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Background Information

the inspiration...

Born into a typical middle-class family, MJF.Ln.Leo Muthu began his career as a government employee and rose to become a highly successful entrepreneur Band made all his fortune from real estate business spread across South India.

Despite being a busy and highly successful businessman, he always found enough time and had the passion to serve the society. He always wanted to make a significant contribution to the society.

He was actively associated with the Lions Movement and was instrumental in starting "the Academy for Blind" and "Home for Aged" under the Community Service Programme of the Lions Club. Besides, he is also actively associated with a large number of Educational, Social and Medical activities in South India.

It was his dream to build a School. And thus was born Sai Matriculation School in the year 1989. It was established with the primary goal of providing educational services to all sections of society. And, it marked the birth of Sai Ram Group of Institutions. It was just the beginning....

Many more institutions followed in the next few years. Sairam Engineering College was started in the year 1995 and ever since it remains as the Flagship Institution of the Sairam Group of Institutions.

In the span of two decades Sai Ram Group of Institutions has grown both in size and reputation. Today, Sairam Group of Institutions with 19 institutions including 3 Engineering Colleges, educate thousands of students every year in a variety of subjects ranging from Engineering, Polytechnic to Indian System of Medicine and Teacher Training through exemplary and exceptionally skilled staff. Today, Sairam Group of Institution has become a name synonymous with quality education.

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MJF. Ln. Leo Muthu, has devoted his life to the cause of Education and social activities. As a true visionary and the Chairman of the Group, he has been the guiding star in spreading the fragrance of education. Under his inspired leadership, the group is planning for more institutions in various parts of South India in the next couple of years.

In short, MJF. Ln. Leo Muthu is a man with golden dreams & a never-ending enthusiasm of converting dreams into reality.

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CASE STUDY: REMAINING LIFE ANALYSIS OF CREEP STRENGTH ENHANCED FERRITIC STEEL T91 AFTER 20 YEARS OPERATION ON 600 MW COAL-FIRED POWER PLANT

Agung Nugroho [1], Meilinda Nurbanasari [2], Suwarno [3] and Eko Supriyanto [4]

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Abstract*—Coal-Fired Power Plant Boiler 600 MW has been operated more than 20 years. Secondary superheater outlet (SSH Outlet) tube bursts had been occurred on this unit. Long-term overheated failure mode was observed at failed tubes on three occasions which was on September 2017, April 2018, and December 2019. The design tubes are called SA-213 T91. On April 2018 and December 2019, the powerplant operator has joined hand with two different public university research institute which are called institution-1 and institution-2 to conduct tests to find the root cause of the failure by hardness test, microstructural examination, creep test and the remaining life analysis. The results of the hardness test on the fail tube on April 2018 and December 2019 were 170.84±1.98 Harness Vickers (HV) and 168-219 HV respectively compared to the new material hardness which are on the average of 258HV. On April 2018, creep tests were resulted that expected time to failure on 750°C and 72.93Mpa was 3.6hours; on 750°C and 93.46 Mpa was 0.4hours; on 650°C and 148.73Mpa was 4.3hours; on 650°C and 186.14 Mpa was 0.7hours; 550°C and 261.80Mpa was 9.6hours; 550°C and 316.05Mpa was 1.7hours. On December 2019, creep tests were resulted that expected time to failure on 680°C and 82.1Mpa was 16.290hours; on 650°C and 152Mpa was 0.84hours; last on 550°C and 201Mpa was 0.269hour. In order to operate more than 25 years, the stress should be less than 89.3Mpa according to ASME II PART D 2019. 6.9mm thickness tube has been resulted hoop stress 62Mpa. Welded metal approached resulted that tube remaining life of 570°C evaluated temperature was 54.4years. 600°C evaluated temperature resulted remaining life was 5.98years. In order to ensure that boiler was not overheated, Metal temperature monitoring and Coal blending has been applied to achieve the best result among bad conditions.

***Keywords*—Long-term Overheating, SA-213 T91, creep tests, Secondary Superheater Outlet tube remaining life analysis.**

I. INTRODUCTION

Creep Strength Enhanced Ferritic Steel (CSEF) steels have been widely used in the modern thermal power plants as high temperature structural components and have been contributed to improve energy efficiency with increased steam temperature and pressure [1]. Secondary Superheater (SSH) Outlet Down-streams were fabricated by T91 and the up-streams were fabricated by T22. There were 64 rows from left (west) to right (east). Each row consists of 24 tubes (tube 1st until 6th were inlet or up-stream; then tube 7th until 18th were outlet or down-stream; last tube 19 until 24 were inlet or upstream.

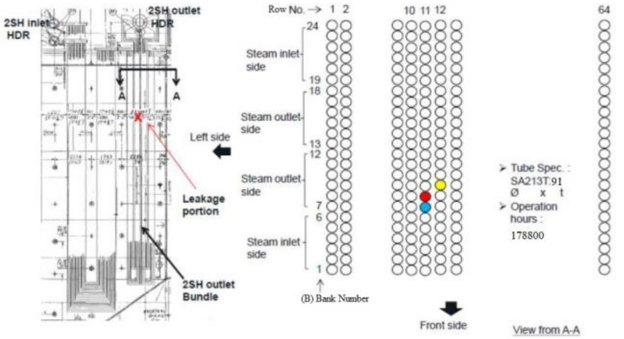

Fig 1. Secondary Superheater Outlet arrangement and tube leakage on April 2018 [7]

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SSH outlet bundle are 64 rows and 24 tube per row. On fig. 1 there is leakage from Row 11 Bank 8 (tube colored with red), bulging tube Row 12 bank 9 (tube colored with yellow). Leakage on 2017 was on Row 11 bank 7 (tube colored with blue). Tube leakage and bulge were found on the tube at high temperature zone and almost the same level in each bank or bundle.

On September 2017 there was secondary superheater (SSH) Outlet tube leakage on row 11 bank 7, whereas on April 2018 there was also tube leakage on row 11 bank 8. Until now, third SSH Outlet tube leakage was on row 10 bank 8 that happened on December 2019. On September 2017 powerplant owner did not conducted the tube failure assessment. Then on April 2018, they had conducted tube failure assessment together with institution-1. On December 2019, the powerplant owner had conducted another tube failure assessment with institution-2. On January 2019 power plant owner conducted boiler tube metal temperature monitoring then some action plans which are been conducted there were:

a. Limiting the maximum coal flow
b. Coal blending to achieve medium or low slagging and fouling potency instead of high or severe slagging and fouling potency
c. Coal feeder speed biasing to 6 levels of burners
d. Furnace exit gas temperature off-line monitoring to reduce risk of slagging
e. flue gas exit temperature monitoring after Economizer to reduce risk of overheating
f. Combustion tuning to balance left and right-side superheater and reheater boiler metal temperature
g. Operate soot-blower just in time
h. Keep coal surface moisture low through longer time to stocking low rank coal (allow water to flow by gravitation)

Creep deformation analysis has been conducted with plotted data which was x-axis was hours and y-axis was Strain (ε). This equation consists of four dependent terms and one constant and time to rupture is estimated as a time to total strain of 10% [9].

Constants of equation (1) on 2012 that evaluation of long-term creep strength of ASME grades 91 has been updated by same author on 2016. Constant a0 of low stress regime has been changed from 24,440.8 to 24,301.8 [10].

Constants of equation (3) on 2012 that evaluation of long-term creep strength of welded joints of ASME grades 91 has been updated by same author on 2016. Constant a0 of low stress regime has been changed from 36,158.6 to 31,306.0 [11].

The nonequilibrium microstructure formed in the HAZ (Heat Affected Zone) after welding (without PWHT) was reported on Sawada et al. MX particles were observed at the positions of 1.0 mm, 1.5 mm, 2.0 mm, 2mm, 3.0 mm and 3.5 mm even after welding. M23C6 particles were also confirmed at the positions of 2.0 mm, 2.5 mm, 3.0 mm and 3.5 mm [8]. Creep fracture occurs in the Heat Affected Zone (HAZ) in the long term because of different microstructural pattern with fusion line and base metal [12]

II. THE MATERIAL AND METHOD

Data were collected from two institutions. Institution-1 was assessed with tube which was failed on April 2018. Then Institution-2 was assessed with tube which was failed on December 2019. Every institution had conducted microstructural analysis, hardness test, creep test. Table 1 and 2 show the result based overheating on each test by Institution-1 and Institution-2.

TABLE I
CHEMICAL COMPOSITION OF TEST PIECE ON INSTITUTION-1 [5]

Tube number tested and standard		Tube 4 th	Tube 6 th	Tube 7 th	SA-213 T91
		tested	tested	tested	Standard
Content (% weight)	C	0.15	0.15	0.12	0.07-0.14
	Mn	0.4	0.4	0.48	0.30-0.60
	P	0.01	0.02	0.02	0.02(max)
	S	0.004	0.05	0.004	0.01(max)
	Si	0.28	0.29	0.39	0.2-0.5
	Cr	8.69	8.69	8.69	8.00-9.50
	Mo	0.97	0.96	1.00	0.85-1.05
	Fe	89.949	89.485	89.296	88.18-90.55

TABLE II
CHEMICAL COMPOSITION OF TEST PIECE ON INSTITUTION-2 [6]

	Contents (%wt)					
Tube 6 th Tested	C	Mn	P	S	Si	Cr
	0.066	0.375	0.0175	0.0032	0.336	8.43
	Ni	Al	Co	Cu	Nb	Ti
	0.0848	0.0037	0.0092	2.94	0.0883	0.0013
	Pb	Sn	B	Ca	N	Se
	0.0015	0.0033	0.0015	0.0001	0.0656	<0.002
	Mo	V	Sb	Fe	W	Ta
	0.906	0.239	0.0341	86.3	0.0077	<0.0046
Tube 9 th New	C	Mn	P	S	Si	Cr
	0.072	0.401	0.0178	0.0031	0.363	8.54
	Ni	Al	Co	Cu	Nb	Ti
	0.0674	0.0071	0.0092	2.49	0.0838	0.0013
	Pb	Sn	B	Ca	N	Se
	<0.001	0.0039	0.0015	0.0001	0.0562	0.0028
	Mo	V	Sb	Fe	W	Ta
	0.931	0.225	0.0147	86.6	0.0052	<0.0046

Microstructural analysis conducted by Scanning Electron Microscope for institution-1 and institution-2. Then, metal-graphical test had conducted to analyze phase, void, damage characteristic and tube oxide scale to look the evidence of long-term overheating. Etching that had been done were 3% nital. After that, hardness test had been done to compare the aging T91 and new (spare) T91.

SSH Outlet tube bundle consists of T91 and T22. Distributed Control System data of metal temperature has been collected off-linely by Compact disc to evaluate whether it has been experiencing over heat. Burning high Natrium Oxide (Na_2O) which was high slagging index and fouling index were contributing to its overheat. This tube had been suffering this coal during 2018.

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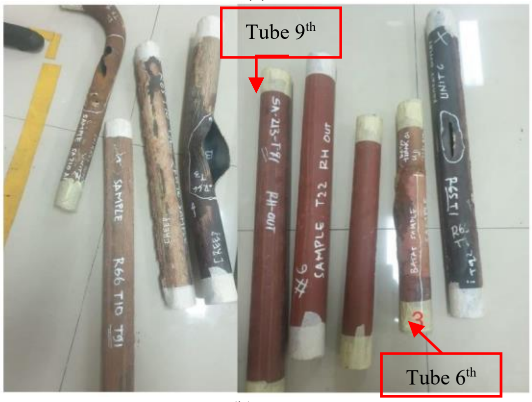
(a)

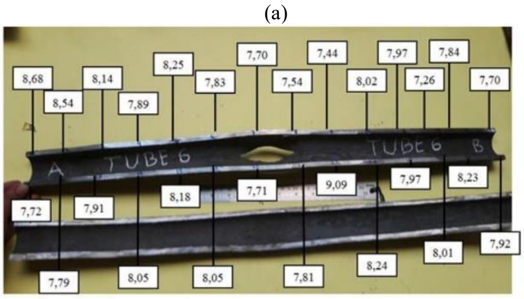


(b)

Fig 2. (a) institution-1 T91 sample tube 3th(effected), 4 th(effected), 5th(effected), 6 th (failed) and 7 th(effected) [5]; (b) institution-2 T91 sample tube 6 th (failed) and 9 th (New) [6]

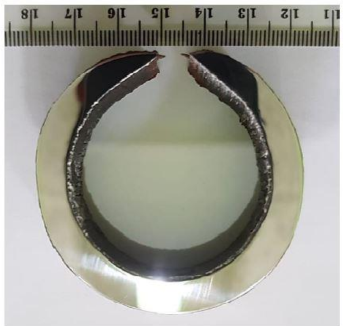
Fig. 2 (a) shows that the failed tube and effected tube that assessed by institution-1 then on (b) showed T91 failed tube (second tube from the right) that assessed by institution-2. On institution-1 T91 failed tube did not compared by the new T91 tube, on the other hand on institution-2 T91 failed tube compared by the new T91 tube.

(a)



(b)

(c)



(d)

Fig 3. (a) and (b) were tube 6th that analyzed by institution-1 [5], then (c) and (d) were tube 6th that examined by institution-2 [6]

Fig. 3 shows that the failed tube that observed by institution-1 and institution-2; (d) was cross section of "CROSS SECTION B"; institution-2 conducted microstructural analysis on "CROSS SECTION A" and "CROSS SECTION B" section to observed void, phase, and oxide scale thicknesses then the tube thickness were measured by both institution (minimum wall thickness from manufacturer were 6.86mm).

Creep rupture data was analyzed on high- and low-stress regimes independently by means of region splitting analysis method [1]. Boundary stress between high- and low-stress regimes was determined as 50% of 0.2% offset yield stress at the temperatures and shown in Table 3. In order to evaluate creep rupture strength, Larson-Miller parameter (LMP) was employed. Second order polynomial equation of stress logarithm (1) was used as follows

$$LMP = (T + 273.15).(C + \log t_r) = \ a_0 + a_1.\log\sigma + a_2.(\log\sigma)^2 \quad (1)$$

Where, T is temperature in °C, t_r is time to rupture in hour, σ is stress in Mpa and C, a_0, a_1, and a_2 are the constants [1].

Table 3(a) shows the constant parameter to plot the Larson Miller Parameter, where R^2 was coefficient of determination, and SE was standard of Error; then Table 3(b) shows the boundary stress to separate the tube which was experiencing higher stress regime (above the boundary stress) or lower stress regime (below the boundary stress). Creep test that had been conducted from institution-1 and institution-2 played on higher stress regime to give quick data for power plant owner. On reality power plant operates on lower stress regime to give reliable operation instead of boiler tube leakage.

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Equation (1) corelated to table III(A) and table III(B)

TABLE III (A)
LARSON MILLER PARAMETER CONSTANT OF BASE METAL FROM KIMURA ET AL [1]

	C	a_0	a_1	a_2	R^2	SE
High stress	36.366	31,802	12,839	-5,312	0.877	0.287
Low stress	20.493	24,301	2,116	-1,670	0.837	0.191

TABLE III (B)
BOUNDARY STRESS USED FOR CREEP RUPTURE DATA ANALYSIS OF BASE METAL FROM KIMURA ET AL [1]

Temperature(ºC)	550	575	600	625	650	675	700
Boundary stress (Mpa)	180	155	130	110	90	70	50

Hoop stress that experienced by the SSH outlet tubes gave on equation (2)

$$S = \frac{P(D-t)+0.005D+PA}{2w(t-0.005D-A)} \quad (2)$$

Where S is allowable hoop stress value at the evaluated temperature (it is hypothesis that thinner wall thickness then hoop stress increased), P is operated main steam pressure, D is outside diameter of tube, t is tube thickness, w is weld joint strength reduction factor, and A is corrosion allowance (assumed equal to zero) [3].

$$LMP = (T + 273.15)(C + \log t_r) = a_0 + a_1 \log\sigma + a_2 (\log\sigma)^2 + a_3\sigma \quad (3)$$

Where, T is temperature in °C, t_r is time to rupture in hour, σ is stress in Mpa and C, a_0, a_1, a_2 and a_3 are the constants [2] Equation (3) corelated to Table III(C) and Table III(D)

TABLE III (C)
LARSON MILLER PARAMETER CONSTANT OF WELD METAL FROM YAGUCHI ET AL [2]

	C	a_0	a_1	a_2	a_3	SE
High stress	34.7767	37,455.9	4,240.8	-2,986.1	0	0.3530
Low stress	22.5811	31,306.0	-4,166.8	0	-0.1728	0.2522

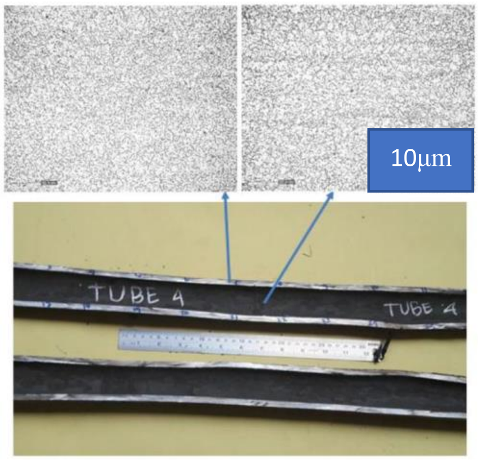
TABLE III (D)
BOUNDARY STRESS USED FOR CREEP RUPTURE DATA ANALYSIS OF WELDED JOINT METAL FROM YAGUCHI ET AL [2]

Temperature (ºC)	550	560	570	575	580
Boundary stress (Mpa)	177	168	160	156	151

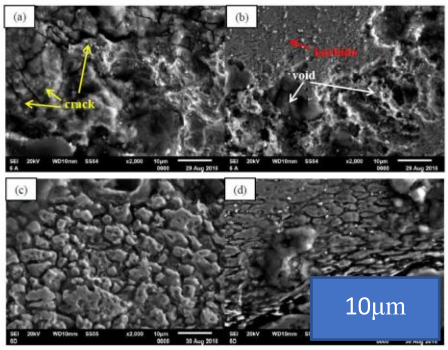
Temperature (ºC)	590	590	600	625	630	650
Boundary stress (Mpa)	143	143	134	113	108	91

III. RESULTS AND DISCUSSION

Microstructural analysis that shows on fig. 4. 4(a) and 4(b) had been conducted by institution-1 whereas 4(c) and 4(d) conducted by institution-2. On fig. 4(b) there were void observed void, crack and carbide. On fig. 4(c) and 4(d) there were new T91 tube microstructural Sample. Their microstructure mostly depends on finishing product that could be bainitic or martensitic temper. Creep strength obtained from solid solution and precipitation hardening on ferrite phase. From the figure shown that martensitic temper was well distributed on the ferrite phase. On fig. 4(c) and 4(d) there were degraded. Their shown that there were carbide spheroidization. And the oxide scale measurement was 0.8-0.95 mm. they showed that the tube experienced a long-term overheating compared to design condition. SEM microstructural also shown condition that severe spheroidization had happened. And micro voids also observed from area that near of the fish-mouthed tube.



(a)



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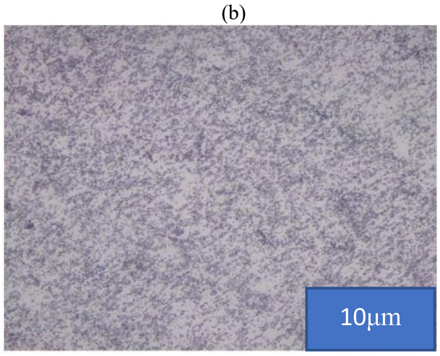

(c)

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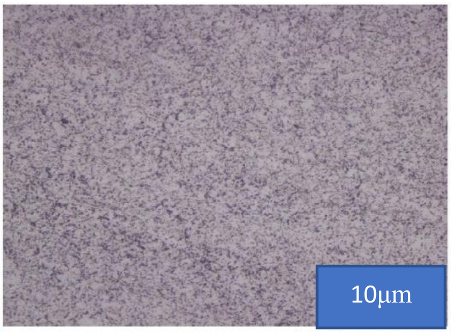

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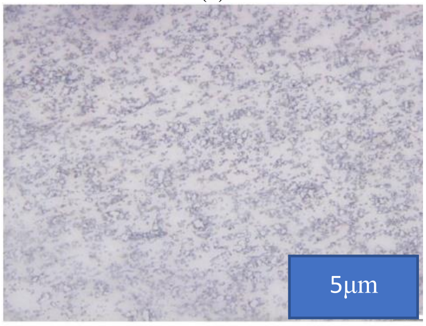

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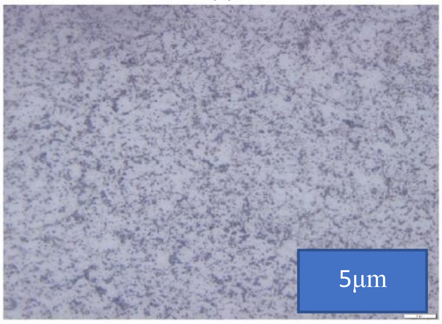
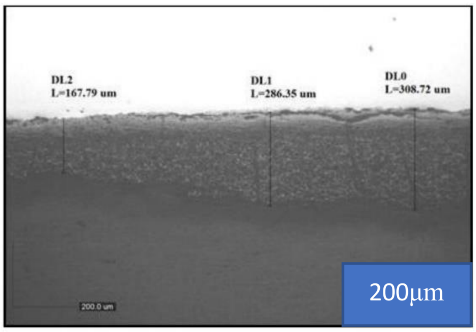


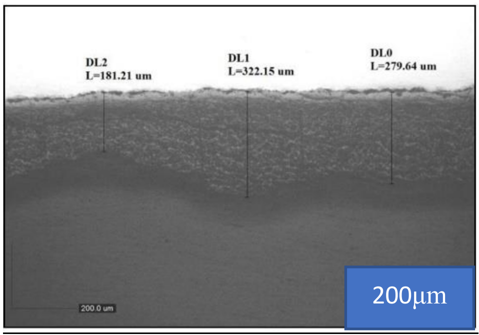
(f)

Fig. 4 (a) and (b) were failed T91 microstructure of sample tube 4th ON 500 times zoom-in by institution-1 [5], then (c) microstructural comparison of T91 failed tube 6th and (d) was a new T91 on 500 times zoom-in by institution-2 [6]; while (e) microstructural comparison of T91 failed tube and (f) was a new T91 on 1000 times zoom-in by institution-2 [6]

Fig. 5 shows that oxide scale that had been developed during tube lifetime that conducted by institution-1 and institution-2. Institution-1 had resulted that oxide scale growth was 0.168 mm until 0.309 mm on tube 6th. The thickness of rupture area from 6th tube (institution-1) was 1.37-3.13 mm. While institution-2 had resulted that oxide scale growth was 0.920-0.946mm on tube 6th. From this evidence we might said that the failed tube had experienced long-term overheating.



(a)



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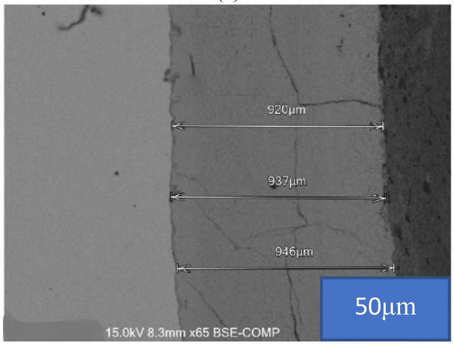
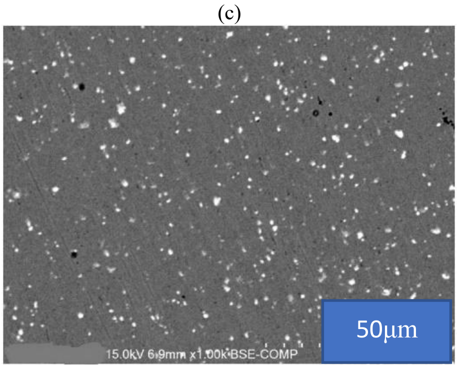


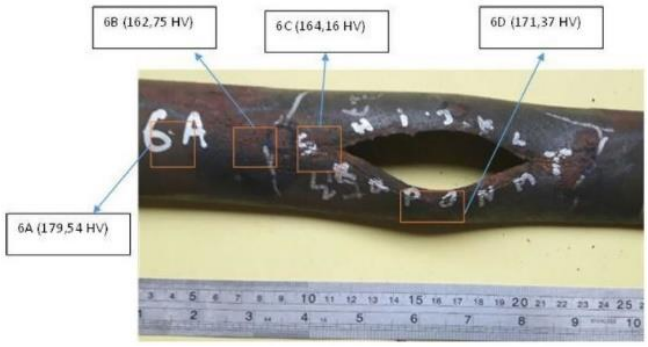
(c)



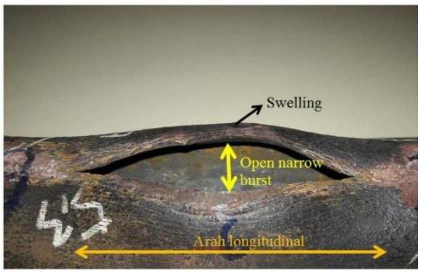
(d)

Fig. 5(a) and (b) oxide scale from tube 6th that conducted by institution-1 [5], then (c) and (d) oxide scale from tube 6th and SEM EDS image conducted by institution-2 [6]

Fig. 6(a) shows the hardness test conducted by institution-1. It had resulted that hardness were 162.75-179.54 HV (tube 6th); (b) shown the bursting area from tube 6th. Then (c) from institution-2 had resulted that average hardness were 168 HV in area A, 219 HV in area B, and 175 HV from area C. (d) showed average hardness from new T91 tube that hardness was **258**. The numbers showed that there were decreasing hardness from the long-term overheated tube.



(a)



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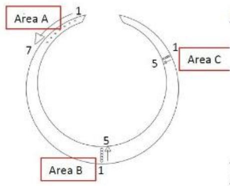
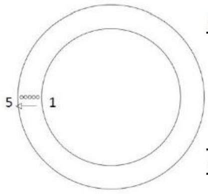


measured number	A AREA	B AREA	C AREA
1	165	214	170
2	167	219	179
3	167	223	170
4	164	222	177
5	168	219	179
6	171		
7	172		
Averaged	168	219	175

(c)



measured number	HV
1	254
2	250
3	269
4	257
5	262
Averaged	258

(d)

Fig. 6(a) and (b) Hardness Vickers tube 6th from institution-1 [5]; then (c) tube 6th Hardness Vickers from institution-2 and (d) tube 9th Hardness Vickers from institution-2 (New tube) [6]

Hoop stress that experienced by SSH Outlet tube was shown on table 4(a). It indicates that minimum wall thickness was 85% of its thickness was 5.83 mm. then main steam pressure from boiler feed pump-turbine driven was 17 Mpa.

TABLE IIIV (A)
HOOP STRESS OF SSH OUTLET TUBE

Tube type	D (mm)	t (mm)	P	w	T steam (°C)	T (°C)	T	S
T91	51	5.83	17	1.00	480	510	540	68.9
T91	51	6.86	17	1.00	480	510	540	56.8
T91	51	5.83	17	0.95	508	538	568	72.5
T91	51	6.86	17	0.95	508	538	568	59.8
T91	51	5.83	17	0.91	536	**566**	596	**75.7**
T91	51	6.86	17	0.91	536	**566**	596	**62.4**
T91	51	5.83	17	0.86	540	593	646	80.1
T91	51	6.86	17	0.86	540	593	646	66.1
T91	51	5.83	17	0.82	540	621	702	84.0
T91	51	6.86	17	0.82	540	621	702	69.3
T91	51	5.83	17	0.77	540	649	758	89.5
T91	51	6.86	17	0.77	540	649	758	73.8

*P: (Mpa)
*w: welded Joint Strength
*T: for evaluation (°C)
*S: hoop stress (Mpa)

TABLE IVV (B)
VALUE OF S (ALLOWABLE STRESS) OF T91 THROUGH INCREASING TEMPERATURE [4]

Temperature (°C)	550	575	600	625	650
allowable stress (Mpa)	98.5	75.5	54.3	36.8	24.0

Table 4(b) indicates that assumed the main steam temperature 540°C and metal temperature 600°C, then evaluated temperature would be 570°C. Thus, maximum allowable stress was **89.3** Mpa [3]. The temperature of the metal to be used in selecting the S value for tubes shall not be less than the maximum expected mean wall temperature, i.e., the sum of the outside and inside tube surface temperatures divided by 2 [3]. This allowable stress valid just when T91 metal temperature 600°C; if its temperature higher than 600°C then S, allowable Stress would be decreased. Boiler manufacturer designed that boiler would withstand hoop stress (related to time dependent properties) on Table 4(a). If evaluated temperature 570°C then on 6.86 mm thickness hoop stress was **63.0** Mpa. Then assumed thickness reduced to 5.83 mm, so hoop stress was **76.4** Mpa. Both stresses were below allowable stress **89.3** Mpa.

Table 5 showed creep test on 2018 from institution-1 in tube 3rd on base metal reference (kimura et al). Table 5 shows on 550°C the specimen could withstand 1.7 hour in 318 Mpa then increased to 9.6 hours in 267 Mpa; On 650°C specimen could withstand 0.7 hour in 190 Mpa then increased to 4.3 hours in 150 Mpa. All of data showed that creep test experiment laid on below the estimation rupture life. On the other hand, table 6 showed in tube 3rd on welded joint metal reference (Yaguchi et al). Table 6 shows on 650°C specimen could withstand higher than estimated rupture life hours.

TABLE V
CREEP TEST HAD BEEN CONDUCTED BY INSTITUTION-1 IN TUBE 3RD ON KIMURA, ET AL (BASE METAL APPROACH) [1]

Tube 3rd (base metal)	LMP	t_r, (Hours)	Experiment (Hours)	Temperature (°C)	Stress (Mpa)
High	30.6579	7.6	1.7	550	318.2
High	31.6764	130.6	9.6	550	267.0
High	33.4805	0.8	0.7	650	189.7
High	34.5989	13.0	4.3	650	149.5

TABLE VI
CREEP TEST HAD BEEN CONDUCTED BY INSTITUTION-1 IN TUBE 3RD ON YAGUCHI, ET AL (WELDED JOINT APPROACH) [5]

Tube 3rd (welded joint Metal)	LMP	t_r, Estimated Rupture Life (Hours)	Experiment (Hours)	Temperature (°C)	Stress (Mpa)
High	29.3652	7.9	1.7	550	318.2
High	30.1647	73.9	9.6	550	267.0
High	31.6203	0.3	0.7	650	189.7
High	32.5566	3.1	4.3	650	149.5

TABLE VII
CREEP TEST HAD BEEN CONDUCTED BY INSTITUTION-1 IN TUBE 5TH ON KIMURA, ET AL (BASE METAL APPROACH) [5]

Tube 5th (Base Metal)	LMP	t_r, Estimated Rupture Life (Hours)	Experiment (Hours)	Temperature (°C)	Stress (Mpa)
High	31.0653	23.6	5.2	550	297.0
High	31.9042	246.9	13.3	550	256.3
High	33.4805	0.8	0.9	650	189.7
High	34.5392	11.2	10.6	650	151.5

TABLE VIII
CREEP TEST HAD BEEN CONDUCTED BY INSTITUTION-1 IN TUBE 5TH ON YAGUCHI, ET AL (WELDED JOINT APPROACH) [5]

Tube 5th (Welded joint Metal)	LMP	t_r, Estimated Rupture Life (Hours)	Experiment (Hours)	Temperature (°C)	Stress (Mpa)
High	29.6833	19.2	5.2	550	297.0
High	30.3455	122.6	13.3	550	256.3
High	31.6203	0.3	0.9	650	189.7
High	32.5058	2.7	10.6	650	151.5

Table 7 shows creep test on 2018 from institution-1 in tube 5th on base metal reference (kimura et al). On 550°C showed that the specimen could withstand 5.2 hour in 297 Mpa then increased to 13.3 hours in 256 Mpa. On 650°C specimen could withstand 0.9 hour (which was higher than estimated rupture life) in 190 Mpa then increased to 10.6 hours in 152 Mpa. On the other hand, Table 8 shows creep test in tube 5th on welded joint reference (Yaguchi et al). On 550°C experiment laid on below the estimated hours to rupture, but on 650°C it laid on above the estimated hours to rupture.

TABLE IX
CREEP TEST HAD BEEN CONDUCTED BY INSTITUTION-2 IN TUBE 6TH ON KIMURA, ET AL (BASE METAL APPROACH) [6]

Tube 6th (Base Metal)	LMP	t_r, Estimated Rupture Life (Hours)	Experiment (Hours)	Temperature (°C)	Stress (Mpa)
High	30.9877	19.0	0.3	550	301.0
High	34.5248	10.8	0.8	650	152.0
High	36.9117	229.0	16.3	680	82.1

TABLE X
CREEP TEST HAD BEEN CONDUCTED BY INSTITUTION-2 IN TUBE 6TH ON YAGUCHI, ET AL JOURNAL (WELDED JOINT METAL APPROACH) [6]

Tube 6th (welded Joint Metal)	LMP	t_r, Estimated Rupture Life (Hours)	Experiment (Hours)	Temperature (°C)	Stress (Mpa)
High	29.6225	16.2	0.3	550	301.0
High	32.4935	2.6	0.8	650	152.0
High	34.6311	36.0	16.3	680	82.1

Table 9 shows creep test on 2020 from institution-2 in tube 6th on base metal reference (kimura et al). On 550°C specimen could withstand 0.3 hour in 301 Mpa; on 650°C it could withstand 0.8 hour in 152 Mpa.; last on 680°C it could withstand 16.3 hours in 82.1 Mpa. All of the data showed they laid on below estimated rupture hours. On the other hand, table 10 showed creep test from institution-2 in tube 6th on welded joint reference (Yaguchi et al). it showed that estimated rupture life on welded joint was lower than base metal. But all experiment data laid on below the estimated rupture hours. Thus, they indicate that the tube experience overheated or microstructural degradation.

Fig. 8(a) shows base metal reference that would be used to compare empirical formula [1] toward creep test from both institutions. On 570°C (540°C main steam temperature and 600°C SSH Outlet metal temperature) and 90 Mpa, plotted graphs had resulted t_r, hours to rupture was 468,511 hours or 53.48 years. Then, on 570ºC and 100 Mpa was 267,412 hours or 30.53 years. After that, on 580°C (540°C main steam temperature and 620°C SSH Outlet metal temperature) and 90 Mpa was 231,232 hours or 26.40 years. Therefore, 10°C increased on temperature was resulting on rupture life decreasing 4.13 years on the same hoop stress.

Fig. 8(b) shows welded joint metal reference that would be used to compare empirical formula [2] toward creep test from both institutions. On 570°C and 90 Mpa, plotted graphs had resulted t_r, hours to rupture was 74,561 hours or 8.51 years. Then, on 570°C and 100 Mpa was 44,089 hours or 5.03 years. After that, on 580°C and 90 Mpa was 37,064 hours or 4.23 years. So, 10°C increased temperature was resulting on rupture life decreasing 4.28 years. The welded joint had resulted smaller hours to rupture than base metal had. It was proved by tube had been bursted in closer time between September 2017 and April 2018. Bulged tube was near the welded joint.

If 175,200 hours or 20 years operation on 570°C, tube was failed on September 2017 (boiler commissioned on September 1997), kimura et al was resulted 108.5 Mpa. Then ruptured tube was welded. On April 2018 tube was failed. Assumed rupture life equal to 6 months or 4320 hours, and if evaluated temperature was 570°C then Yaguchi et al resulted 157.4 Mpa (which was nearly 176% of allowable hoop stress (89.3 Mpa)). On December 2019 tube was failed. Assumed rupture life equal to 20 months or 14,400 hours, and if temperature was 570°C then Yaguchi et al resulted 125.7 Mpa (nearly 141% of allowable hoop stress (89.3 Mpa)).

If 175,375 hours or 20 years operation on 580°C, tube was failed on September 2017 (boiler commissioned on September 1997), kimura et al was resulted 94.9 Mpa. Then ruptured tube was welded. On April 2018 tube was failed. Assumed rupture life equal to 6 months or 4324 hours, and if evaluated temperature was 580°C then Yaguchi et al resulted 137.9 Mpa (which was nearly 154% of allowable hoop stress (89.3 Mpa)). On December 2019 tube was failed. Assumed rupture life equal to 20 months or 14,400 hours, and if temperature was 580°C then Yaguchi et al resulted 108.1 Mpa (nearly 121% of allowable hoop stress (89.3 Mpa)).

If 175,550 hours or 20 years operation on 590°C, tube was failed on September 2017 (boiler commissioned on September 1997), kimura et al was resulted 82.9 Mpa (which was smaller than 89.3 Mpa). Then ruptured tube was welded. On April 2018 tube was failed. Assumed rupture life equal to 6 months or 4326 hours, and if evaluated temperature was 590°C then Yaguchi et al resulted 119.5 Mpa (which was nearly 134% of allowable hoop stress (89.3 Mpa)). On December 2019 tube was failed. Assumed rupture life equal to 20 months or 14,462 hours, and if temperature was 590°C then Yaguchi et al resulted 93.3 Mpa (nearly 104% of allowable hoop stress (89.3 Mpa)).

The latest Tube thickness assessment had resulted 7.4mm minimum. Oxide scale that measured was 0.5mm. So, evaluated thickness was 6.9mm. hoop stress that experienced was 62Mpa. if evaluated temperature was 570°C, then according to Yaguchi et al remaining life of tube are 476,546 hours or 54.4 years. if evaluated temperature was 580°C, then remaining life of tube was 222,265 hours or 25.37. If evaluated temperature was 590°C then remaining life of tube

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are 105,515 hours or 12.05 years. If evaluated temperature was 600°C then remaining life of tube are 52,413hours or 5.98 years.

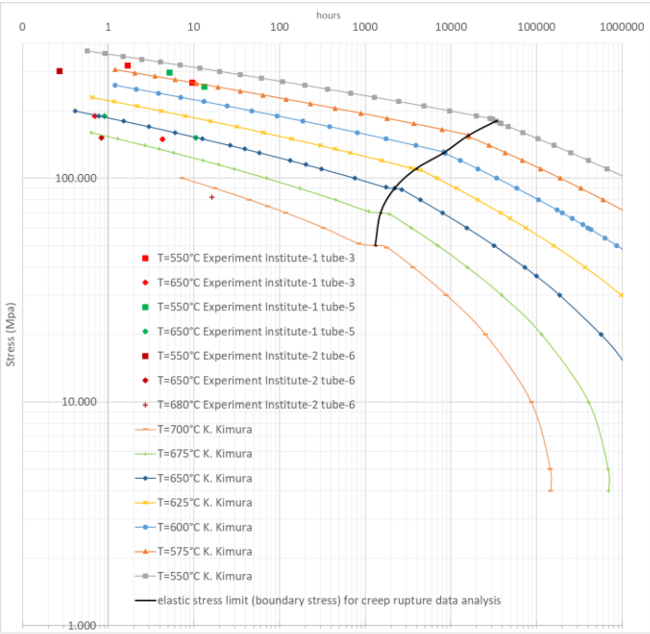

Fig. 8(a) Creep test by both institution on base metal reference (kimura et al).

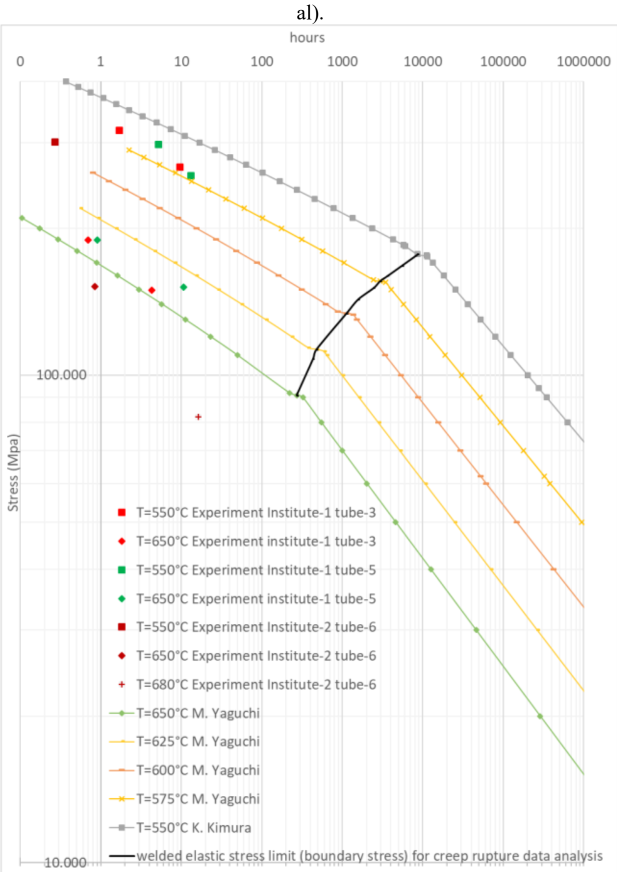

Fig. 8(b) Creep test by both institution on welded joints metal reference (Yaguchi et al)

Thus, increasing 10°C of evaluated temperature then decreasing remaining life of T91 tube **2.1** times. From above calculation, evaluated metal temperature 590°C have had closing the creep simulation. This paper did not showed metal temperature monitoring. SSH Outlet Metal temperature monitoring are critical on full load turbine guarantee operation to reduce risk of tube leakage.

IV. Conclusions

From above narrations we could concluded that T91 tubes were experiencing long-term overheating and microstructural degradation indicated by void, intergranular cracked, decreasing carbide precipitate decreasing or spheroidization, Vickers hardness decreasing, oxide scale growth almost 946 micron-meter, lower rupture hours compared to kimura, et al and Yamaguchi, et al. Operating beyond 200 thousand hours, reliable and efficient were still the biggest challenge and many strategies had conducted to lowering the risk of boiler tube leakages (there were many failure mode besides creep rupture, such as fly-ash and soot-blower erosion, corrosion, mechanical or thermal fatigue, weld defect, rubbing or fretting). if 6.9mm tube thickness (hoop stress 62Mpa) evaluated temperature was 570°C, then remaining life of tube are 476,546 hours or 54.4 years. if evaluated temperature was 580°C, then remaining life of tube was 222,265 hours or 25.37. If evaluated temperature was 590°C then remaining life of tube are 105,515 hours or 12.05 years. If evaluated temperature was 600°C then remaining life of tube are 52,413hours or 5.98 years. If hoop stress that tube had been suffered still smaller than empirical allowable stress from ASME code I year 2019, then it was supposed to be there were no boiler leakage in the years to come before conducted re-tubing Secondary superheater Outlet tube. The next overhaul creep test specimen should have to be taken to find remaining life from welded joint metal reference.

References

[1] K. Kimura, Re-Evaluation Of Long-Term Creep Strength Of Base Metal Of ASME Grade 91 Steel, Proc. PVP2016, Vancouver, CANADA, PVP2016-63355, (2016).

[2] M. Yaguchi, Re-Evaluation Of Long-Term Creep Strength Of Welded Joint of ASME Grade 91 Type Steel, Proc. PVP2016, Vancouver, CANADA, PVP2016-63316, (2016)

[3] American Society of Mechanical Engineer (ASME) Section I Boiler and Pressure Vessel Code, Rules for Construction of Power Boilers, (2019)

[4] American Society of Mechanical Engineer (ASME) Section II Part D Boiler and Pressure Vessel Code, Materials Properties, (2019)

[5] M. Nurbanasari, Final Report of "Jasa Pengujian Mechanical Properties dan Remaining Life Assessment Boiler Tube", LAPI ITB (2018).

[6] Suwarno, Final Report of "Jasa Pengujian Mekanikal Properties Boiler Tube", PT. ITS TEKNO SAINS (2020). archive/macros/latex/contrib/supported/IEEEtran/

[7] Mitsubishi Hitachi Power Systems. *"Report of Risk Based Maintenance Inspection.",* (2019)

[8] Sawada, "Microstructure characterization of heat affected zone after welding in Modified 9Cr-1Mo Steel" (2015)

[9] K. Kimura, "Evaluation of Creep Deformation Property Of Grade 91 Steels" (2015).

[10] K. Kimura, Evaluation of Long-Term Creep Strength of ASME Grades 91, 92, And 122 Type Steels (2012).

[11] M. Yaguchi*, Evaluation of Long-Term Creep Strength of Welded Joints of ASME Grades 91, 92 And 122 Type Steels,* (2012)

[12] J. A. Francis, W. Mazur, H. K. D. H. Bhadeshia, "Type IV cracking in ferritic power plant steels", Mater. Sci. Technol. 22 (2006) 1387–1395.