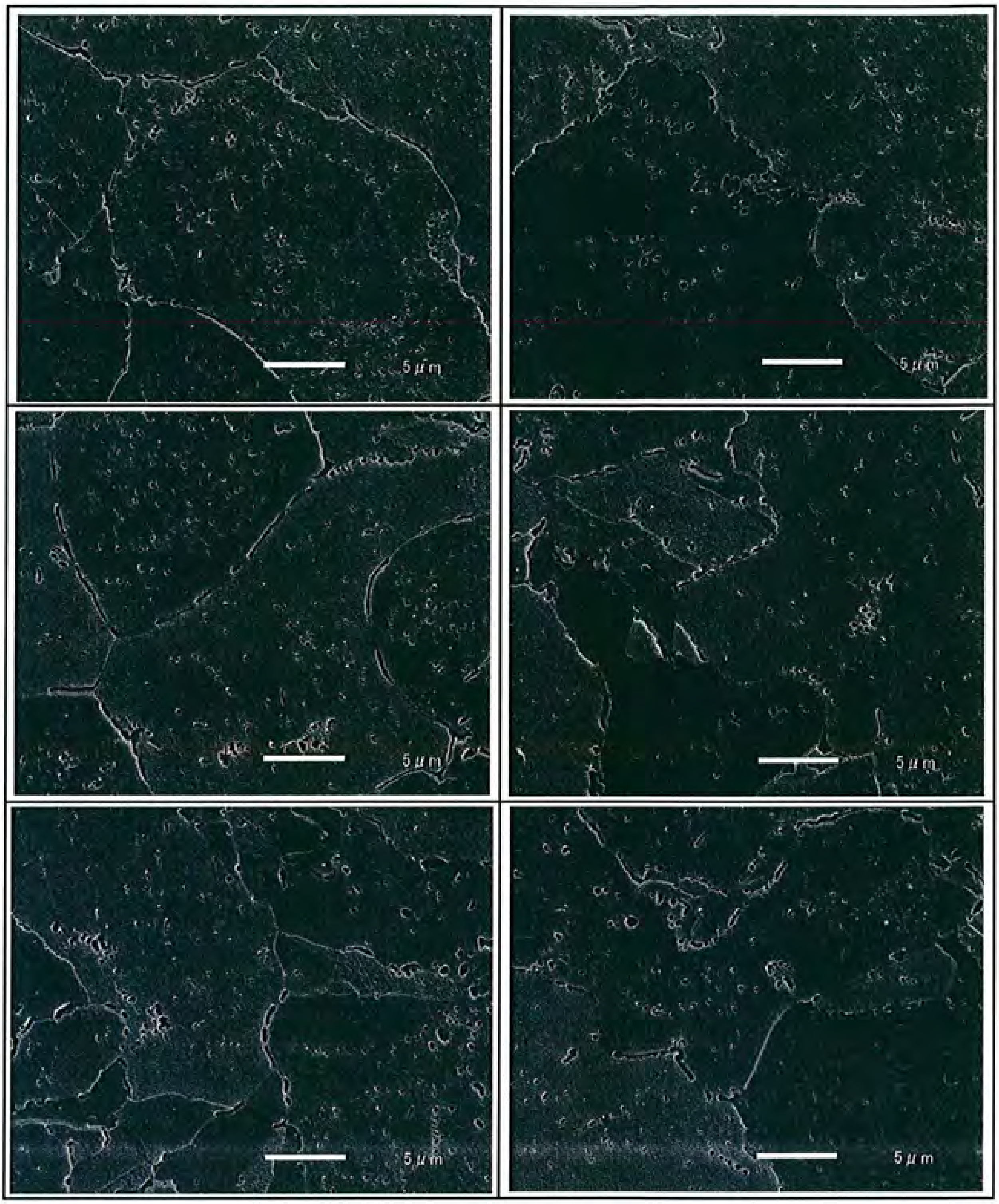


Photo I -41 Microstructure observation at cross section of sample tube
〔RH-Penthouse（Weld Metal）〕



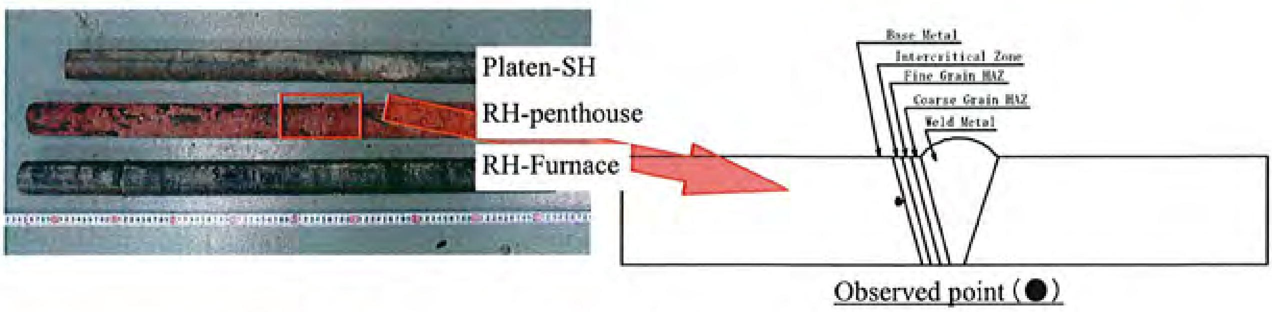
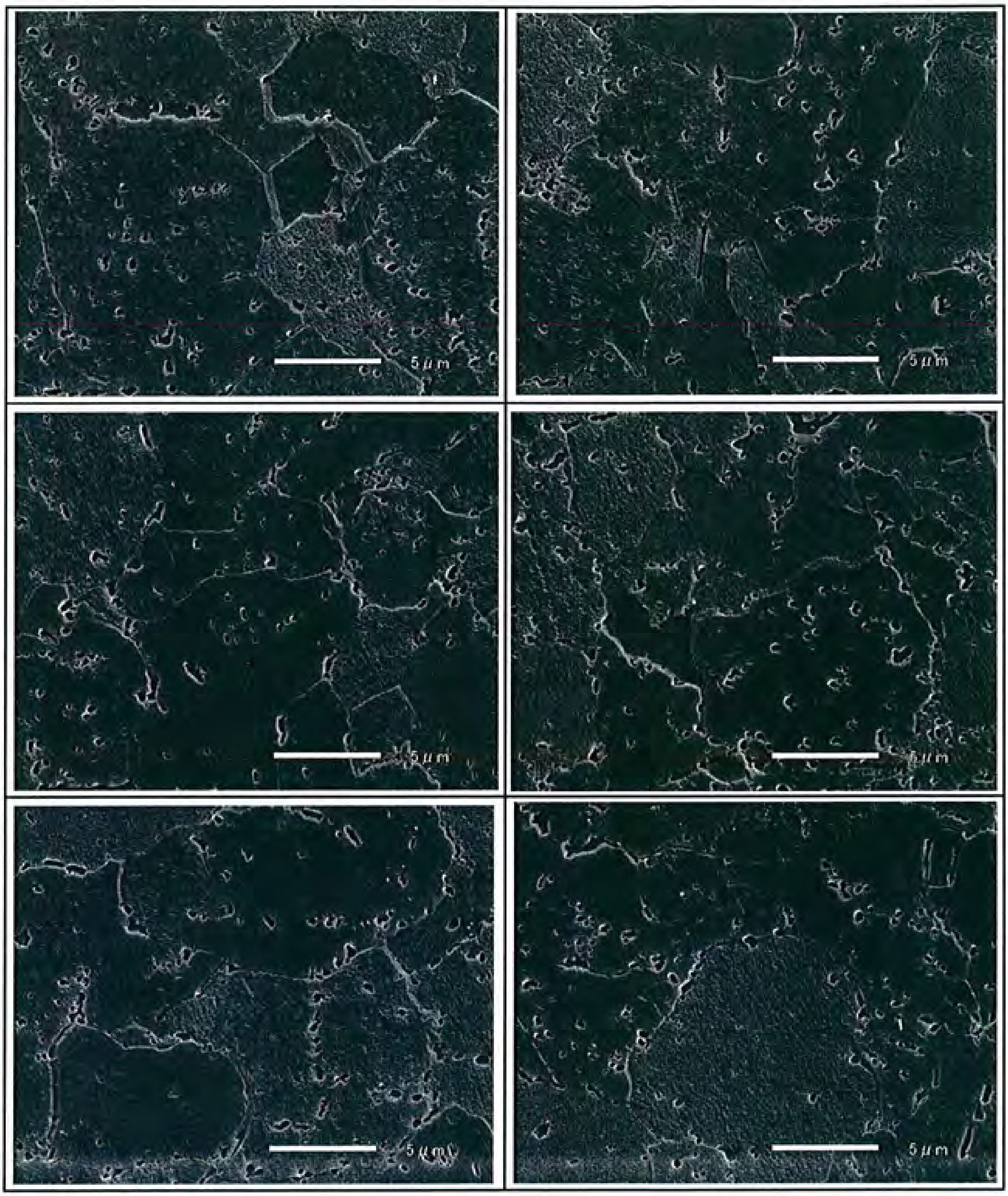
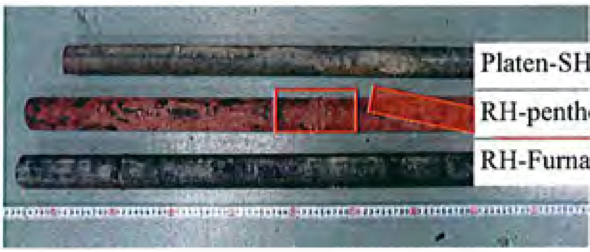


Photo I -42 Precipitates along grain boundary by SEM observatior
〔RH-Penthouse（Base Metal）〕





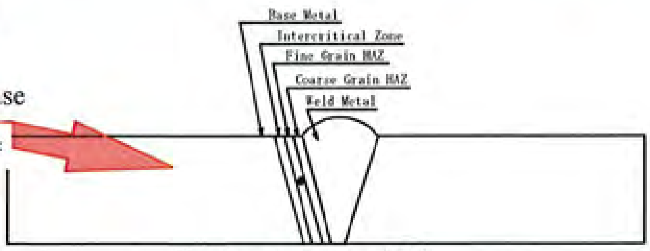
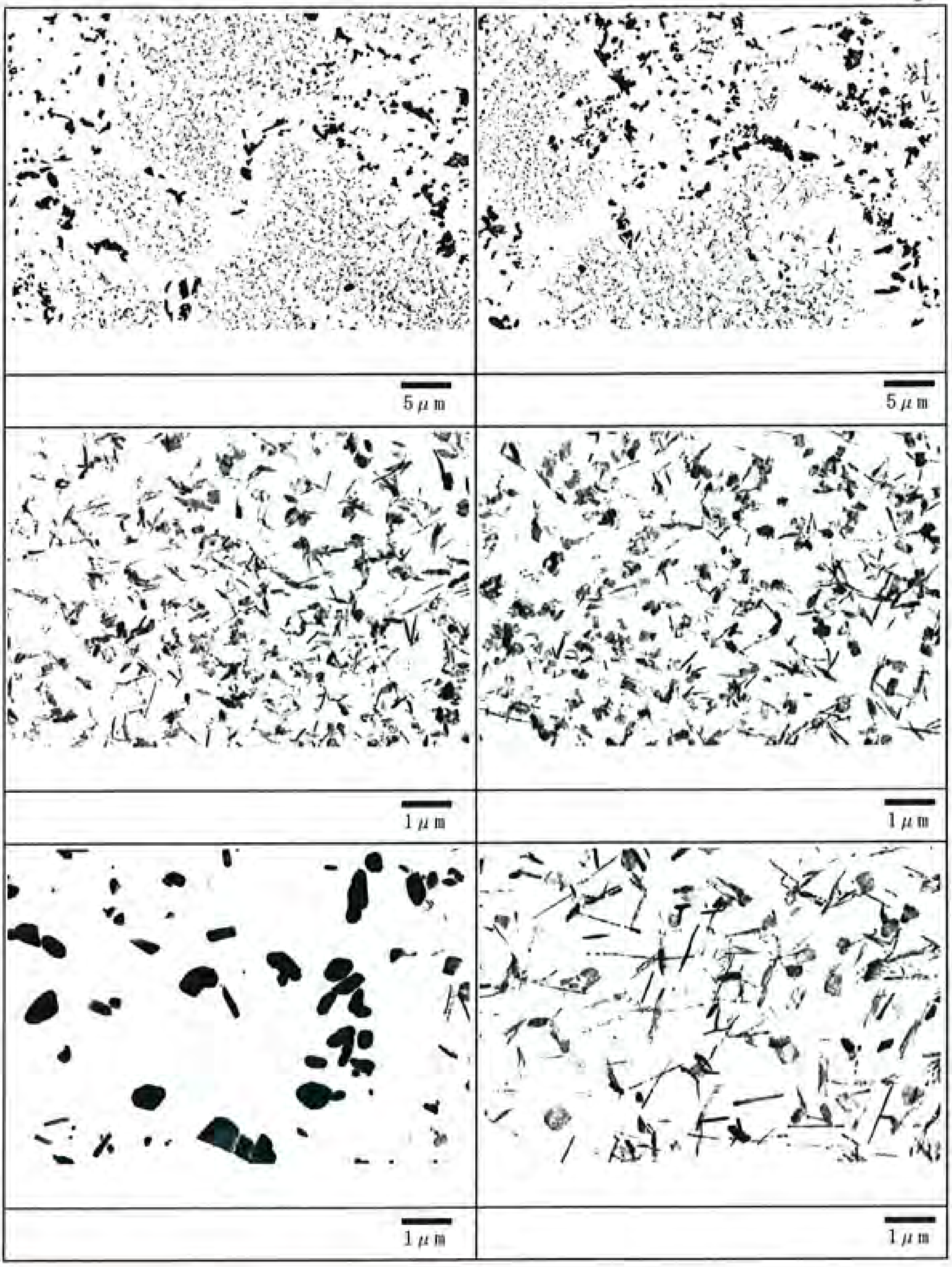


Photo I -43 Precipitates along grain boundary by SEM observatior
〔RH-Penthouse（Fine Grain HAZ）〕



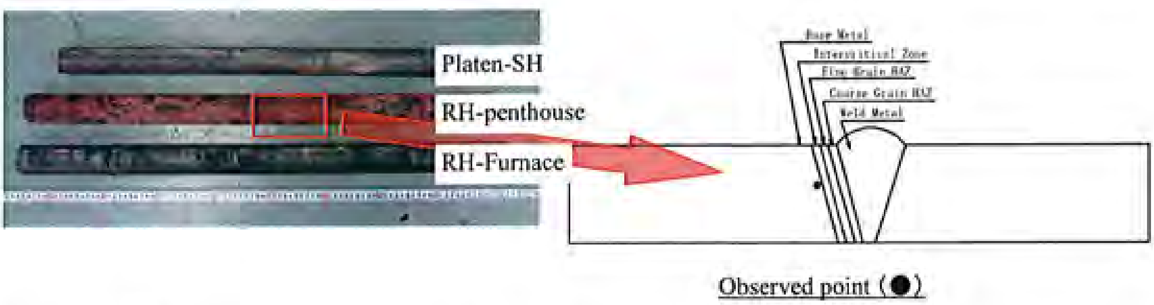
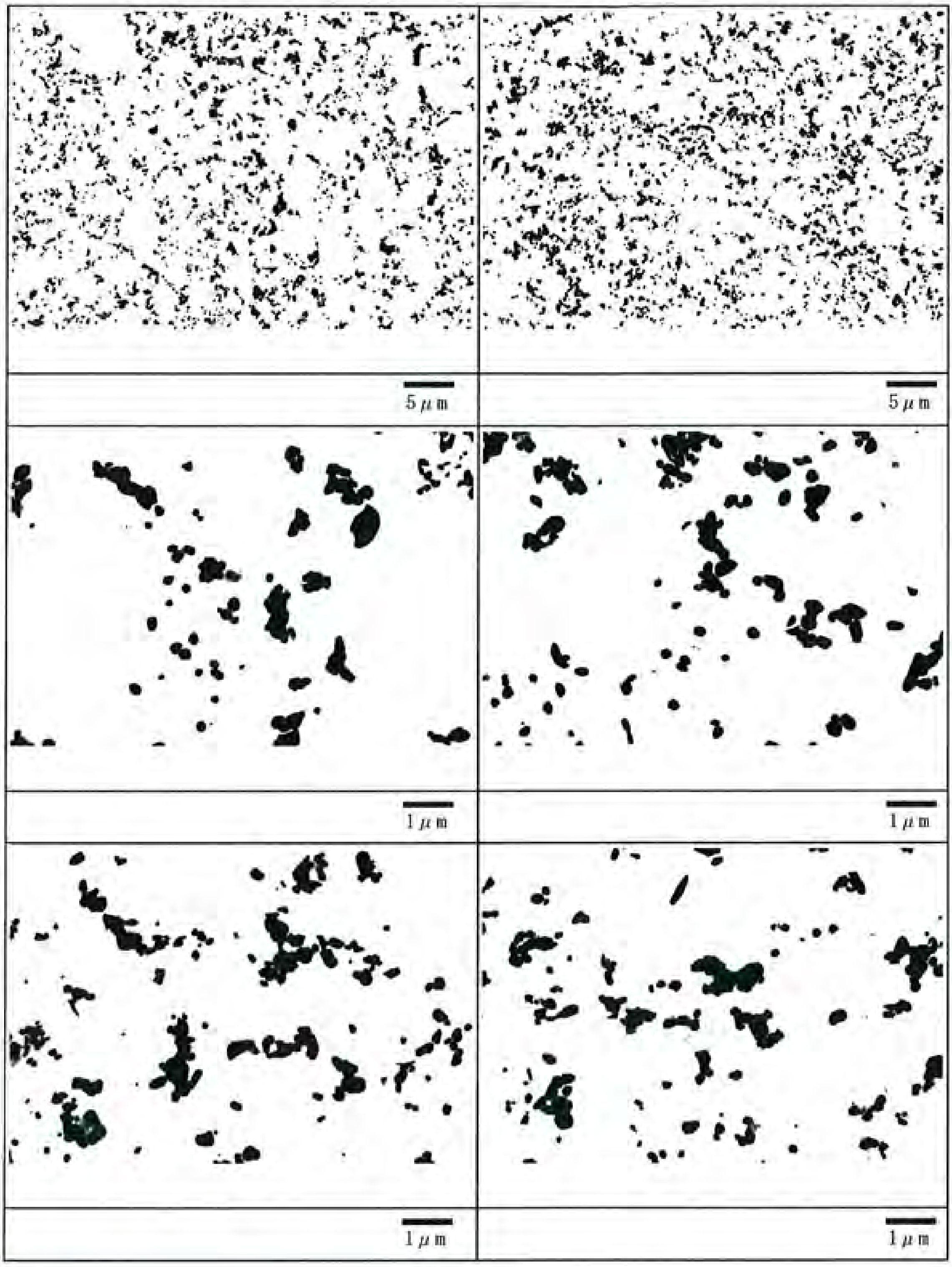
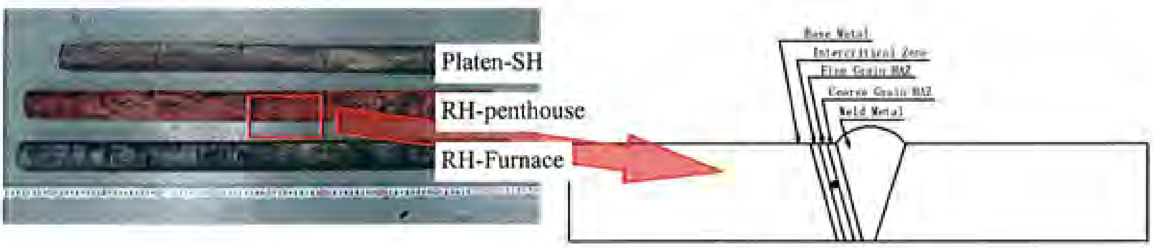


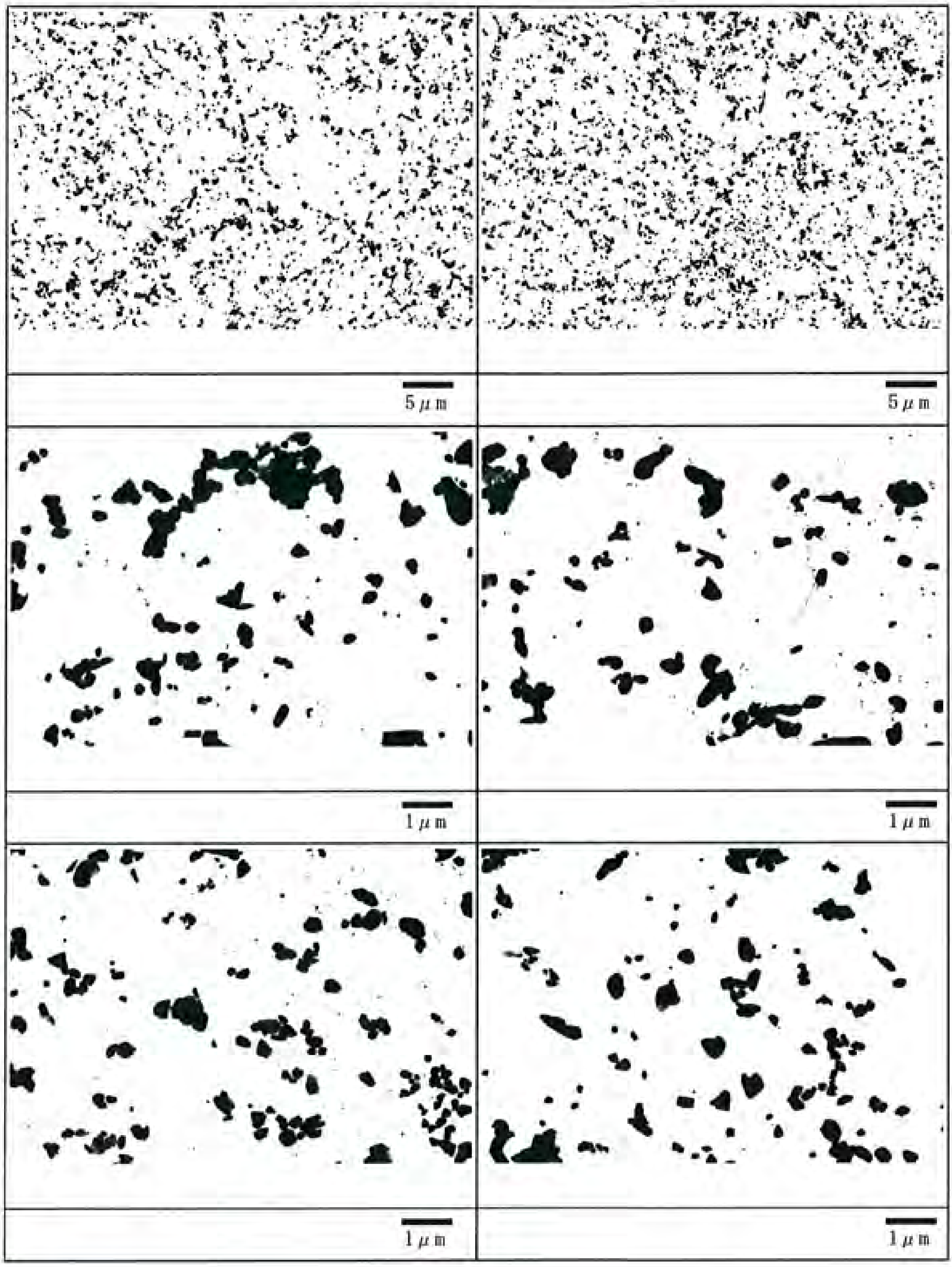
Photo I -44 Precipitates distribution by TEM observation〔RH-Penthouse (Base Metal) 〕





Observed point (●)

Photo I -45 Precipitates distribution by TEM observation〔RH-Penthouse (Fine Grain HAZ) 〕



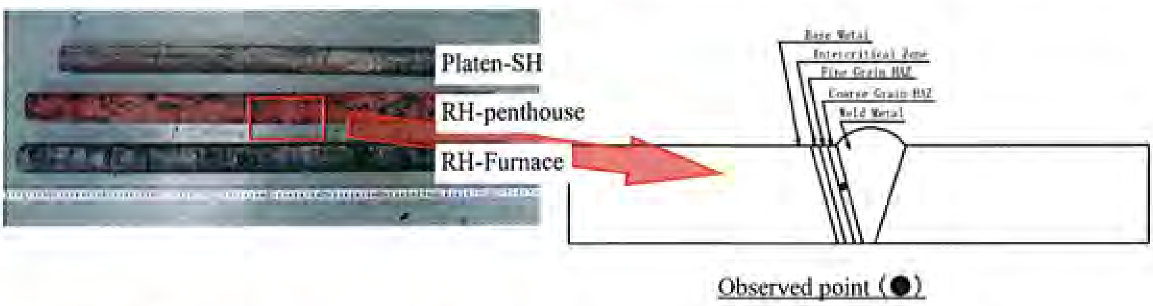
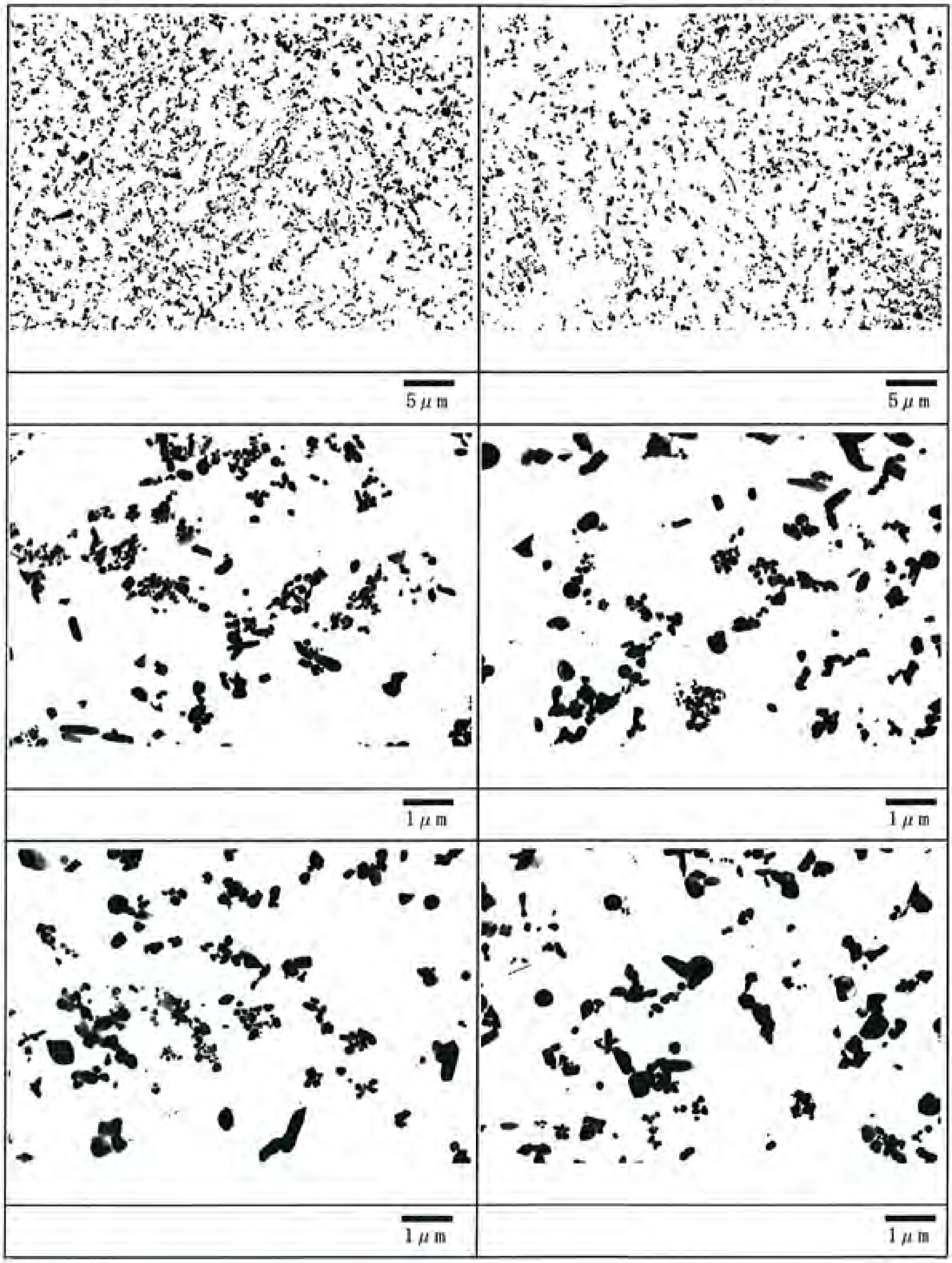
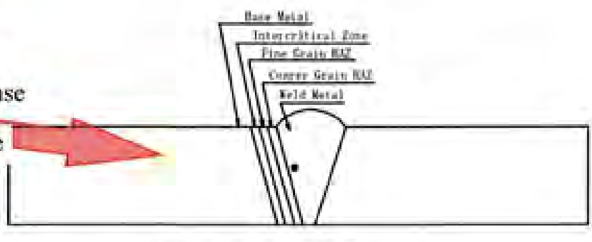


Photo I -46 Precipitates distribution by TEM observation〔RH-Penthouse（Coarse Grain HAZ）〕





Observed point (●)

Photo I -47 Precipitates distribution by TEM observation〔RH-Penthouse (Weld Metal) 〕

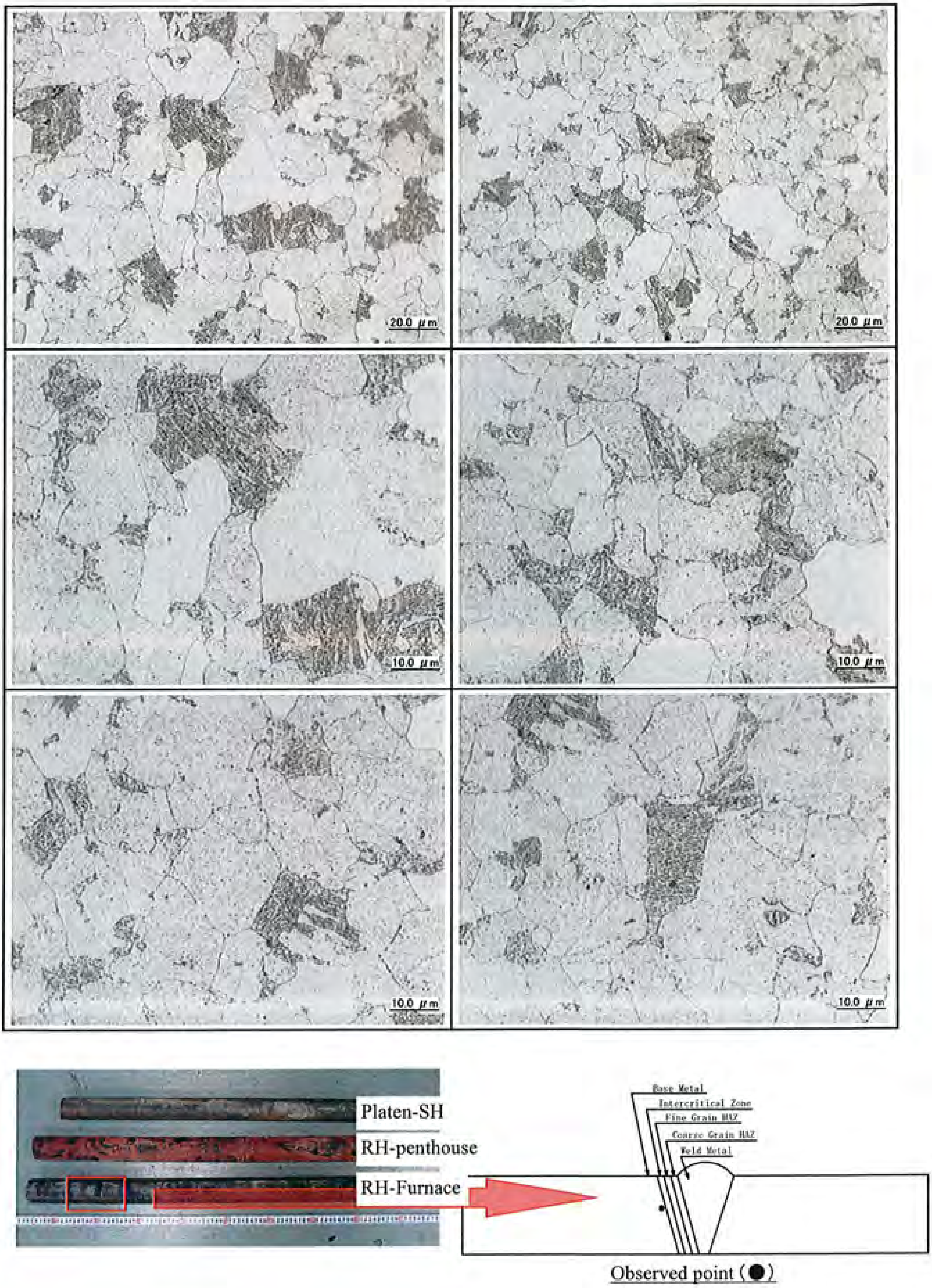
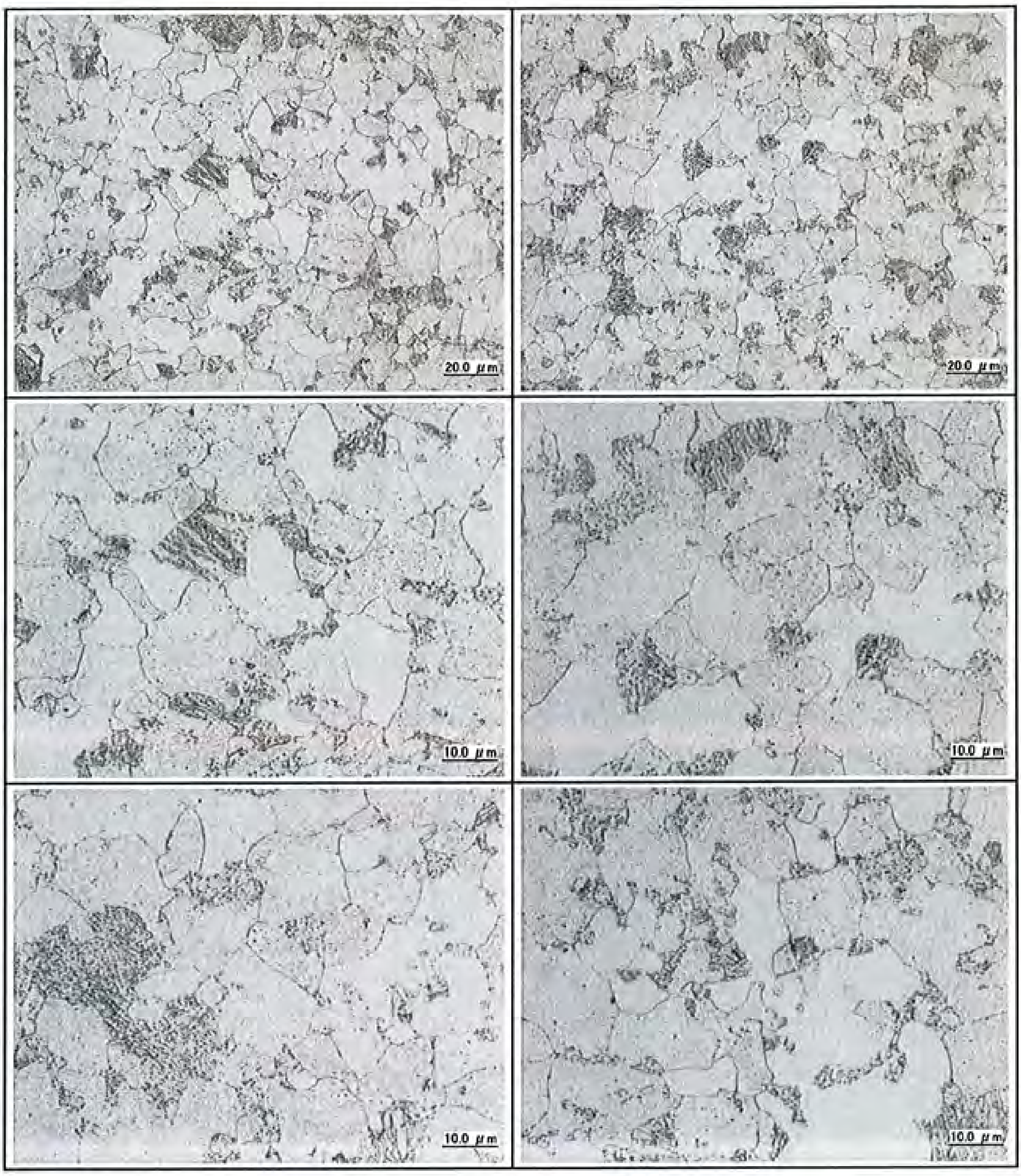


Photo I -48 Microstructure observation at cross section of sample tube
〔RH-Furnace（Base Metal）〕



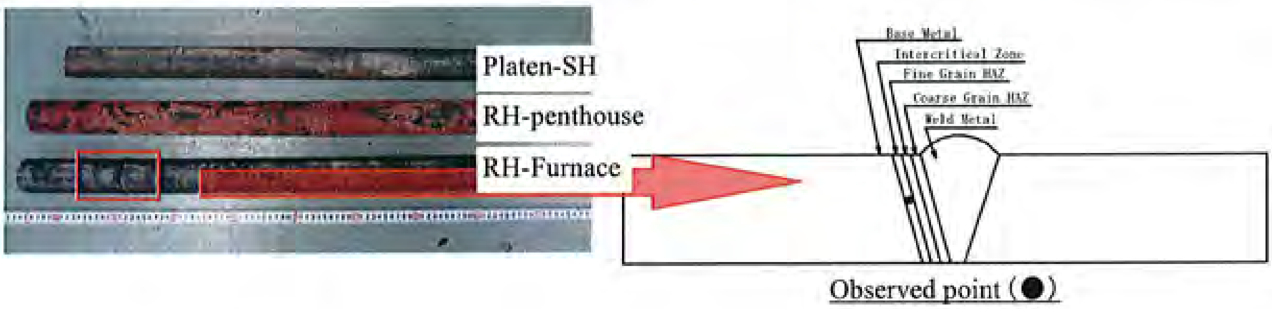
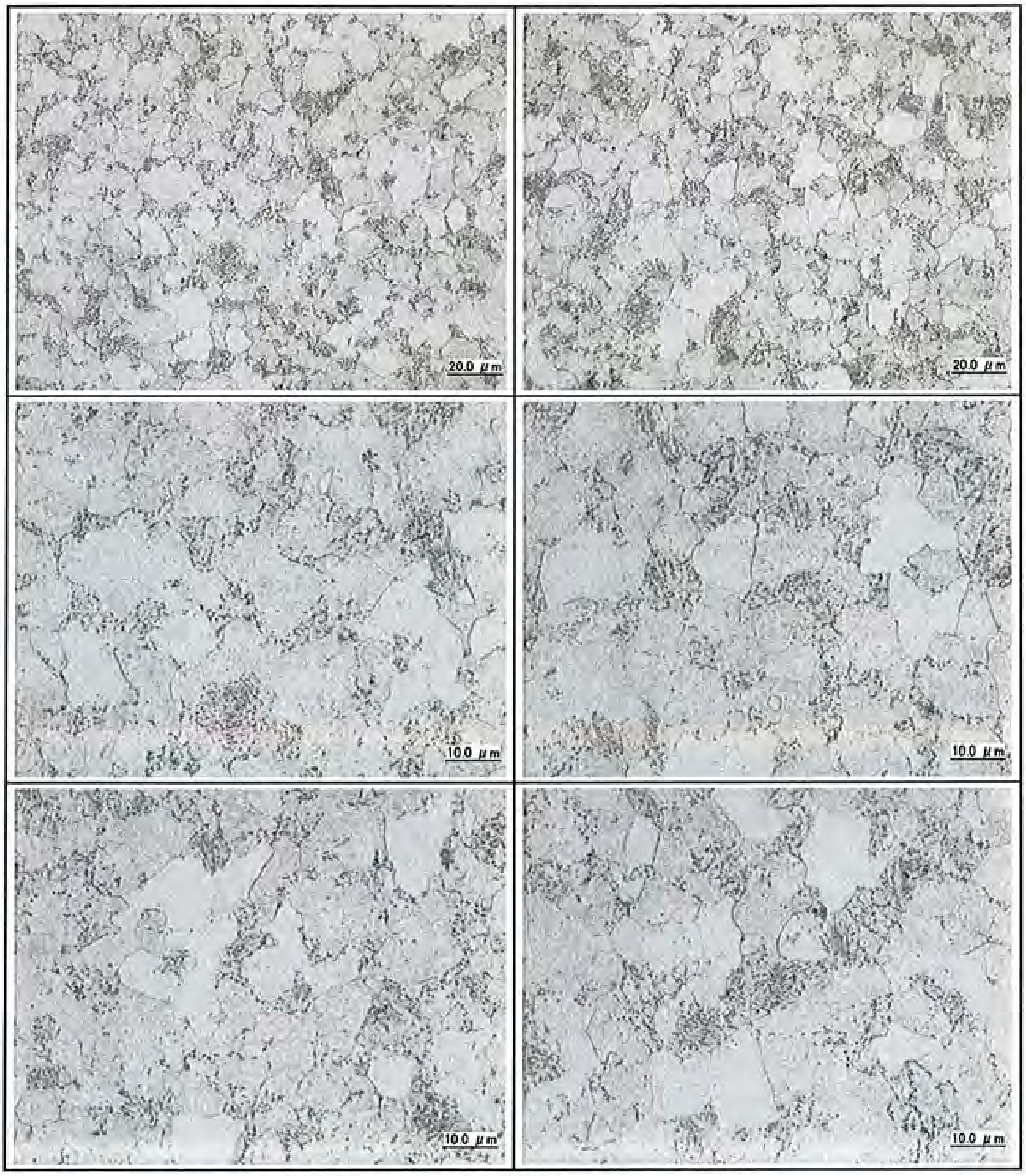


Photo I -49 Microstructure observation at cross section of sample tube
〔RH-Furnace（Intercritical Zone）〕



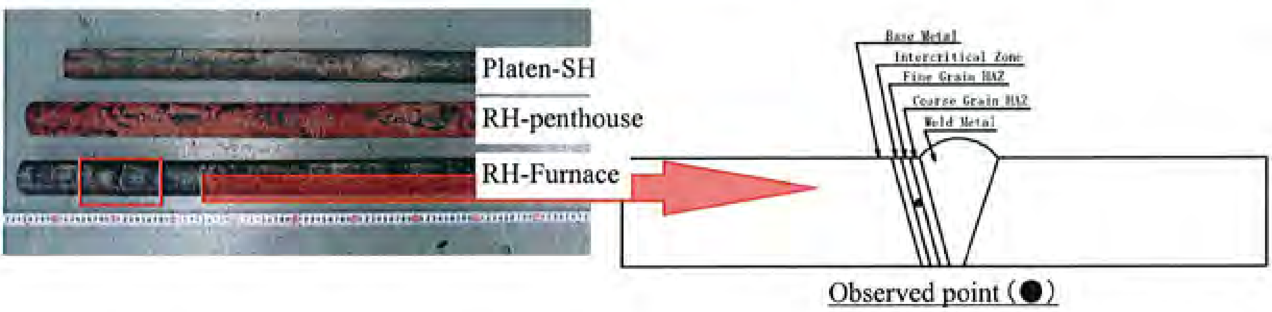
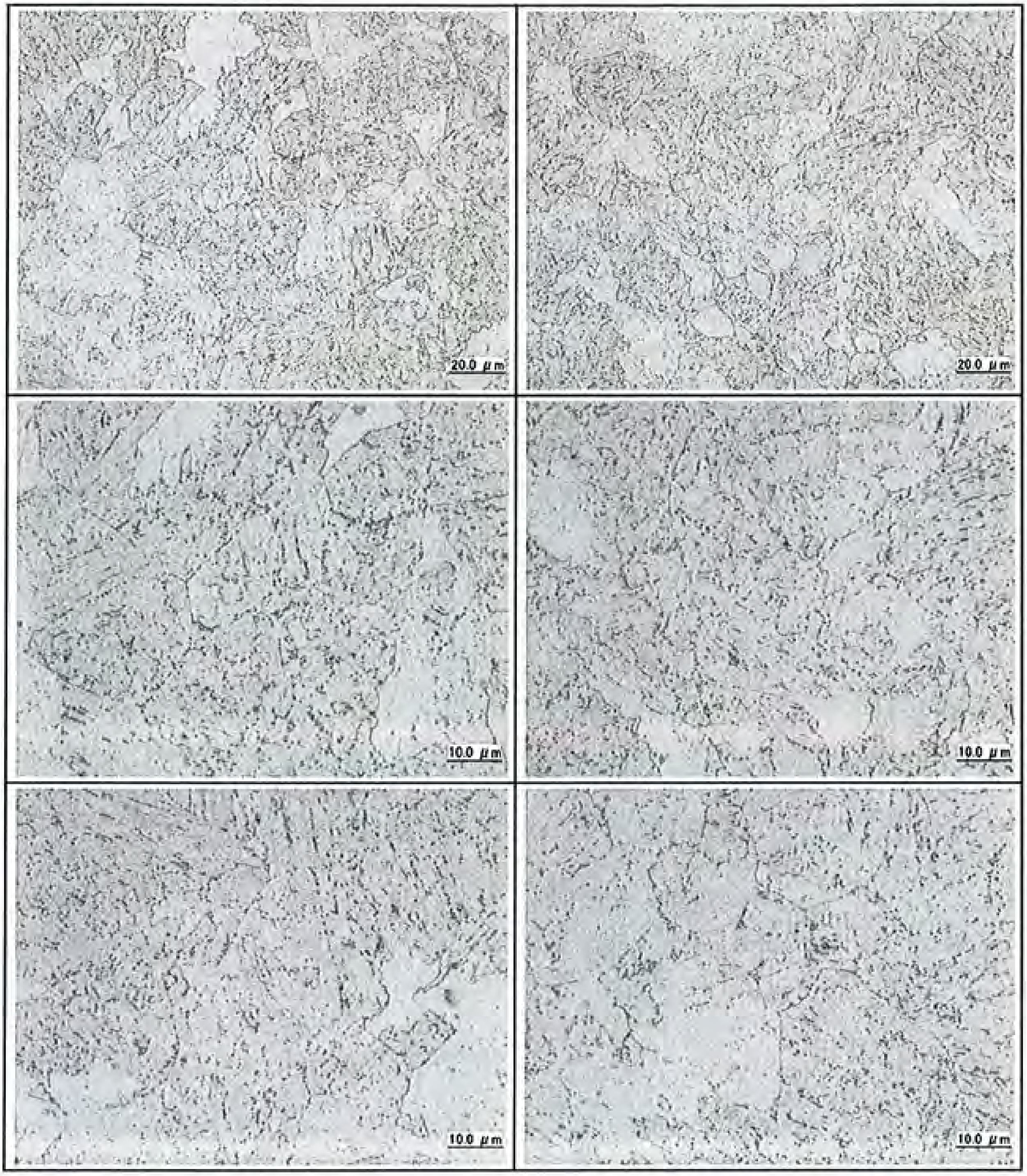
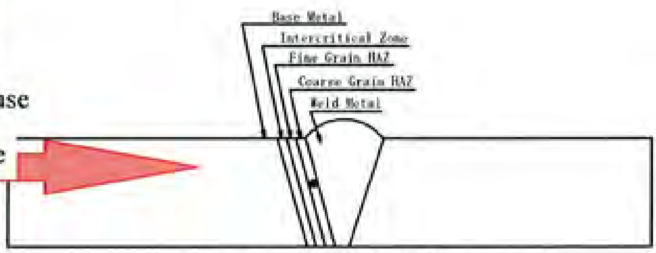


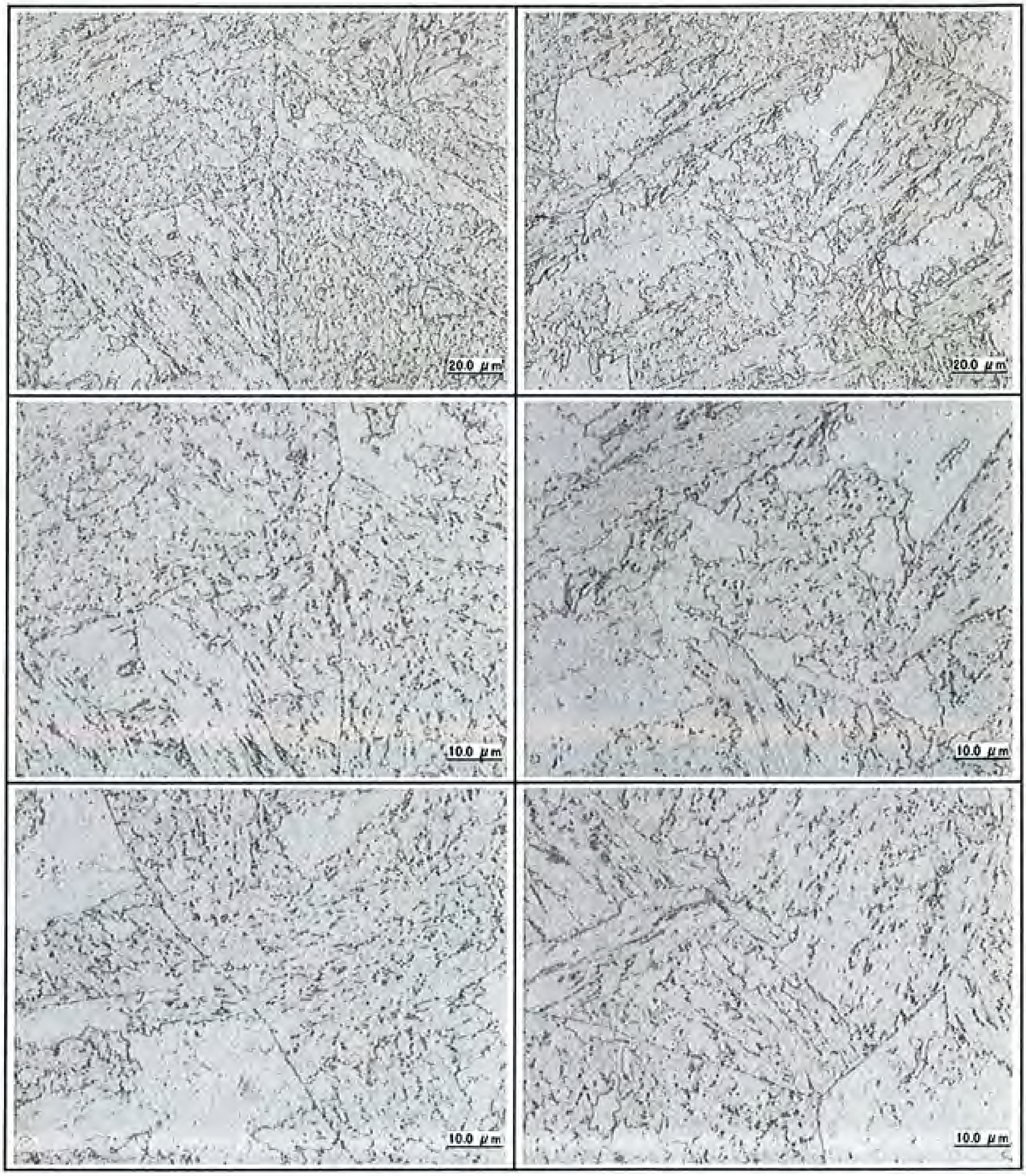
Photo Ⅰ-50 Microstructure observation at cross section of sample tube
〔RH-Furnace (Fine Grain HAZ) 〕





Observed point (●)

Photo Ⅰ-51　Microstructure observation at cross section of sample tube
〔RH-Furnace（Coarse Grain HAZ）〕



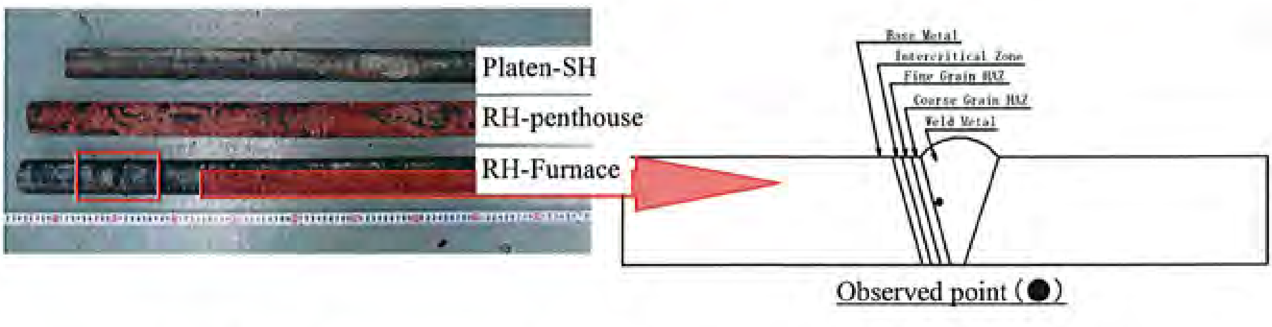
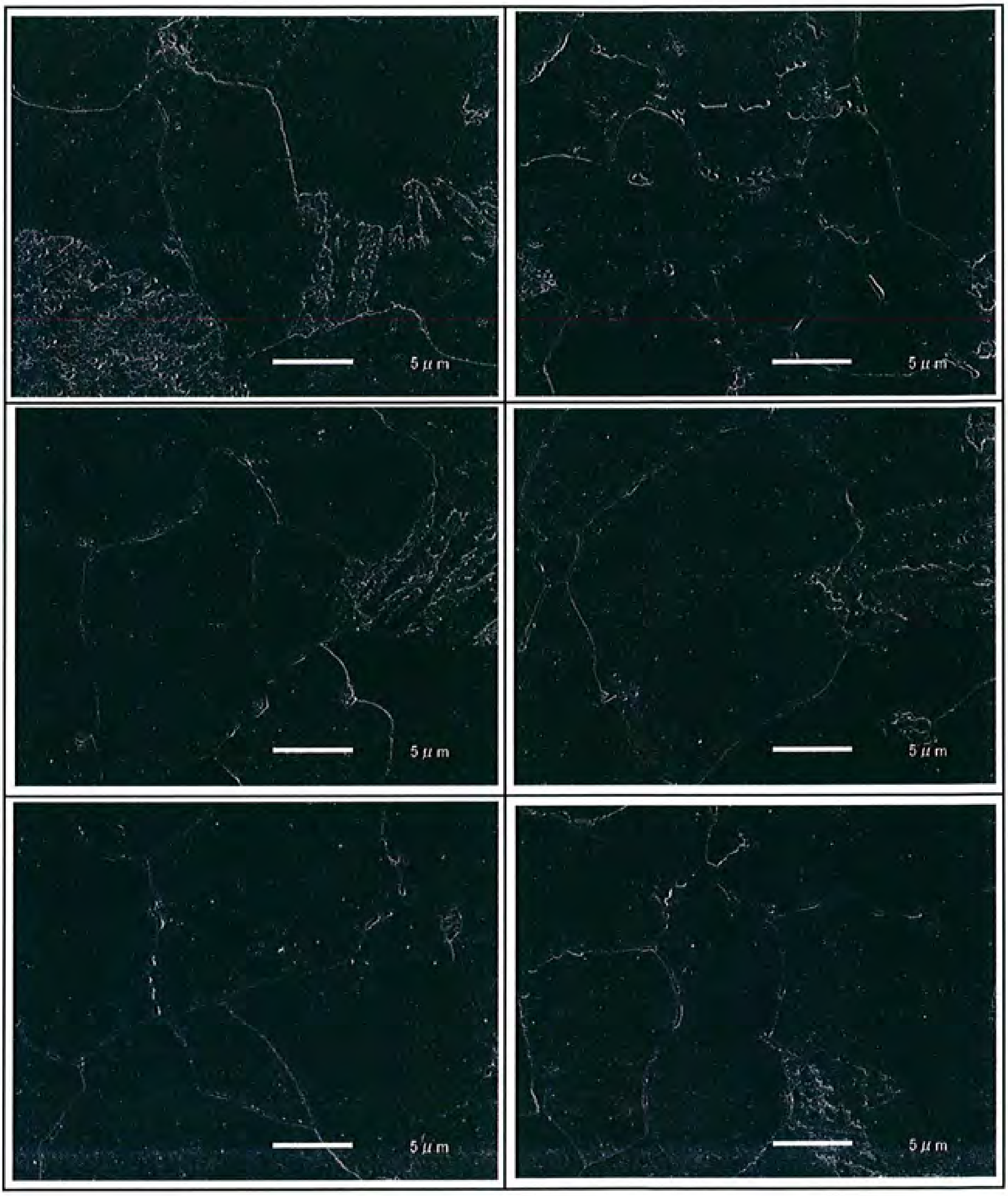


Photo I -52 Microstructure observation at cross section of sample tube
〔RH-Furnace（Weld Metal）〕



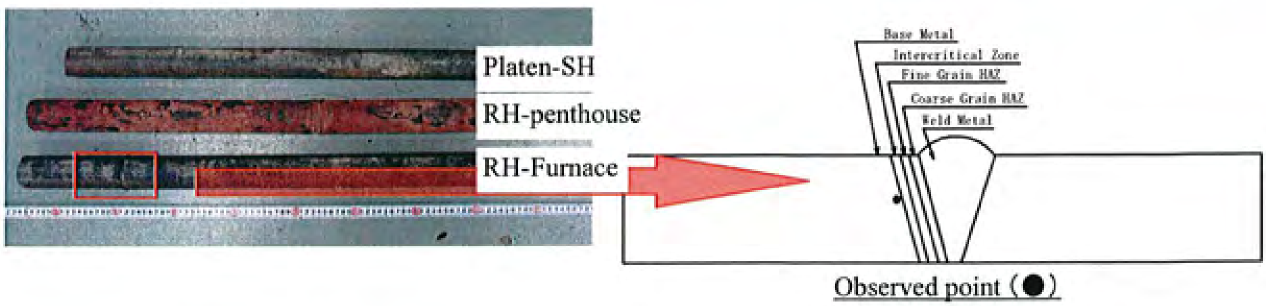
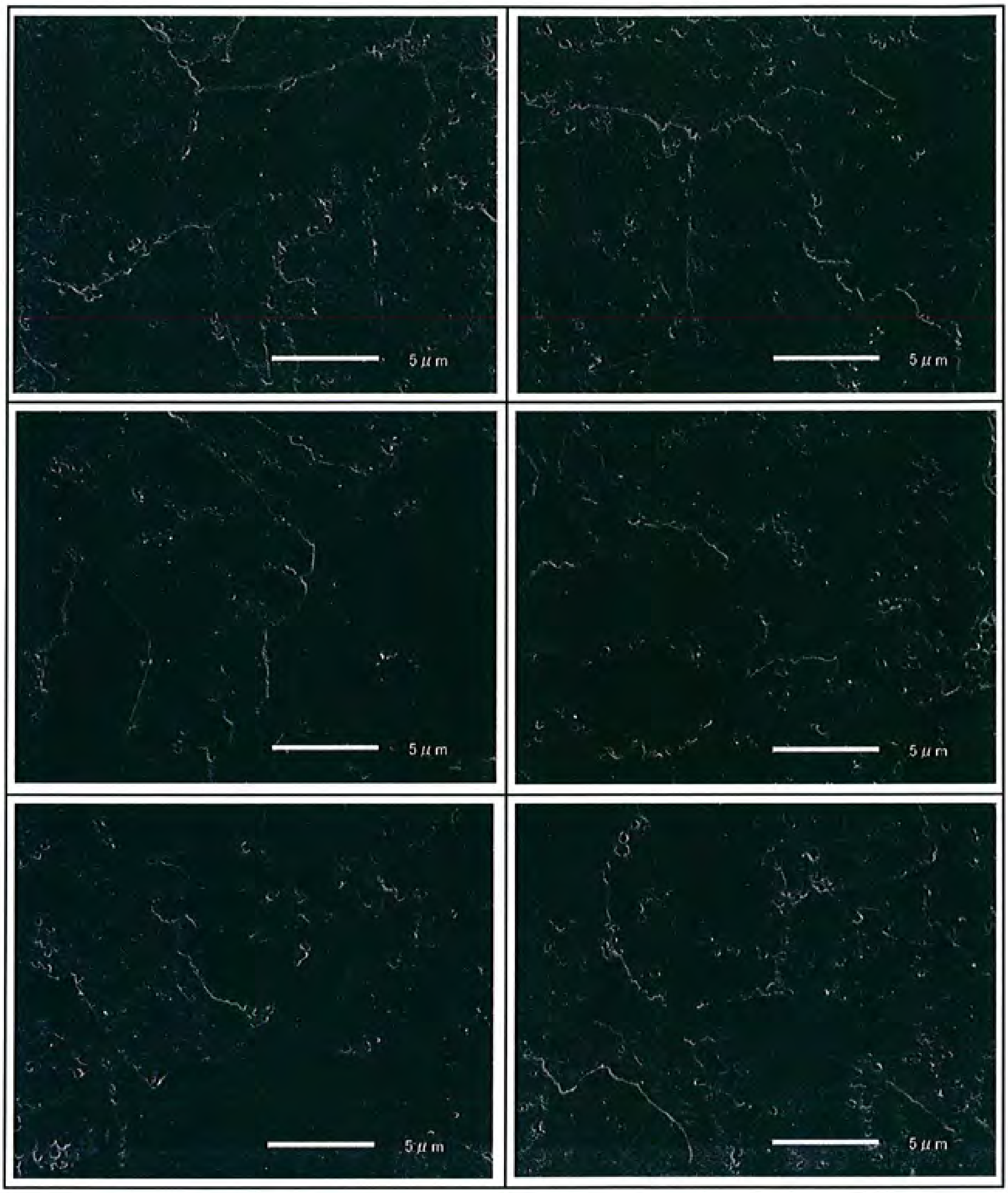


Photo I -53 Precipitates along grain boundary by SEM observatior
〔RH-Furnace (Base Metal) 〕



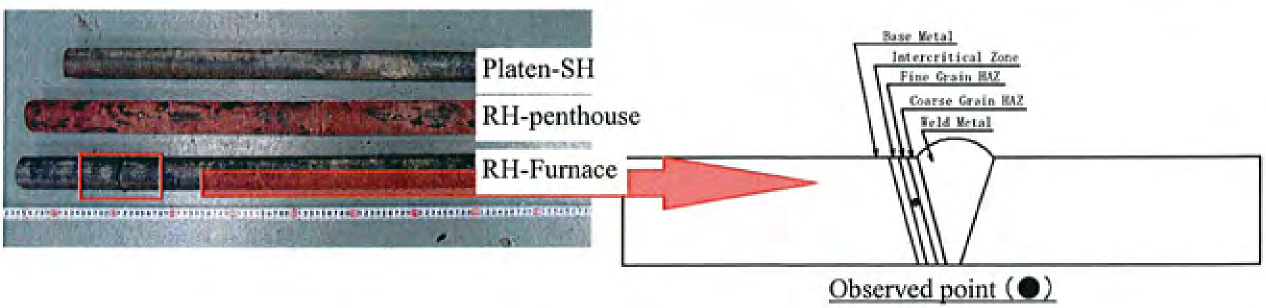


Photo I -54　Precipitates along grain boundary by SEM observatior
〔RH-Furnace（Fine Grain HAZ）〕

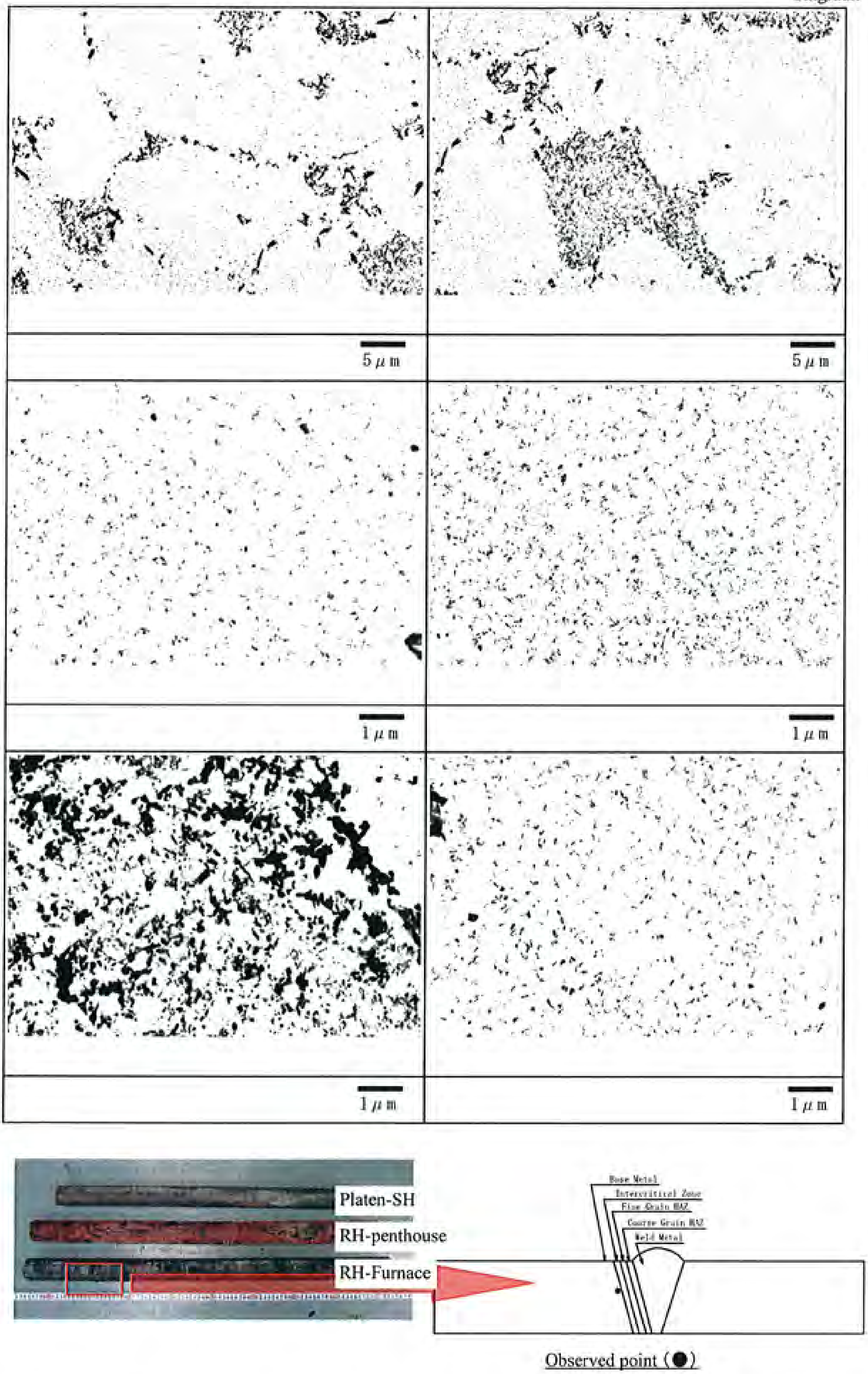


Photo I -55 Precipitates distribution by TEM observation〔RH-Furnace (Base Metal)〕

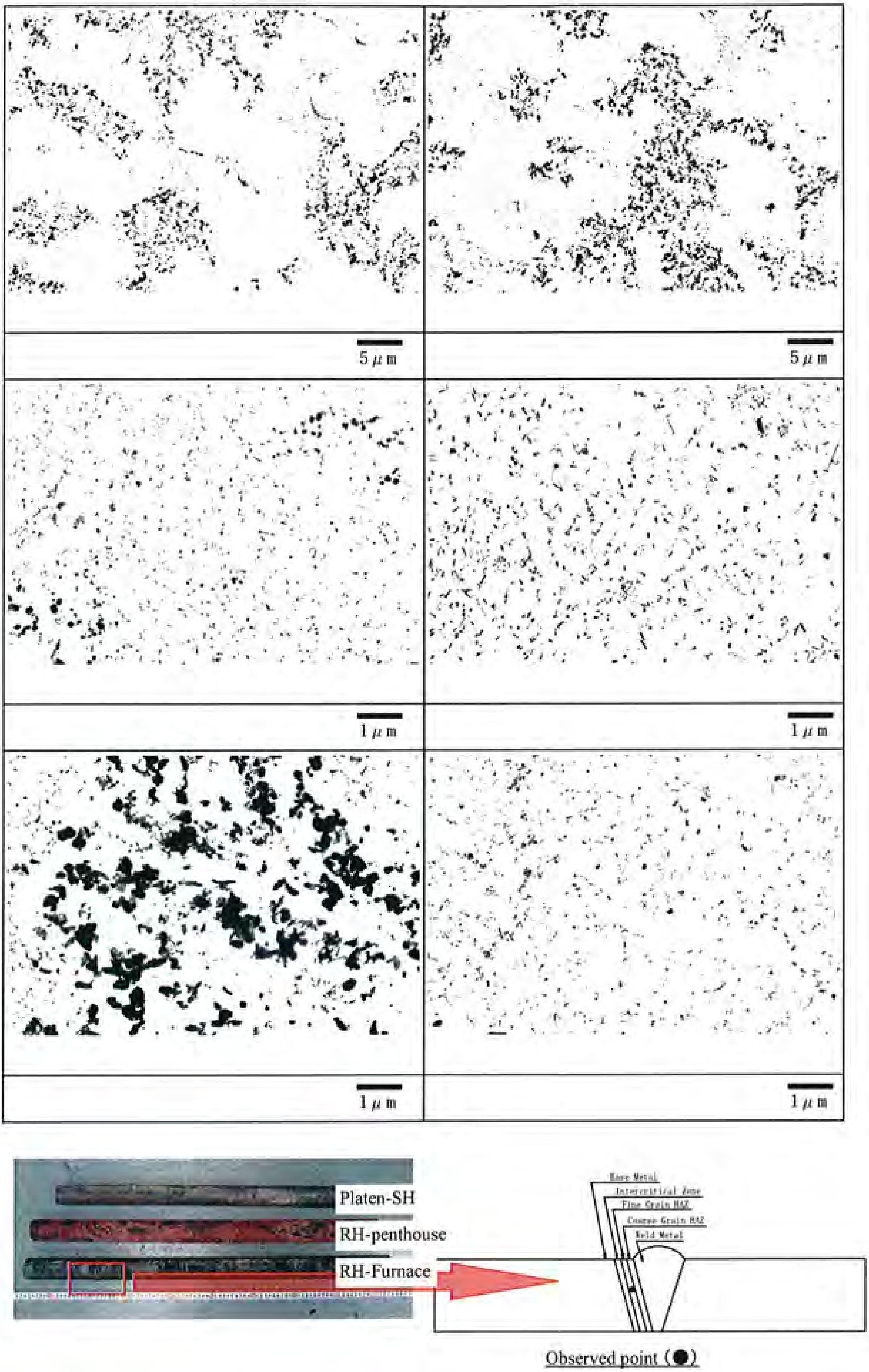
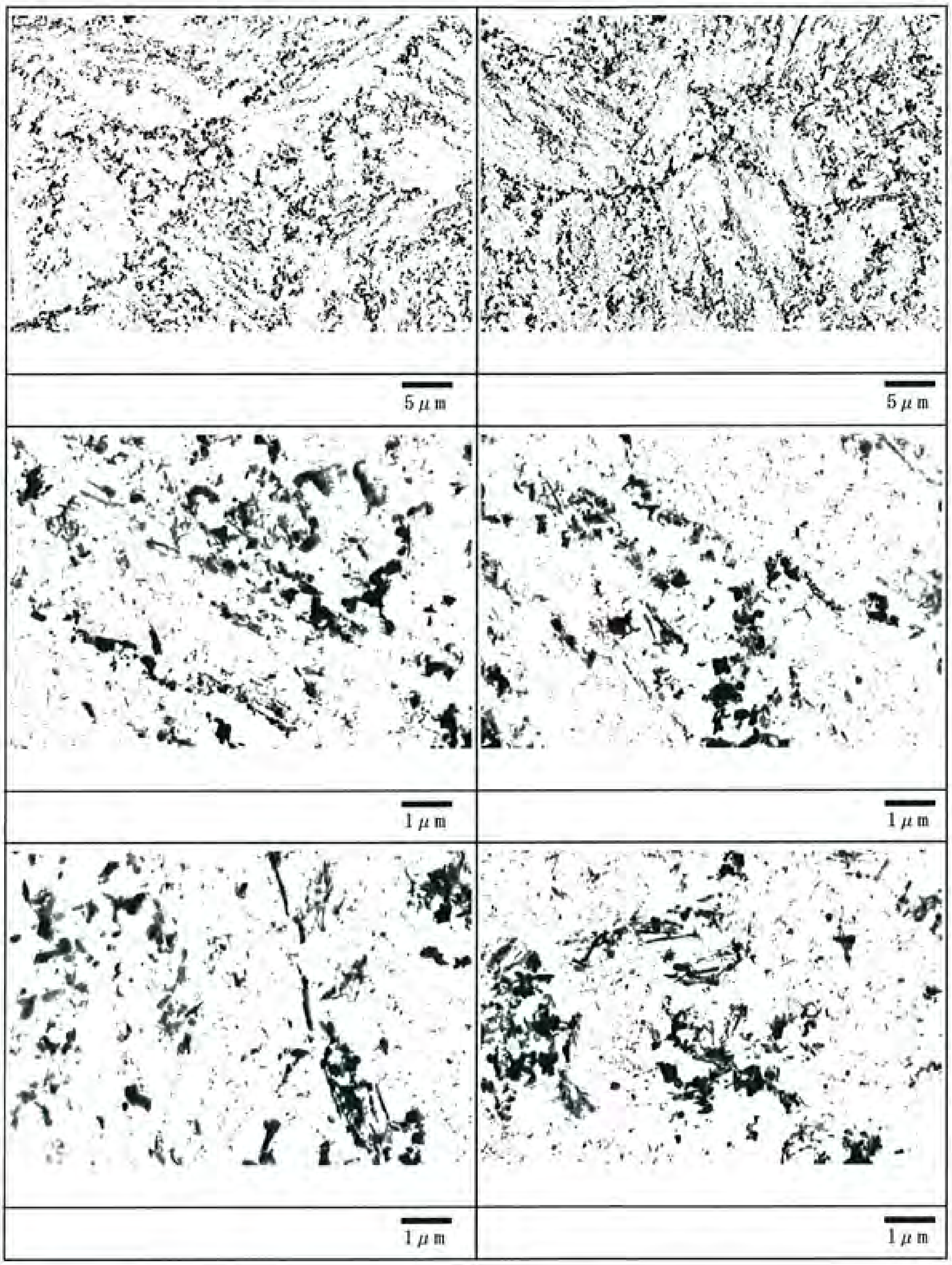
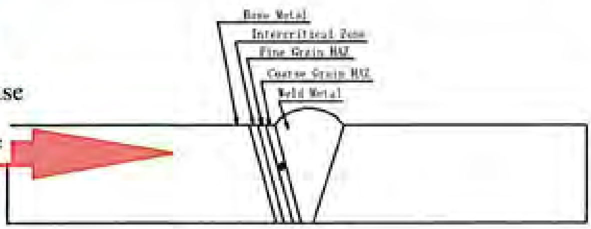


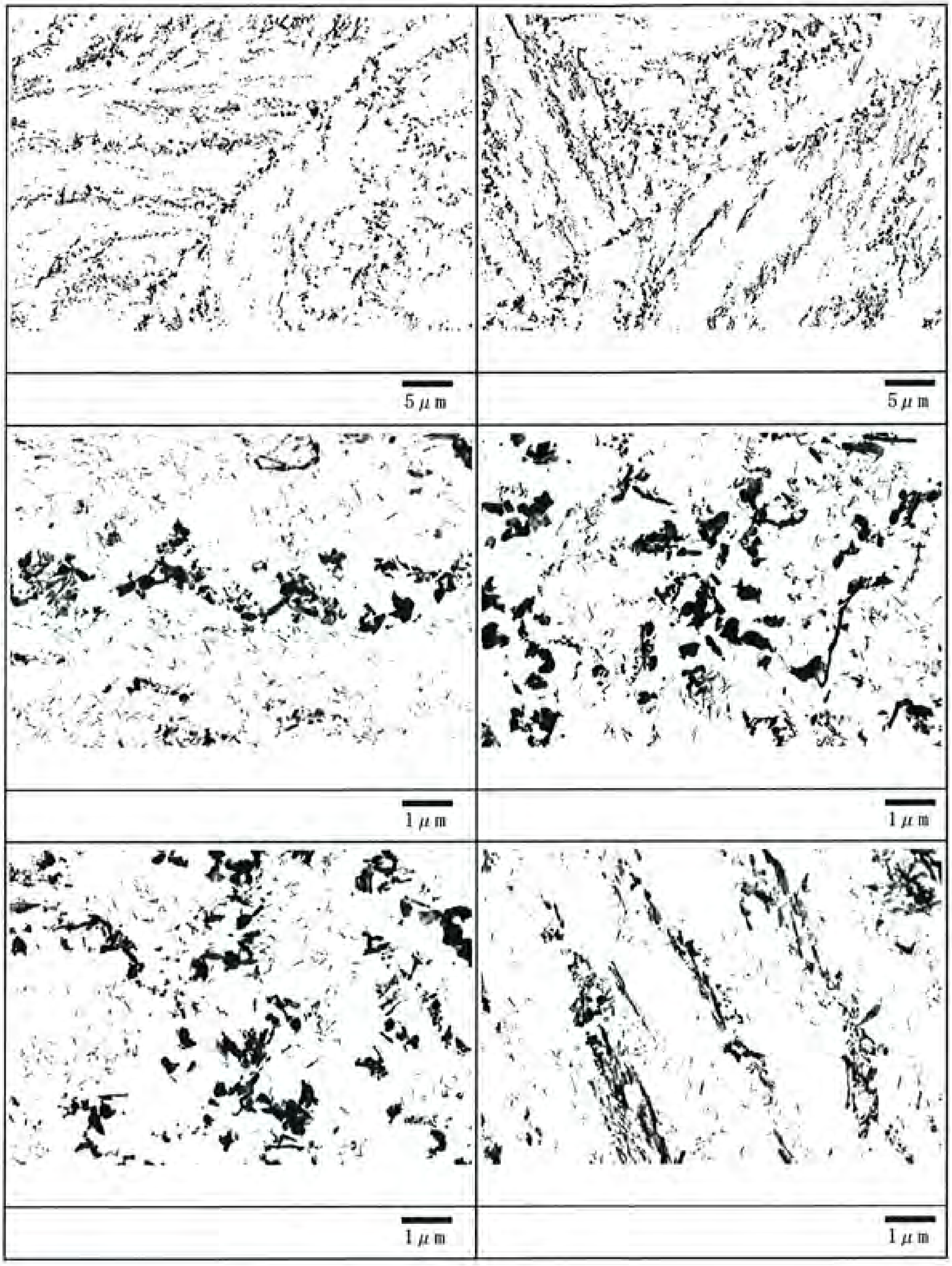
Photo I -56 Precipitates distribution by TEM observation〔RH-Furnace (Fine Grain HAZ) 〕

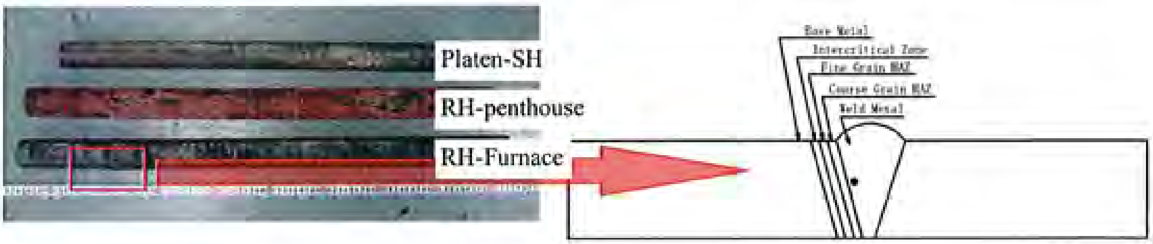




Observed point (●)

Photo I -57 Precipitates distribution by TEM observation〔RH-Furnace (Coarse Grain HAZ) 〕





Observed point (●)

Photo I -58 Precipitates distribution by TEM observation〔RH-Furnace (Weld Metal) 〕

Inspection at Unchahar #2

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

Feroze Gandhi Unchahar Thermal Power Station #2 unit

2. Operation condition

(1) Cumulative operation hours: 139,098 hours

(2) Cumulative start and stop times: 96 times

3. Summary of residual life assessment results

- The highest creep life consumption ratio among evaluated pipes and headers was 50% at Main Steam Pipe-Right (Intrados) with the evaluated residual life 69,000 hours.
- The evaluated results for base metal and fine grain HAZ of Main Steam Pipe-Right (intrados, near the stop valve) were regarded as the reference, since OD measurement was not carried out. The estimated residual life in base metal varies from 8,000 to 130,000 hrs due to no OD measurements applied, while microstructure shows a little degradation. For accurate estimation of residual life, creep strain (OD) measurement along with microstructure is recommended to be carried out preferably within 8,000 hrs or practically at the earliest opportunity.
- The evaluated residual life for the other components was 96,000 hours or more.

Residual life assessment results by microstructural comparison method

Components	Location	Max. creep life consumption ratio(%)	Min. Evaluated residual life(h)	Evaluated region
Final SH Outlet Header	Circumferential weld at right side	20	270,000	Coarse grain HAZ
De-Suerheater-Left	Circumferential weld	42	96,000	Coarse grain HAZ
De-Suerheater-Right	Circumferential weld	42	96,000	Coarse grain HAZ
RH Outlet Header	Circumferential weld at left side	9	700,000	Fine grain HAZ
	Circumferential weld at right side,top	20	270,000	Coarse grain HAZ
	Circumferential weld at right side,front	20	270,000	Coarse grain HAZ
Main Steam Pipe-Right	Circumferential weld,intrados	50	69,000	Coarse grain HAZ
		(74)※	(24,000)※	Base Metal
	Circumferential weld.near the stop valve	20	270,000	Coarse grain HAZ
		(89)※	(8.000)※	Base Metal
Hot Reheat Pipe-Right	Circumferential weld	22	240,000	Fine grain HAZ

※ : Regarded as reference for OD measurement was not carried out.

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 was observed for Water wall tubes around short soot blower, corner portion, burner portion and Platen SH and RH tube at the highest level of soot blower.
- 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 (101points in total), the measured thickness for a number of tubes (min.4.2mm) was less than tsr (thickness required) 6.1mm calculated with designed OD, pressure and allowable stress at the designed temperature.
- As a result of thickness measurement for mainly for outermost tubes of rear side portion of Platen SH tube (71points in total) at the highest and the second soot blower level, no measured thickness value was found to be below the designed value.

(3) OD measurement

- As a result of OD measurement for Final-SH Outlet Header-Right, De-Super Heater (Left&Right), RH Outlet Header (Left&Right),Hot Reheat Pipe-Right, 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 Platen-SH tube (87 points;29tubes× bottom bend 3portions), SUS scale deposition was not significant with 15% fullness for 4 points, 10% fullness for 2 points and less than 10% fullness for the other portions.

(5) Dye penetrant inspection

- As a result of Dye penetrant inspection for 4 stub weld portions of # 3 panel from right of Platen-SH Inlet Header, no linear indication was detected.

(6) UT inspection

- As a result of UT inspection for 1ring of circumferential weld of Final SH outlet Header-Right, no flaw echo exceeding the criteria was detected.

(7) TOFD inspection

- As a result of TOFD inspection at the location identical to UT inspection location in Final-SH Outlet Header, no flaw echo judged as a crack was detected, although a continuous subtle flaw echoes were detected at about 80mm in depth from surface.

5. Components for residual life assessment and inspection

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

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

Table II-1 Components for residual life assessment

Component	Location	Material		Designed				
		ASME	JIS	O.D. (mm)	t (mm)	Temperature (°C)	Pressure (MPa)	Pressure (kg/cm²)
Final SH Outlet Header	Circumferential weld at right side	SA335P22	STPA24	457.2	100.0	555	15.75	160.6
De-Suerheater-Left	Circumferential weld	SA335P12	STPA22	406.4	45.0	450	16.44	167.6
De-Suerheater-Right	Circumferential weld	SA335P12	STPA22					
RH Outlet Header	Circumferential weld at left side	SA335P22	STPA24	558.8	45.0	555	4.32	44.1
	Circumferential weld at right side,top	SA335P22	STPA24					
	Circumferential weld at right side,front	SA335P22	STPA24					
Main Steam Pipe-Right	Circumferential weld, intrados side	SA335P22	STPA24	355.6	50.3	540	15.74	160.5
	Circumferential weld,near the stop valve	SA335P22	STPA24					
Hot Reheat Pipe-Right	Circumferential weld	SA335P22	STPA24	508.0	28.0	540	3.69	37.6

Table II-2 Components for the other inspections

Portion	Inspection method
Water wall tube	Visual check
	Thickness measurement of tubes
Platten SH	Visual check
	Thickness measurement of tubes
	SUS scale deposition inspection
	Tube sampling for sample tube inspection (inspected in Japan).
	Creep rupture test (inspected in Japan)
Reheater	Visual check
Super heater header	Visual check
	DPT
	UT
	TOFD
	Replica inspection
De superheater pipe	Replica inspection
Reheater header	Replica inspection
Hot Reheat Pipe	Replica inspection

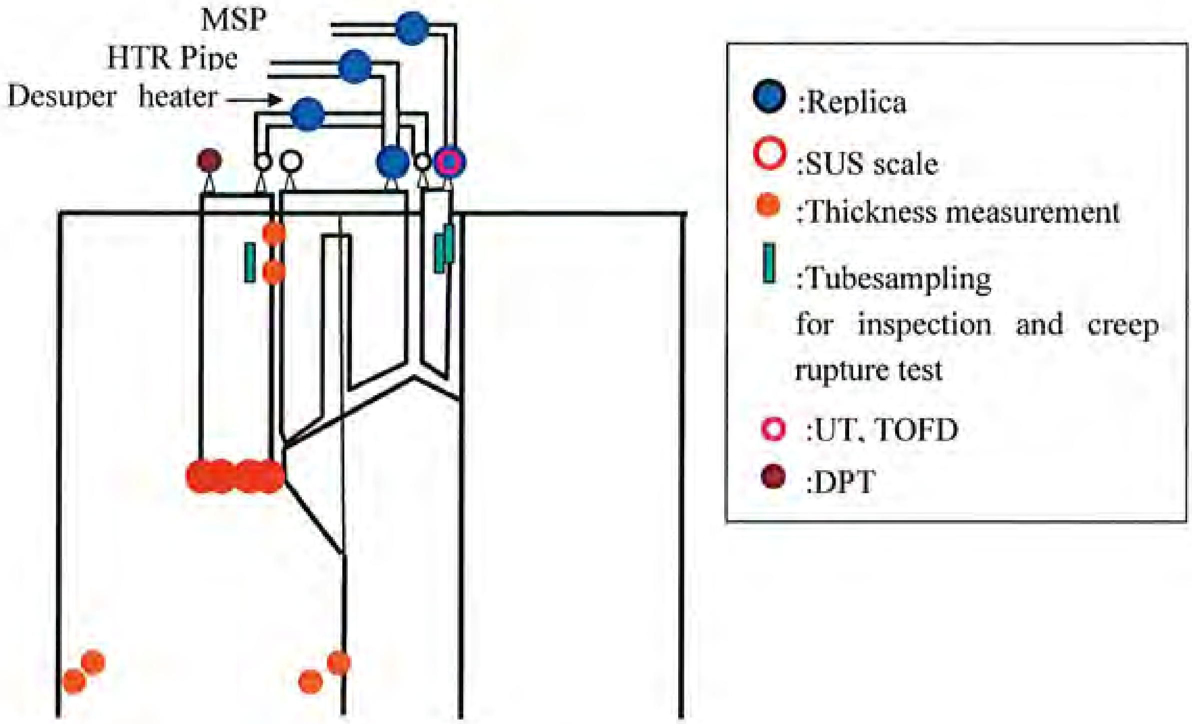


Fig. II-1 Location for each inspection

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6. Items for residual life assessment

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

Table II -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
Final SH Outlet Header	Circumferential weld at right side	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
De-Suerheater-Left	Circumferential weld	SA335P12	Base metal	○	○			○	
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
De-Suerheater-Right	Circumferential weld	SA335P12	Base metal	○	○			○	
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
RH Outlet Header	Circumferential weld at left side	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
	Circumferential weld at right side,top	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
	Circumferential weld at right side,front	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
Main Steam Pipe-Right	Circumferential weld,intrados	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
	Circumferential weld,near the stop valve	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				
Hot Reheat Pipe-Right	Circumferential weld	SA335P22	Base metal	○	○		○	○	○
			Intercritical zone	○					
			Fine grain HAZ	○	○		○	○	
			Coarse grain HAZ	○	○	○			
			Weld metal	○	○				

(1) Microstructure evaluation

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

a. Observed region

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

b. 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)

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) Final SH Outlet Header (circumferential weld at right side (SA335P22)

(Microstructure observation)

The results of microstructure observation are shown in Photo II -4-1～5.

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

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

(Creep void observation)

The results of creep void observation are shown in Photo II -4- 6～8.

The summary of observation results is shown in Table II -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 II -4-9～10.

- 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 II -4-11～14.

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

- Precipitates free zone along grain boundary and disappearance of fine precipitates in bainite grain were observed in base metal.

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

(Microstructure observation)

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

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

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

(Creep void observation)

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

The summary of observation results is shown in Table II -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 II -5-9～10.

- 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 II -5-11～14.

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

- Spherodized precipitates were observed in coarse grain HAZ.

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

(Microstructure observation)

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

The summary of observation results is shown in Table II -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 II -6-6～8.

The summary of observation results is shown in Table II -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 II -6-9～10.

- 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 II -6-11～14.

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

- No remarkable degradation of precipitates distribution was observed.

(4) RH Outlet Header (circumferential weld at left side (SA335P22))

(Microstructure observation)

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

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

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

(Creep void observation)

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

The summary of observation results is shown in Table II -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 II -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 II -7-11～14.

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

- Precipitates free zone along grain boundary and disappearance of fine precipitates in bainite grain were observed in base metal.
- Disappearance of fine precipitates were observed in fine grain HAZ and coarse grain HAZ.

(5) RH Outlet Header (circumferential weld at right side,top（SA335P22）)

(Microstructure observation)

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

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

- Precipitates at gain boundary were observed in base metal, intercritical zone and fine grain HAZ and coarse 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 II -8-6～8.

The summary of observation results is shown in Table II -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 II -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 II -8-11～14.

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

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

(6) RH Outlet Header (Circumferential weld at right side,front（SA335P22）)

(Microstructure observation)

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

The summary of observation results is shown in Table II -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 II -9-6～8.

The summary of observation results is shown in Table II -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 II -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 II -9-11～14.

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

- Precipitates free zone along grain boundary and disappearance of fine precipitates in bainite grain were observed in base metal.
- Fine precipitates had spherodized in fine grain HAZ and coarse grain HAZ.

(7) Main Steam Pipe-Right (Circumferential weld, intrados (SA335P22))

(Microstructure observation)

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

The summary of observation results is shown in Table II -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 II -10-6～8.

The summary of observation results is shown in Table II -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 II -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 II -10-11～14.

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

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

(8) Main Steam Pipe-Right (Circumferential weld,near the stop valve (SA335P22))

(Microstructure observation)

The results of microstructure observation are shown in Photo II -11-1～5.

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

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

(Creep void observation)

The results of creep void observation are shown in Photo II -11-6～8.

The summary of observation results is shown in Table II -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 II -11-9～10.

- 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 II -11-11～14.

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

- Precipitates free zone along grain boundary and disappearance of fine precipitates in bainite grain were observed in base metal.
- Spherodized precipitates were observed in fine grain HAZ and coarse grain HAZ.

(9) Hot Reheat Pipe-Right(Circumferential weld （SA335P22）)

(Microstructure observation)

The results of microstructure observation are shown in Photo Ⅱ-12-1～5.

The summary of observation results is shown in Table Ⅱ-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 Ⅱ-12-6～8.

The summary of observation results is shown in Table Ⅱ-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 Ⅱ-12-9～10.

- 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 Ⅱ-12-11～14.

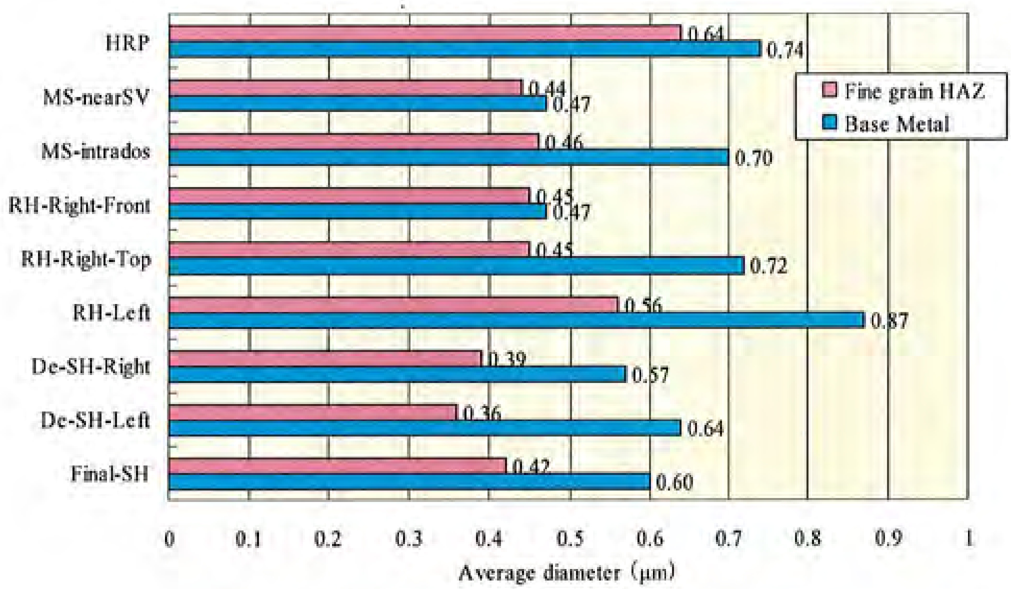
The summary of observation results is shown in Table Ⅱ-6.

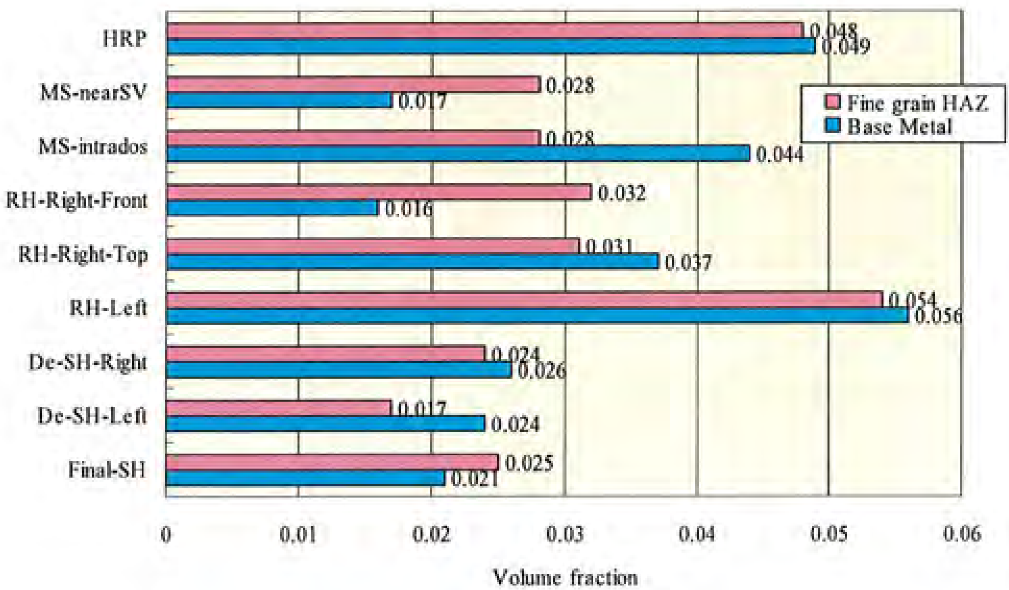
- Precipitates free zone along grain boundary and disappearance of fine precipitates in bainite grain were observed in base metal.
- Fine precipitates had disappeared in fine grain HAZ, coarse grain HAZ and weld metal.

7-2 Quantitative evaluation of grain boundary precipitates

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

- The max. value of average diameter of grain boundary precipitates was 0.87 μm in base metal at RH Outlet Header-Left, 0.64 μm in fine grain HAZ at Hot Reheat Pipe-Right.
- The max. value of volume fraction of grain boundary precipitates was 0.056 in base metal at RH Outlet Header-Left, 0.054 in fine grain HAZ at RH Outlet Header-Left.



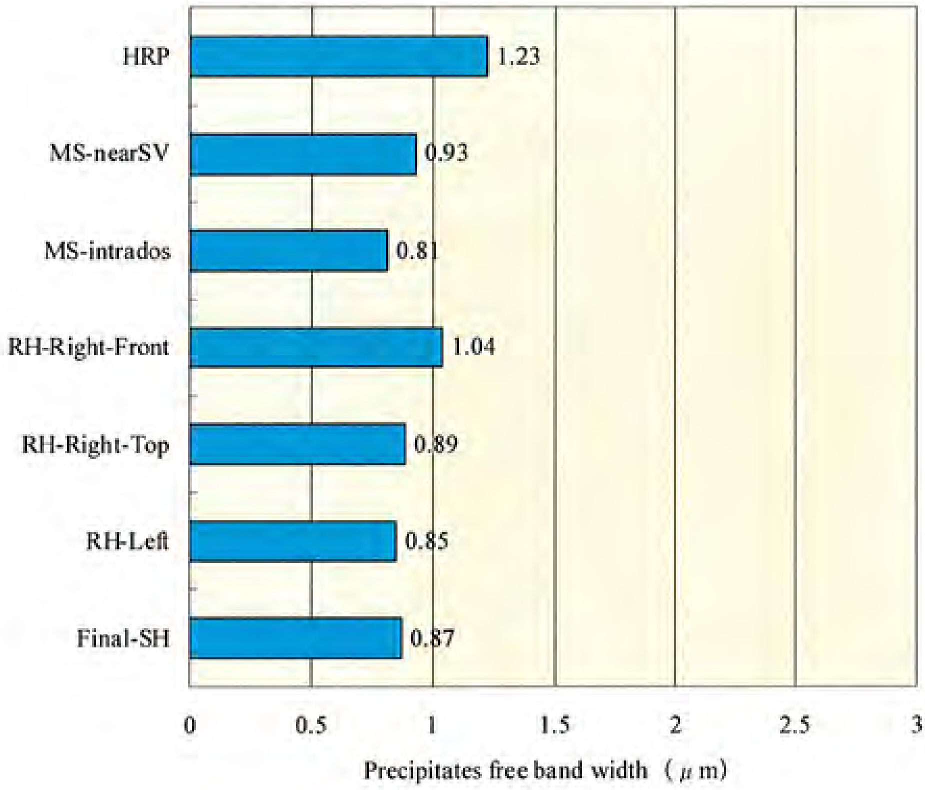


Quantitative evaluation of grain boundary precipitates 〔extracted Table II -7〕

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 Ⅱ-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 1.23 μm at Hot Reheat Pipe-Right.



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

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8. Residual life assessment results

8-1 Operational condition of evaluated components

Operational condition of evaluated components is shown in Table Ⅱ-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 Ⅱ-1～9 and Table Ⅱ-10. The summary of evaluation results is shown in Ⅱ-11.

- The highest creep life consumption ratio among evaluated pipes and headers was 50% at Main Steam Pipe-Right (Intrados) with the evaluated residual life 69,000 hours.
- The evaluated results for base metal and fine grain HAZ of Main Steam Pipe-right (intrados, near the stop valve) were regarded as the reference, since OD measurement was not carried out. The estimated residual life in base metal varies from 8,000 to 130,000 hrs due to no OD measurements applied, while microstructure shows a little degradation. For accurate estimation of residual life, creep strain (OD) measurement along with microstructure is recommended to be carried out preferably within 8,000 hrs or practically at the earliest opportunity. For the other components, the evaluated residual life was 96,000 hours or more.

Table Ⅱ-11　Summary of residual life evaluation results

Components	Location	Max. creep life consumption ratio(%)	Min. Evaluated residual life(h)	Evaluated region
Final SH Outlet Header	Circumferential weld at right side	20	270,000	Coarse grain HAZ
De-Suerheater-Left	Circumferential weld	42	96,000	Coarse grain HAZ
De-Suerheater-Right	Circumferential weld	42	96,000	Coarse grain HAZ
RH Outlet Header	Circumferential weld at left side	9	700,000	Fine grain HAZ
	Circumferential weld at right side,top	20	270,000	Coarse grain HAZ
	Circumferential weld at right side,front	20	270,000	Coarse grain HAZ
Main Steam Pipe-Right	Circumferential weld,intrados	50	69,000	Coarse grain HAZ
		(74)※	(24,000)※	Base Metal
	Circumferential weld,near the stop valve	20	270,000	Coarse grain HAZ
		(89)※	(8,000)※	Base Metal
Hot Reheat Pipe-Right	Circumferential weld	22	240,000	Fine grain HAZ

※ :Regarded as reference for OD measurement was not carried out.

9. The other inspection results

9-1 Visual inspection, Thickness measurement

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

(Erosion of Water Wall tube around short soot blower)

- Erosion by soot blower were 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 II -13～16.
- Min.thickness was 5.3mm at a rear wall tube around #1 short soot blower from right, that was less than the designed value tsr (thickness required) 6.1mm calculated with designed OD, pressure and allowable stress at the designed temperature.

Erosion of rear wall tube
〔extracted from Table II -12〕

(Erosion of Water Wall tube around burner portion)

- Erosion by soot blower was observed at a number of Water Wall tubes around burner portion.
- The thickness measurement was carried out at the eroded portion as shown in Table II -17.
- Min.thickness was 4.7 mm, that was less than the tsr 6.1mm.

Erosion of Water Wall tube around burner portion 〔extracted from Table II -12〕

(Erosion of Water Wall tube around corner portion)

- Erosion around corner portion at soot blower level was observed.
- The thickness measurement was carried out at the eroded portion as shown in Table II-18.
- Min.thickness was 4.2 mm, that was less than the tsr 6.1mm.

Erosion of Water Wall tube around corner portion〔extracted from Table II-12〕

(Erosion of Platen SH tube at the highest level of soot blower)

- Slight erosion of Platen SH tube was observed at the highest level of soot blower.
- The thickness measurement was carried out at the eroded portion as shown in Table II-19.
- Min.thickness was 9.8mm, that was larger than the designed thickness 9.6 mm.

Erosion of Platen SH tube at the highest level of soot blower〔extracted from Table II-18〕

9-2 OD measurement results

OD measurement results of residual life evaluated portion are shown in Table II-20～23.

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

Table II-24 OD measurement results of each portion
(Increase in measured average OD to designed value)

Components	Location	Material	(Averaged measured value-Designed OD) /Designed OD(%)
Final SH Outlet Header	Circumferential weld at right side	SA335P22	0.74
De-Superheater-Left	Circumferential weld	SA335P12	0.44
De-Superheater-Right	Circumferential weld	SA335P12	0.46
RH Outlet Header	Circumferential weld at left side	SA335P22	0.20
	Circumferential weld at right side,top	SA335P22	0.57
	Circumferential weld at right side,front	SA335P22	
Main Steam Pipe-Right	Circumferential weld, intrados	SA335P22	—
	Circumferential weld, near the stop valve	SA335P22	—
Hot Reheat Pipe-Right	Circumferential weld	SA335P22	0.01

OD measurement was not carried out for Main Steam Pipe-Right, because the OD of Main Steam Pipe was out of the measurement range of prepared outside micrometers.

9-3 SUS scale deposition inspection

Applied equipment and inspection condition are shown in Table Ⅱ-25.

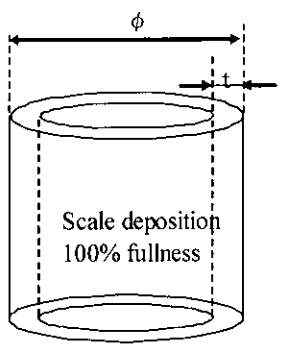
Table II-25 Applied equipment and inspection condition

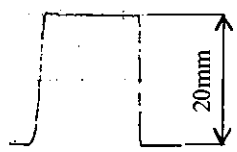
DETECTOR	MAKER・TYPE	UNI-ELECTRONICS,Inc. ・SSD－1
	I.D.№	34A3382 (64SCA02101)
	CHECK DATE·PERSON	2009 June 5th ・Shinichi Aizawa
	VAIDITY DATE	2010 June 4th
RECORDER	MAKER・TYPE	HIOKI E. E. CORPORATION ・8205-10
	I.D.No.	041213164 (64SCZ05102)
	CHECK DATE·PERSON	2009 May 28th ・Shinichi Aizawa
	VAIDITY DATE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

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 outermost tube bend portion, bottom tube straight portion φ54.0×t9.5 (ID.No.50-21-1) φ54.0×t5.6 (I.D. No : 50-20-1)

REMARKS

Shape of reference test piece and wave form





Wave form
by reference test piece

SUS scale deposition inspection was carried out at outer most tube bottom bend and horizontal portion of Platen-SH as shown in Fig. II -2.

Platen-SH

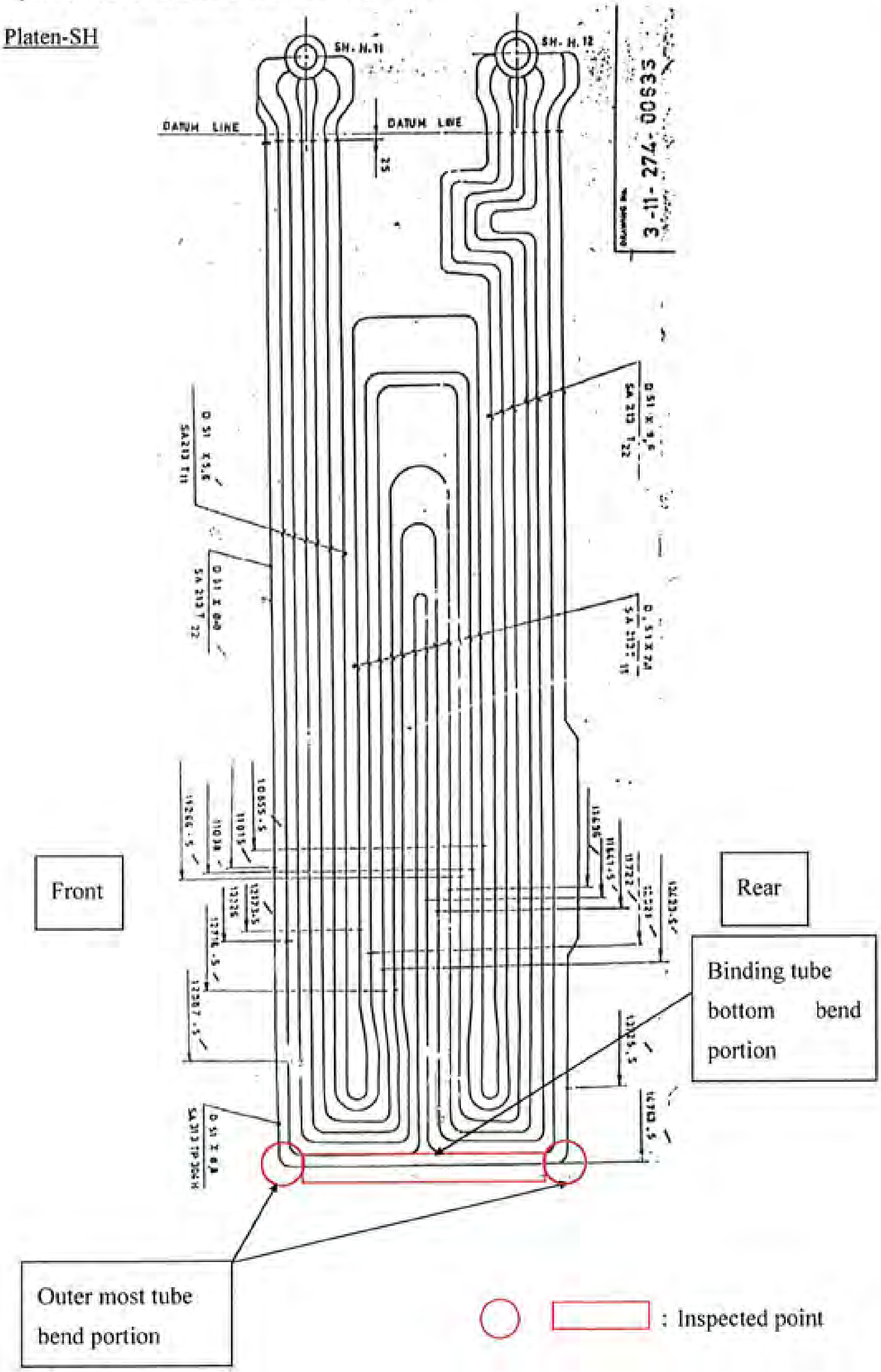


Fig. II -2 Inspection location

SUS scale deposition inspection results are shown in Table Ⅱ-26.

SUS scale deposition was not significant with 15% fullness for 4 points, 10% fullness for 2 points and less than 10% fullness for the other portions.

Table II-26 SUS scale deposition inspection results

Platen Super Heater (Outermost tube bend portion)			
Front		Rear	
Panel No.	Fullness (%)	Panel No.	Fullness (%)
17	10	27	15
18	15		
19	10		
20	15		
22	15		

〔Remarks〕

- Standard curve with ϕ 54.0×t9.5 was used for evaluation of fullness.
- The signal by magnetization of tube material with heat was recognized at front bend, rear bend and horizontal portion.

The representative deposition signal for this inspection is shown in Fig. Ⅱ-3.

The standard curve used is shown in Fig. Ⅱ-4.

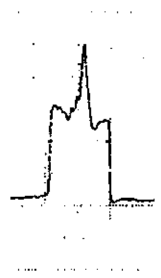
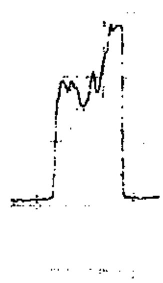
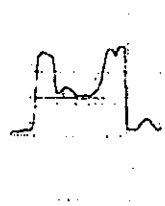
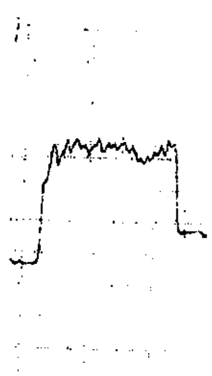
	Scanning from bottom surface	Scanning from side surface
Platen SH outermost tube front bend portion #20 panel Fullness 15%		
Platen SH outermost tube rear bend portion # 27panel Fullness 15%		
Platen SH bottom straight portion # 14 panel Fullness 0%		

Fig. II-3 Representative deposition signal for this inspection

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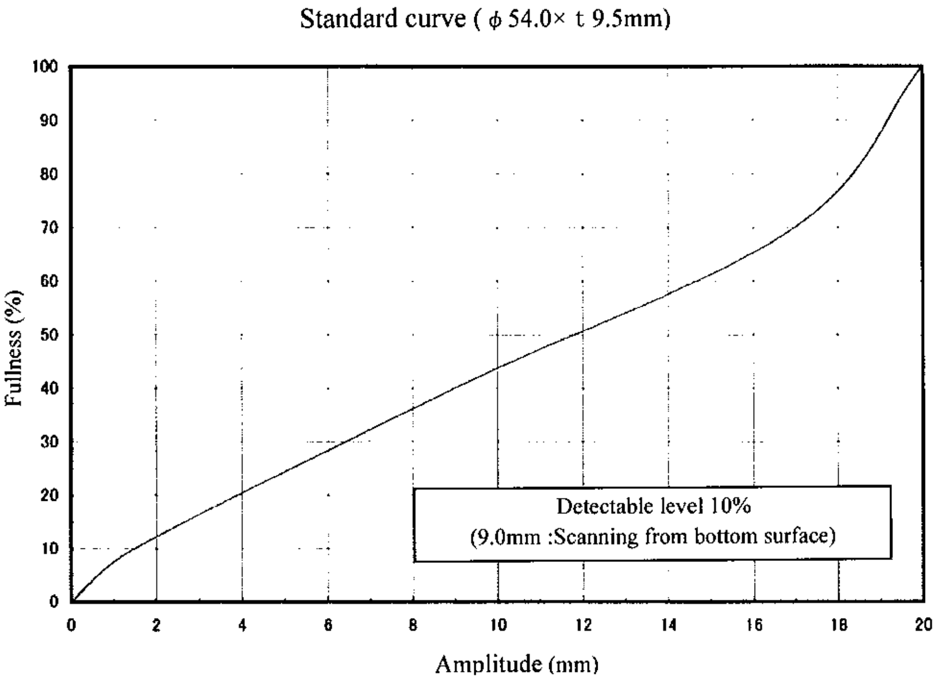

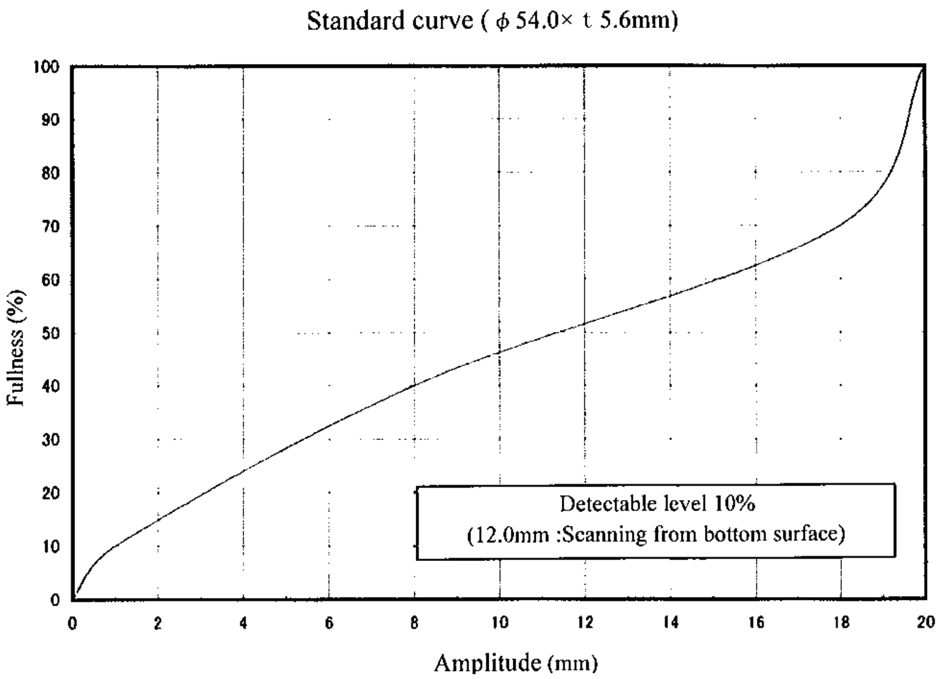

Fig. II -4 Standard curve used for evaluation

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9-4 DPT

Applied material and examination condition are shown in Table Ⅱ-27.

Table Ⅱ-27 Applied material and examination 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

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

DPT inspection were carried out at 4 stub weld portions of #3 panel from right in Platen SH inlet header front side.

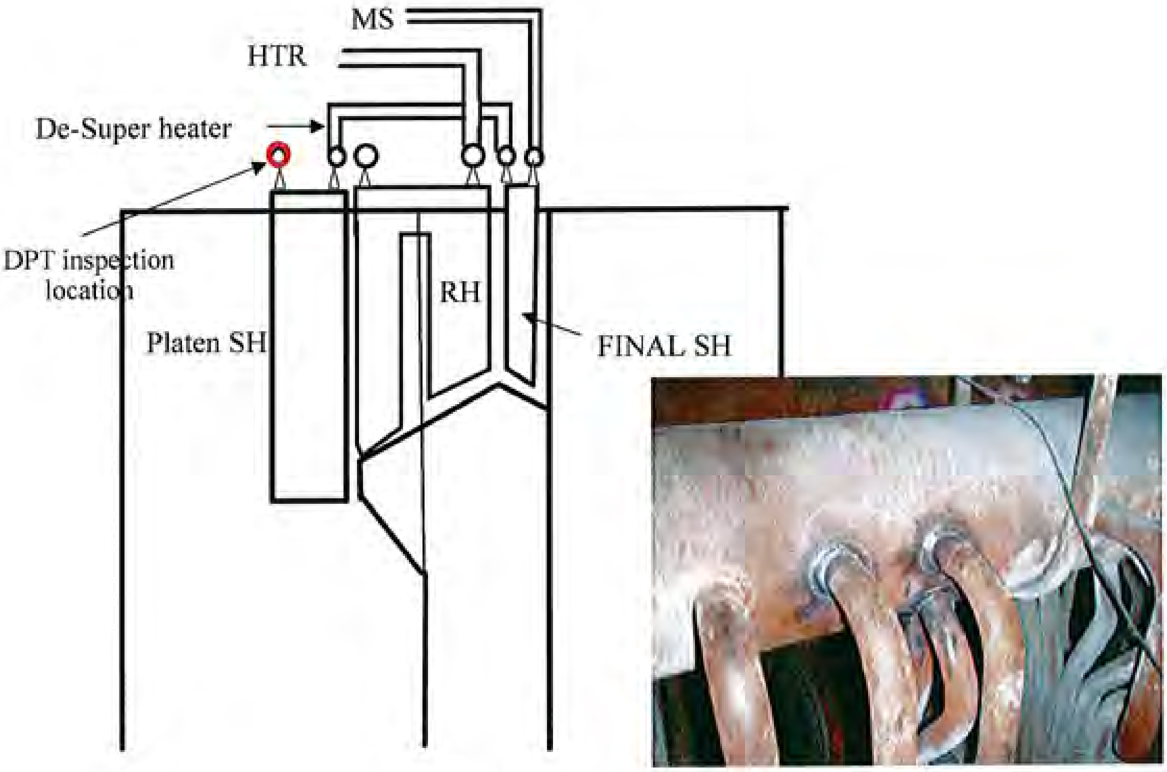

Fig. II -5 DPT inspection location

The indication pattern detected location is shown in Fig. II -6.

Two for each of ϕ2mm and ϕ1mm circular indication pattern were detected at 4th tube from front, although no indication pattern was judged as crack. After grinding off these indications, a new ϕ2mm circular indication pattern appeared. The new indication has been left since it was not judged as crack.

Before grinding off

After grinding off

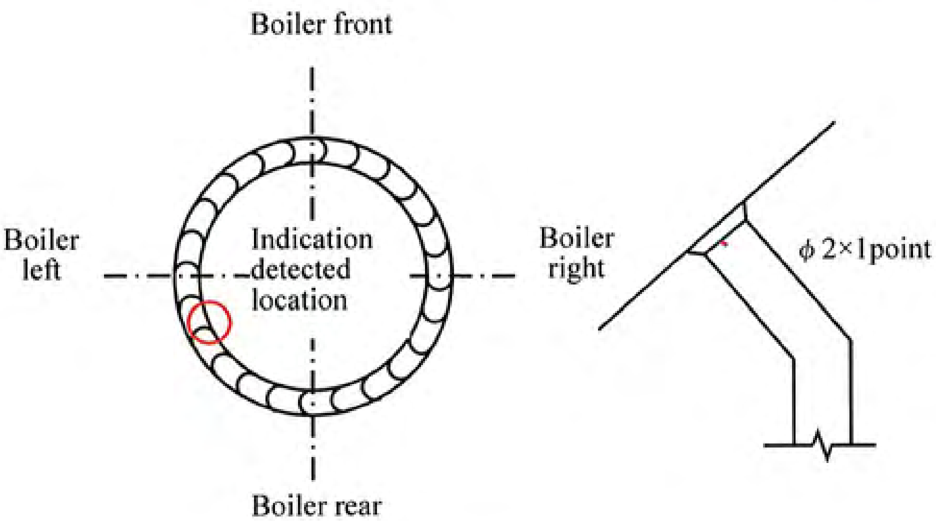

Fig. II-6 The indication pattern detected location

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9-5 UT

Applied equipment and examination condition are shown in Table Ⅱ-28.

Table Ⅱ-28 Applied equipment and examination 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	40dB or more		
	CHECK DATE・PERSON	2008 November 20th ・ Hidekazu Ishihara(UT-2)		
	VAIDITY DATE	2009 November 19th		
PROBE	TYPE	angle beam probe	angle beam probe	
	DESIGNATION	2C14×14A45	2C14×14A60	
	MAKER	KGK	KGK	
	SERIAL No.	XA7426	18421	
	DEAD ZONE	7.5mm	8mm	
	STB ANGLE OF REFRACTION	45 degree	60 degree	
	ACCESIBLE LIMIT DISTANCE	14mm	15mm	
	FAR SURFACE RESOLUTION	7mm	7mm	
	CHECK DATE・PERSON	2009 August 26th Kawazu (UT-2)	2009 May 22th Kawazu (UT-2)	
	VAIDITY DATE	2010 February 25th	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	Crack length is 19mm or less
REFERENCE BLOCK OR CALIBRATION BLOCK	RB-41 №2 RB-41 №2
ANGLE OF REFRACTION IN TEST OBJECT	ANGLE OF REFRACTION : – CALCULATION METHOD : ☐Ratio of sound velocity of STB ☐ V path technique

Inspected location of UT is shown in Fig. II -7.

UT inspection was carried out at circumferential weld of right side in Final-SH Outlet Header.

As a result of UT inspection, no flaw echo exceeding the criteria was detected.

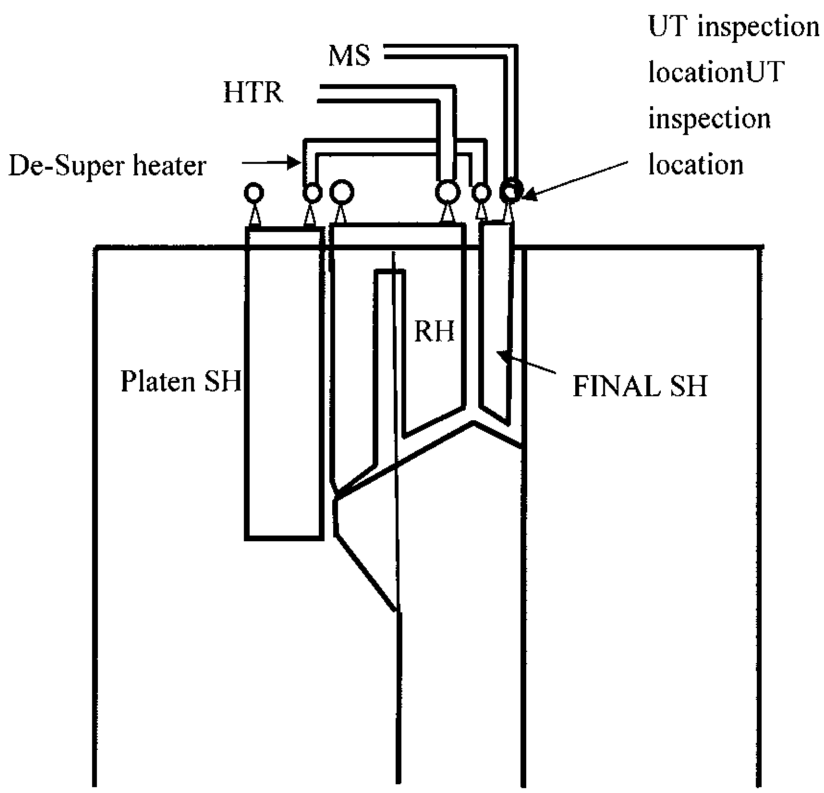

Fig. II -7 Inspected location of UT

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9-6 TOFD

Applied equipment and examination condition are shown in Table Ⅱ-29.

TOFD inspection was carried out at the location identical to UT inspection location in Final-SH Outlet Header with three sets of detection in different depth of focal point from surface.

TOFD detection results are shown in Fig. Ⅱ-8～11.

No flaw echo judged as a crack was detected, although continuous subtle flaw echoes were detected at about 80mm in depth from surface.

Table Ⅱ-29 Applied equipment and examination 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°and 45°
	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	――――――
ACCEPTANCE CRITERIA	――――――
REFERENCE BLOCK OR CALIBRATION BLOCK	φ 4.8mm side cylindrical hole (d=20,40,60,80,100mm)

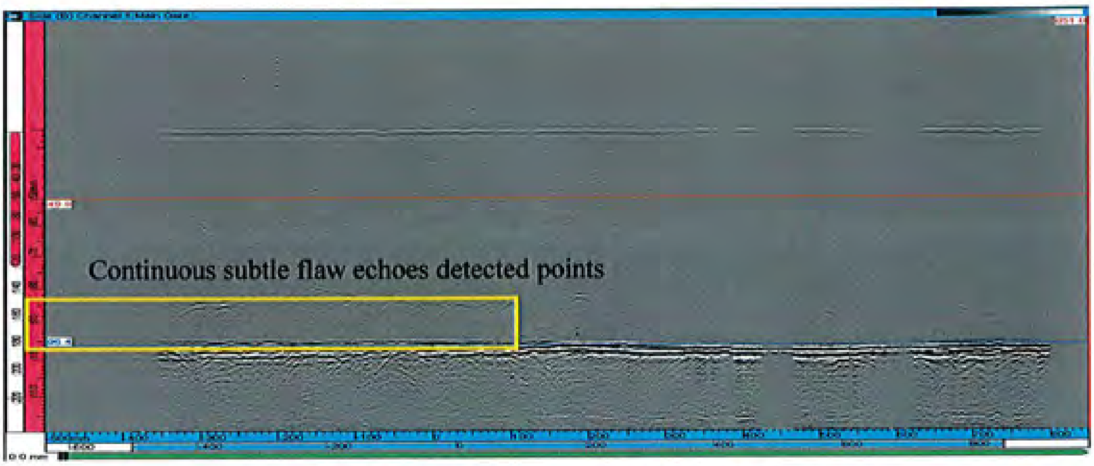


Fig. II -8　Set1 (Monitor range : 50mm～bottom)

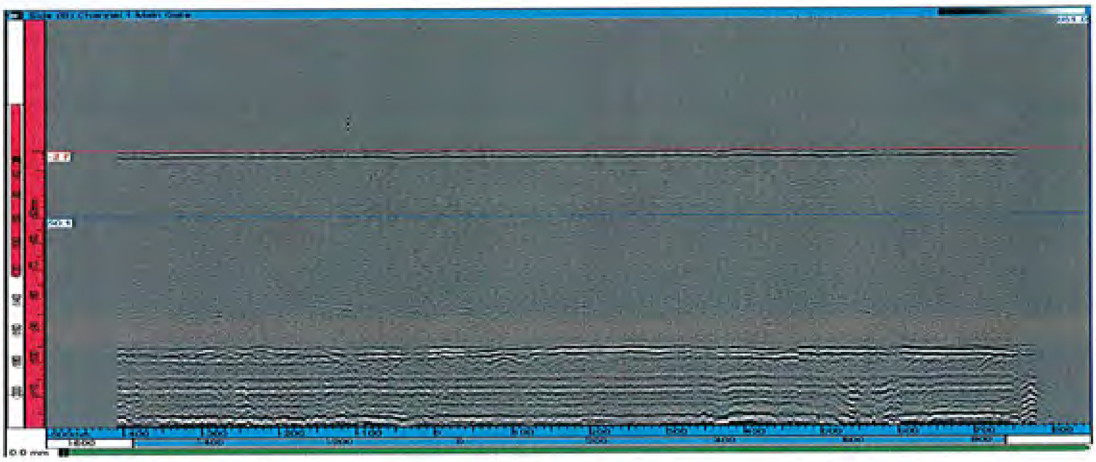


Fig. II -9　Set2 (Monitor range : Surface～50mm)

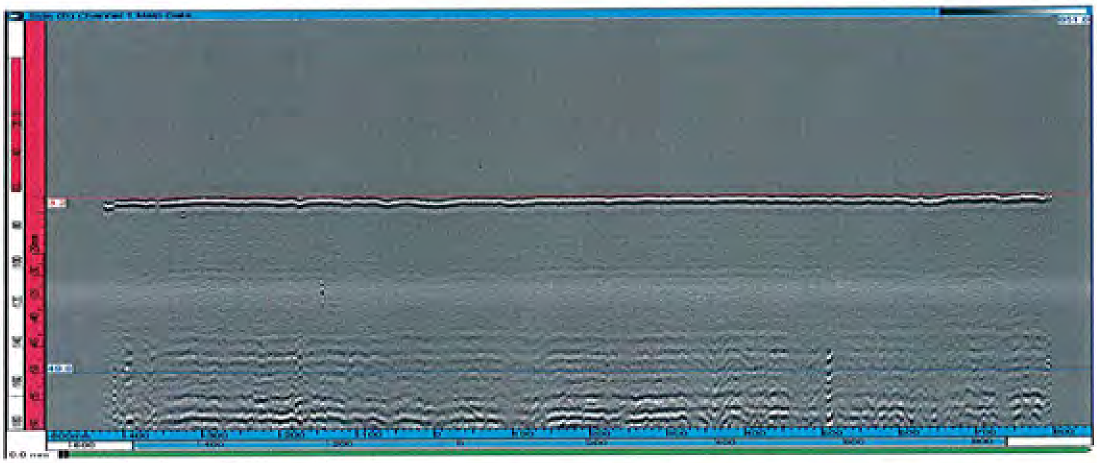


Fig. II -10　Set3 (Monitor range : Near surface〔Weld toe portion, left side〕)

Fig. II -11　Set3 (Monitor range : Near surface〔Weld toe portion, right side〕)

Water wall around burner

・Visual inspection ・Thickness measurement

Water wall around short soot blower

・Visual inspection ・Thickness measurement

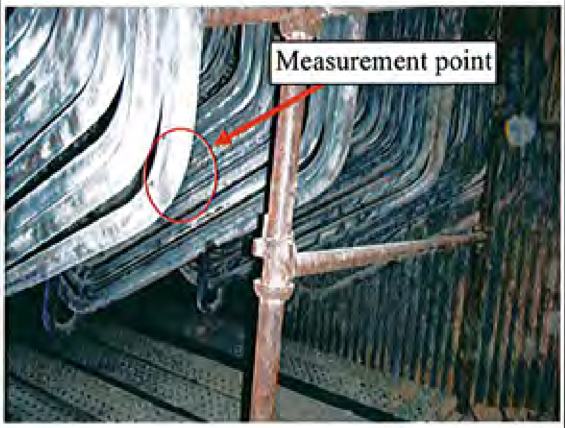
Platen SH at soot blower level

・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

・Visual inspection

Photo II-1 Inspection location

final-SH#1 tube sampling location

・Sample tube inspection

final-SH#119 tube sampling location

・Sample tube inspection
・Creep rupture test

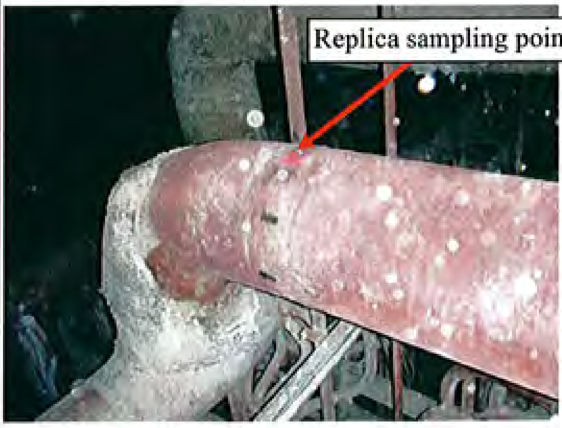
Platen SH intlet Header

・PT

Final SH outtlet Header

・Replica inspection ・OD measurement
・UT ・TOFD

De-superheater(Boiler left side



・Replica inspection ・OD measurement

De-superheater(Boiler right side

・Replica inspection ・OD measurement

Photo II -2 Inspection location

RH Outlet header(Boiler left side)

・Replica inspection　　・OD measurement

RH Outlet header(Boiler right side)

・Replica inspection　　・OD measurement

Main Steam Pipe-Right(intrados)

・Replica inspection

Main Steam Pipe-Right(near the stop valve)

・Replica inspection

Hot Reheat Pipe-Right

・Replica inspection　　・OD measurement

Photo II -3　Inspection location

Table II -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
Final SH outlet header (SA 335 P22)	Rightside of header	Circumferential weld	Base metal	Appeared	Not appeared				
			Intercritical zone	Not appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Appeared					
			Weld metal						
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Base metal	Appeared	Not appeared	Not appeared	Not appeared		
			Intercritical zone	Appeared				Remaining	Not appeared
			Fine grain HAZ	Appeared					Not appeared
			Coarse grain HAZ	Not appeared					Not appeared
			Weld metal					Appeared	
	Right de superheater	Circumferential weld	Base metal	Appeared	Not appeared	Not appeared	Not appeared		
			Intercritical zone	Appeared				Remaining	Not appeared
			Fine grain HAZ	Appeared					Not appeared
			Coarse grain HAZ	Appeared					Not appeared
			Weld metal					Appeared	
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Base metal	Appeared	Not appeared				
			Intercritical zone	Appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Not appeared					
			Weld metal						
	Right	Circumferential weld	Base metal	Appeared	Not appeared				
			Intercritical zone	Appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Appeared					
			Weld metal						
		Circumferential weld (Abnormal microstructure)	Base metal	Appeared	Not appeared				
			Intercritical zone	Appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Appeared					
			Weld metal						
Main steam pipe (SA 335 P22)	Right	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Not appeared				
			Intercritical zone	Appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Appeared					
			Weld metal						
	Right	Circumferential weld (near the stop valve)	Base metal	Appeared	Not appeared				
			Intercritical zone	Appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Not appeared					
			Weld metal						
Hot reheat pipe (SA 335 P22)	Right	Circumferential weld	Base metal	Appeared	Not appeared				
			Intercritical zone	Appeared	Not appeared				
			Fine grain HAZ	Appeared					
			Coarse grain HAZ	Appeared					
			Weld metal						
View nos. for each area				×500 (2 views) ×1000 (4 views)					

Table Ⅱ-5 Creep void observation results

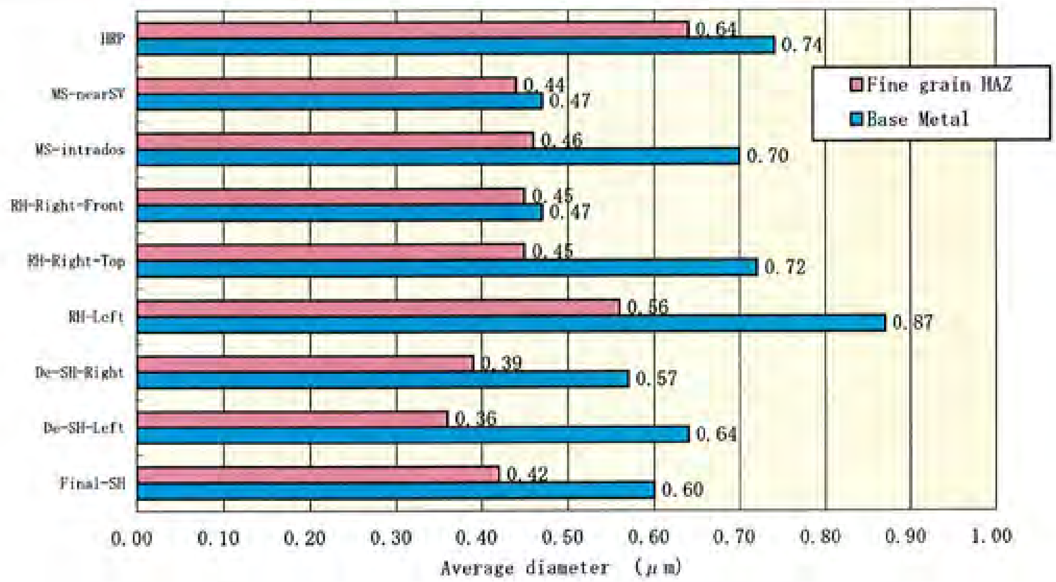
Components	Location		Observed region	SEM (Scanning Electron Microscope observation)
				Ceep void damage
Final SH outlet h	Rightside of heade	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
De-Superheater pipe (SA 335 P12)	Left de superheater	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
	Right de superheat	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
		Circumferential weld (Abnormal microstructure)	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
Main steam pipe	Right	Circumferential weld (near the stop valve) intrados side	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
	Right	Circumferential weld (near the stop valve)	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
Hot reheat pipe	Right	Circumferential weld	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 II-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
Final SH outlet header (SA 335 P22)	Left outlet header	Circumferential weld	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Remaining				
			Coarse grain HAZ			Remaining					
			Weld metal			Remaining					
De superheater pipe	Left de superheater	Circumferential weld	Base metal	Not appeared		Remaining in ferrite grain			Disintegrated	Not appeared	
			Fine grain HAZ			Remaining				Not appeared	Coexist
			Coarse grain HAZ			Remaining					Dcrease of rod-shaped precipitates and spherodized
			Weld metal			Remaining					
	Right de superheater	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					
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Disappeared				
			Coarse grain HAZ			Disappeared					
			Weld metal			Remaining					
	Right	Circumferential weld	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Spherodized				
			Coarse grain HAZ			Remaining					
			Weld metal			Remaining					
	Right	Circumferential weld (Abnormal microstructure)	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared			
			Fine grain HAZ				Spherodized				
			Coarse grain HAZ			Remaining					
			Weld metal			Remaining					
Main steam pipe (SA 335 P22)	Right	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Disappeared			
			Fine grain HAZ				Disappeared				
			Coarse grain HAZ			Disappeared					
			Weld metal			Disappeared					
	Right	Circumferential weld (near the stop valve)	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Disappeared			
			Fine grain HAZ				Spherodized				
			Coarse grain HAZ			Remaining					
			Weld metal			Remaining					
Hot reheat pipe (SA 335 P22)	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					
View nos. for each area				×2000 (2 views), ×10000 (4 views)							

Table Ⅱ-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
Final SH Outlet Header	Circumferential weld at right side	SA335P22	0.60	0.42	0.021	0.025
De-Suerheater-Left	Circumferential weld	SA335P12	0.64	0.36	0.024	0.017
De-Suerheater-Right	Circumferential weld	SA335P12	0.57	0.39	0.026	0.024
RH Outlet Header	Circumferential weld at left side	SA335P22	0.87	0.56	0.056	0.054
	Circumferential weld at right side,top	SA335P22	0.72	0.45	0.037	0.031
	Circumferential weld at right side,front	SA335P22	0.47	0.45	0.016	0.032
Main Steam Pipe-Right	Circumferential weld,intrados	SA335P22	0.70	0.46	0.044	0.028
	Circumferential weld,near the stop valve	SA335P22	0.47	0.44	0.017	0.028
Hot Reheat Pipe-Right	Circumferential weld	SA335P22	0.74	0.64	0.049	0.048



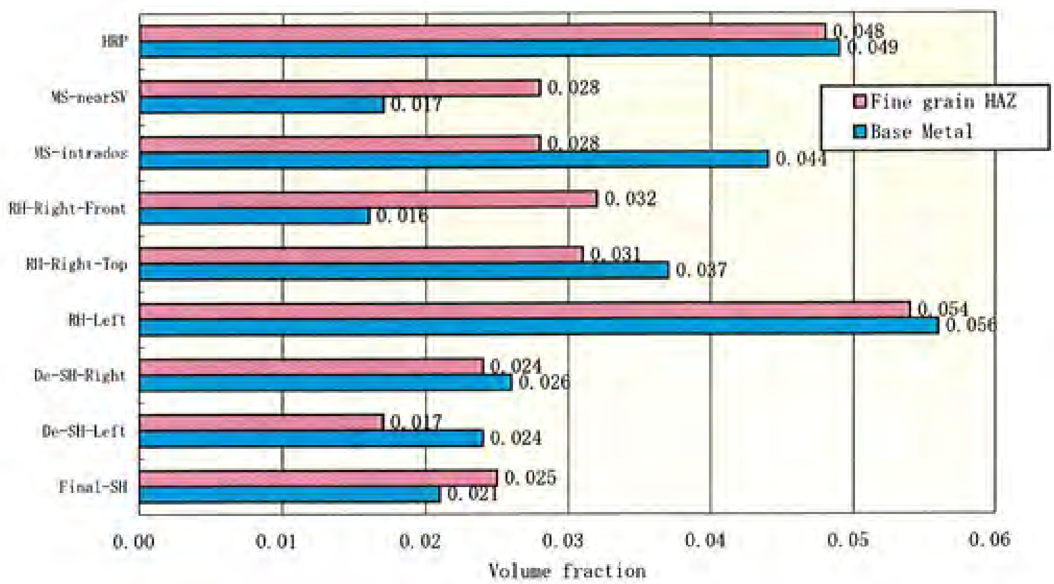


Table Ⅱ-8 Precipitates free band width along grain boundary

Component	Evaluated location	Material	Precipitates free band width (μm) ※1
			Base Metal
Final SH Outlet Header	Circumferential weld at right side	SA335P22	0.87
RH Outlet Header	Circumferential weld at left side	SA335P22	0.85
	Circumferential weld at right side,top	SA335P22	0.89
	Circumferential weld at right side,front	SA335P22	1.04
Main Steam Pipe-Right	Circumferential weld,intrados	SA335P22	0.81
	Circumferential weld,near the stop valve	SA335P22	0.93
Hot Reheat Pipe-Right	Circumferential weld	SA335P22	1.23

※1 : Average value of 10 measured points

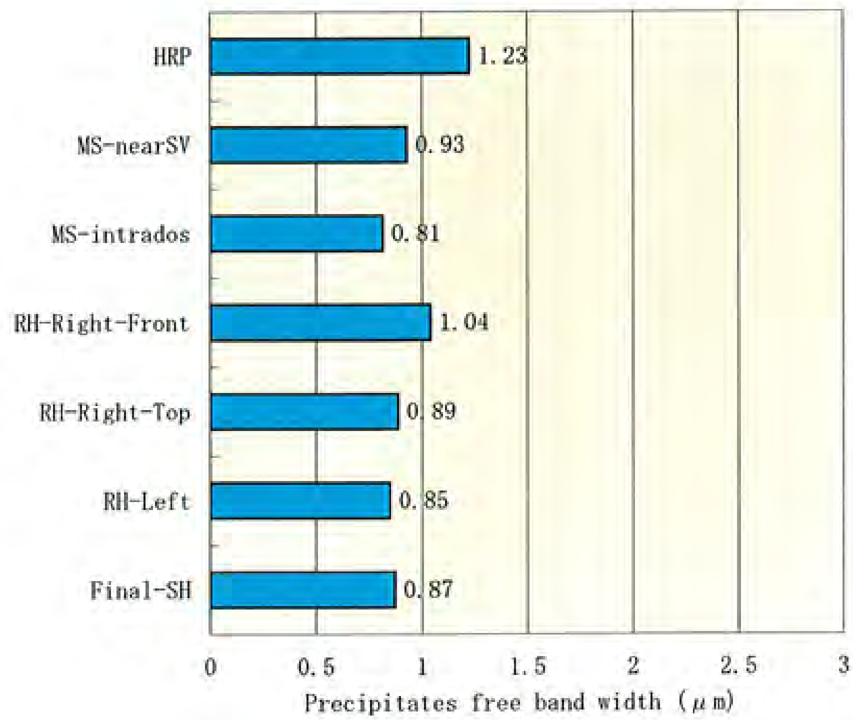


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Table II -9 Operational condition of evaluated components(Unchahar)

Component	Location	Material ASME	Material JIS	Designed O.D. (mm)	Designed t (mm)	Designed Temperature (°C)	Designed Pressure (MPa)	Designed Pressure (kg/cm^2)	Hoop Stress (MPa)	Hoop Stress (kg/mm^2)
Final SH Outlet Header	Circumferential weld at right side	SA335P22	STPA24	457.2	100.0	555	15.75	160.6	28.13	2.87
De-Suerheater-Left	Circumferential weld	SA335P12	STPA22	406.4	45.0	450	16.44	167.6	66.00	6.73
De-Suerheater-Right	Circumferential weld	SA335P12	STPA22							
RH Outlet Header	Circumferential weld at left side	SA335P22	STPA24	558.8	45.0	555	4.32	44.1	24.69	2.52
	Circumferential weld at right side,top	SA335P22	STPA24							
	Circumferential weld at right side,front	SA335P22	STPA24							
Main Steam Pipe-Right	Circumferential weld, intrados side	SA335P22	STPA24	355.6	50.3	540	15.74	160.5	47.77	4.87
	Circumferential weld,near the stop valve	SA335P22	STPA24							
Hot Reheat Pipe-Right	Circumferential weld	SA335P22	STPA24	508.0	28.0	540	3.69	37.6	31.61	3.22

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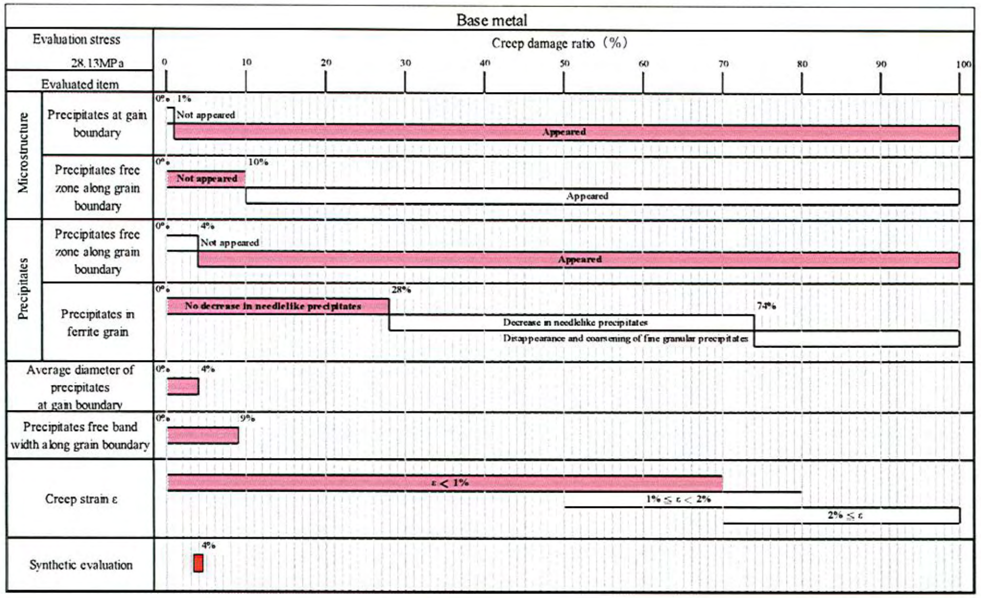
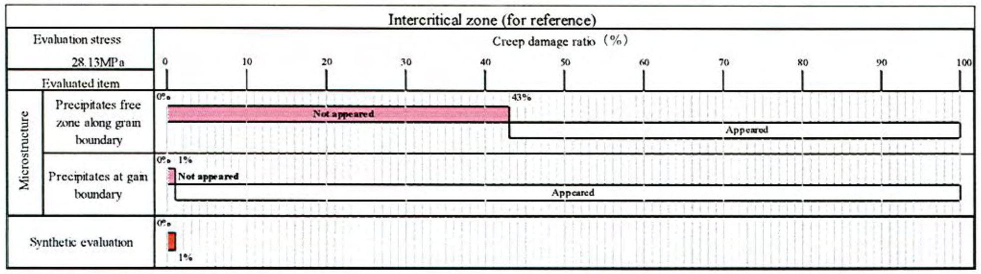
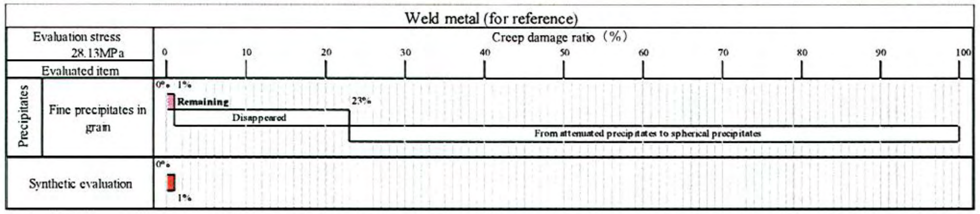
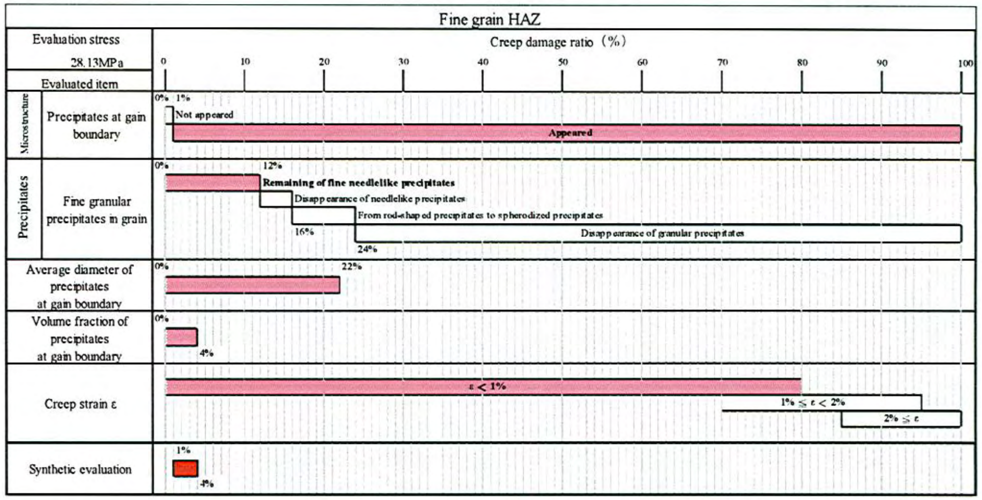
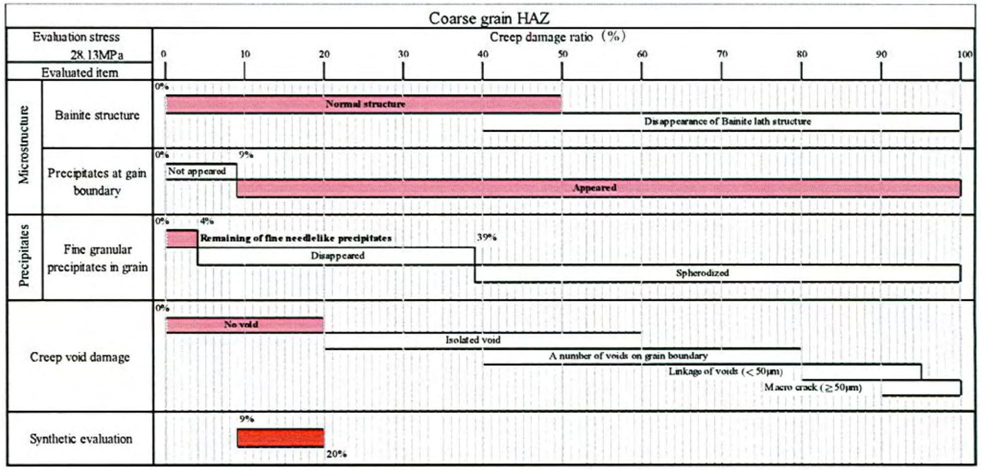


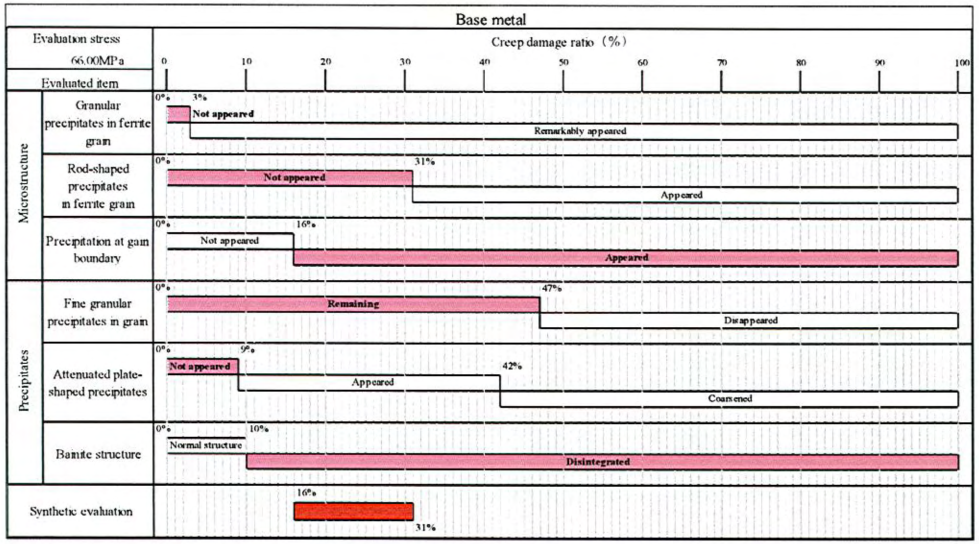


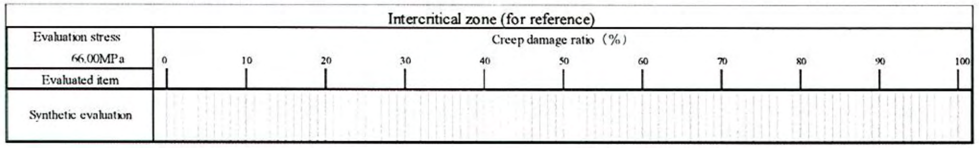


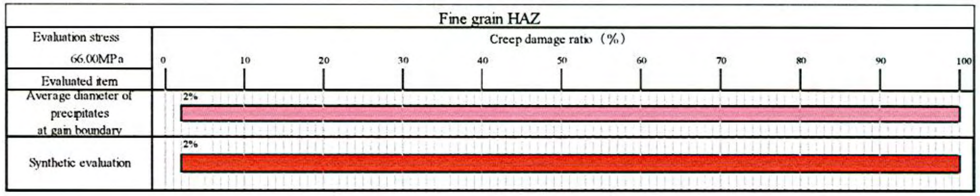


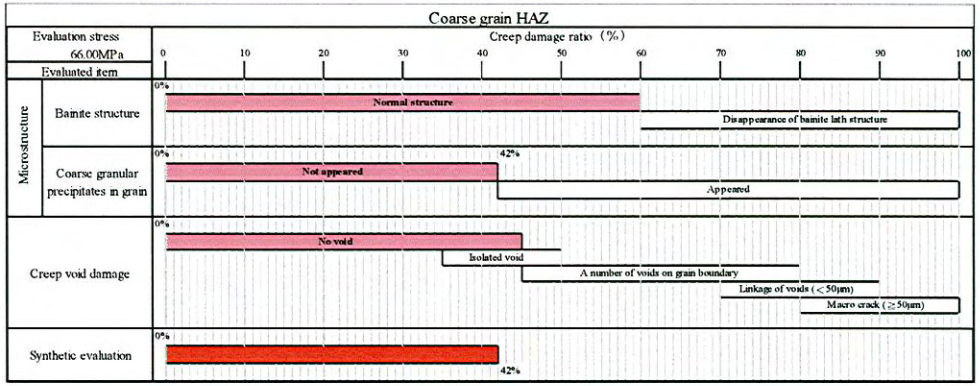


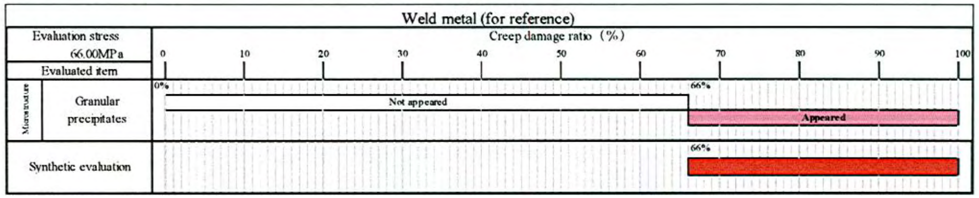
Evaluation Results II－1　Final SH Outlet Header Circumferential weld at right side











Evaluation Results II－2　De-Suerheater-Left　Circumferential weld

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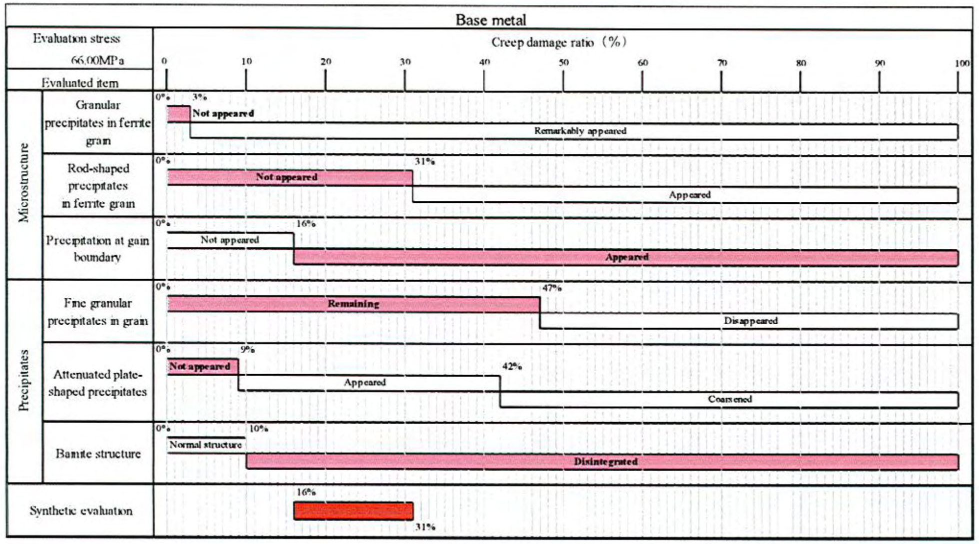

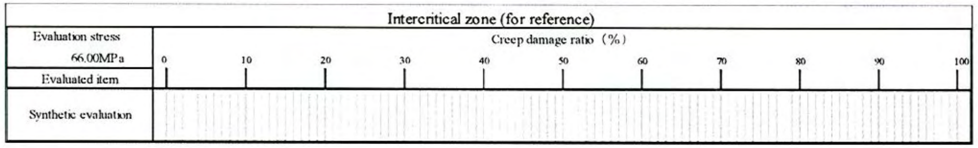

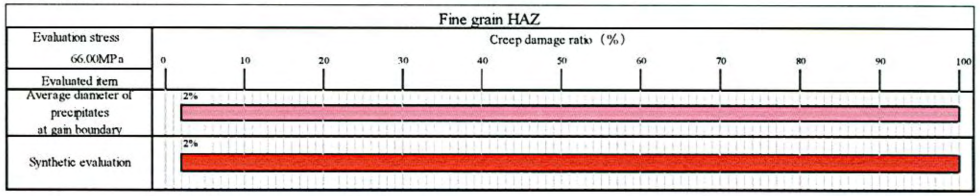

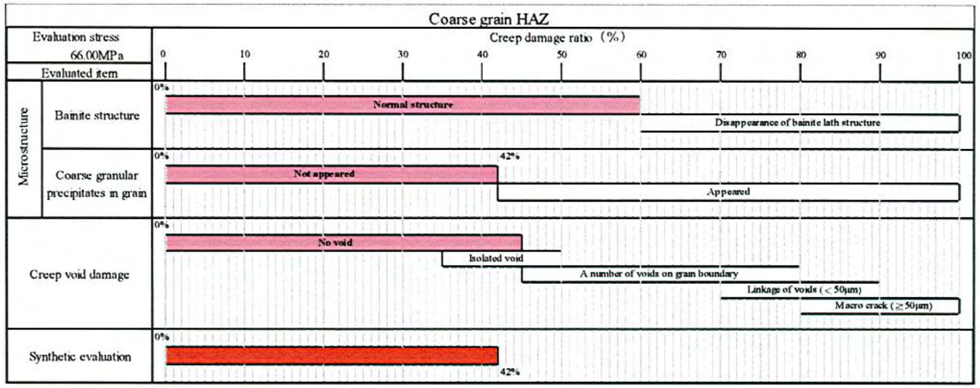

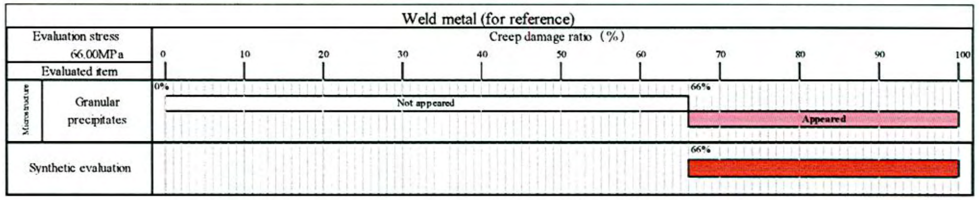

Evaluation Results II－3　De-Suerheater-Right　Circumferential weld

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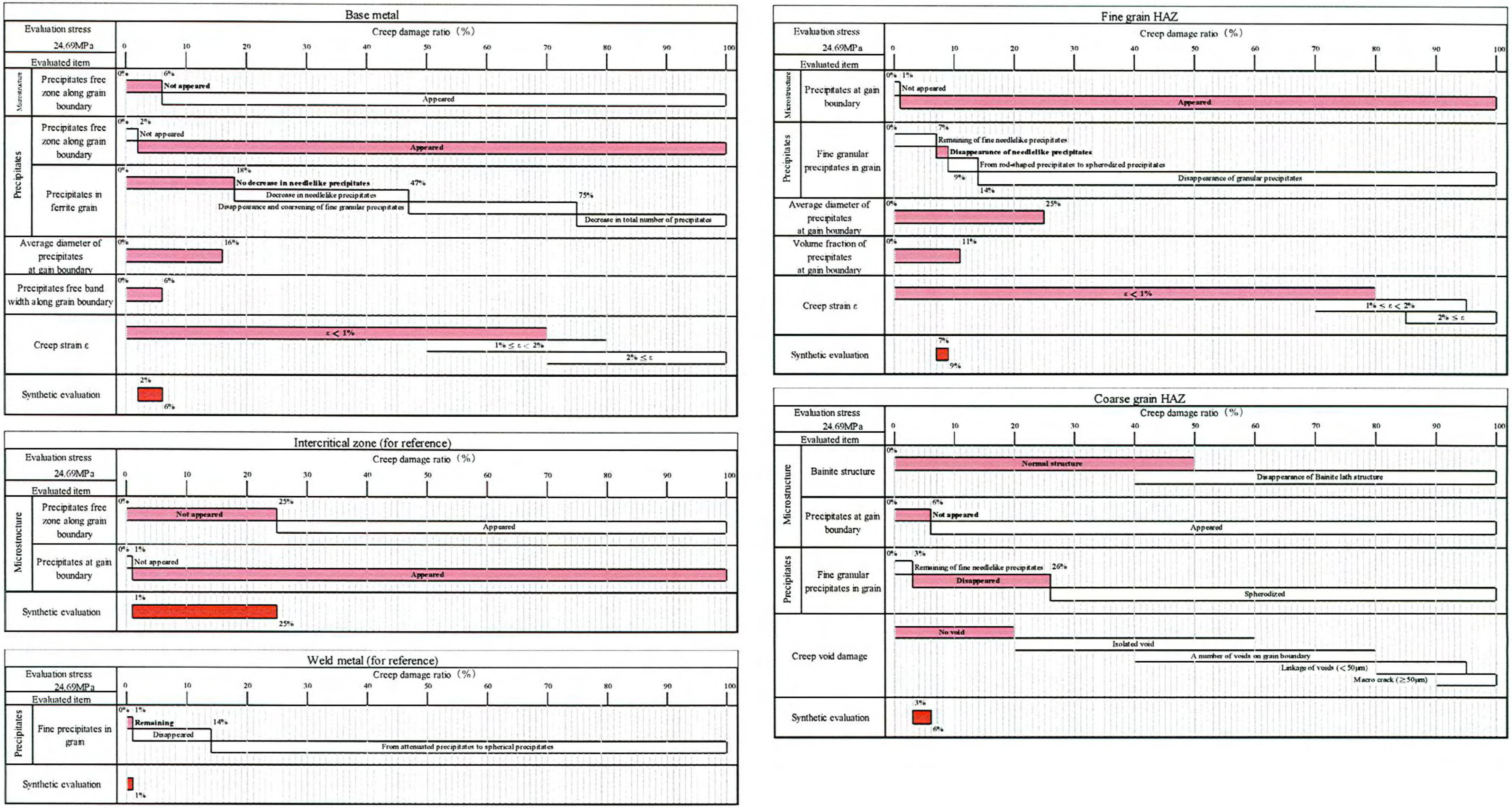
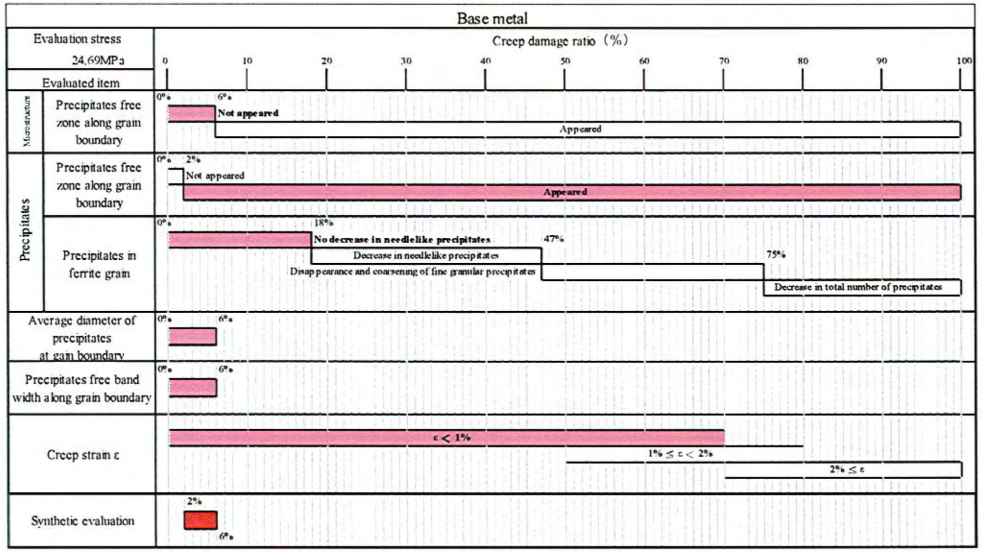
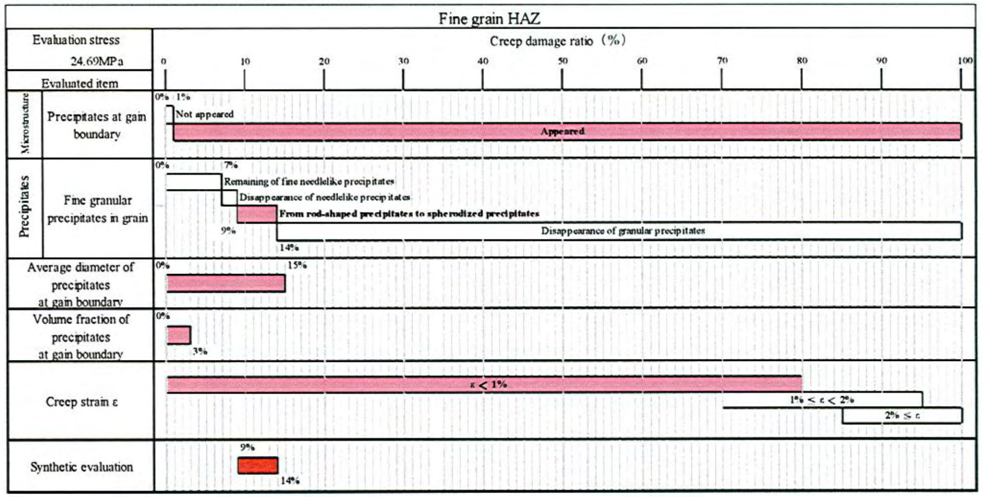
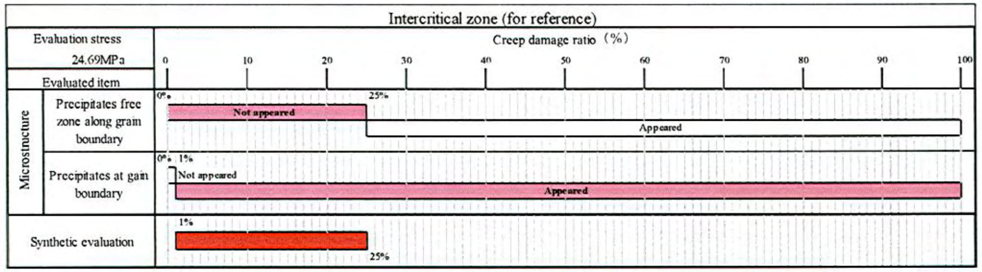
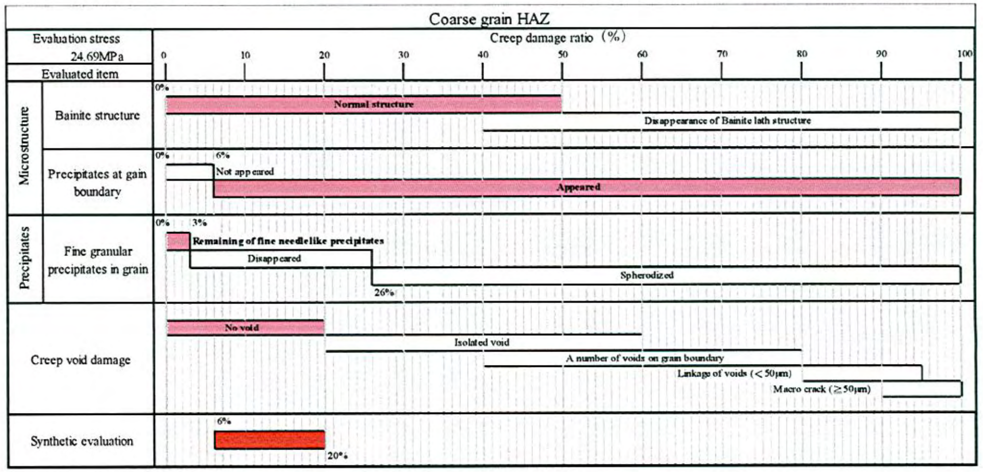


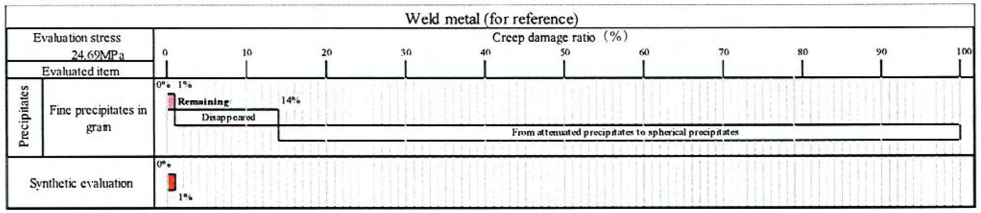
Evaluation Results II－4　RH Outlet Header　Circumferential weld at left side



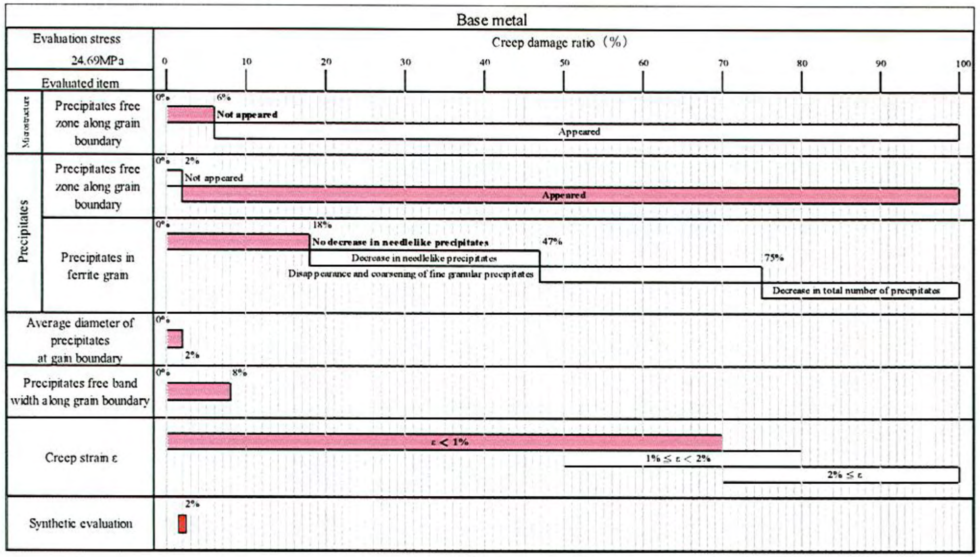


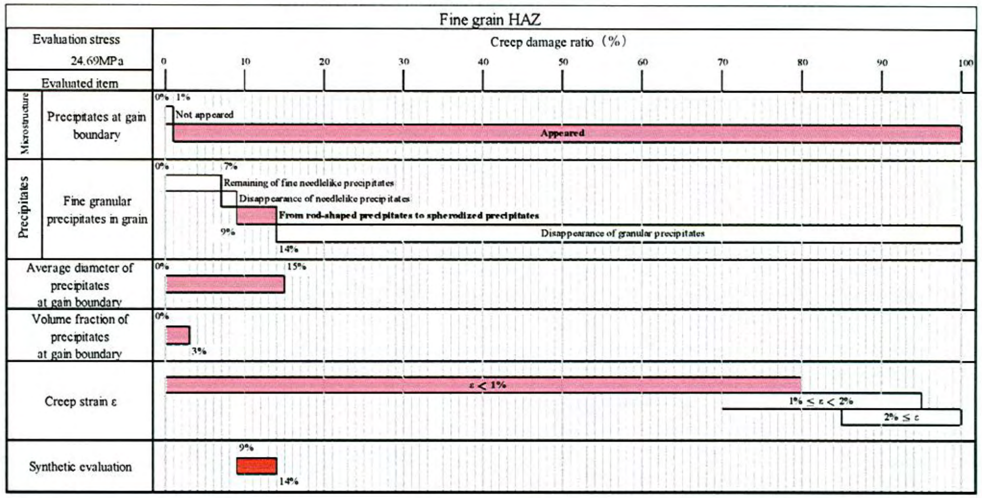


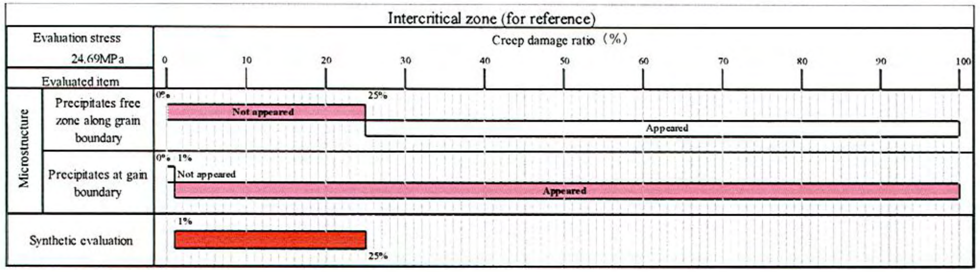


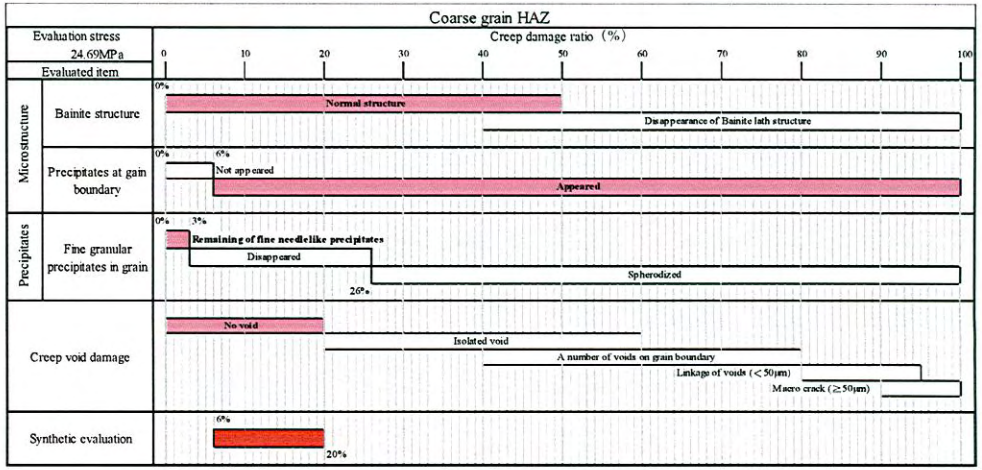


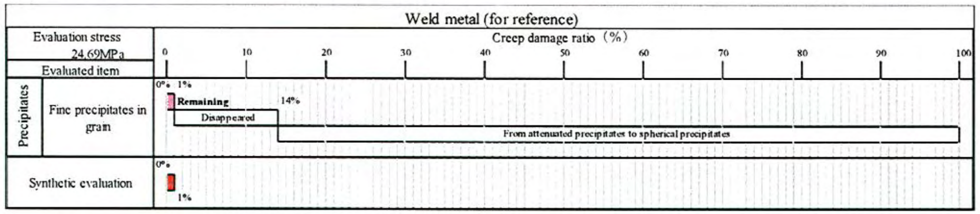
Evaluation Results II－5 RH Outlet Header Circumferential weld at right side, top



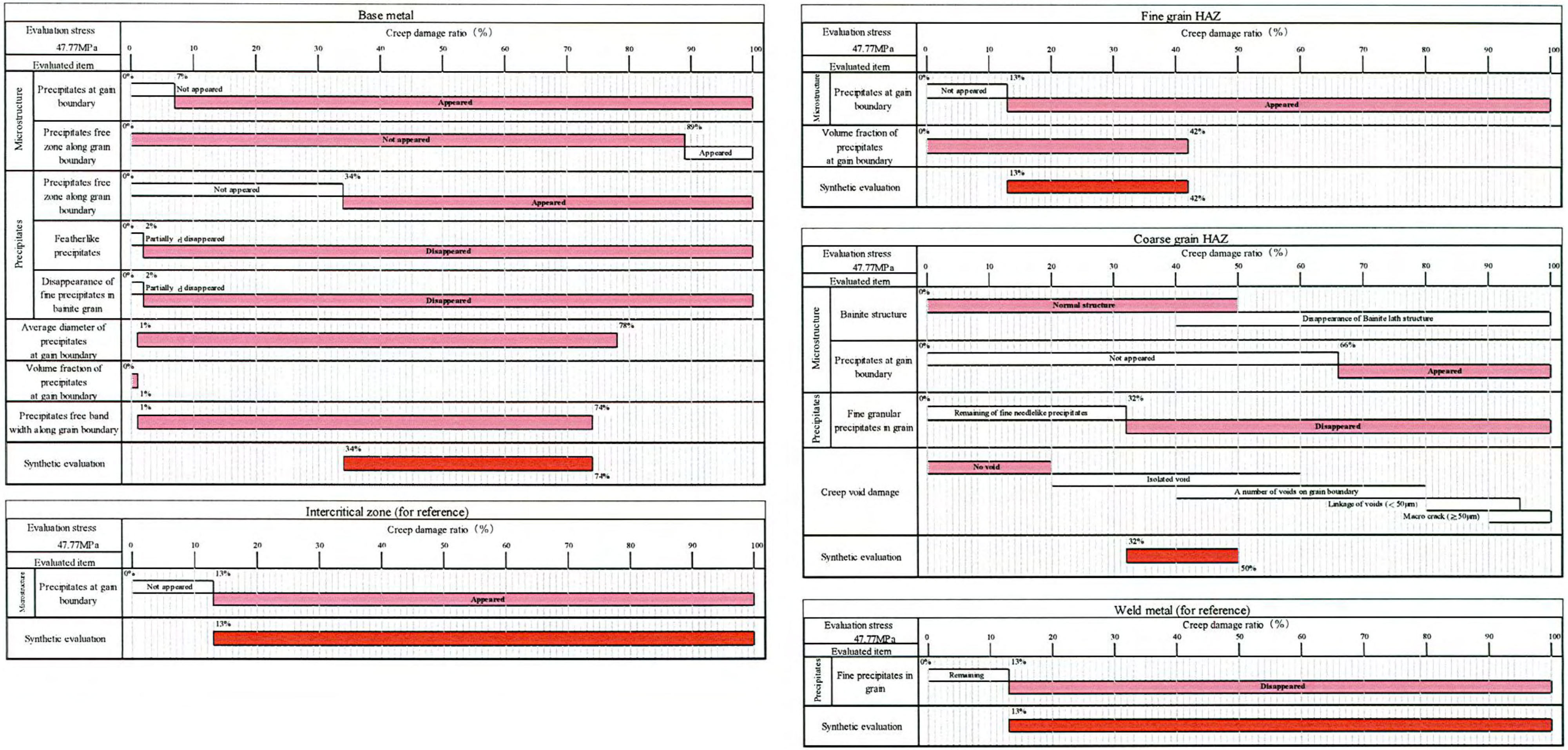




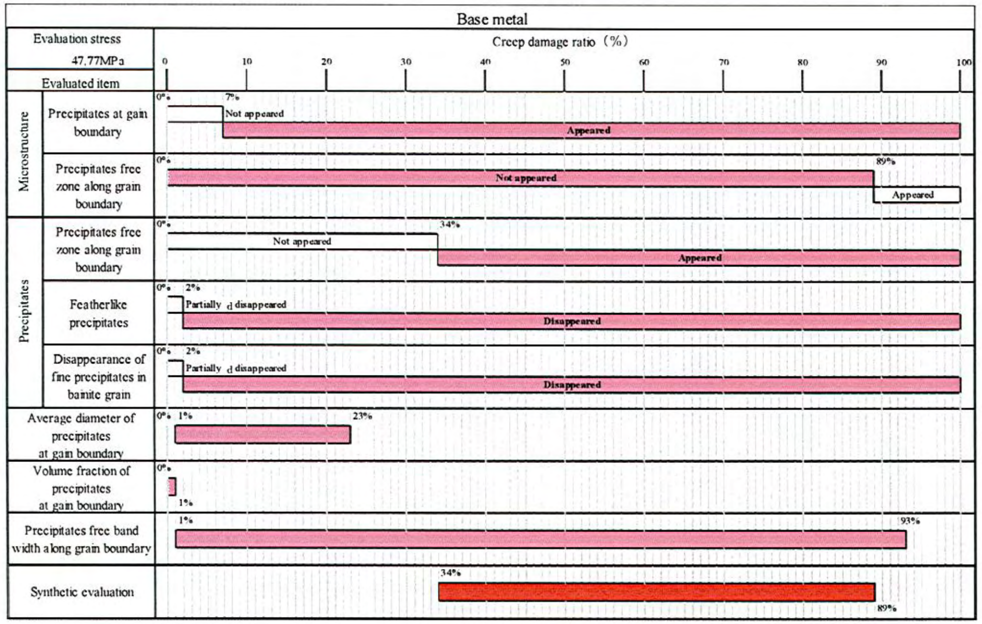


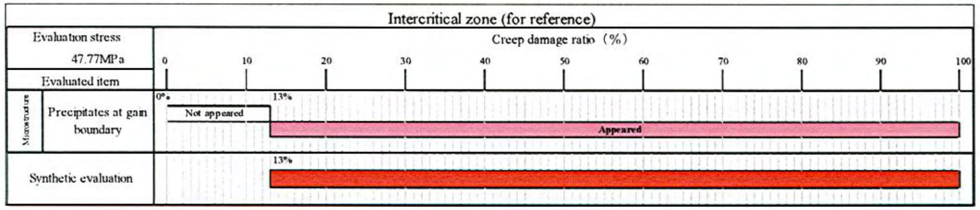


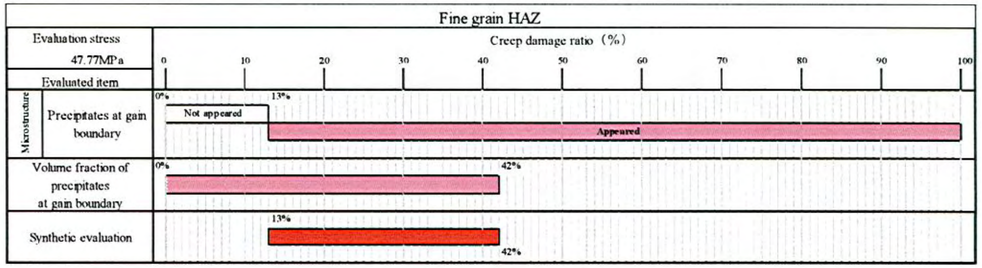
Evaluation Results II－6　RH Outlet Header　Circumferential weld at right side, front

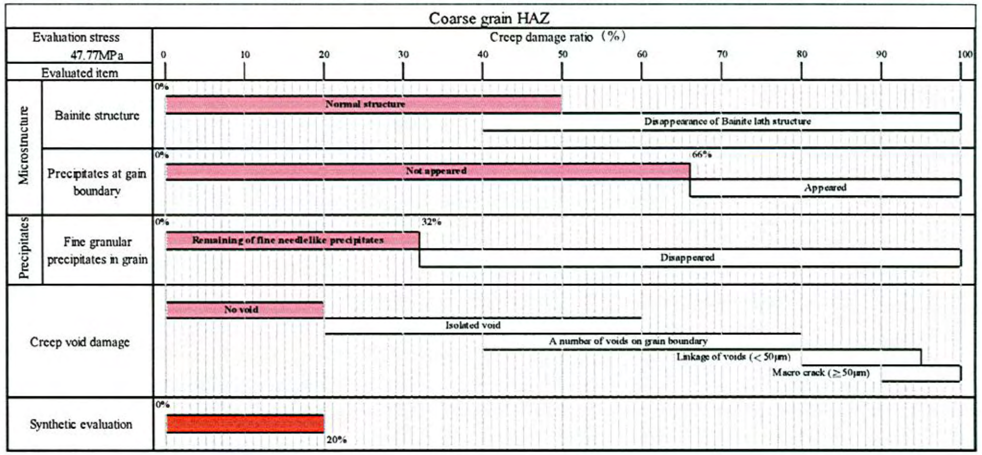


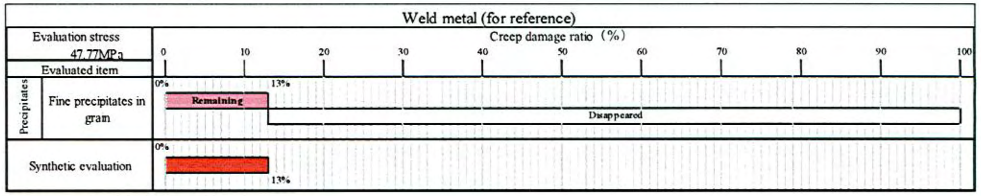
Evaluation Results II −7 Main Steam Pipe-Right Circumferential weld, intrados



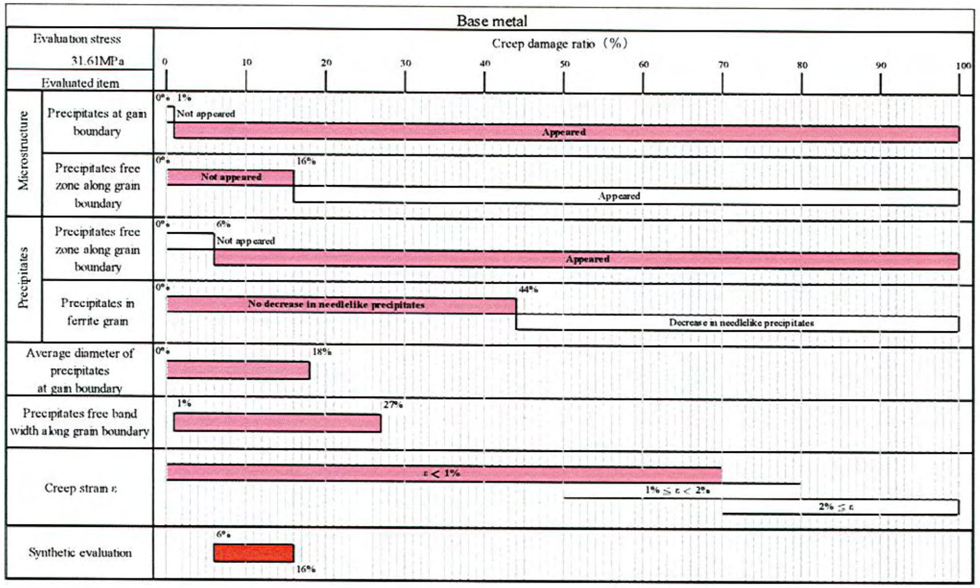


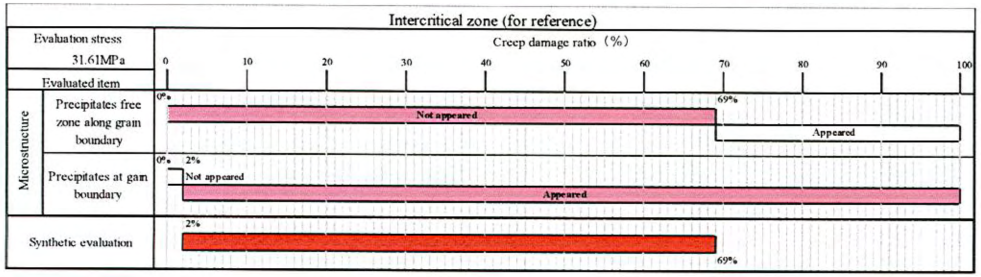


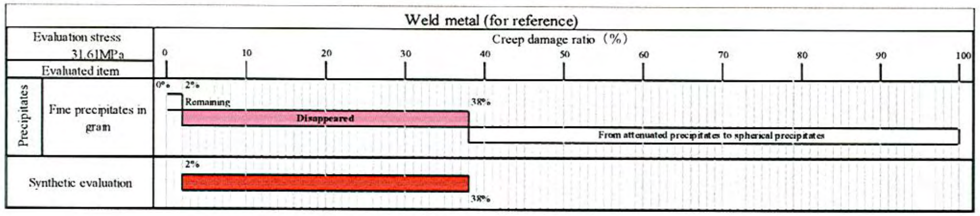


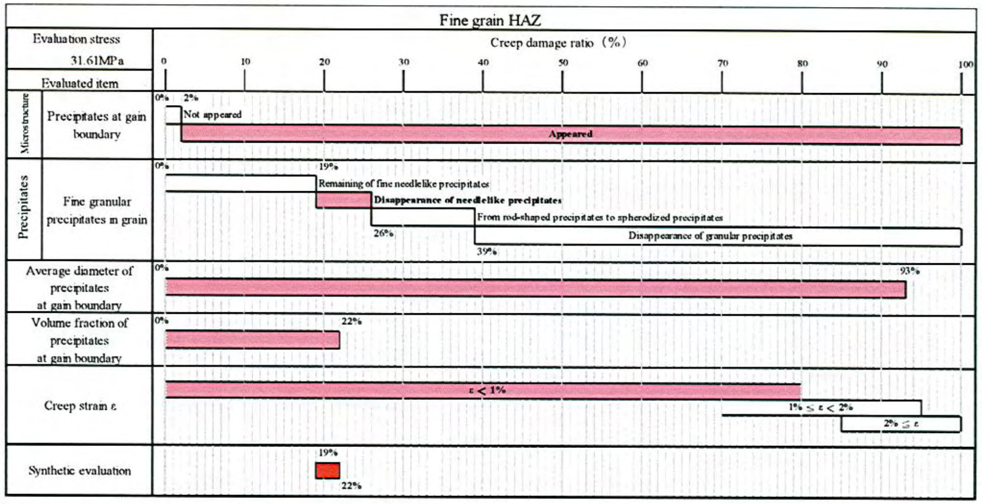


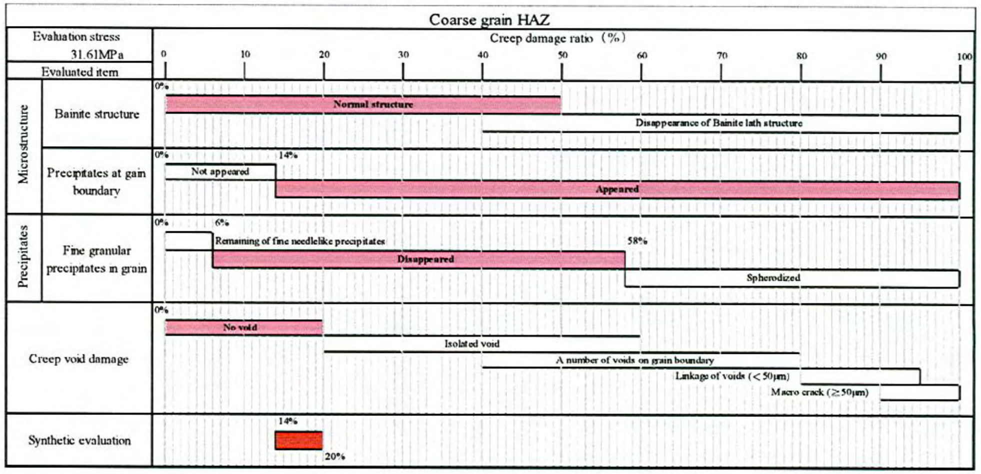
Evaluation Results II −8 Main Steam Pipe-Right Circumferential weld, near the stop valve











Evaluation Results II－9　Hot Reheat Pipe-Right　Circumferential weld

Table II－10 Residual life assessment results

Components	Location	Material	Region	Evaluation results		
				Creep life consumption ratio (%)	Residual life (hr)	Evaluated residual life (h)
Final SH Outlet Header	Circumferential weld at right side	SA 335 P22	Base Metal	4	3,338,000	270,000
			Fine grain HAZ	1 ～ 4	3,338,000 ～ 13,771,000	
			Coarse grain HAZ	9 ～ 20	556,000 ～ 1,406,000	
De-Suerheater-Left	Circumferential weld	SA 335 P12	Base Metal	16 ～ 31	310,000 ～ 730,000	96,000
			Coarse grain HAZ	0 ～ 42	192,000 <	
De-Suerheater-Right	Circumferential weld	SA 335 P12	Base Metal	16 ～ 31	310,000 ～ 730,000	96,000
			Coarse grain HAZ	0 ～ 42	192,000 <	
RH Outlet Header	Circumferential weld at left side	SA 335 P22	Base Metal	2 ～ 6	2,179,000 ～ 6,816,000	700,000
			Fine grain HAZ	7 ～ 9	1,406,000 ～ 1,848,000	
			Coarse grain HAZ	3 ～ 6	2,179,000 ～ 4,498,000	
	Circumferential weld at right side,top	SA 335 P22	Base Metal	2 ～ 6	2,179,000 ～ 6,816,000	270,000
			Fine grain HAZ	9 ～ 14	854,000 ～ 1,406,000	
			Coarse grain HAZ	6 ～ 20	556,000 ～ 2,179,000	
	Circumferential weld at right side,front	SA 335 P22	Base Metal	2	6,816,000	270,000
			Fine grain HAZ	9 ～ 14	854,000 ～ 1,406,000	
			Coarse grain HAZ	6 ～ 20	556,000 < 2,179,000	
Main Steam Pipe-Right	Circumferential weld,intrados	SA 335 P22	(Base Metal)※4	(34) ～ (74)	(49,000) ～ (270,000)	69,000 (24,000※4)
			(Fine grain HAZ)※4	(13) ～ (42)	(192,000) ～ (931,000)	
			Coarse grain HAZ	32 ～ 50	139,000 ～ 296,000	
	Circumferential weld,near the stop valve	SA 335 P22	(Base Metal)※4	(34) ～ (89)	(17,000) ～ (270,000)	270,000 (8,000※4)
			(Fine grain HAZ)※4	(13) ～ (42)	(192,000) ～ (931,000)	
			Coarse grain HAZ	0 ～ 20	556,000 <	
Hot Reheat Pipe-Right	Circumferential weld	SA 335 P22	Base Metal	6 ～ 16	730,000 ～ 2,179,000	240,000
			Fine grain HAZ	19 ～ 22	493,000 ～ 593,000	
			Coarse grain HAZ	14 ～ 20	556,000 ～ 854,000	

※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
※4: : Regarded as reference for OD measurement was not carried out.

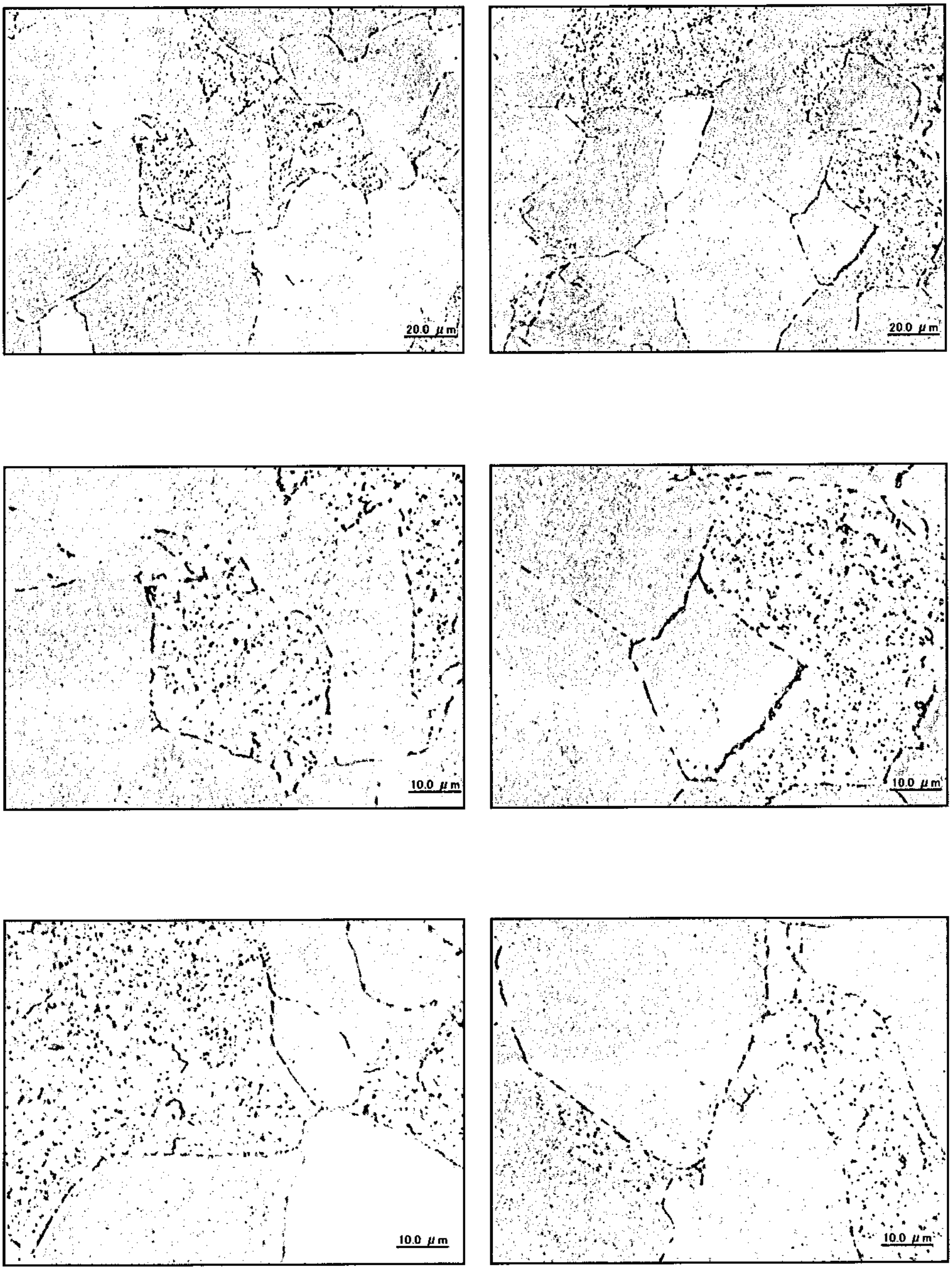


Photo II-4-1 Microstructure observation
Final SH Outlet Header (Circumferential weld at right side : Base metal)

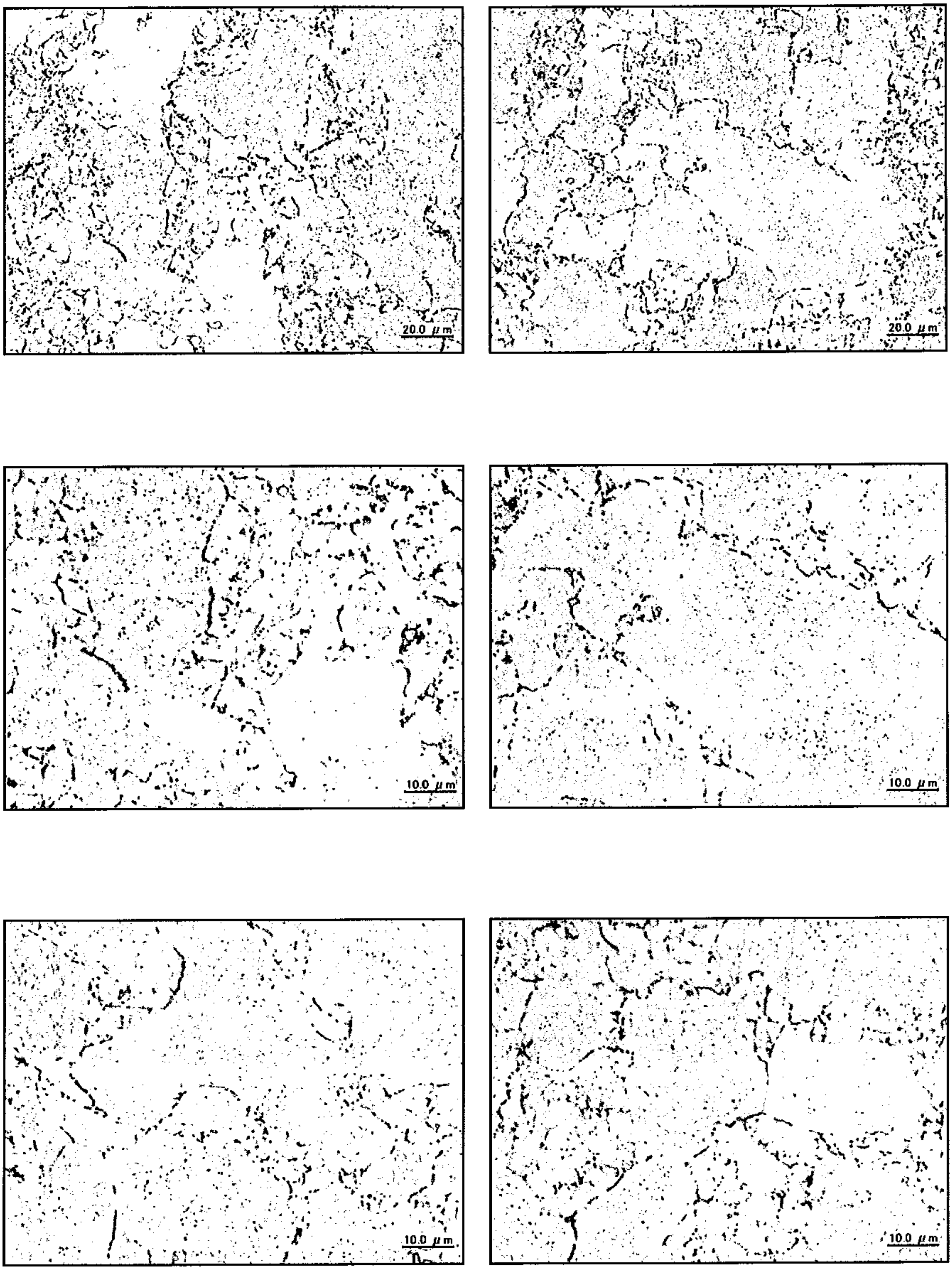


Photo II-4-2 Microstructure observation
Final SH Outlet Header (Circumferential weld at right side : Intercritical zone)

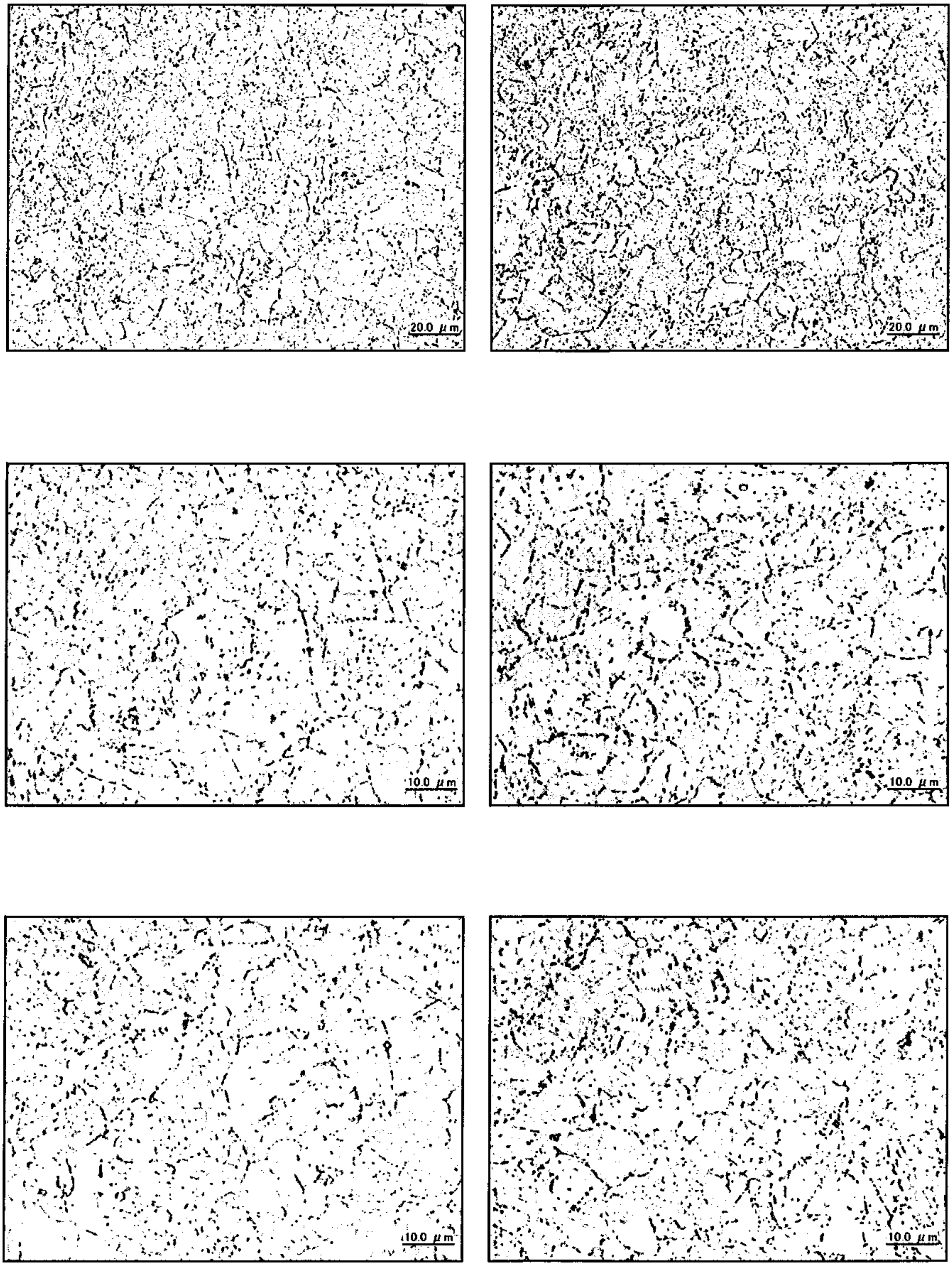


Photo Ⅱ-4-3 Microstructure observation
Final SH Outlet Header (Circumferential weld at right side : Fine grain HAZ)

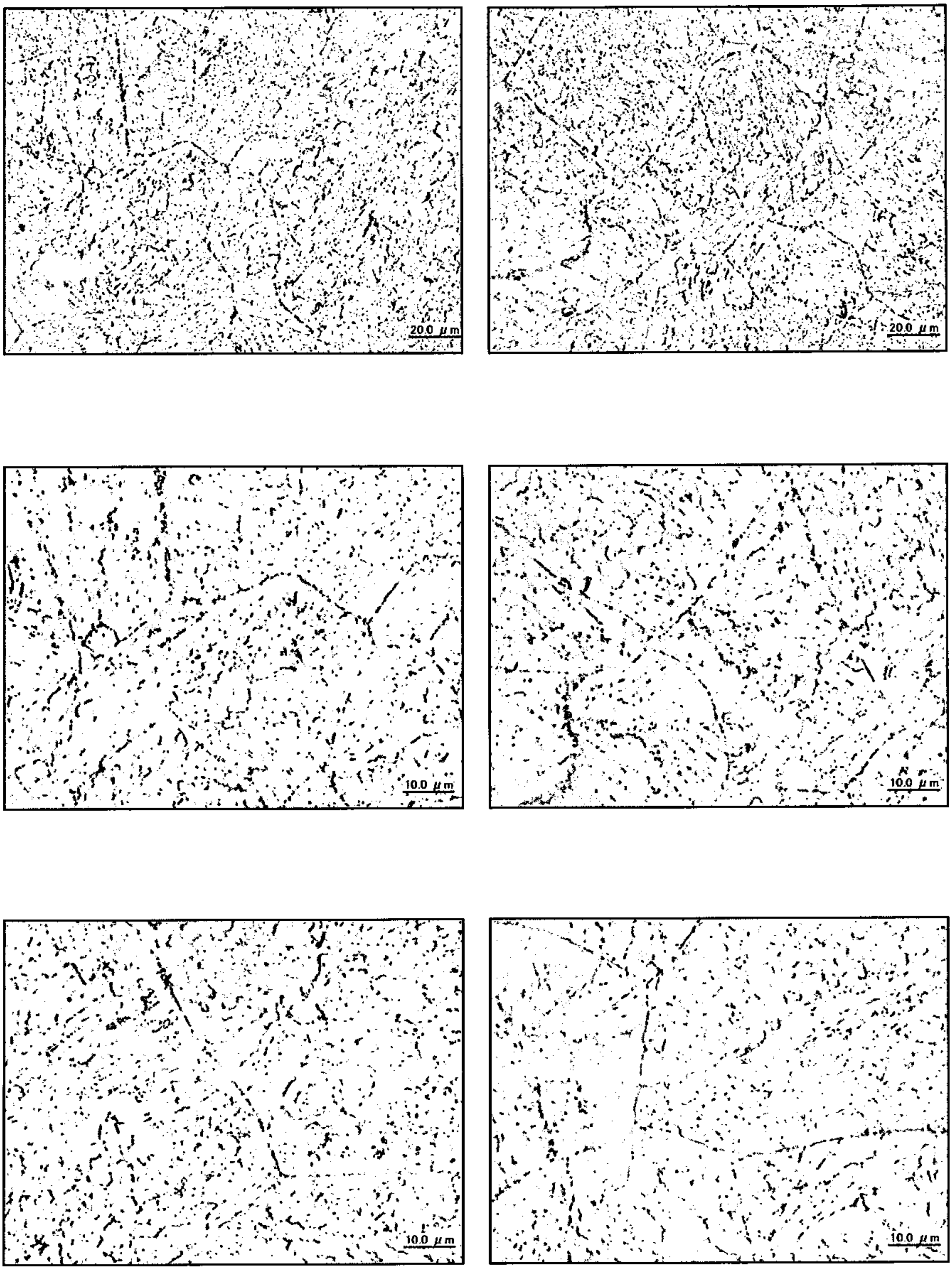


Photo Ⅱ-4-4 Microstructure observation

Final SH Outlet Header (Circumferential weld at right side : Coarse grain HAZ)

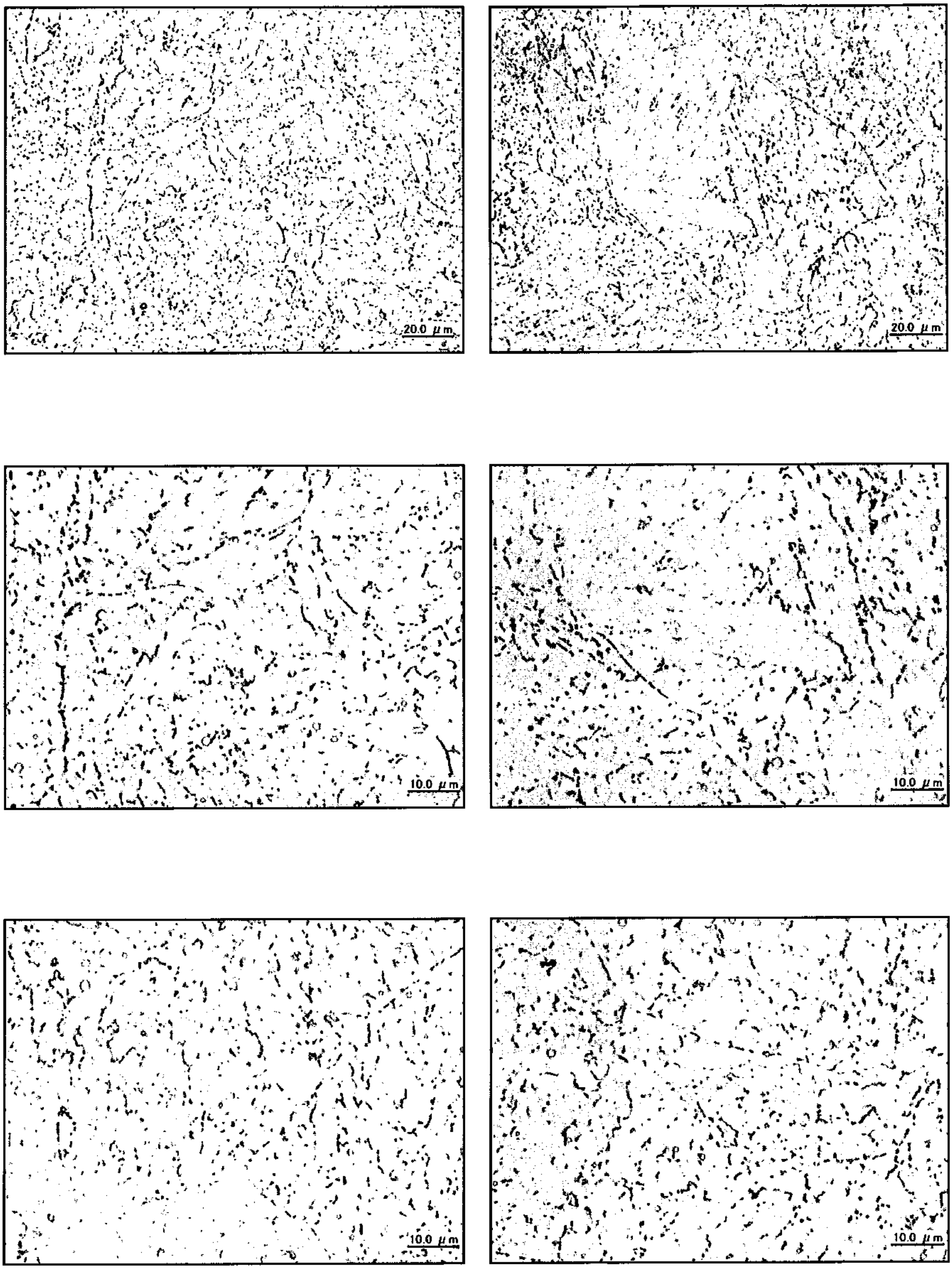


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Photo II-4-5 Microstructure observation
Final SH Outlet Header (Circumferential weld at right side : Weld metal)

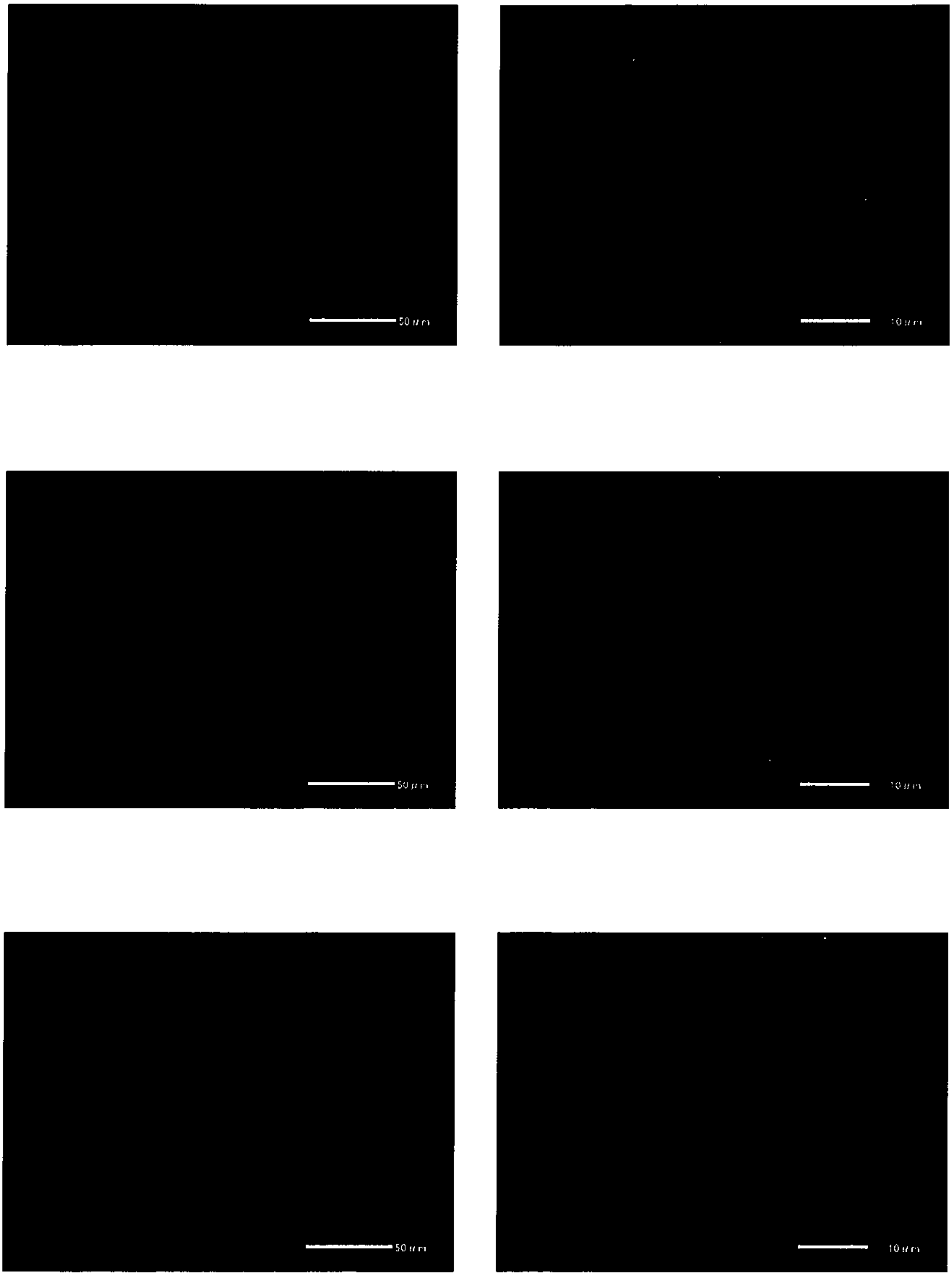


Photo II-4-6 SEM(Scanning electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Fine grain HAZ)

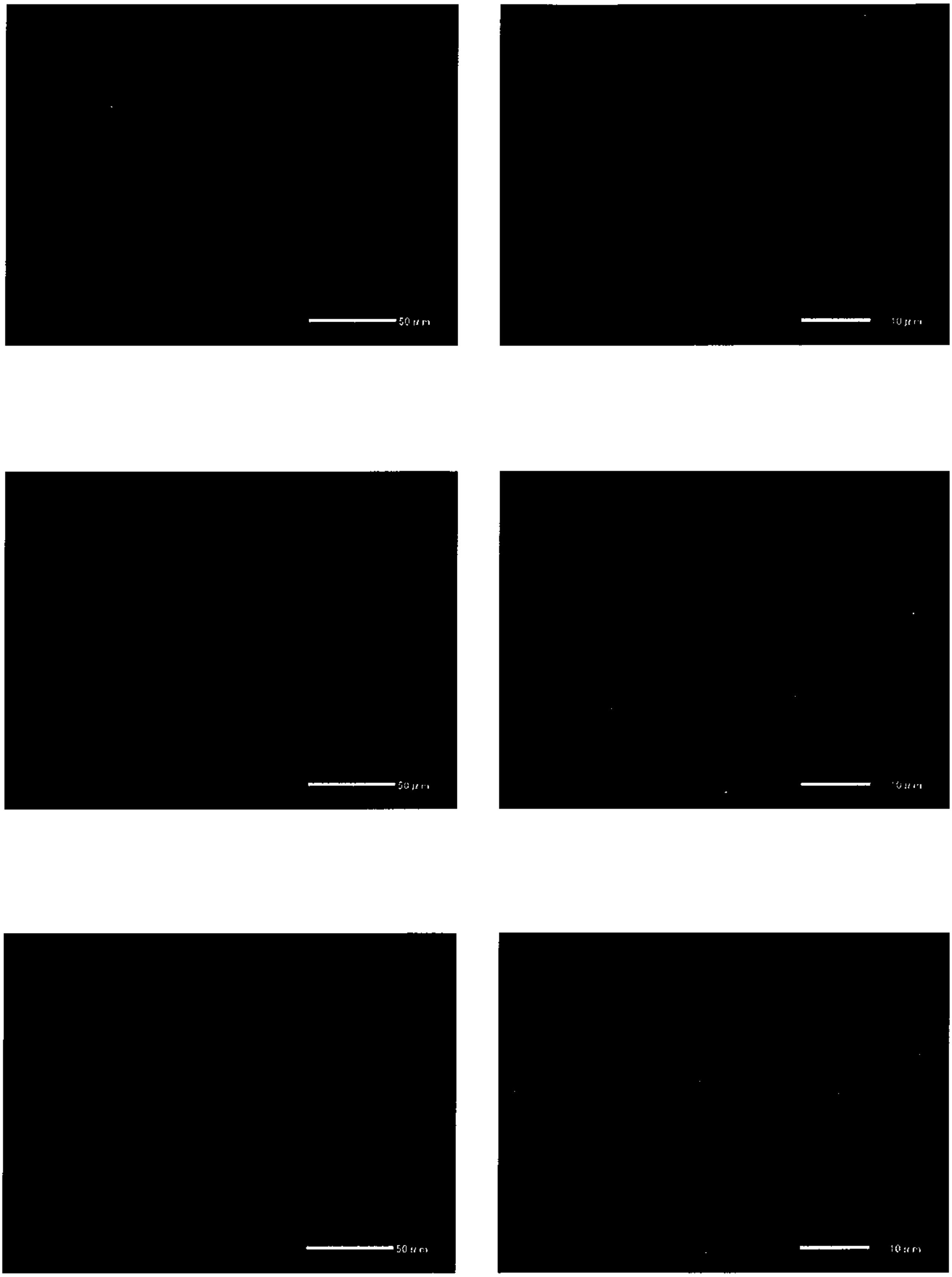


Photo Ⅱ-4-7 SEM(Scanning electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Coarse grain HAZ)

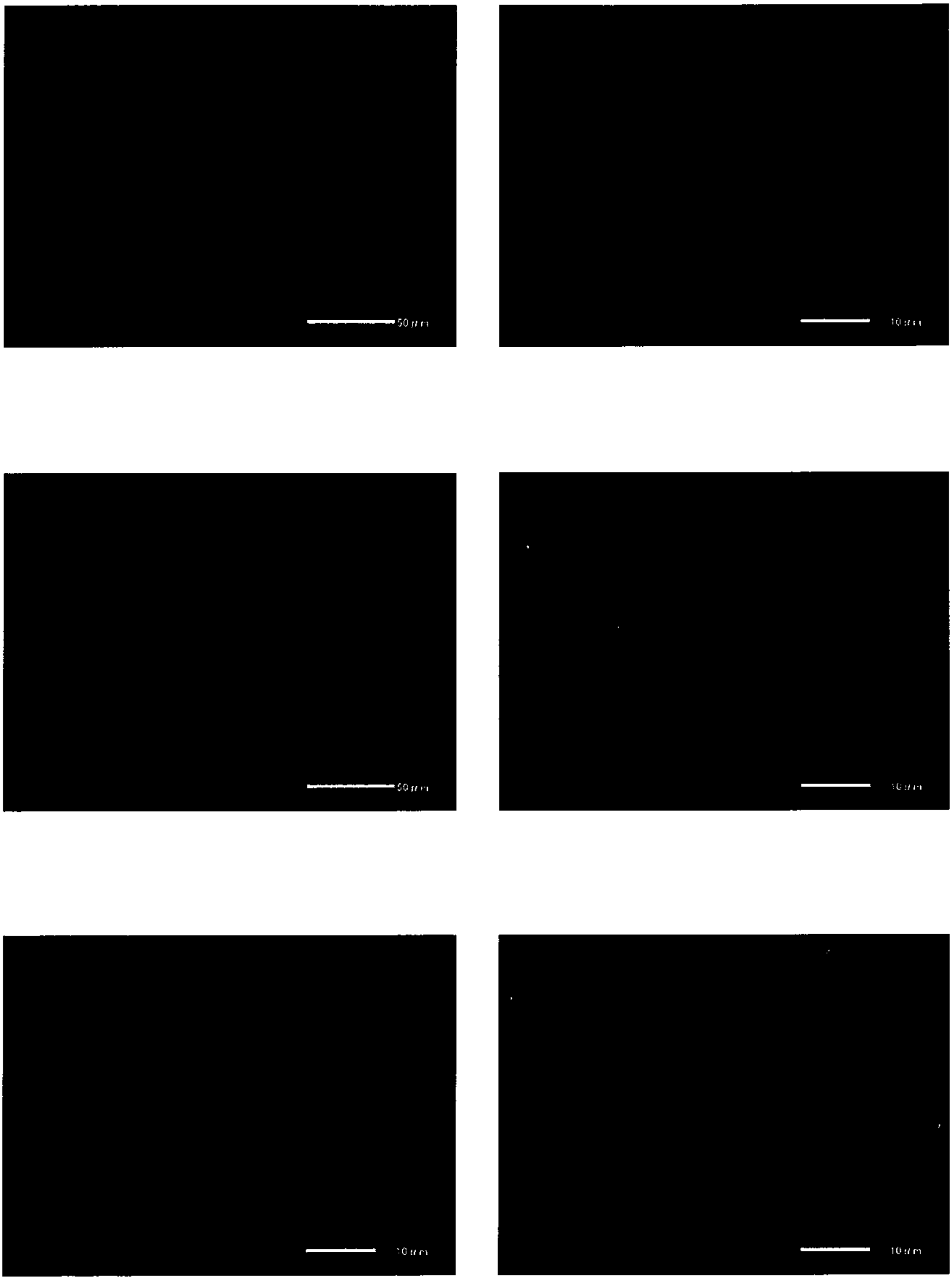


Photo Ⅱ-4-8 SEM(Scanning electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Weld metal)

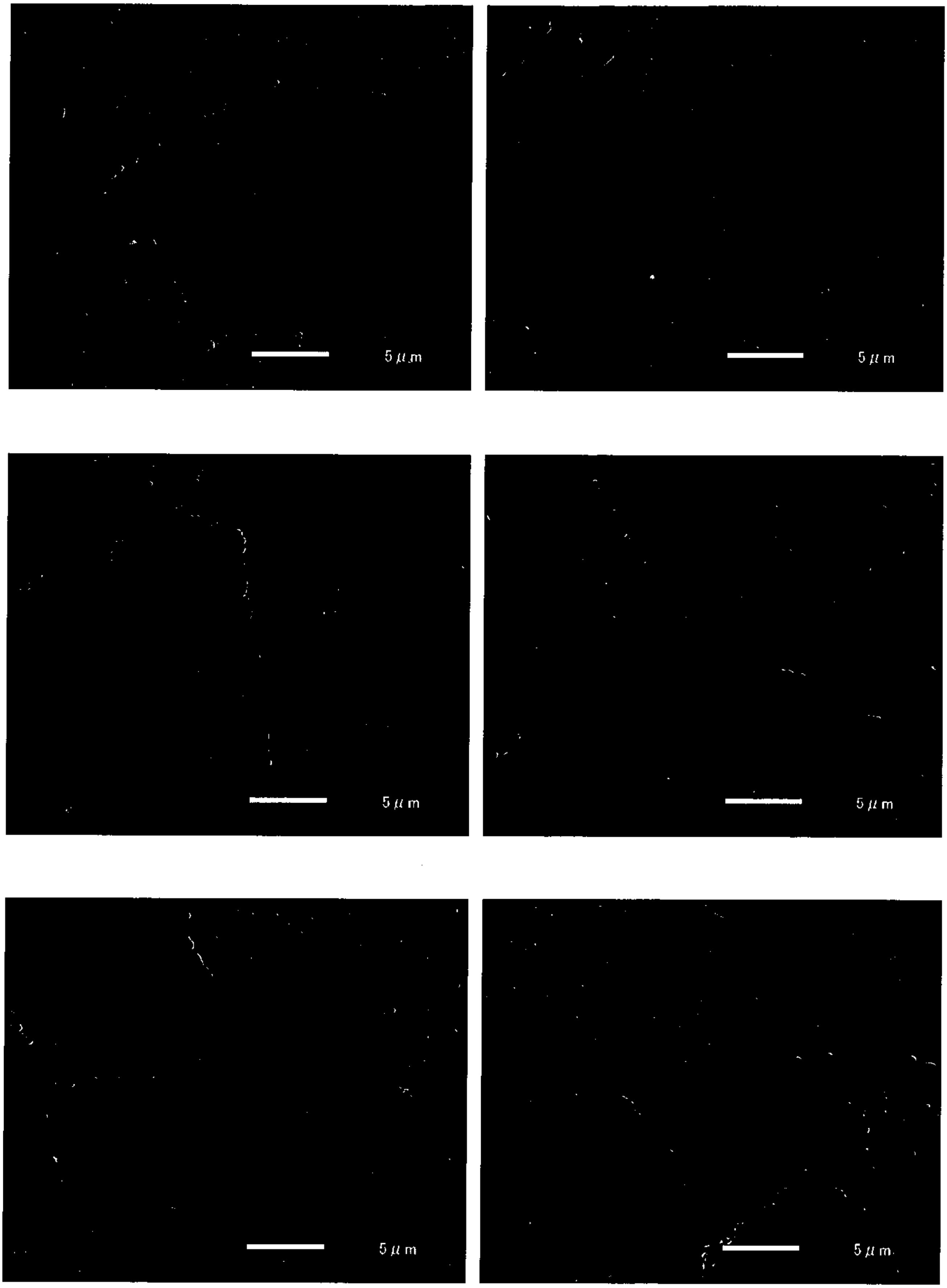


Photo II-4-9 Precipitates along grain boundary by SEM observation
Final SH Outlet Header (Circumferential weld at right side : Base metal)

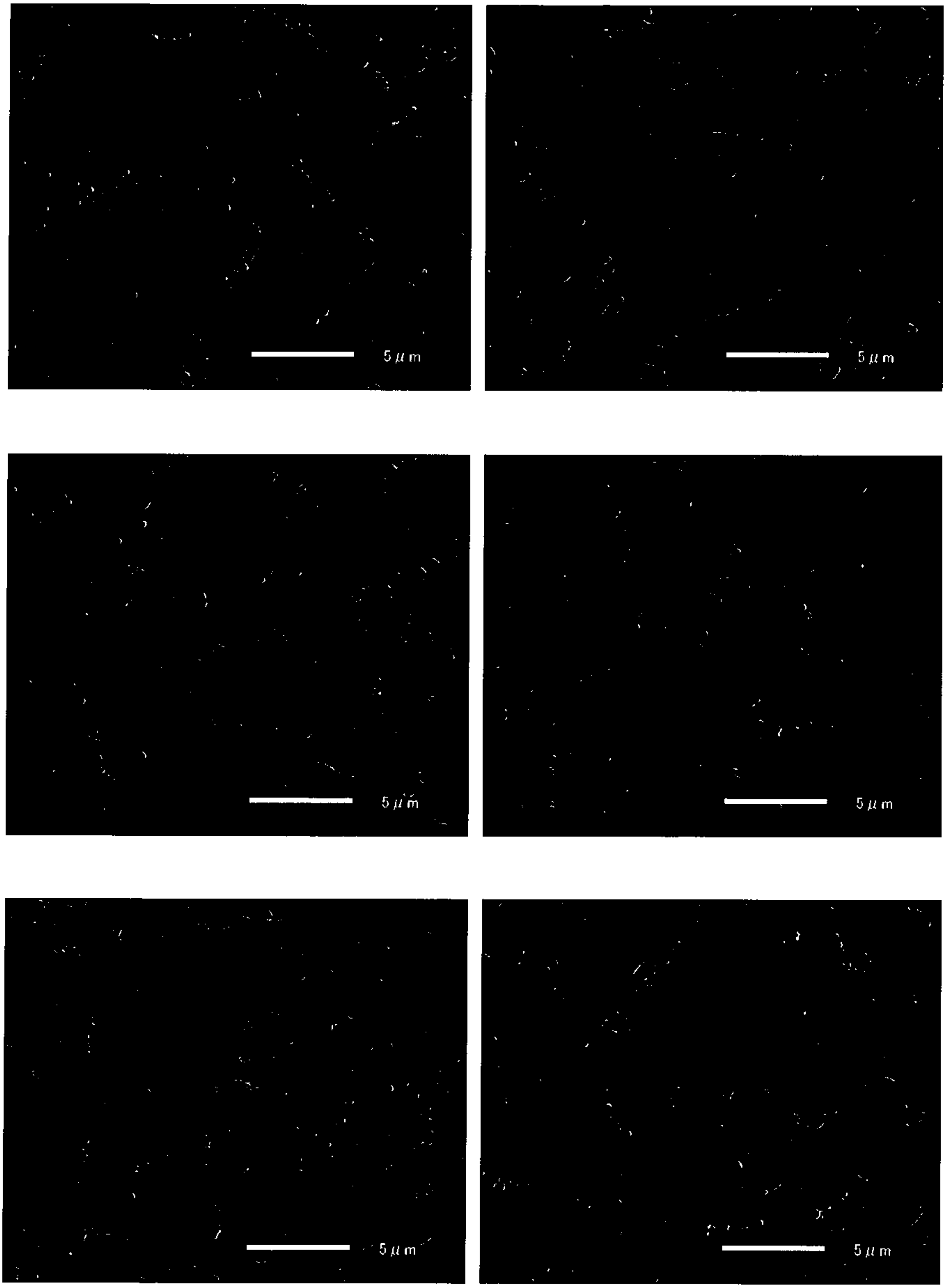


Photo II-4-10 Precipitates along grain boundary by SEM observation
Final SH Outlet Header(Circumferential weld at right side : Fine grain HAZ)

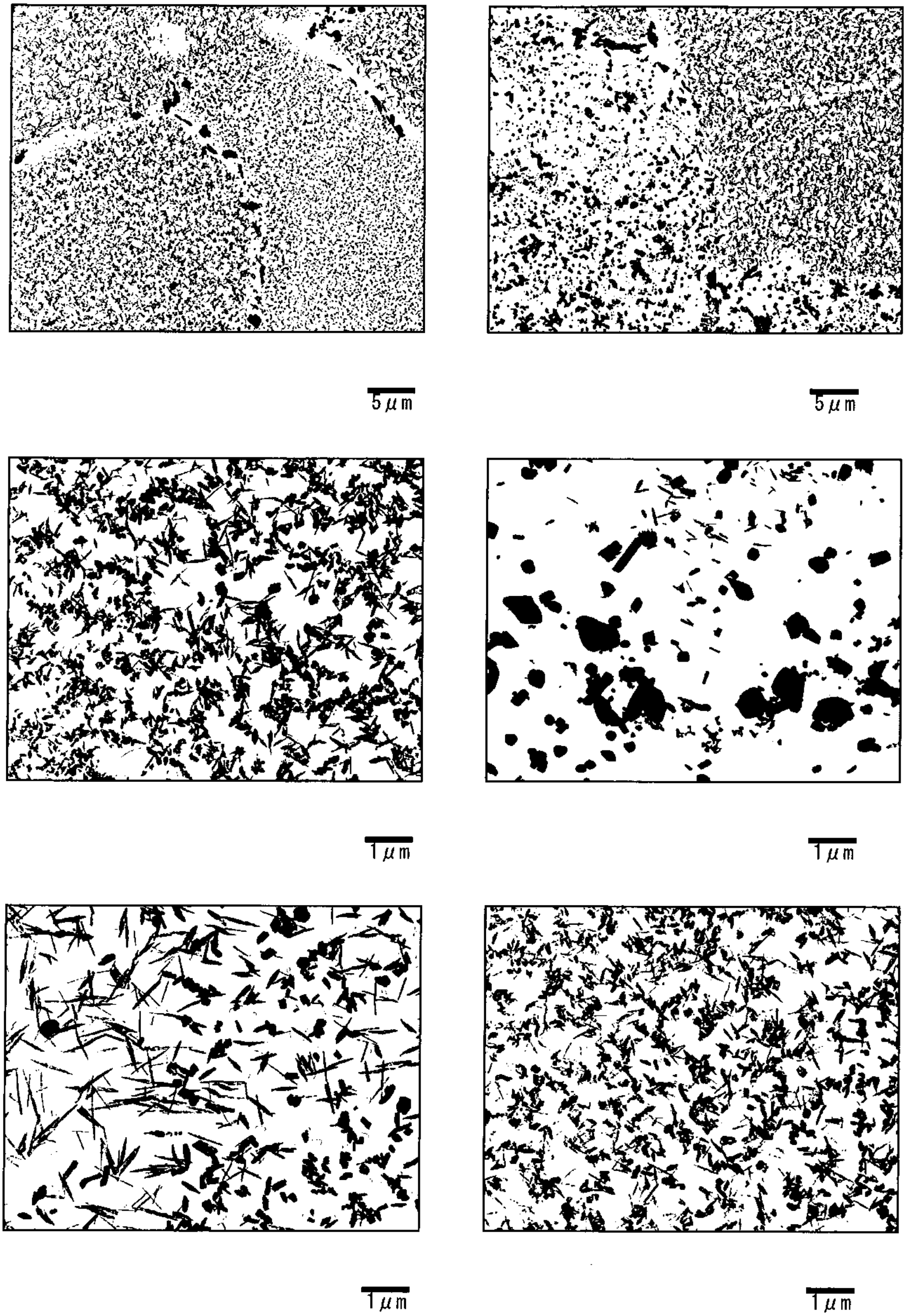


Photo II-4-11 Precipitates by TEM (Transmission electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Base metal)

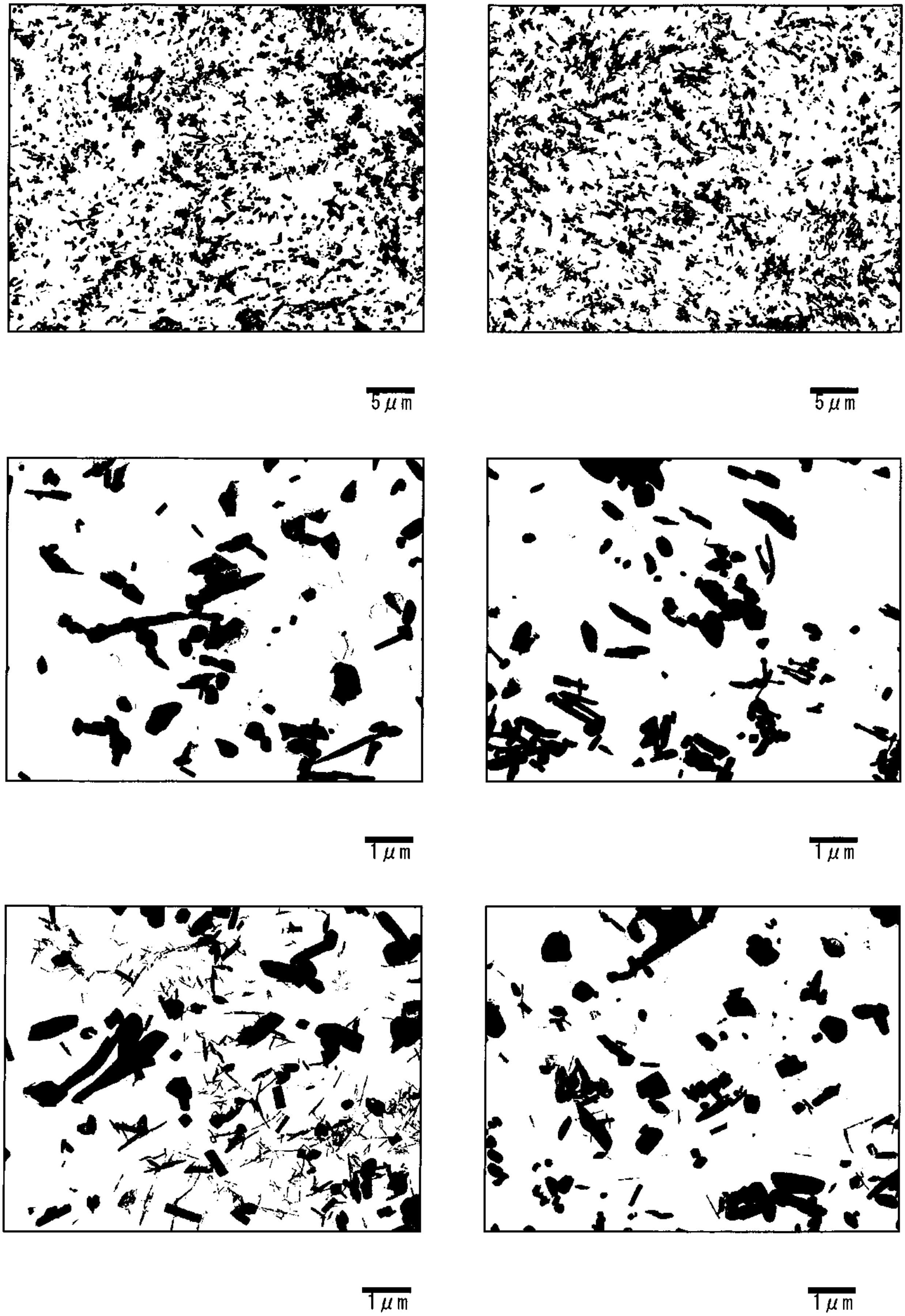


Photo II-4-12 Precipitates by TEM (Transmission electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Fine grain HAZ)

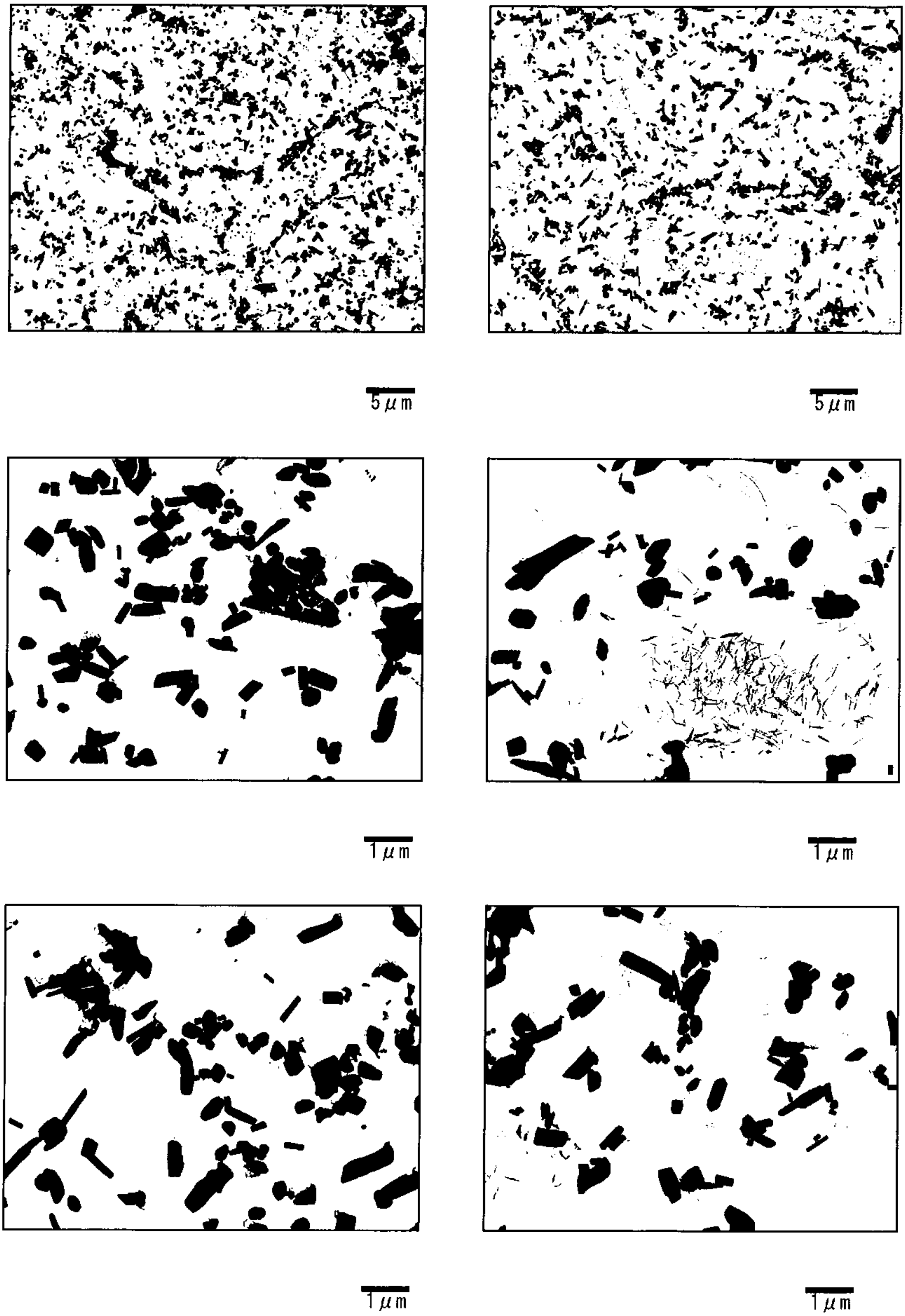


Photo II -4-13 Precipitates by TEM (Transmission electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Coarse grain HAZ)

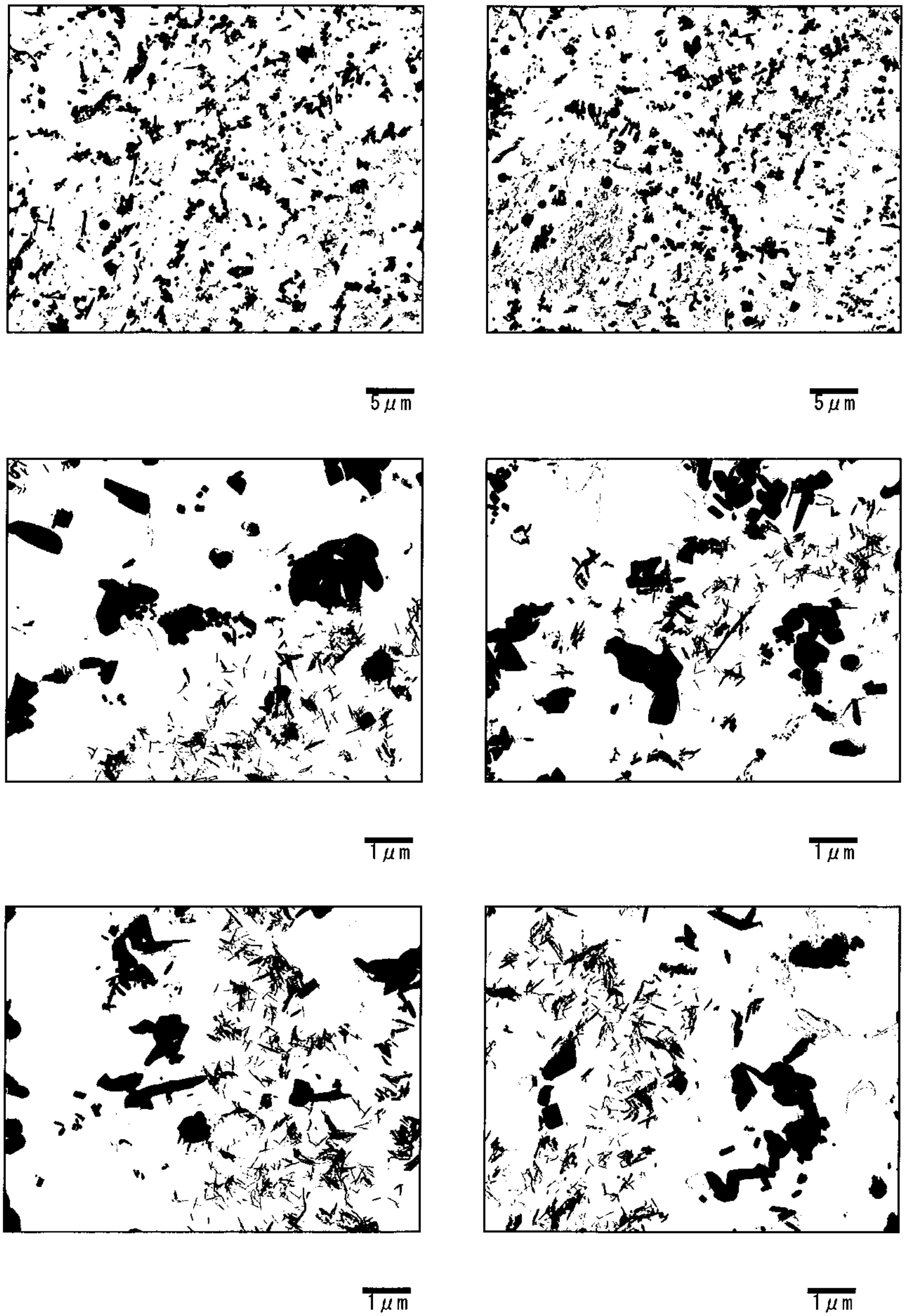


Photo II-4-14 Precipitates by TEM (Transmission electron microscope) observation
Final SH Outlet Header(Circumferential weld at right side : Weld metal)

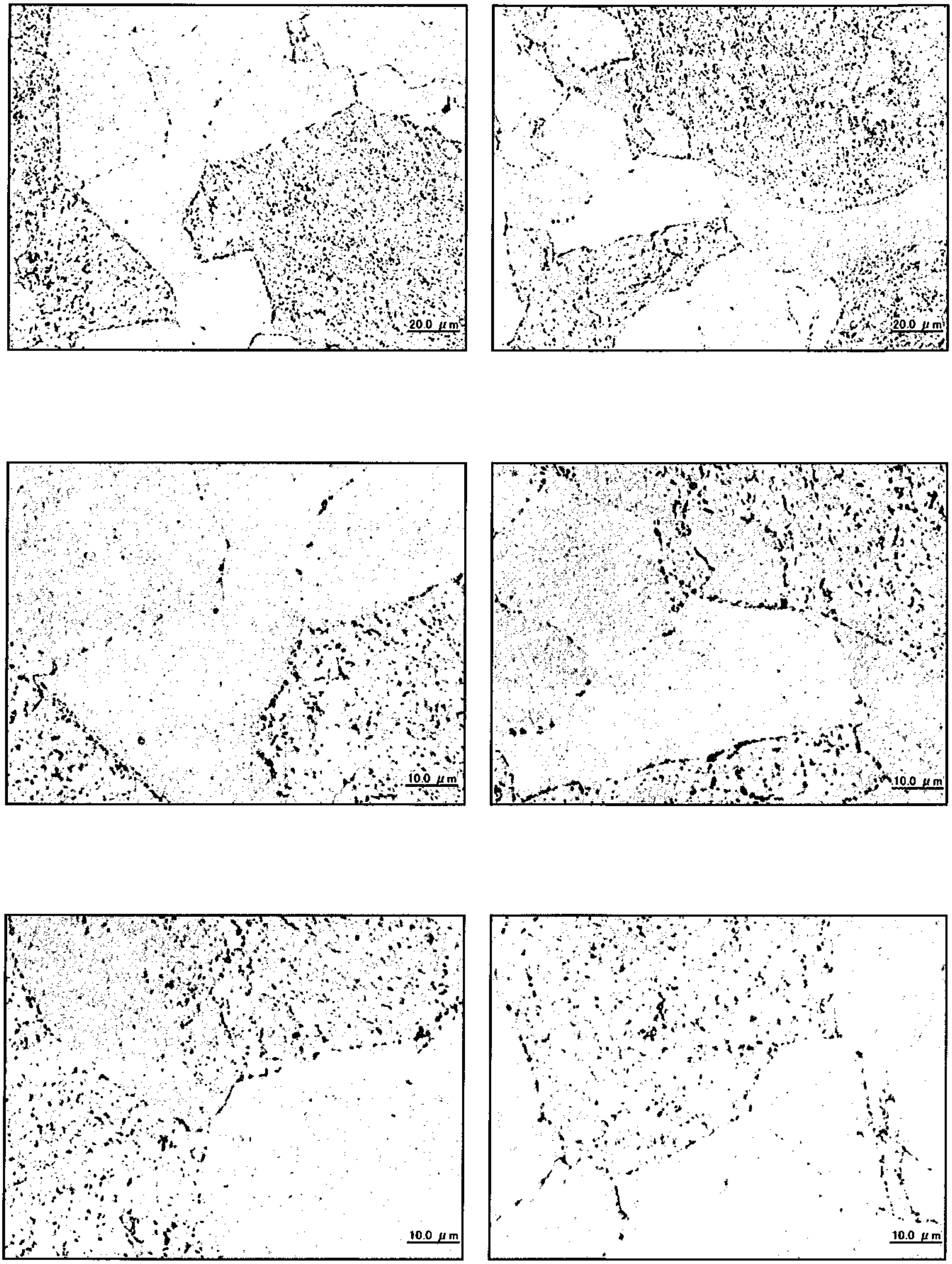
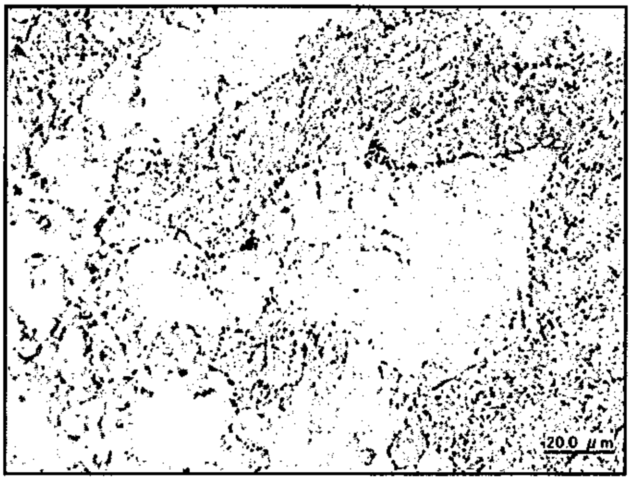
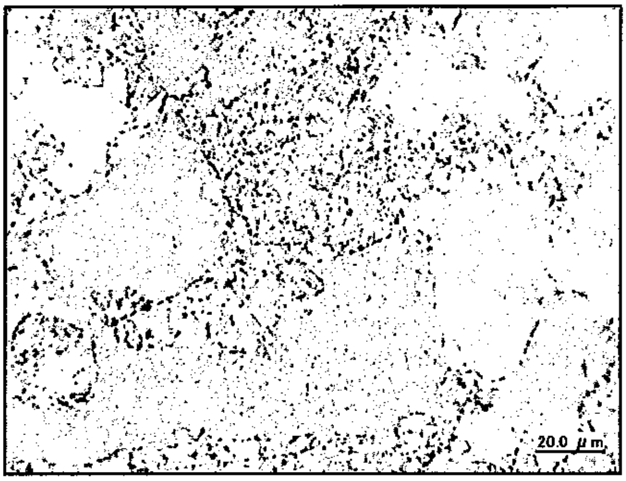
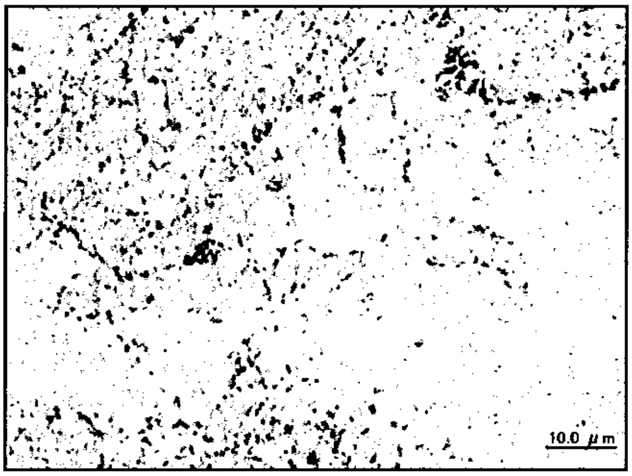
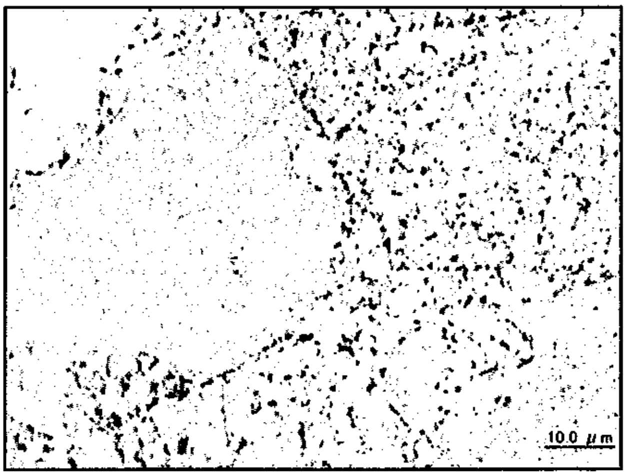


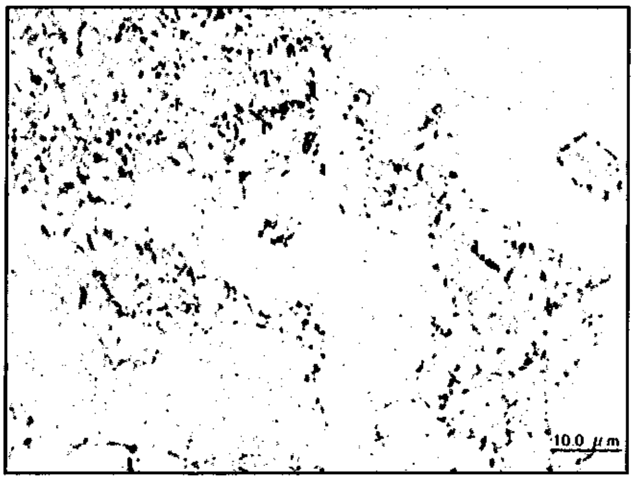
Photo II-5-1 Microstructure observation
De-Superheater-Left (Circumferential weld : Base metal)











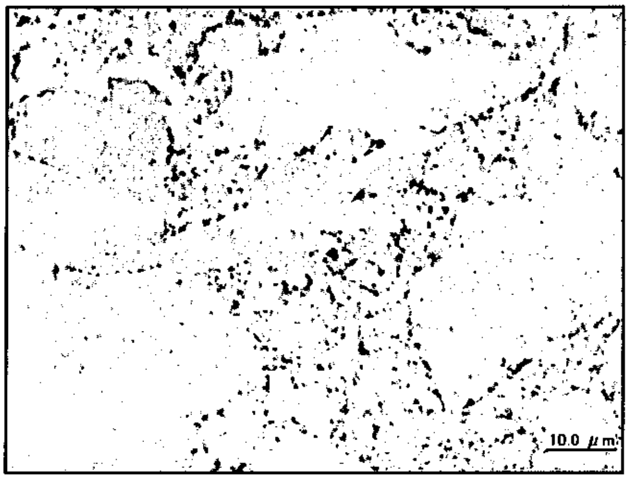


Photo II-5-2 Microstructure observation
De-Superheater-Left (Circumferential weld : Intercritical zone)

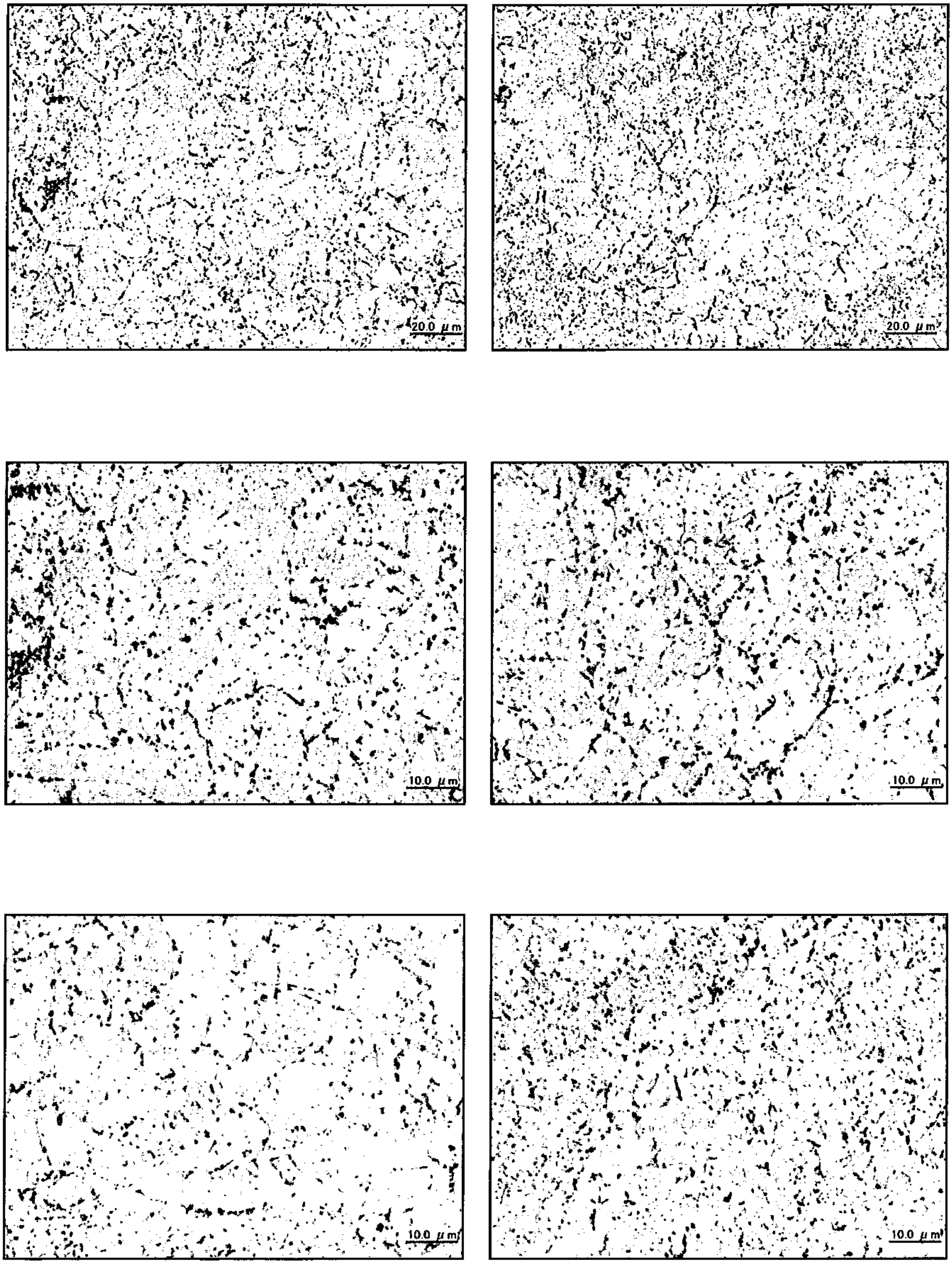


Photo Ⅱ-5-3 Microstructure observation
De-Superheater-Left (Circumferential weld : Fine grain HAZ)

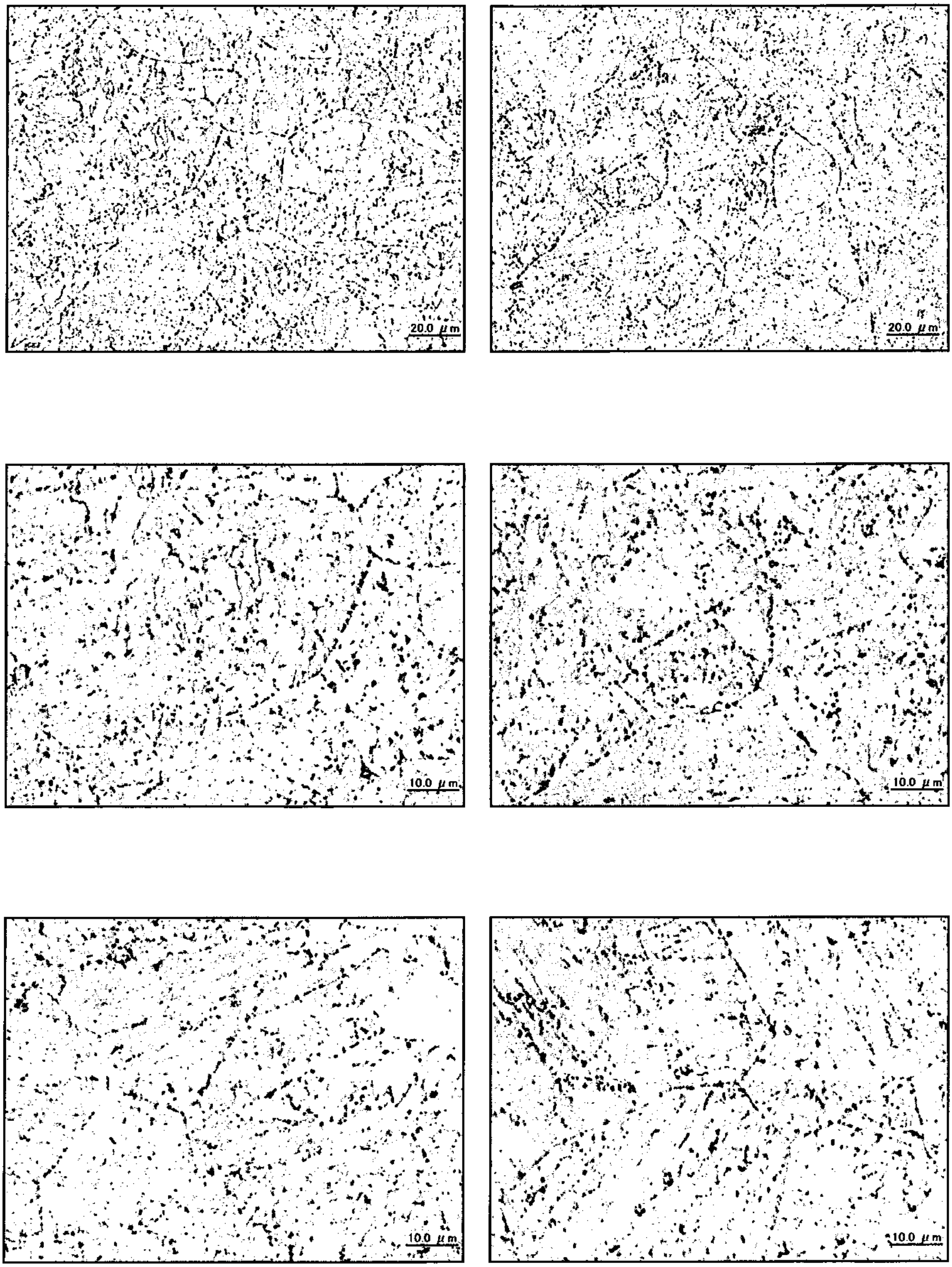


Photo II -5-4 Microstructure observation
De-Superheater-Left (Circumferential weld : Coarse grain HAZ)

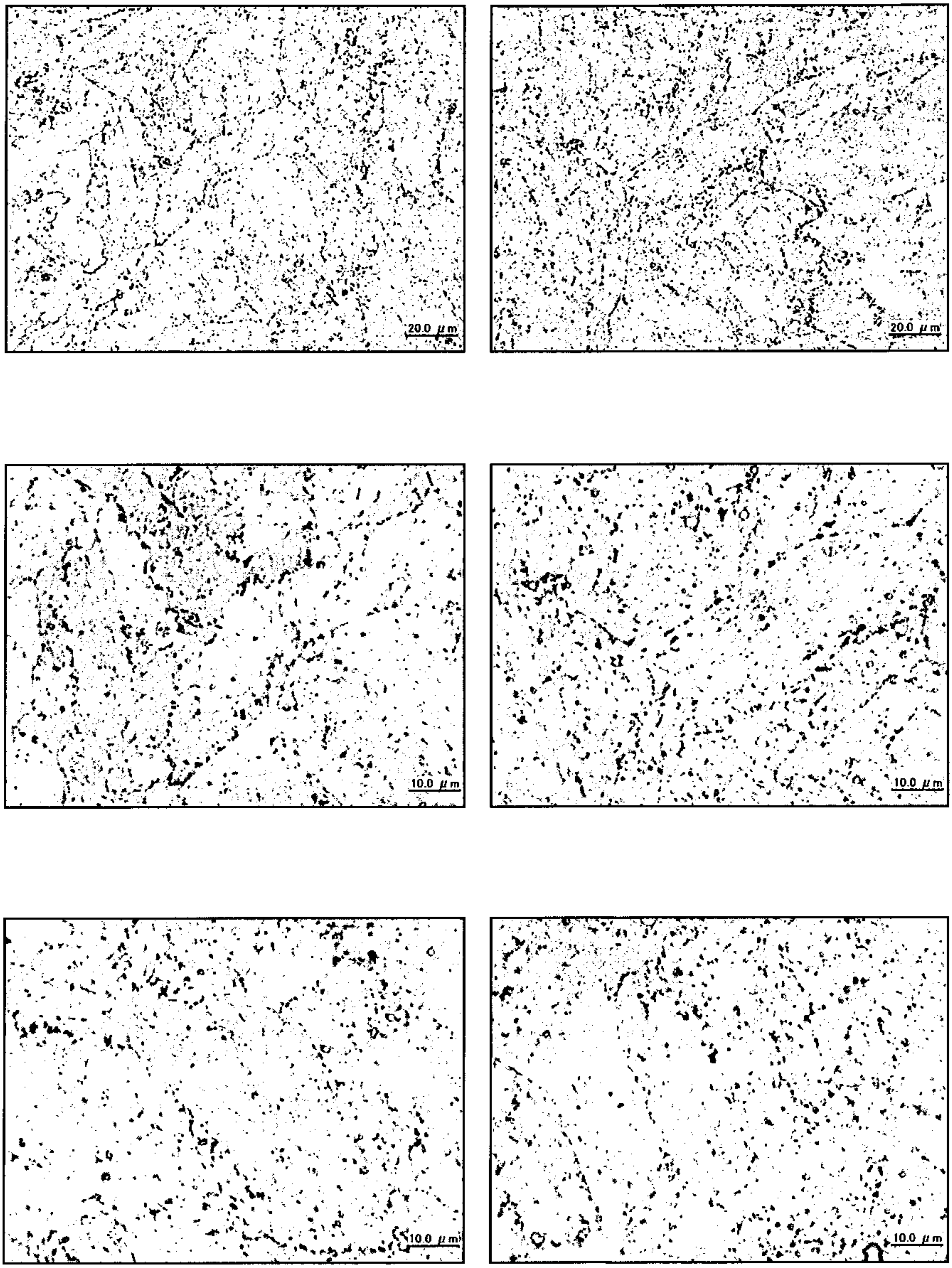
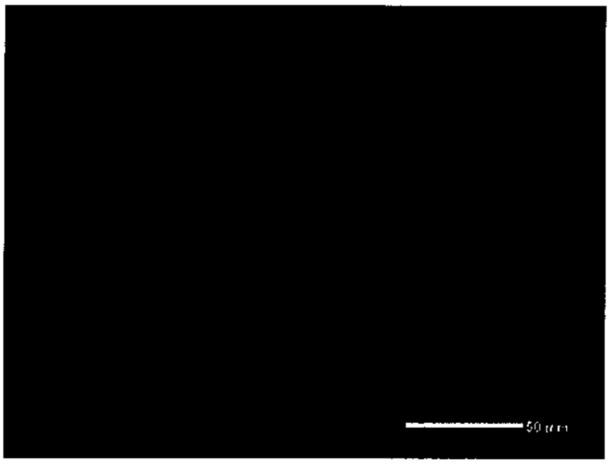
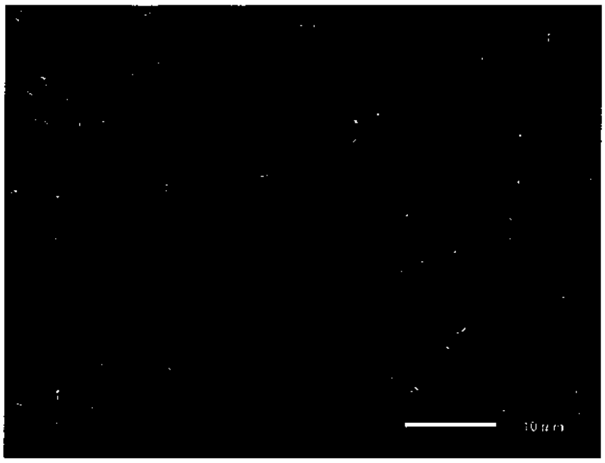
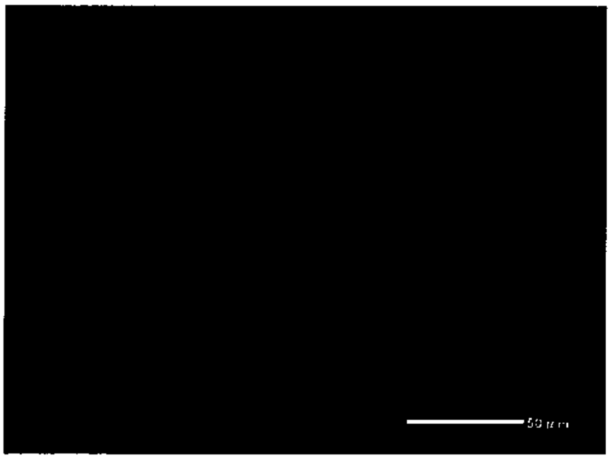
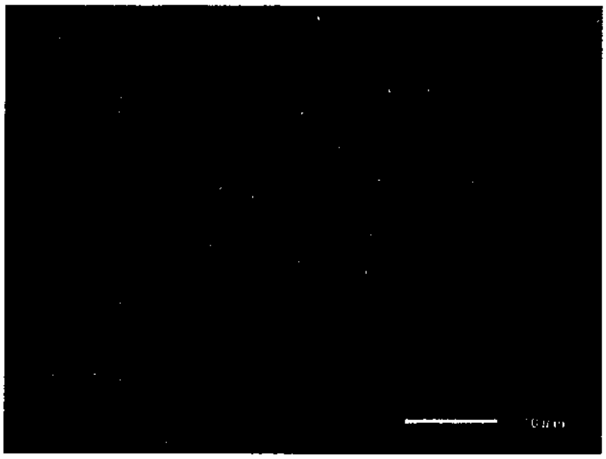


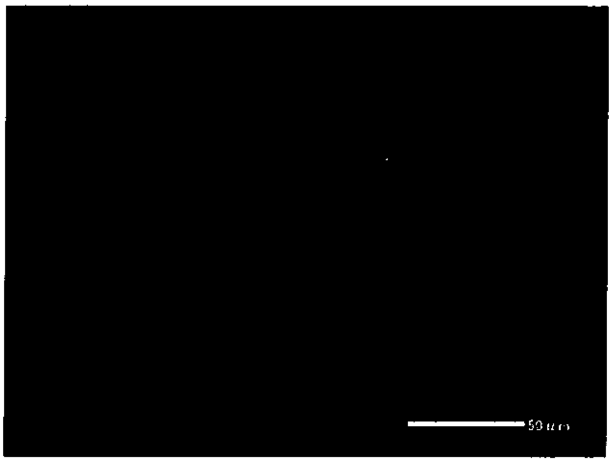
Photo II-5-5 Microstructure observation
De-Superheater-Left (Circumferential weld : Weld metal)











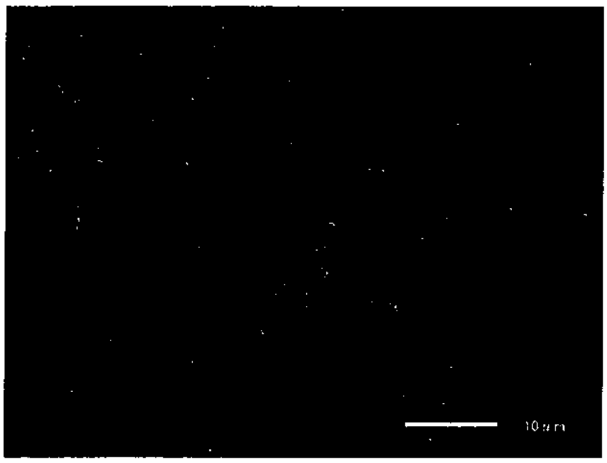


Photo II-5-6 SEM(Scanning electron microscope) observation
De-Superheater-Left(Circumferential weld : Fine grain HAZ)

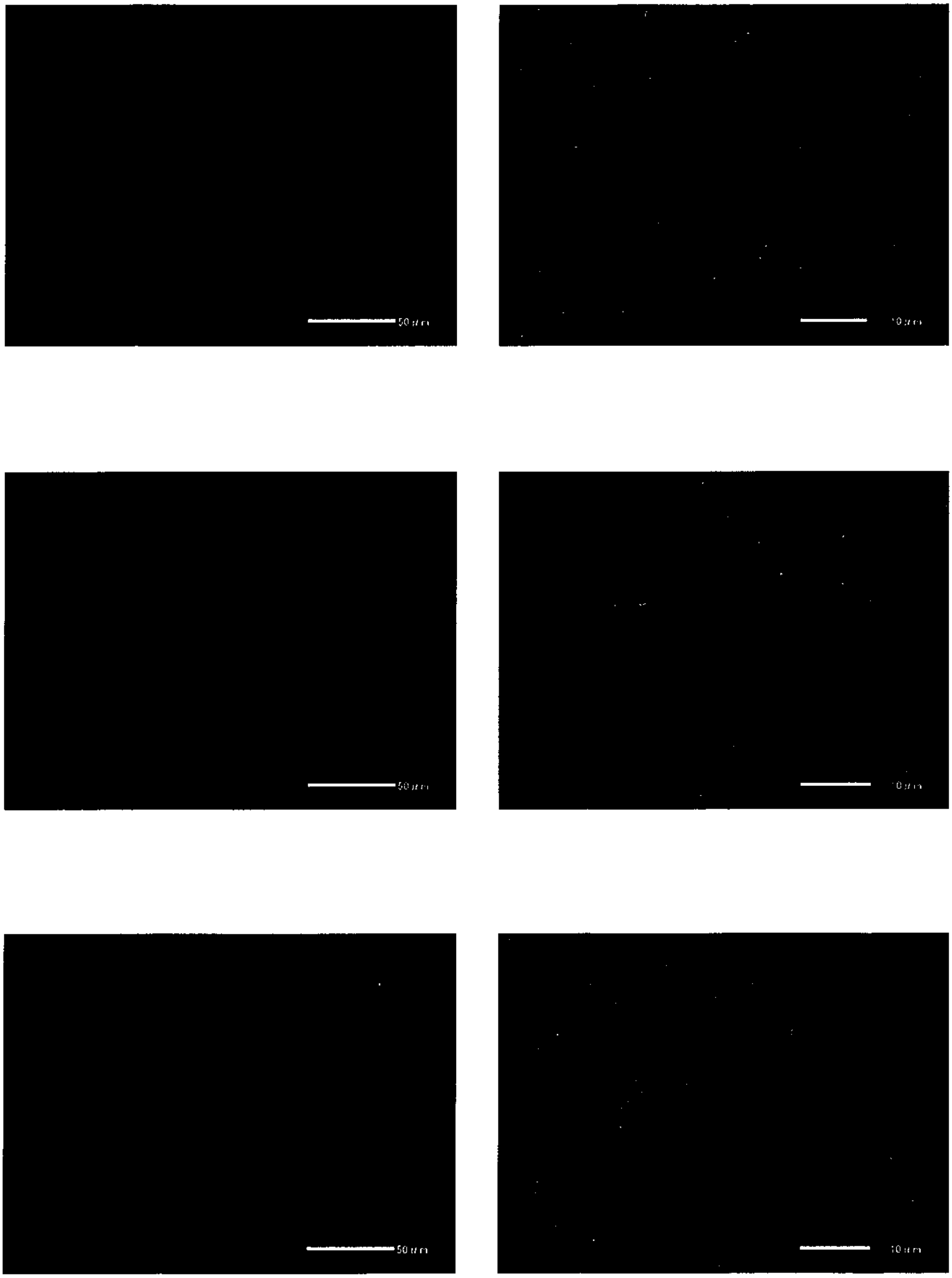


Photo Ⅱ-5-7 SEM(Scanning electron microscope) observation
De-Superheater-Left(Circumferential weld : Coarse grain HAZ)

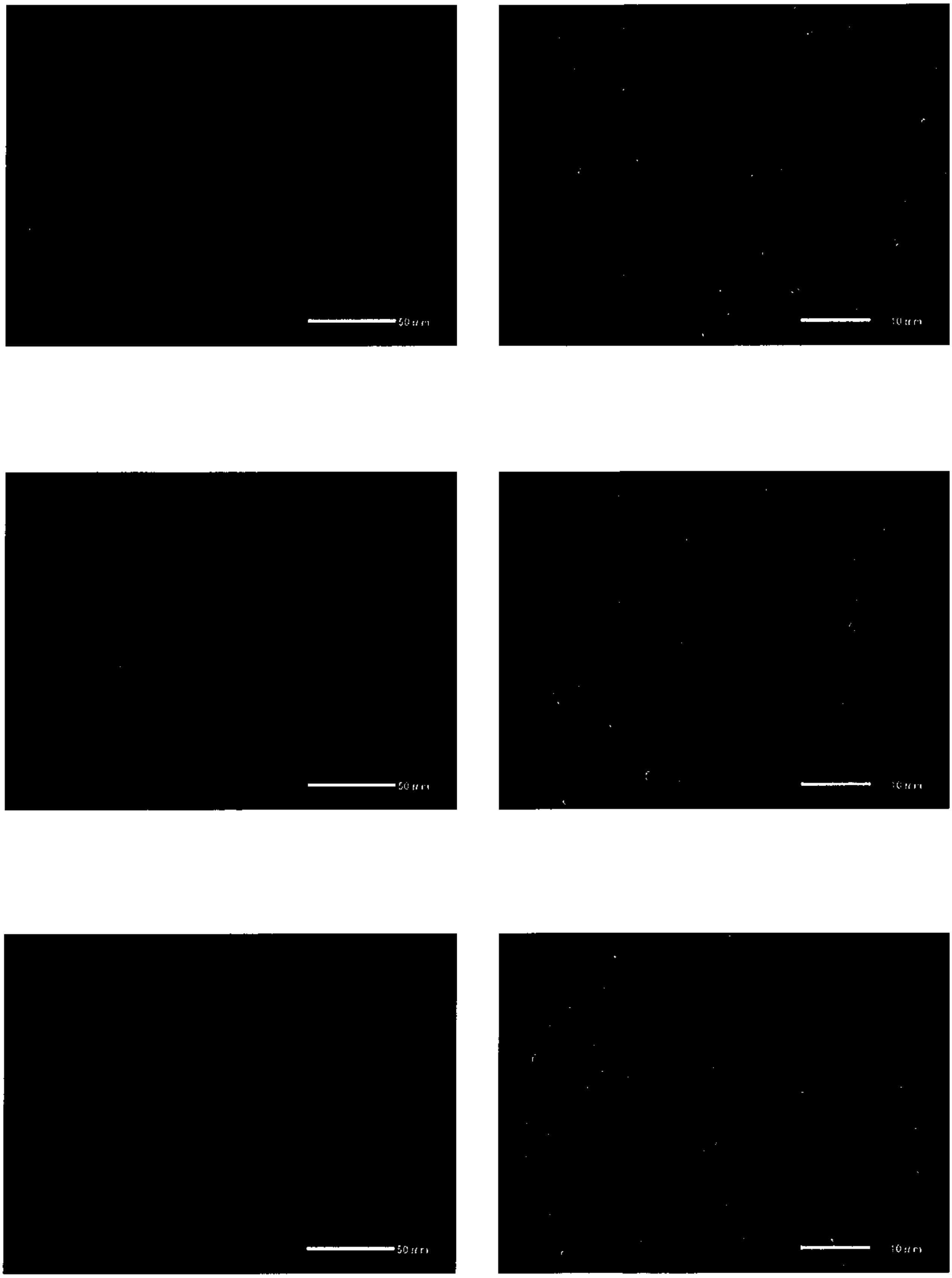


Photo Ⅱ-5-8 SEM(Scanning electron microscope) observation
De-Superheater-Left (Circumferential weld : Weld metal)

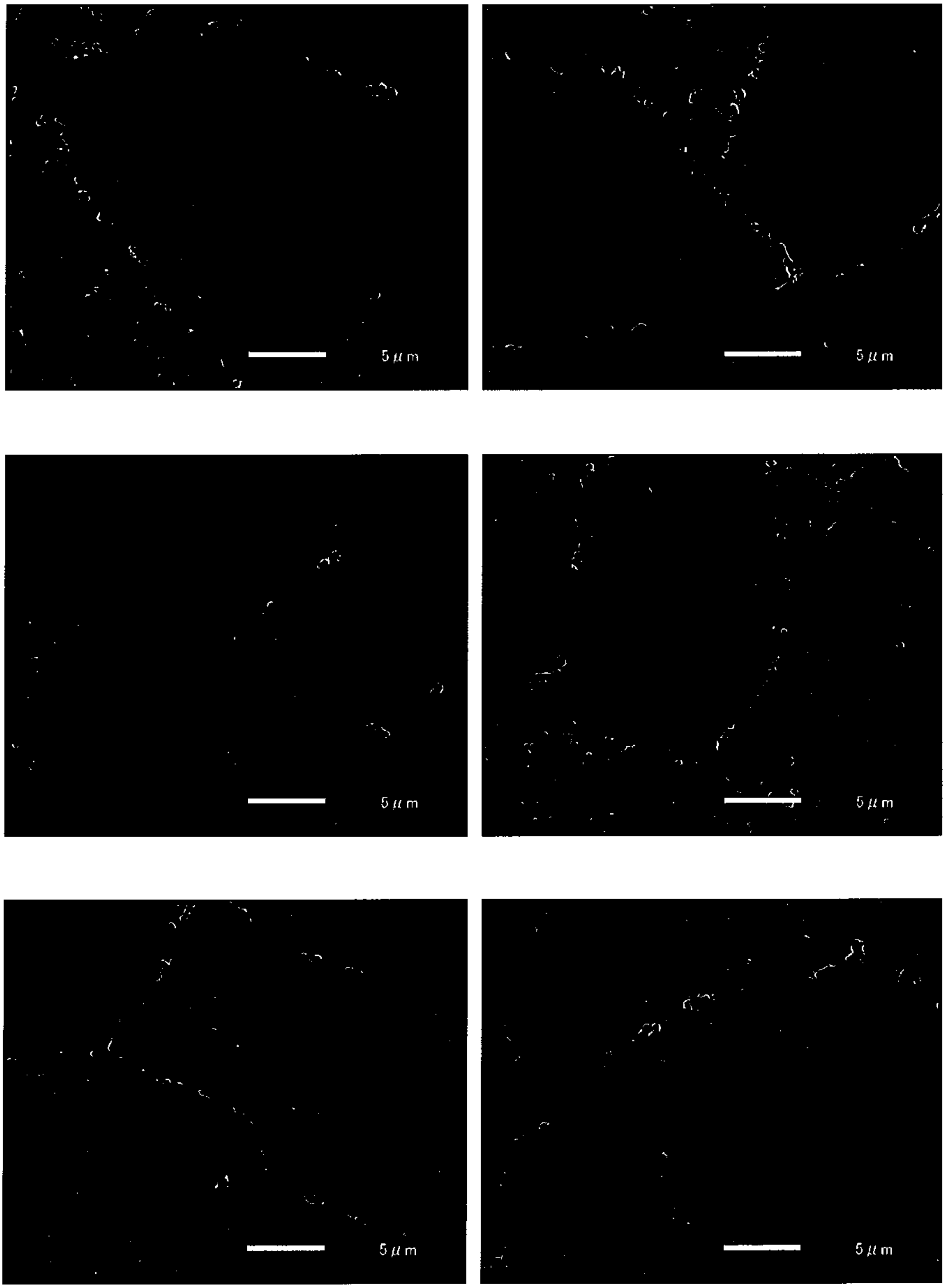


Photo II-5-9 Precipitates along grain boundary by SEM observation
De-Superheater-Left (Circumferential weld : Base metal)

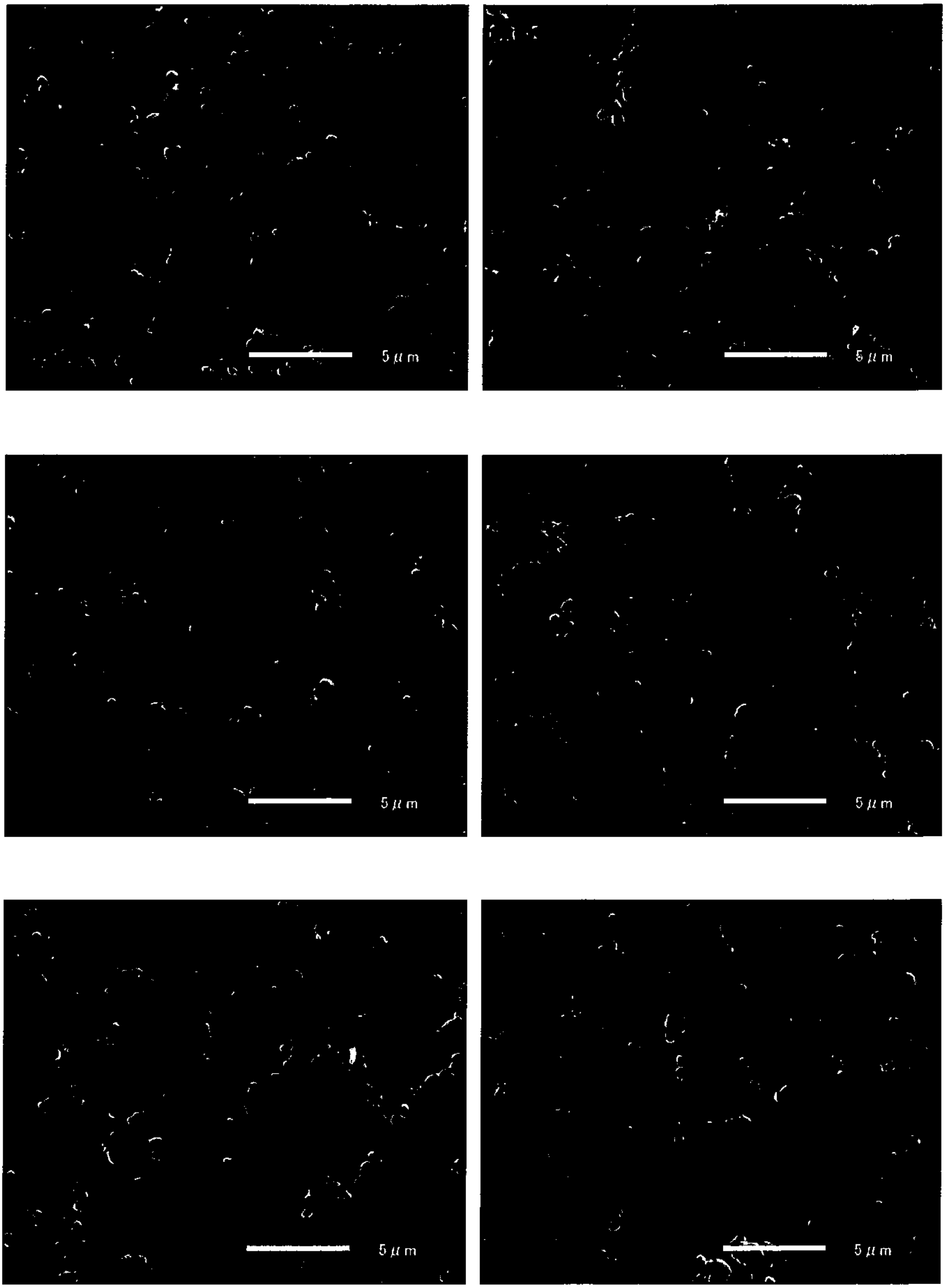
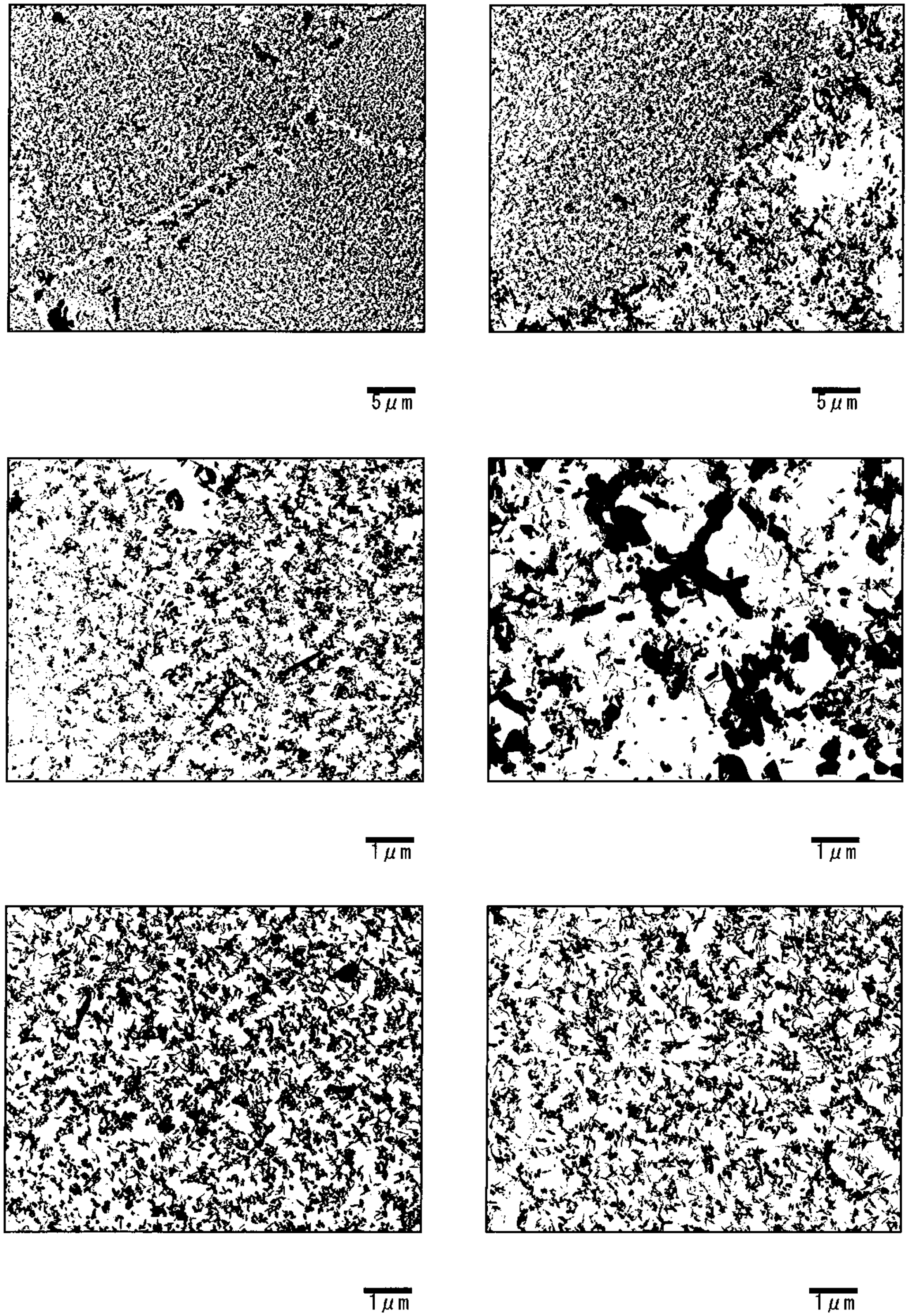


Photo Ⅱ-5-10 Precipitates along grain boundary by SEM observation
De-Superheater-Left (Circumferential weld : Fine grain HAZ)



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

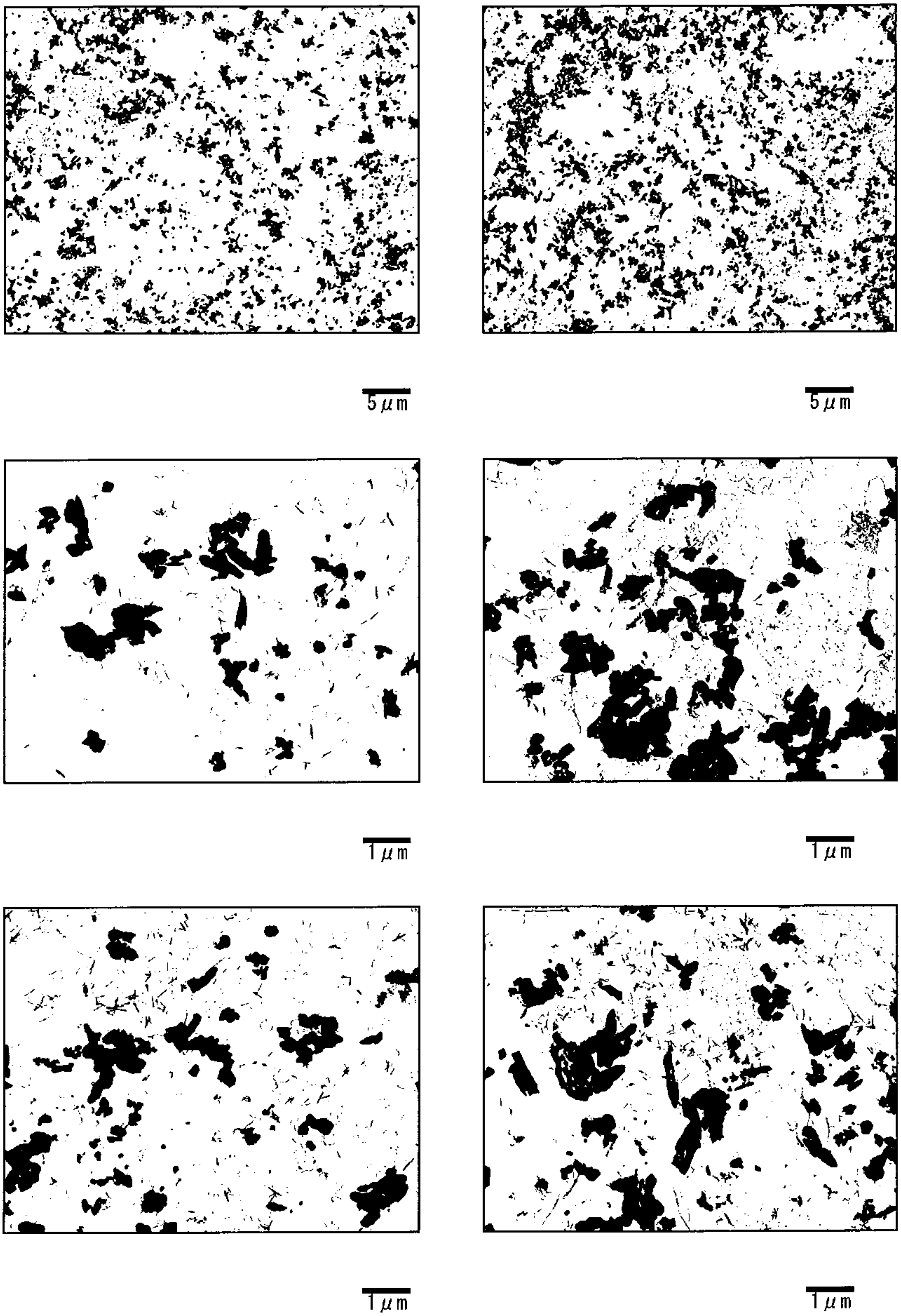


Photo II-5-12 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Left(Circumferential weld : Fine grain HAZ)

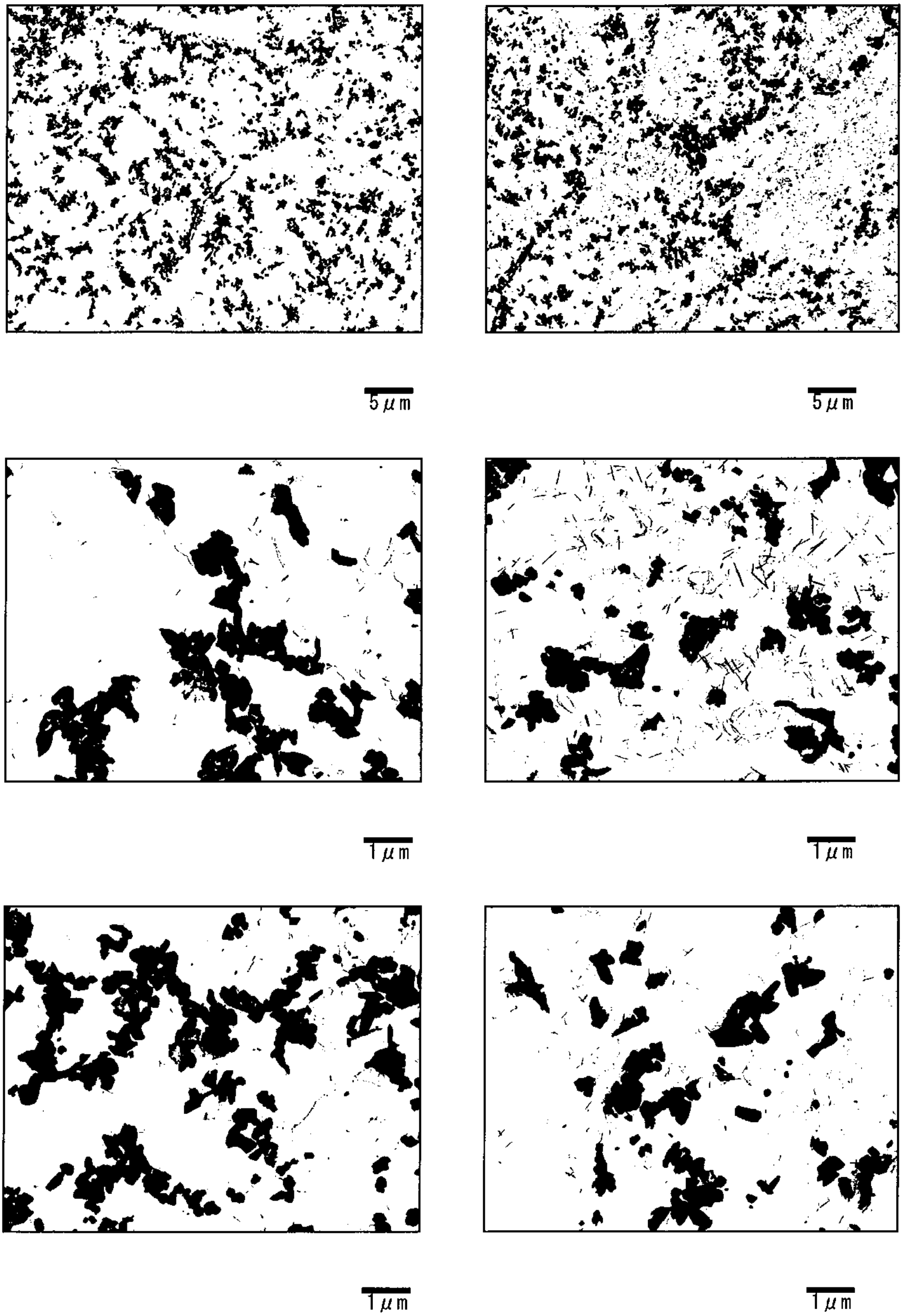
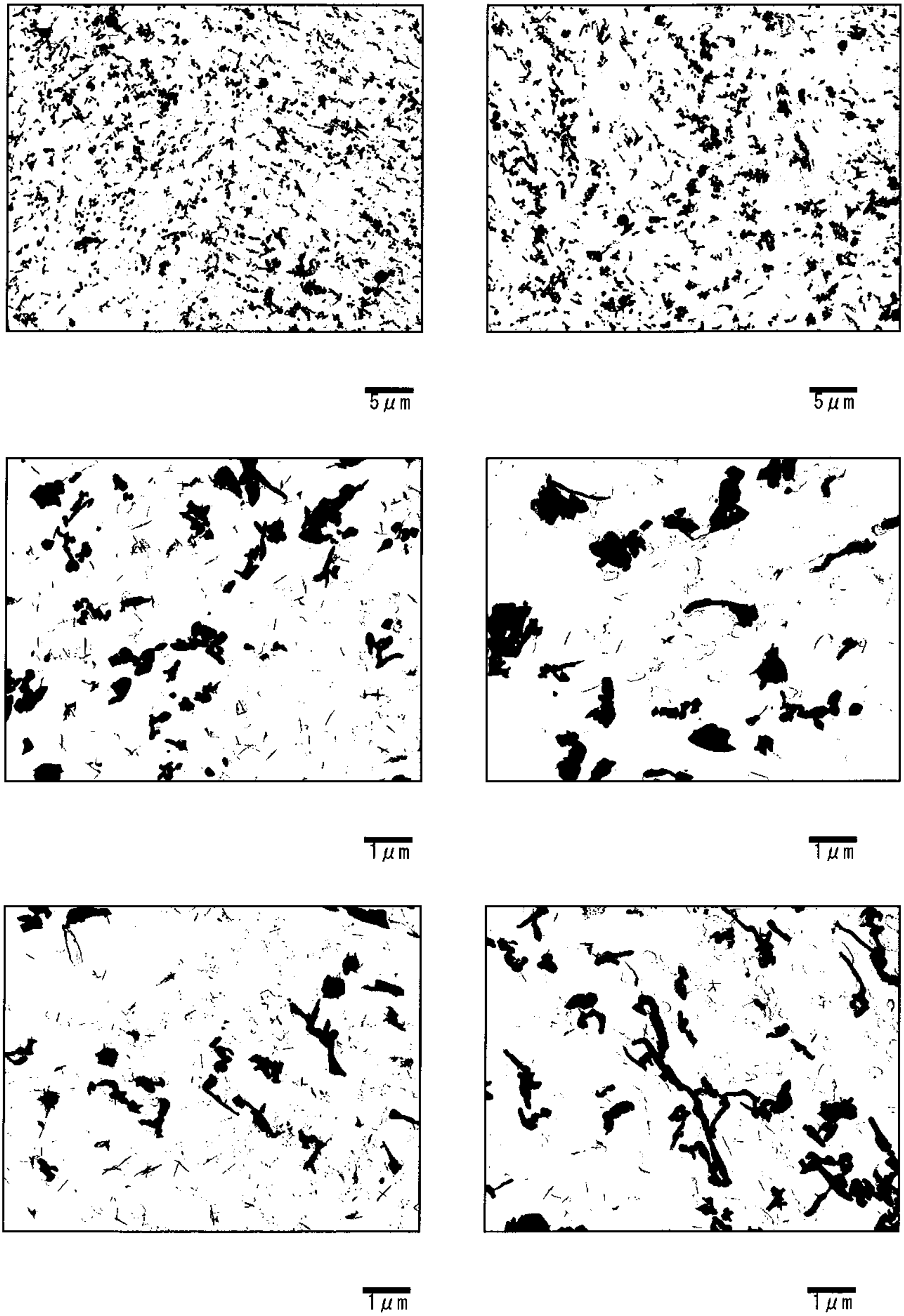


Photo II-5-13 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Left (Circumferential weld : Coarse grain HAZ)



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

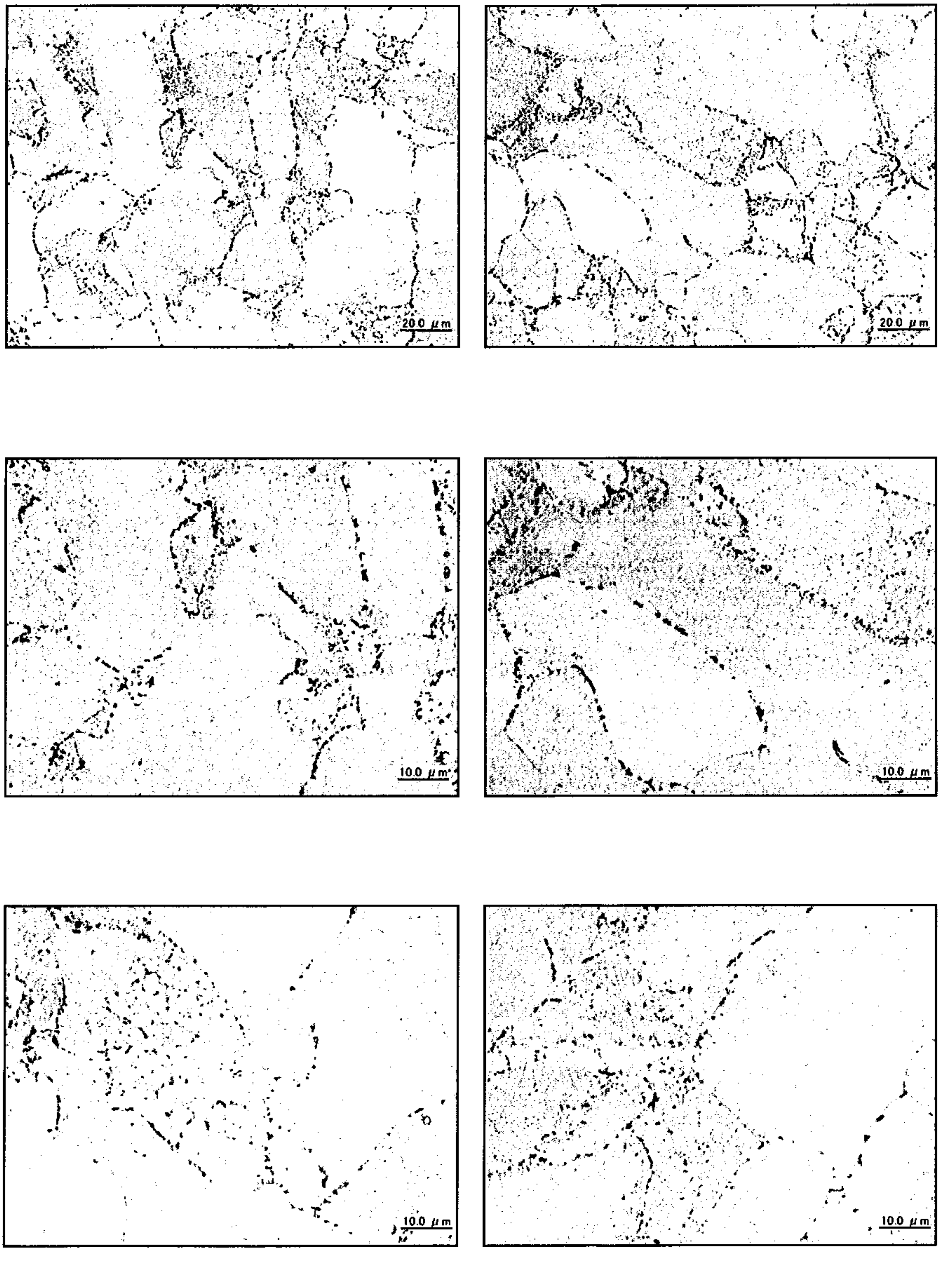


Photo Ⅱ-6-1 Microstructure observation
De-Superheater-Right (Circumferential weld : Base metal)

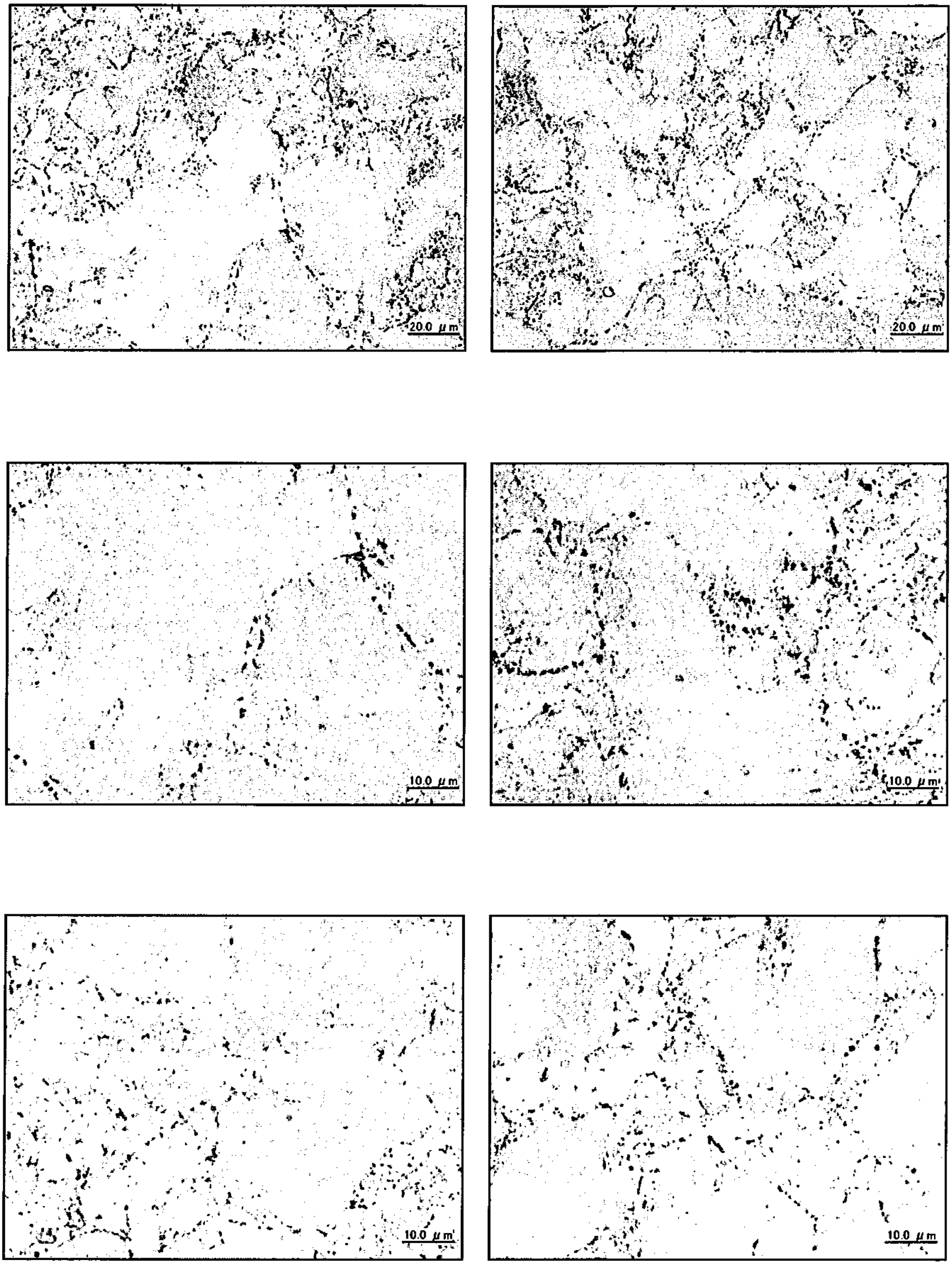


Photo Ⅱ-6-2 Microstructure observation
De-Superheater-Right (Circumferential weld : Intercritical zone)

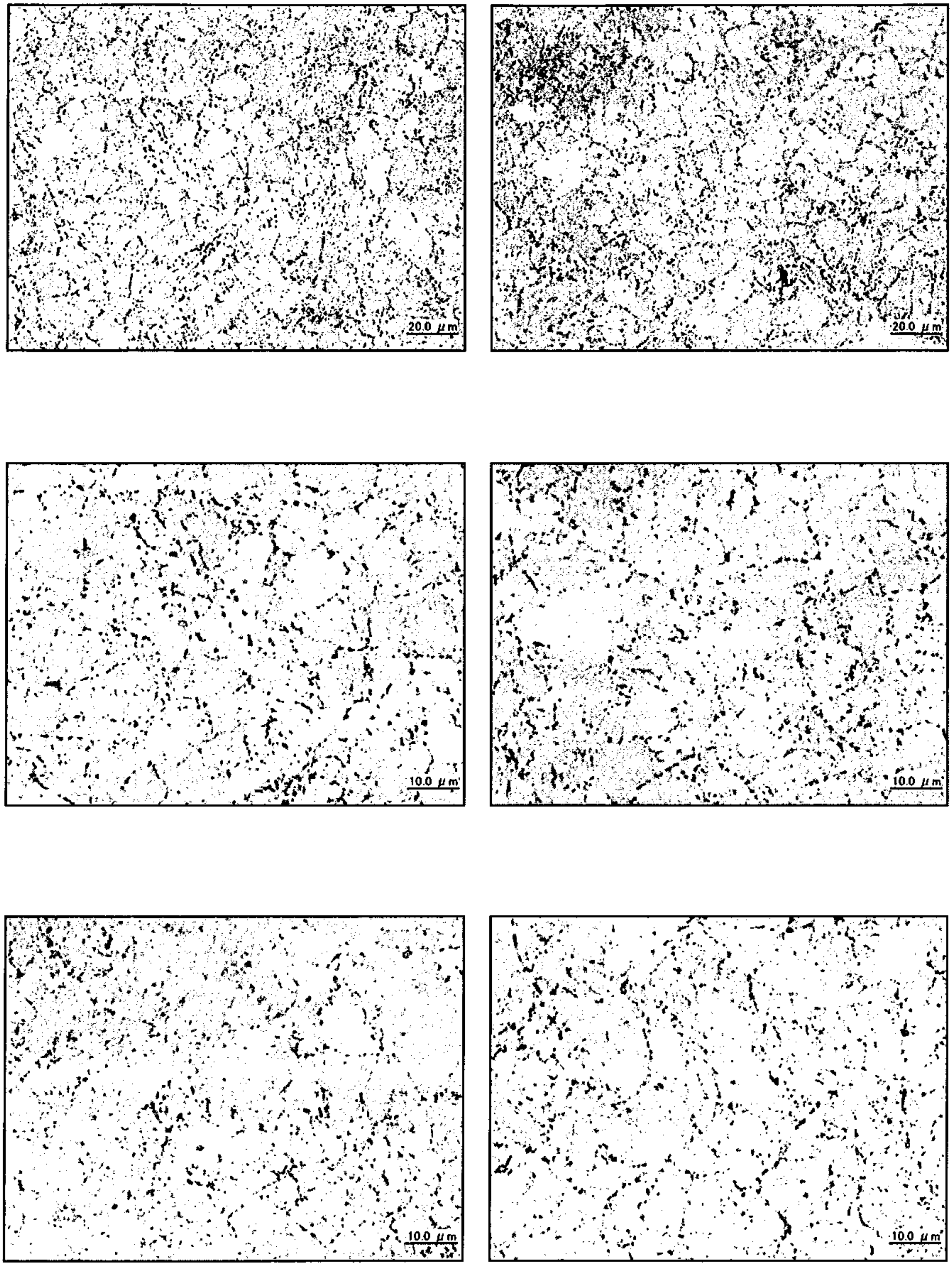


Photo Ⅱ-6-3 Microstructure observation
De-Superheater-Right (Circumferential weld : Fine grain HAZ)

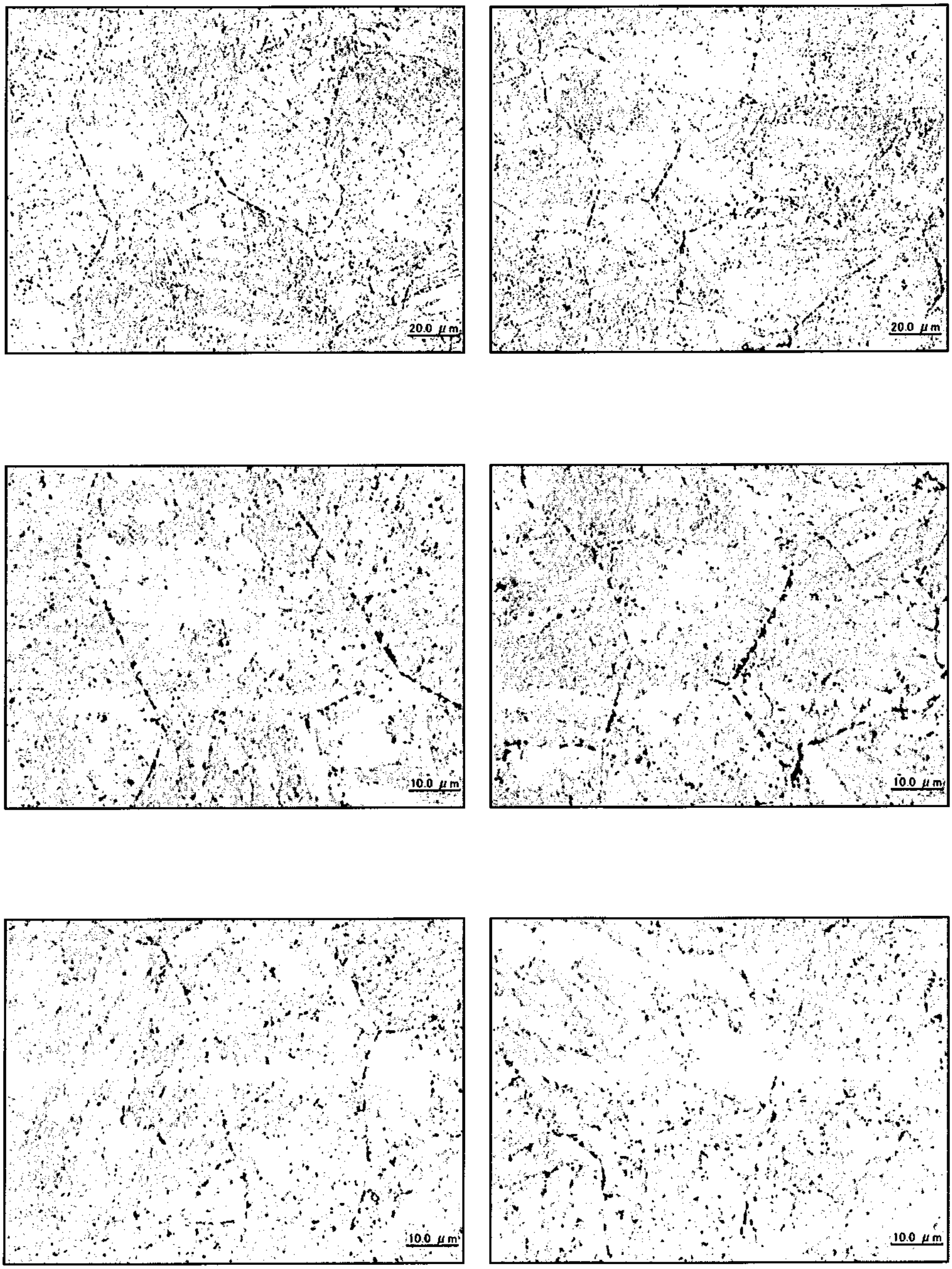


Photo II-6-4 Microstructure observation
De-Superheater-Right (Circumferential weld : Coarse grain HAZ)

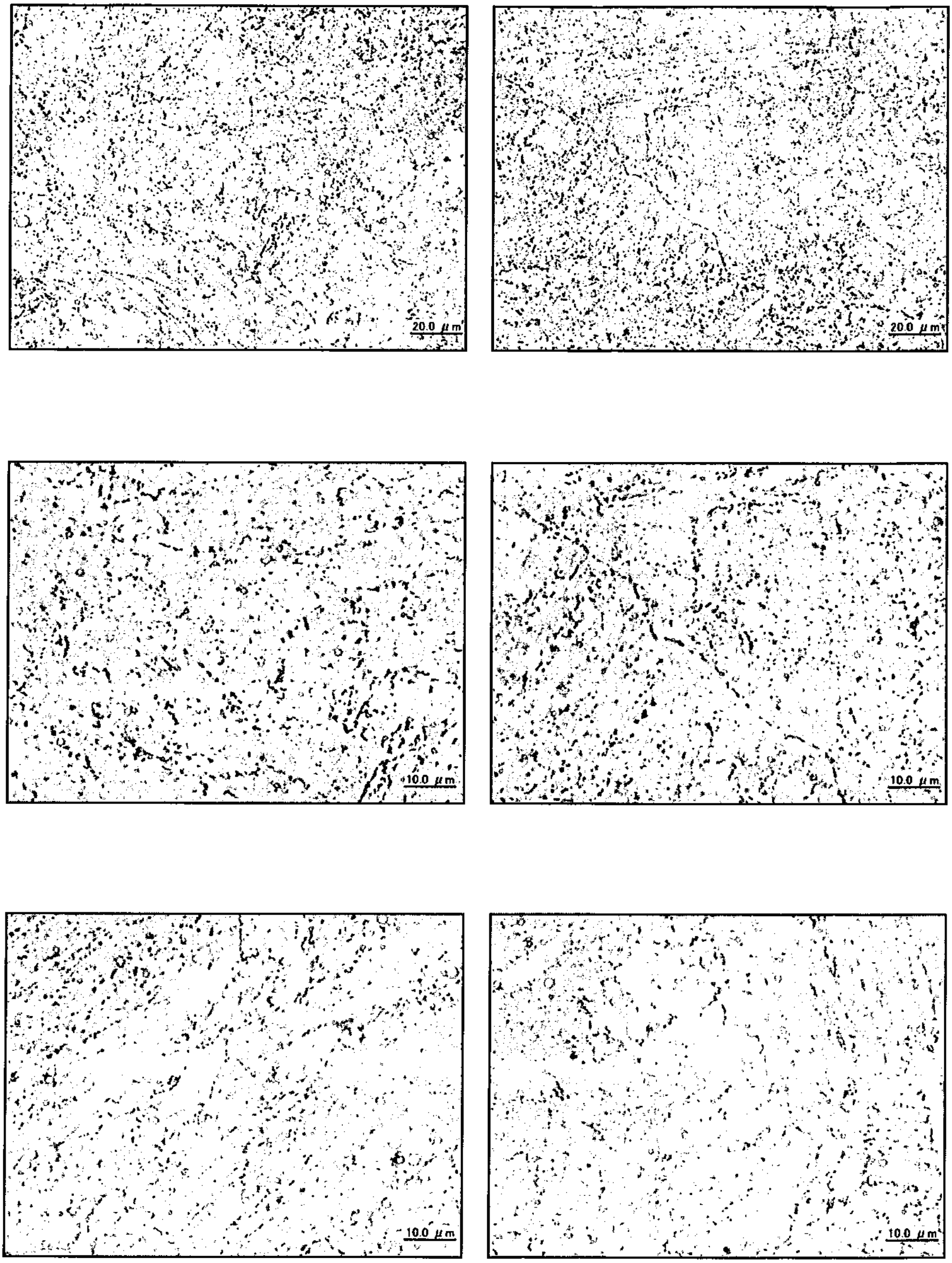
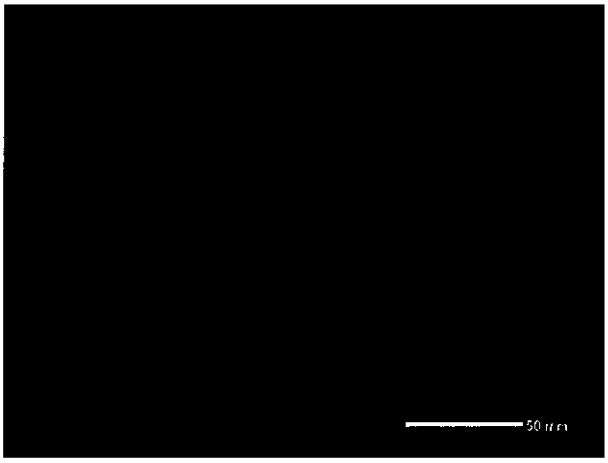
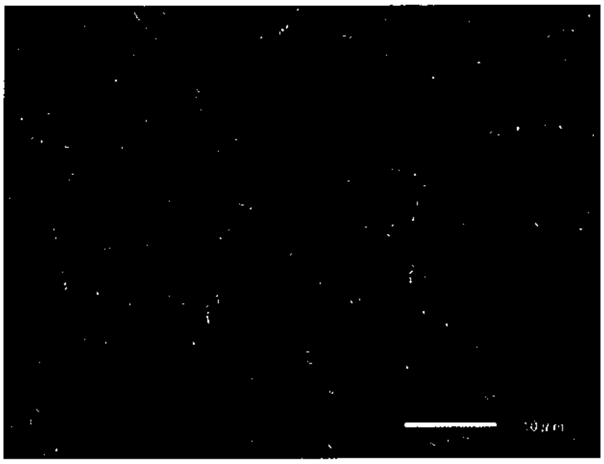
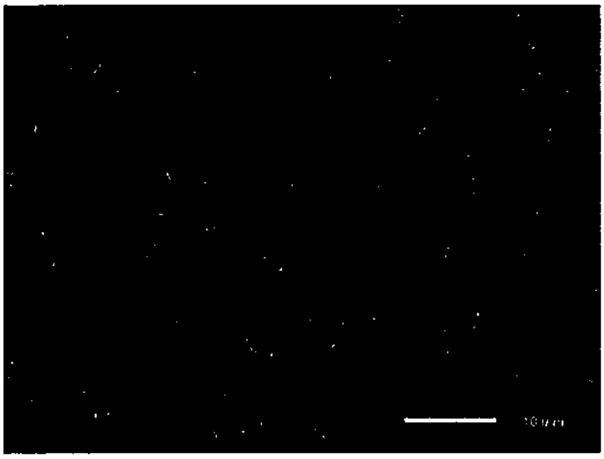


Photo Ⅱ-6-5 Microstructure observation
De-Superheater-Right (Circumferential weld : Weld metal)



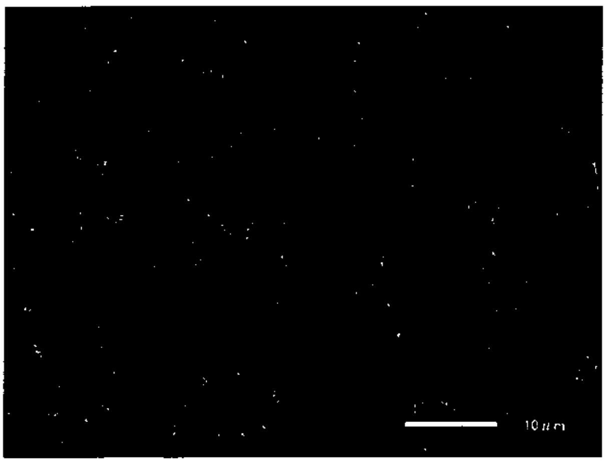


Photo Ⅱ-6-6 SEM(Scanning electron microscope) observation
De-Superheater-Right(Circumferential weld : Fine grain HAZ)

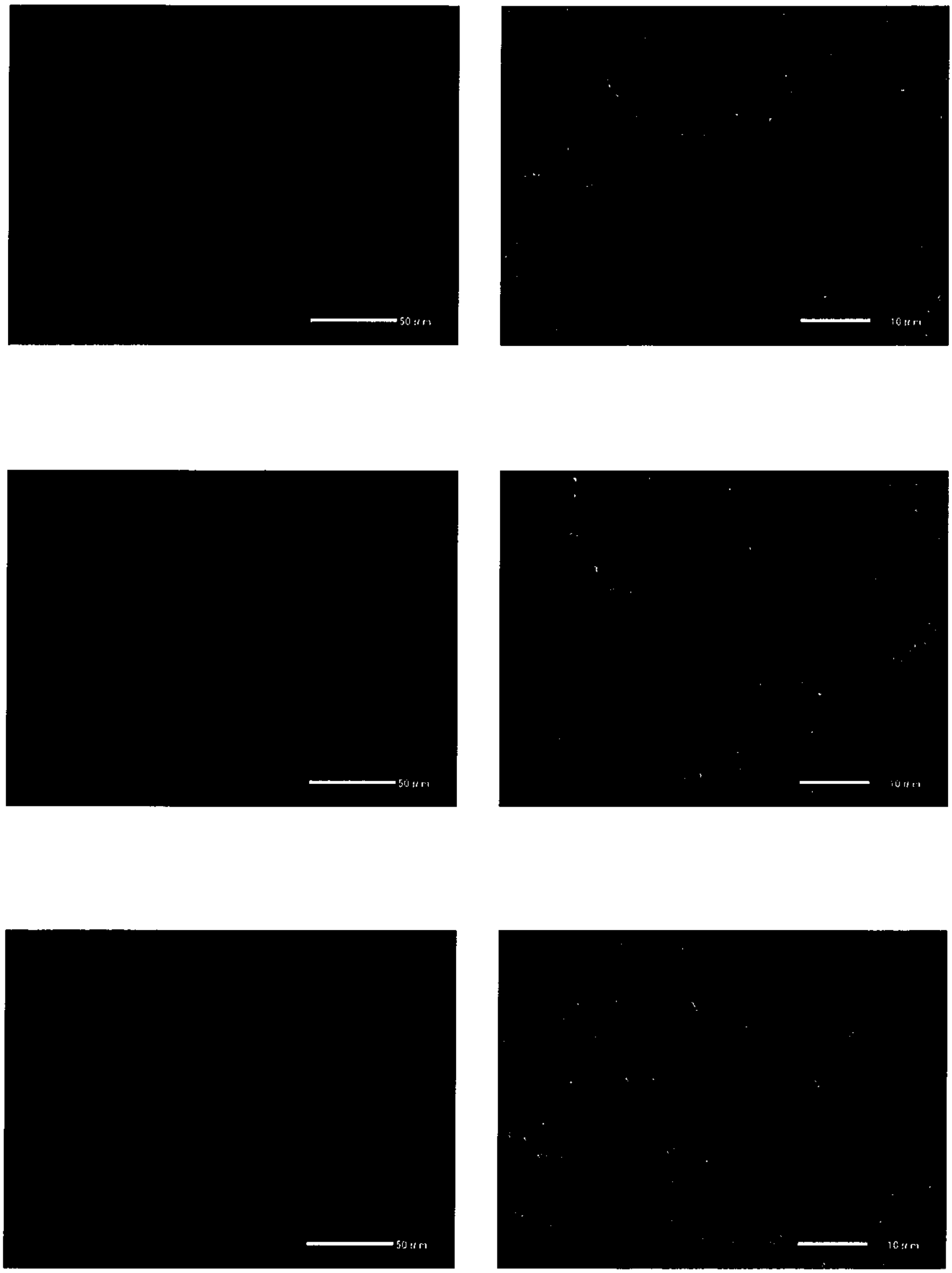


Photo II-6-7 SEM(Scanning electron microscope) observation
De-Superheater-Right(Circumferential weld : Coarse grain HAZ)

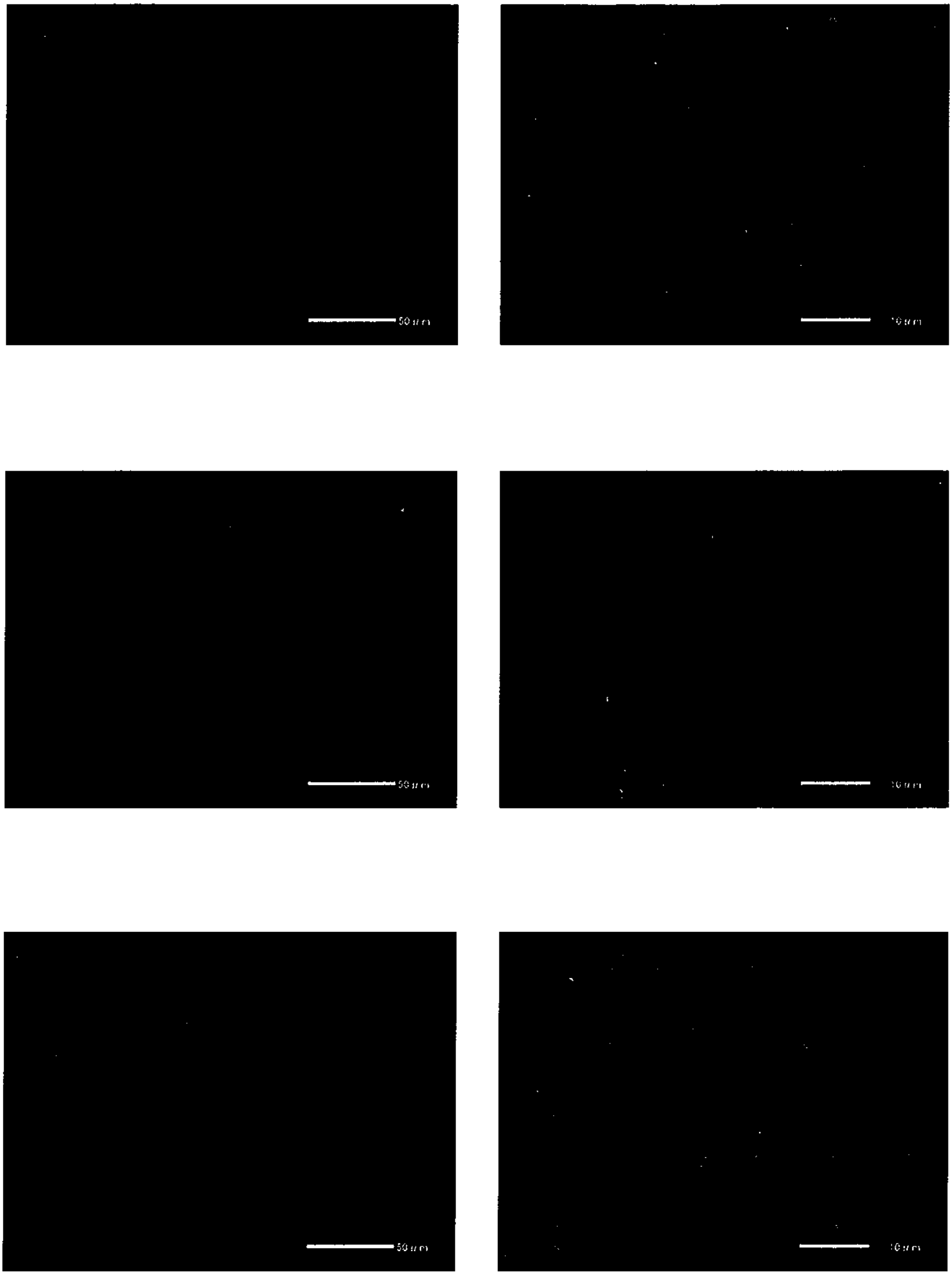


Photo Ⅱ-6-8 SEM(Scanning electron microscope) observation
De-Superheater-Right(Circumferential weld : Weld metal)

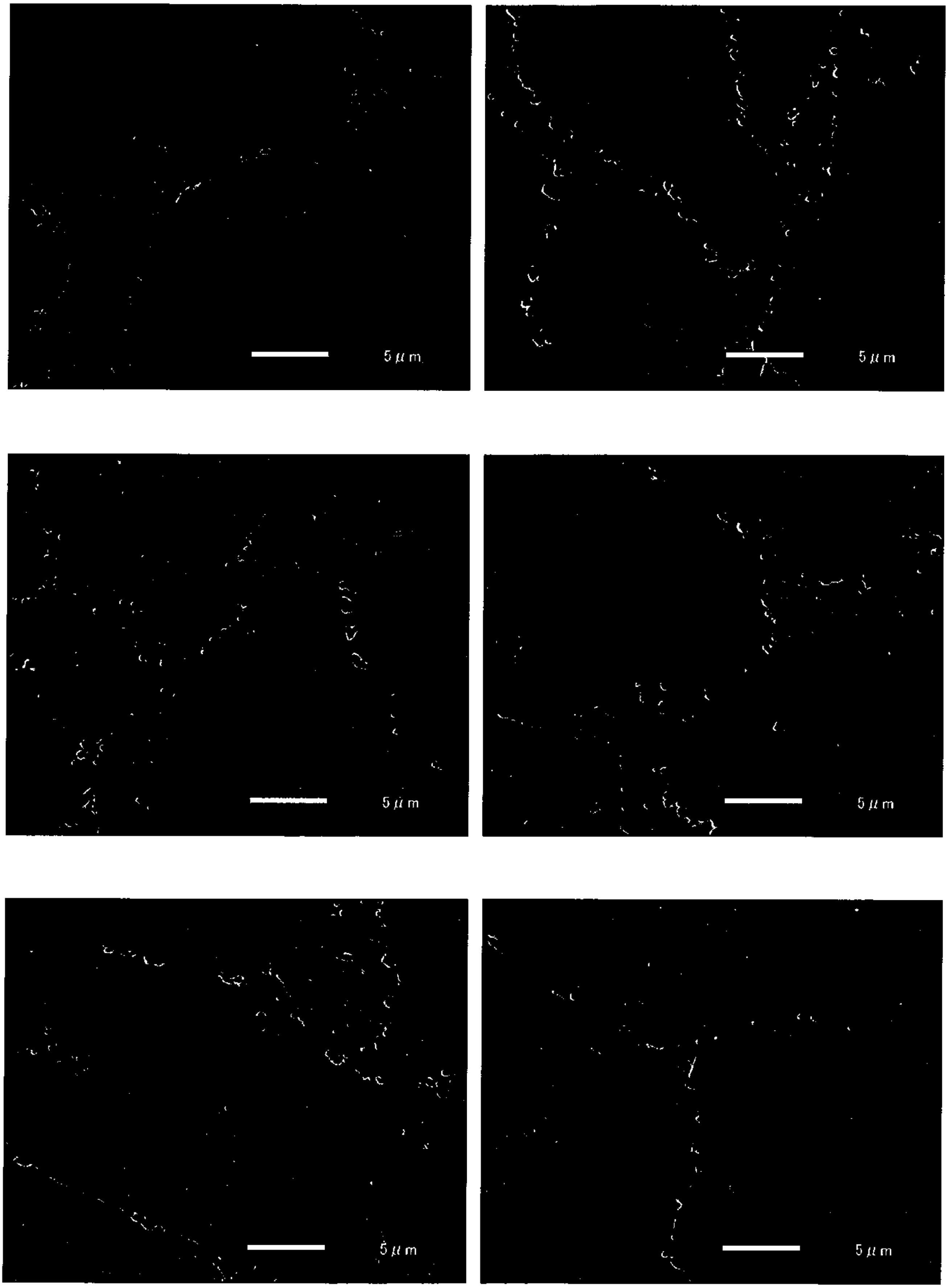


Photo Ⅱ-6-9 Precipitates along grain boundary by SEM observation
De-Superheater-Right (Circumferential weld : Base metal)

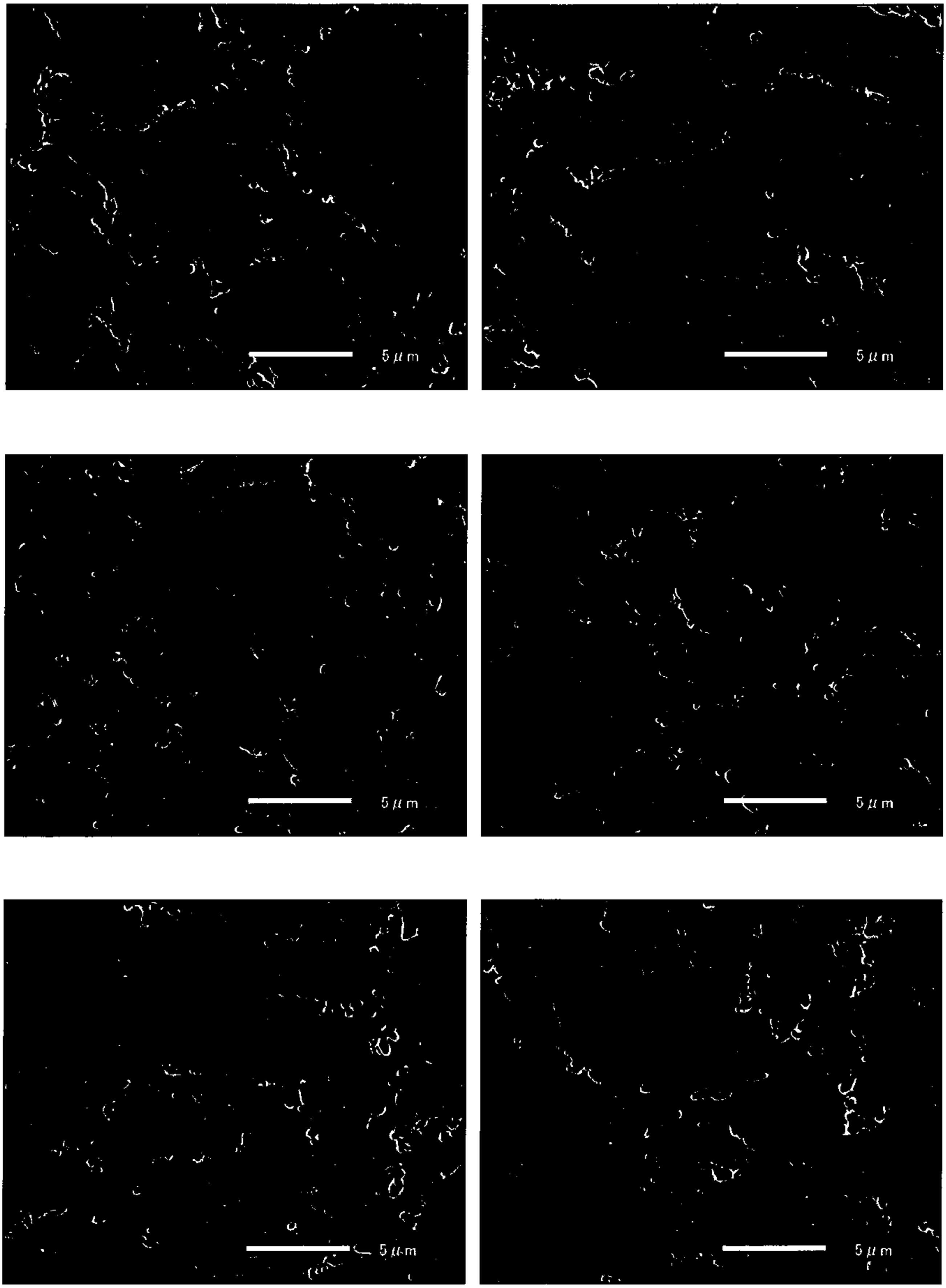
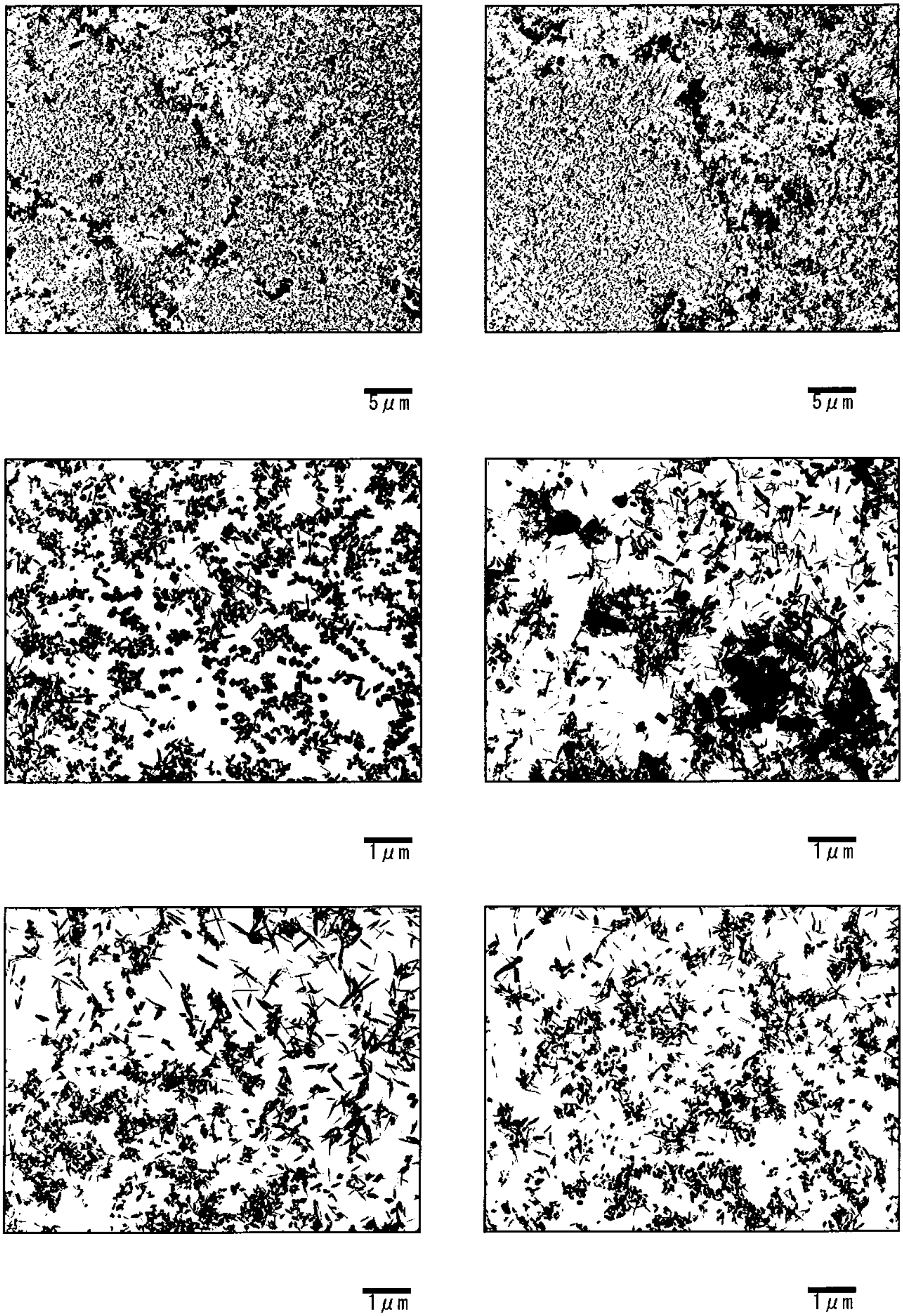


Photo Ⅱ-6-10 Precipitates along grain boundary by SEM observation
De-Superheater-Right (Circumferential weld : Fine grain HAZ)



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

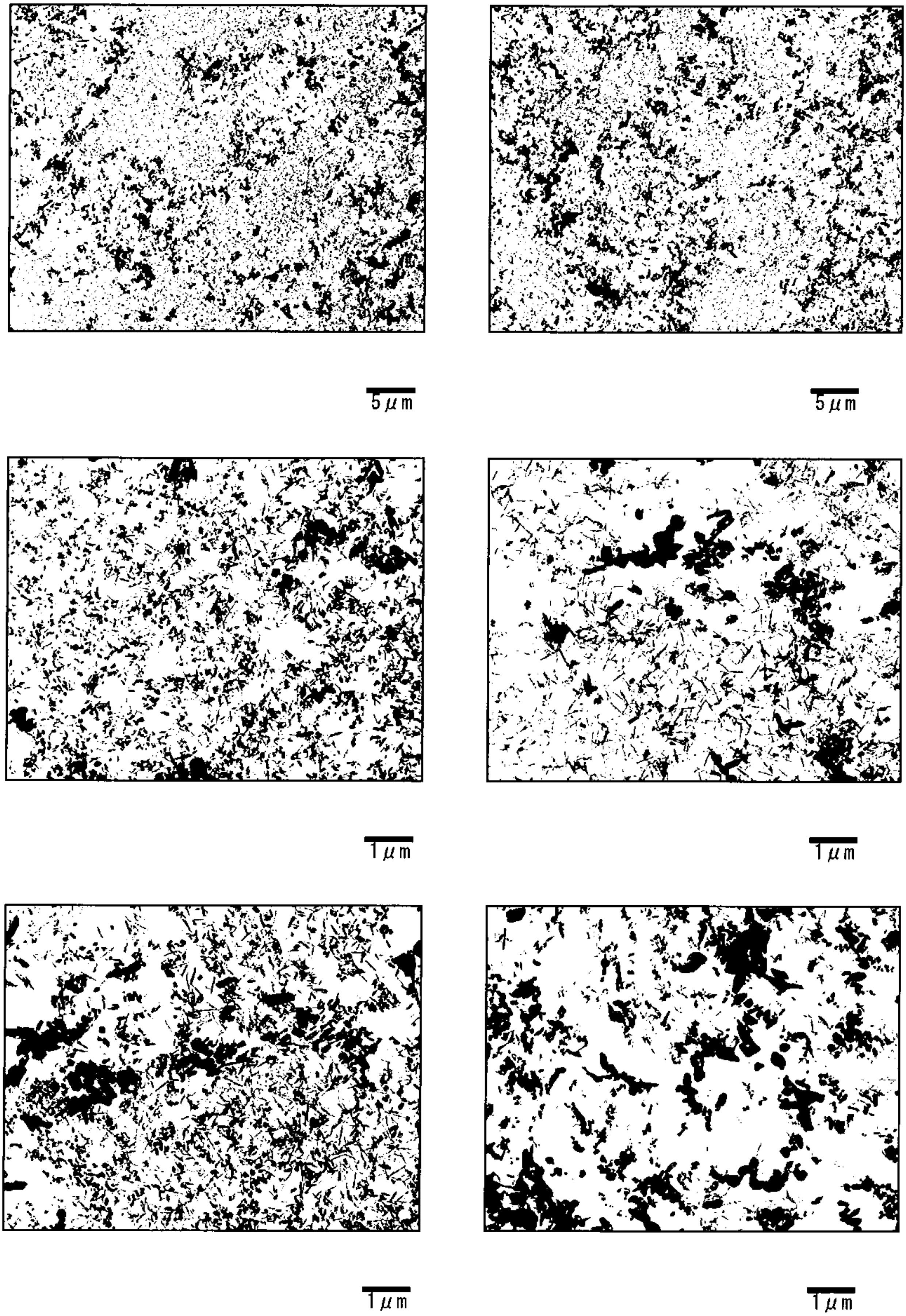


Photo II-6-12 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Right (Circumferential weld : Fine grain HAZ)

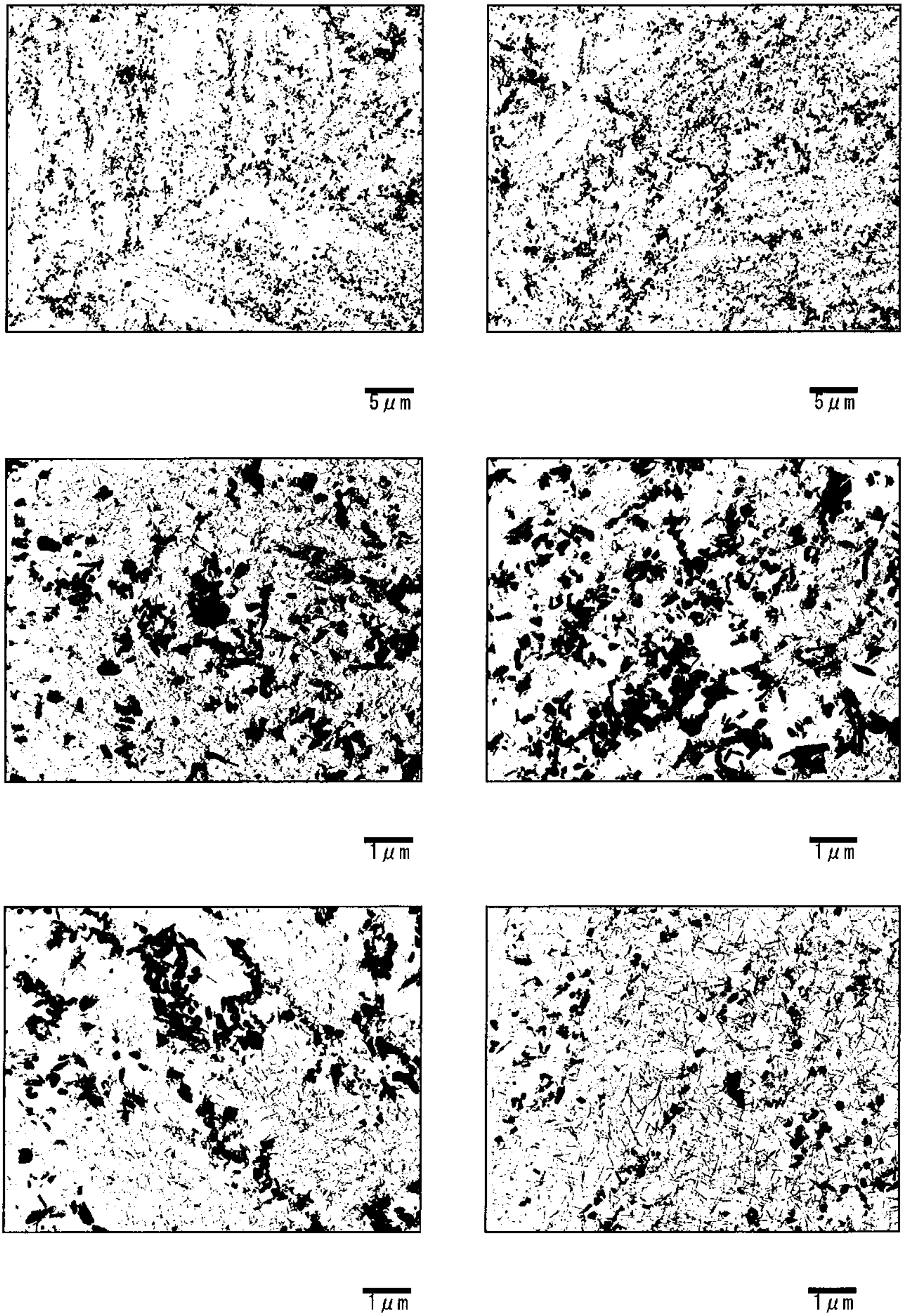
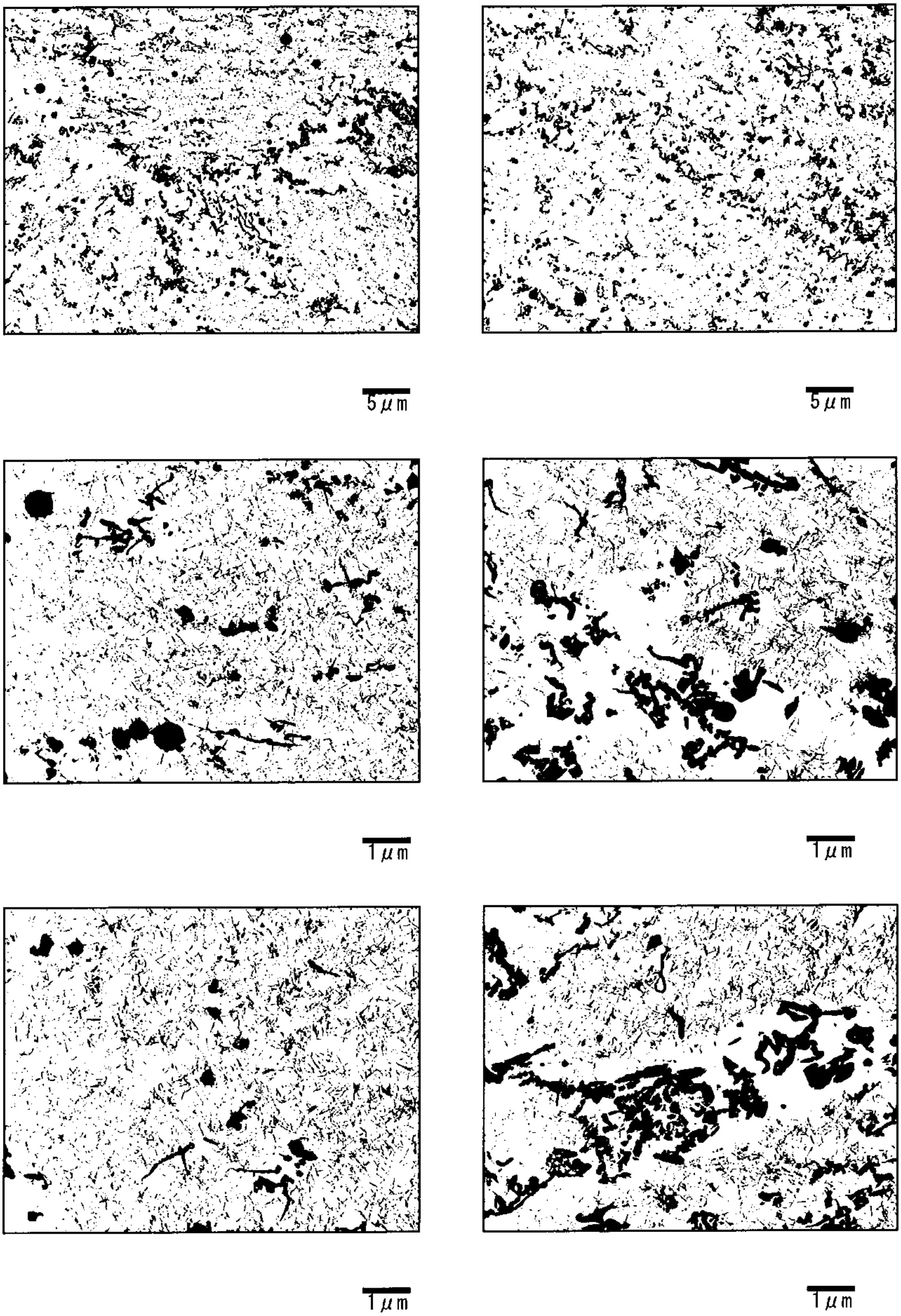


Photo Ⅱ-6-13 Precipitates by TEM (Transmission electron microscope) observation
De-Superheater-Right (Circumferential weld : Coarse grain HAZ)



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

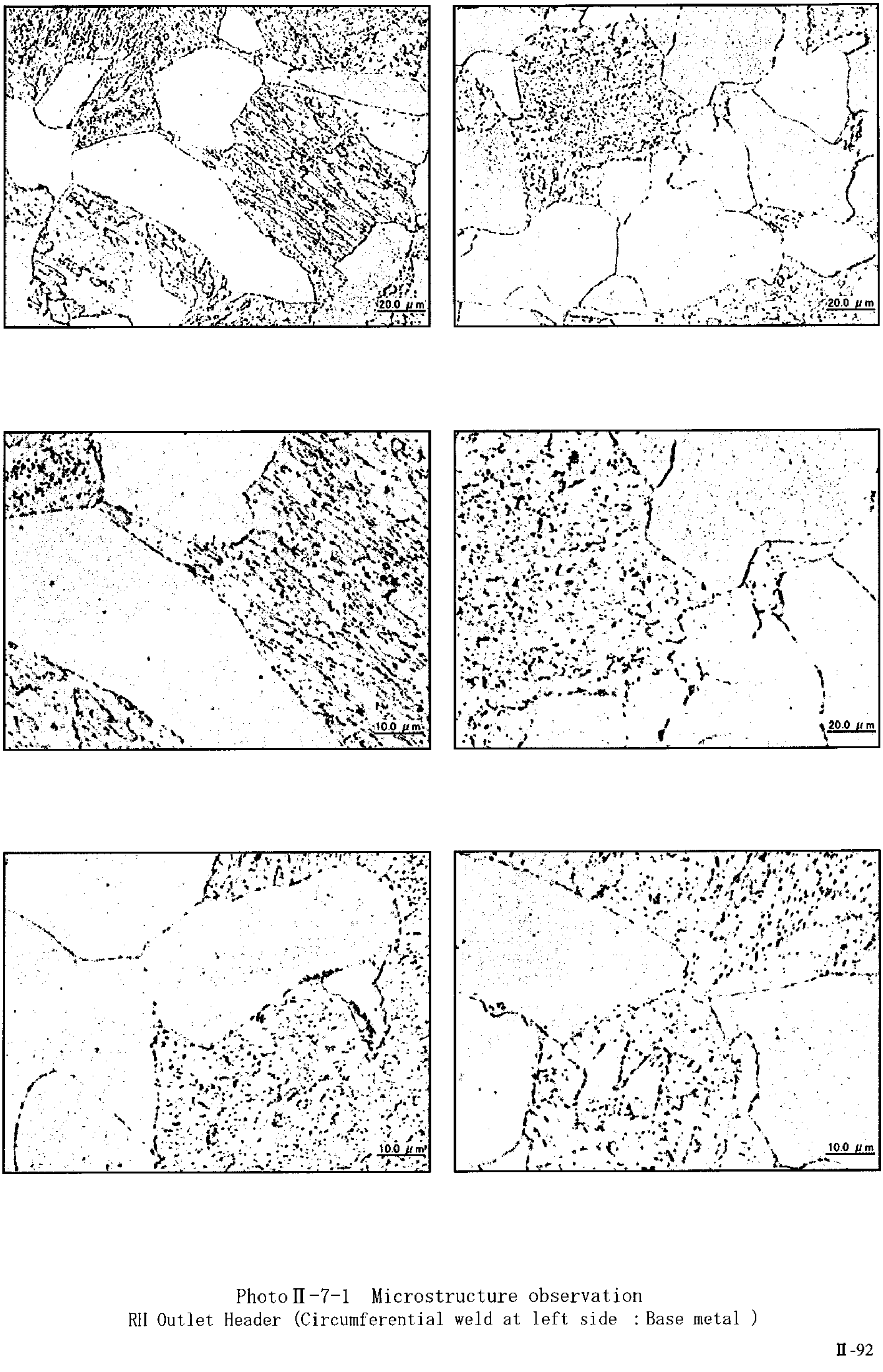


Photo Ⅱ-7-1 Microstructure observation
RH Outlet Header (Circumferential weld at left side : Base metal)

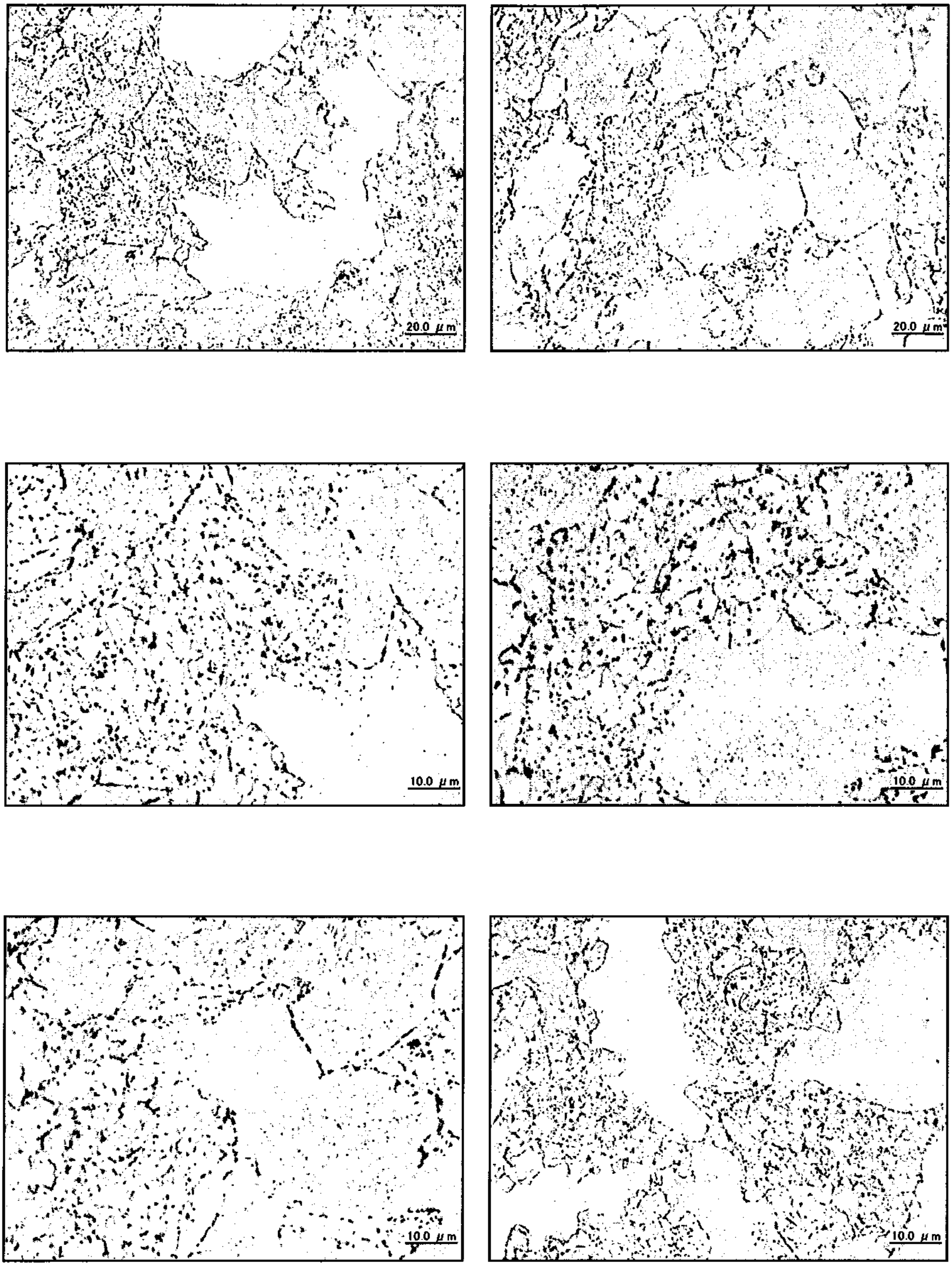
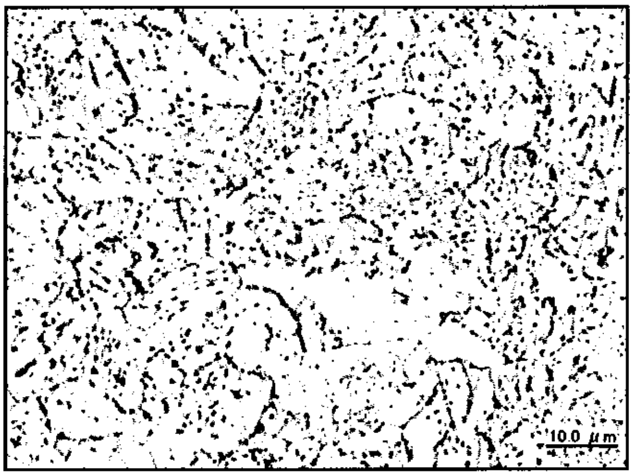
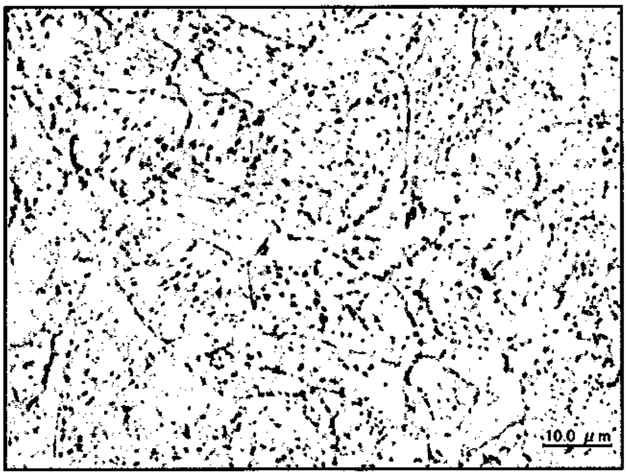
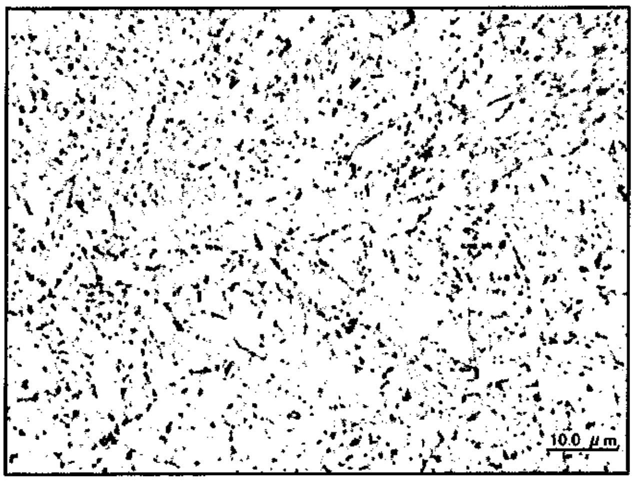


Photo Ⅱ-7-2 Microstructure observation
RH Outlet Header (Circumferential weld at left side : Intercritical zone)







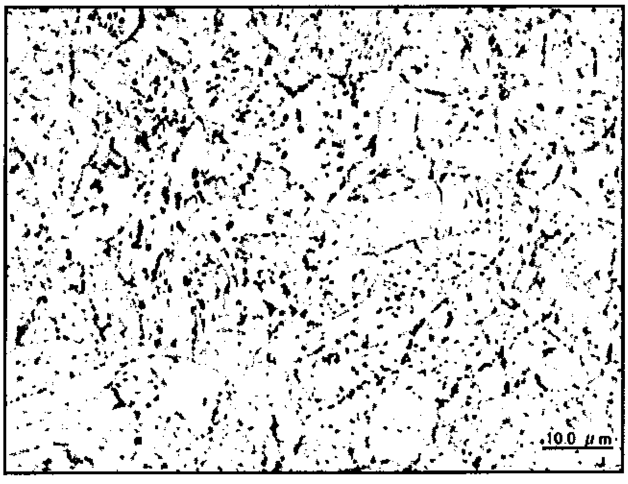


Photo II-7-3 Microstructure observation
RH Outlet Header (Circumferential weld at left side : Fine grain HAZ)

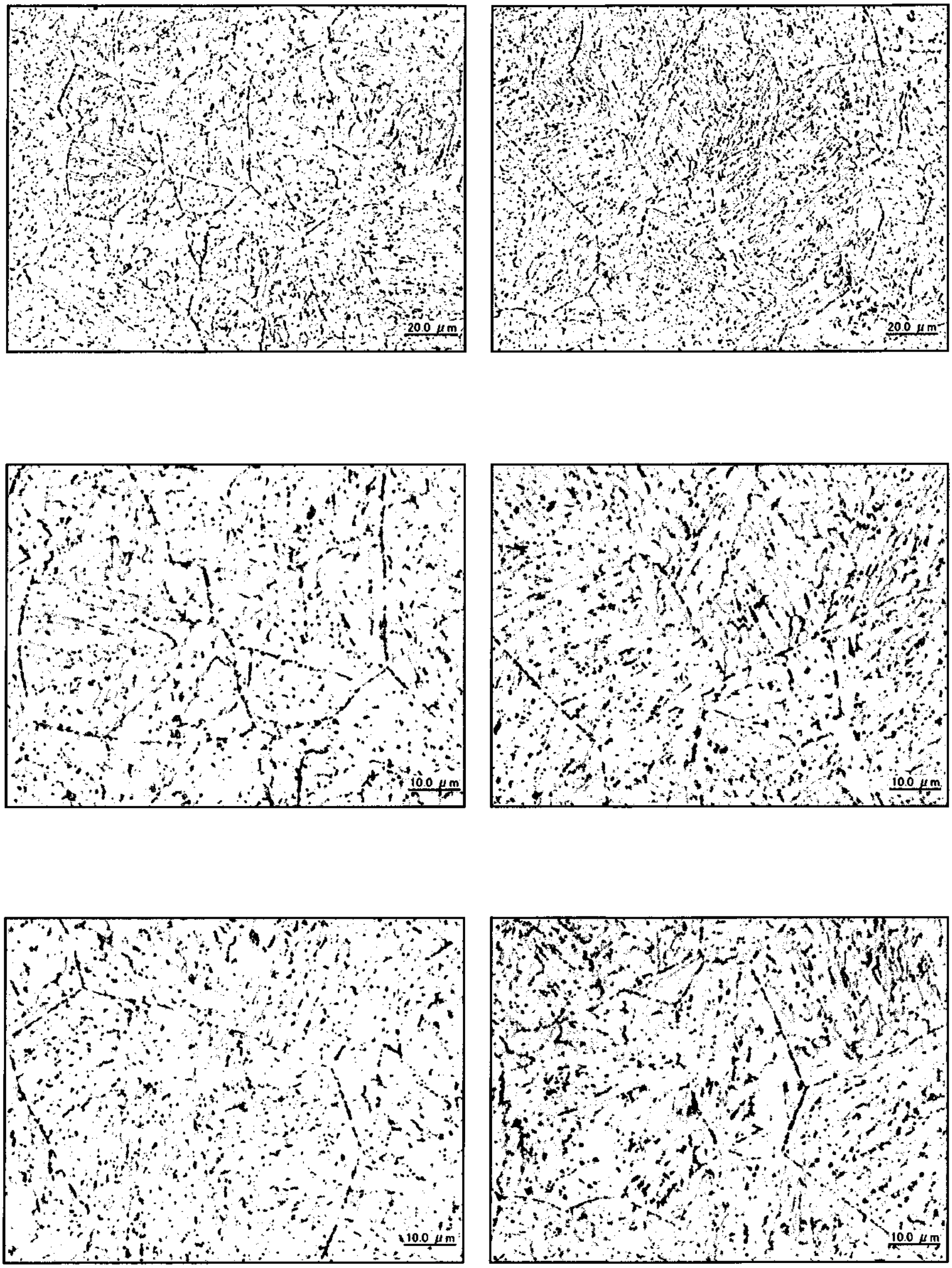


Photo Ⅱ-7-4 Microstructure observation
RH Outlet Header (Circumferential weld at left side : Coarse grain HAZ)

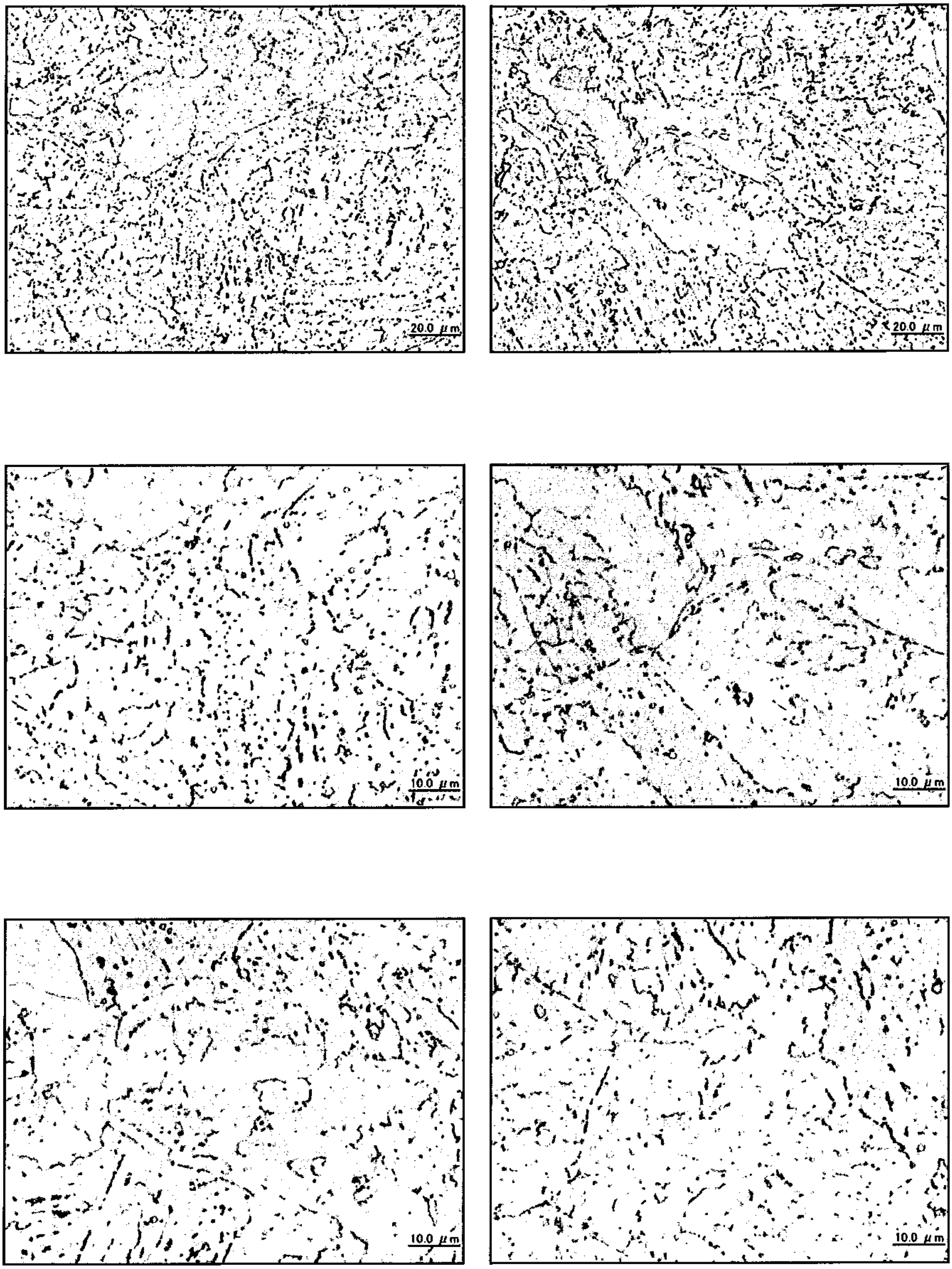
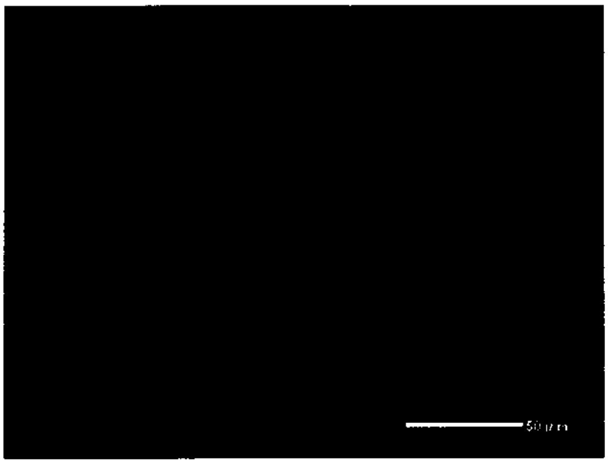
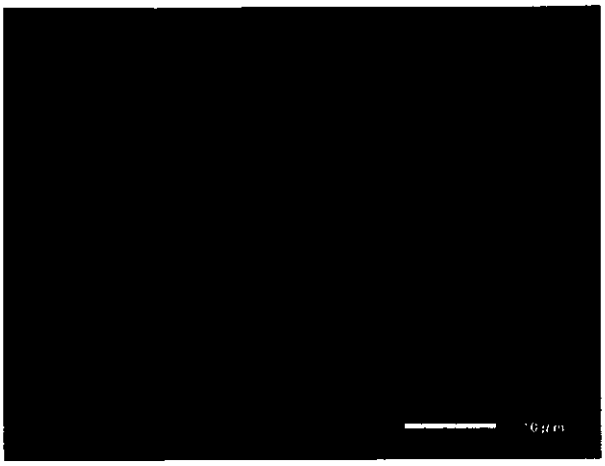
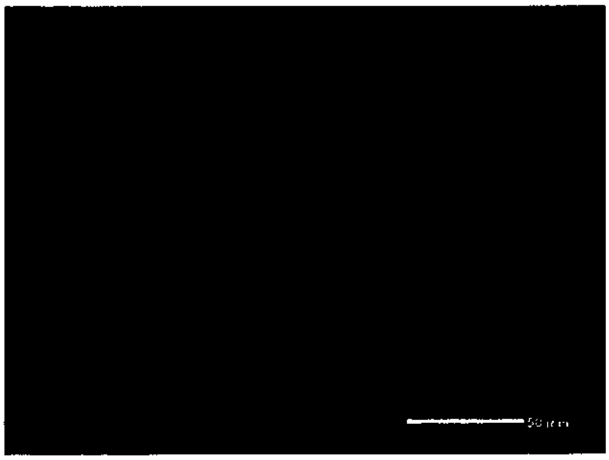
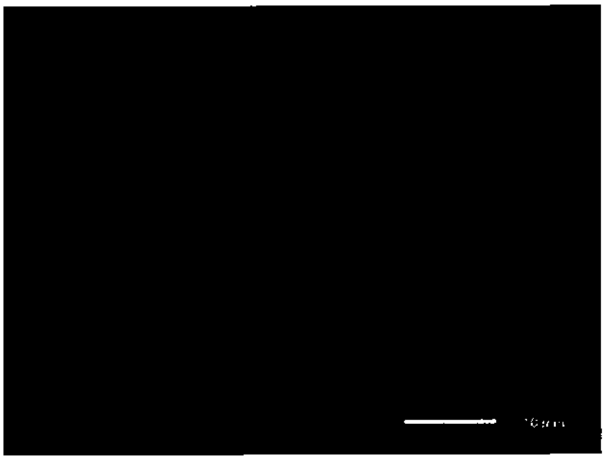


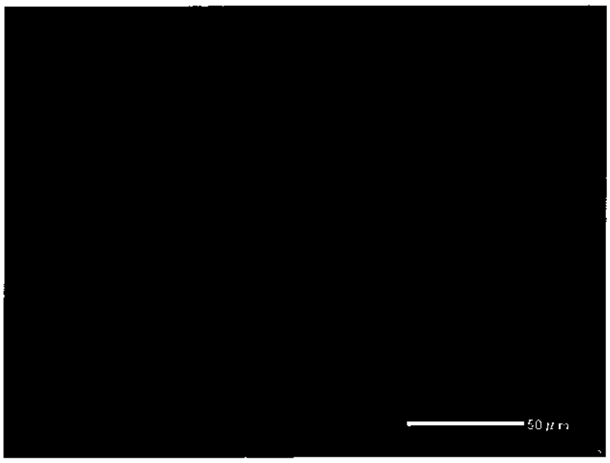
Photo Ⅱ-7-5 Microstructure observation
RH Outlet Header (Circumferential weld at left side : Weld metal)











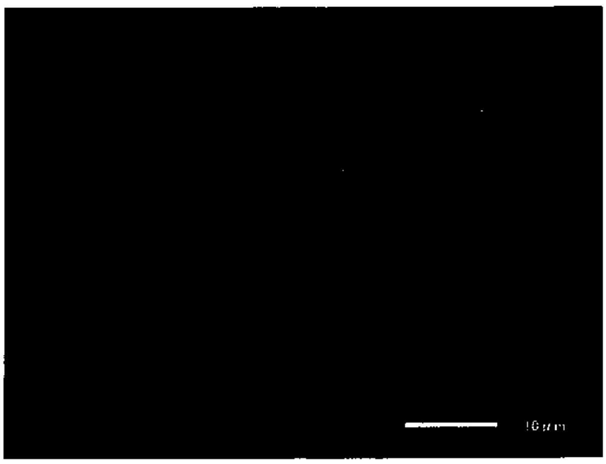


Photo II-7-6 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Fine grain HAZ)

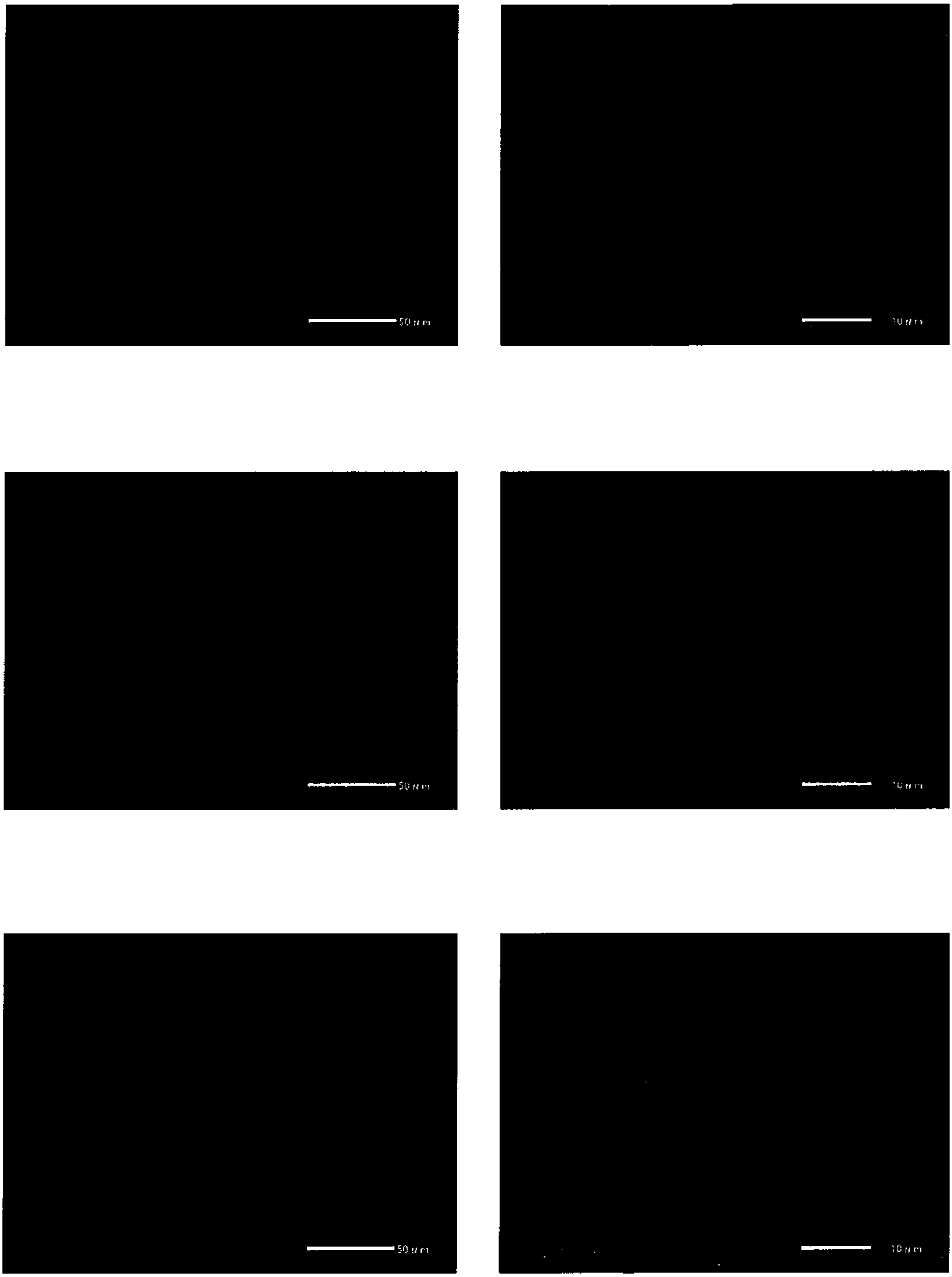
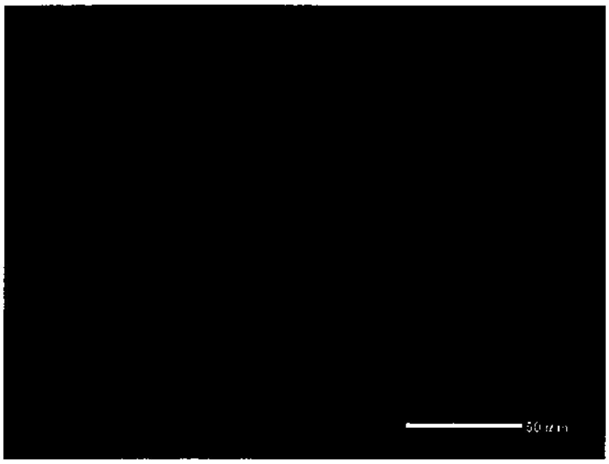
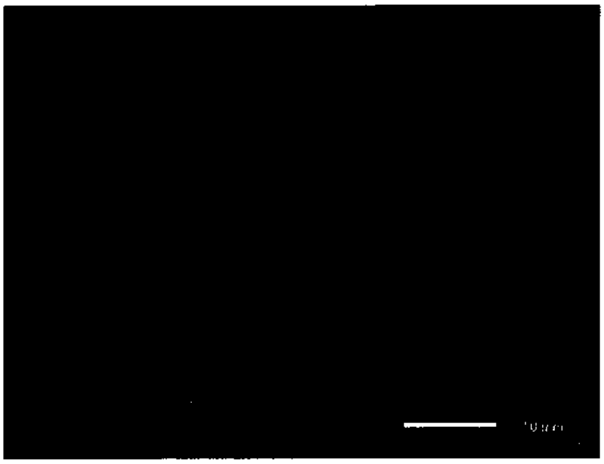
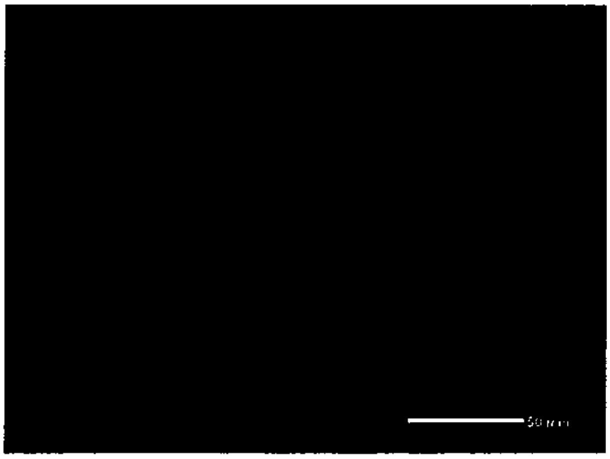
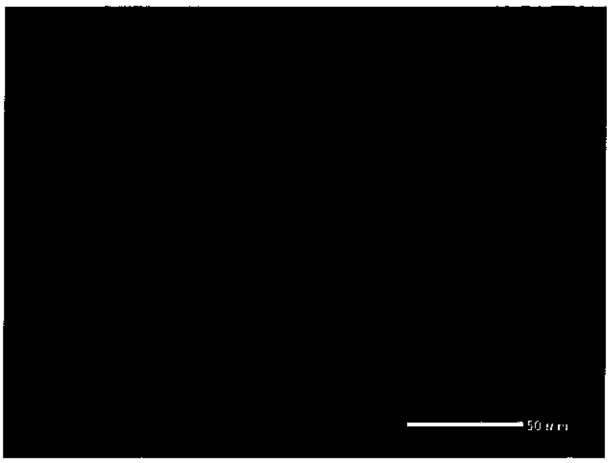


Photo II-7-7 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Coarse grain HAZ)









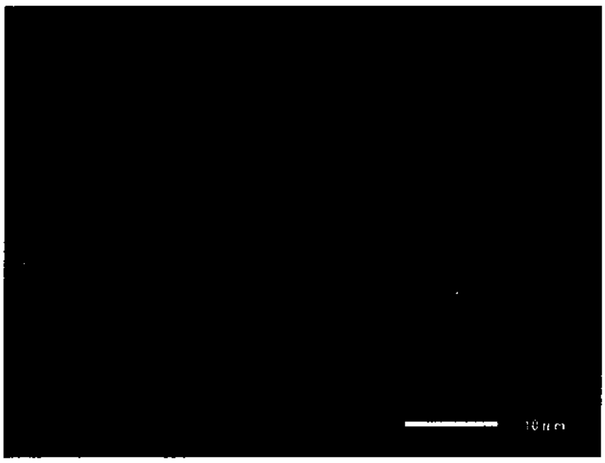


Photo II-7-8 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Weld metal)

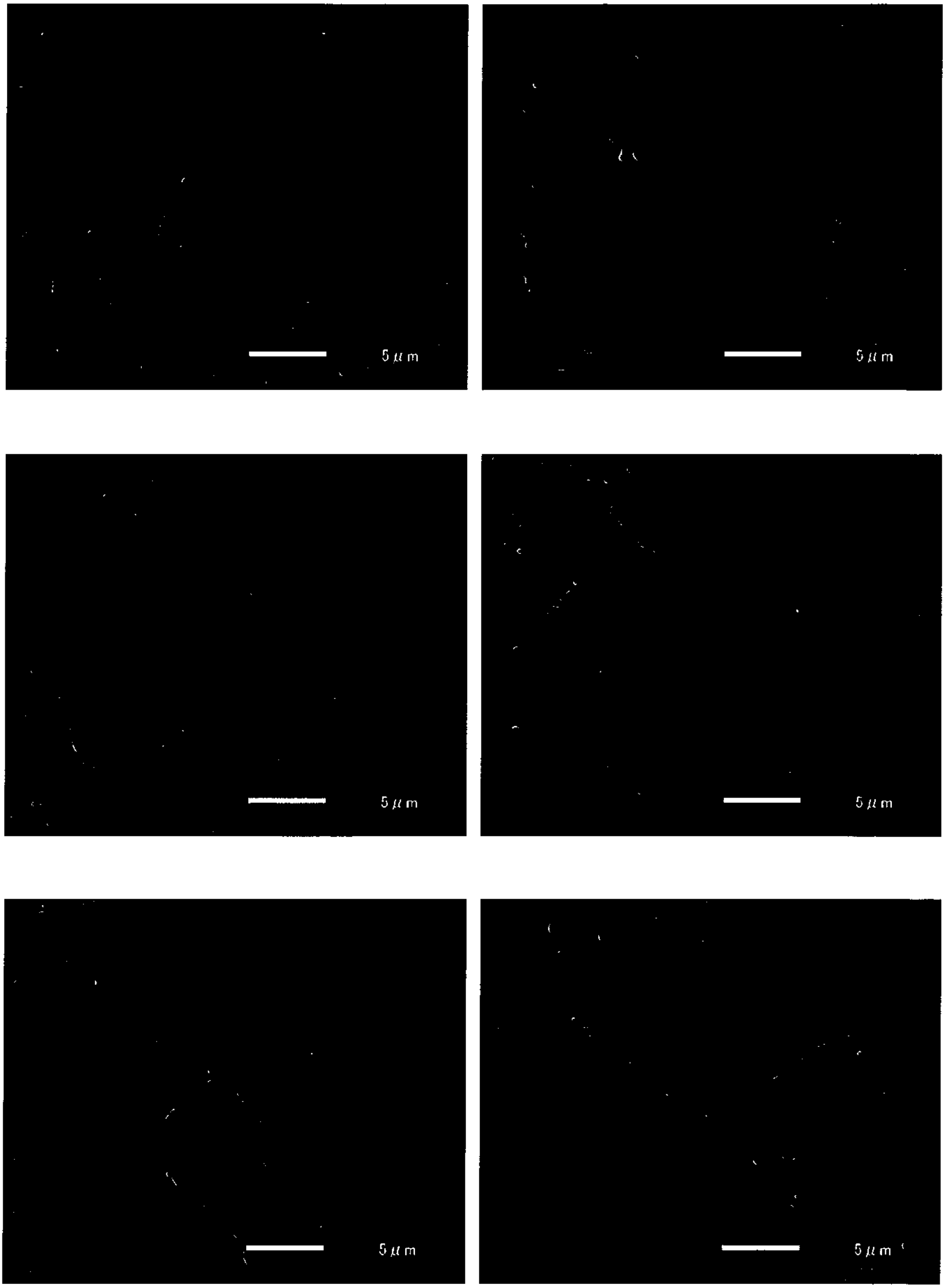


Photo Ⅱ-7-9 Precipitates along grain boundary by SEM observation
RH Outlet Header(Circumferential weld at left side : Base metal)

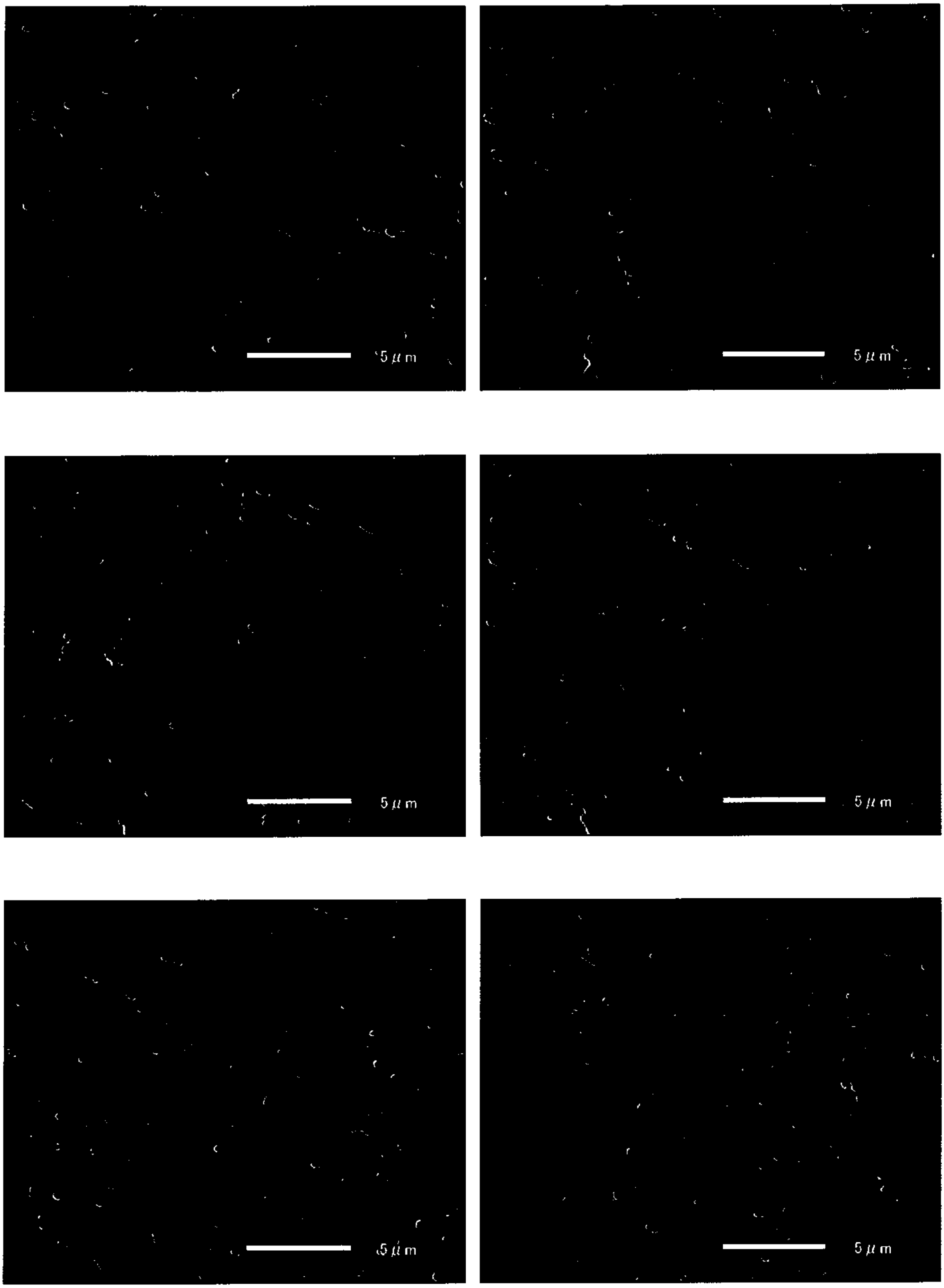


Photo Ⅱ-7-10 Precipitates along grain boundary by SEM observation
RH Outlet Header(Circumferential weld at left side : Fine grain HAZ)

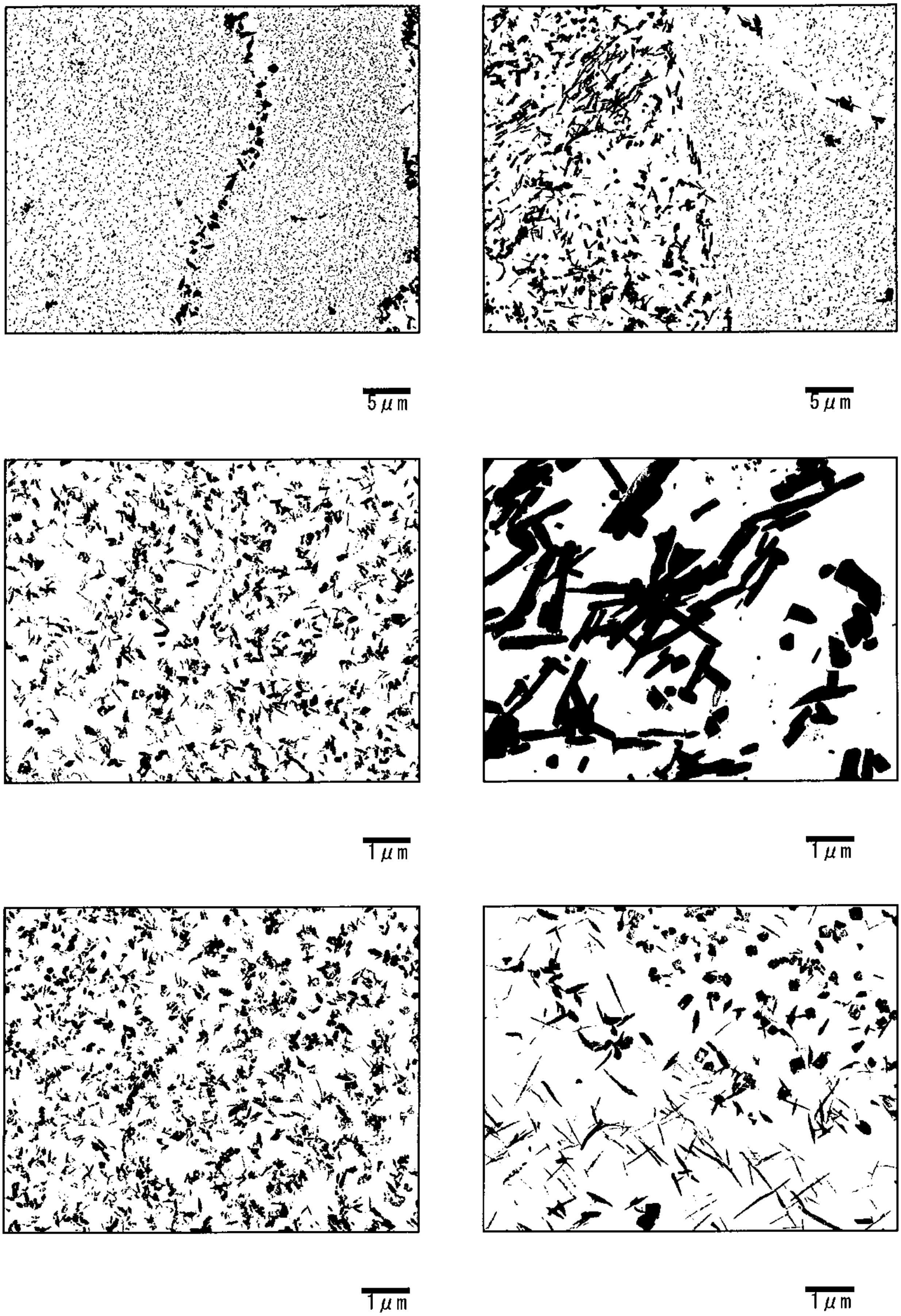


Photo II-7-11 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Base metal)

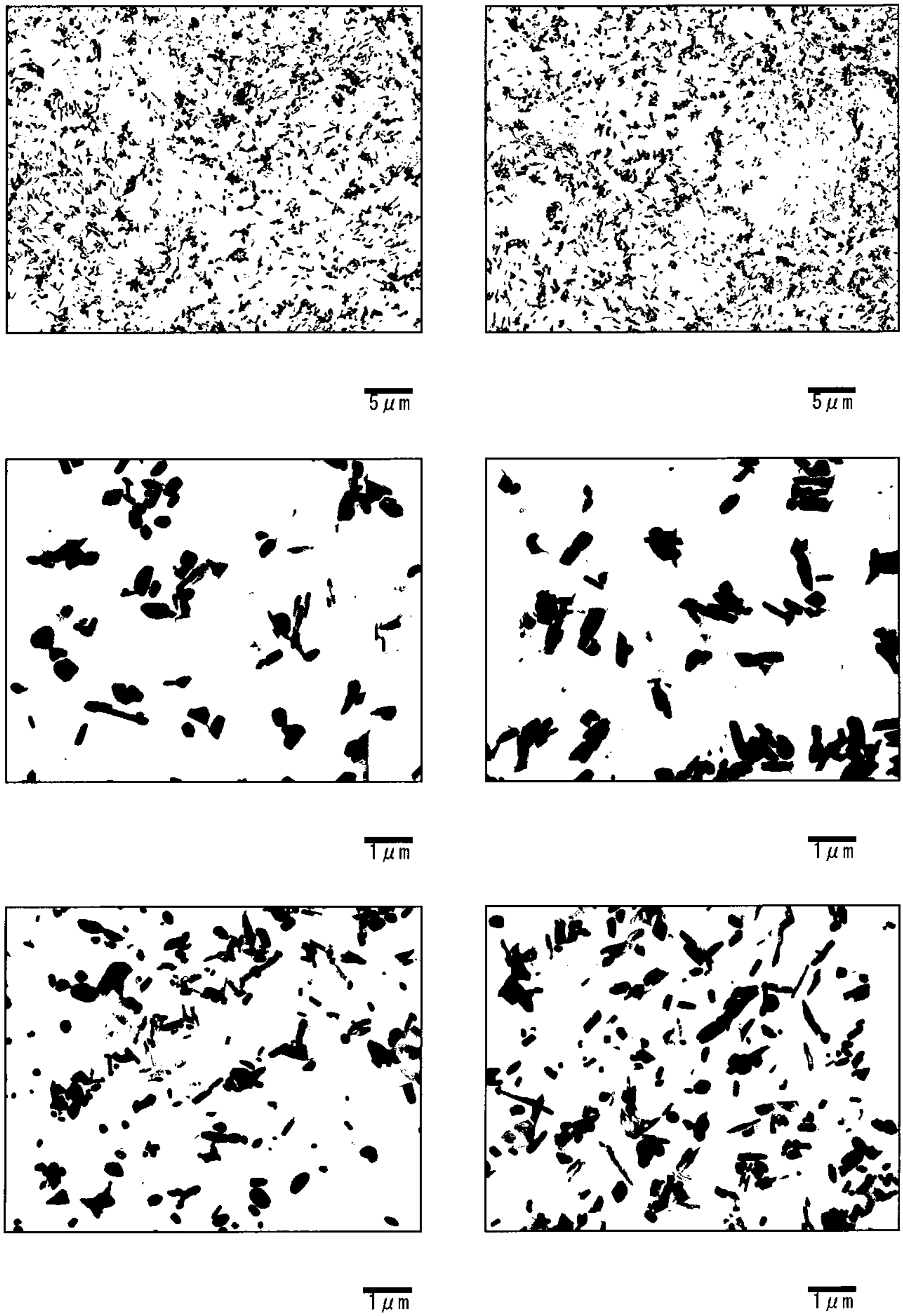


Photo II-7-12 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Fine grain HAZ)

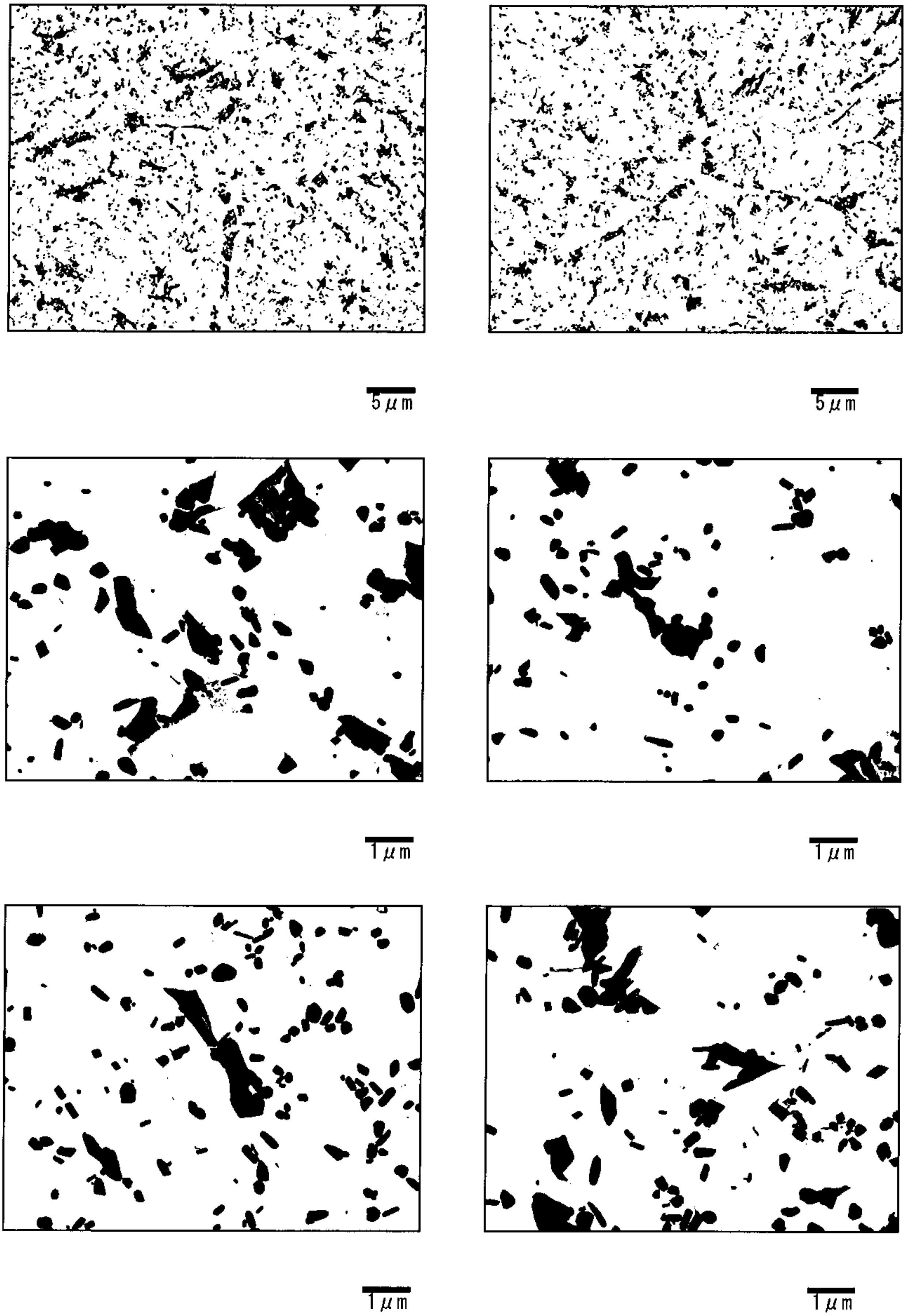


Photo Ⅱ-7-13 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Coarse grain HAZ)

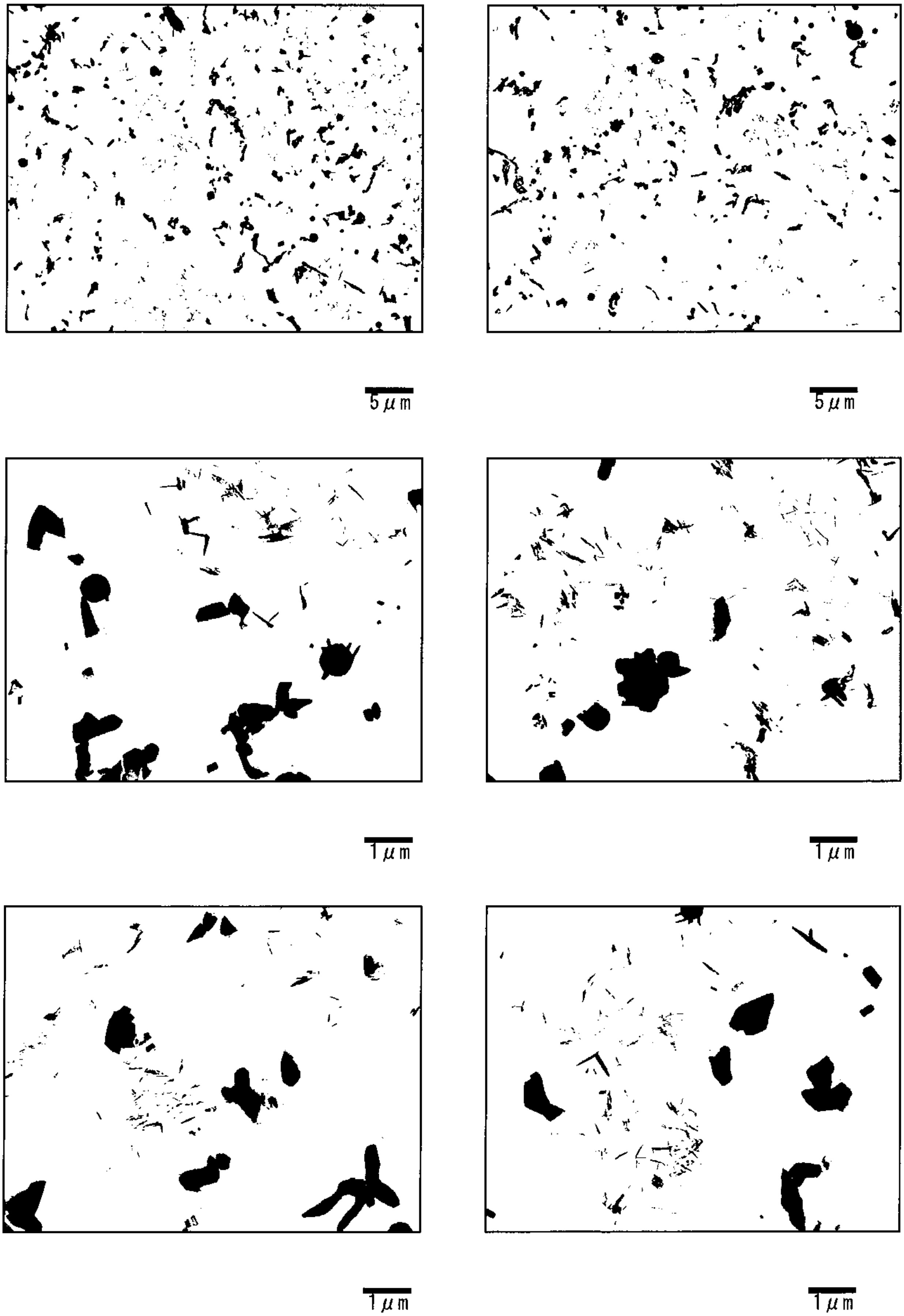


Photo II-7-14 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at left side : Weld metal)

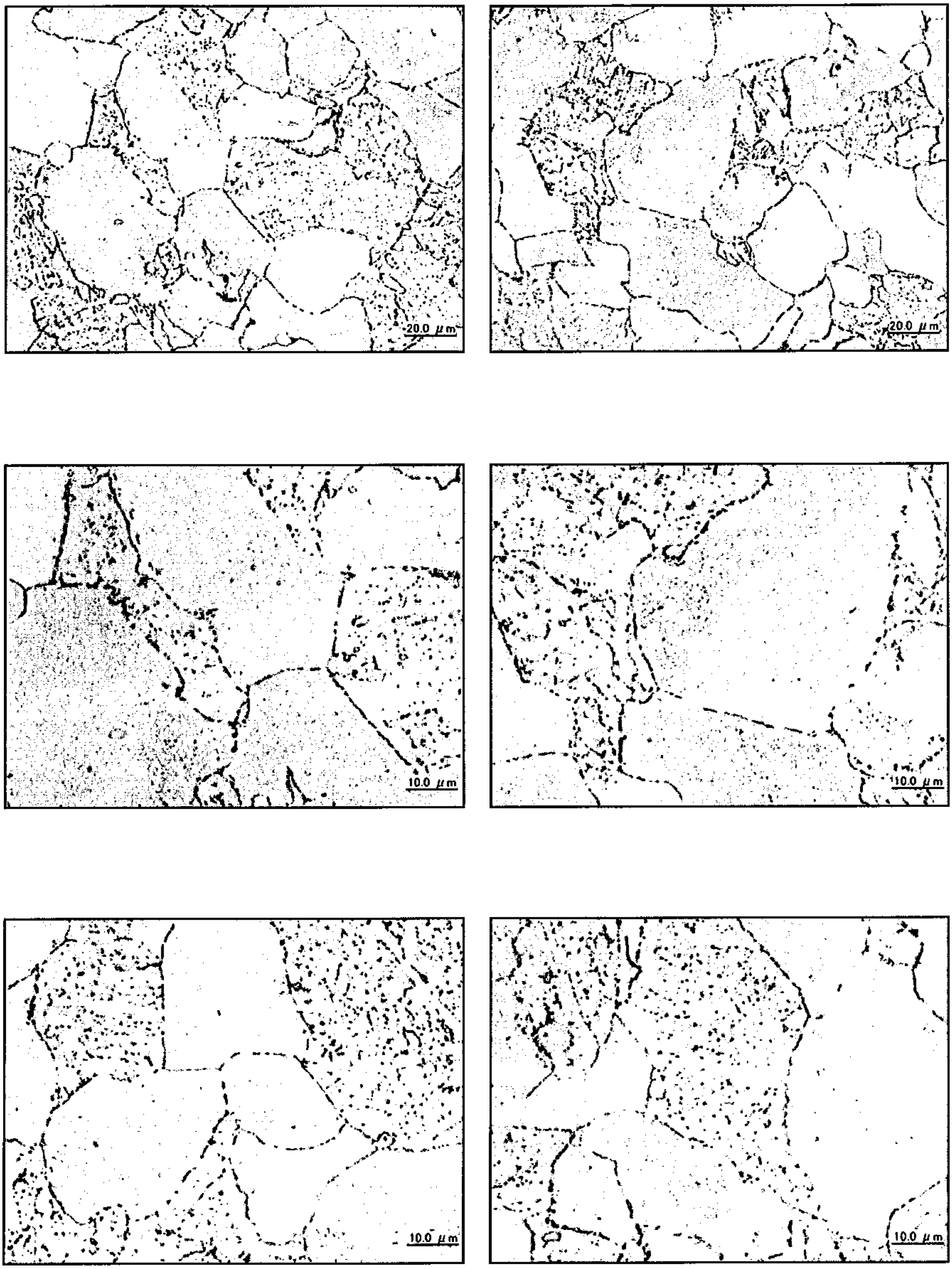


Photo II-8-1 Microstructure observation
RH Outlet Header (Circumferential weld at right side, top : Base metal)

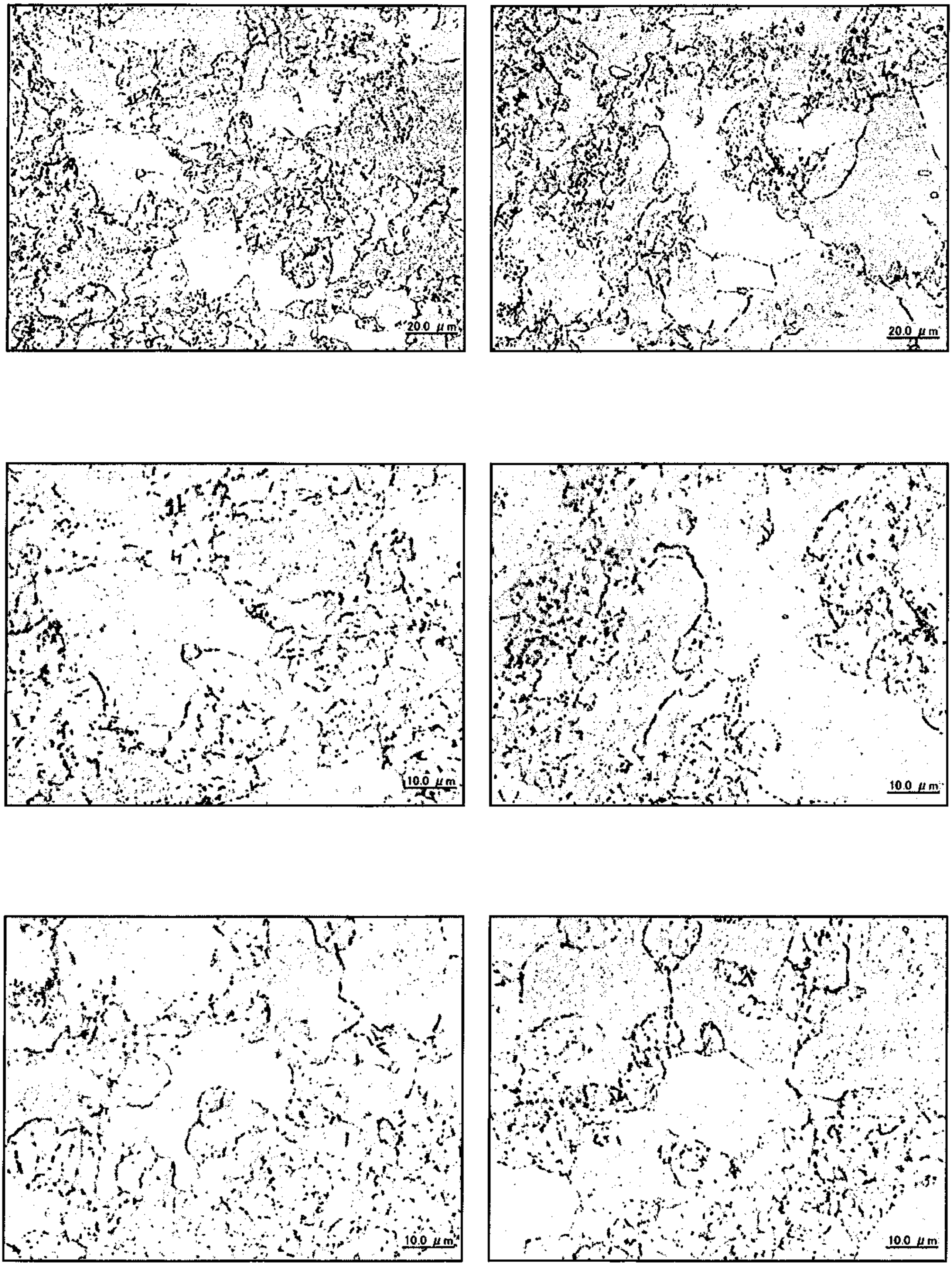


Photo II-8-2 Microstructure observation

RH Outlet Header (Circumferential weld at right side, top : Intercritical zone)

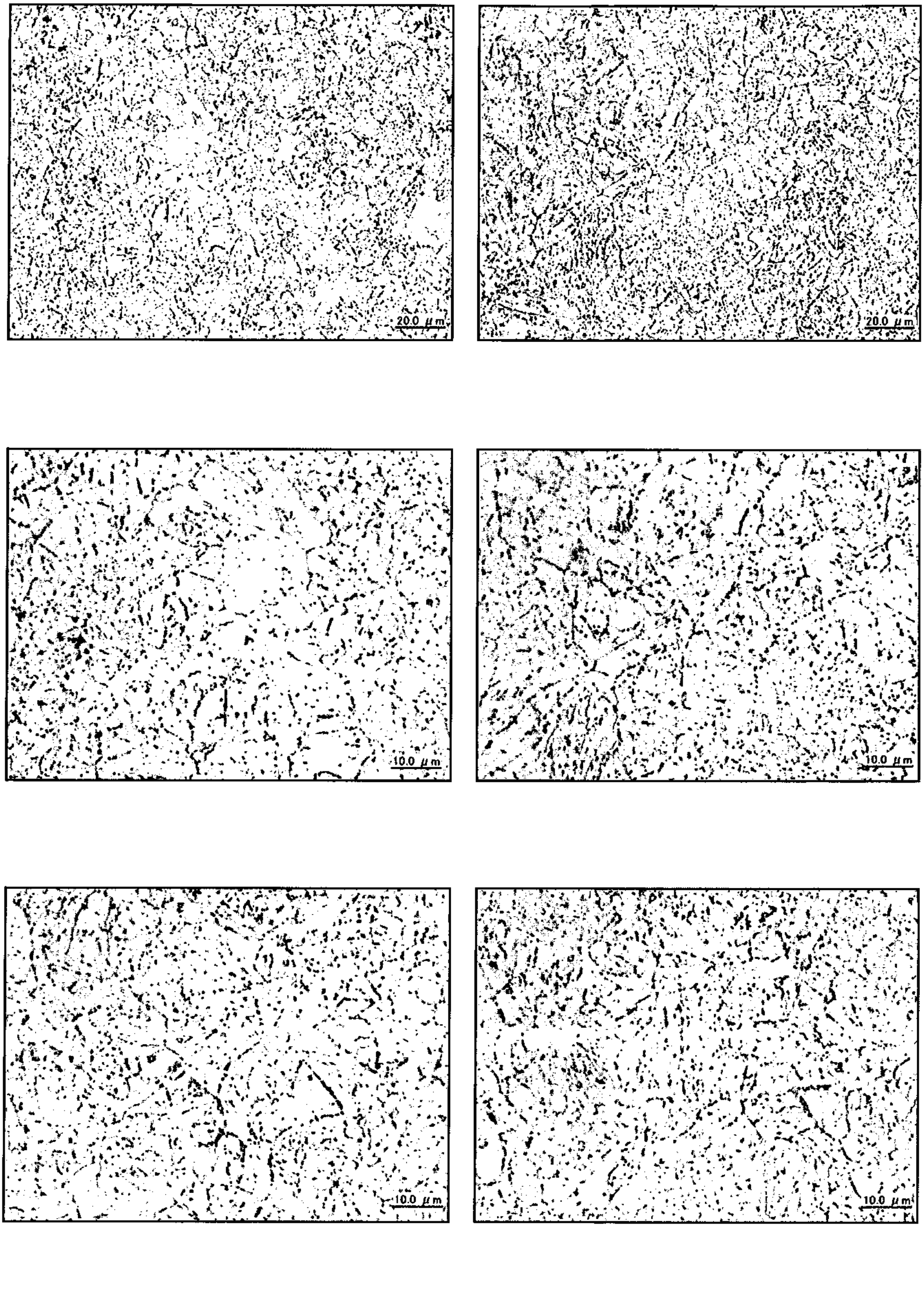


Photo II-8-3 Microstructure observation
RH Outlet Header (Circumferential weld at right side, top : Fine grain HAZ)

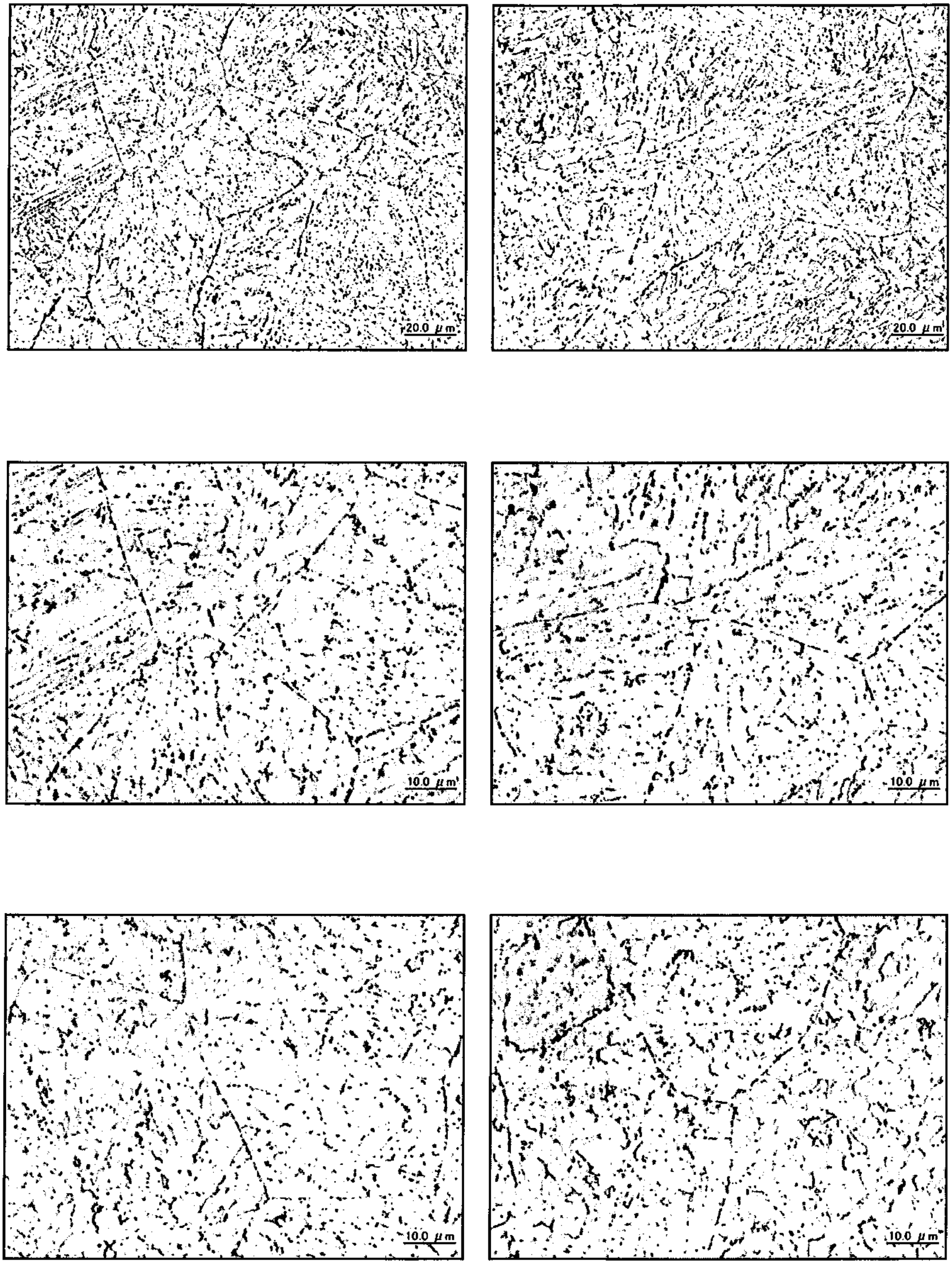


Photo II-8-4 Microstructure observation
RH Outlet Header (Circumferential weld at right side, top : Coarse grain HAZ)

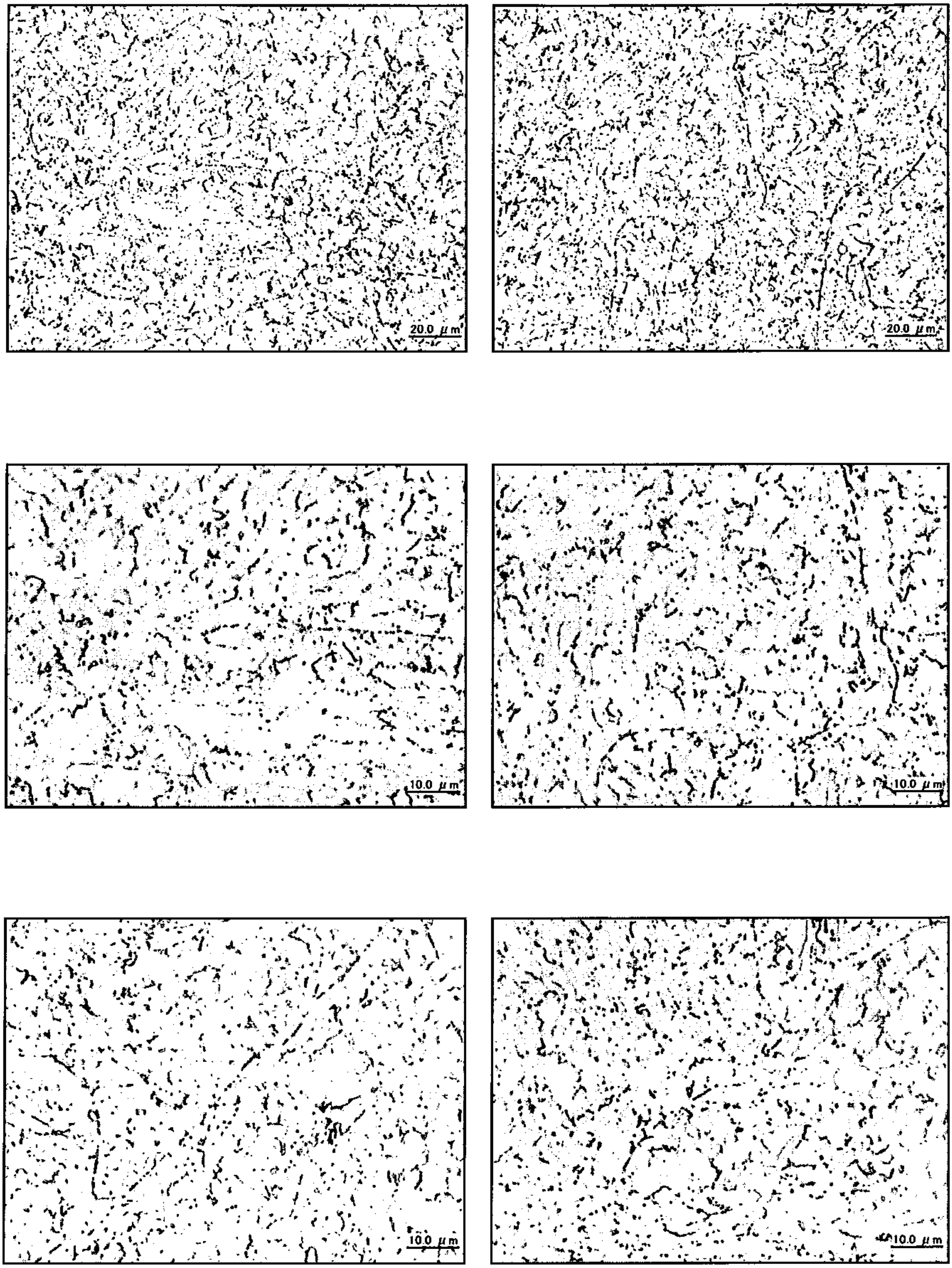


Photo II-8-5 Microstructure observation
RH Outlet Header (Circumferential weld at right side, top : Weld metal)

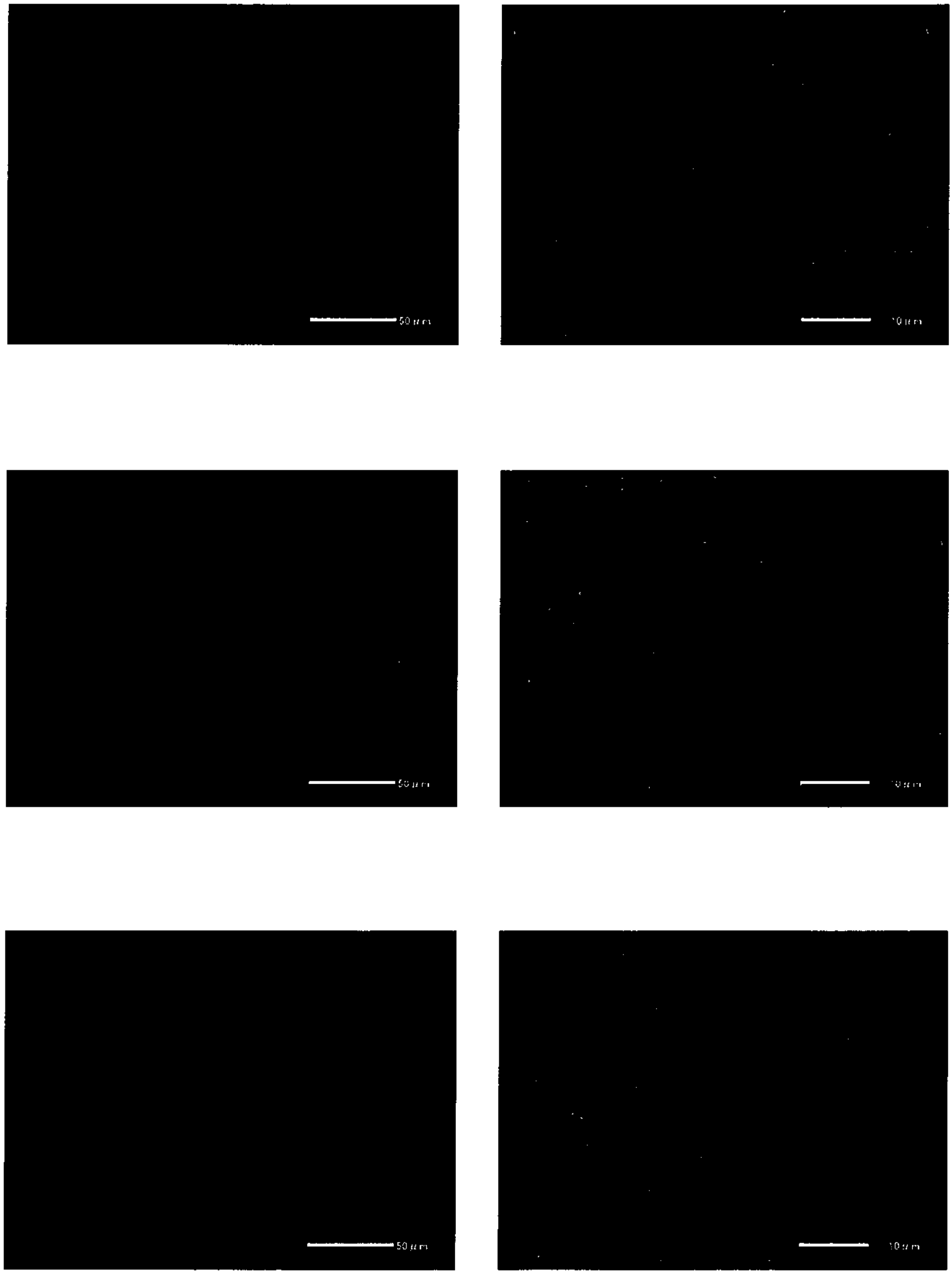
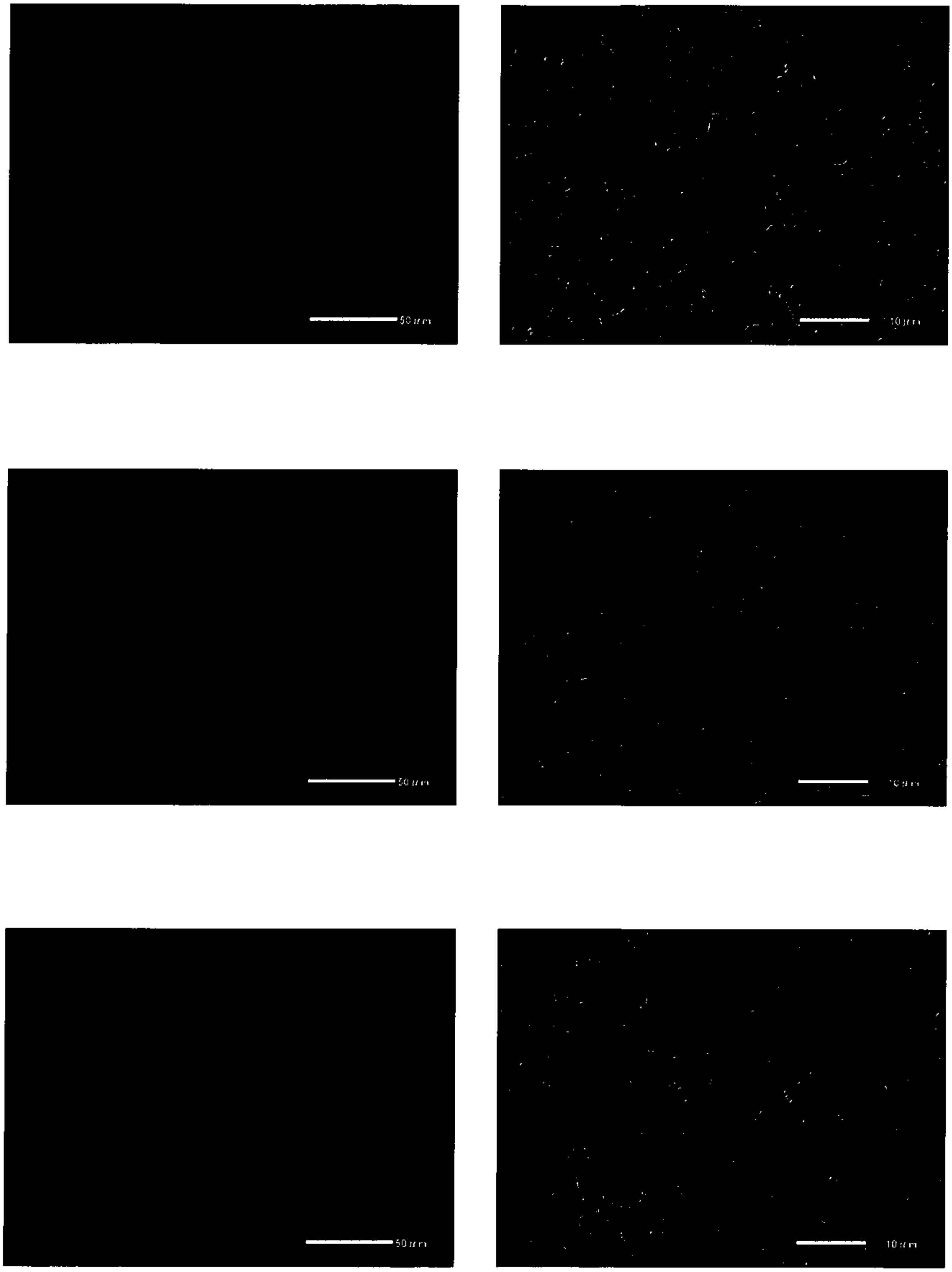


Photo Ⅱ-8-6 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at right side, top : Fine grain HAZ)



PhotoⅡ-8-7 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at right side, top : Coarse grain HAZ)

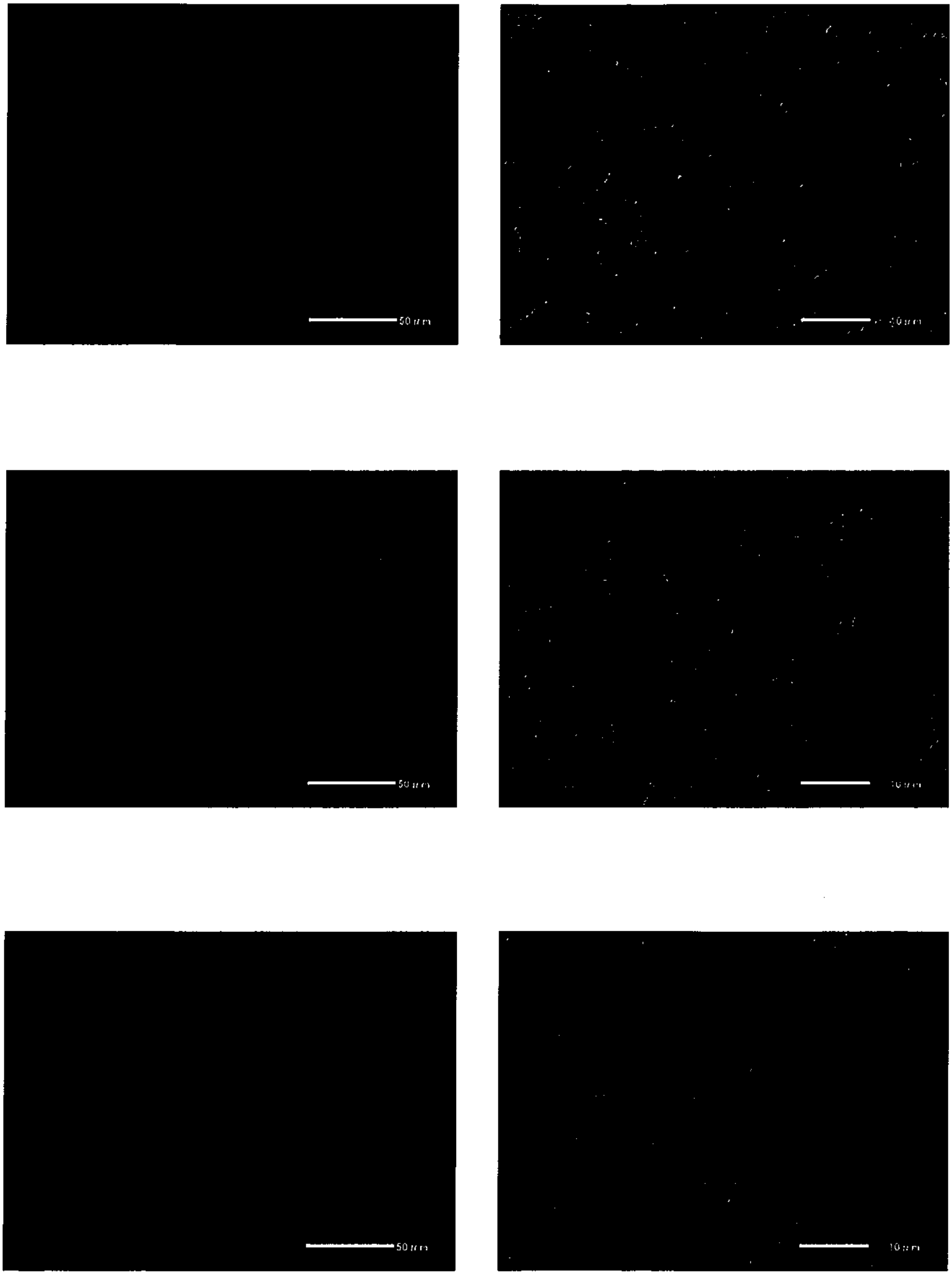


Photo II-8-8 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at right side, top : Weld metal)

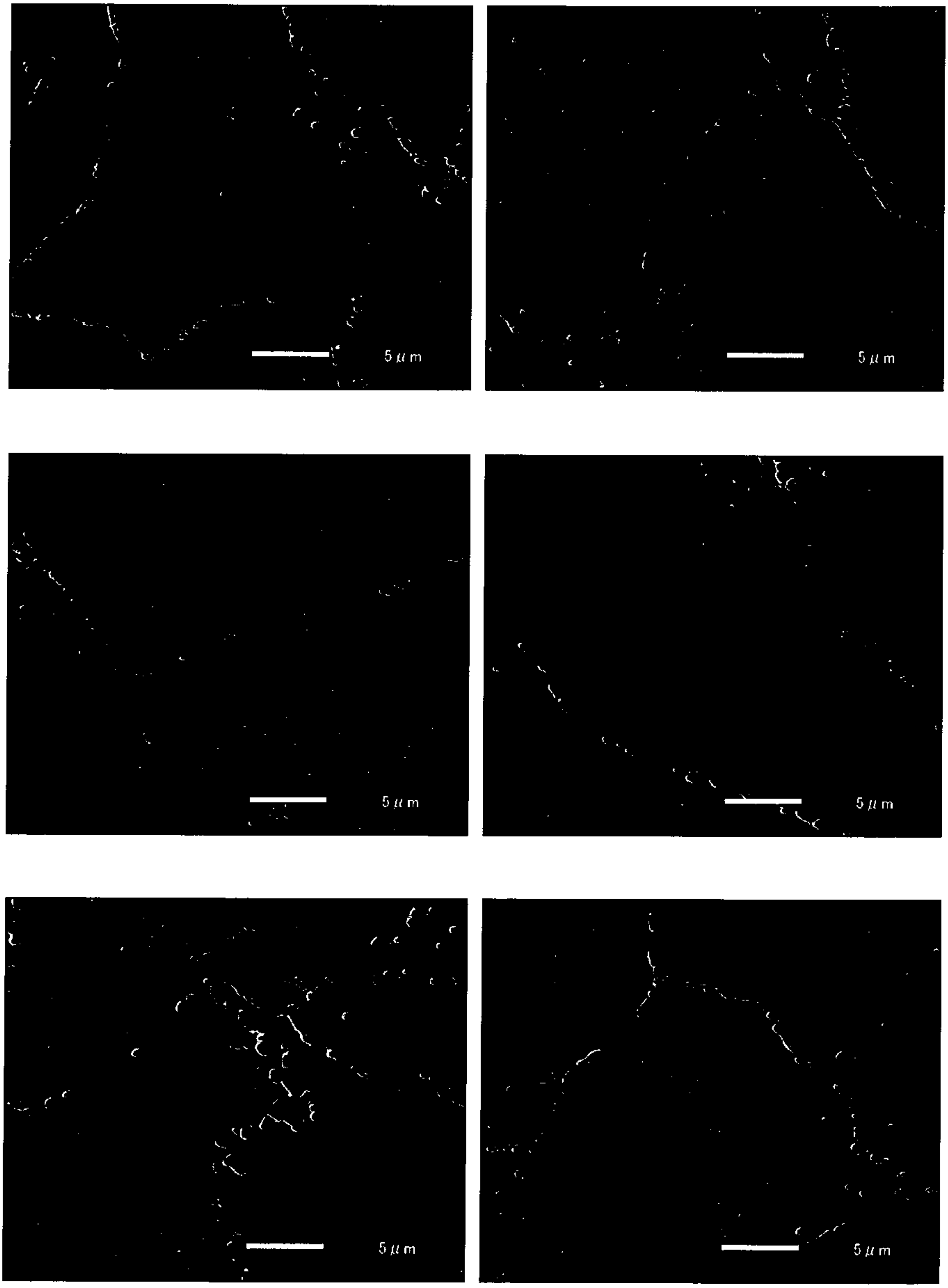


Photo II-8-9 Precipitates along grain boundary by SEM observation
RH Outlet Header (Circumferential weld at right side, top : Base metal)

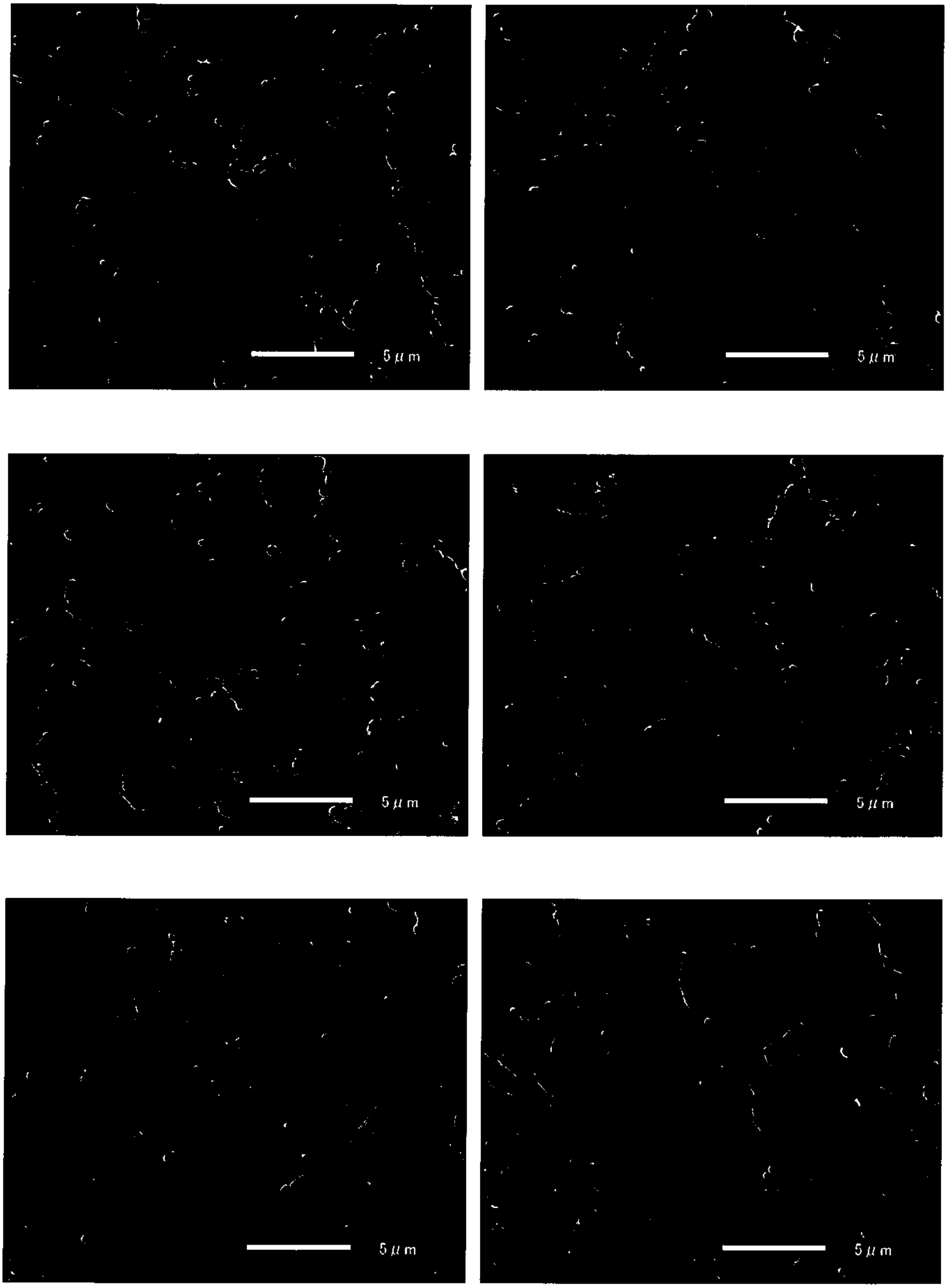


Photo II-8-10 Precipitates along grain boundary by SEM observation
RH Outlet Header (Circumferential weld at right side, top : Fine grain HAZ)

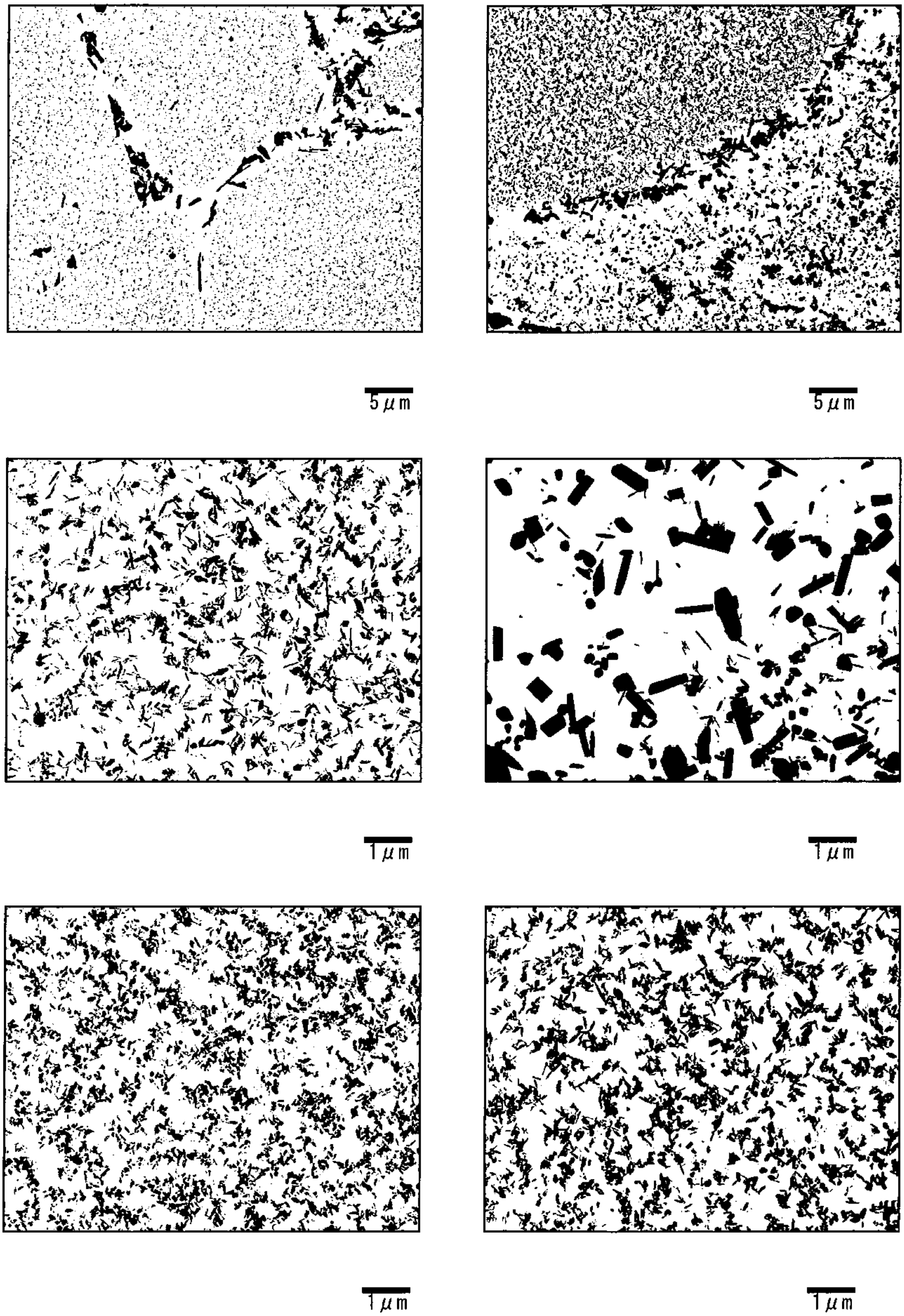
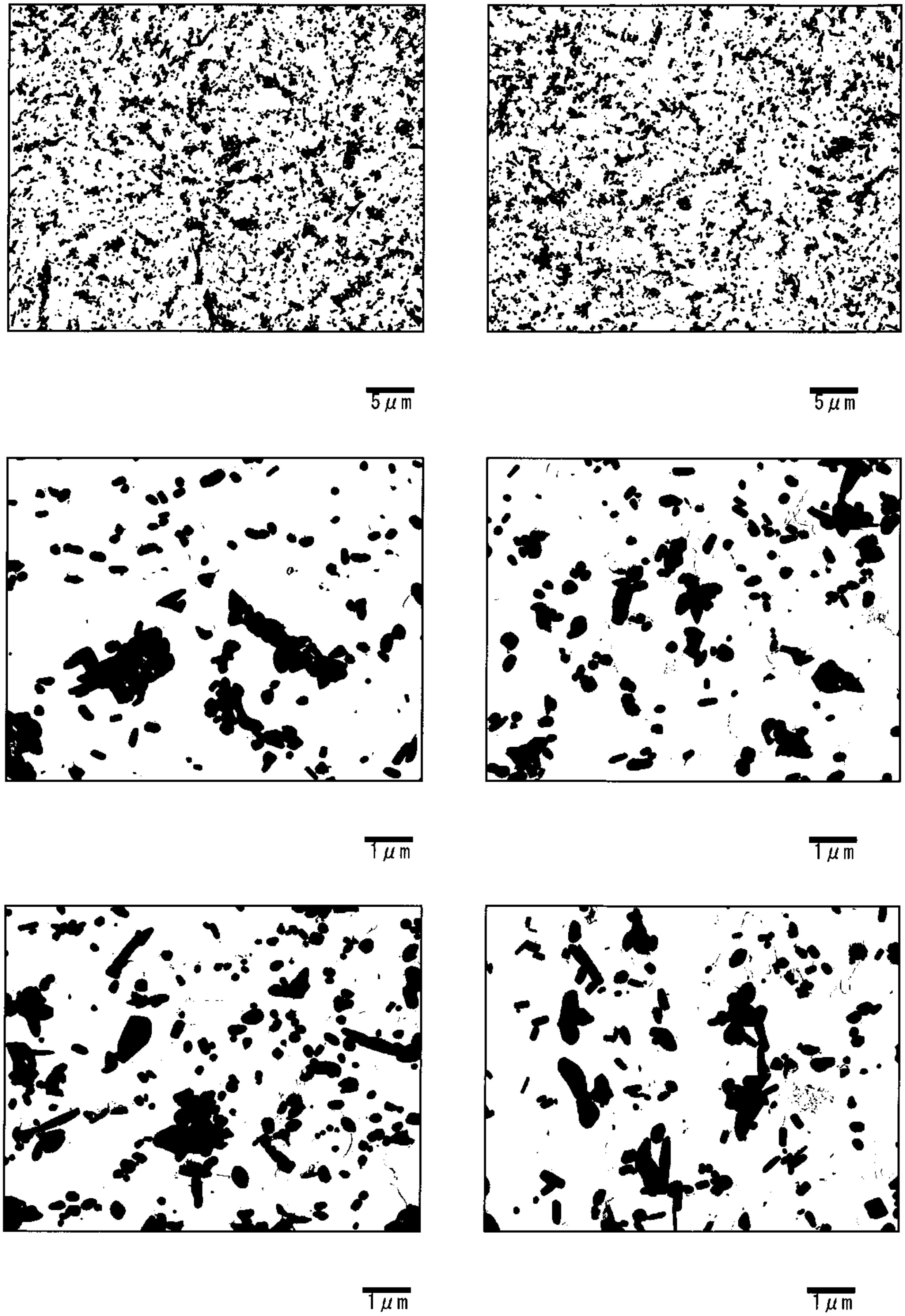


Photo Ⅱ-8-11 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at right side, top : Base metal)



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

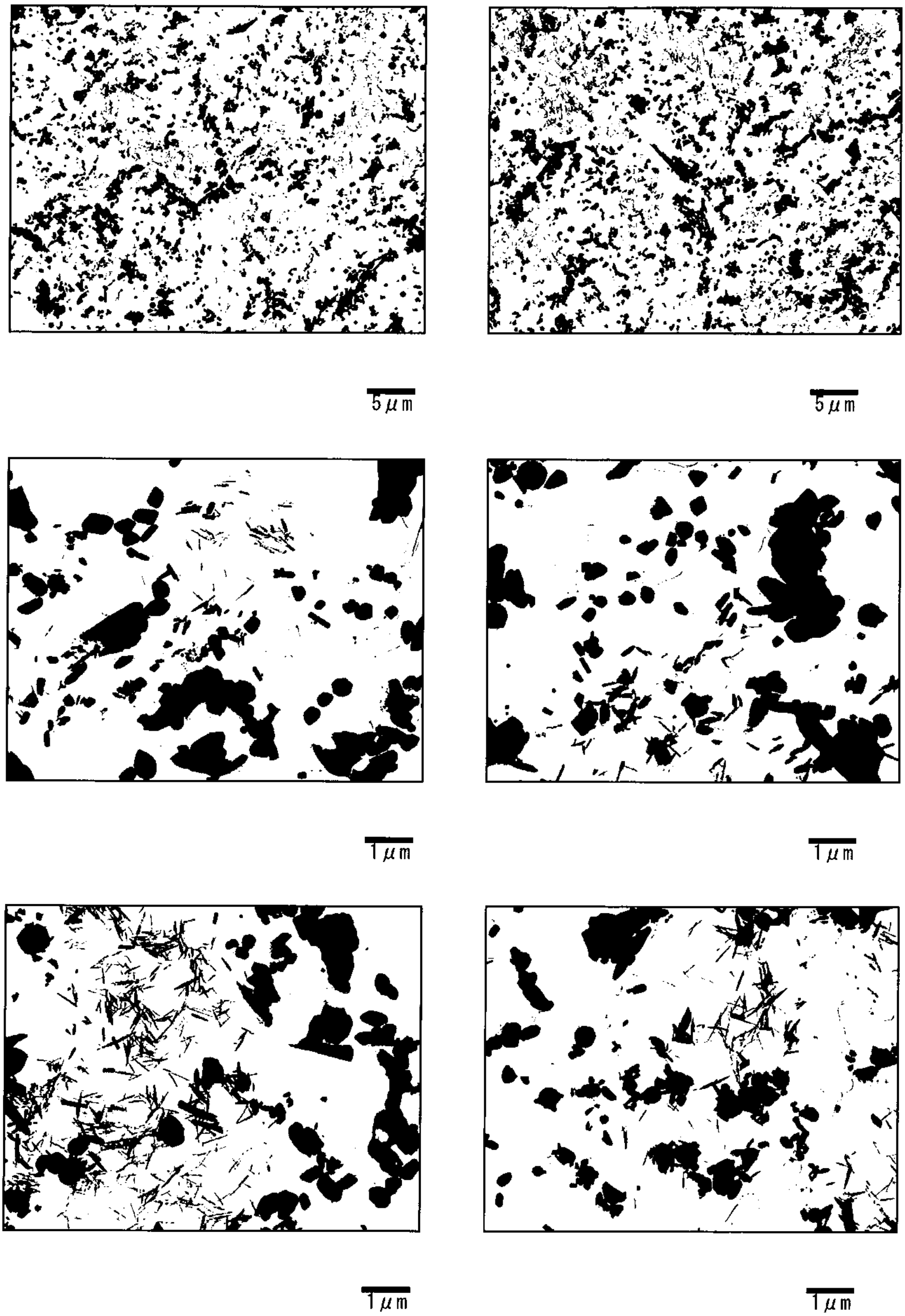


Photo II-8-13 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at right side, top : Coarse grain HAZ)

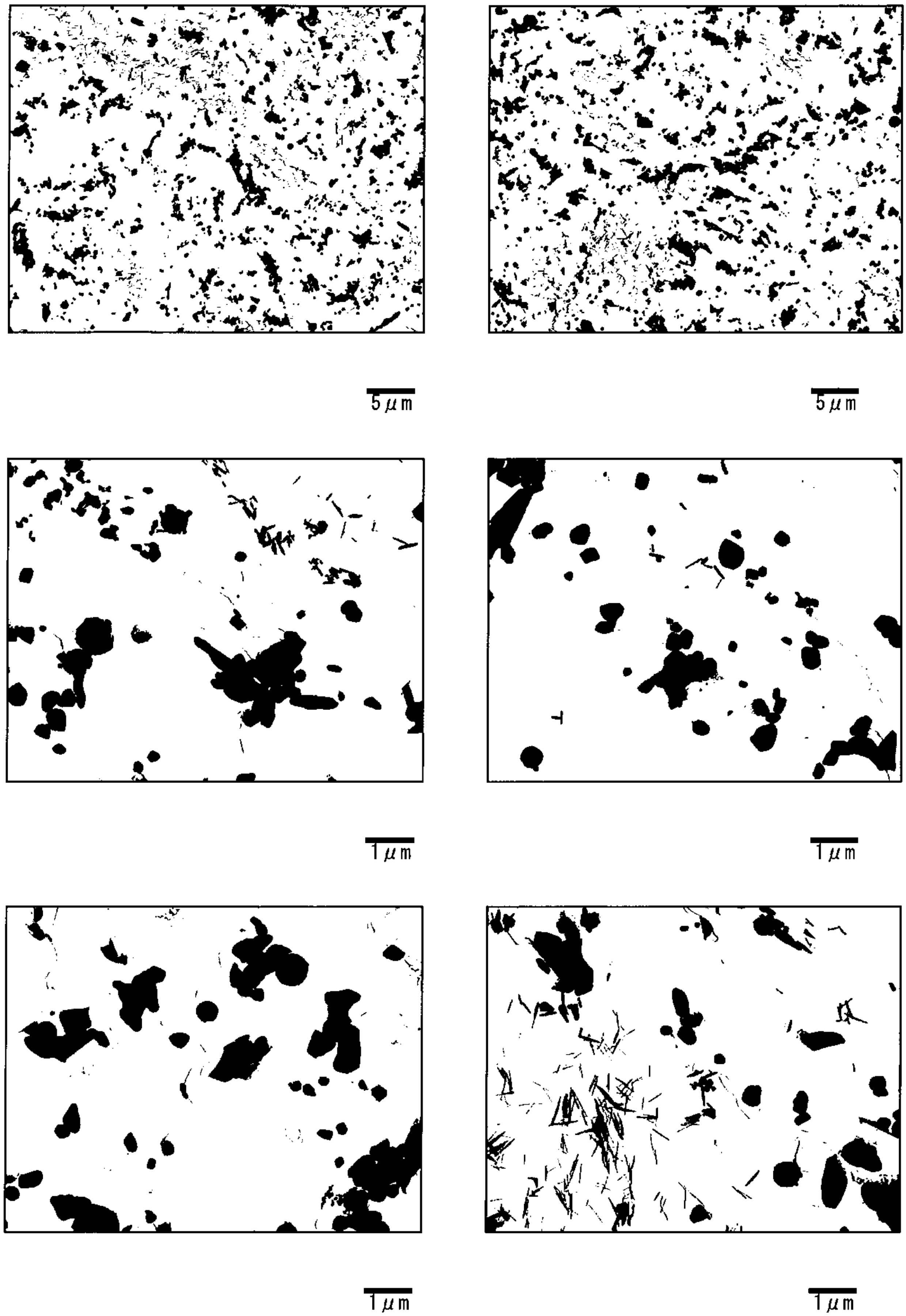


Photo II-8-14 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at right side,top : Weld metal)

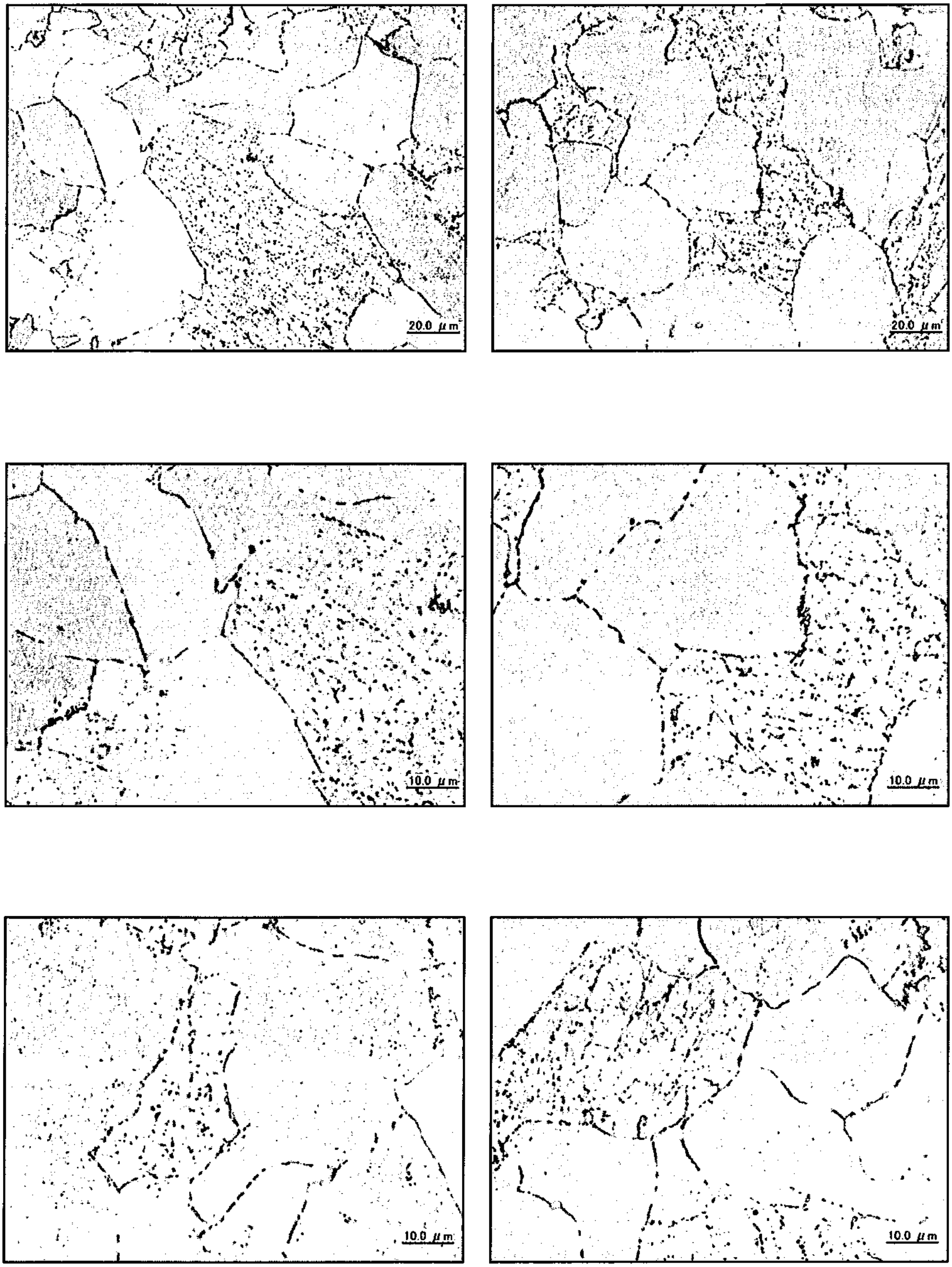


Photo Ⅱ-9-1 Microstructure observation
RH Outlet Header (Circumferential weld at right side, front : Base metal)

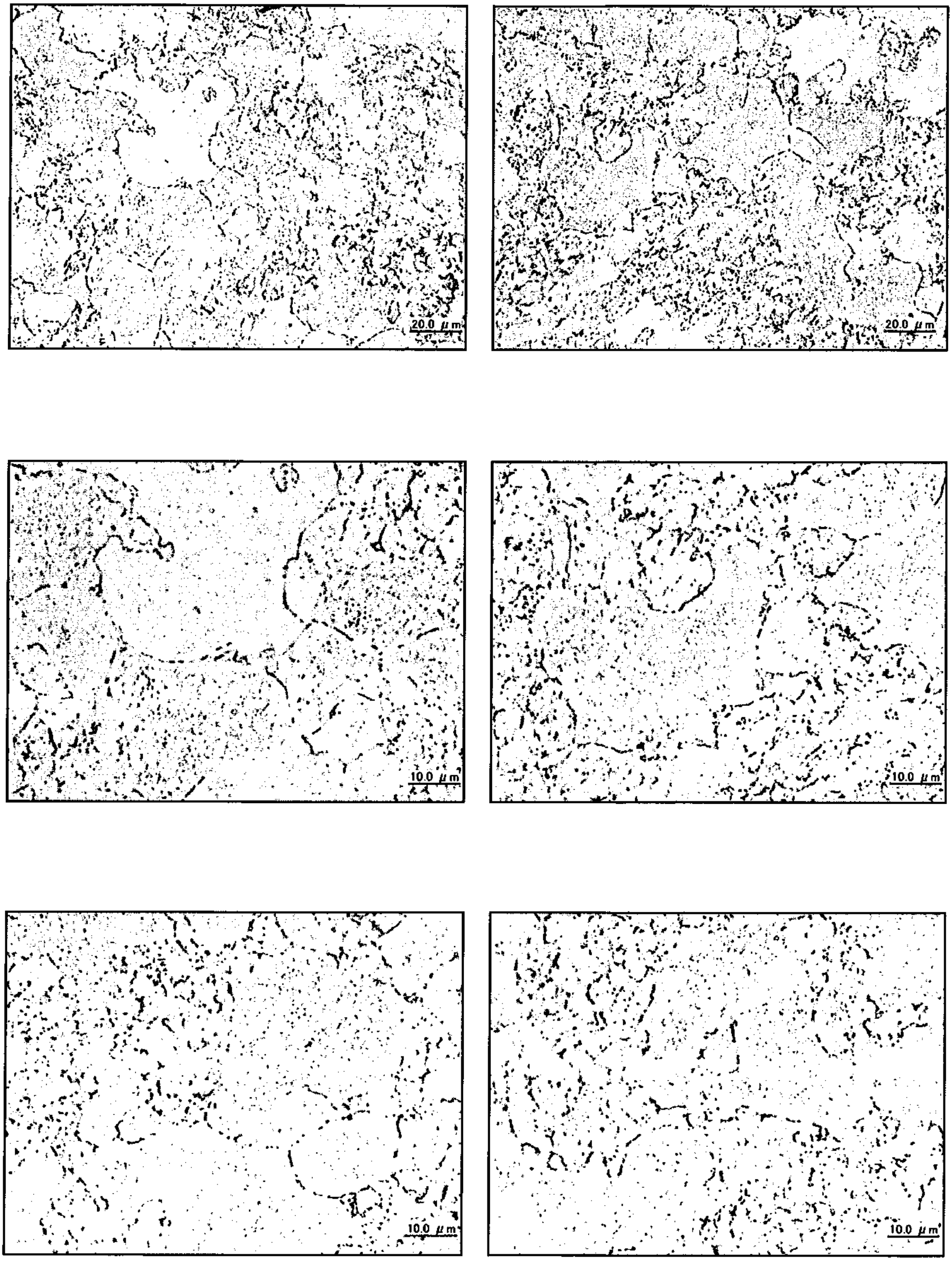


Photo II-9-2 Microstructure observation
RH Outlet Header (Circumferential weld at right side, front : Intercritical zone)

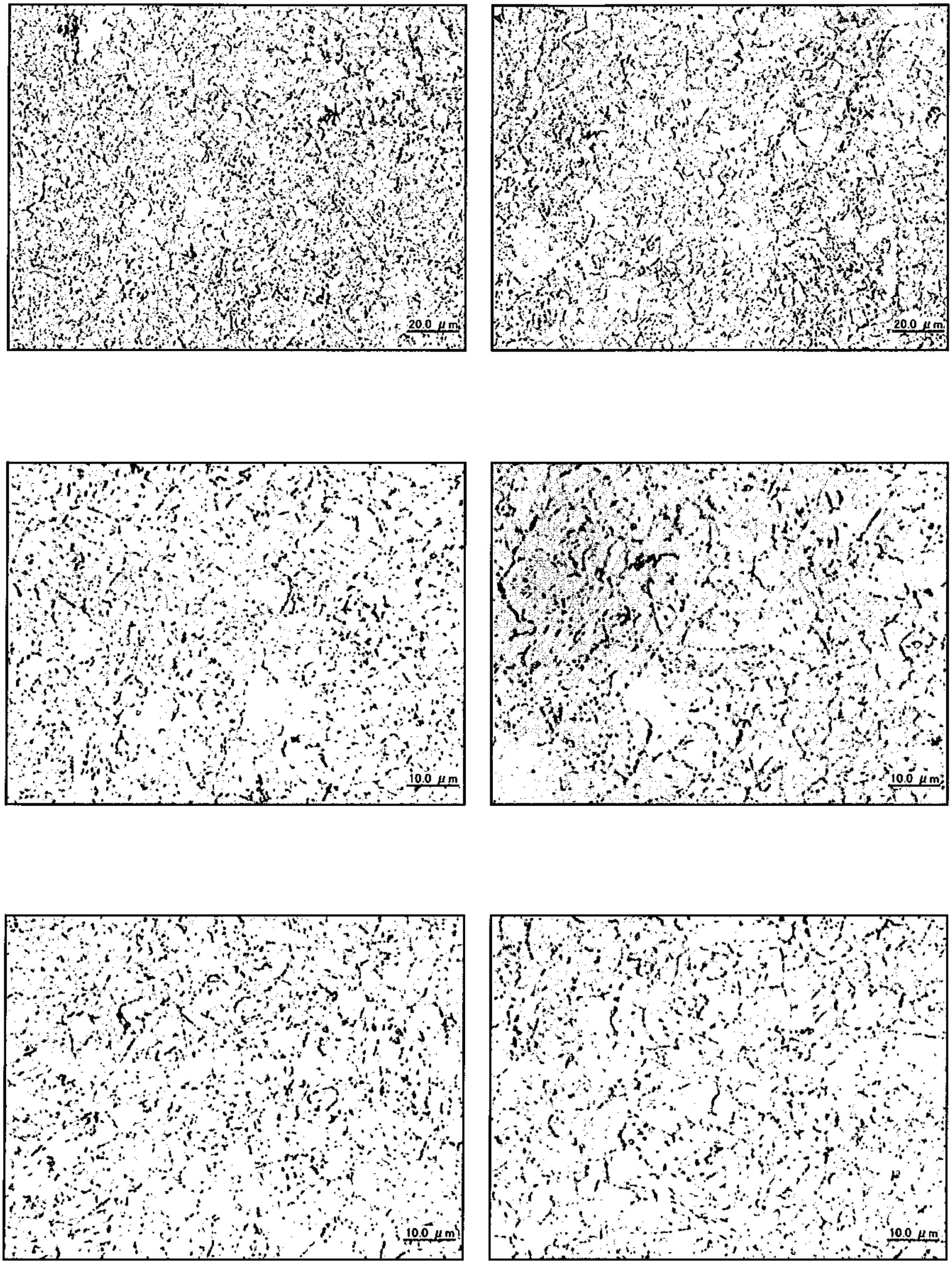


Photo II-9-3　Microstructure observation

RH Outlet Header (Circumferential weld at right side, front ：Fine grain HAZ)

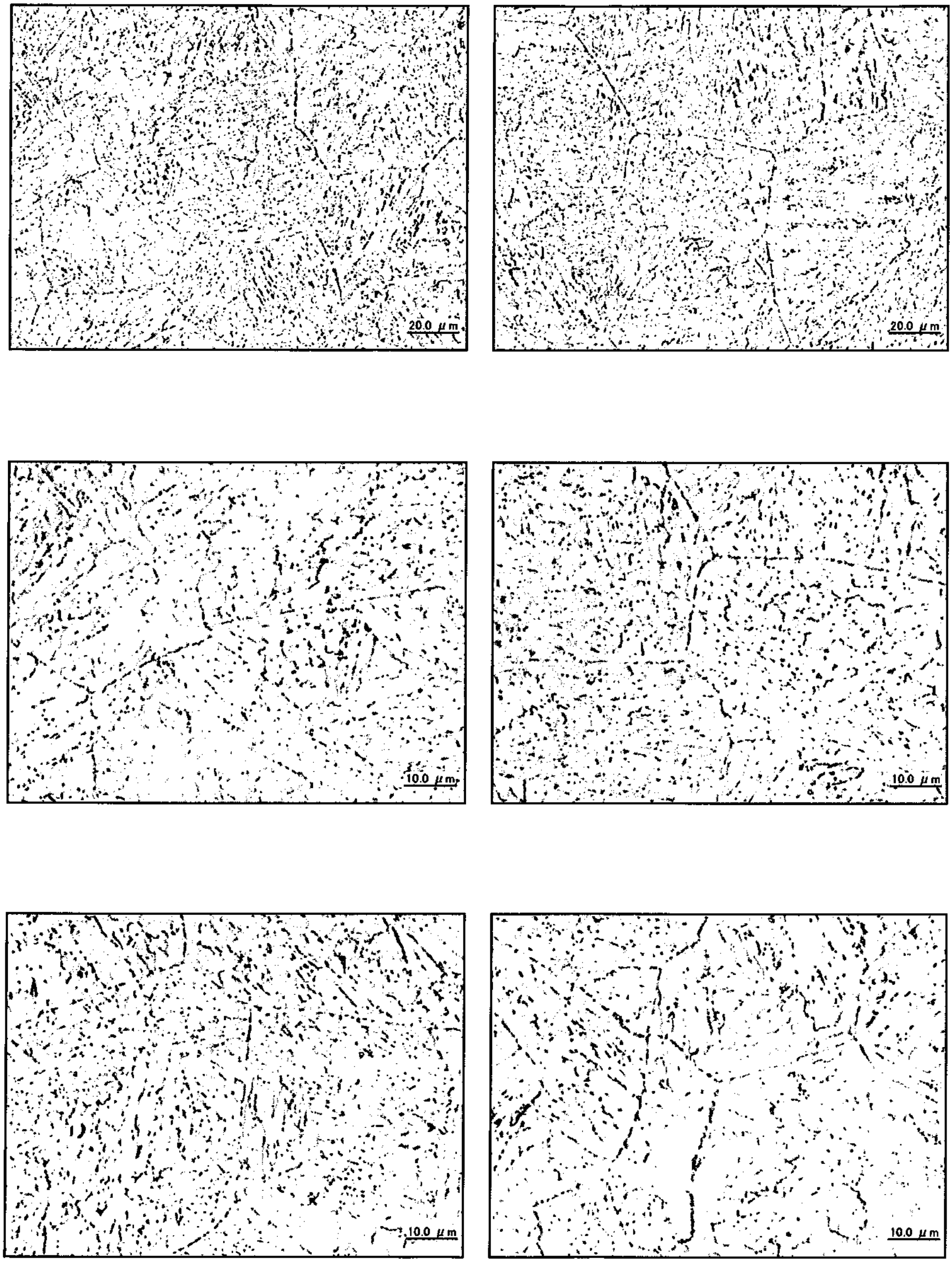


Photo II-9-4 Microstructure observation
RH Outlet Header (Circumferential weld at right side, front : Coarse grain HAZ)

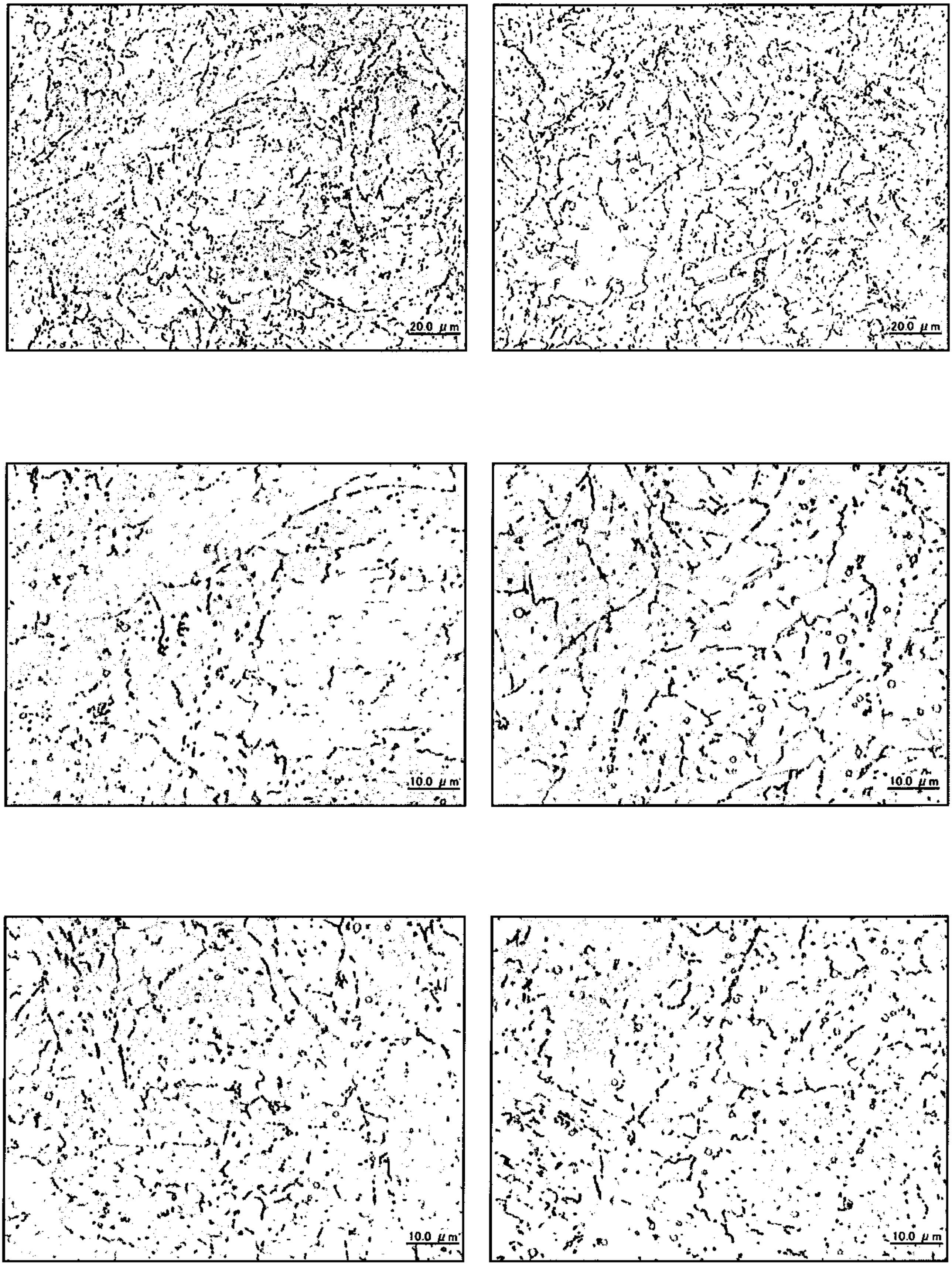


Photo II-9-5 Microstructure observation
RH Outlet Header (Circumferential weld at right side, front : Weld metal)

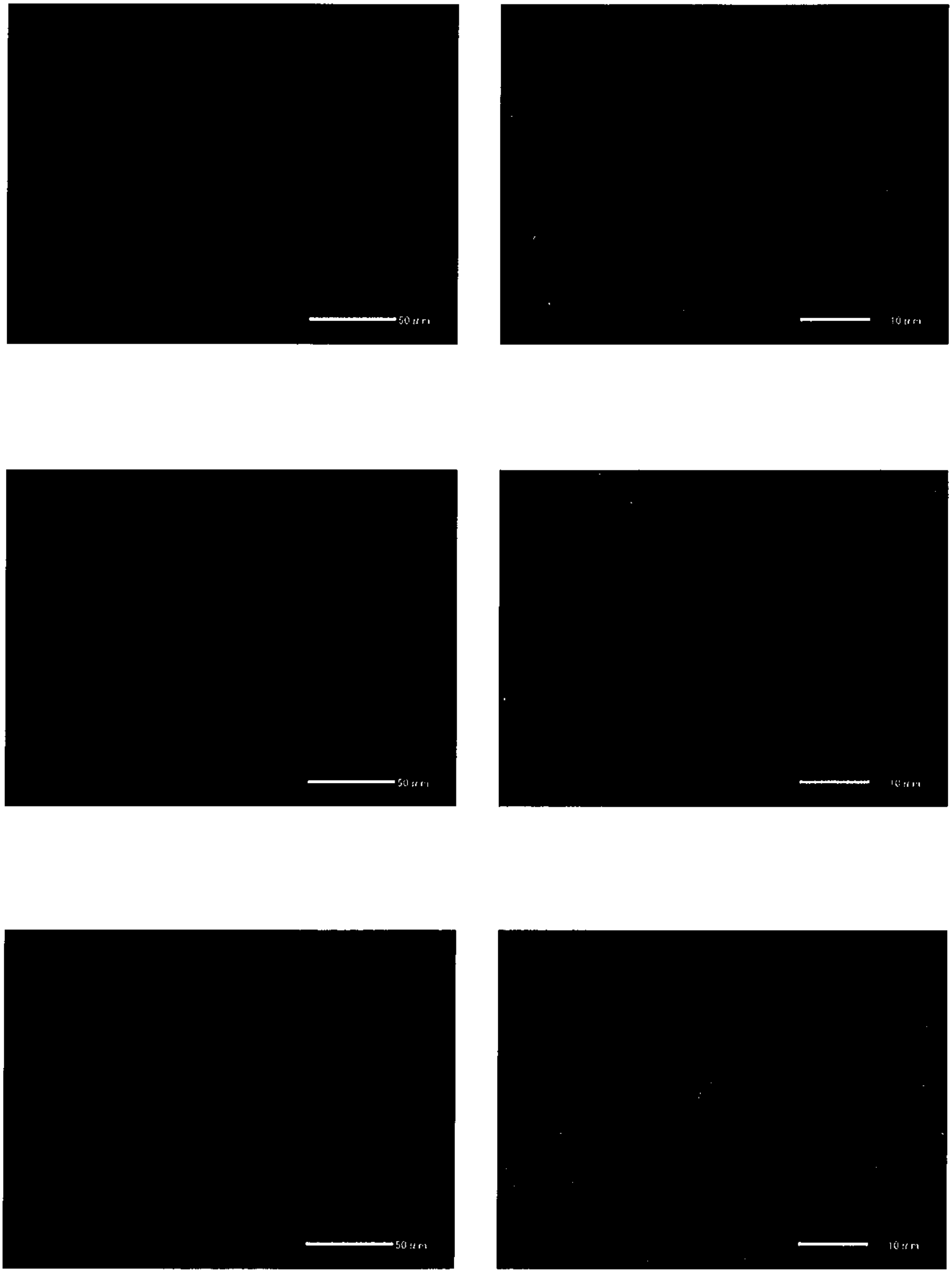
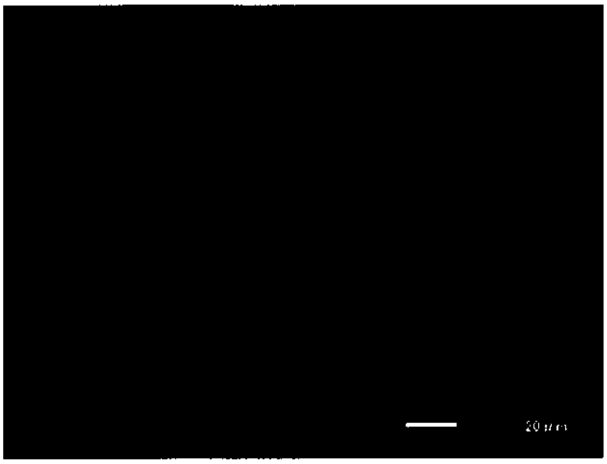
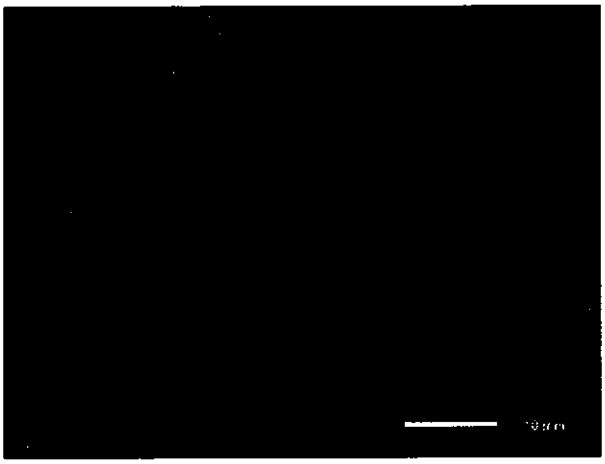
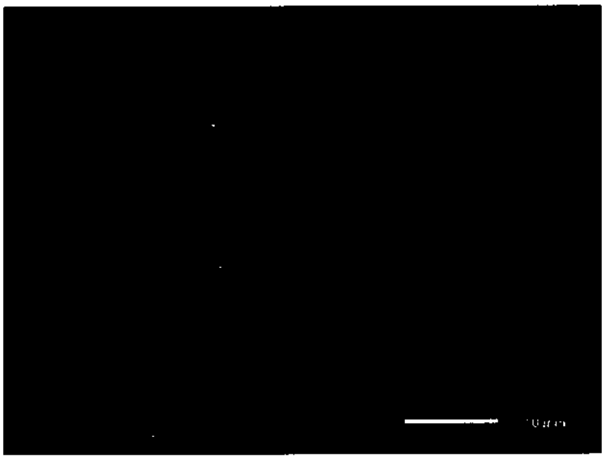
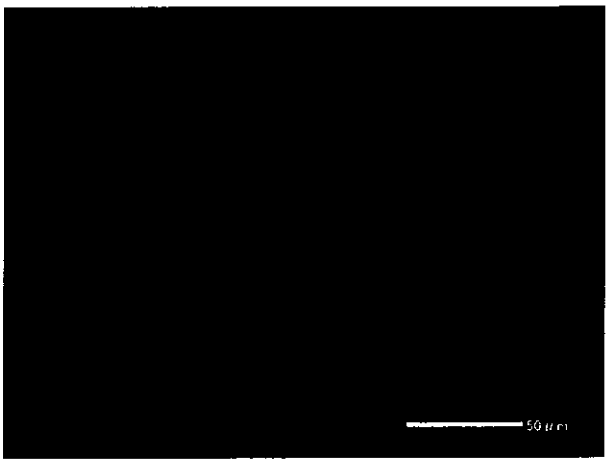


Photo Ⅱ-9-6 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at right side, front : Fine grain HAZ)









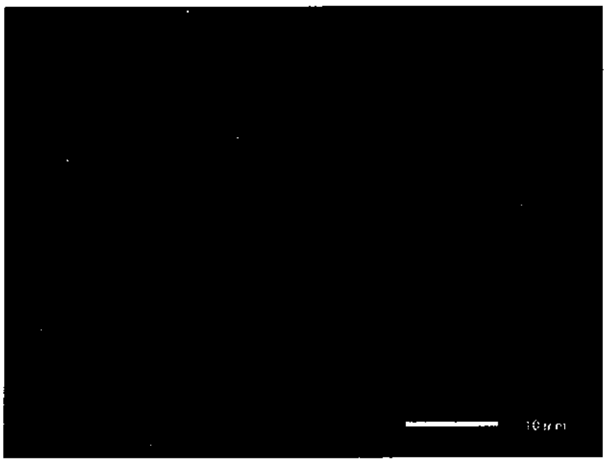


Photo II-9-7 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at right side, front : Coarse grain HAZ)

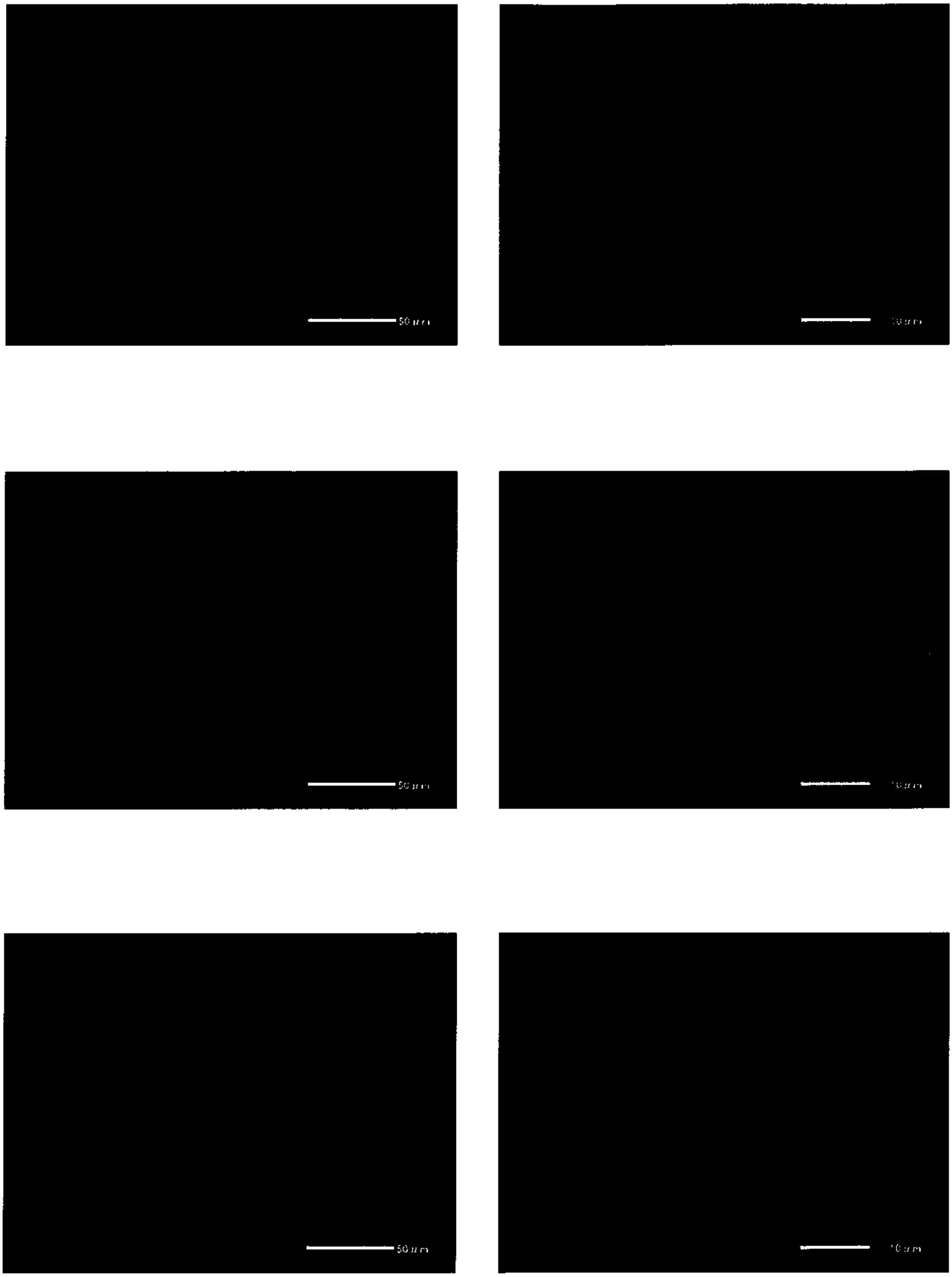


Photo II-9-8 SEM(Scanning electron microscope) observation
RH Outlet Header(Circumferential weld at right side, front : Weld metal)

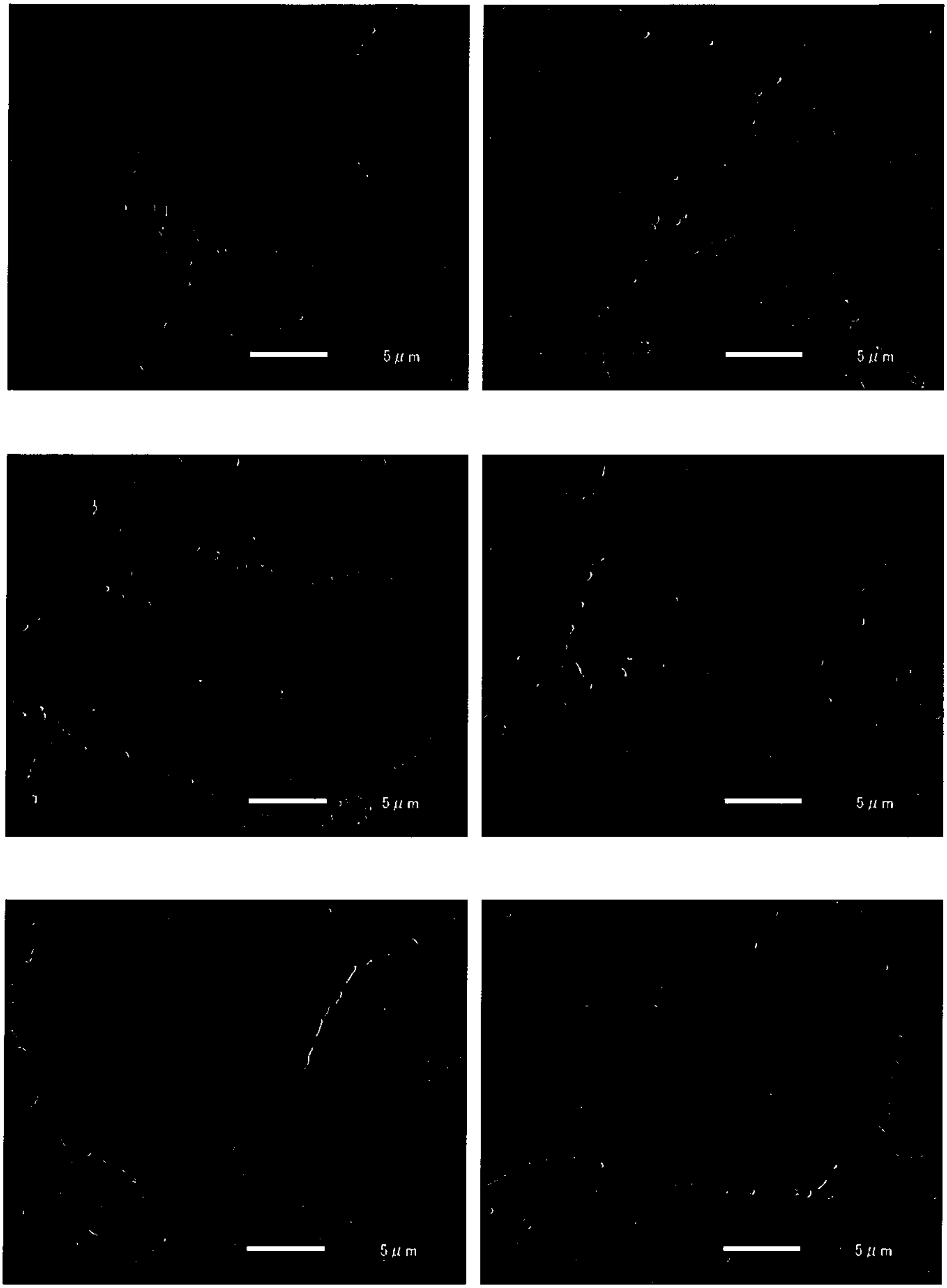


Photo II-9-9 Precipitates along grain boundary by SEM observation
RH Outlet Header (Circumferential weld at right side, front : Base metal)

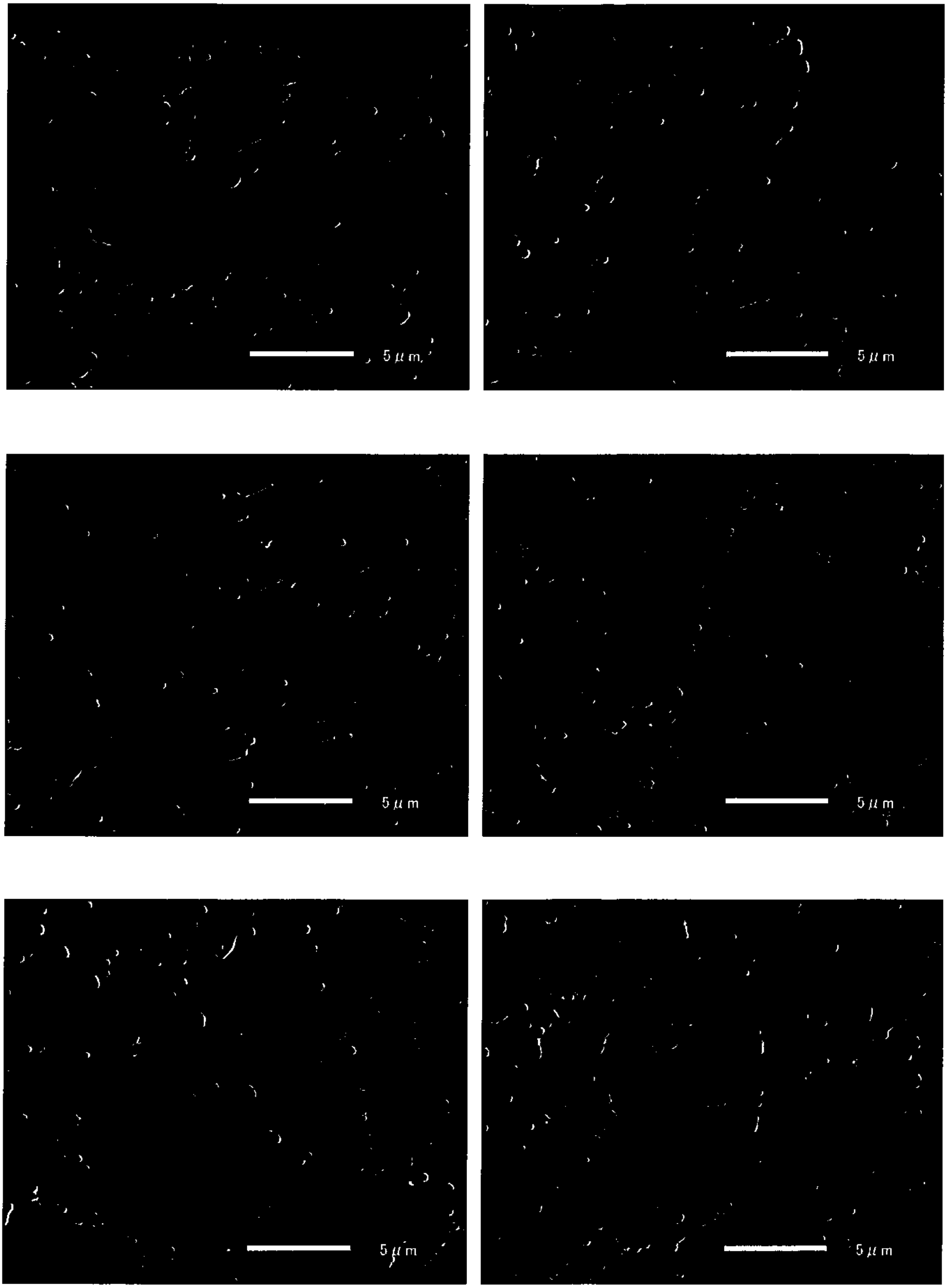


Photo II-9-10 Precipitates along grain boundary by SEM observation
RH Outlet Header(Circumferential weld at right side, front : Fine grain HAZ)

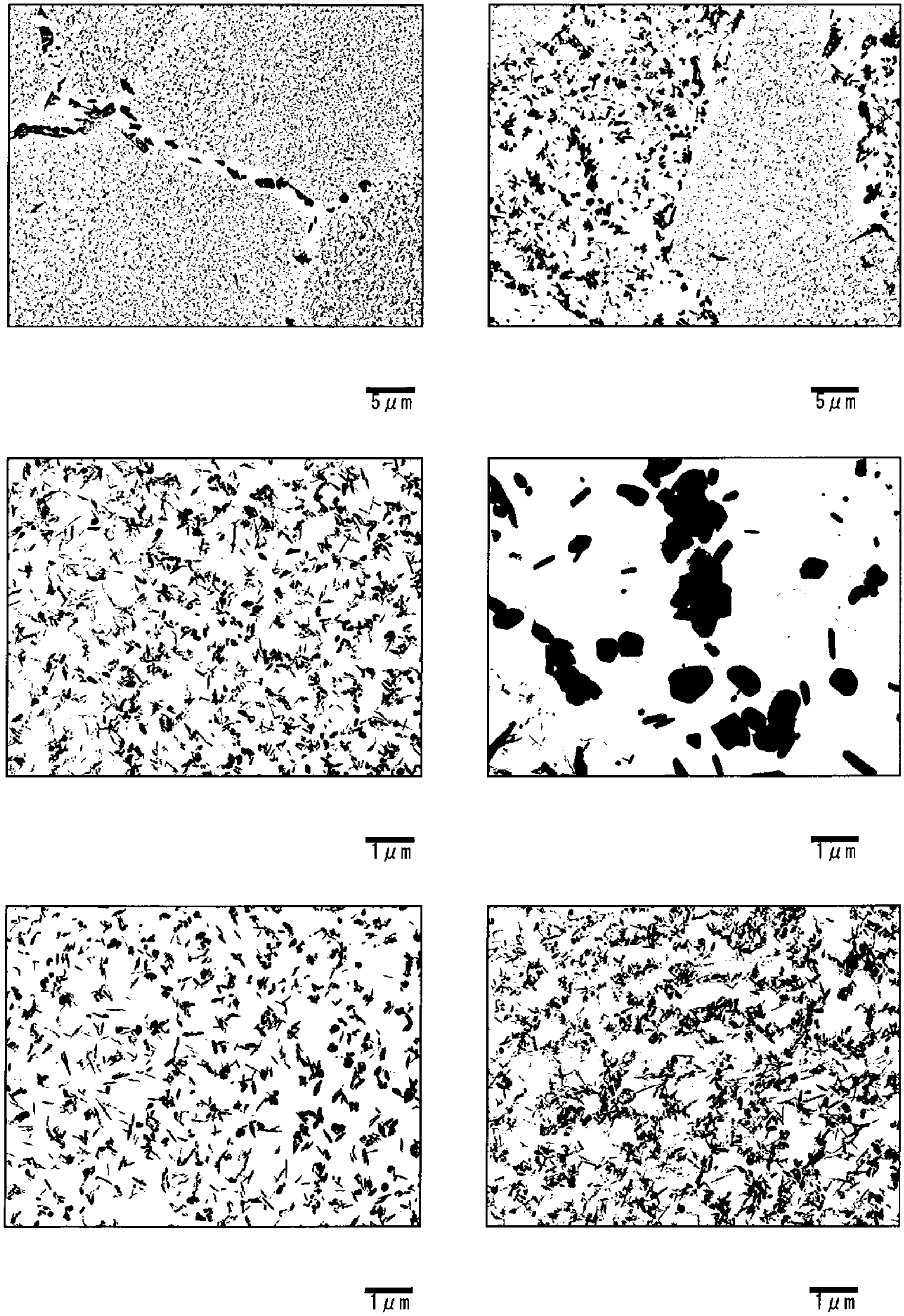


Photo II-9-11 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header (Circumferential weld at right side, front : Base metal)

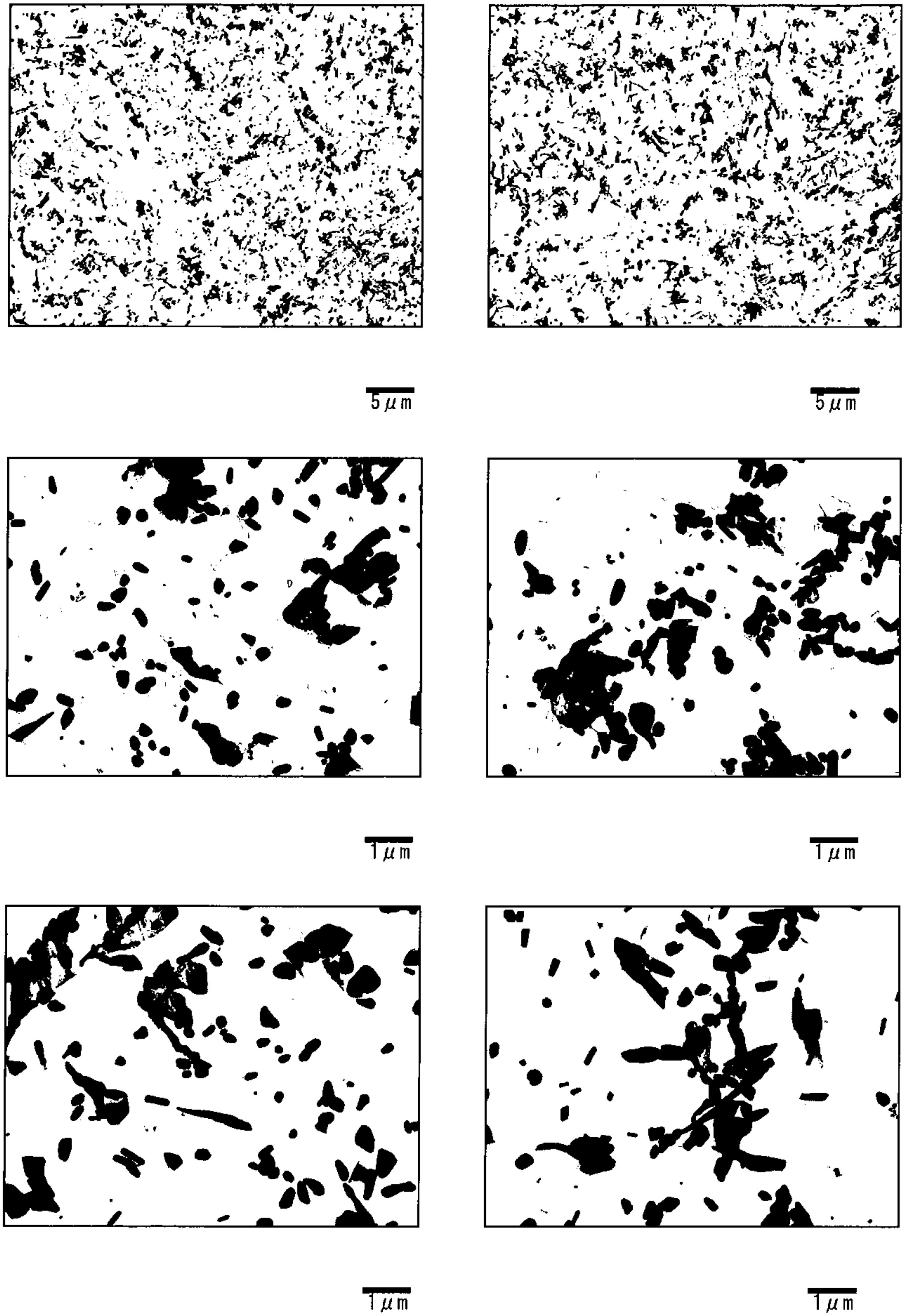


Photo II-9-12 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header (Circumferential weld at right side, front : Fine grain HAZ)

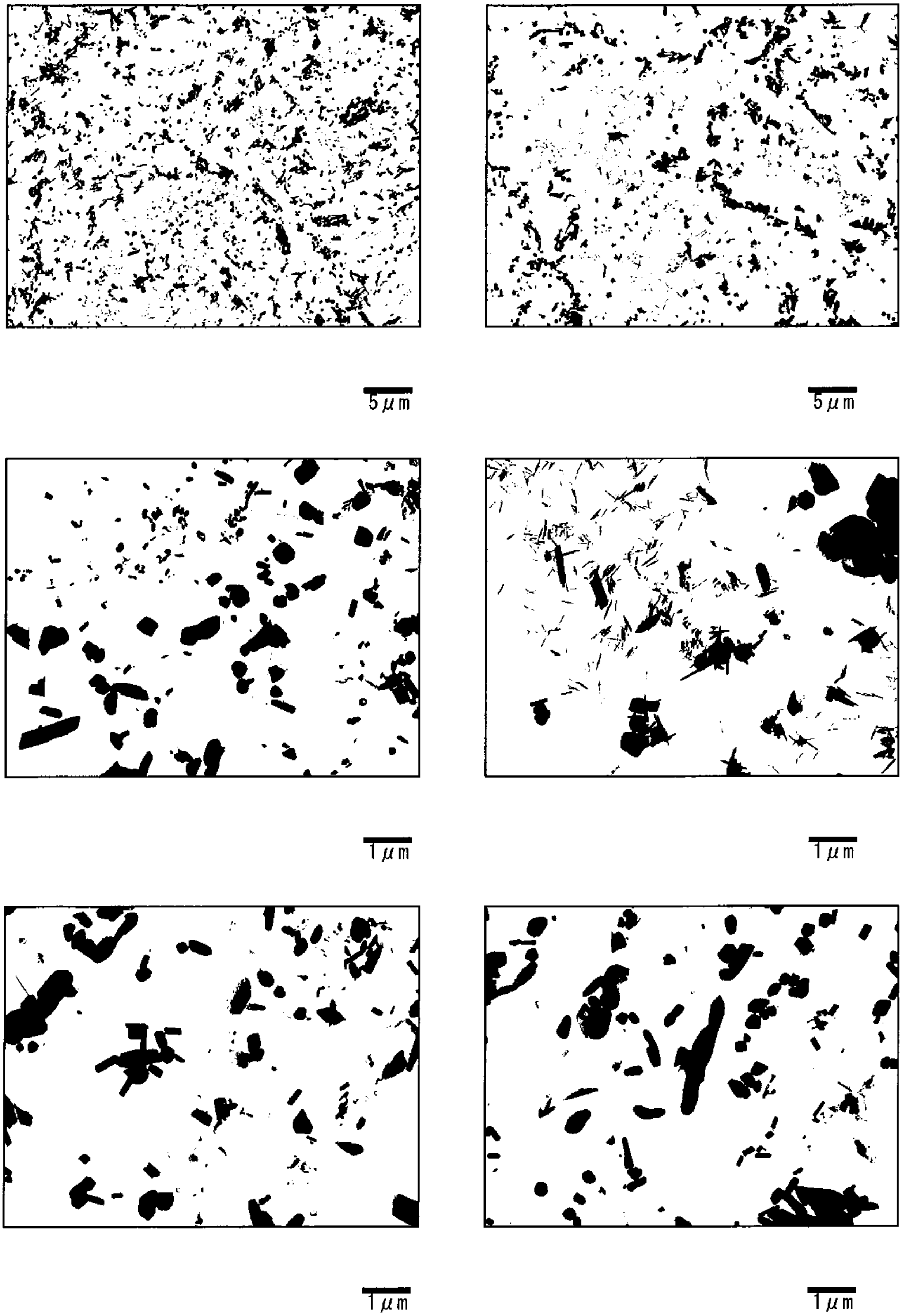


Photo II-9-13 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at right side,front : Coarse grain HAZ)

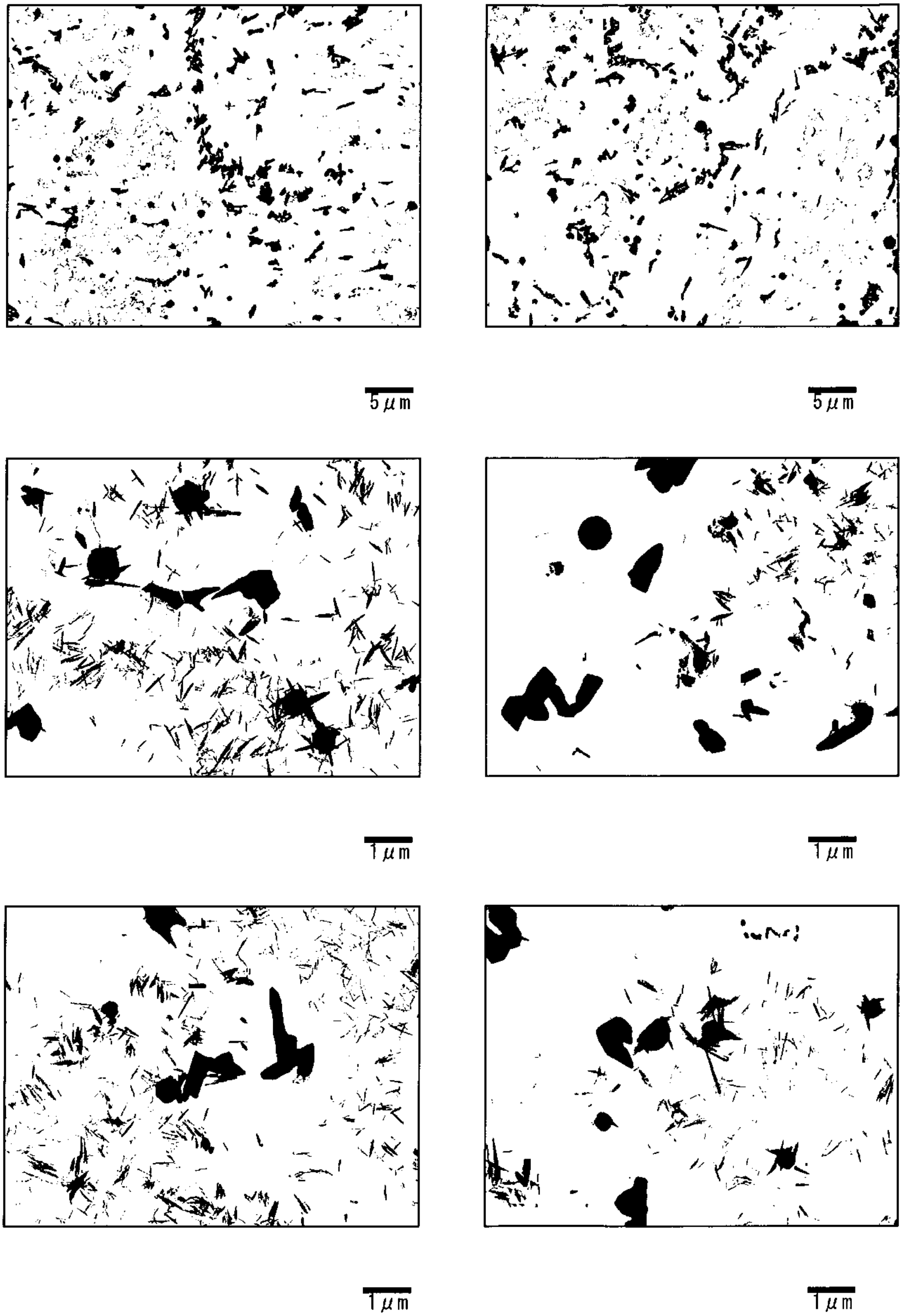


Photo II-9-14 Precipitates by TEM (Transmission electron microscope) observation
RH Outlet Header(Circumferential weld at right side, front : Weld metal)

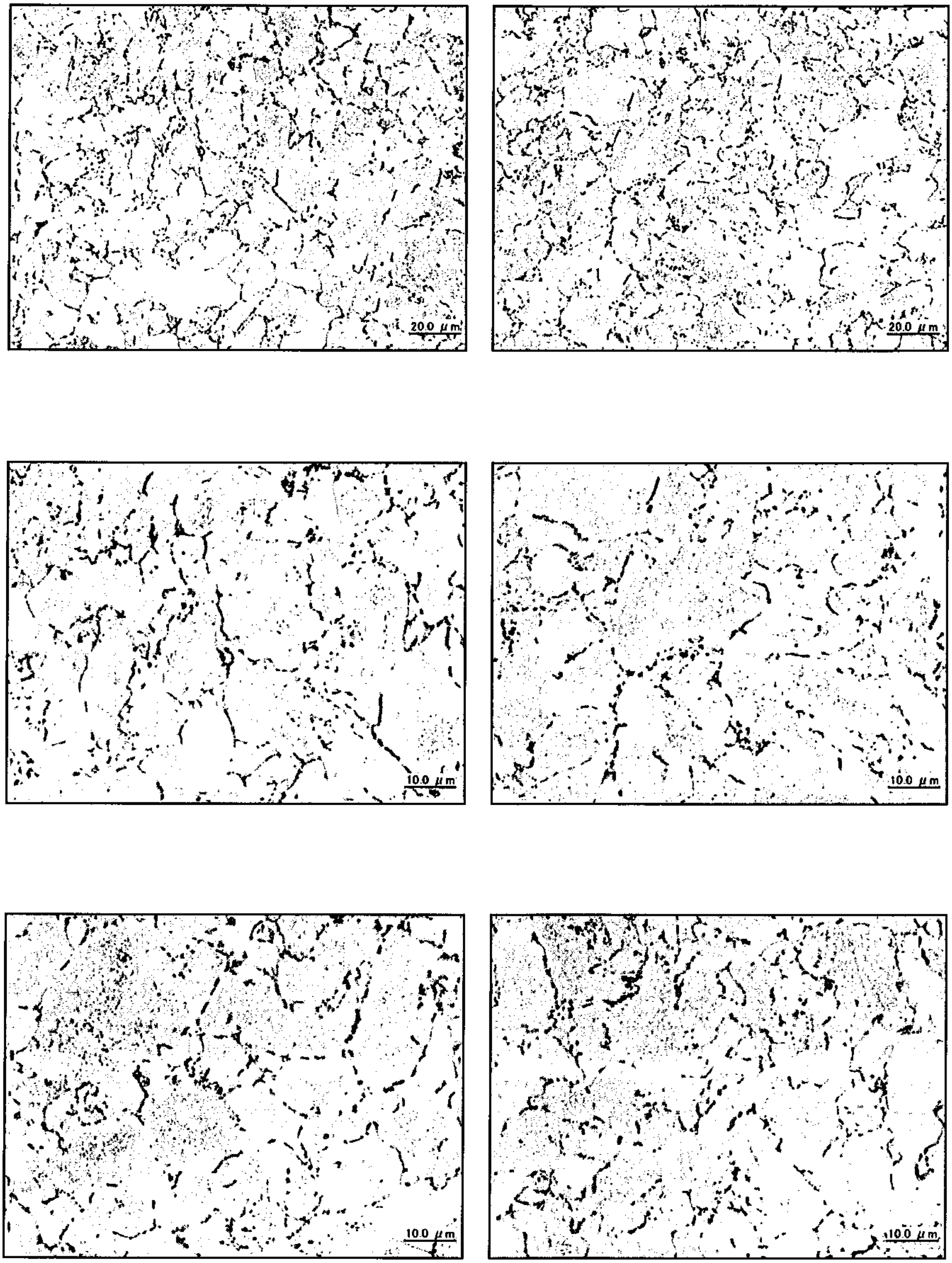


Photo Ⅱ-10-1 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, intrados : Base metal)

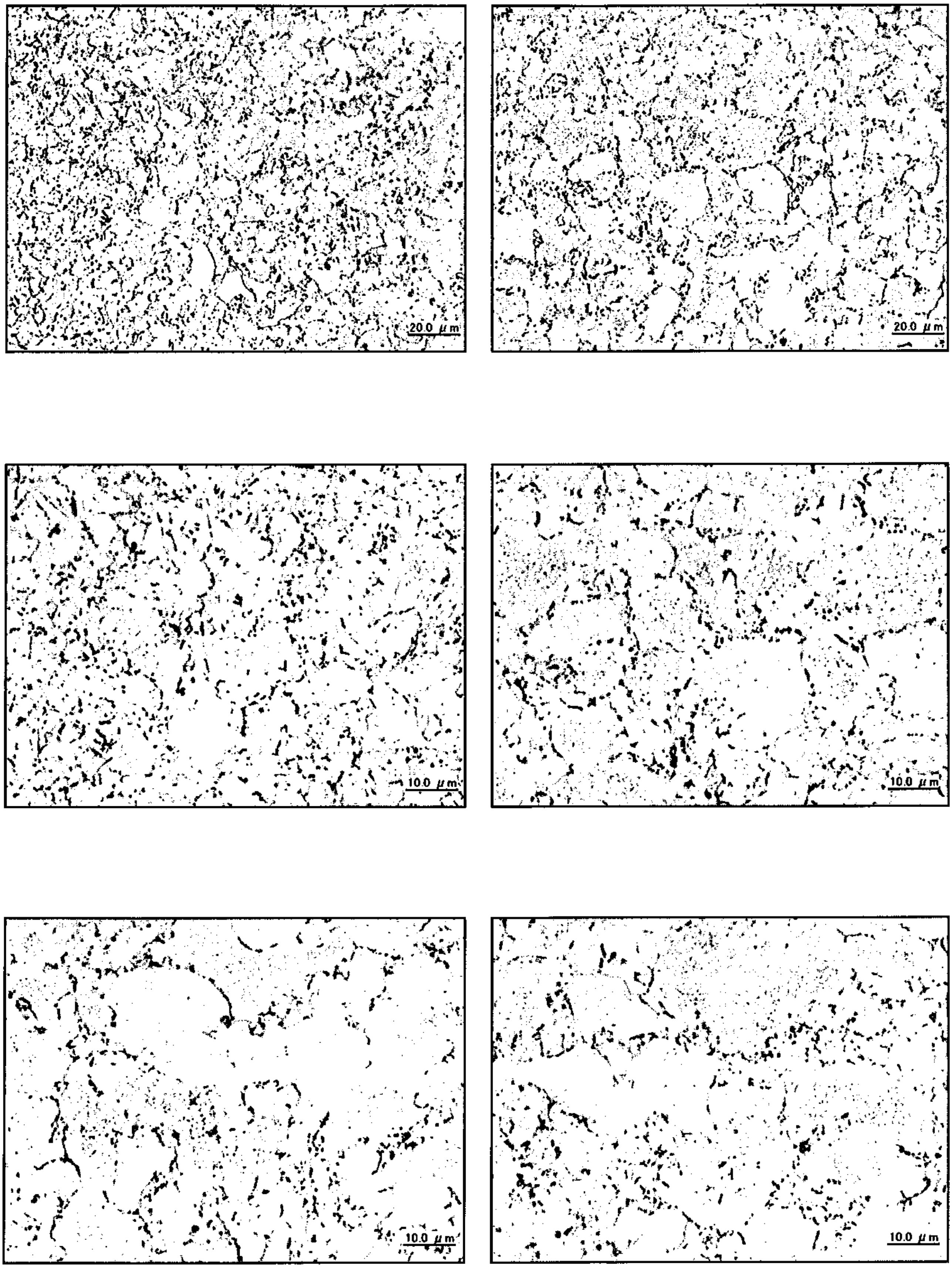


Photo Ⅱ-10-2　Microstructure observation

Main Steam Pipe-Right (Circumferential weld, intrados : Intercritical zone)

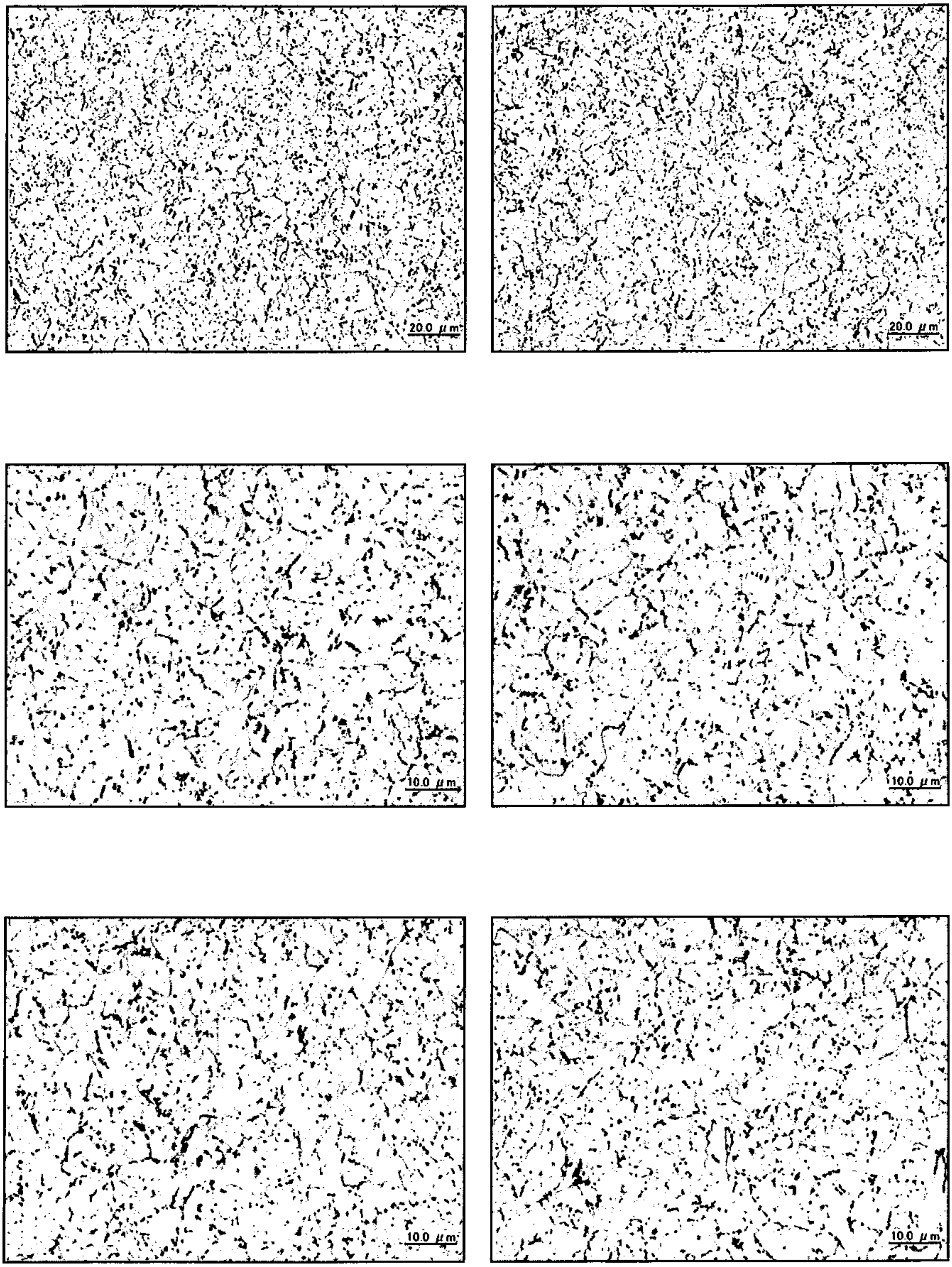


Photo II-10-3 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, intrados : Fine grain HAZ)

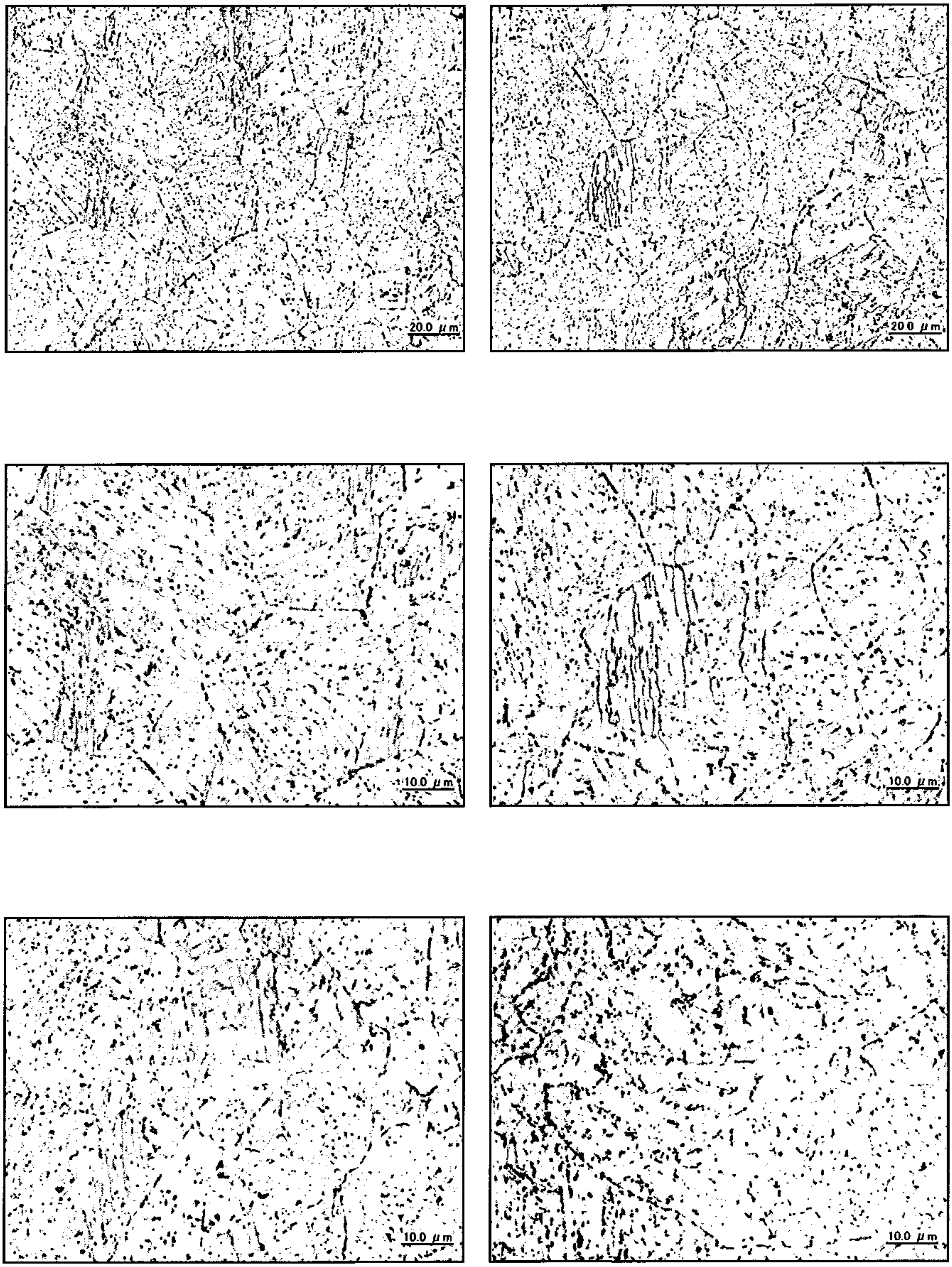


Photo Ⅱ-10-4 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, intrados : Coarse grain HAZ)

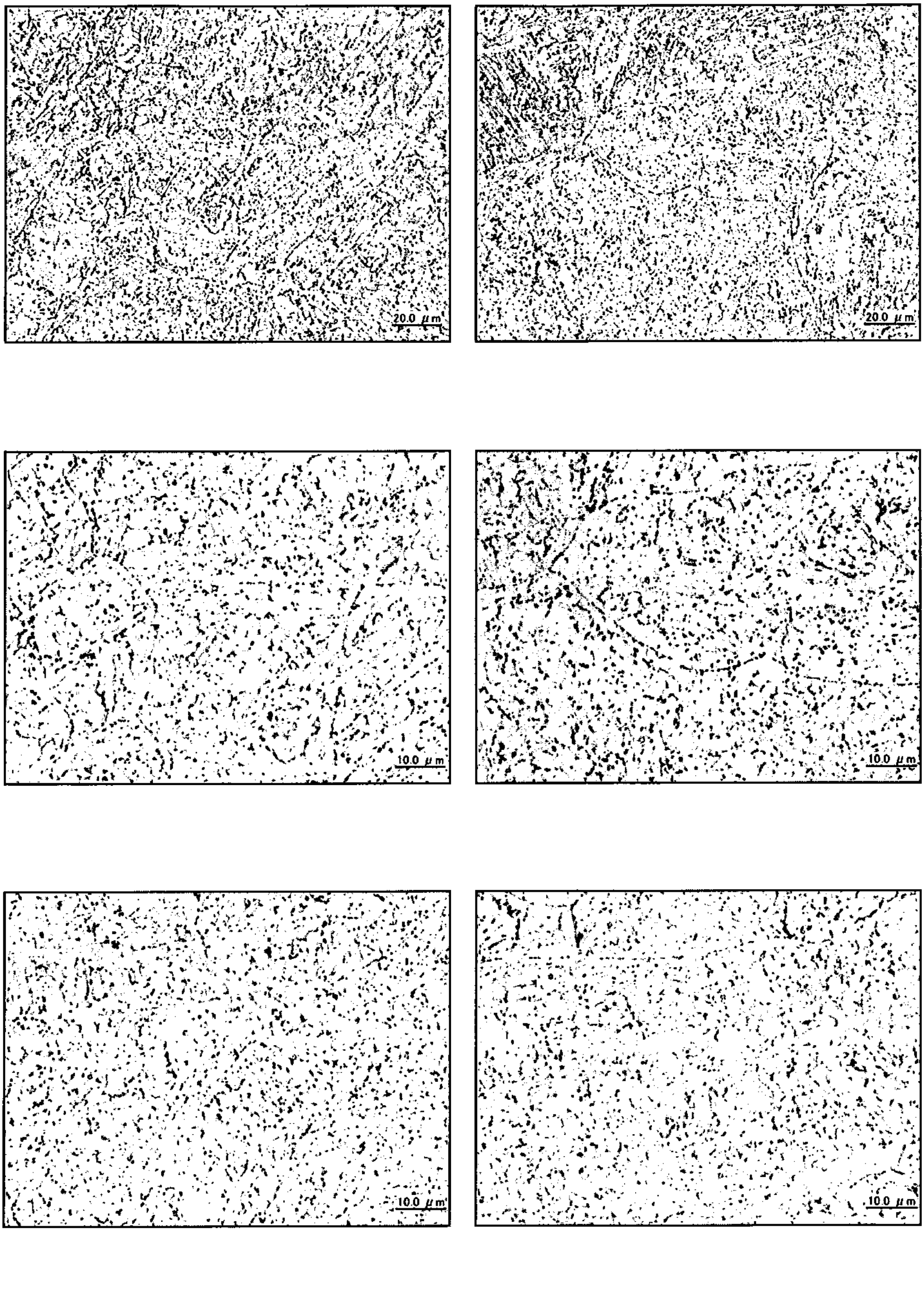


Photo Ⅱ-10-5 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, intrados : Weld metal)

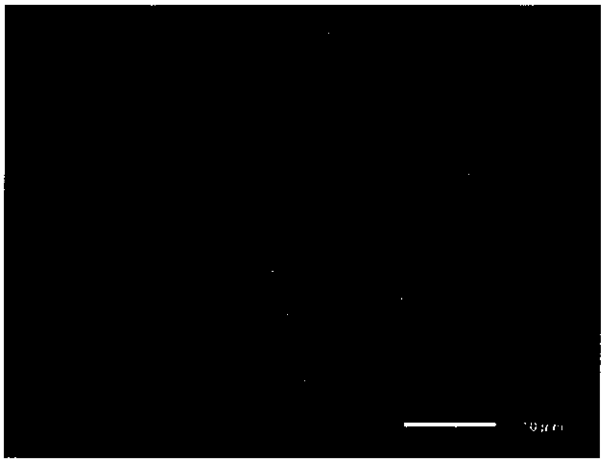
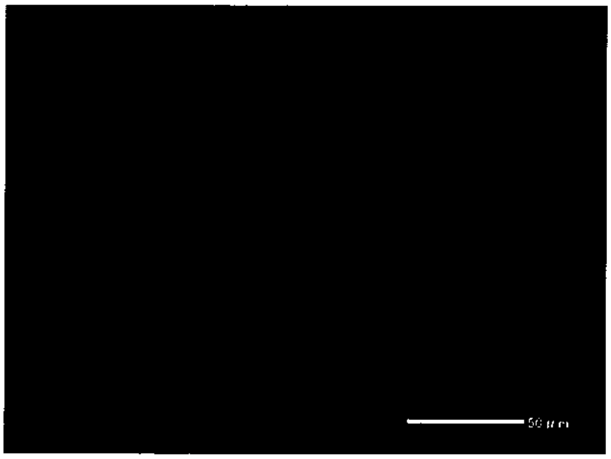
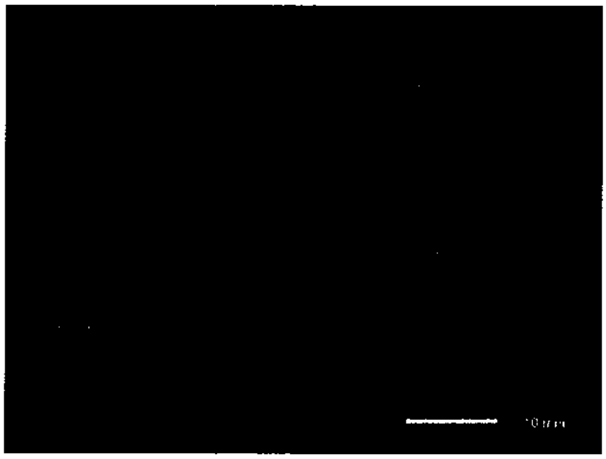
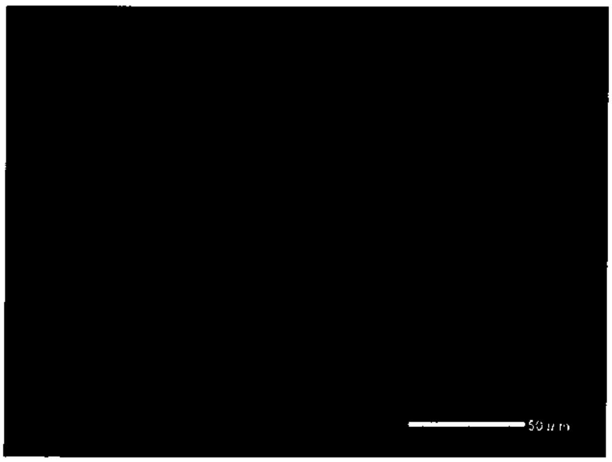
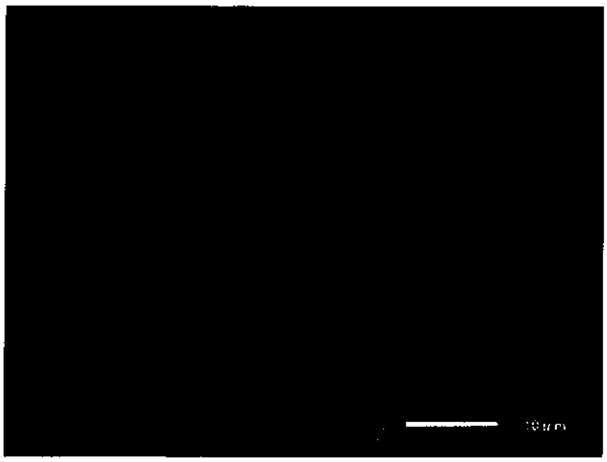







Photo Ⅱ-10-6 SEM(Scanning electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, intrados : Fine grain HAZ)

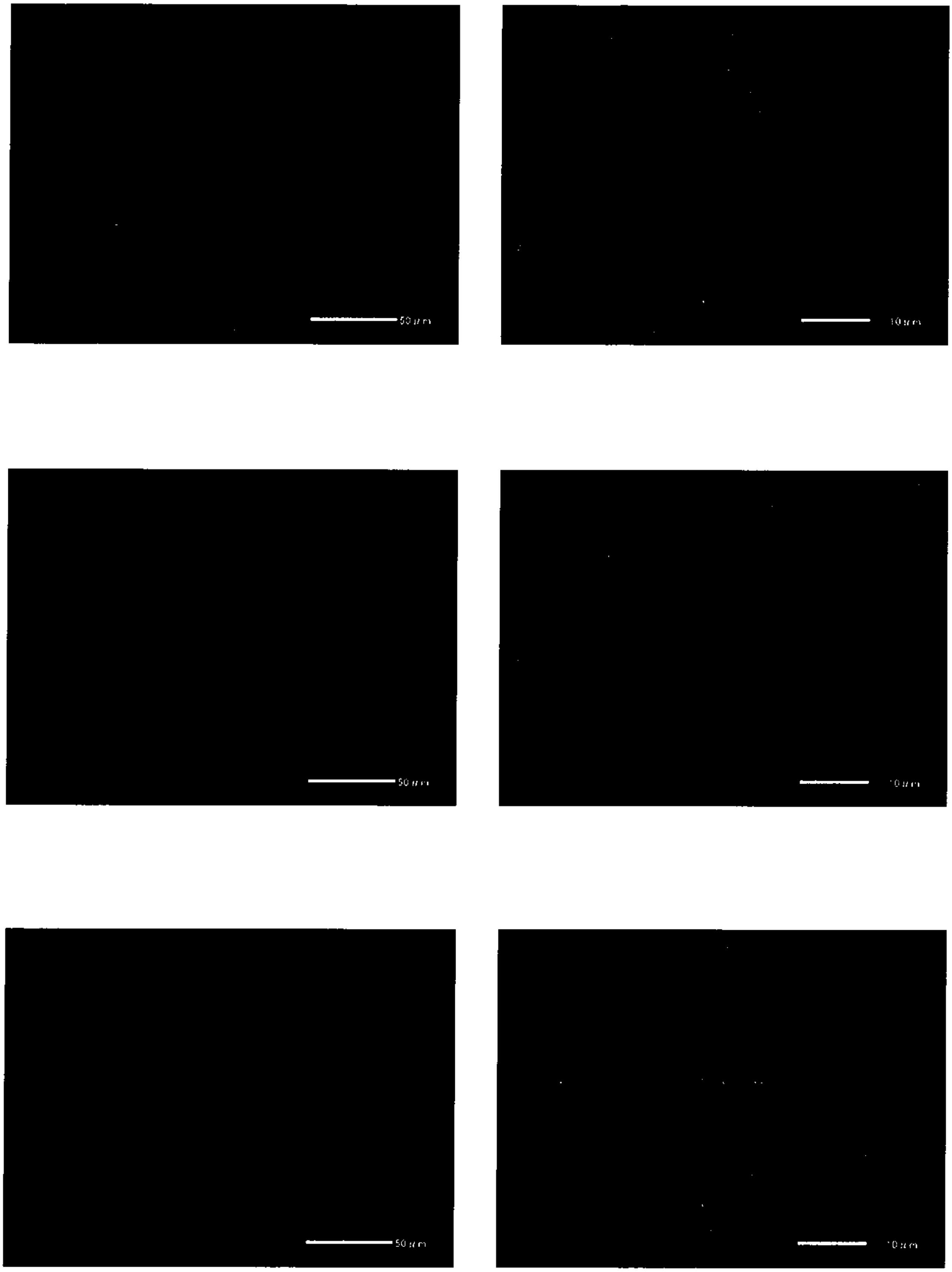


Photo Ⅱ-10-7 SEM(Scanning electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, intrados : Coarse grain HAZ)

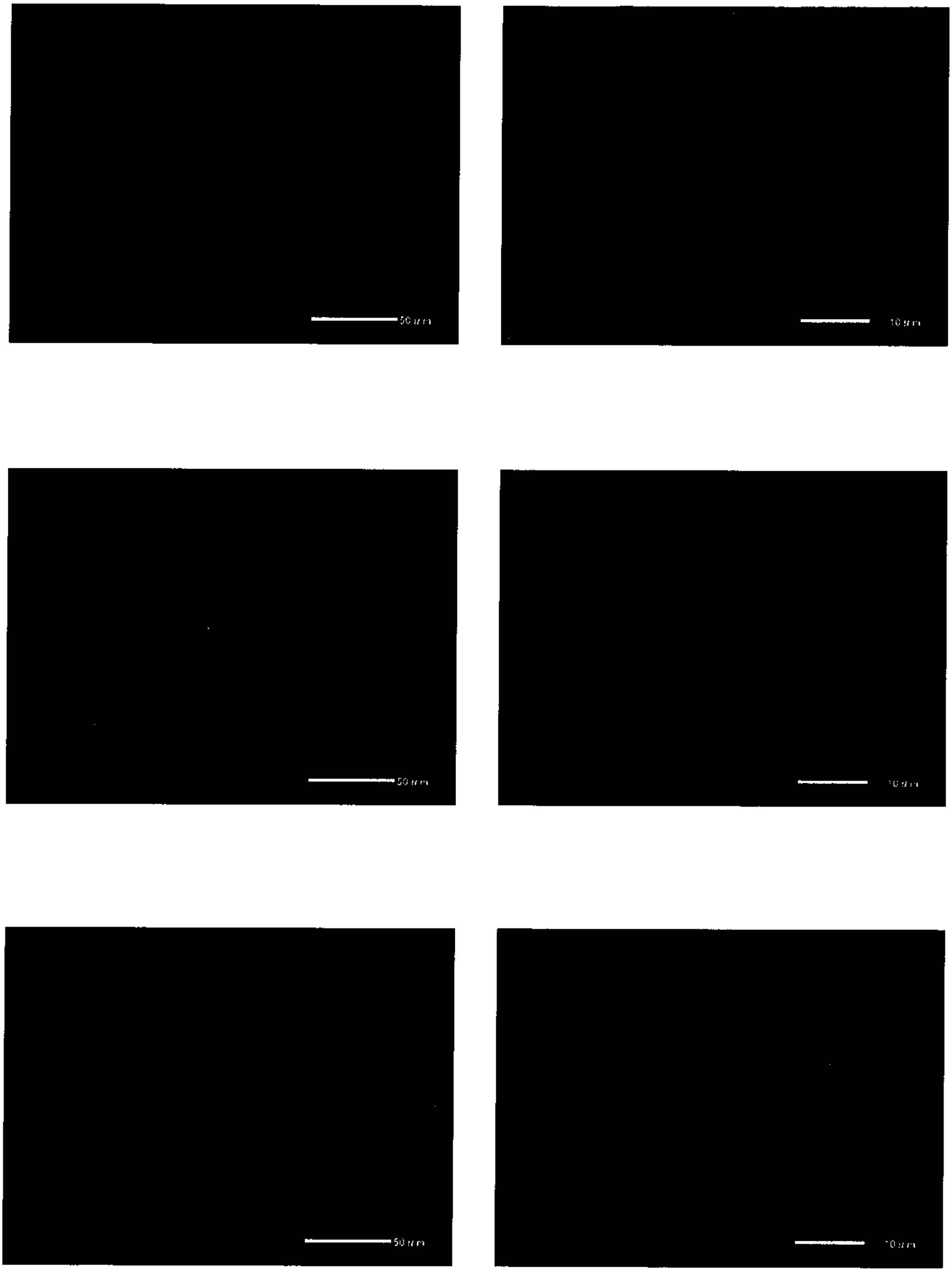


Photo II-10-8 SEM(Scanning electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, intrados : Weld metal)

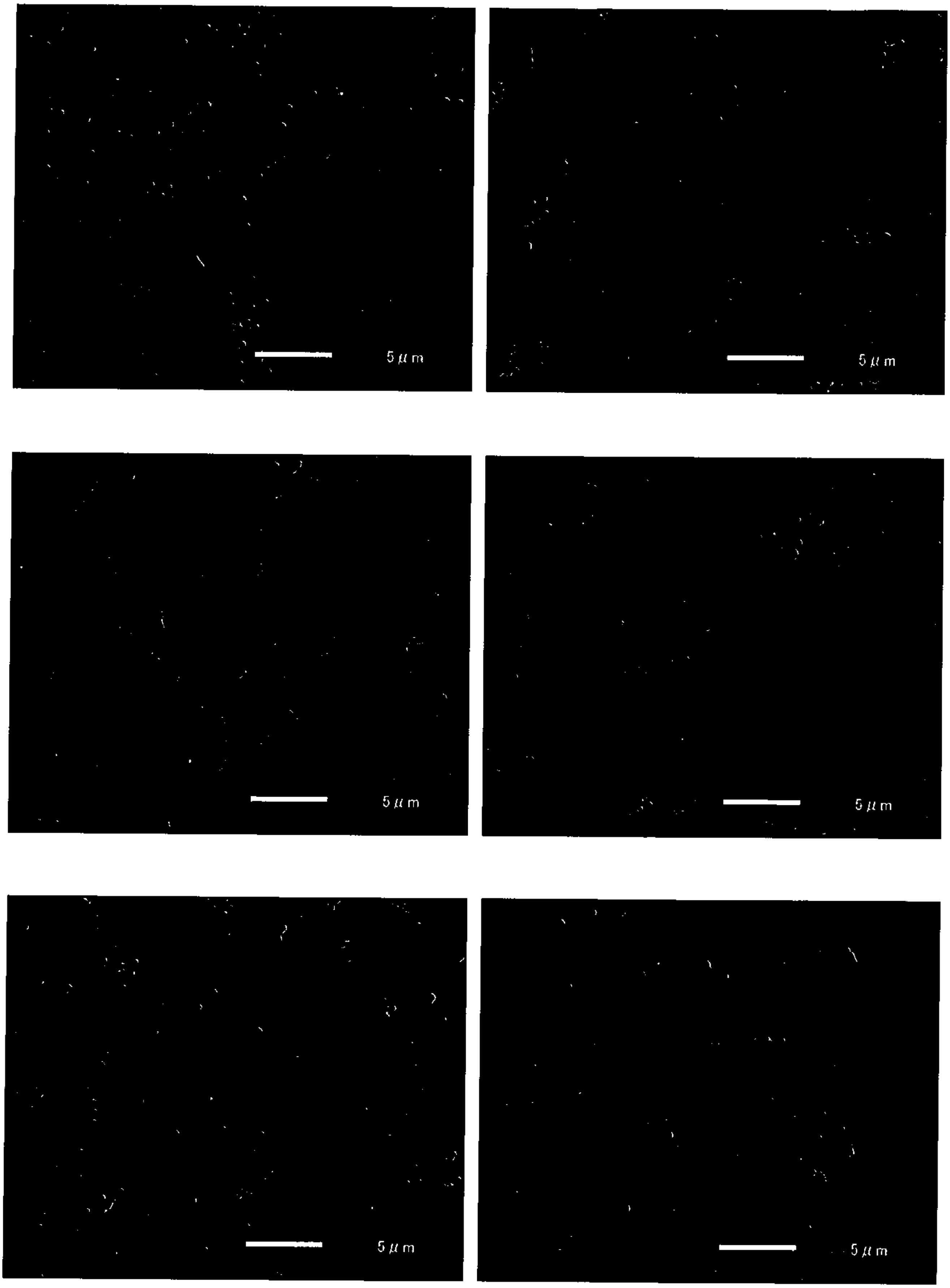


Photo II-10-9 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Right (Circumferential weld, intrados : Base metal)

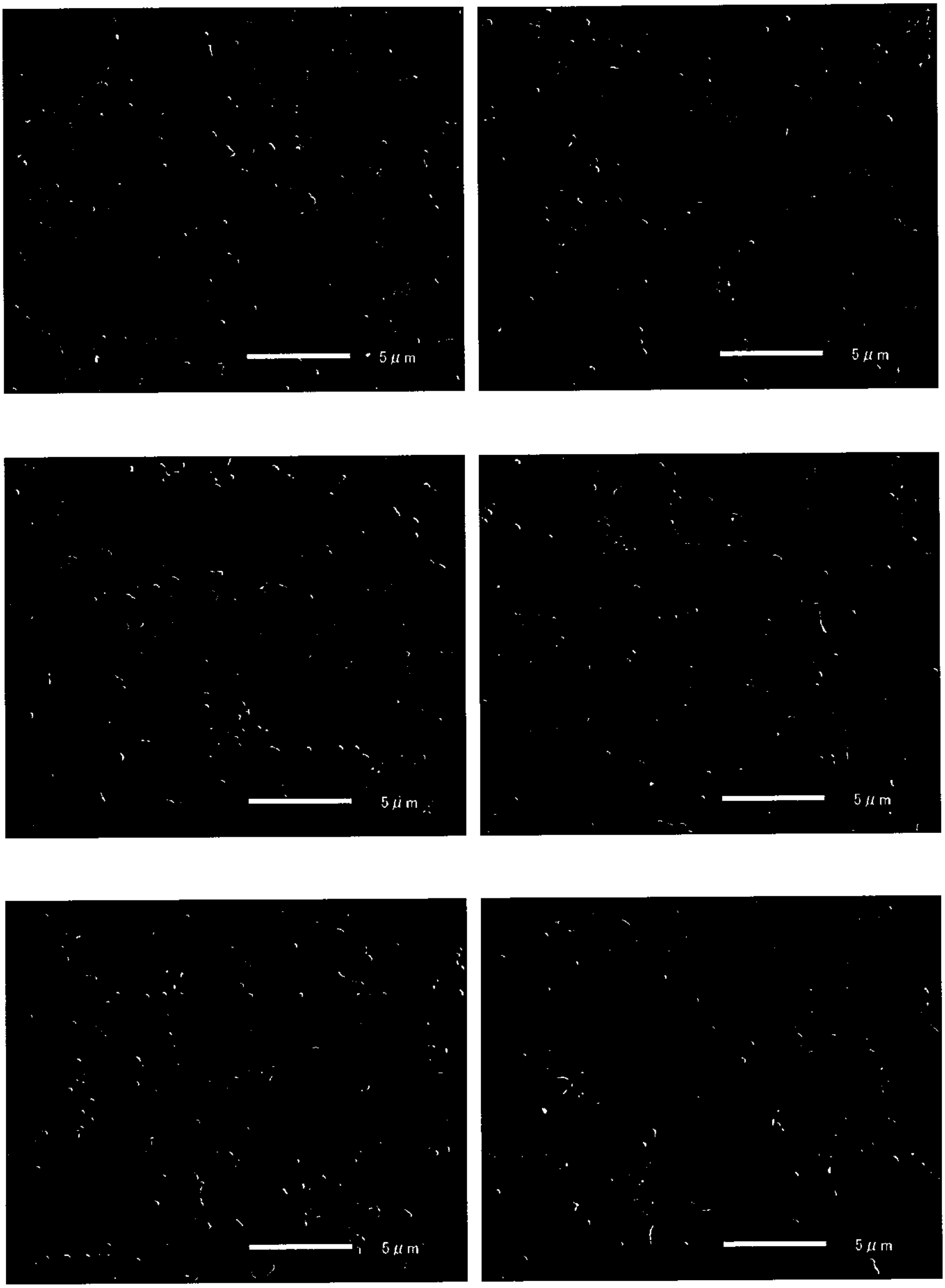
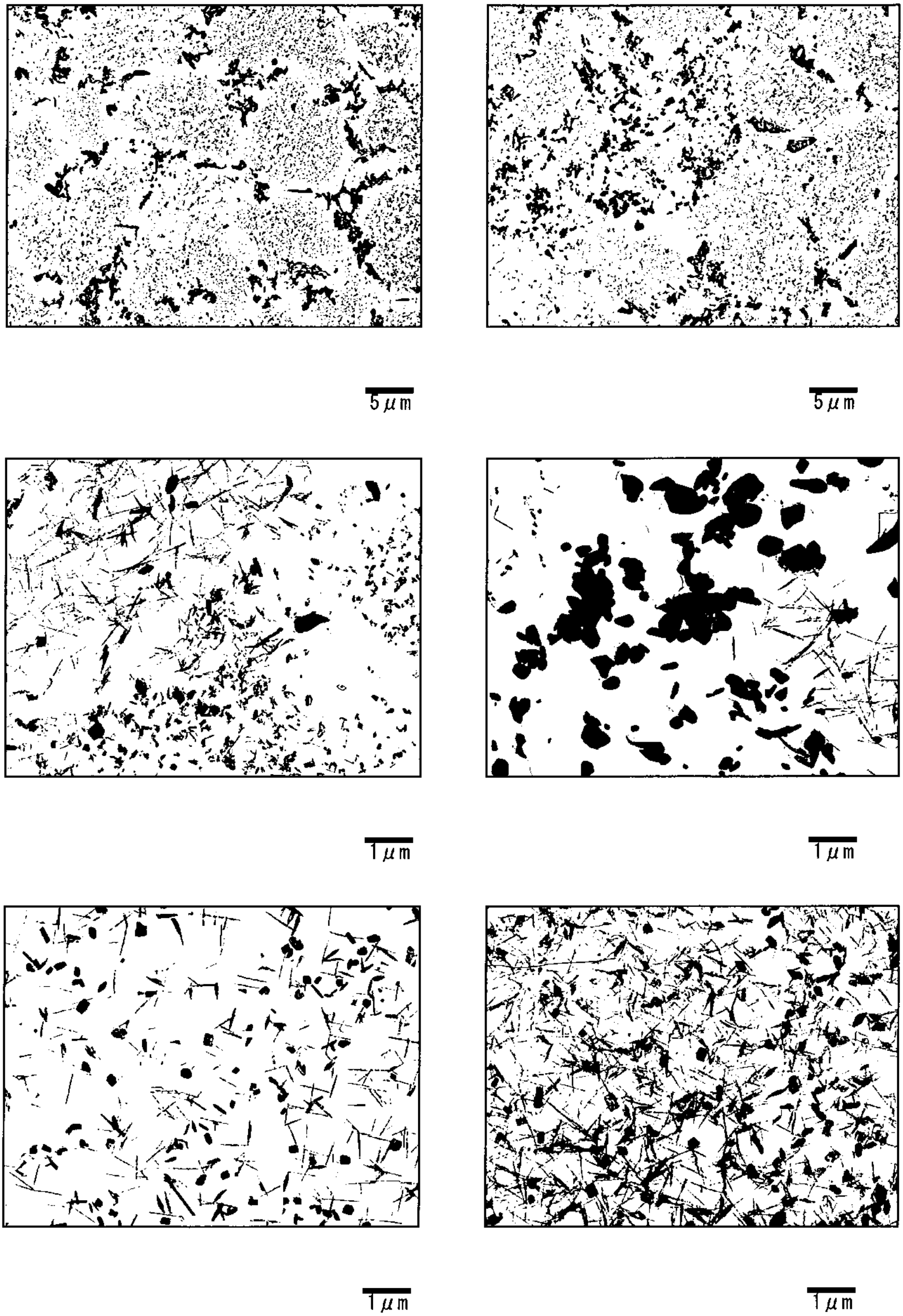


Photo II-10-10 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Right (Circumferential weld, intrados : Fine grain HAZ)



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

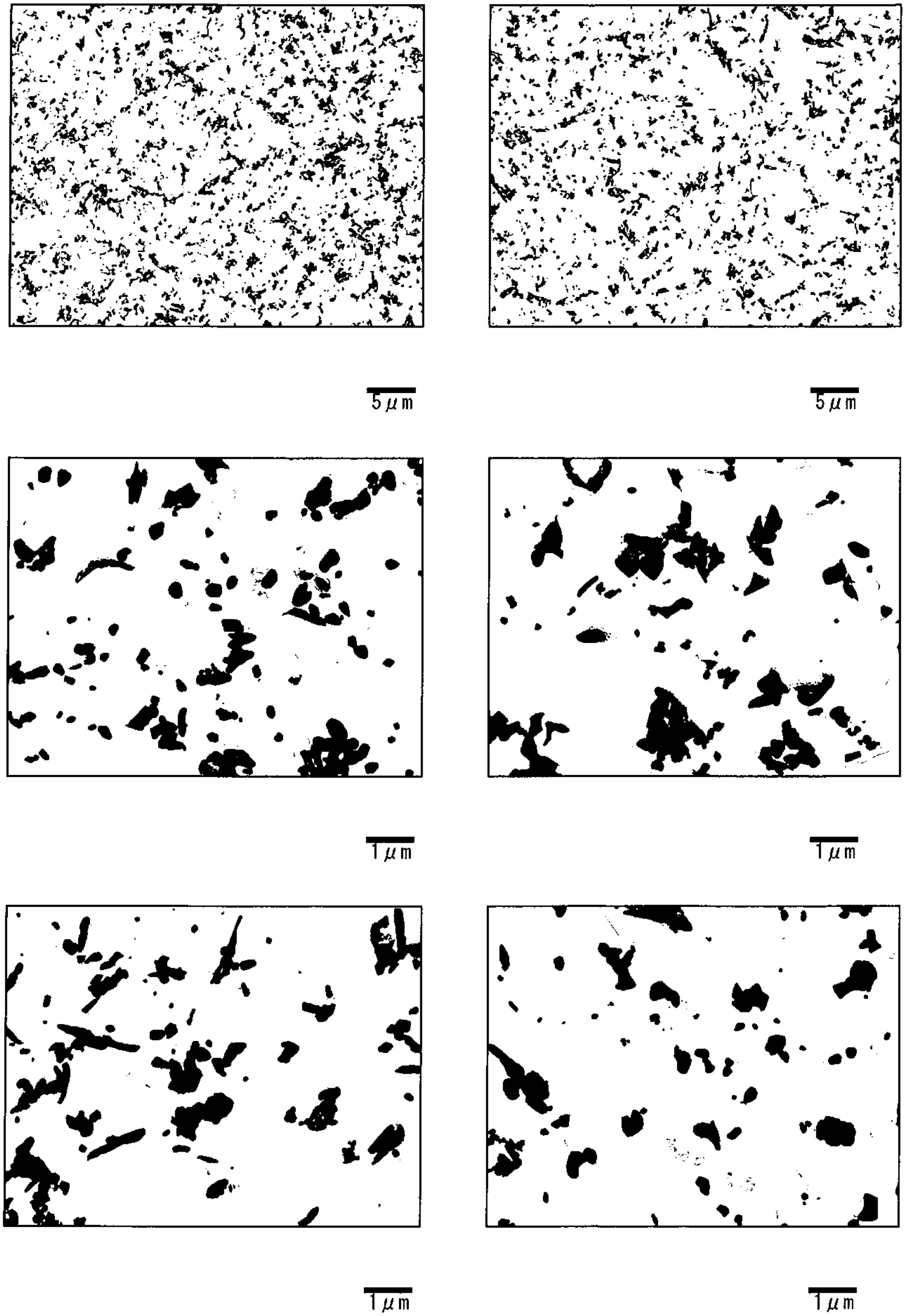


Photo II-10-12 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right (Circumferential weld, intrados : Fine grain HAZ)

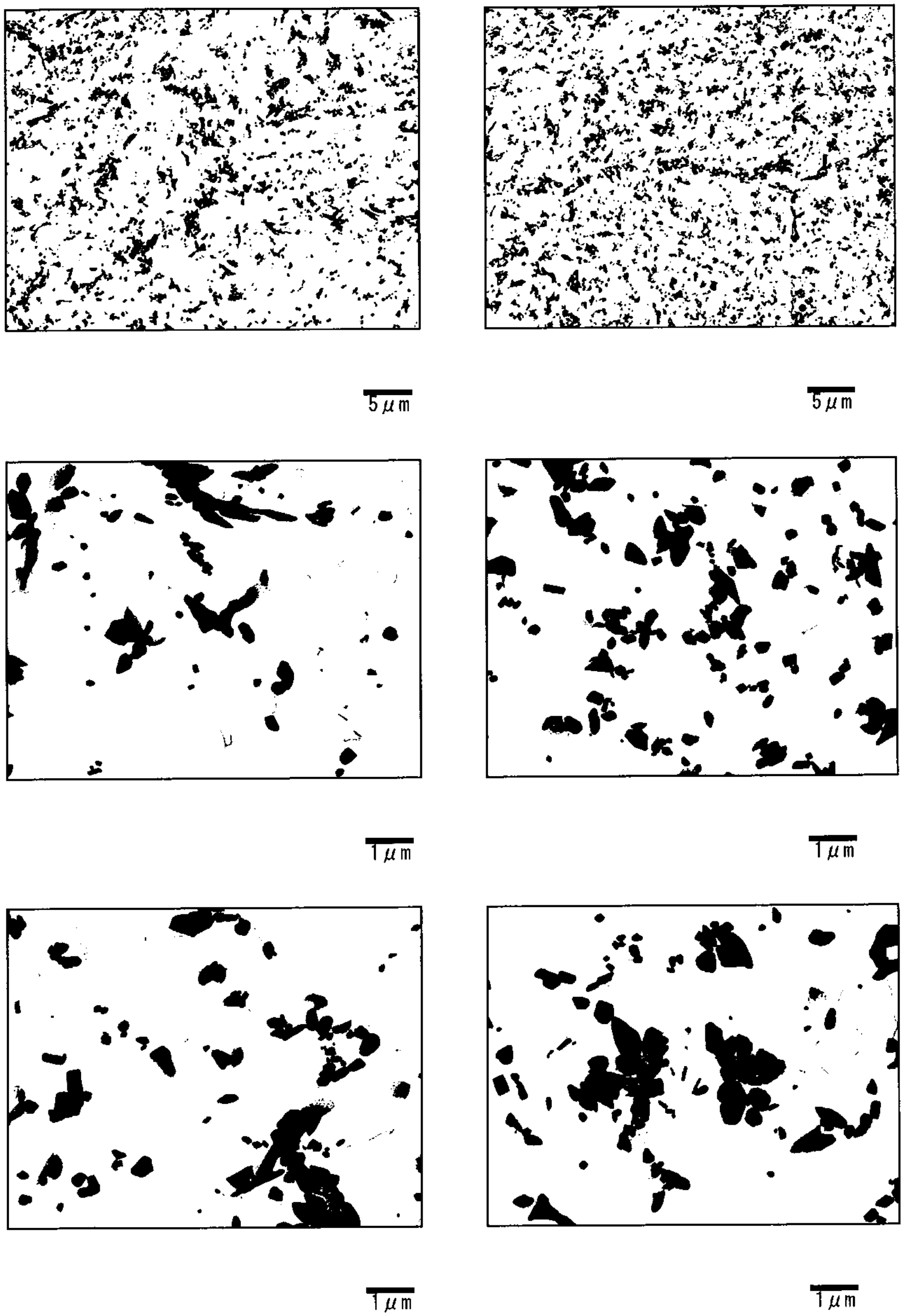


Photo II-10-13 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right (Circumferential weld, intrados : Coarse grain HAZ)

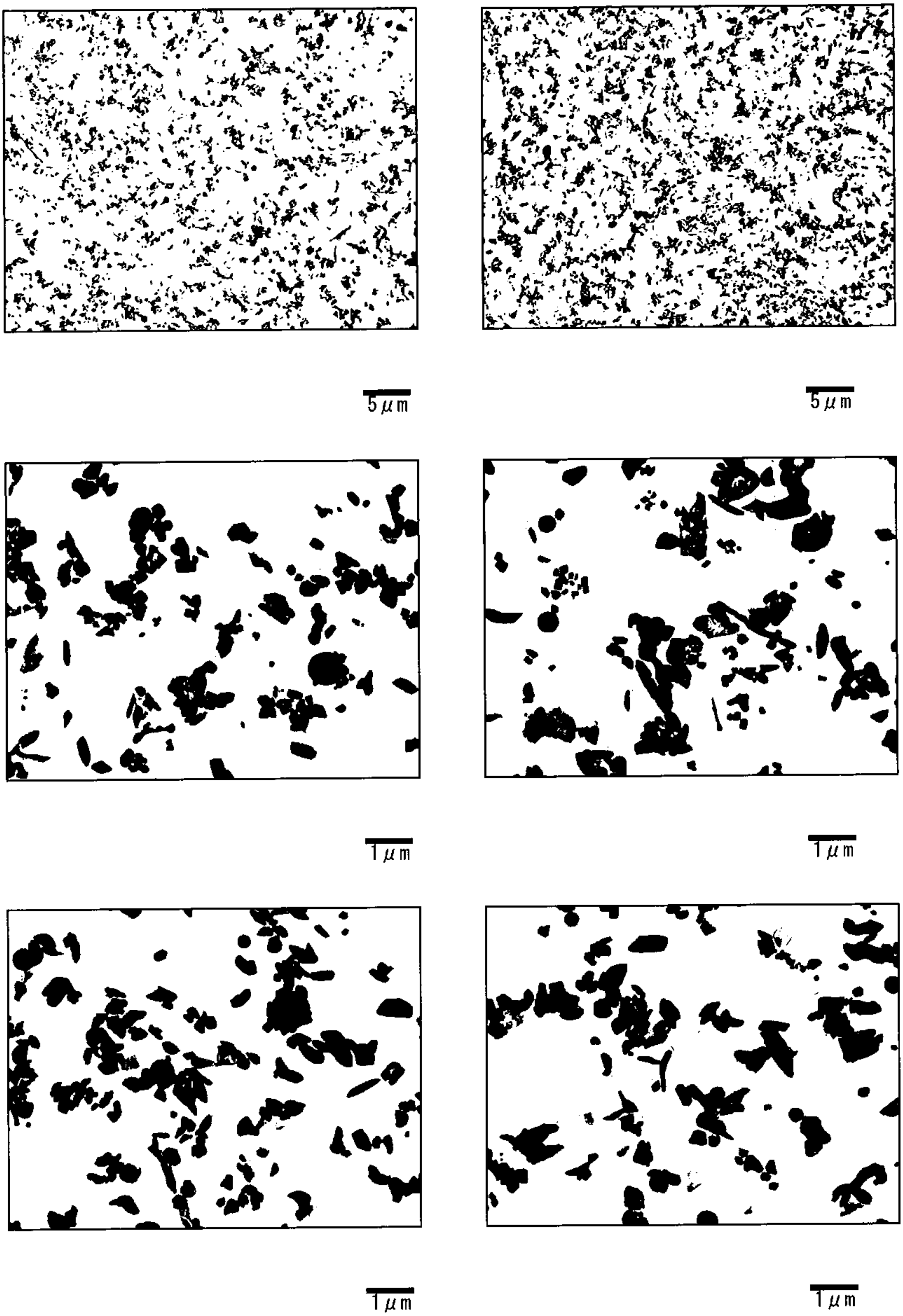


Photo II-10-14 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right (Circumferential weld, intrados : Weld metal)

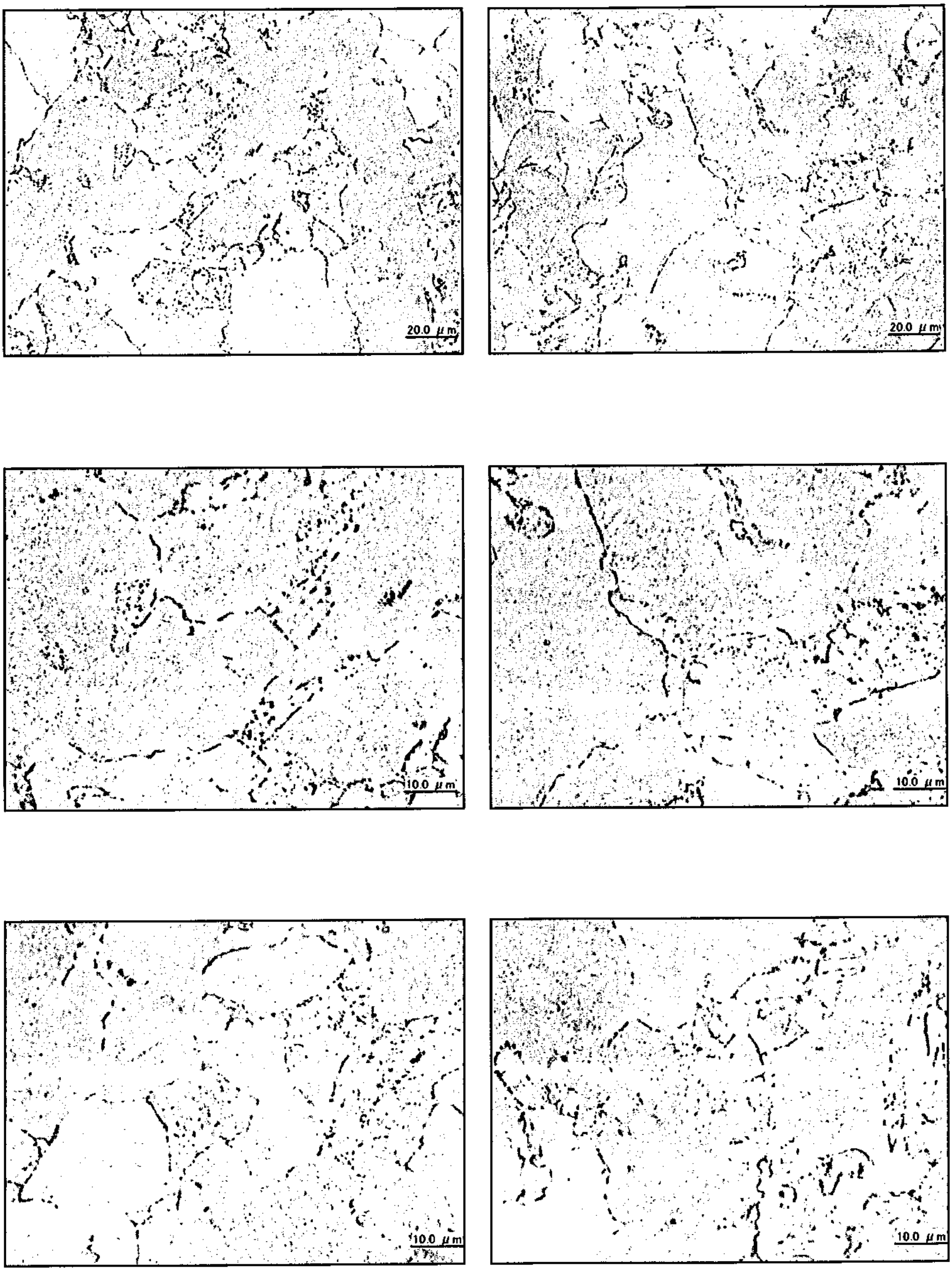


Photo II-11-1 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Base metal)

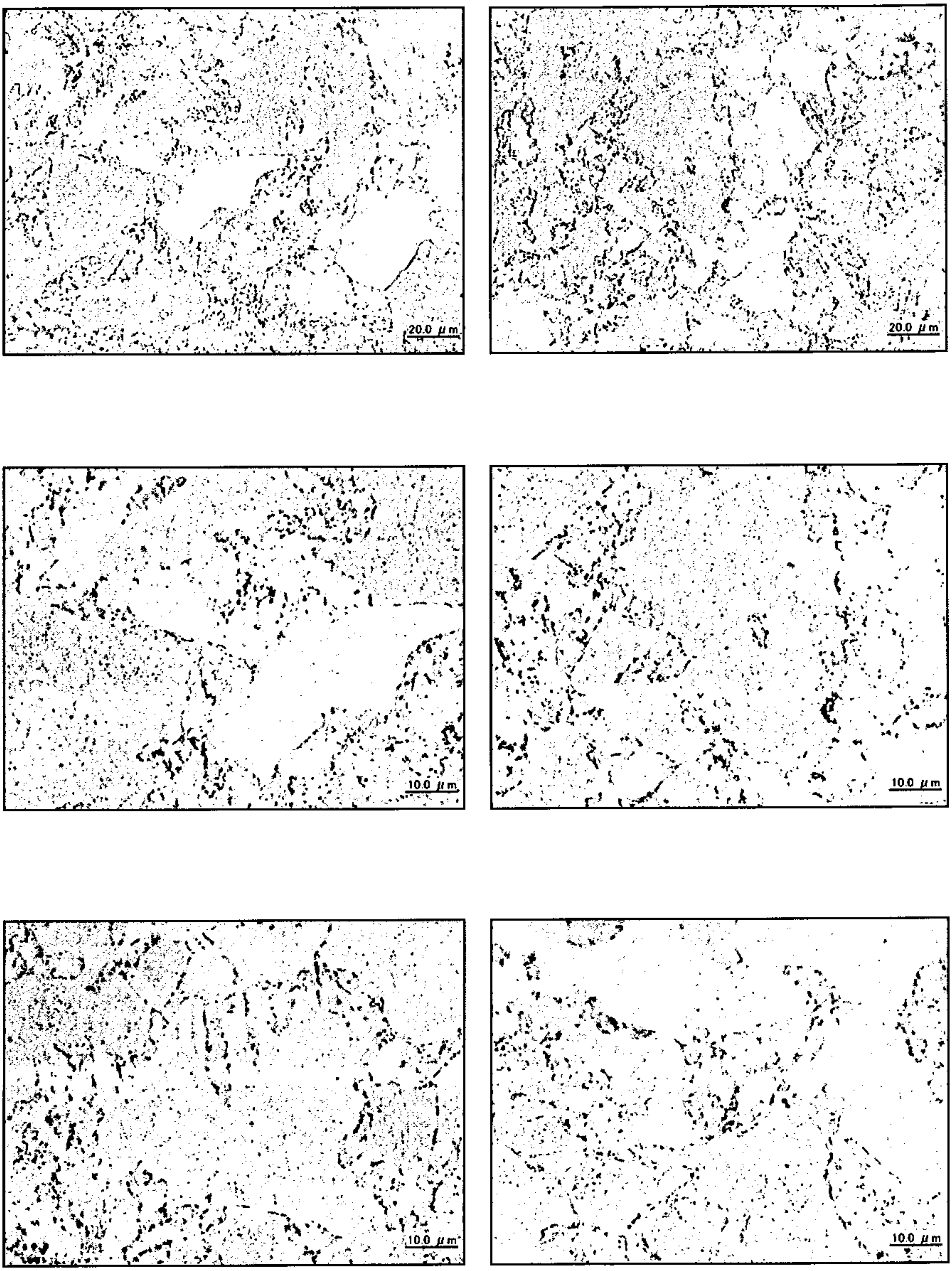


Photo Ⅱ-11-2 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Intercritical zone)

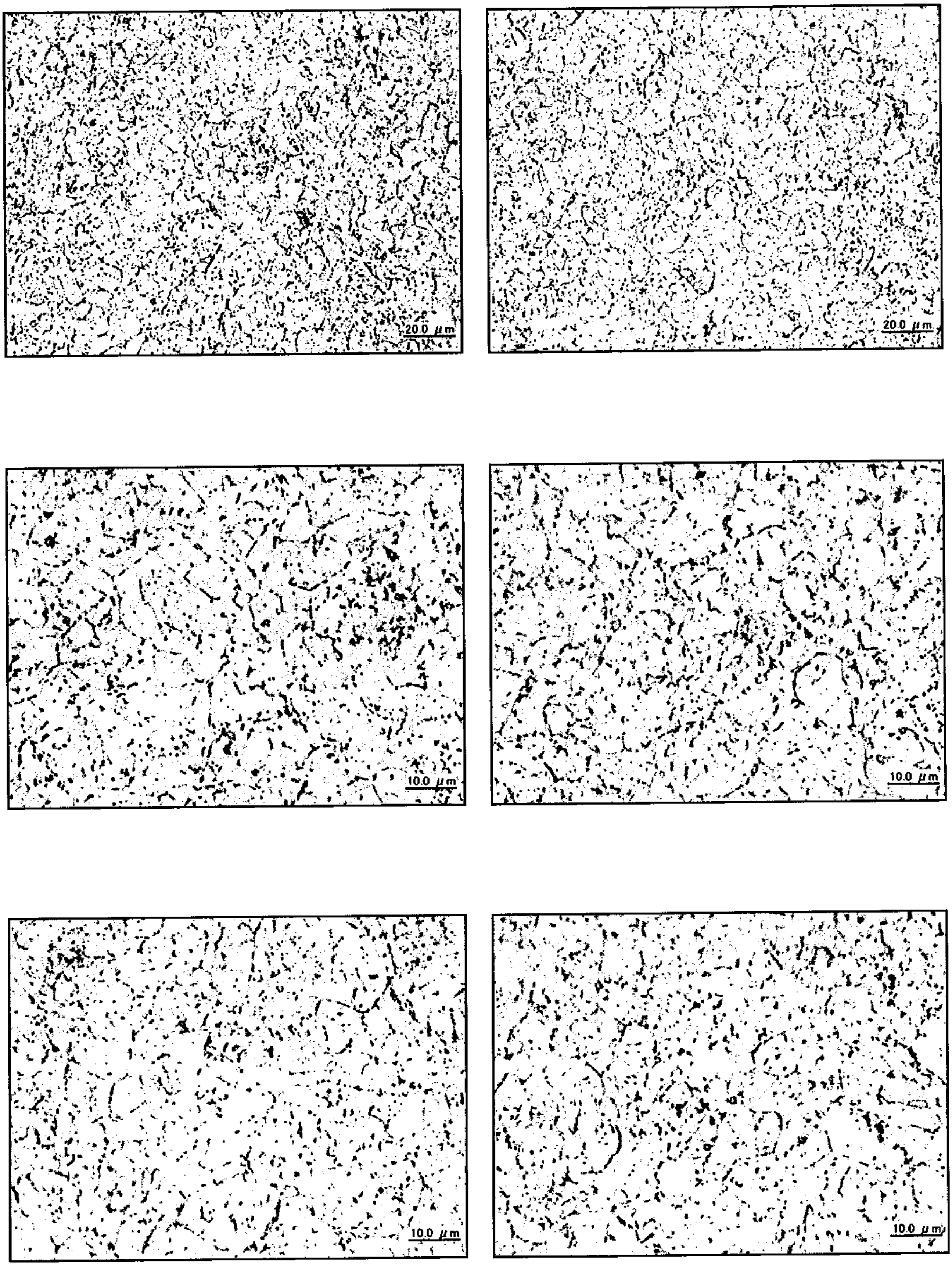


Photo II-11-3 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Fine grain HAZ)

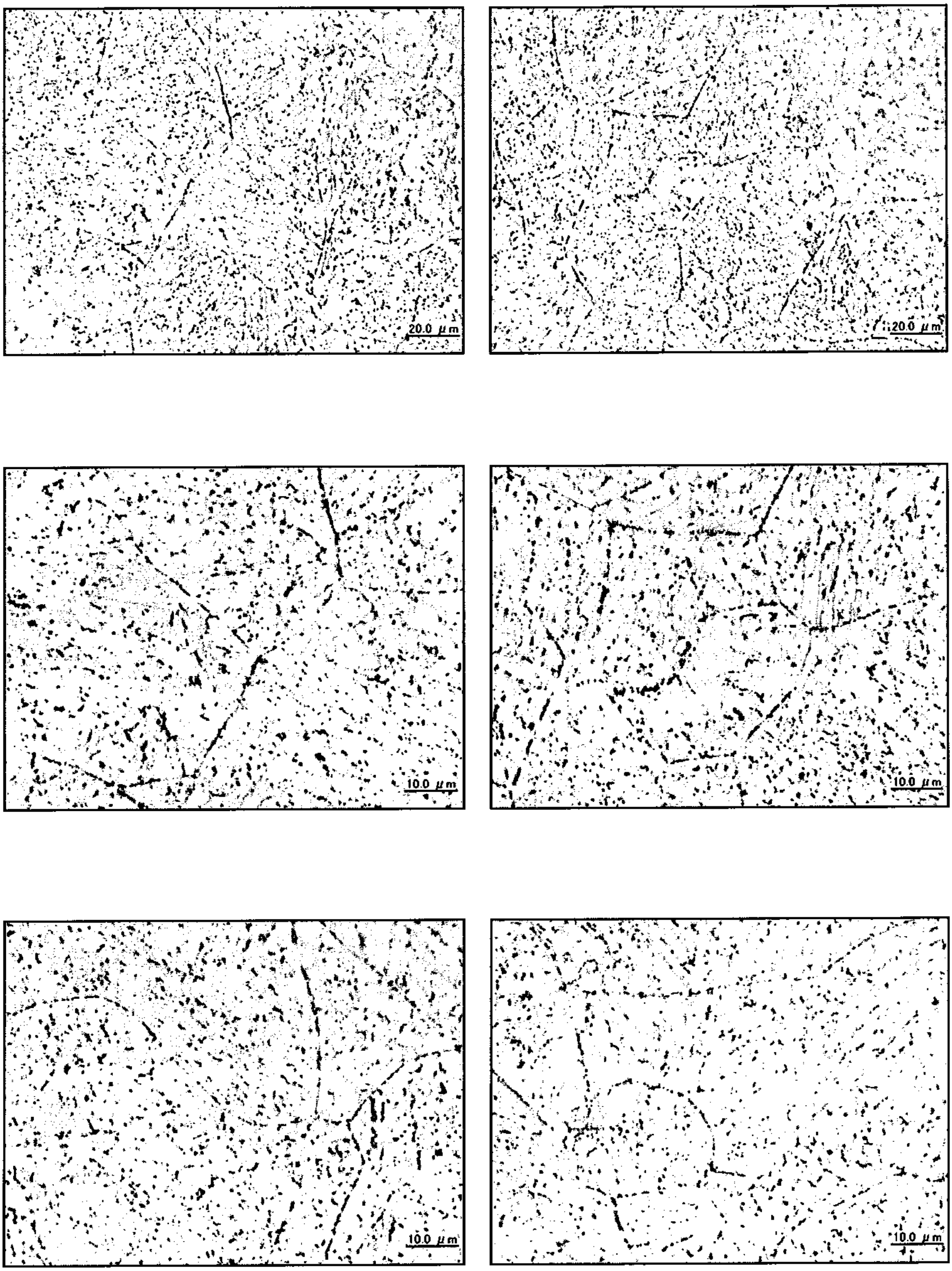
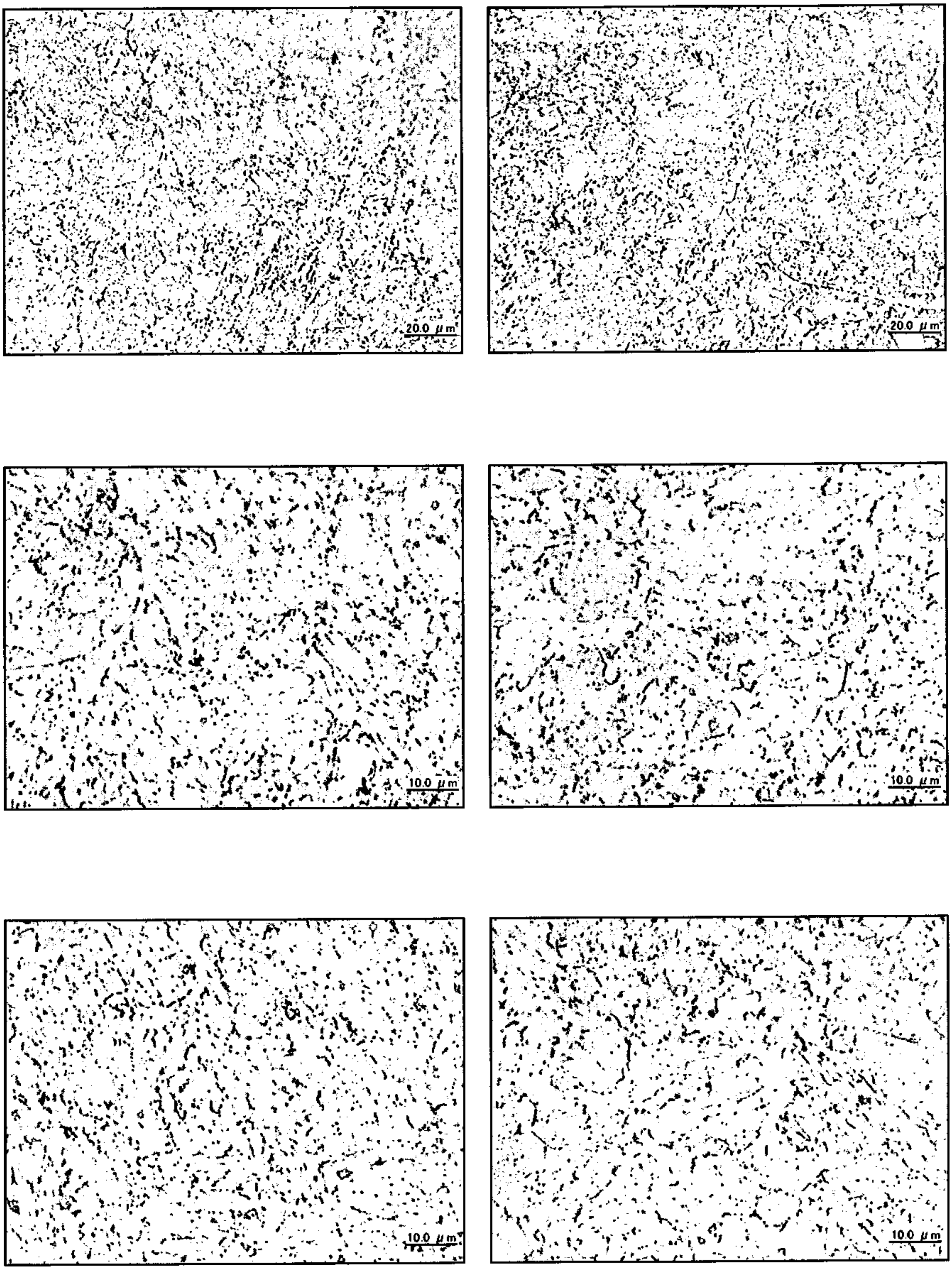


Photo Ⅱ-11-4 Microstructure observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Coarse grain HAZ)



PhotoⅡ-11-5 Microstructure observation
Main Steam Pipe-Right (Circumferential weld,near the stop valve : Weld metal)

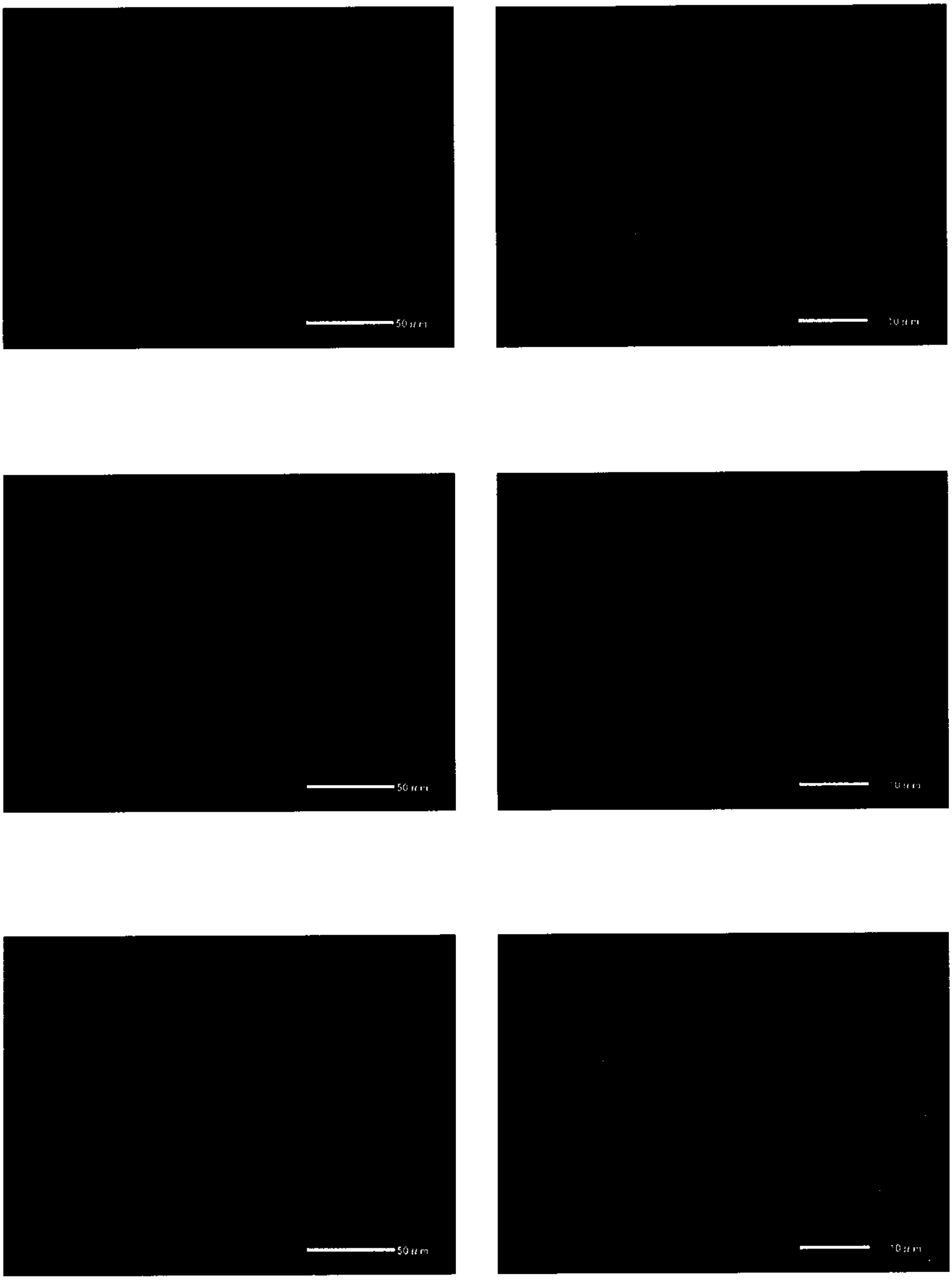
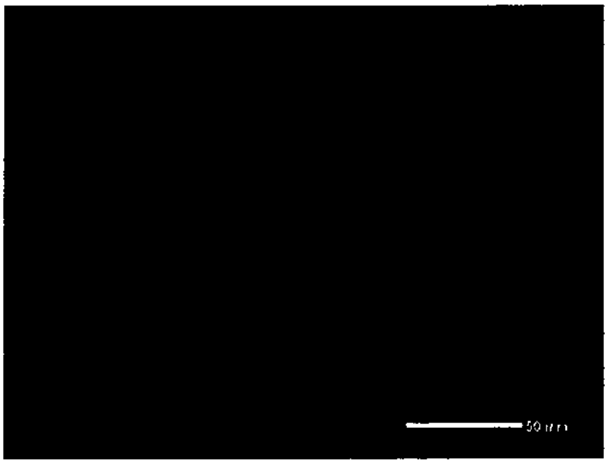
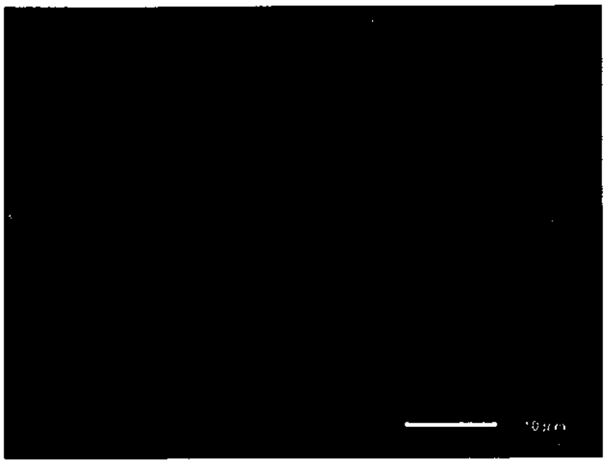
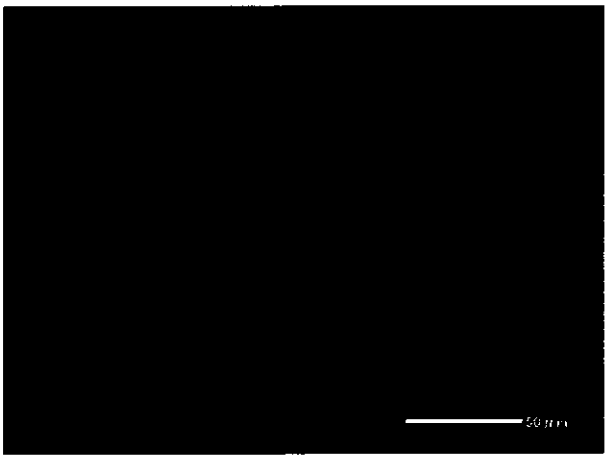
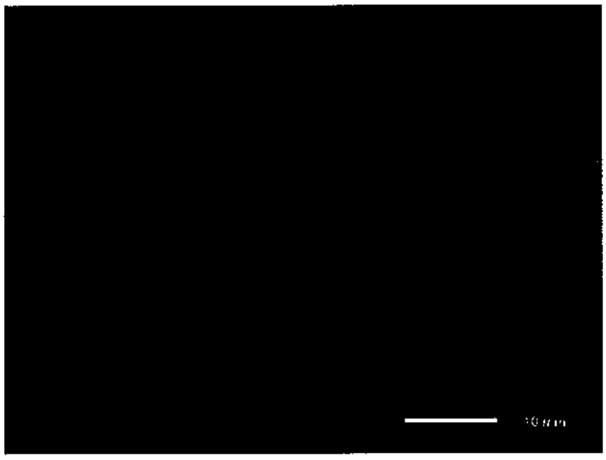


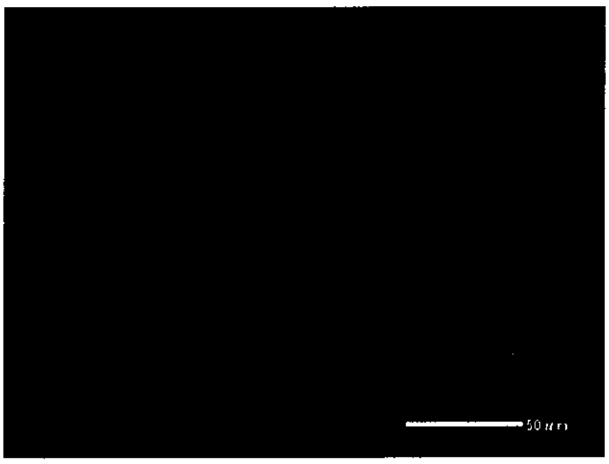
Photo II-11-6 SEM(Scanning electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, near the stop valve : Fine grain HAZ)











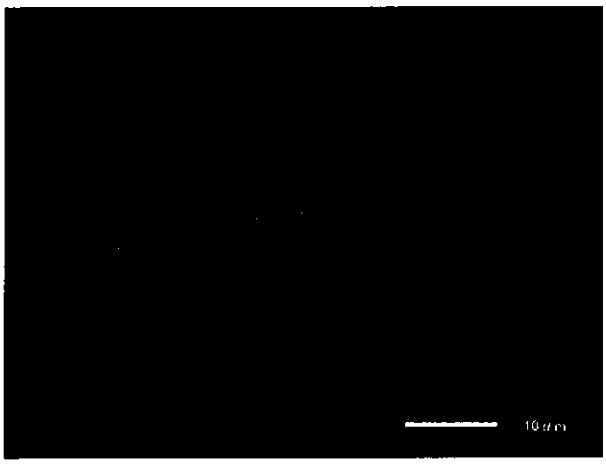


Photo Ⅱ-11-7 SEM(Scanning electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, near the stop valve : Coarse grain HAZ)

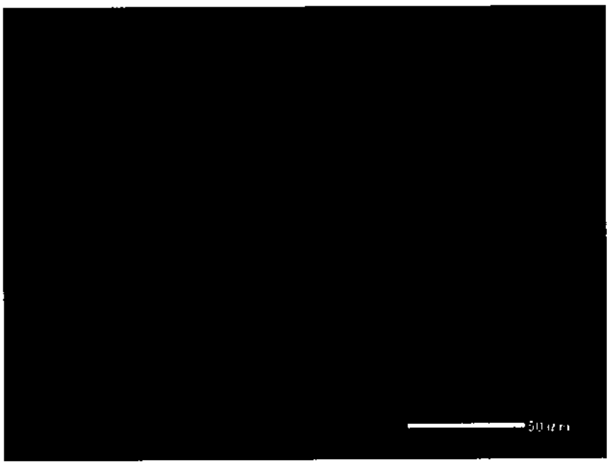
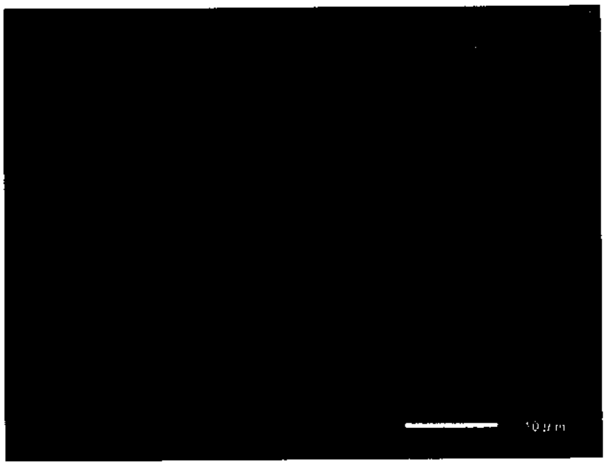
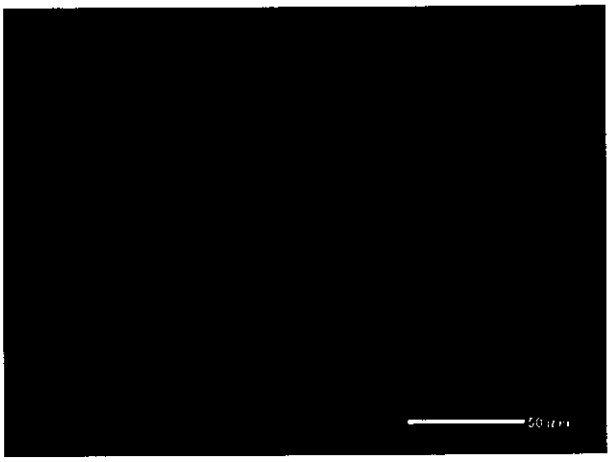
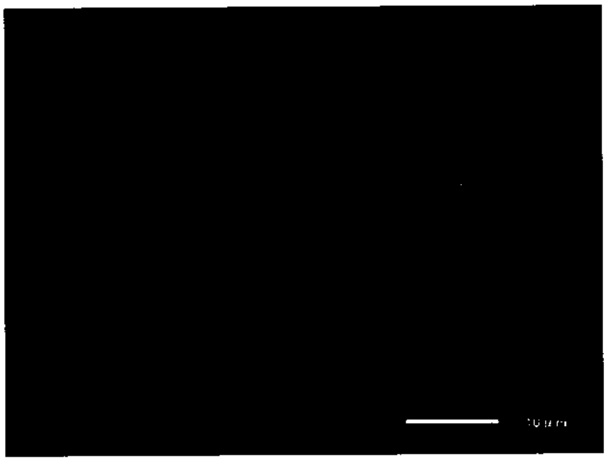
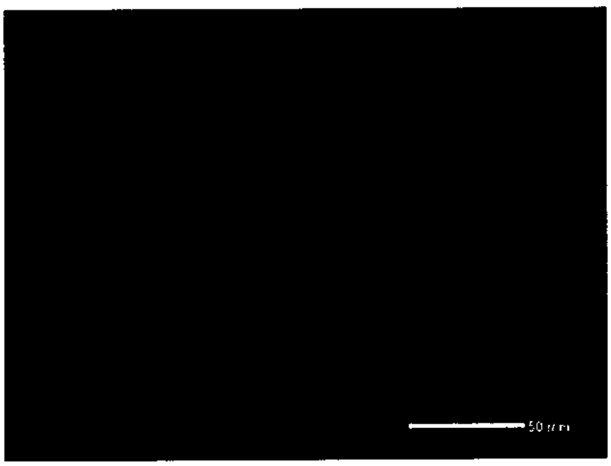
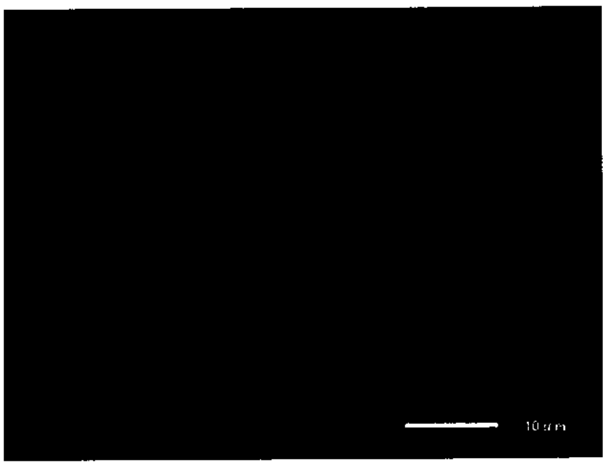







Photo Ⅱ-11-8 SEM(Scanning electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, near the stop valve : Weld metal)

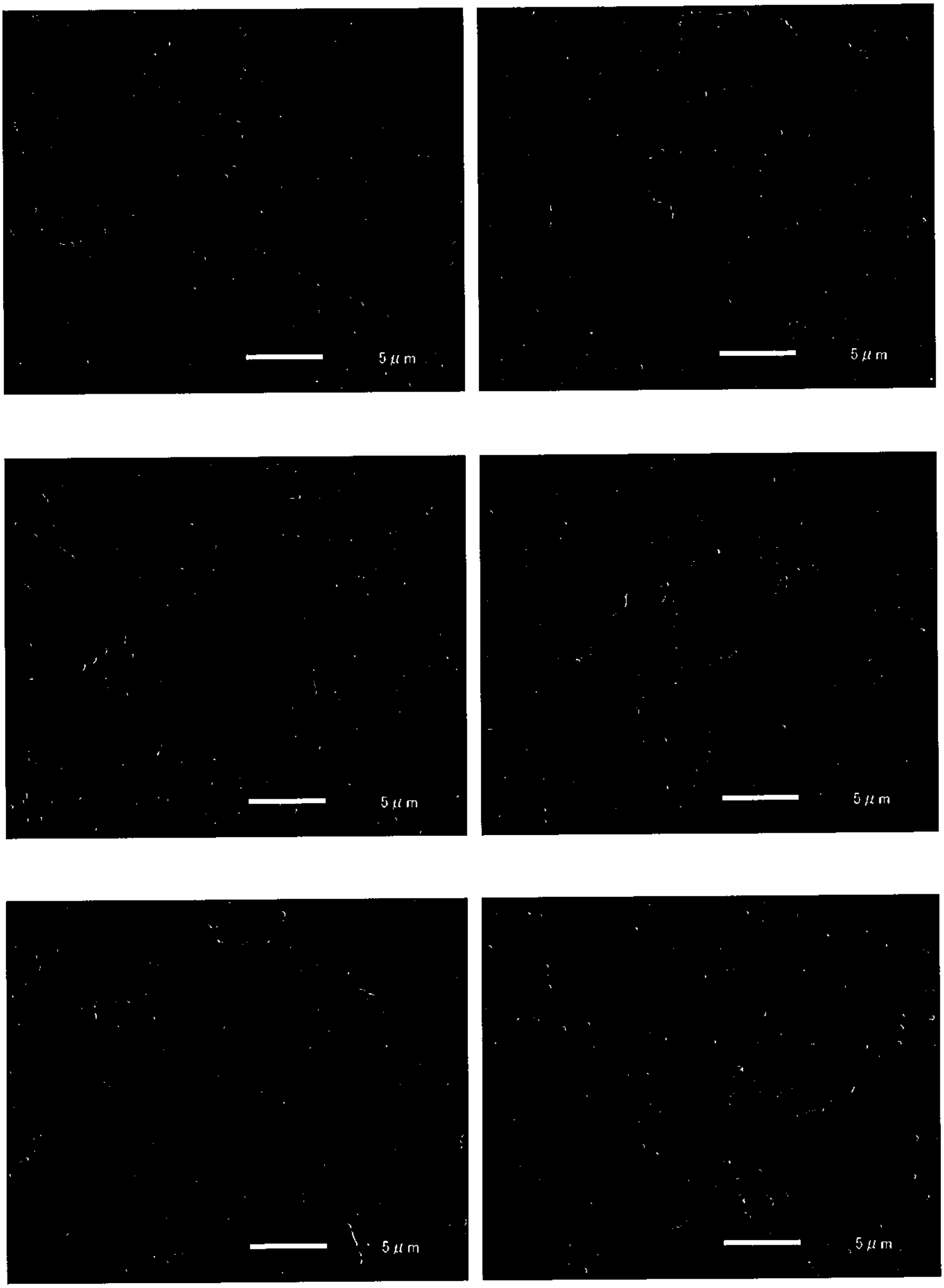


Photo Ⅱ-11-9 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Right(Circumferential weld, near the stop valve : Base metal)

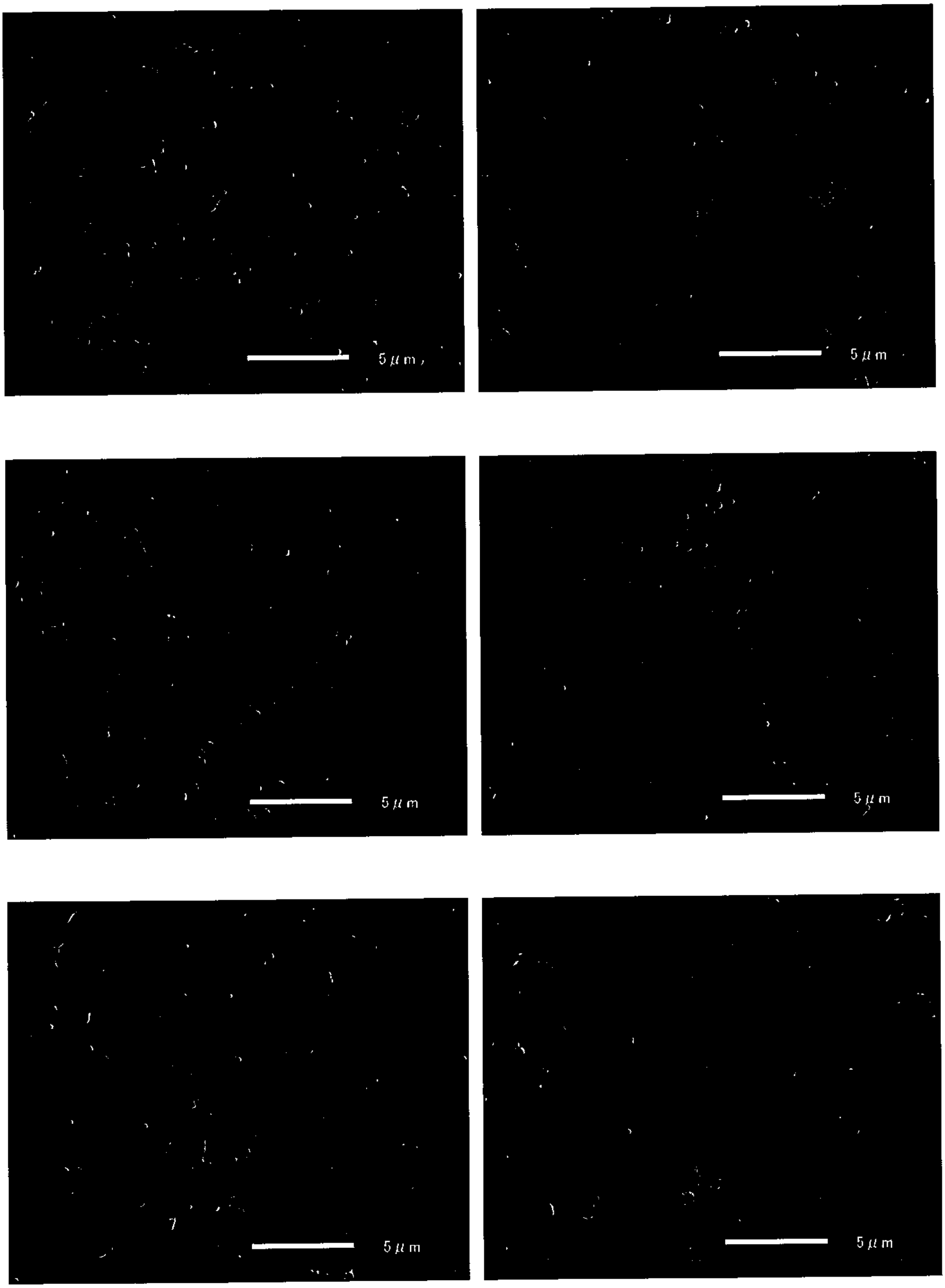


Photo Ⅱ-11-10 Precipitates along grain boundary by SEM observation
Main Steam Pipe-Right(Circumferential weld, near the stop valve : Fine grain HAZ)

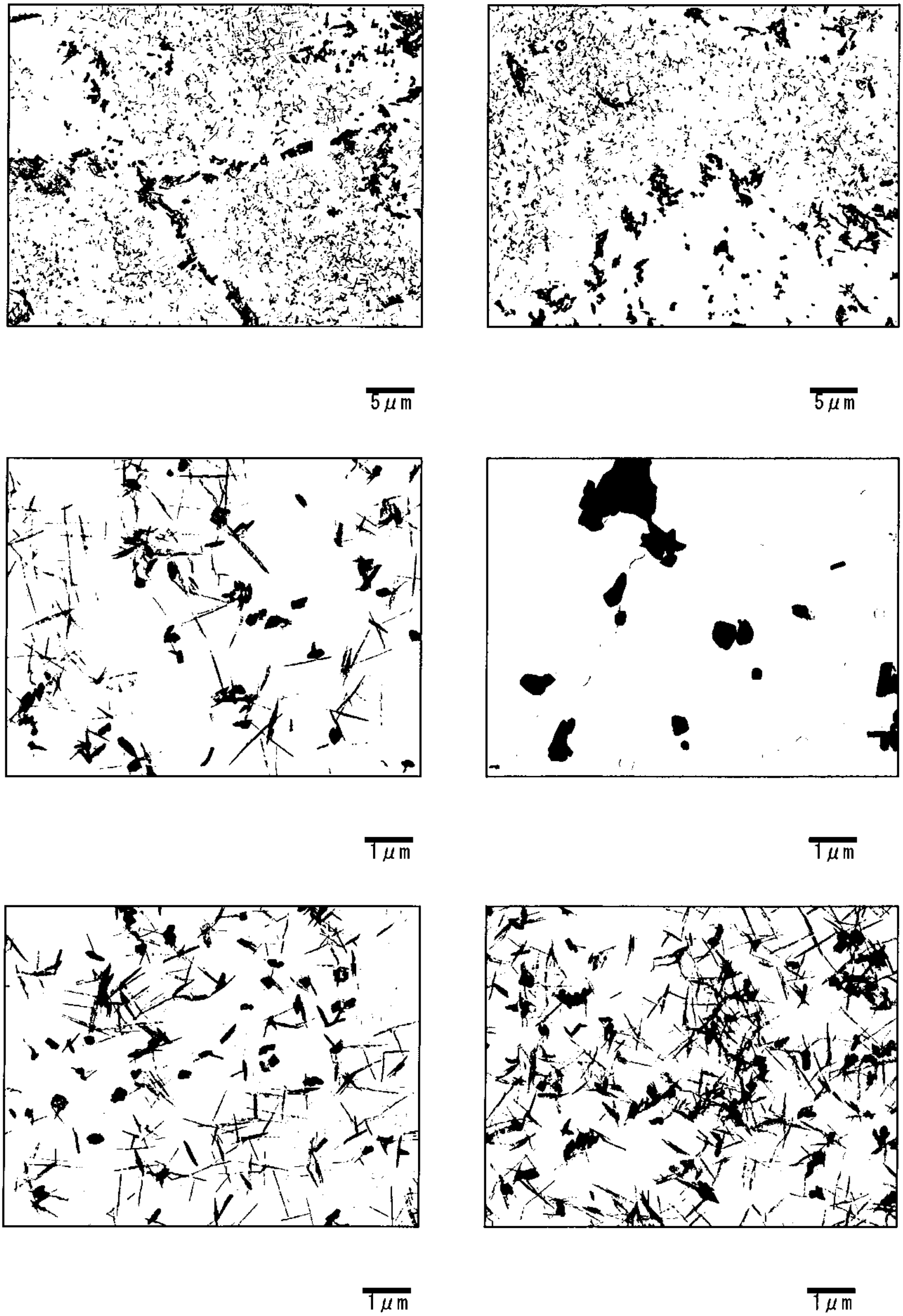


Photo Ⅱ-11-11 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Base metal)

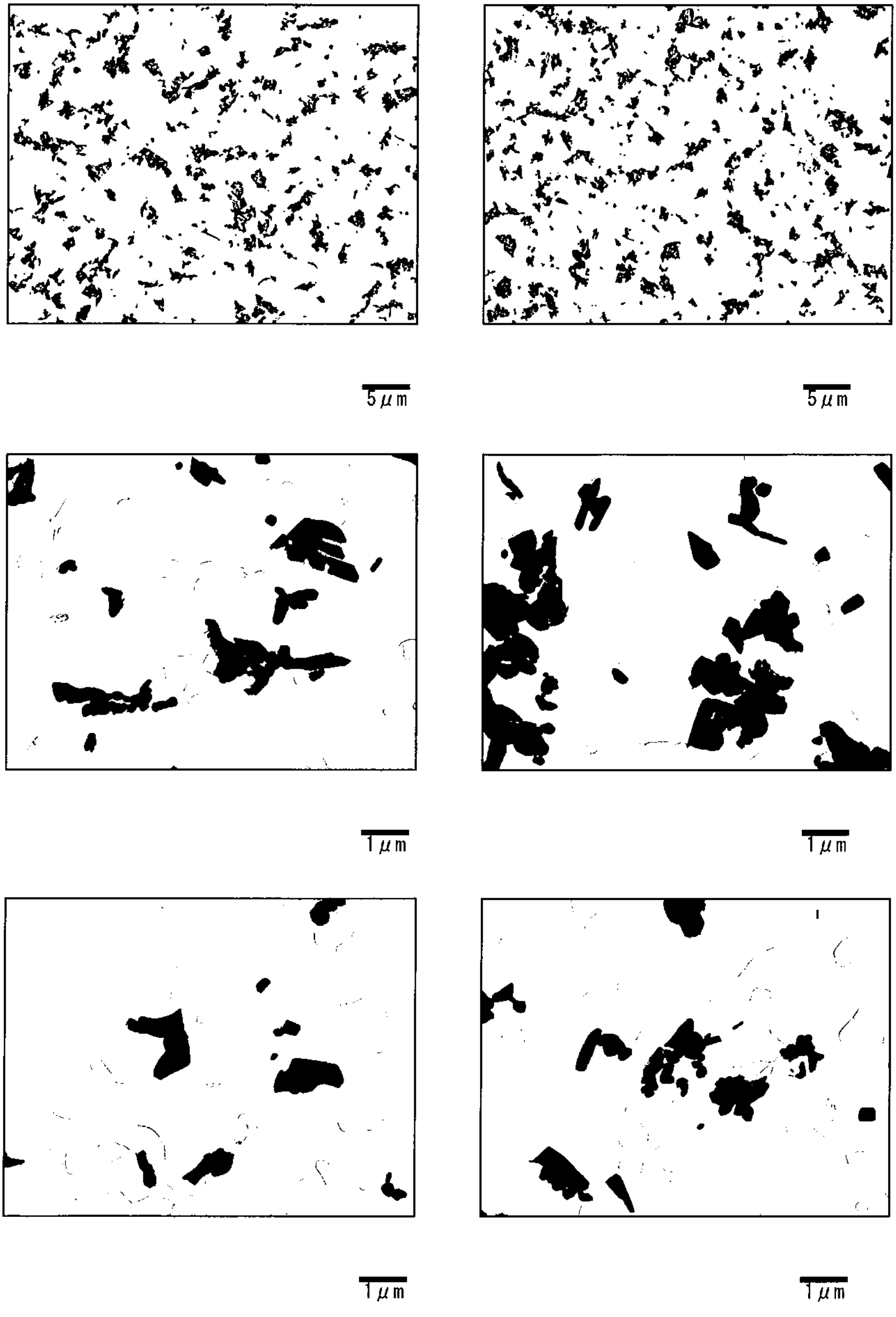


Photo II-11-12 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Fine grain HAZ)

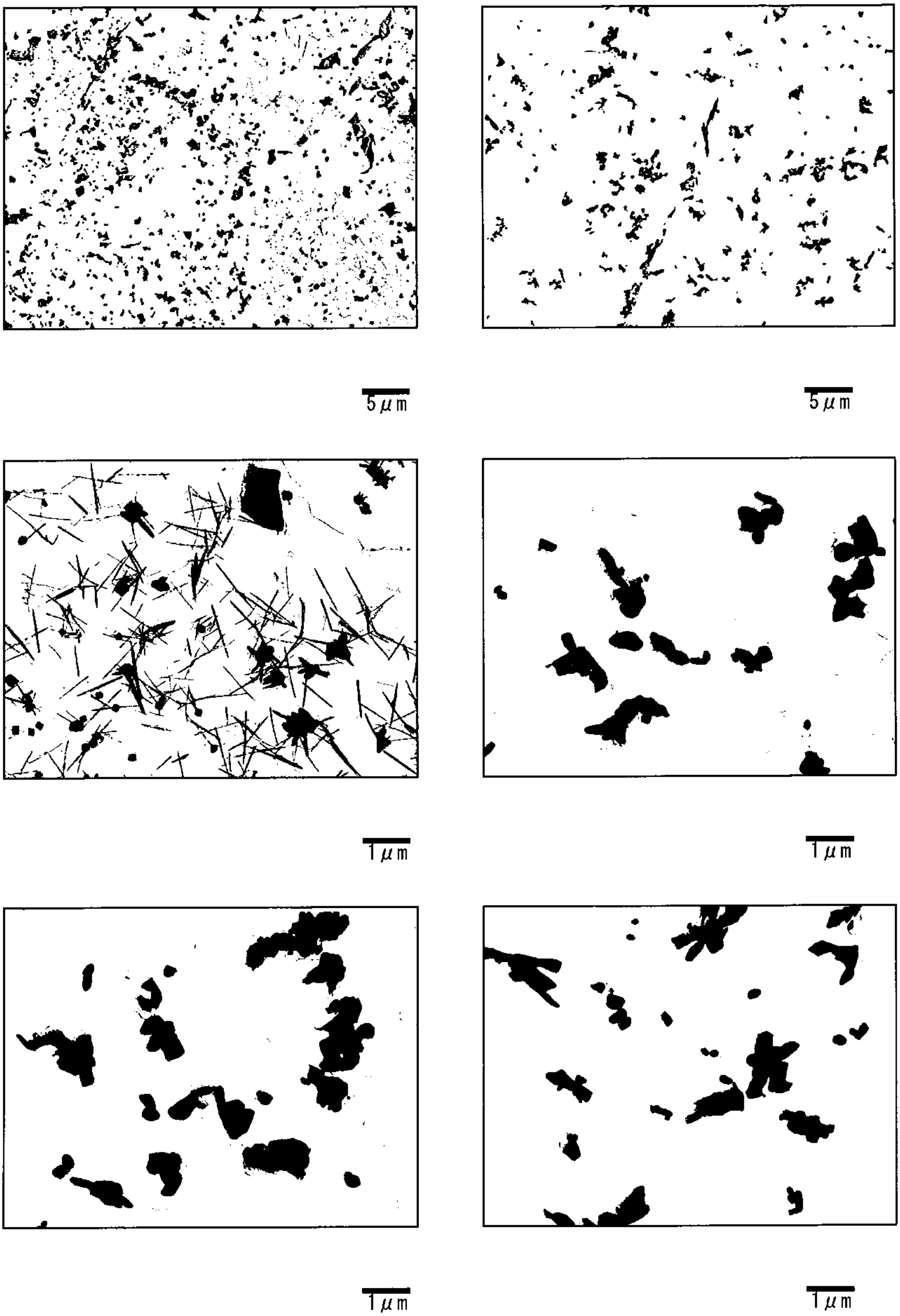


Photo II-11-13 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right(Circumferential weld, near the stop valve : Coarse grain HAZ)

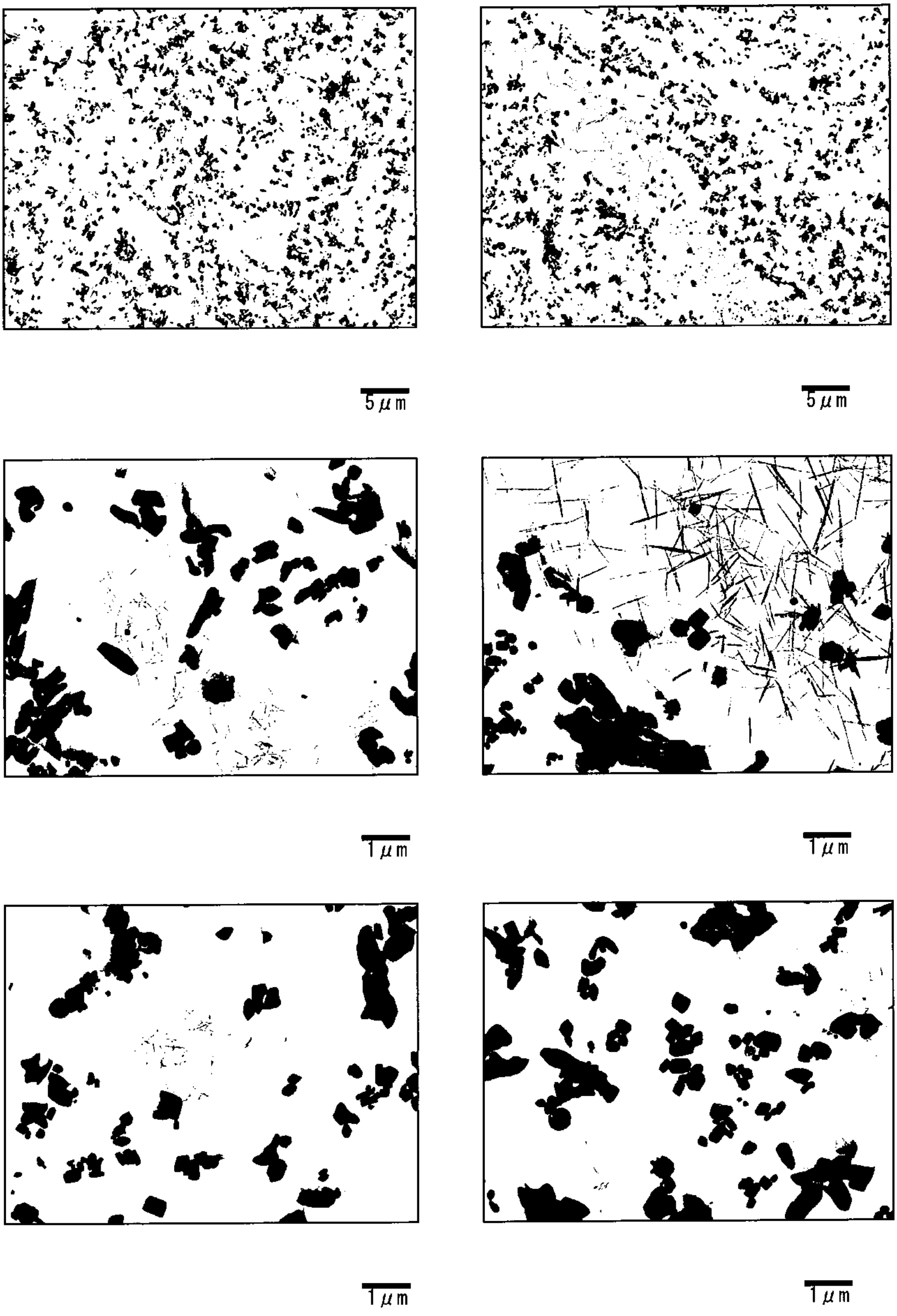


Photo II-11-14 Precipitates by TEM (Transmission electron microscope) observation
Main Steam Pipe-Right (Circumferential weld, near the stop valve : Weld metal)

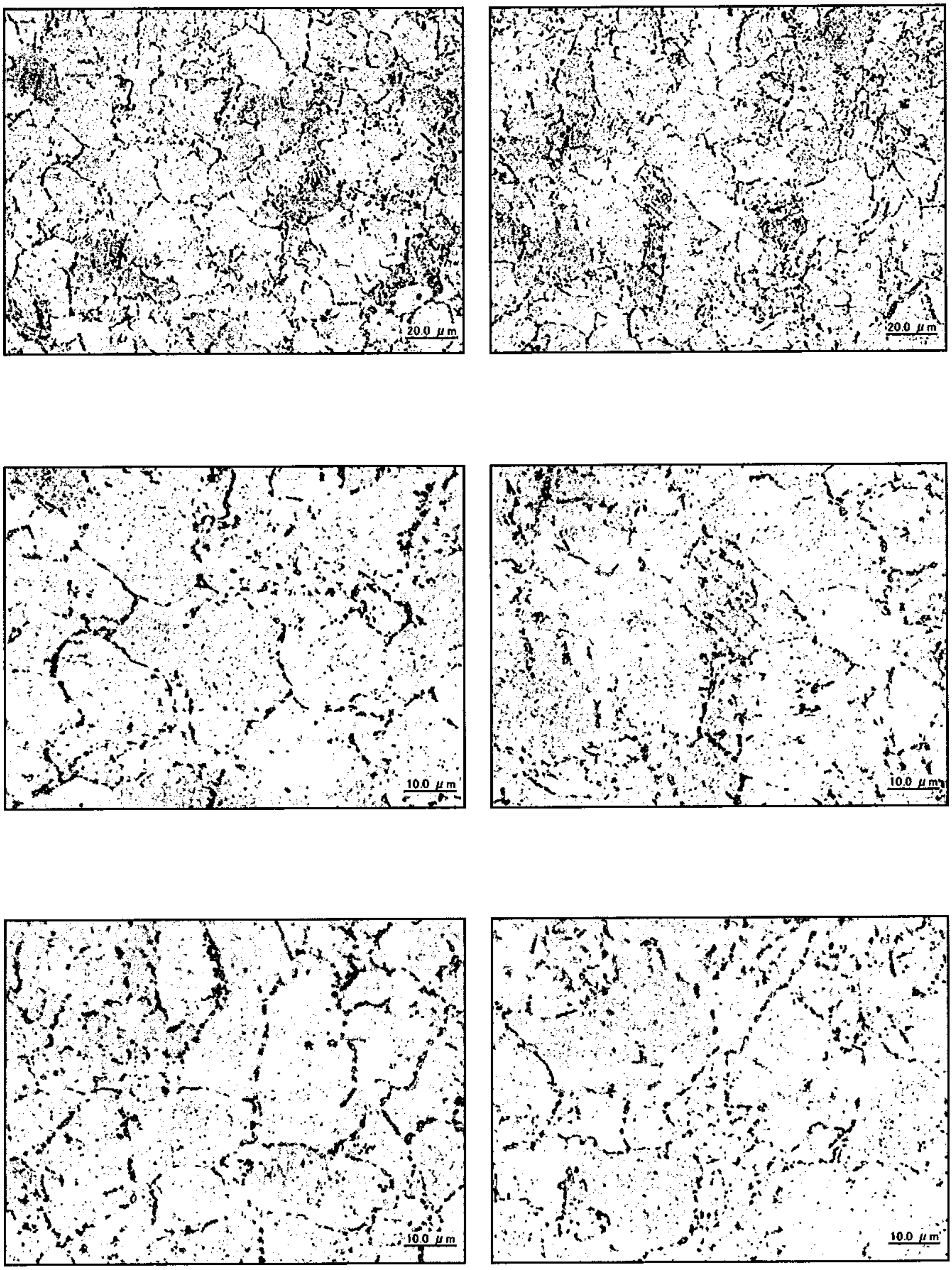


Photo II-12-1 Microstructure observation
Hot Reheat Pipe-Right (Circumferential weld : Base metal)

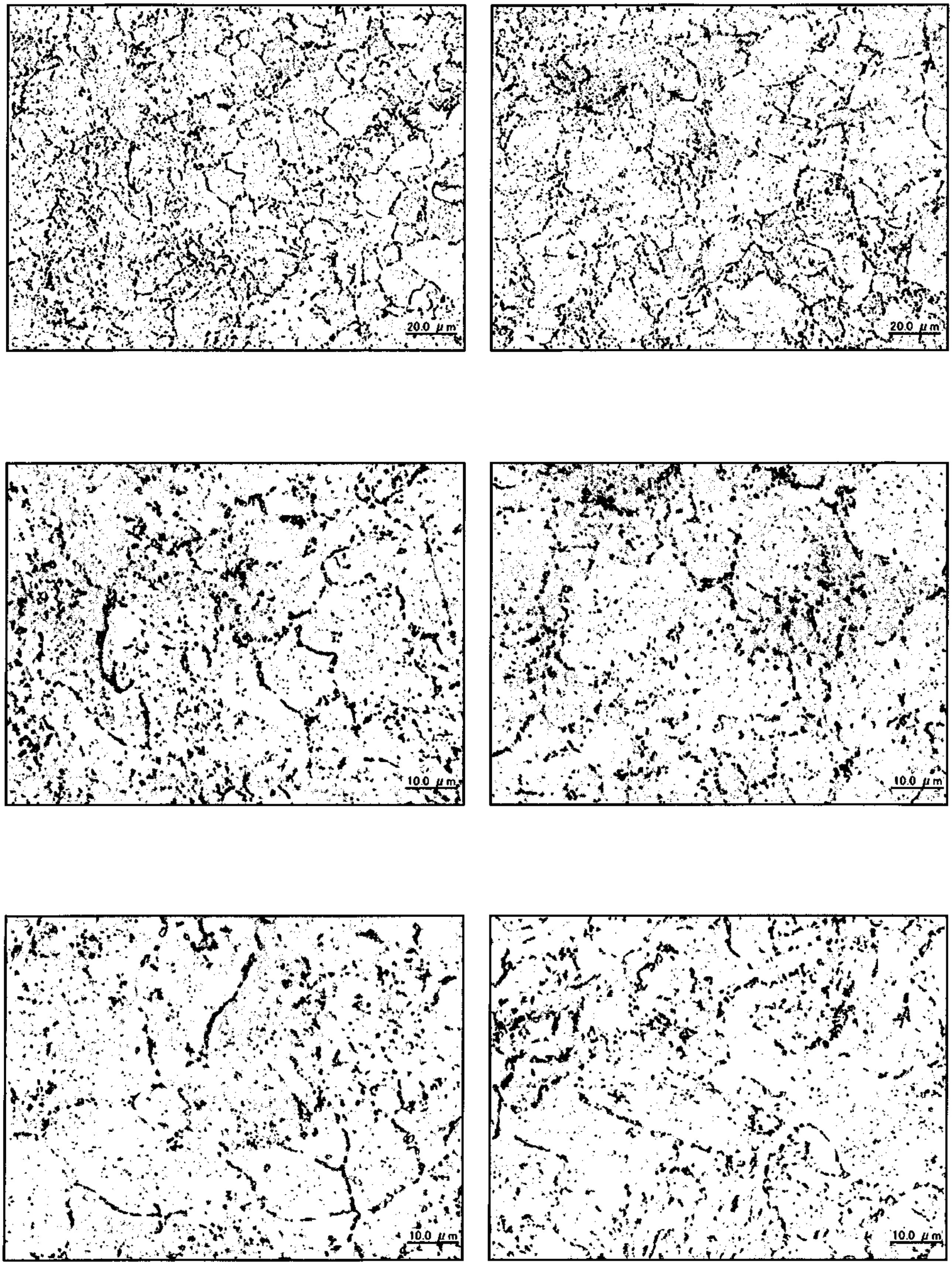


Photo II-12-2 Microstructure observation
Hot Reheat Pipe-Right (Circumferential weld : Intercritical zone)

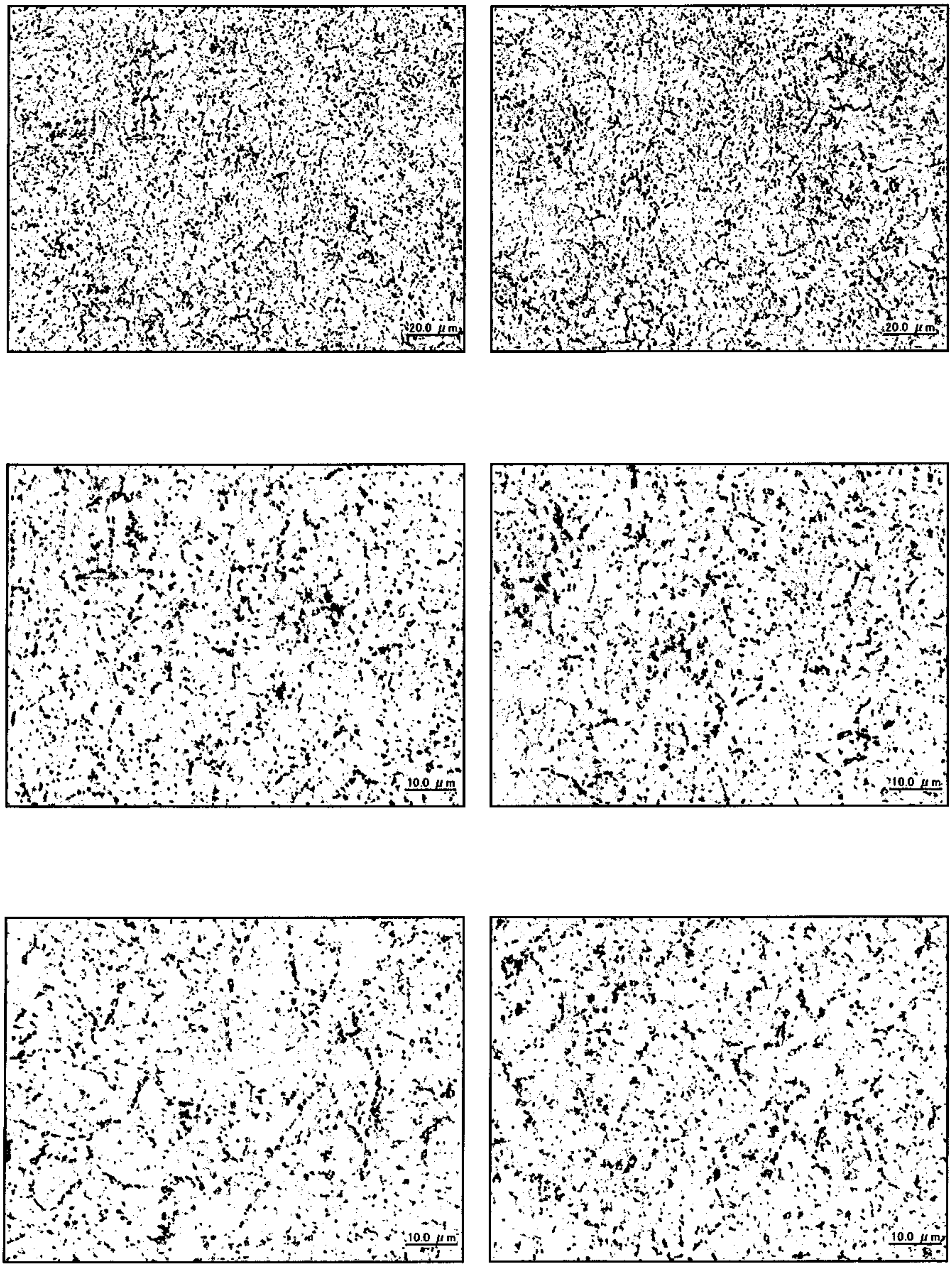


Photo Ⅱ-12-3 Microstructure observation
Hot Reheat Pipe-Right (Circumferential weld : Fine grain HAZ)

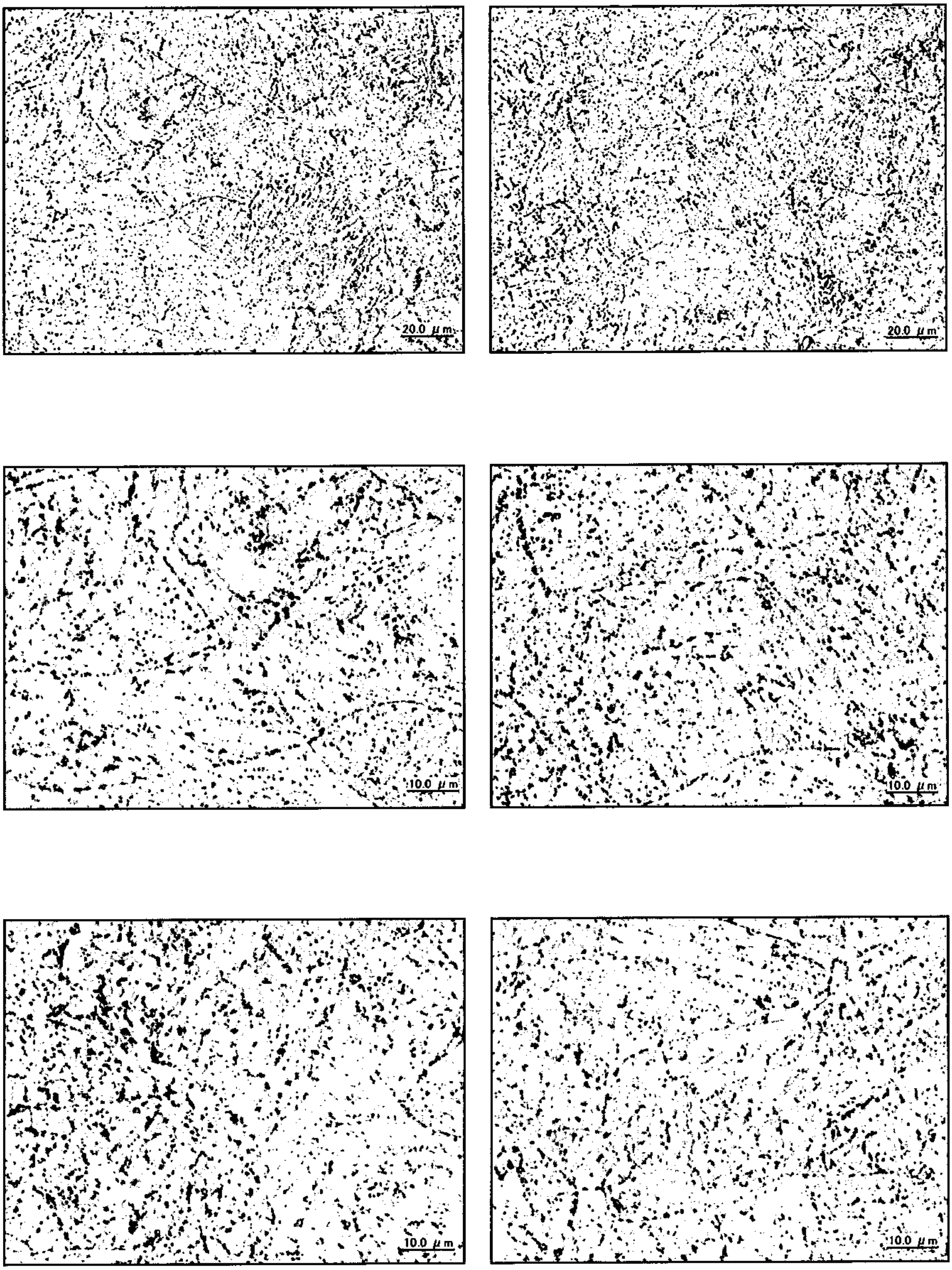
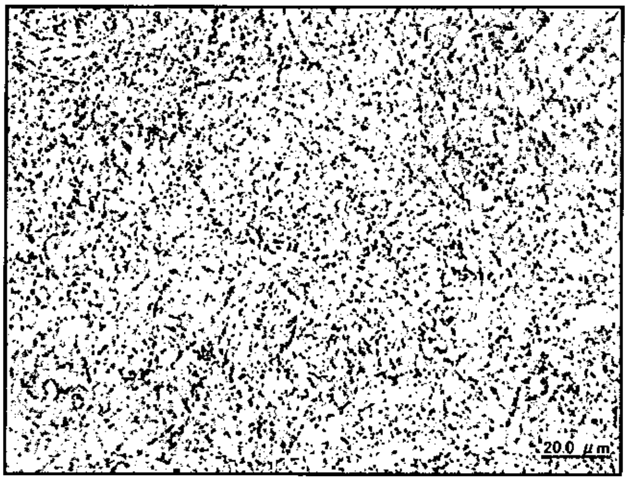
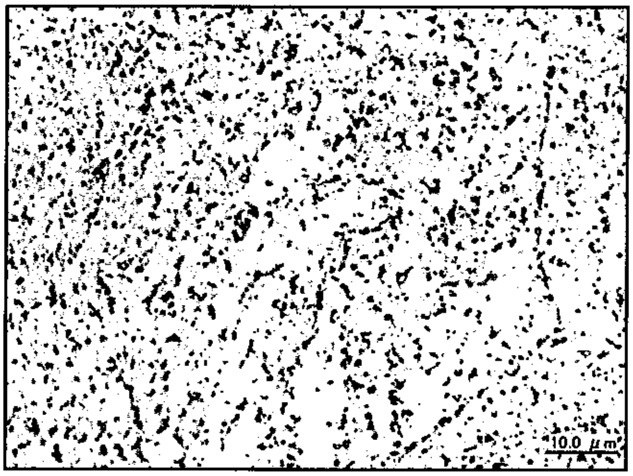
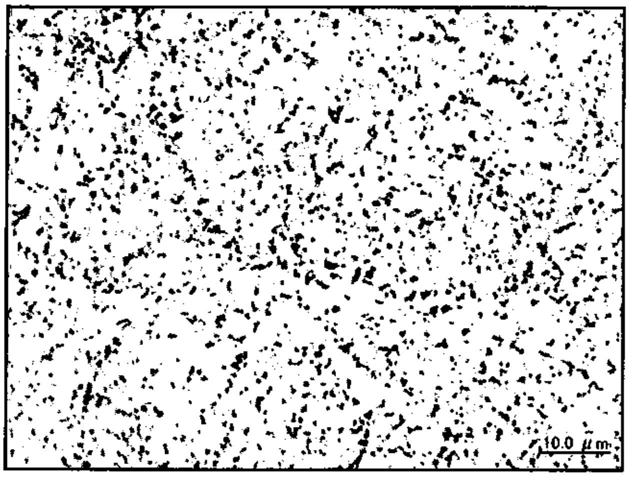
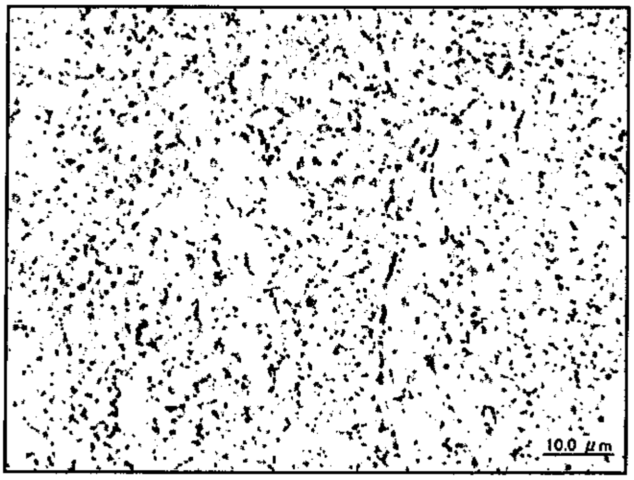


Photo II-12-4 Microstructure observation
Hot Reheat Pipe-Right (Circumferential weld : Coarse grain HAZ)









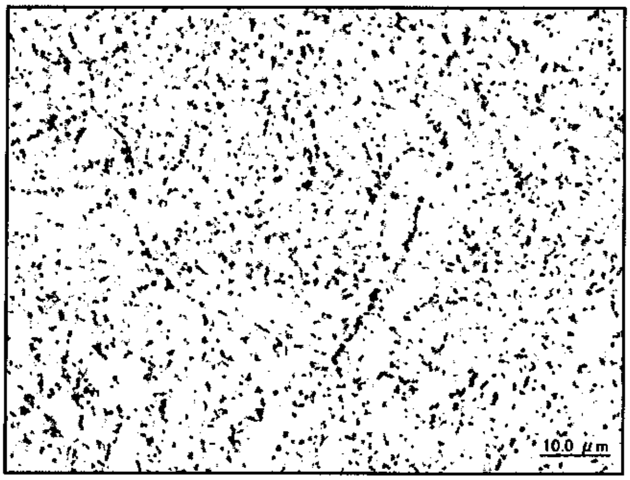


Photo II-12-5 Microstructure observation
Hot Reheat Pipe-Right (Circumferential weld : Weld metal)

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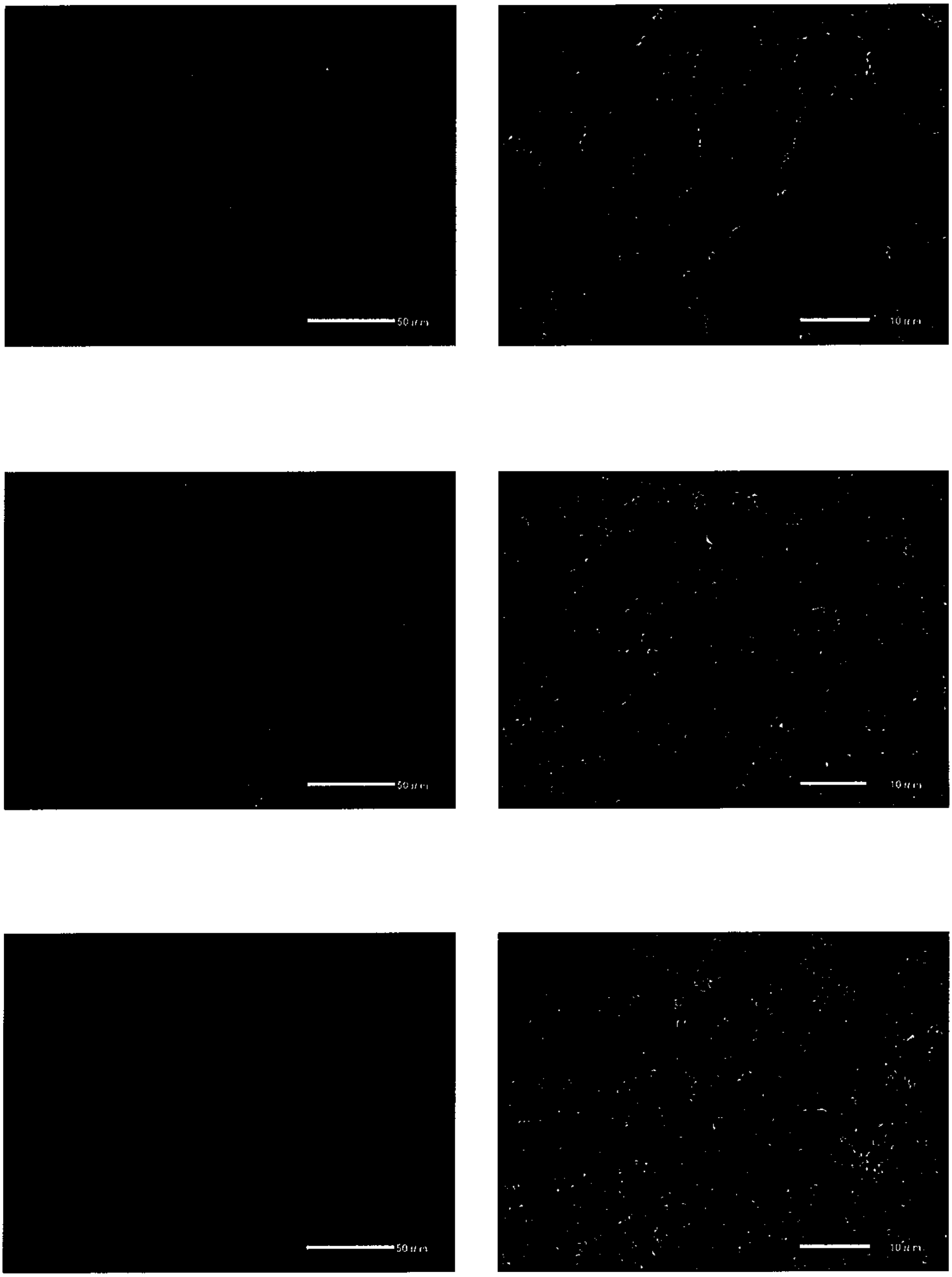


Photo Ⅱ-12-6 SEM(Scanning electron microscope) observation
Hot Reheat Pipe-Right(Circumferential weld : Fine grain HAZ)

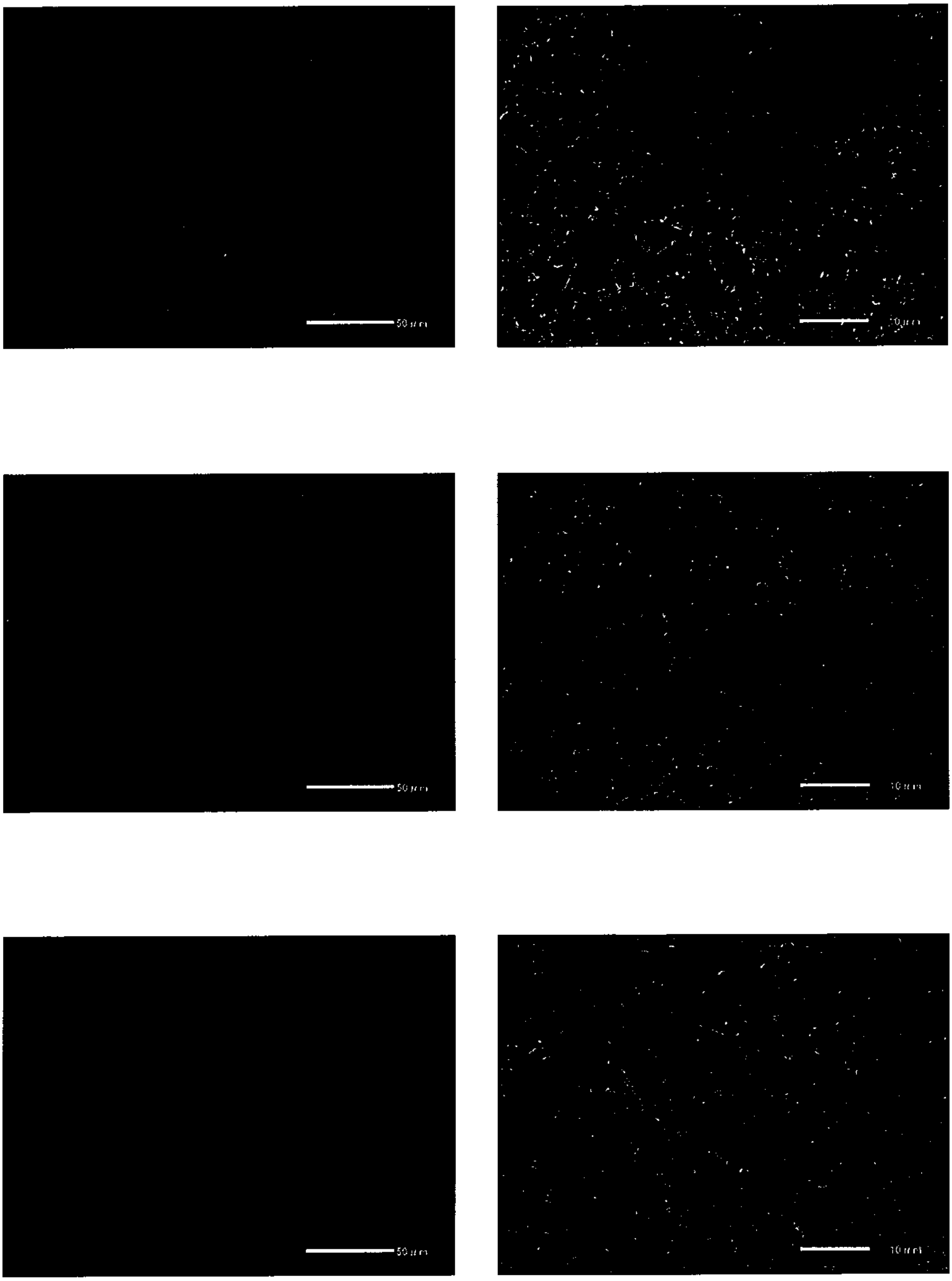


Photo II-12-7 SEM(Scanning electron microscope) observation
Hot Reheat Pipe-Right(Circumferential weld : Coarse grain HAZ)

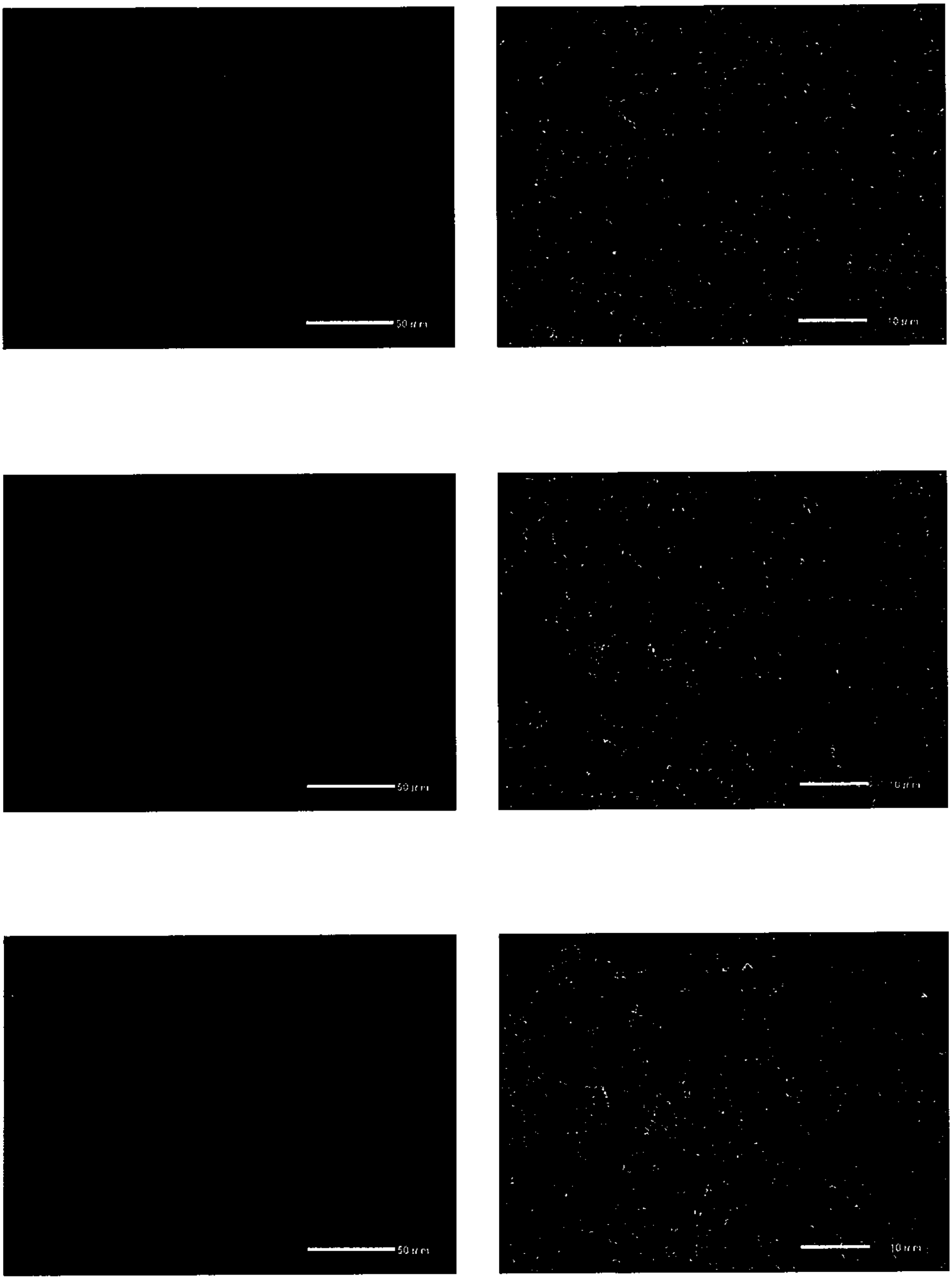


Photo Ⅱ-12-8 SEM(Scanning electron microscope) observation
Hot Reheat Pipe-Right(Circumferential weld : Weld metal)

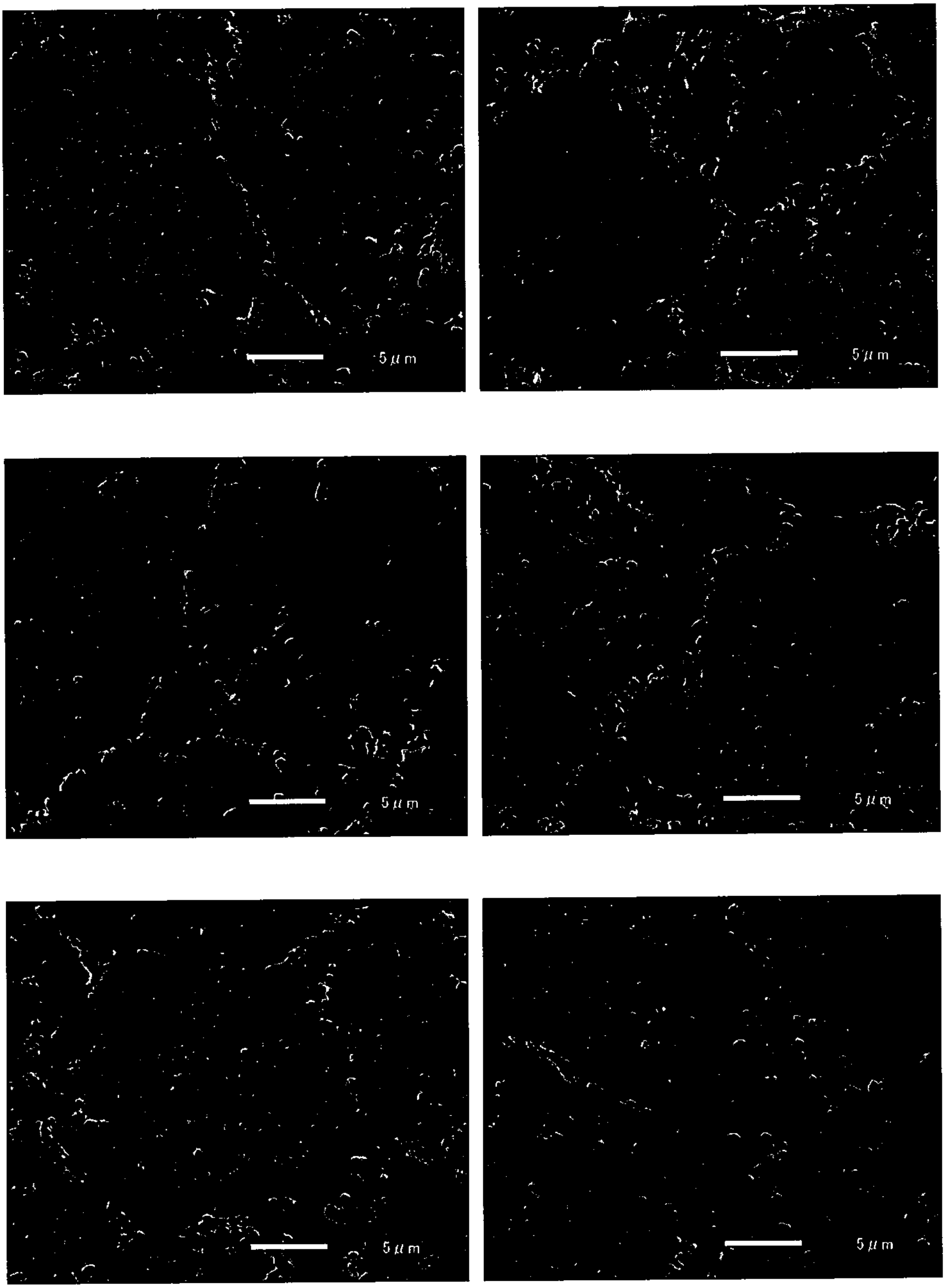
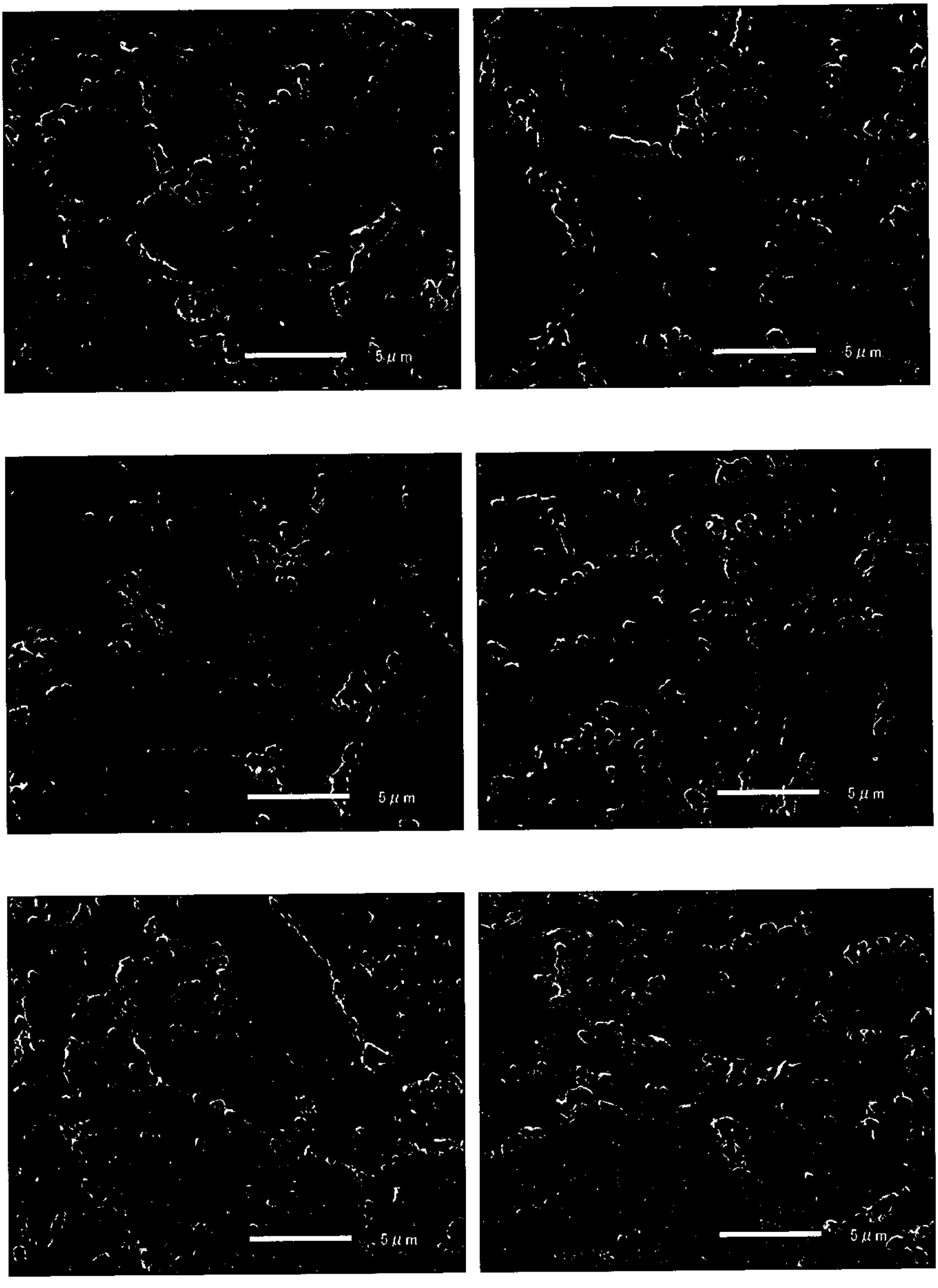


Photo II-12-9 Precipitates along grain boundary by SEM observation
Hot Reheat Pipe-Right(Circumferential weld : Base metal)



PhotoⅡ-12-10 Precipitates along grain boundary by SEM observation
Hot Reheat Pipe-Right(Circumferential weld : Fine grain HAZ)

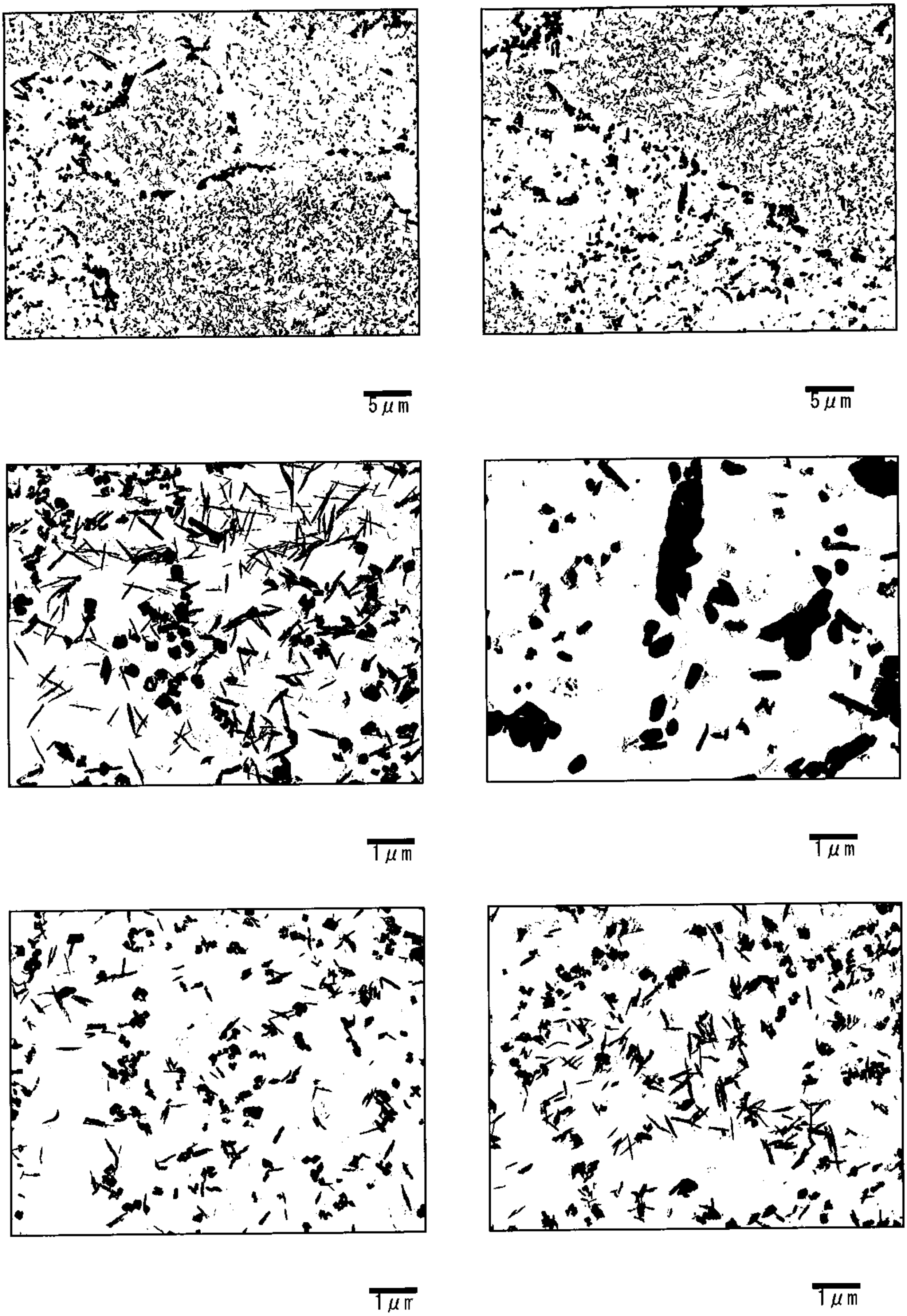


Photo II-12-11 Precipitates by TEM (Transmission electron microscope) observation
Hot Reheat Pipe-Right(Circumferential weld : Base metal)

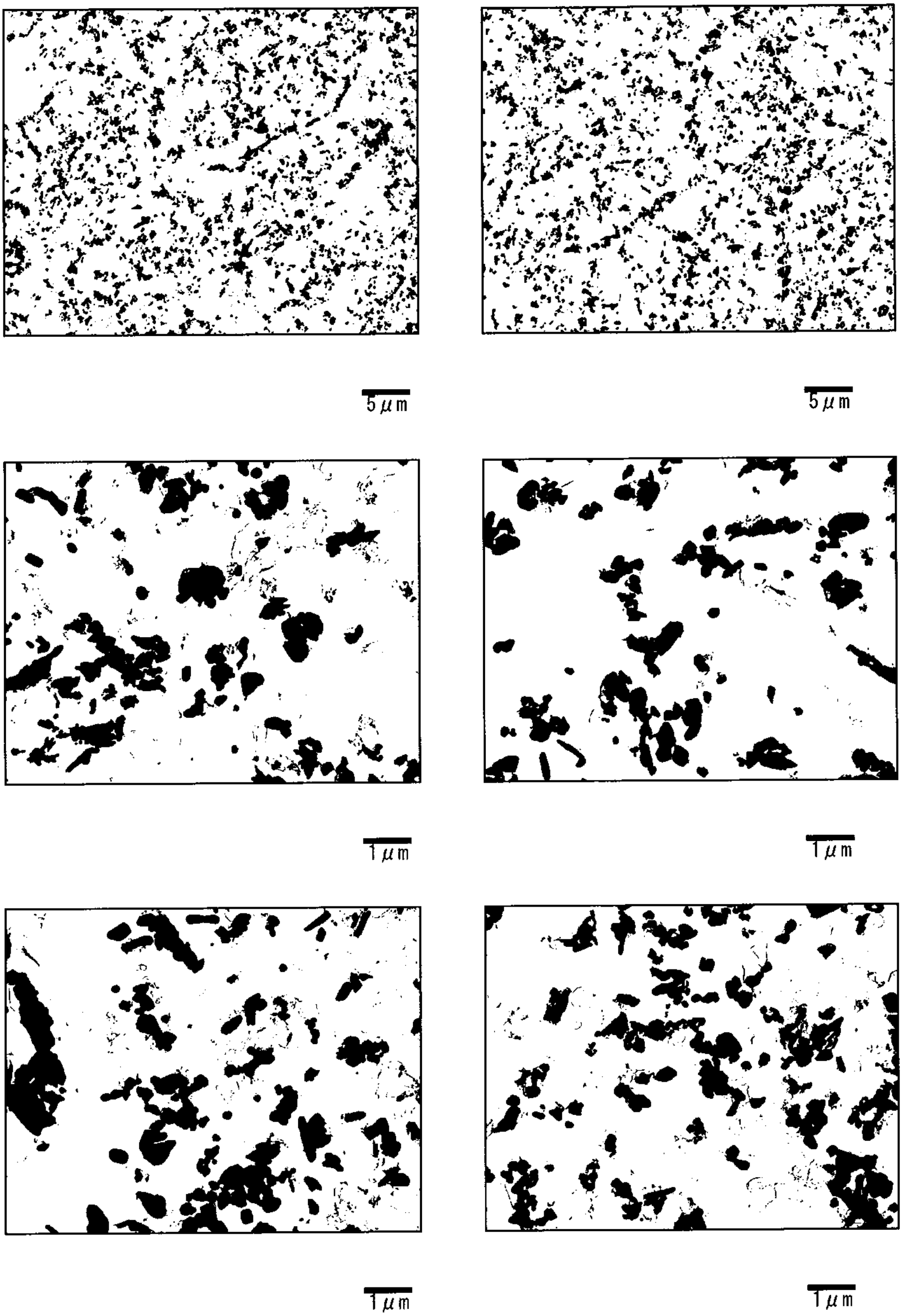


Photo II-12-12 Precipitates by TEM (Transmission electron microscope) observation
Hot Reheat Pipe-Right (Circumferential weld : Fine grain HAZ)

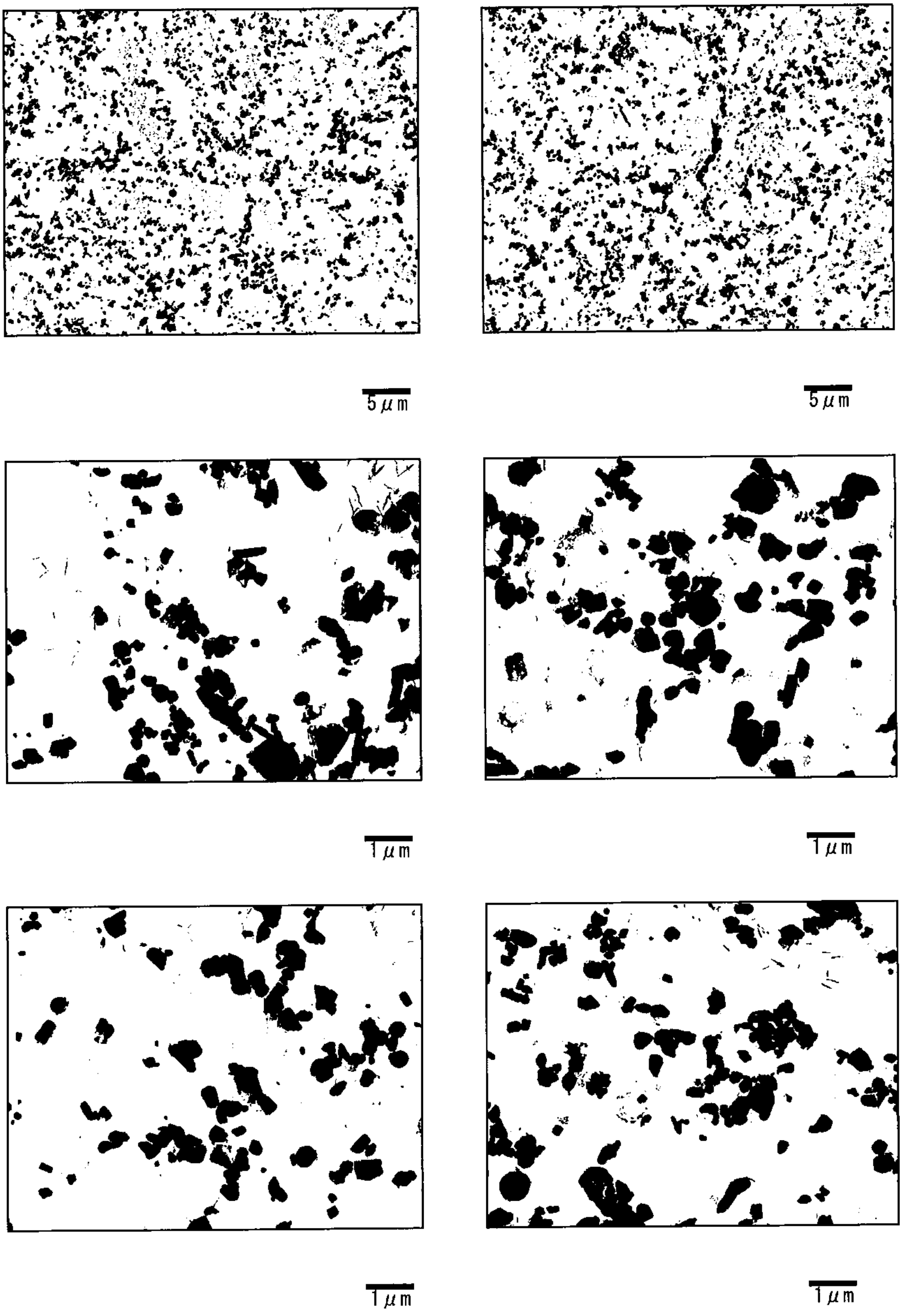


Photo II-12-13 Precipitates by TEM (Transmission electron microscope) observation
Hot Reheat Pipe-Right (Circumferential weld : Coarse grain HAZ)

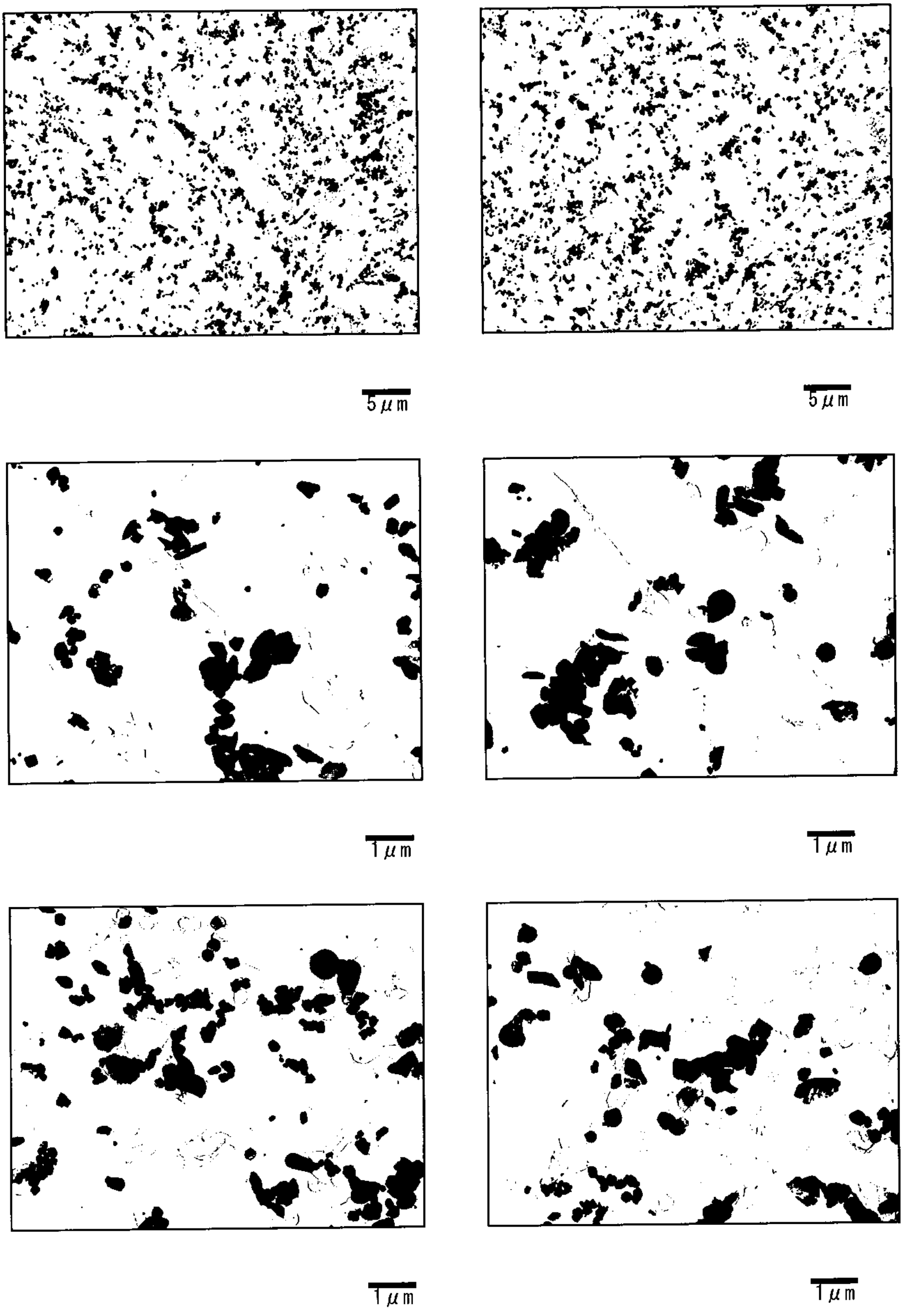
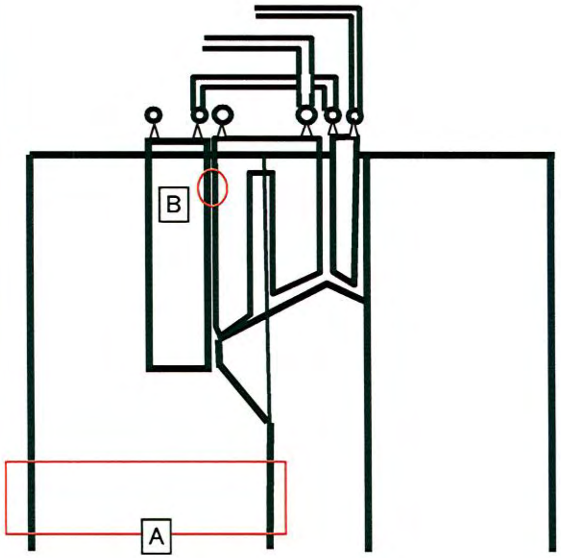


Photo II-12-14 Precipitates by TEM (Transmission electron microscope) observation
Hot Reheat Pipe-Right (Circumferential weld : Weld metal)

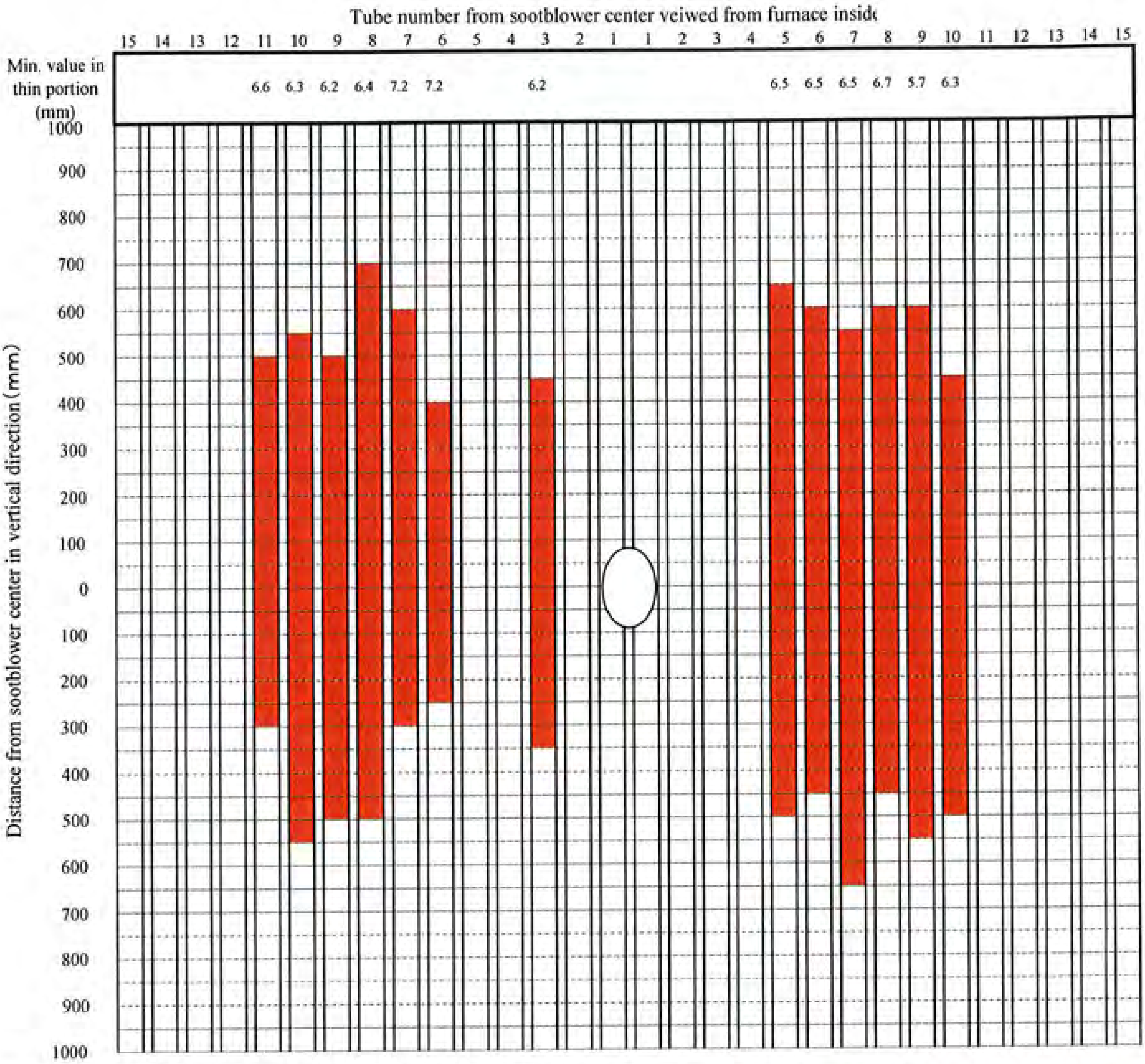
Table Ⅱ-12 Unchahar #2 Boiler Findings by visual inspection



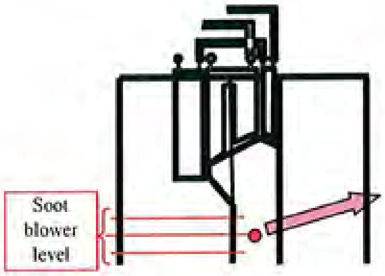
Potion noted

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	

Table Ⅱ-13 (Unchahar) WATER WALL Front wall Thickness Measurement Results



Tube specification SA210Gr.A φ63.5×t6.3(tsr6.1mm)



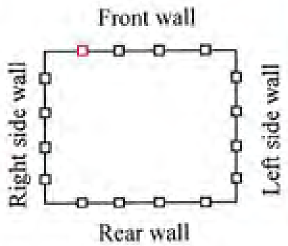
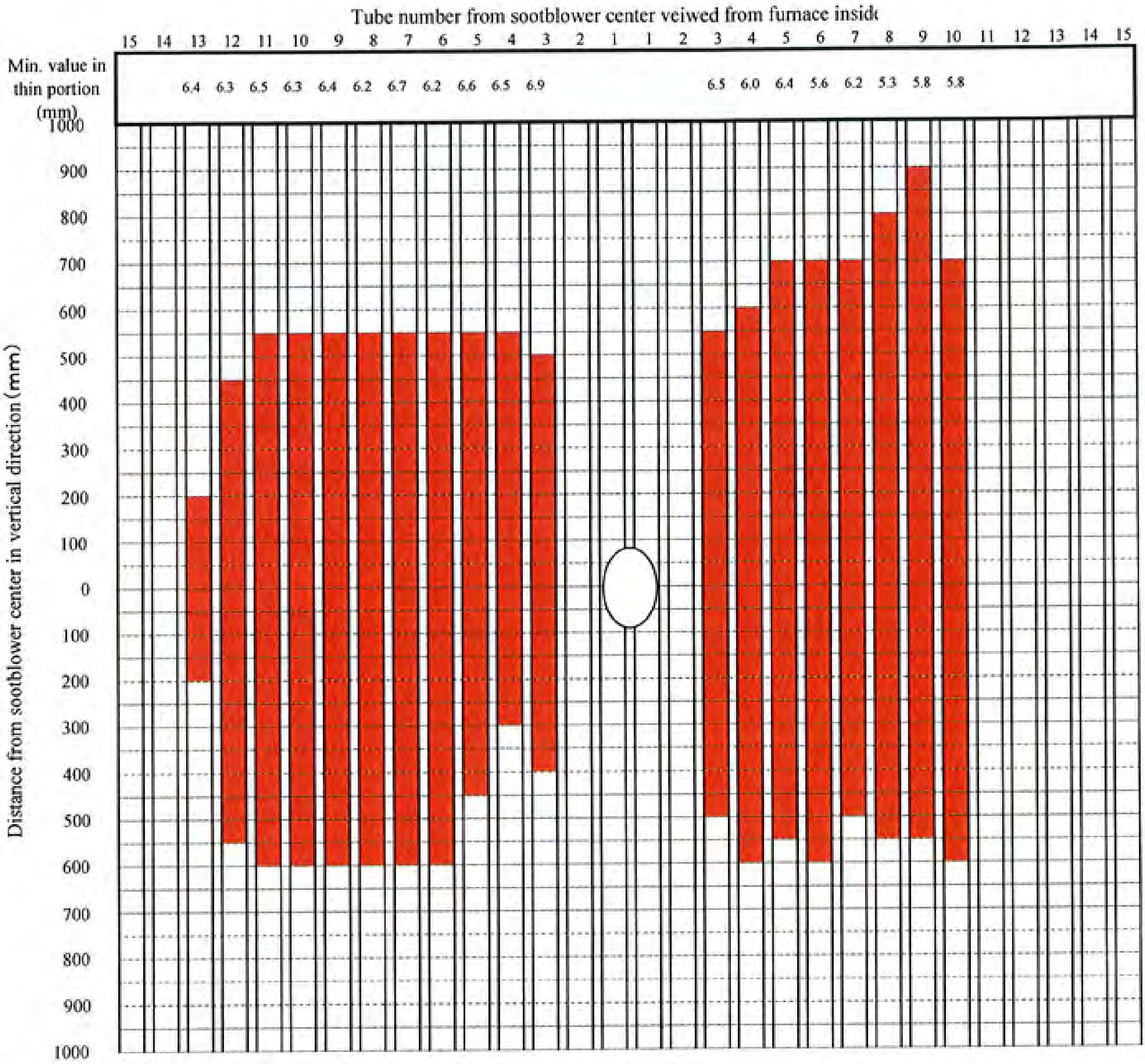
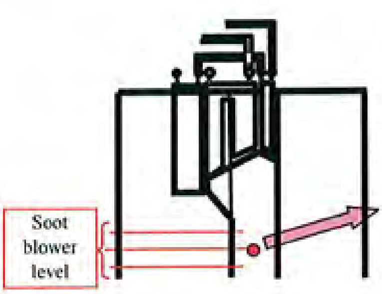


Table Ⅱ-14 (Unchahar) WATER WALL Rear wall Thickness Measurement Results



Tube specification SA210Gr.A φ63.5×t6.3(tsr6.1mm)



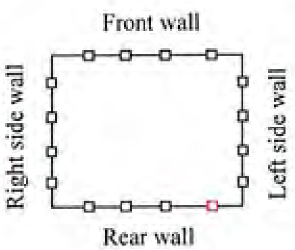
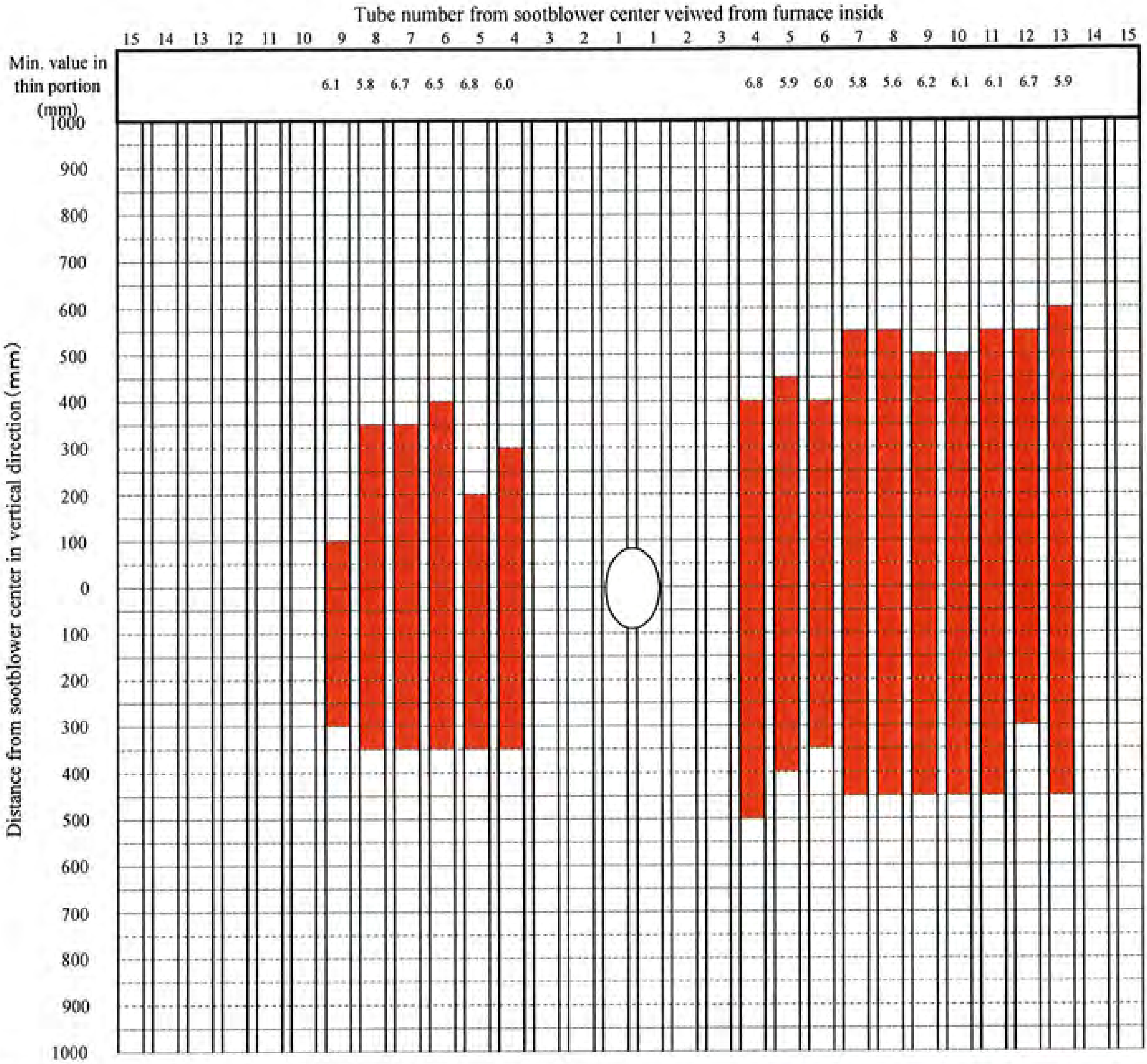
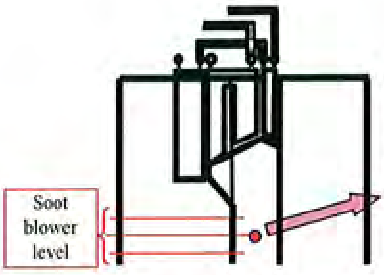


Table Ⅱ-15 (Unchahar) WATER WALL Left side wall Thickness Measurement Results



Tube specification SA210Gr.A φ63.5×t6.3(tsr6.1mm)



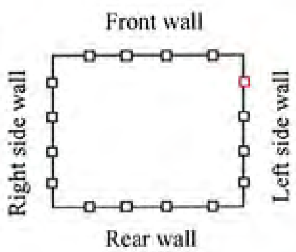
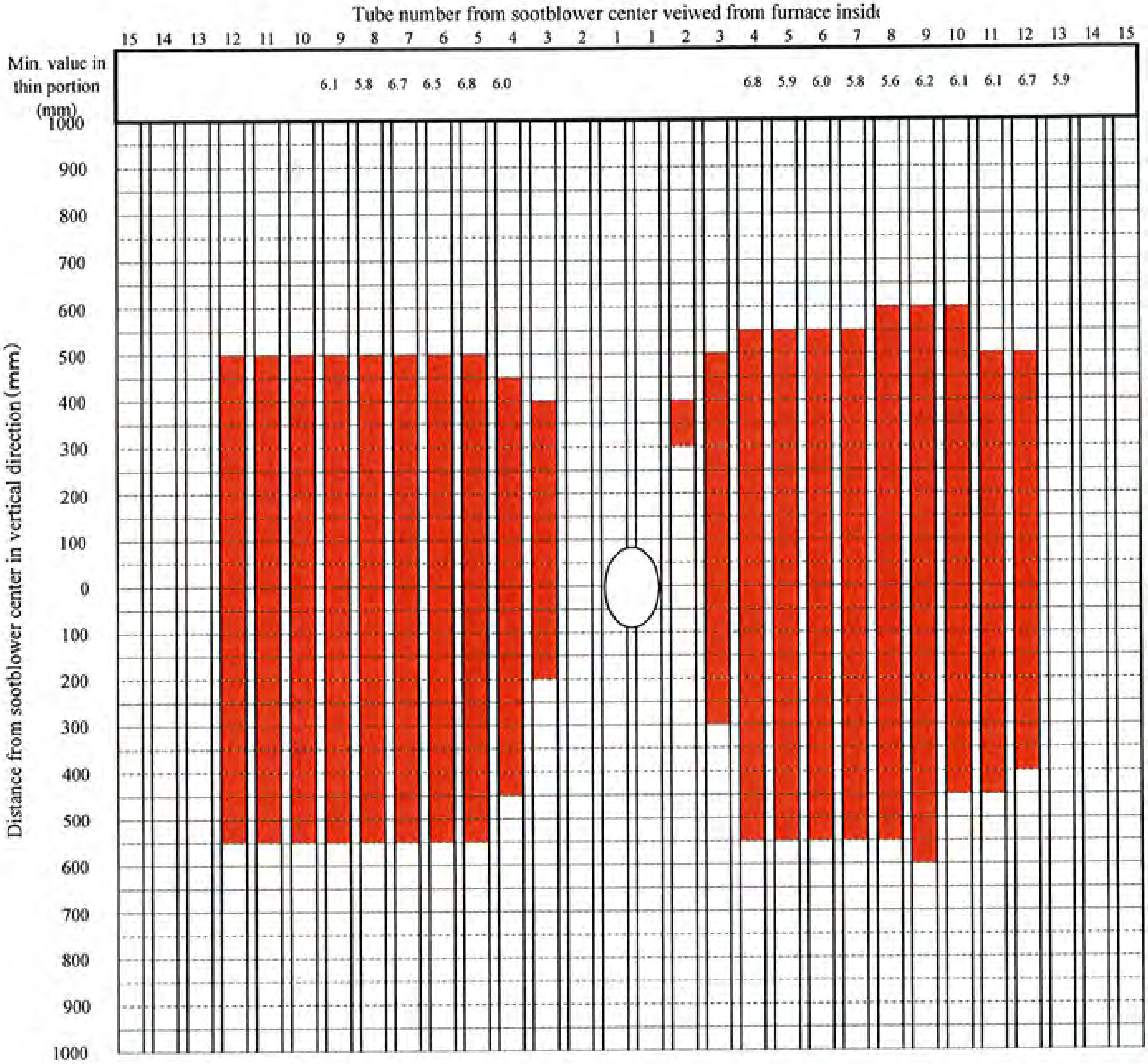
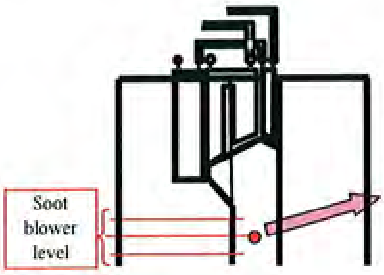


Table Ⅱ-16 (Unchahar) WATER WALL Right side wall Thickness Measurement Results



Tube specification SA210Gr.A φ63.5×t6.3(tsr6.1mm)



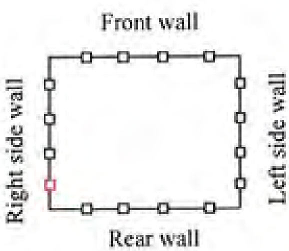
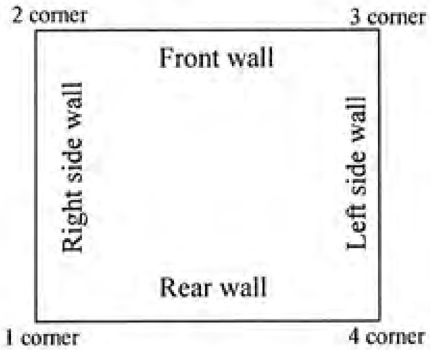
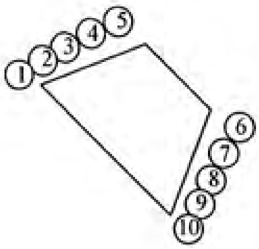


Table Ⅱ-17 (Unchahar) WATER WALL around burner Thickness Measuremen Results





Number of tubes around burne

Tube specification: SA210Gr.A φ63.5×t6.3(tsr6.1mm)

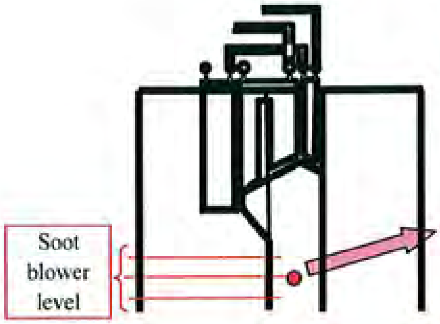
Tube No.	1 corner	2 corner	3 corner	4 corner
1	-	-	-	-
2	6.5	-	-	-
3	6.2	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	6.2
7	-	-	-	4.7
8	6.4	5.7	-	5.1
9	6.1	-	-	-
10	6.5	-	-	-

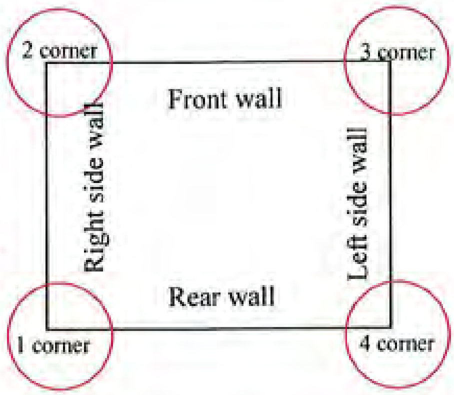
Erosion part at 1corner

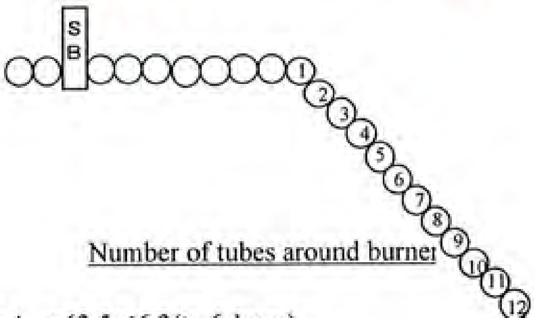
Erosion part at 2 corner

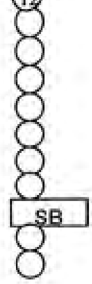
Erosion part at 3 corner

Table Ⅱ-18 (Unchahar) WATER WALL corner tube Thickness Measurement Results









Tube specification: SA210Gr.A φ63.5×t6.3(tsr6.1mm)

Tube No.	1 corner	2 corner	3 corner	4 corner
1	5.7	5.8	4.4	6.4
2	4.9	4.3	4.2	5.1
3	5.0	4.7	5.0	5.5
4	5.7	5.6	5.8	-
5	-	6.2	-	-
6	-	-	-	-
7	-	-	-	-
8	-	7.2	-	-
9	-	6.2	-	-
10	6.9	6.2	6.3	-
11	6.3	6.0	6.8	6.0
12	6.5	6.4	-	6.1

1 corner aspect

2 corner aspect

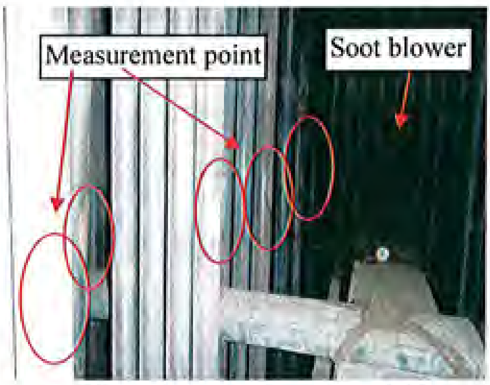
3 corner aspect

4 corner aspect

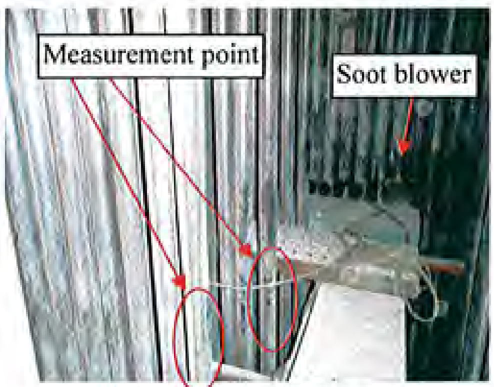
Table Ⅱ-19 (Unchahar) Platen SH Thickness Measuremen Results

Tube specification: SA213T22 φ51.0×t9.6(tsr9.4mm)

Panel No. (From left)	Soot blower leve			
	1st soot blower level ●			2nd soot blower level ●
	1st tube from rear	2nd tube from rear	5th tube from rear	1st tube from rear
1	9.8	-	-	10.0
2	9.9	-	-	10.0
3	10.0	-	-	10.2
4	10.2	-	-	10.4
5	9.9	-	-	10.2
6	10.3	-	-	10.3
7	10.1	-	-	10.2
8	10.1	-	-	10.1
9	9.9	10.1	-	10.1
10	10.1	-	-	10.3
11	10.1	10.0	-	10.2
12	10.1	-	-	10.2
13	10.0	-	-	10.1
14	9.9	-	-	10.0
15	10.1	-	10.2	10.3
16	10.1	-	-	10.3
17	9.9	-	-	9.9
18	10.2	-	-	10.2
19	10.2	-	-	10.1
20	10.1	-	-	10.2
21	10.0	-	-	10.1
22	10.3	-	-	10.3
23	10.3	-	-	10.2
24	10.3	-	-	10.2
25	10.0	-	-	10.1
26	10.2	-	-	10.2
27	10.2	-	-	10.2
28	10.2	-	-	10.3
29	10.2	-	-	10.3



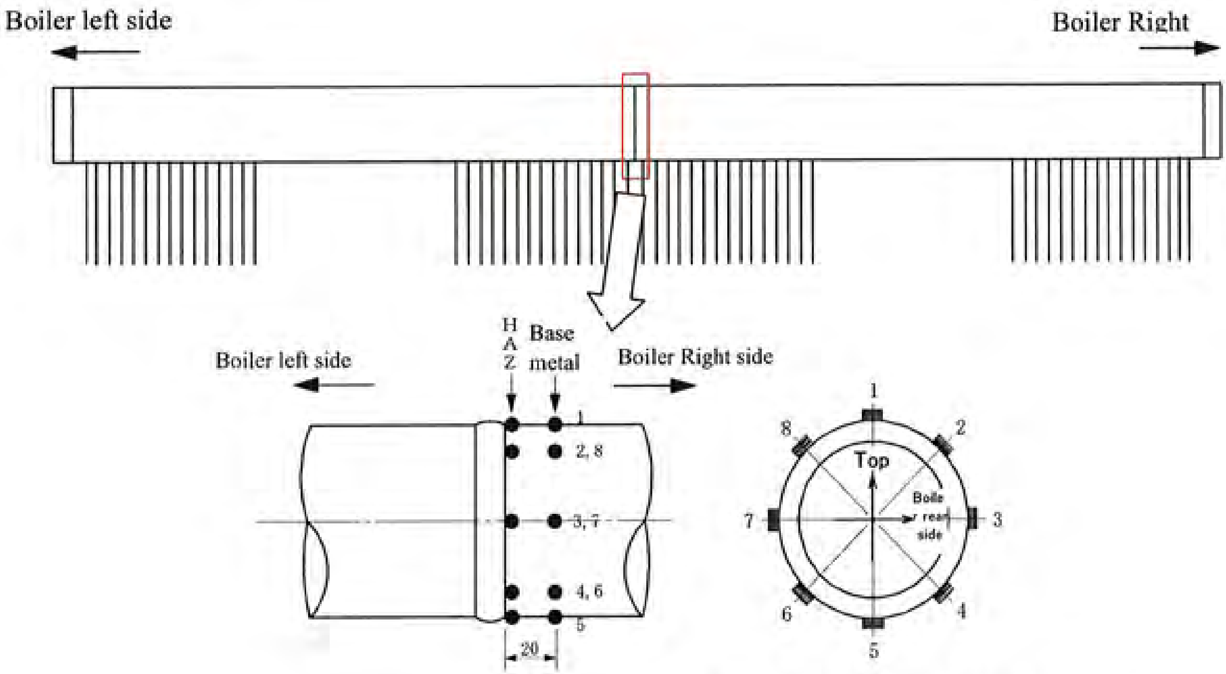
Around 1st soot blower level



Around 2nd soot blower level

Table II -20 (Unchahar) Final SH Outlet Header Outside Diameter Measurement Results

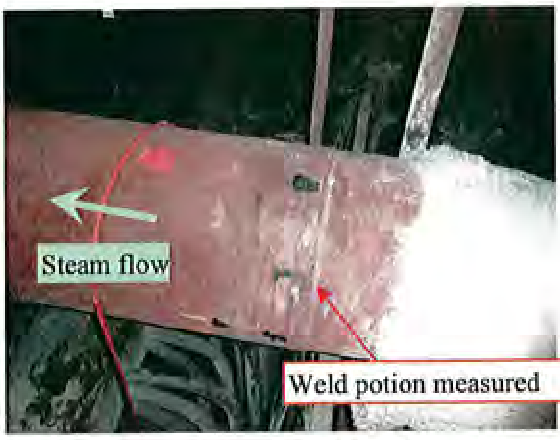
Components	Material	Designed OD	Position	Region	Measured value (mm)				Averaged (mm)	(Averaged measured value-Designed OD) /Designed OD(%)
					1⇔5	2⇔6	3⇔7	4⇔8		
Final SH Outlet Header	SA335 P-22	457.2mm	Upstream side (Elbow side)	Base metal	460.60	460.73	460.40	-	460.57	+0.74
				HAZ	460.46	460.12	460.19	-	460.26	+0.67



View from boiler right side

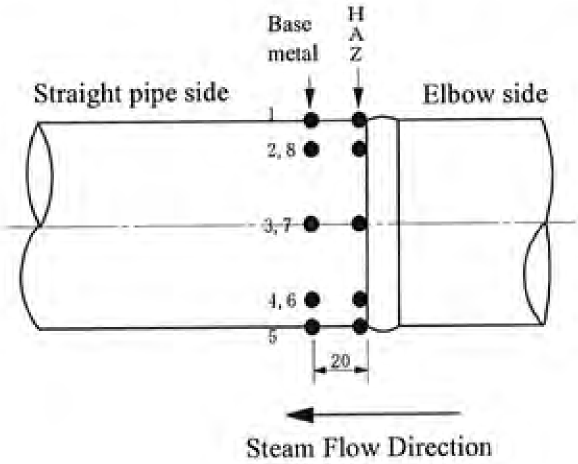
Table Ⅱ-21 (Unchahar) De-Superheater Pipe Outside Diameter Measurement Results

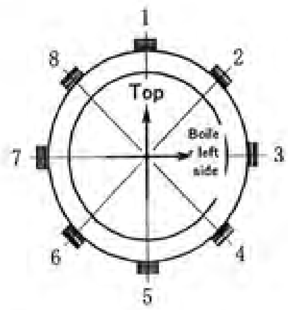
Components	Material	Designed OD	Position	Region	Measured value (mm)				Averaged (mm)	(Averaged measured value-Designed OD) /Designed OD(%)
					1⇔5	2⇔6	3⇔7	4⇔8		
De-Superheater Pipe(Right)	SA335 P-12	406.4mm	Downstream side (Straight pipe side)	Base metal	408.08	407.37	409.15	408.43	408.26	+0.46
				HAZ	407.66	407.06	408.15	407.97	407.71	+0.32
De-Superheater Pipe(Leftt)	SA335 P-12	406.4mm	Downstream side (Straight pipe side)	Base metal	408.26	408.29	407.81	408.40	408.19	+0.44
				HAZ	408.02	407.63	408.26	407.65	407.89	+0.37



Measurement point of right De-superheater pipe

Measurement point of left De-superheater pipe





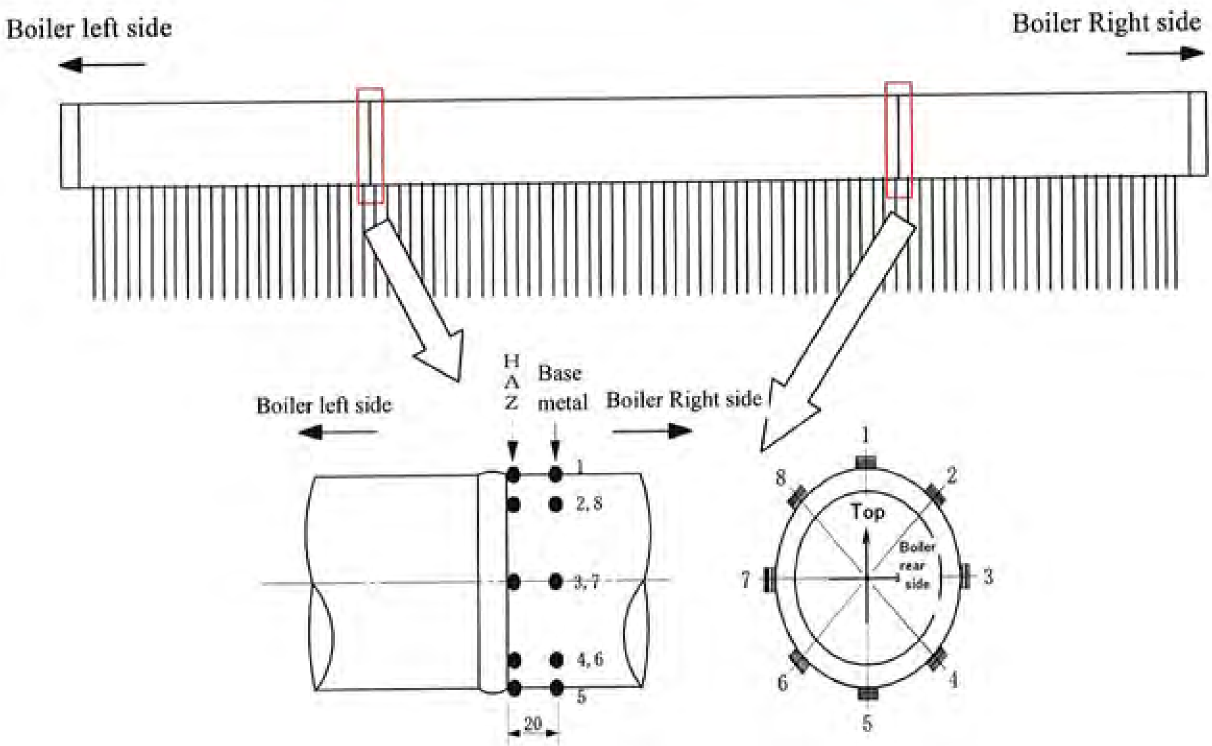
View from boiler downstream

Table Ⅱ-22 (Unchahar) Re-Heater Outlet Header Outside Diameter Measurement Results

Components	Material	Designed OD	Region	Area	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	558.62	566.60	562.37	560.43	562.00	+0.57
				HAZ	557.15	560.16	561.75	559.92	559.75	+0.17
Re-Heater Outlet Header(Left)	SA335 P-22	558.8mm	(Header side)	Base metal	559.24	559.63	560.57	560.22	559.92	+0.20
				HAZ	558.96	559.16	560.19	559.96	559.57	+0.14

Measurement point of left side of RH outlet header

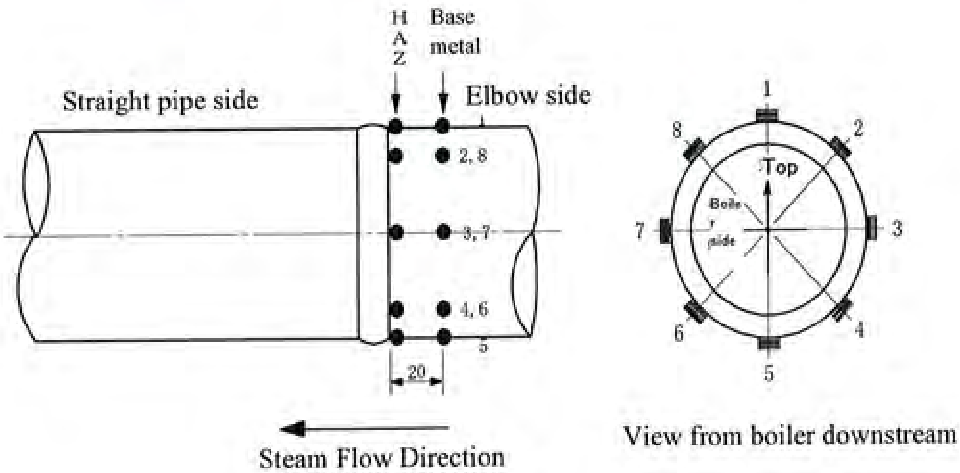
Measurement point of right side of RH outlet header



View from boiler right side

Table Ⅱ-23 (Unchahar) Hot Reheat 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		
Hot Reheat Pipe	SA335 P-22	508.0mm	Downstream side (straight pipe side)	Base metal	510.00	507.57	506.39	508.33	508.07	+0.01
				HAZ	508.17	506.77	505.17	507.77	506.97	-0.20



Sample tube inspection〔Unchahar #2〕

Sample tube inspection and creep rupture test were carried out as one of the boiler residual life assessment items for Unchahar Super Thermal Power Station #2 unit. The results are reported as follows.

1. Unit for evaluation

Unchahar Super Thermal Power Station #2 unit

2. Sample tube for inspection

- Platen-SH tube
- Final-SH tube (#1,#119)

3. Operation condition

(1) Cumulative operation hours:	139,098	hours
(2) Cumulative start and stop times:	96	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 each tube was less than designed value, and the thickness of each tube was larger than the designed value.

(3) As a result of steam oxide scale examination, steam oxide scale was adhering evenly by cross sectional observation for each tube.
Average thickness of steam oxide scale mainly consisting of Fe and O was larger in the order of Final-SH #1, Final-SH #119 and Platen-SH tube.

(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 7,800,000 hours for base metal, 6,800,000 hours for weld joint portion at designed temperature 503℃.
As for Final-SH #119 tube, the evaluated residual life was 400,000 hours for base metal, 350,000 hours for weld joint portion at designed temperature 534℃and 41,000 hours for base metal, 35,000 hours for weld joint portion at equivalent temperature 573℃ estimated by comparison with the average creep rupture data of NIMS.
It is recommended that the residual life assessment for Final-SH #119 tube be carried out again before reaching the min.evaluated residual life 35,000 hours.

(6) As a result of microstructure comparison method, the min.evaluated residual life was 120,000 hours.

5. Sample tube specification

Sample tube specification is shown in Table II -30.

Table II -30 Sample tube specification

Sample	Material	Designed ODxt(mm)	Designed Temperature (℃)	Designed Pressure (MPa)
Platen-SH #3-8	SA213T22	Φ51.0×t9.6	553	17.24
	SA213T11※	Φ51.0×t7.1	503	
Final-SH #1	SA213T22	Φ51.0×t9.6	554	17.24
	SA213T22※	Φ51.0×t8.8	545	
Final-SH #119	SA213T22	Φ51.0×t9.6	545	17.24
	SA213T22※	Φ51.0×t8.8	534	

※ : Chemical composition analysis was conducted as shown below.
The material of sample tubes for evaluation with creep rupture test and microstructural comparison method was confirmed same as the drawing by chemical composition analysis.

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

Sample tube	C	Si	Mn	P	S	Cr	Mo
Platen-SH #3-8	0.09	0.58	0.44	0.032	0.010	1.12	0.49
Final-SH #1	0.10	0.24	0.42	0.030	0.012	2.20	0.95
Final-SH #119	0.10	0.24	0.42	0.030	0.013	2.22	0.96
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

6. Inspection item and inspected portion

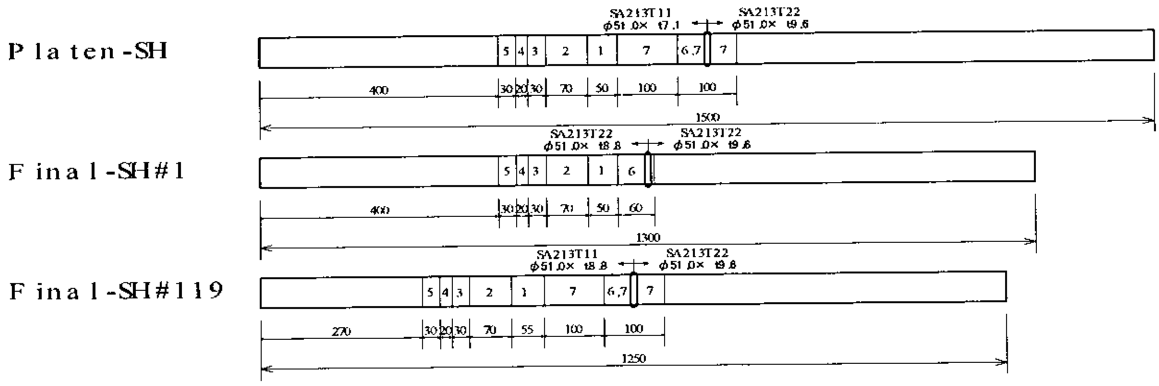
Inspection item and inspected portion are shown in Table Ⅱ-31.

Table Ⅱ-31 Inspection item

Sample	Inspection item						
	1	2	3	4	5	6	7
	Outer surface appearance	Internal surface	Tube dimension・	Metallography	Scale analysis	RLA by microstructure	Creep rupture test
Platen-SH	○	○	○	○	○	○	○
Fainal-SH#1	○	○	○	○	○	○	−
Fainal-SH#119	○	○	○	○	○	○	○

Sample tube appearance and sampling location are shown in Photo Ⅱ-13.

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

7. Inspection results

(1) Tube appearance

a. Tube appearance from outside (Photo Ⅱ-14)

- Hard oxide scale with grayish white color was adhering for each sample tube outer surface.
- 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 Ⅱ-15～20)

(Platen SH tube)

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

(Final SH #1 tube)

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

(Final SH #119 tube)

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

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

a. OD measurement

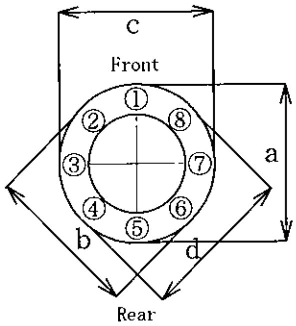
OD of each tube was measured to be less than designed values.

b. Thickness measurement

Thickness of each tube was measured to be larger than designed value.

Table Ⅱ-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	Φ51.0×t7.1	a	50.95	35.05	8.00				7.95			
		b	51.00	35.00		8.05				8.00		
		c	50.95	34.95			8.05				7.95	
		d	50.95	34.95				8.05				7.95
FINAL-SH #1	Φ51.0×t8.8	a	50.80	32.45	9.20				9.15			
		b	50.95	32.45		9.25				9.25		
		c	50.85	32.45			9.15				9.25	
		d	50.90	32.45				9.15				9.30
FINAL-SH #119	Φ51.0×t8.8	a	50.90	32.40	9.20				9.30			
		b	50.90	32.40		9.20				9.35		
		c	50.90	32.40			9.20				9.30	
		d	50.85	32.40				9.25				9.20



Platen-SH

Final-SH #1

Final-SH #119

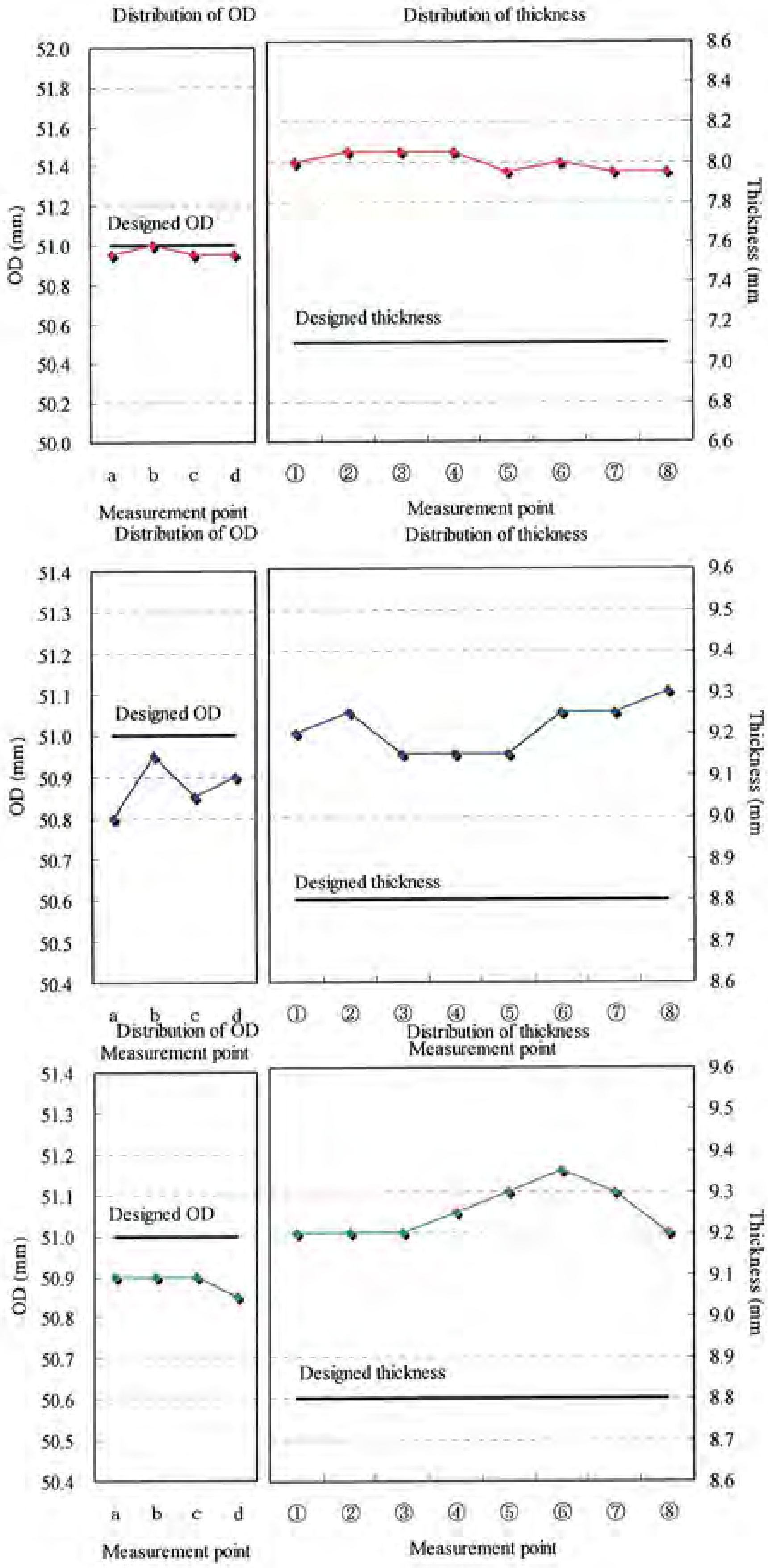


Fig II-12 Tube dimension measurement results

(3) Steam oxide scale adhesion on internal surface

a. Cross sectional observation of internal surface (Photo II -21)

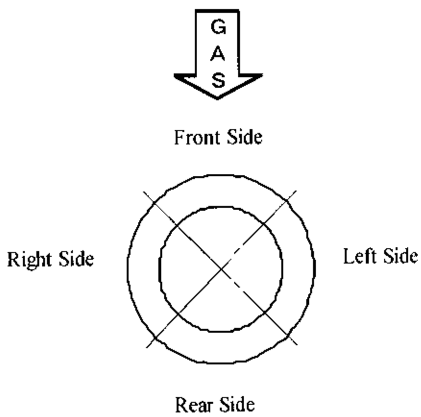
- Steam oxide scale was adhering evenly by cross sectional observation for each location with dual layer consisting of dense inner layer and slightly porous outer layer..

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

- Average thickness of steam oxide scale mainly consisting of Fe and O was larger in the order of Final-SH #1, Final-SH #119 and Platen-SH tube.

Table II -33 Steam oxide scale thickness measurement results

Sample tube	Position	Scale thickness (μm)	
		Average among 90°range	Max. among 90° range
Platen-SH	Front Side	130.3	135.0
	Right Side	130.5	137.0
	Rear Side	125.7	130.0
	Left Side	130.3	138.0
FINAL-SH#1	Front Side	227.4	263.0
	Right Side	198.0	232.0
	Rear Side	202.1	221.0
	Left Side	225.5	257.7
FINAL-SH#119	Front Side	177.4	188.0
	Right Side	182.3	196.0
	Rear Side	179.6	193.0
	Left Side	169.8	186.0



c. EPMA analysis of steam oxide scale on internal surface (Fig. Ⅱ-13～24,Table Ⅱ-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 as the other detected elements.
- In Final-SH #1 tube, Fe, Cr and Mo were detected as tube material elements, and O, Ca , Si as the other detected elements.
- In Final-SH #119 tube, Fe, Cr and Mo were detected as tube material elements, and O, Mn as the other detected elements.

Table Ⅱ-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	■		■			■	■	■	■		■			■
Final-SH#1	Front Side	■					■	■	■	■		■			■
	Right Side	■					■	■	■	■		■			■
	Rear Side	■					■	■	■	■		■			■
	Left Side	■					■	■	■	■		■			■
Final-SH#119	Front Side	■							■	■		■			■
	Right Side	■							■	■		■			■
	Rear Side	■							■	■		■			■
	Left Side	■							■	■		■			■

■ : Elements detected clearly

(4) Hardness measurement (Fig. Ⅱ-35, Table Ⅱ-25)

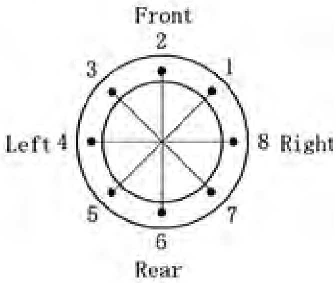
- The hardness of Platen-SH tube (SA213T11) was higher than the normal value of virgin material by Japanese steal manufacturer.
- The hardness of Final-SH#1,#119 tube (SA213T22) were lower than the normal value of virgin material by Japanese steal manufacturer.

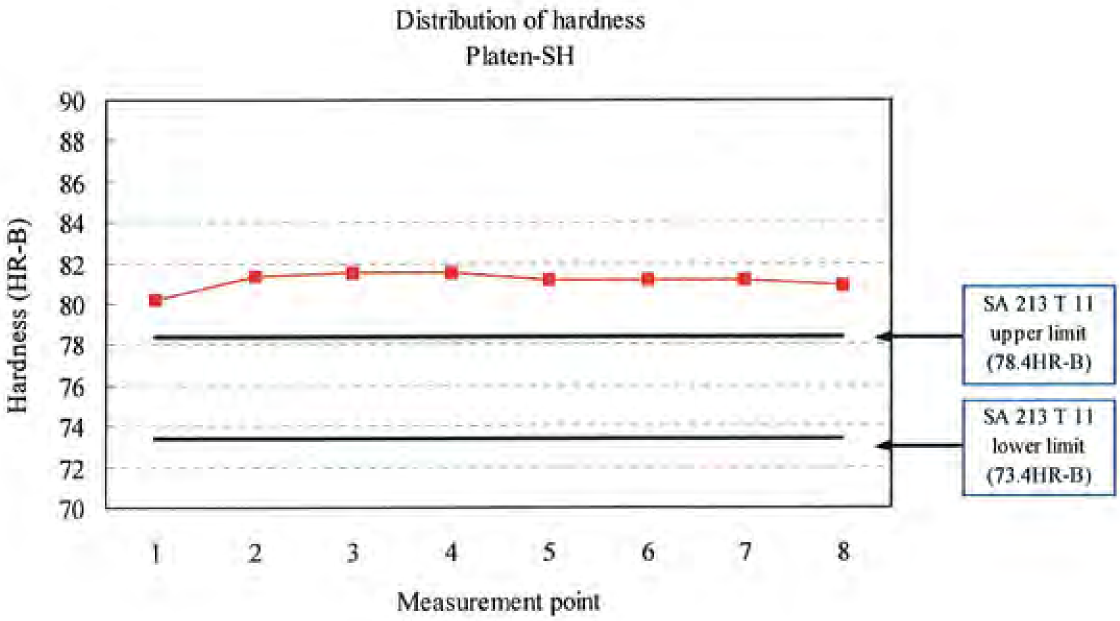
Table Ⅱ-35 Hardness measurement results

(unit:HR-B)

Sample tube	Marterial	1	2	3	4	5	6	7	8
Platen-SH	SA 213 T 11	80	81	82	82	81	81	81	81
FINAL-SH#1	SA 213 T 22	74	74	75	75	75	75	76	75
FINAL-SH#119	SA 213 T 22	74	74	74	74	74	75	74	75

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)





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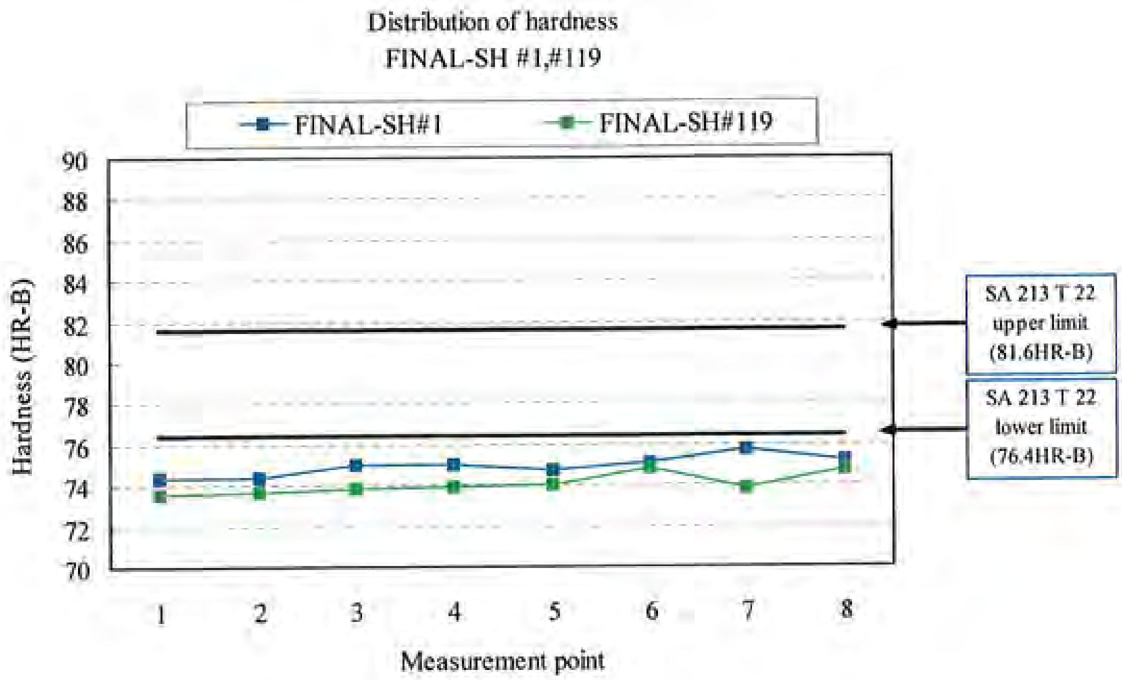


Fig II -25 Hardness measurement results

(5) Metallographic observation

Microstructure observation results at cross section in circumferential direction of sample tube were shown in Photo II -22~27.

(Platen-SH tube (SA 213 T11))

- Microstructural degradation with disintegration of pearlite structure and precipitation in ferrite grain was not observed, though precipitation at gain boundary were observed.

(Final-SH#1,#119 tube (SA 213 T22))

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

(6) Creep rupture test

a. Test condition

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

3 specimens were cut out from each of base metal portion and weld portion in Platen-SH tube and Final-SH #119 tube with a set of three test conditions for each portion.

As the shape of test specimens, ϕ 6mm round bar specimen was applied.

Table II-36 Creep test condition

Sample tube	Portion	Material	Test condition		Shape of specimen
			Tem. (℃)	Stress (MPa)	
Platen-SH	Base Metal	SA213T11	635	68.6	φ6
			635	83.4	
			665	45.9	
	Weld Metal	SA213T11	665	68.6	
			665	83.4	
			700	45.9	
Final-SH #119	Base Metal	SA213T22	665	63.7	φ6
			665	78.5	
			700	38.3	
	Weld Metal	SA213T22	665	63.7	
			665	78.5	
			700	38.3	

φ 6round bar

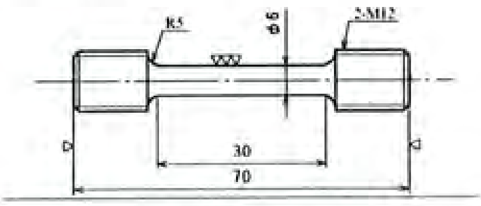
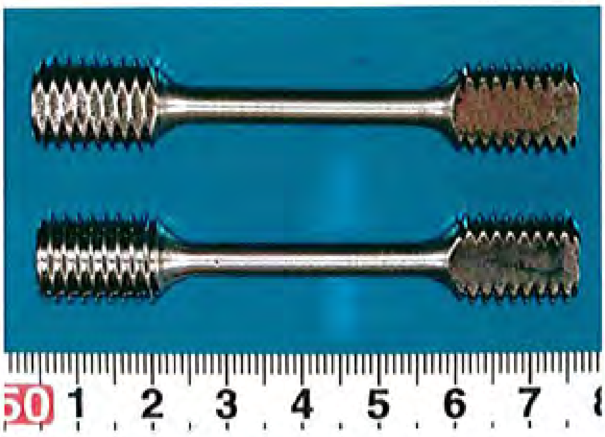


Fig II-26 Shape of test specimens

Test specimens before and after creep rupture test

Before machining ⇒



After machining ↑

After creep rupture test ↑

Creep rupture testing machine ⇒

b. Test results

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

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

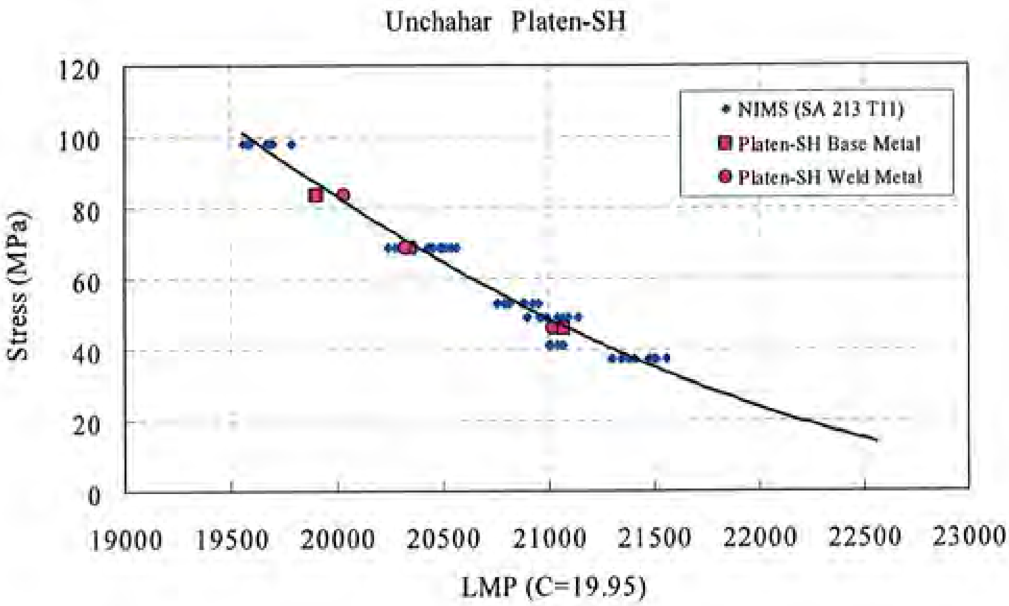
Component		Material	Test condition		Rupture time	LMP	Fracture elongation	Reduction of area
			Temp. T(℃)	Stress (MPa)	t (h)	C=19.95	(%)	(%)
Platen-SH	Base Metal	SA 213 T11	635	68.6	278.7	20,341	62	94
			635	83.4	90.8	19,899	57	91
			665	45.9	322.4	21,072	86	94
	Weld Metal	SA 213 T11	635	68.6	264.3	20,320	16	81
			635	83.4	127.5	20,033	18	82
			665	45.9	287.5	21,026	13	80

Table Ⅱ-37-2 Creep rupture test results (Final-SH #119)

Component		Material	Test condition		Rupture time	LMP	Fracture elongation	Reduction of area
			Temp. T(℃)	Stress (MPa)	t (h)	C=15.77	(%)	(%)
Final-SH#119	Base Metal	SA 213 T22	665	63.7	113.1	16,725	69	91
			665	78.5	32.1	16,212	55	92
			700	38.3	162.6	17,503	67	94
	Weld Metal	SA 213 T22	665	63.7	86.0	16,614	30	84
			665	78.5	27.3	16,146	31	83
			700	38.3	143.7	17,451	22	81

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

- The test results for base metal and weld joint in Platen-SH tube indicate almost same creep rupture strength as NIMS data.
- The test results for base metal and weld joint in Final-SH#119 tube indicate the lower creep rupture strength than NIMS data.



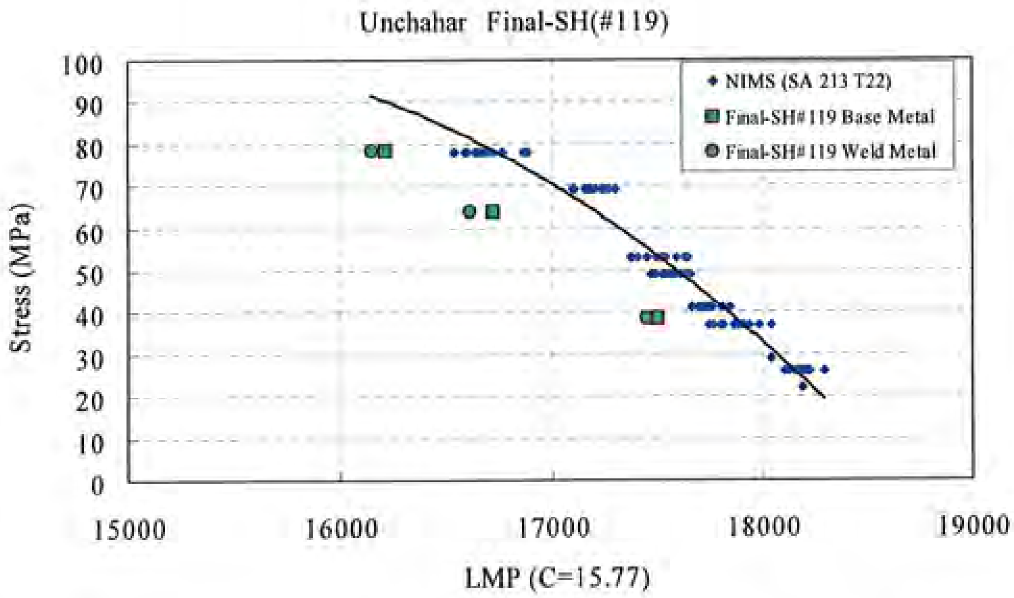


Fig II-27 The comparison of the test results and the creep rupture data of virgin materials by NIMS (National Institute for Materials science).

c. Residual life evaluation results

Residual life evaluation results by creep rupture test are shown in Table II-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 7,800,000 hours for base metal, 6,800,000 hours for weld joint portion at designed temperature 503℃.

Equivalent temperature could not be evaluated since the test results for base metal in Platen-SH tube indicate higher creep rupture strength than NIMS data.

(Final-SH #119 tube)

The evaluated residual life (half of residual life evaluated by creep rupture test) of Final-SH #119 tube was 400,000 hours for base metal, 350,000 hours for weld joint portion at designed temperature 534℃.

In case of evaluation at equivalent temperature 573℃ estimated by comparison with the average creep rupture data of NIMS, the evaluated residual life of Final-SH #119 tube was 41,000 hours for base metal, 35,000 hours for weld joint portion.

It is recommended that the residual life assessment for Final-SH #119 tube be carried out again before reaching the min.evaluated residual life 35,000 hours.

Table II -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	Designed temp. (℃)	Residual life (h)	Creep life consumption ratio	Evaluated residual life (h)
Platen-SH	Base Metal	SA 213 T11	139,098	45.9	503	15,726,180	0.01	7,800,000
	Weld Metal	SA 213 T11	139,098	45.9	503	13,692,433	0.01	6,800,000
Final-SH#119	Base Metal	SA 213 T22	139,098	38.3	534	812,994	0.15	400,000
	Weld Metal	SA 213 T22	139,098	38.3	534	700,466	0.17	350,000

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	139,098	45.9	Non evaluation(※1)			
	Weld Metal	SA 213 T11	139,098	45.9				
Final-SH#119	Base Metal	SA 213 T22	139,098	38.3	573	82,798	0.63	41,000
	Weld Metal	SA 213 T22	139,098	38.3	573(※2)	71,826	0.66	35,000

※1; Equivalent temperature could not be evaluated since the test results for base metal in Platen-SH tube indicate higher creep rupture strength than NIMS data.

※2; 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 II -28～32.

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

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

- Granular precipitates in grain were observed in base metal, intercritical zone, fine grain HAZ , coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates by SEM observation are shown in Photo Ⅱ-33～34.

- 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 Ⅱ-35～38.

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

- Precipitates free zone along grain boundary was observed in base metal.
- Rod-shaped precipitates were observed in base metal and coarse grain HAZ Fine needlelike precipitates had disappeared in base metal, fine grain HAZ, coarse grain HAZ.
- Disintegration of pearlite like structure was observed in base metal and fine grain HAZ.

b. Final-SH #1 tube

(Microstructure observation)

The results of microstructure observation are shown in Photo Ⅱ-39～43.

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

- Precipitates at gain boundary were observed in base metal, fine grain HAZ and weld metal.
- Granular precipitates in grain were observed in base metal, fine grain HAZ , coarse grain HAZ and weld metal.

(Grain boundary precipitates observation)

The results of grain boundary precipitates by SEM observation are shown in Photo Ⅱ-44～45.

- 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 Ⅱ-46～49.

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

- Precipitates free zone along grain boundary and rod-shaped precipitates was observed in base metal.
- Fine needlelike precipitates had disappeared in coarse grain HAZ.

c. Final-SH #119 tube

(Microstructure observation)

The results of microstructure observation are shown in Photo Ⅱ-50～54.

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

- Precipitates at gain boundary were 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 Ⅱ-55～56.

- Precipitation 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 Ⅱ-57～60.

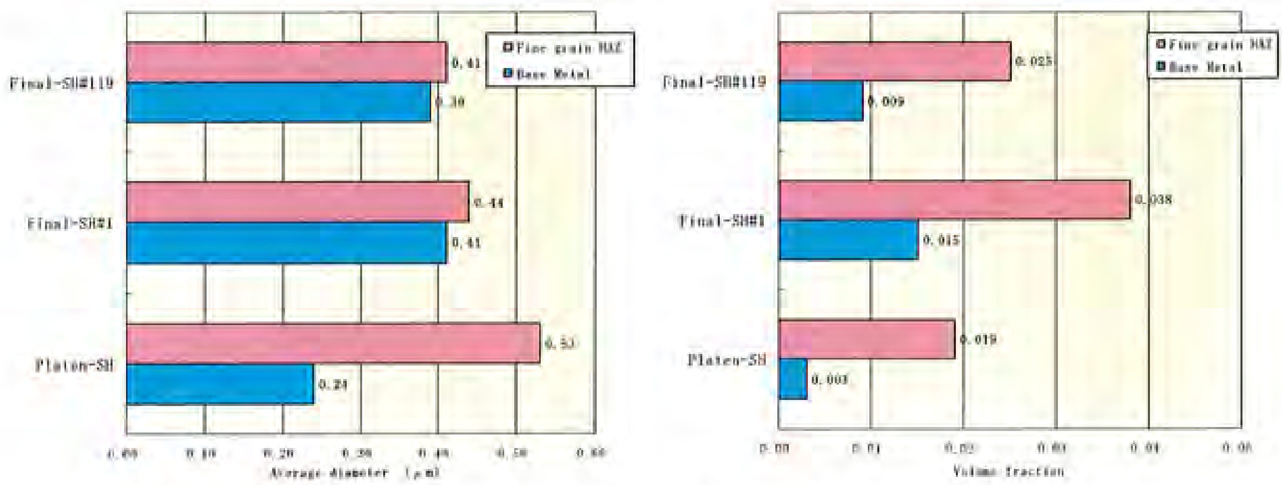
The summary of observation results is shown in Table Ⅱ-40.

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

d. Quantitative evaluation of grain boundary precipitates

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

- The max. value of average diameter of grain boundary precipitates was 0.41μm in base metal at Final-SH #1 tube, 0.53μm in fine grain HAZ at Platen-SH tube.
- The max. value of volume fraction of grain boundary precipitates was 0.015 in base metal at Final-SH #1 tube, 0.038 in fine grain HAZ at Final-SH #1 tube.



Quantitative evaluation of grain boundary precipitates〔extracted Table Ⅱ-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 Ⅱ-42.

- The quantitative evaluation was focused on base metal of SA 213 T22 for Final-SH #1 tube and Final-SH #119 tube.
- The precipitates free band width along grain boundary was 0.55μm. for Final-SH #1 tube and 0.60μm for Final-SH #119 tube.

f. Operational condition of residual life evaluation portion

Operational condition of evaluated components are shown in Table Ⅱ-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 Ⅱ-43 Operational condition of evaluated components

Component	Material	Operational condition				
		OD※1 mm	t※1 mm	Designed Temperature ℃	Designed Pressure MPa	Hoop Stress MPa
Platen-SH	SA213T11	51.0	8.0	503	17.2	46.3
Final-SH#1	SA213T22	50.9	9.2	545	17.2	39.1
Final-SH#119	SA213T22	50.9	9.3	545	17.2	38.6

※1 : Measured value

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. Ⅱ-28～30 and evaluation results are shown in Table Ⅱ-44.

- The highest creep life consumption ratio was evaluated at Final-SH #1 tube with 36% and evaluated residual creep life (half of residual life evaluated microstructure comparison method) was 120,000 hours.

Table Ⅱ-44 Residual life evaluation results

Component	Material	Region	Residual life evaluation results: Creep life consumption ratio (%)	Residual life (h)	Evaluated residual life (h)
Platen-SH	SA213T11	Base Metal	9	1,406,000	290,000
		Fine grain HAZ	0 ～ 2	6,816,000 <	
		Coarse grain HAZ	2 ～ 19	593,000 ～ 6,816,000	
Final-SH#1	SA213T22	Base Metal	28 ～ 36	247,000 ～ 358,000	120,000
		Fine grain HAZ	3	4,498,000	
		Coarse grain HAZ	6 ～ 11	1,125,000 ～ 2,179,000	
Final-SH#119	SA213T22	Base Metal	27 ～ 33	282,000 ～ 376,000	140,000
		Fine grain HAZ	23	466,000	
		Coarse grain HAZ	5 ～ 11	1,125,000 ～ 2,643,000	

Table II-39 Microstructure observation resuluts

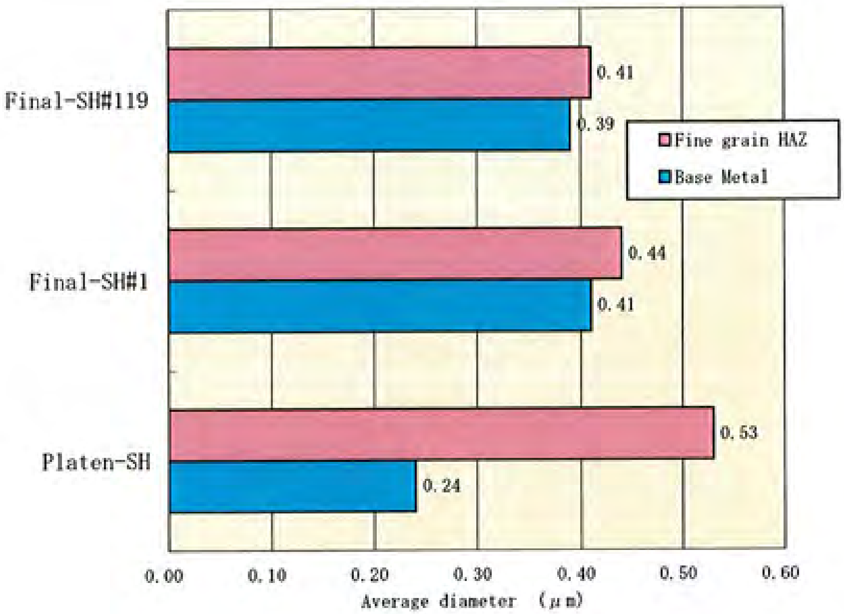
Components	Location		Observed region	OM						
				Microstructural features						
				Precipitation at gain boundary	Precipitates free zone along grain boundary	Precipitation in ferite grain		Pearlite structure	Subgrain boundary	Ferrite grain
						Granular precipitates	Rod-shaped precipitates			
Platen SH tube (SA 213 T11)	#3-8th tube from rear	Circumferential weld	Base metal	Appeared	Not appeared	Appeared	Not appeared	Disintegrated		
			Intercritical zone	Appeared		Appeared	Appeared	Disintegrated	Normal	
			Fine grain HAZ	Appeared		Not appeared	Not appeared			
			Coarse grain HAZ	Appeared		Appeared				
			Weld metal	Not appeared		Appeared				Appeared
Final SH tube (SA 213 T22)	#1-3rd tube from rear	Circumferential weld	Base metal	Appeared	Not appeared	Appeared	Not appeared	Normal		
			Intercritical zone	Not appeared		Not appeared	Not appeared			
			Fine grain HAZ	Appeared		Appeared	Not appeared			
			Coarse grain HAZ	Not appeared		Appeared				
			Weld metal	Appeared		Appeared				
	#19-3rd tube from rear	Circumferential weld	Base metal	Appeared	Not appeared	Appeared	Not appeared	Normal		
			Intercritical zone	Appeared		Appeared	Not appeared			
			Fine grain HAZ	Appeared		Appeared	Not appeared			
			Coarse grain HAZ	Not appeared		Appeared				
			Weld metal	Not appeared		Appeared				
View nos. for each area				×500 (2 views) ×1000 (4 views)						

Table Ⅱ-40 Precipitates distribution observation results

Components	Location		Observed region	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 platedlike precipitates		
Platen SH tube (SA 213 T11)	#3-8th tube from rear	Circumferential weld	Base metal	Appeared	Remaining	Appeared	Not appeared	Disintegrating	
			Fine grain HAZ		Remaining	Not appeared	Not appeared	Disintegrated	
			Coarse grain HAZ		Remaining	Appeared	Not appeared		Disintegrated
			Weld metal		Remaining				
Final SH tube (SA 213 T22)	#1-3rd tube from rear	Circumferential weld	Base metal	Appeared	Remaining	Appeared	Not appeared	Normal	
			Fine grain HAZ		Remaining		Not appeared		
			Coarse grain HAZ		Disappeared		Not appeared		
			Weld metal		Remaining				
	#19-3rd tube from rear	Circumferential weld	Base metal	Appeared	Remaining	Not appeared	Not appeared	Remarkably disintegrated	
			Fine grain HAZ		Disappeared		Not appeared		
			Coarse grain HAZ		Disappeared		Not appeared		
			Weld metal		Remaining				
View nos. for each area				×2000 (2 views) ×1000 (4 views)					

Table Ⅱ-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	0.24	0.53	0.003	0.019
Final-SH#1	SA213T22	0.41	0.44	0.015	0.038
Final-SH#119	SA213T22	0.39	0.41	0.009	0.025



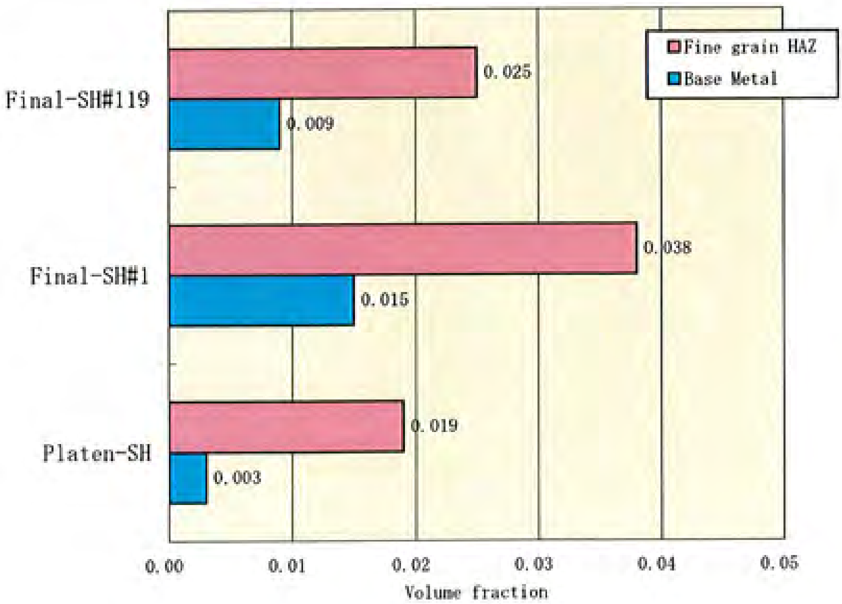
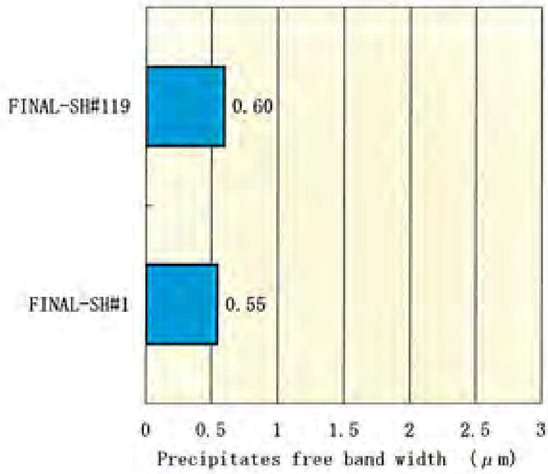


Table Ⅱ-42 Precipitates free band width along grain boundary

Sample tube	Material	Precipitates free band width (μm) ※1
		Base Metal
FINAL-SH#1	SA213T22	0.55
FINAL-SH#119	SA213T22	0.60

※1 : Average value of 10 measured points



505

905

Fig II-28 Evaluation Results Platen SH

605

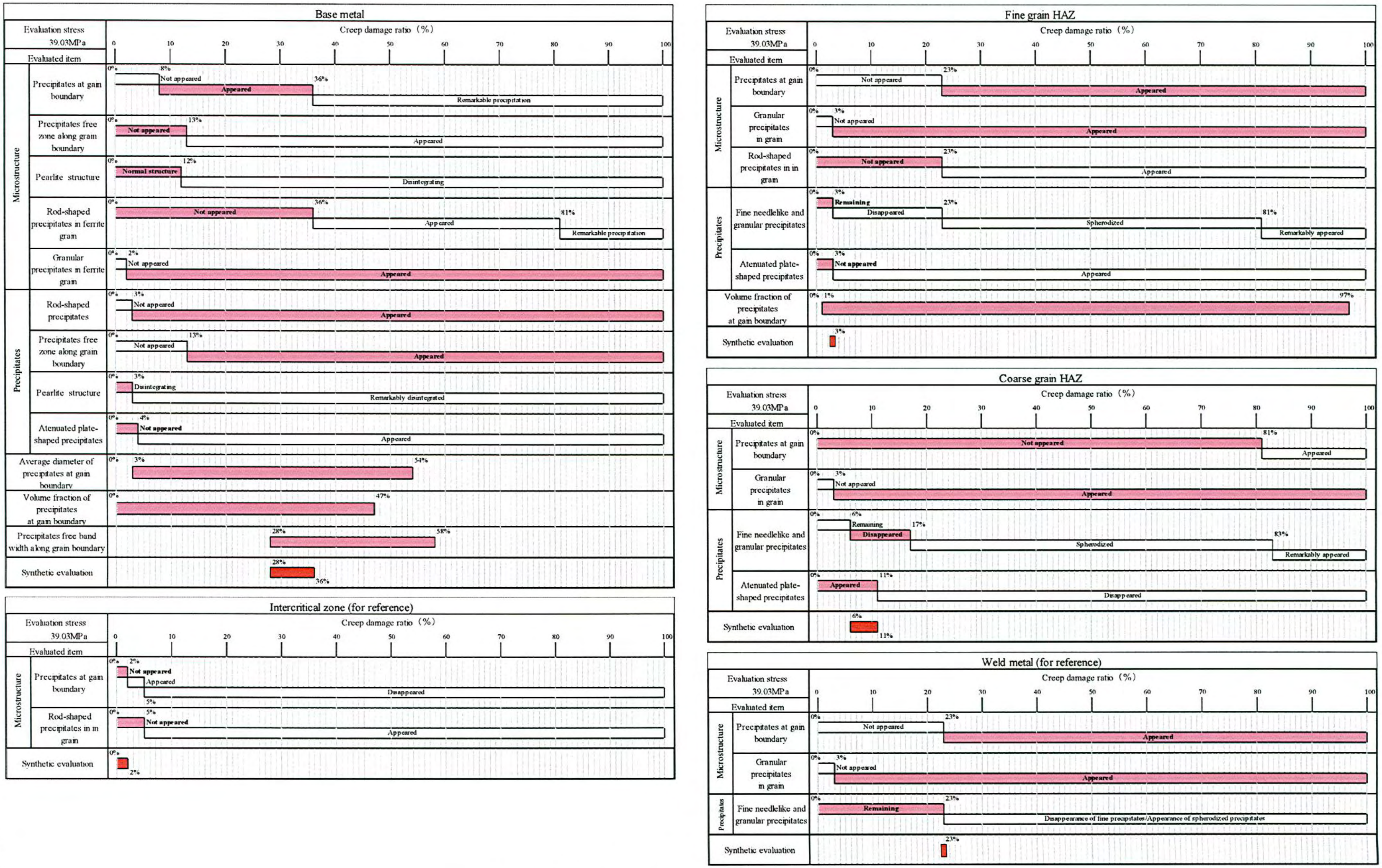


Fig Ⅱ-29 Evaluation Results Final SH #1

8e5

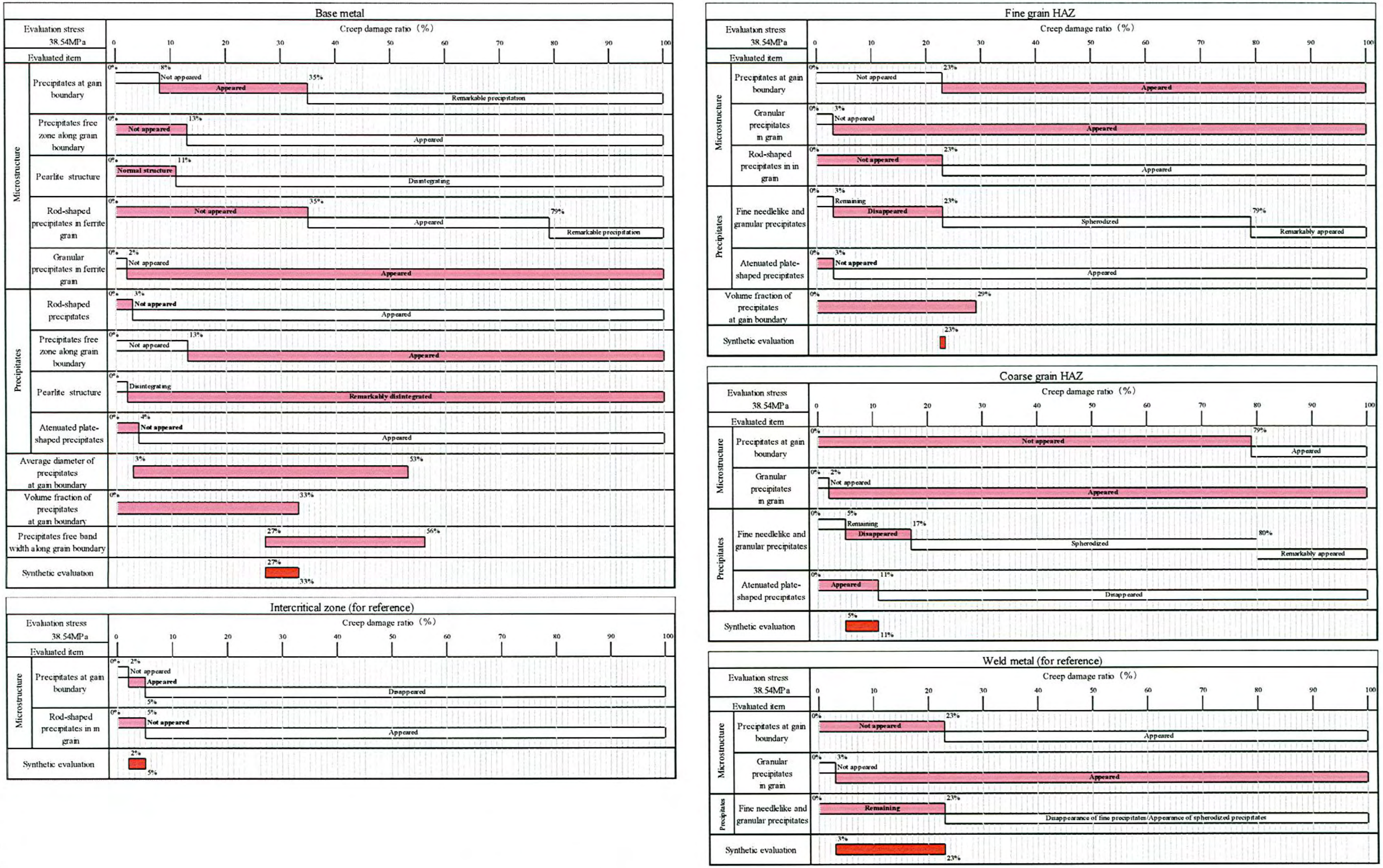


Fig II-30 Evaluation Results Final SH #119