| | | 1.1 | 10-1-11 | | 1.0 | Measured | value (mm) | | (Averaged | |
|------------------|------------|----------------|---------------|------------|--------|----------|------------|--------|------------------|--|
| Components | Material | Designed OD | Region | Area | 105 | 2⇔6 | 3⇔7 | 4⇔8 | Averaged (mm) | measured value- Designed OD) /Designed OD(%) |
| Re-Heater Outlet | 6.7007.0 | 12.5 | | Base metal | 558.62 | 566.60 | 562.37 | 560.43 | 562.00 | +0.57 |
| Header(Right) | SA335 P-22 | 558.8mm | (Header side) | HAZ | 557.15 | 560.16 | 561.75 | 559.92 | 559.75 | +0.17 |
| Re-Heater Outlet | 1 | 1.000 | | Base metal | 559.24 | 559.63 | 560.57 | 560.22 | 559.92 | +0.20 |
| Header(Left) | SA335 P-22 | 558.8mm | (Header side) | HAZ | 558.96 | 559.16 | 560.19 | 559.96 | 559.57 | +0.14 |

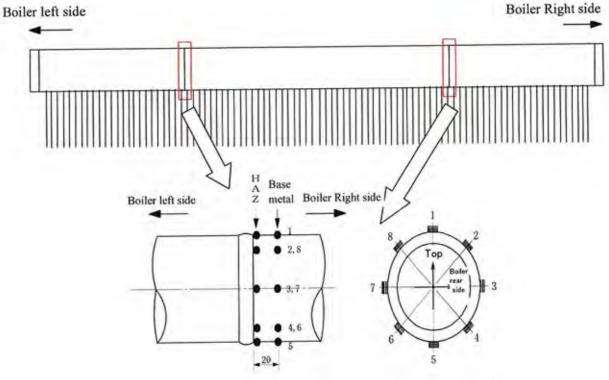
Table II -22 (Unchahar) Re-Heater Outlet Header Outside Diameter Measurement Results





Measurement point of left side of RH outlet header

Measurement point of right side of RH outlet header



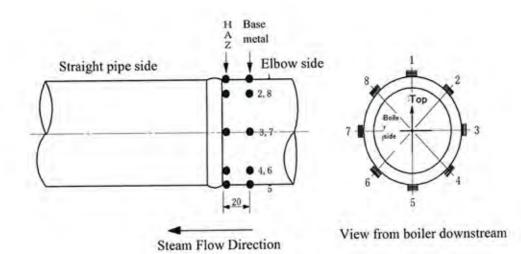
View from boiler right side

Ⅱ-186

| Components Material Designed OD Po | 1 million 1 million | | 1 | Measured | value (mm) | | (Averaged measured | | | |
|------------------------------------|---------------------|--|----------------------|------------|------------|--------|--------------------|--------|--------|---------------------------------------|
| Components | Material | 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1 | Position | Region | 105 | 2⇔6 | 3⇔7 | 4⇔8 | (mm) | value-Designed OD) /Designed OD(%) |
| a sala di ar i | | | Downstream side | Base metal | 510.00 | 507.57 | 506.39 | 508.33 | 508.07 | +0.01 |
| Hot Reheat Pipe | SA335 P-22 | 508.0mm | (straight pipe side) | HAZ | 508.17 | 506.77 | 505.17 | 507.77 | 506,97 | -0.20 |

Table II -23 (Unchahar) Hot Reheat Pipe Outside Diameter Measurement Results





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°C. 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°C and 41,000 hours for base metal, 35,000 hours for weld joint portion at equivalent temperature 573°C 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

5

Sample tube specification is shown in Table II -30.

| Sample | Material | Designed OD×t(mm) | Designed Temperature (°C) | Designed Pressure (MPa) |
|----------------|------------------------|----------------------|---------------------------------|-------------------------------|
| | SA213T22 | \$\$1.0×t9.6 | 553 | 17.24 |
| Platen-SH #3-8 | SA213T11 ^{**} | Ø51.0×t7.1 | 503 | 17.24 |
| D: 1011 //1 | SA213T22 | Ф51.0×t9.6 | 554 | 17.24 |
| Final-SH #1 | SA213T22* | \$\$1.0×t8.8 | 545 | 17.24 |
| E: 1 CH (110 | SA213T22 | Φ51.0×t9.6 | 545 | 17.24 |
| Final-SH #119 | SA213T22* | \$\$1.0×t8.8 | 534 | 17.24 |

| Table II-30 | Sample tube | specification |
|-------------|-------------|---------------|
|-------------|-------------|---------------|

* : 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 | С | Si | Mn | Р | S | Cr | Мо |
|--------------------------|-------|-----------|-----------|--------|--------|-----------|-----------|
| 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 |

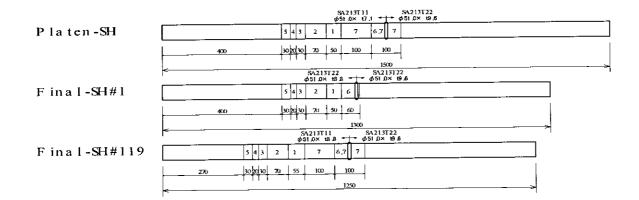
6. Inspection item and inspected portion

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

| | | | 42 . | Inspection item | l | | |
|---------------|-----------------------------|---------------------|---------------------|-----------------|----------------|--------------------------|-----------------------|
| Comple | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Sample | Outer surface appearance | Internal surface | Tube dimension • | Metallography | Scale analysis | RLA by microstructure | Creep rupture test |
| Platen-SH | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fainal-SH#1 | 0 | 0 | 0 | 0 | 0 | 0 | _ |
| Fainal-SH#119 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Table II | -31 In | spection | item |
|----------|--------|----------|------|
|----------|--------|----------|------|

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 $\,\mathrm{II}$ -15 \sim

20)

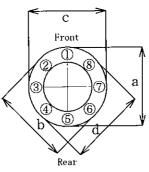
(Platen SH tube)

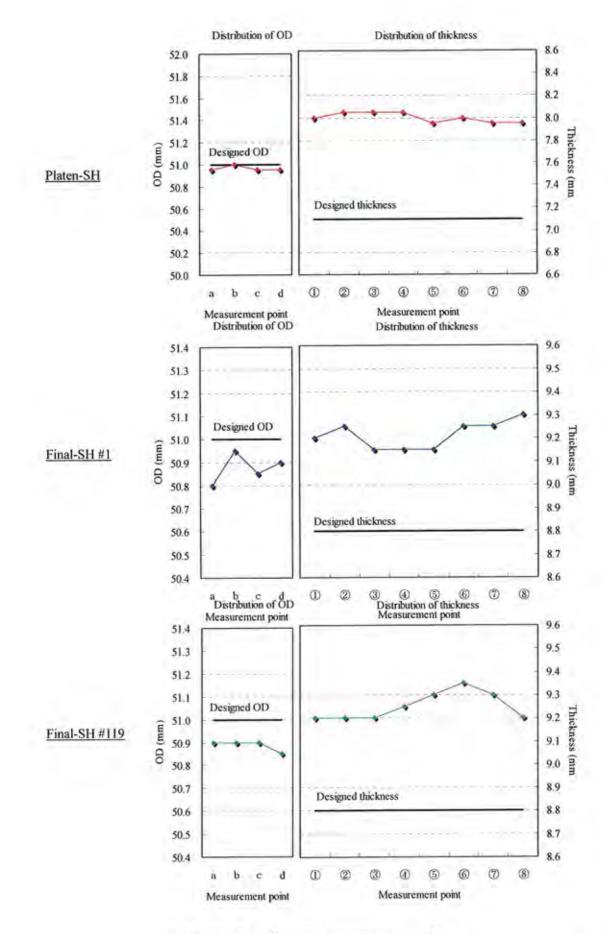
- Internal surface of both front and rear side were covered with gray color steam oxide scale with spotted rust.
- > Slight rough internal surface was observed after acid cleaning.
- (Final SH #1 tube)
 - > Internal surface of both front and rear side were covered with gray color steam oxide scale.
 - > 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.

| | | |) DD (mm) | | | | Thickness (mm) | | | | | | | |
|-------------|---------------|-----------|--------------|-------|------|------|----------------|------|------|------|------------|------|--|--|
| Sample tube | Specification | Direction | OD | ID | 1 | 2 | 3 | 4 | 6 | 6 | \bigcirc | 8 | | |
| | | a | 50.95 | 35.05 | 8.00 | | | | 7.95 | | | | | |
| DI . (11) | A 51 0 17 1 | b | 51.00 | 35.00 | | 8.05 | | | | 8.00 | | | | |
| Platen-SH | Φ51.0×t7.1 | с | 50.95 | 34.95 | | | 8.05 | | | | 7.95 | | | |
| | | d | 50.95 | 34.95 | | | | 8.05 | | | | 7.95 | | |
| | | a | 50.80 | 32.45 | 9.20 | | | | 9.15 | | | | | |
| FINAL-SH | A 51 0.000 | b | 50.95 | 32.45 | | 9.25 | | | | 9.25 | | | | |
| #1 | Φ51.0×t8.8 | с | 50.85 | 32.45 | | | 9.15 | | | | 9.25 | | | |
| | | d | 50.90 | 32.45 | | | | 9.15 | | | | 9.30 | | |
| | | a | 50.90 | 32.40 | 9.20 | | | | 9.30 | | | | | |
| FINAL-SH | A51.0.49.0 | b | 50.90 | 32.40 | | 9.20 | | | | 9.35 | | | | |
| #119 | Φ51.0×t8.8 | с | 50.90 | 32.40 | | | 9.20 | | | | 9.30 | | | |
| | | d | 50.85 | 32.40 | | | | 9.25 | | | | 9.20 | | |

Table II-32 Tube dimension measurement results





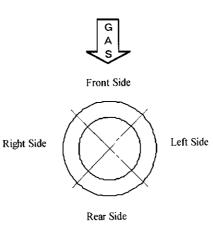


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- (3) Steam oxide scale adhesion on internal surface
 - a. Cross sectional observation of internal surface (Photo II -21)
 - Steam oxide scale was adhering evenly by cross sectional observation for each location with dual layer consisting of dense 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.

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

Table II -33 Steam oxide scale thickness measurement results



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.

| C FOUND | - 00 T | Element | | | | | | | | | | | | | |
|--------------|-------------------|---------|------|-----|----|------|-----|-----|----|----|------|----|-------|--------|----|
| Sample tube | Position | 0 | S | Р | N | Na | Si | Ca | Mn | Fe | Ti | Cr | Ni | Zn | Mo |
| | Front Side | - | | 11 | | | | | | | - 21 | | 1 | \geq | M |
| Platen-SH | Right Side | 12 | - | | 1 | | | | 1 | 0 | | | i = 1 | | |
| Platen-Sri | Rear Side | | | | | 10.1 | | | | | | | 1-1 | | |
| | Left Side | 1 | - | | | 5 | 1 | 1 | | | | - | | | |
| | Front Side | - | - | . 1 | | 11.5 | | 100 | | 1 | | 1 | | i – | 1 |
| Tinal Plan | Right Side | | | | | | | | 3 | | | | | 1 | 2 |
| Final-SH#1 | Rear Side | 1. | 10.1 | | 10 | 111 | | | | 0 | | | 10 | | |
| | Left Side | 1 | 1 | | 1 | | 1 Y | | - | | | 4 | 1.1 | 1 | |
| | Front Side | 1 | | | | | | | 1 | | 6 | 1 | 10 | 1 | |
| Final CUALLO | Right Side | | | | | UC. | | | 1 | | |) | 1.5 | | 1 |
| Final-SH#119 | Rear Side | - | - | | | | | 11 | | | | 8 | (pri | | |
| | Left Side | 100 | 1 | | | in f | 1 | | | | | | | | |

Table II -34 Elements detected by EPMA analysis

:Elements detected clearly

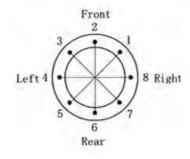
(4) Hardness measurement (Fig. II -35, Table II -25)

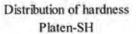
- The hardness of Platen-SH tube (SA213T11) was higher than the normal value of virgin material by Japanese steal manufacturer.
- The hardness of Final-SH#1,#119 tube (SA213T22) were lower than the normal value of virgin material by Japanese steal manufacturer.

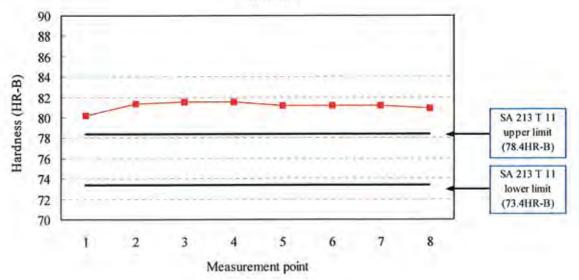
| Sample tube | Marterial | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------|-------------|----|----|----|----|----|----|----|----|
| Platen-SH | SA 213 T 11 | 80 | 81 | 82 | 82 | 81 | 81 | 81 | 81 |
| FINAL-SH#1 | SA 213 T 22 | 74 | 74 | 75 | 75 | 75 | 75 | 76 | 75 |
| FINAL-SH#119 | SA 213 T 22 | 74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

Table II-35 Hardness measurement results

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







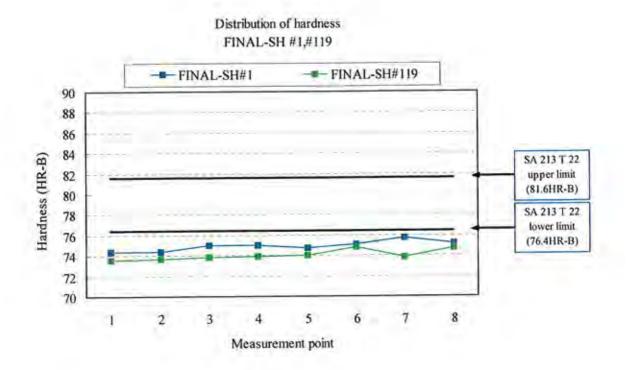


Fig II -25 Hardness measurement results

(5) Metallographic observation

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

| | | | Test c | ondition | Shape | | |
|-------------|--|----------|--------------|-----------------|----------------|--|--|
| Sample tube | Portion | Material | Tem. (°C) | Stress (MPa) | of specimer | | |
| | | 1 | 635 | 68.6 | | | |
| | Base Metal | SA213T11 | 635 | 83.4 | | | |
| Distan CII | 100000000000000000000000000000000000000 | | 665 | 45.9 | φ6 | | |
| Platen-SH | 1.4.1.1.1.1.1 | | 665 | 68.6 | | | |
| | Weld Metal | SA213T11 | 665 | 83.4 | | | |
| | | | 700 | 45.9 | | | |
| | 10 1977 | | 665 | 63.7 | | | |
| | Base Metal | SA213T22 | 665 | 78.5 | | | |
| Final-SH | | | 700 | 38.3 | φ6 | | |
| #119 | No. of Contract | | 665 | 63.7 |] \$0 | | |
| | Weld Metal | SA213T22 | 665 | 78.5 | | | |
| | in the second se | 1.000 | 700 | 38.3 | | | |

Table II-36 Creep test condition



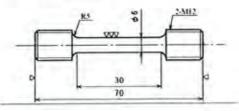


Fig II -26 Shape of test specimens

Test specimens before and after creep rupture test

Before machining \Rightarrow





After machining ↑

After creep rupture test 1



Creep rupture testing machine \Rightarrow

b. Test results

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

| | | | Test co | ondition | Rupture | LMP | Fracture | Reduction |
|-----------|------------|--------------------|---------------|-----------------|---------------|---------|-------------------|----------------|
| Compo | Component | | Temp. T(℃) | Stress (MPa) | time t (h) | C=19.95 | elongation (%) | of area (%) |
| | Base Metal | | 635 | 68.6 | 278.7 | 20,341 | 62 | 94 |
| | | SA 213 T 11 | 635 | 83.4 | 90.8 | 19,899 | 57 | 91 |
| | | | 665 | 45.9 | 322.4 | 21,072 | 86 | 94 |
| Platen-SH | | SA 213 T11 | 635 | 68.6 | 264.3 | 20,320 | 16 | 81 |
| | Weld Metal | | 635 | 83.4 | 127.5 | 20,033 | 18 | 82 |
| | | | 665 | 45.9 | 287.5 | 21,026 | 13 | 80 |

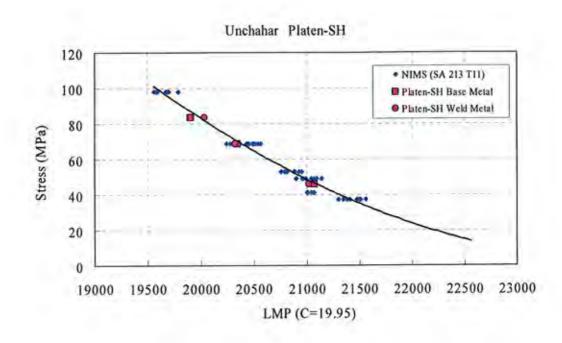
 Table II - 37-1
 Creep rupture test results (Platen-SH)

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

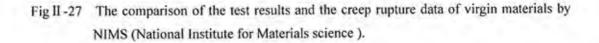
| | | | Test co | ondition | Rupture | LMP | Fracture | Reduction |
|--------------|------------|--------------|---------------|-----------------|---------------|---------|-------------------|----------------|
| Compo | Component | | Temp. T(℃) | Stress (MPa) | time t (h) | C=15.77 | elongation (%) | of area (%) |
| | | | 665 | 63.7 | 113.1 | 16,725 | 69 | 91 |
| | Base Metal | SA 213 T22 | 665 | 78.5 | 32.1 | 16,212 | 55 | 92 |
| E' 1000//110 | | | 700 | 38.3 | 162.6 | 17,503 | 67 | 94 |
| Final-SH#119 | | | 665 | 63.7 | 86.0 | 16,614 | 30 | 84 |
| | Weld Metal | l SA 213 T22 | 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.



Unchahar Final-SH(#119) 100 + NIMS (SA 213 T22) 90 Final-SH#119 Base Metal 80 O Final-SH#119 Weld Metal 70 0 0 Stress (MPa) 60 50 40 30 20 10 0 17000 19000 18000 16000 15000 LMP (C=15.77)



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° C.

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° C.

In case of evaluation at equivalent temperature 573° C 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 parametermethod | d |
|--------------|---------------|------------|------------|-------|---------|------|--------------------|---|
|--------------|---------------|------------|------------|-------|---------|------|--------------------|---|

| | | Рага | meter metho | d (evaluated at | designed tem | p.) | | |
|--------------|------------|------------|---------------------------|-----------------|---------------------------|-------------------------|------------------------------------|-----------------------------------|
| Component | | Material | Operation hours (h) | Hoop Stress | Designed temp. (°C) | Residual life (h) | Creep life consumption ratio | Evaluated residual life (h) |
| | Base Metal | SA 213 T11 | 139,098 | 45.9 | 503 | 15,726,180 | 0.01 | 7,800,000 |
| Platen-SH | Weld Metal | SA 213 T11 | 139,098 | 45.9 | 503 | 13,692,433 | 0.01 | 6,800,000 |
| 5. 1011/110 | Base Metal | SA 213 T22 | 139,098 | 38.3 | 534 | 812,994 | 0.15 | 400,000 |
| Final-SH#119 | Weld Metal | SA 213 T22 | 139,098 | 38.3 | 534 | 700.466 | 0.17 | 350,000 |

| | | Parar | neter method | l (evaluated at o | equivalent tem | .p.) | | | |
|--------------|------------|------------|---------------------------|----------------------|-----------------------------------|-------------------------|---|-----------------------------------|--|
| Component | | Material | Operation hours (h) | Hoop Stress (MPa) | Equivalent temperature (°C) | Residual life (h) | Creep life consumption <u>ratio</u> | Evaluated residual life (h) | |
| | Base Metal | SA 213 T11 | 139,098 | 45.9 | Non evaluation($\%1$) | | | | |
| Platen-SH | Weld Metal | SA 213 T11 | 139,098 | 45.9 | | | | | |
| E' 1011#110 | Base Metal | SA 213 T22 | 139,098 | 38.3 | 573 | 82,798 | 0.63 | 41,000 | |
| Final-SH#119 | Weld Metal | SA 213 T22 | 139,098 | 38.3 | 573(※2) | 71,826 | 0.66 | 35,000 | |

X I; 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 \sim 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 $II-33\sim$ 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 $-35 \sim 38$.

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 \sim 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 \sim 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 \sim 49.

The summary of observation results is shown in Table Π -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 $II - 50 \sim 54$.

The summary of observation results is shown in Table $\ \mbox{II}$ -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 \sim 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.

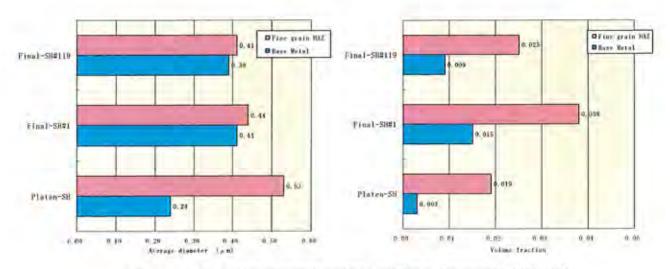
The summary of observation results is shown in Table II -40.

- 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.

| | | Operational condition | | | | | | | |
|--------------|----------|-----------------------|--------------|----------------|-----------------|---------------|--|--|--|
| Component | Material | OD ^{×1} | <u>ا</u> **۱ | Desig | Ноор | | | | |
| | Materia | mm | | Temperature °C | Pressure MPa | 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 | | | |

| Table II -43 | Operational condition of evaluated components |
|--------------|---|
|--------------|---|

※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 \sim 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.

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

Table II -44 Residual life evaluation results

| ß | | | | | | | ОМ | | | | | | | | | | | | | | | | |
|-------------------------------|--|---|--------------------|-----------------------------------|-----------------------------------|----------------------------|----------------------------|--------------------|-------------------|-------------------|------------|--------------------|------------|-------------------|-------------------|----------------|----------|--------|----------|--------------|------|------|------------------|
| Components | | LOID | | | | Mic | rostructural feat | ures | • | | | | | | | | | | | | | | |
| Dodu | | Locauon | Observed region | Precipitation at | Precipitates | Precipitation | | Pearlite | Subgrain | | | | | | | | | | | | | | |
| Ŝ | - | | | gain boundary | free zone along grain boundary | Granular _ precipitates | Rod-shaped precipitates | structure | boundary | Ferrite grain | | | | | | | | | | | | | |
| | ear | - | Base metal | Appeared | Not appeared | Appeared | Not appeared | Disintegrated | | | | | | | | | | | | | | | |
| H tube | rater 5r1 tuoe (SA 213 T11) #3-8th tube from rear Circumferential weld | erential d | Intercritical zone | Appeared | | Appeared | Appeared | Disintegrated | Normal | | | | | | | | | | | | | | |
| aten S SA 21: | | Circumfe wel | Fine grain HAZ | Appeared | | Not appeared | Not appeared | | | | | | | | | | | | | | | | |
| E O | | O O | Coarse grain HAZ | Appeared | | Appeared | \square | | | | | | | | | | | | | | | | |
| | | | Weld metal | Not appeared | | Appeared | \langle | | | Appeared | | | | | | | | | | | | | |
| | La la | | Base metal | Appeared | Not appeared | Appeared | Not appeared | Normal | | | | | | | | | | | | | | | |
| | rom re | rcumferent weld | Intercritical zone | Not appeared | | Not appeared | Not appeared | | | | | | | | | | | | | | | | |
| | #1-3rd tube from rear | | Circumfere weld | Circumfer weld | Circumfer weld | Circumfere weld | Circumfere | Circumfere weld | Circumfer weld | Circumfer weld | Circumfere | Circumfere weld | Circumfere | Circumfer weld | Circumfer weld | Fine grain HAZ | Appeared | | Appeared | Not appeared | | | |
| e (1 | #]-3rd | | | | | | | | | | | | | | | Cire | Circ | Circle | Circe | Cire | Circ | Circ | Coarse grain HAZ |
| Final SH tube (SA 213 T22) | | | Weld metal | Appeared | | Appeared | | | | | | | | | | | | | | | | | |
| Final : (SA 2 | car | | Base metal | Appeared | Not appeared | Appeared | Not appeared | Normal | | | | | | | | | | | | | | | |
| | from r | ential | Intercritical zone | Appeared | | Appeared | Not appeared | | | | | | | | | | | | | | | | |
| | d tube | Circumferential weld | Fine grain HAZ | Appeared | | Appeared | Not appeared | | | | | | | | | | | | | | | | |
| | #19-3r | #19-3rd tube from rear Circumferential weld | Coarse grain HAZ | Not appeared | | Appeared | | | | | | | | | | | | | | | | | |
| | | | Weld metal | Not appeared | | Appeared | | | | | | | | | | | | | | | | | |
| | Viev | v nos. : | for each area | ×500 (2 views) ×1000 (4 views) |) | | | | | | | | | | | | | | | | | | |

Table II-39 Microstructure observation resuluts

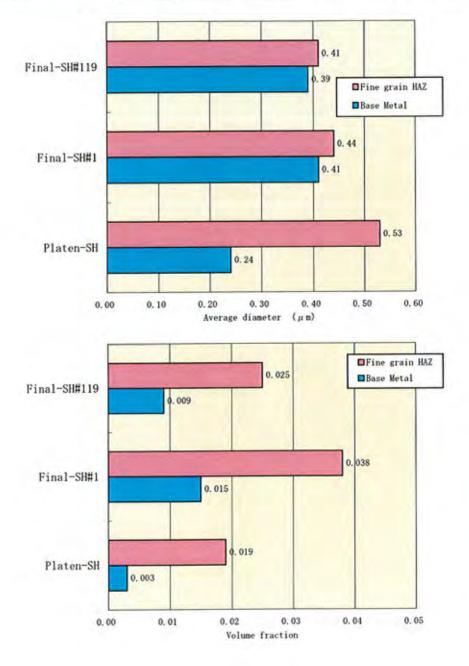
| | | | | TEM (| Transmission | Electron M | icroscope ob | servation) | | | | | | | | | | | | | | | | |
|--------------------------------|------------------------|-------------------------|------------------|------------------------------|------------------------------------|-------------------------|---|--------------------------|-----------------------------|--------|--------|--------|--------|--------|--------|--|---------|------------------|--|-------------|--|--------------|--|--|
| ents | ş | II. | | | _ | Precipitates f | eatures | • | | | | | | | | | | | | | | | | |
| Uod | ter. | Call(| Observed region | Precipitates free | Precip | itation in ferite | e grain | | Aggromerate | | | | | | | | | | | | | | | |
| Components | Observed regio | | | zone along grain boundary | Fine needlelike and granular | Rod-shaped precipitates | Atenuated platedlike precipitates | Pearlite structure | d precipitates structure | | | | | | | | | | | | | | | |
| a _ | rear | - | Base metal | Appeared | Remaining | Appeared | Not appeared | Disintegrating | | | | | | | | | | | | | | | | |
| Platen SH tube (SA 213 T11) | #3-8th tube from rear | Circumferential weld | Fine grain HAZ | | Remaining | Not appeared | Not appeared | Disintegrated | | | | | | | | | | | | | | | | |
| laten 3 SA 21 | 8th tub | Circum | Coarse grain HAZ | | Remaining | Appeared | Not appeared | | Disintegrated | | | | | | | | | | | | | | | |
| щ | #3- | | Weld metal | | Remaining | | | | | | | | | | | | | | | | | | | |
| | rear | l | Base metal | Appeared | Remaining | Appeared | Not appeared | Normal | | | | | | | | | | | | | | | | |
| | #1-3rd tube from rear | mferentia weld | Fine grain HAZ | | Remaining | | Not appeared | | | | | | | | | | | | | | | | | |
| | 3rd tub | Circumf | Circumf | Circumf | Circum | Circum | Circum | Circum | Circum | Circum | Circum | Circum | Circum | Circum | Circum | | Circumf | Coarse grain HAZ | | Disappeared | | Not appeared | | |
| l SH tube 213 T22) | #1- | Ŭ | Weld metal | | Remaining | | | | | | | | | | | | | | | | | | | |
| Final SH tube (SA 213 T22) | і геаг | RI I | Base metal | Appeared | Remaining | Not appeared | Not appeared | Remarkably disintegrated | | | | | | | | | | | | | | | | |
| | #19-3rd tube from rear | Circumferential weld | Fine grain HAZ | | Disappeared | | Not appeared | | | | | | | | | | | | | | | | | |
| | -3rd tul | Circam | Coarse grain HAZ | | Disappeared | | Not appeared | | | | | | | | | | | | | | | | | |
| | 61# | | Weld metal | | Remaining | | | | | | | | | | | | | | | | | | | |
| | 1/2 | | | ×2000 (2 views) | | | | | | | | | | | | | | | | | | | | |
| | view | nos. I | or each area | ×1000 (4 views) | | | | | | | | | | | | | | | | | | | | |

Je.

Table II -40 Precipitates distribution observation results

| | | Average diam | neter (µm) | Volume fraction | | |
|--------------|----------|--------------|-------------------|-----------------|-------------------|--|
| Component | Material | 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-41 Quantitative evaluation of grain boundary precipitates

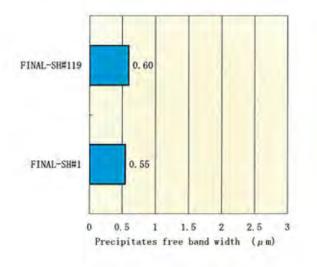


Xer

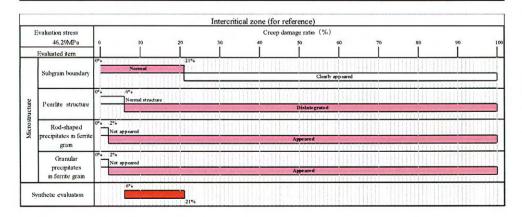
| Sample tube | Material | Precipitates free band width (µm) * | | | | | | | |
|--------------|----------|-------------------------------------|--|--|--|--|--|--|--|
| Sample tube | Wateria | Base Metal | | | | | | | |
| FINAL-SH#1 | SA213T22 | 0.55 | | | | | | | |
| FINAL-SH#119 | SA213T22 | 0.60 |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

Table II -42 Precipitates free band width along grain boundary

※1 : Average value of 10 measured points



| _ | | | _ | | Base meta | 1 | | | | | |
|----------------|---|-----------------------|--------|----|-----------|--------------|---------|----|-------------------|----|-------------|
| 1 | Evaluation stress | | | | Creep | damage ratio | (%) | | | | |
| | 46.29MPa | 10 | 20 | 30 | 40 | 50 | 60 I | 70 | 80 | 90 | 100 |
| - | Evaluated item | • 1% | _ | _ | | | | | | | |
| | Precipitates at gain boundary | Appeared | | | HI KUI | Coarsen | | | ilidid Dichici | | |
| | Precipitates free zone along grain | 9% Not appeared | 911411 | | | Appeare | d | | | | |
| ructure | boundary | • 9% | * | | | | | | | | |
| Microstructure | Pearlite structure | | | | | Disintegr | sting | | | | the second |
| - | Rod-shaped precipitates in ferrite grain | Not appeared | | | | Appeared | | | | | |
| | Granular precipitates | Not appeared | | | HILLI | Appeared | | | | | |
| | in ferrite grain Rod-shaped precipitates | • 9% Not appeared | | | | Appeared | | | | | |
| Precipitates | Precipitates free zone along grain boundary | • 8*5 Not appeared | | | | Appeared | | | | | |
| 8 | Pearlite structure | 9% Normal structur | re | | | Disintegr | ating | | | | a filmeters |
| | verage diameter of recipitates at gain boundary | | | | | 52% | | | | | |
| s | ynthetic evaluation | 9% | | | | | | | | | |

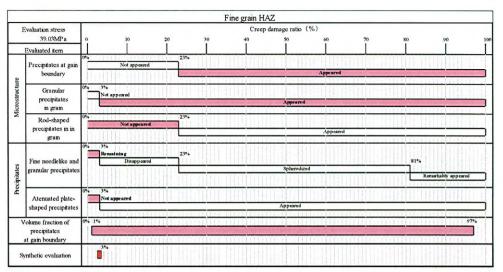


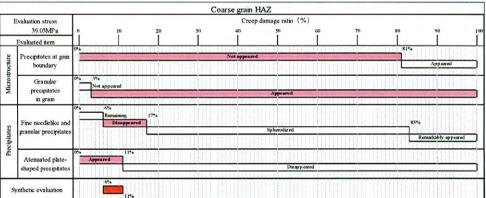
| | | | | | | | | Fi | ne grain | HAZ | | | | | | |
|----------------|--|-----|----------------------|-----------|---------|-------|----------|-------|----------|----------|-------------|----------|---------|-----------|-------------|------|
| I | Evaluation stress | | | | | | | | Cr | eep dama | ige ratio (| %) | | | | |
| _ | 46.29MPa | 0 | | 10 | | 20 | 30 | | 40 | | 50 | 60 | 70 | 80 | 90 | 1 |
| | Evaluated item | | | | | | | | _ | | | | | | | |
| e | Granular | 0% | 511D | 8% Not ap | speared | 111.1 | 1911 | 1111 | HHI | | | 111111 | IIII. | | | 11H |
| nuctur | | | 11111 | | | 10111 | 0110711 | TECTI | 11111 | 11116 | Appeared | | THEFT | DETROT | | |
| Microstructure | Rod-shaped precipitates in ferrite grain | 0%6 | 13111) Mar 19,500 | - | 13% | arrd | | | 1111 | Mah | | 11110 | 1111103 | | | |
| 2 | | 1 | 11111 | 1.11 | | - | | | | | Ap | eared | | | | |
| | | | 124 14 | | 11111 | 1111 | COLUMN 1 | | 11111 | 11111 | | 11111111 | TUTLICE | 111111111 | 11111111111 | 11.1 |
| Precipitates | Fine needlelike and | 0% | 2% Remainin | ng | | | | 1141 | 0110 | | 11111 | | 1011111 | | | |
| ecip | granular precipitates | | | | | | | | | 1 | Disappeared | | | | | |
| 2 | | | | | | | | | | | 1 1 1 1 1 1 | | | | | |

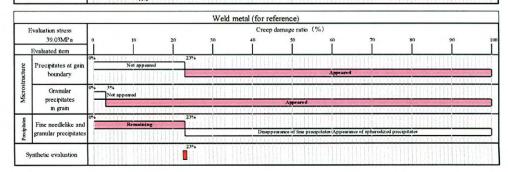
| aluation stress 46.29MPa | | | | | | | | | | | |
|---|---|---|--|---|---|---|---|-----------------------------|----------------------|---|--|
| 46.29MPa | | | | | Creep d | amage ratio | (%) | | | | |
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| valuated item | | | | | | | | | | | |
| Precipitates at gain boundary Granular mecipitates | 0%6 | 2% Not appeared | | | HHHH | 1.11111 | | 11HIIII | | | nıl: |
| | | addies the state of the state of | ing the second second | See Manutan | Maria Managana na | Appeared | | | | 2 1 M 1 M | and the second |
| | | | | | | 11111111 | 11111111 | HIMILIN | | | |
| Granular | 5 | | | | | | | | | | |
| precipitates in ferrite grain | | William Chronic Street Arrows | South Street and | the set of the set | Network With Start | Appeared | and the state of the second | Carlos and the state of the | Norman States | a second a second second second | |
| | 11 | | 11111111 | 11111111 | TUTTUET | 1 1 2 1 4 1 1 1 | CELO PED | TUTIER | THE PERIOD | THE PROPERTY OF | 131 |
| Atenuated plate- | 0% | Not appeared | 19% | | | | | MANDER | | | |
| shaped precipitates | | | 11 | | | | Appeared | | | | |
| | | | dining | J. Chilled | CHAIL FILL | 1111111 | | HUDLES | LING | INTERNA DE LA COMPANSIÓN D | 111 |
| thetic evaluation | | 2% | | | | | | | | | |
| s | Precipitates at gain boundary Granular precipitates in ferrite gran Atenuated plate- haped precipitates | recipitates at gain boundary Granular precipitates in ferrite grain Atenuated plate- haped precipitates | Trecipitales at gain boundary Granular precipitales in ferrite grain Atenuated plate- haped precipitales 2% | Precipitales at gain boundary Granular precipitales in ferrite grain Atemated plate- haped precipitates 2% | receptates at gain receptates receptates receptates receptates receptates | recipitates at gain precipitates in ferrite grain Atemated plate- haped precipitates 7% Not appeared 7% Not appeared 7% Not appeared 7% Not appeared 7% Not appeared 7% Not a | receptates at gain receptates a | Precipitates at gain | Precipitales at gain | Precipitales at gain | Precipitates at gain Appeared Precipitates at gain Appeared Precipitates at gain Appeared Precipitates at gain Appeared Precipitates Appeared Precipitates Appeared Precipitates Appeared Precipitates Appeared Precipitates Appeared Precipitates Precipita |

| I | Evaluation stress | | | | | Creep | damage ratio (| (%) | | | | |
|--------|--|-------|---------------------|-------------------|------------------------------|-----------------------------------|----------------|-----------|------------------------------------|---------------------------------|------------------------------|-------------------|
| | 46.29MPa | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 10 |
| | Evaluated item | | | | | | | | | | | |
| an | Precipitates at gain boundary Granular | 0% | 6% Not appeared | | | | | | | | | |
| 2 | | 1111 | | | | | Appeared | 4 | | | | |
| ELS | | 1115 | | | | 1010101 | 11-12 11-11-11 | 11111111 | 1111111111 | | | ULL LT |
| Micros | | 0% | 6% Not app cared | | | | | | | | | |
| ~ | precipitates | 1111 | College and a state | Calle Called | and the second second second | and the state of the state of the | Appeare | destation | and the state of the second second | Chargest Hilfson and Parket Com | and the second second second | and the should be |
| | m gram | 11111 | | 1.1.1.1.1.1.1.1.1 | | | | | | | | |

| | | Base metal |
|----------------|---|--|
| E | valuation stress | Creep damage ratio (%) |
| | 39.03MPa | 0 10 20 30 40 50 60 70 80 90 100 1 1 1 1 1 1 1 1 1 1 |
| | Evaluated item | 0% 8% Not appared |
| | Precipitates at gain boundary | Not appeared 36% Appeared Remarkable proceptition |
| e | Precipitates free zone along gram boundary | OP = 13% Not appeared Appeared |
| Microstructure | Pearlite structure | 0% 12% Normal structure Dustograng |
| | Rod-shaped precipitates in ferrite grain | 0°+ 38% 81% 81% 81% Remarkable proop if dion |
| | Granular precipitates in ferrite grain | 0° = 2° 5 Not appeared Appeared Appeared |
| | Rod-shaped precipitates | Offe 37e Not appeared Appeared |
| Precipitates | Precipitates free zone along grain boundary | Off. 13%. Not appeared Appeared |
| Precip | Pearlite structure | 0° = 3% Deintograting Remarkably desintograted |
| | Atenuated plate- shaped precipitates | CP. 47: |
| | recapt diameter of recapitates at gain boundary | 0*6 3*6 |
| 2 | olume fraction of precipitates at gain boundary | 47% 47% 38% |
| | cipitates free band along grain boundary | 28% |
| Sy | nthetic evaluation | 36% |
| | | Intercritical zone (for reference) |
| | Evaluation stress 39.03MPa | Creep damage ratio (%) 0 10 20 30 40 50 60 70 80 90 100 1 </td |
| Microstructure | Evaluated item Precipitates at gain boundary | Not appeared Job provided Description of the second description of th |
| Micros | Rod-shaped precipitates in m grain | (P* 5%) Not appeared Appeared |
| Sy | inthetic evaluation | |



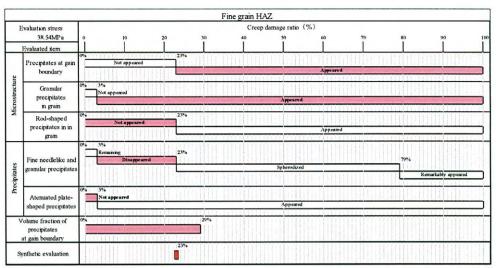


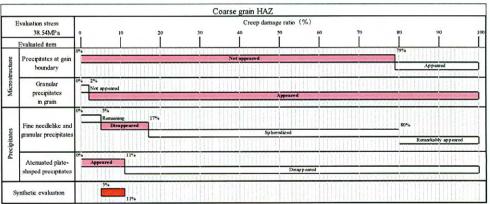


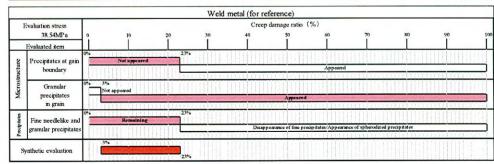
FigII-29 Evaluation Results Final SH #1

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| | | | | | | Base m | etal | | | | | | | |
|----------------|--|-------------------------------|---------------------------|----------|---|------------|-----------|--|--------|---------------|--------|--------|-------------------|-----|
| E | valuation stress | | | | | | eep dama | ge ratio (% | | | | | | |
| | 38.54MPa Evaluated item | 0 | 10 | 20 | 30 | 40 | | 50 1 | 60 | 70 | 80 |) | 90 | 100 |
| | Precipitates at gain boundary | 0°• 8 | ines Not appeared A | Appeared | | 35% | | | Remar | kable precipr | ation | | | |
| ure | Precipitates free zone along grain boundary | 0%. Not appear | 13% | | | | | Арро | sared | | | | | |
| Microstructure | Pearlite structure | 0%. Normal structu | | | | | np. | Disinte | gaing | | | | | |
| M | Rod-shaped precipitates in ferrite gram | 0%• | Not app | eared | | 35*• | | Арре | cared | | | Remark | able precipitatio | n |
| | Granular precipitates in ferrite grain | 0% 2% Not appears | 5d | | | | | ppeared | | | | | | |
| | Rod-shaped precipitates | Not apper | ared | | | | | Appeared | | | 211111 | 11111 | | |
| Precipitates | Precipitates free zone along grain boundary | 0°o Not appears | nd 13% | | | | | Аррея | red | | | | | |
| Precip | Pearlite structure | 0*s Disintegrati | ng | | | | Remarkabl | y disinte gratee | 4 | | | | | |
| | Atenuated plate- shaped precipitates | (Po 4%) Not app | wared | | | | 1110 | Appeared | | | | 11.11 | | |
| | rerage diameter of precipitates at gain boundary | 3% | | | u Qurb Coriada | | | 53% | | | | | | |
| | olume fraction of precipitates at gain boundary | 0*• | | | | 3% | | | | | | | | |
| | cipitates free band along grain boundary | | | | 27% | | | 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | 6% | | | | | |
| Sy | mthetic evaluation | | | | and the second se | 3% | | | | | | | | |
| | | | | | Intercrit | tical zone | | | | | | | | |
| F | Evaluation stress 38.54MPa | 0 | 10 | 20 | 30 | 40 | reep dam: | ige ratio (% | 60 | 70 | 8 | 0 | 90 | 100 |
| Microstructure | Evaluated item Precipitates at gain boundary | 0% 2% Not appear Appear | | | | | | Duappeared | | | | | | |
| Micros | Rod-shaped precipitates in m grain | 0% 5% Not a | ppeared | | | | | Appeared | | | | | | |
| Sy | withetic evaluation | 2% 5% | | | | | | | | | | | | |







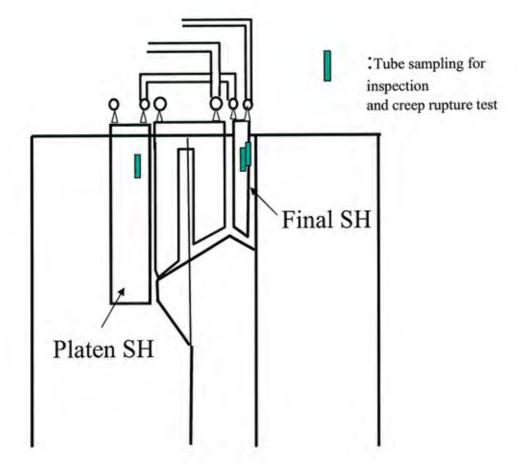
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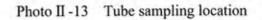
FigII-30 Evaluation Results

Final SH #119

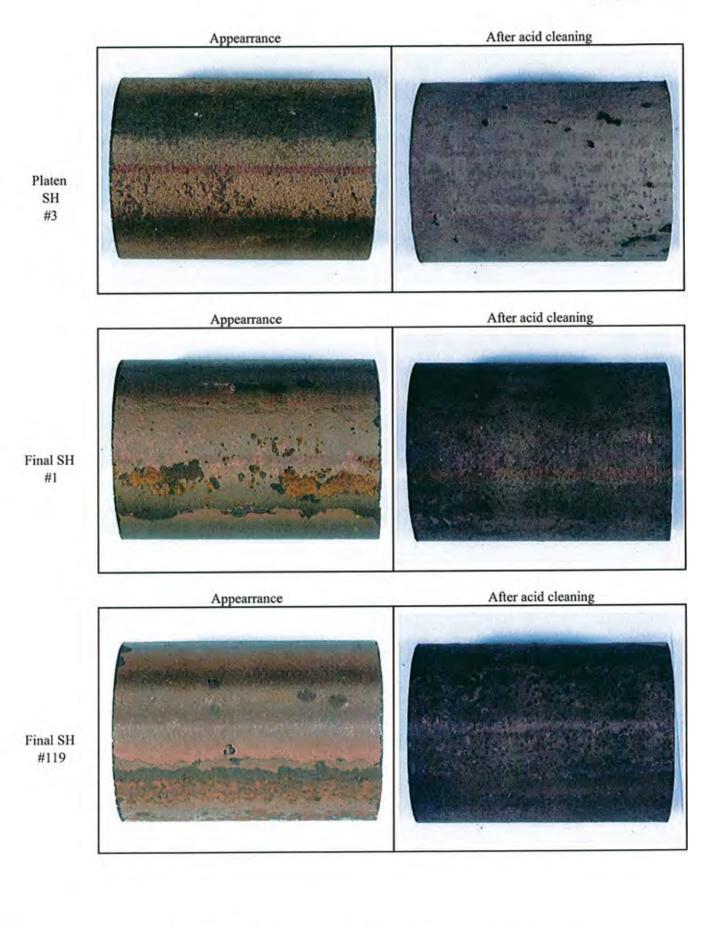
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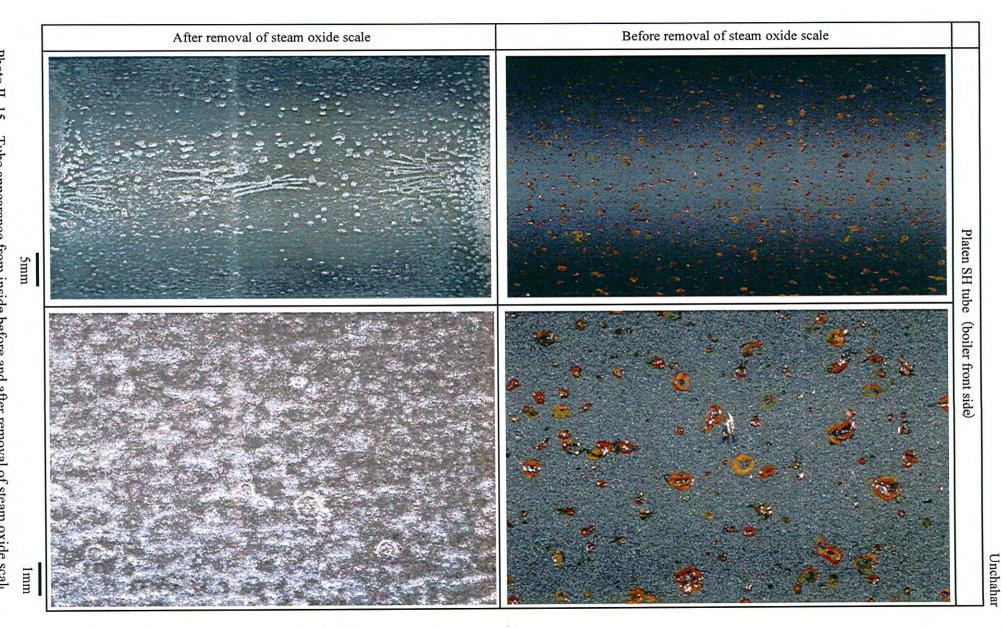




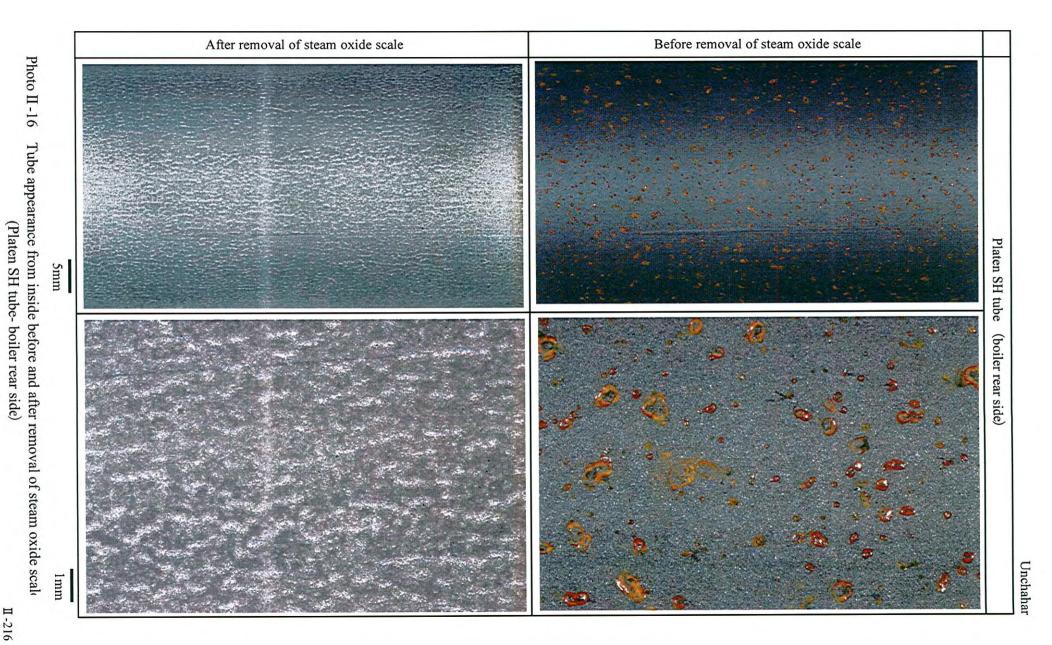


Unchahar









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