CREEP BEHAVIOR OF WELDED FERRITE-PEARLITE 2¼Cr – 1 Mo STEEL

Supriadi, H. Agus Suhartono

National Research and Innovation Agency
National Laboratory For Structural Strength Technology
E-mail: hagussuhartono@yahoo.co.id

ABSTRACT

This research aimed to study the creep and creep-rupture behavior of 2¼ Cr-1Mo steel on as-received and as-welded specimens. The tests were carried out on two different specimen types of the as-received specimen and as-welded specimen. The tests were executed based on 100 hours, 300 hours, 1000 hours, and 3000 hours of rupture time under constant load at 550°C, 600°C, and 650°C, respectively. In this paper, the creep and creep-rupture behavior of this material is presented based on the results obtained and followed by related discussions. The study showed that at the same condition, the part with the weld joint has the same rupture time as the other smooth un-welded parts.

Keywords: Creep; life prediction; Ferritic steel
Received: 2021-10-22; Revised: 2021-12-03; Accepted: 2021-12-09

INTRODUCTION

Numerous machine and structural components are subjected to loads under the conditions that involve elevated temperatures for long periods. One of the most critical factors determining the integrity of elevated temperature components is their creep behavior. Due to thermal activation, materials can slowly and continuously deform even under constant load (stress) and eventually fail. The time-dependent, thermally assisted deformation of components under load (stress) is known as creep[1]).

The 2¼Cr–1Mo steels are materials commonly used for boiler application. These steels can undergo creep deformation by a combination of stress and elevated temperature [2], [3], [4], [5]. Since joining in the boiler is usually done by welding, it is gaining the attention of many researchers to study weldment and material for high-temperature application [6], [7], [8], [9]. [10], [11], [12]. This research work is therefore aimed to study creep and creep-rupture behavior of 2¼ Cr–1Mo steels on as-received and as-welded specimens.

MATERIAL AND METHOD

Chemical Composition and Mechanical Properties

The material investigated was a normalized and tempered 2¼Cr-1Mo steel as-received and welded material. The Chemical composition of the as-received material is shown in table 1. Mechanical properties of the as-received and as-welded are shown in table 2.

Table 1. Chemical composition (%W).

Element	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Nb
Composition (%W)	0.08	0.23	0.43	0.05	0.04	2.19	0.04	2.19	0.98	0.01

Table 2. Mechanical properties.

Specimen	Temp (°C)	$\sigma_{0.2}$ (N/mm^2)	σ_B (N/mm^2)
As-received	R.T	302.0	451.27
As-received	R.T	296.0	453.75
As-welded	R.T	307.7	456.25

Specimen and Testing Procedure

The testing was carried out on two specimens groups, namely the as-received and as-welded specimens. The as-received specimen dimension is shown in figure 1, accurately machined from as-received $2^1/4$Cr-1Mo steel plate

The as-welded specimens have the same dimension as the received specimens, machined from welded 2¼Cr-1Mo steel. The welding was carried out using electrode JIS Z3223 - DT2415. The welding quality had been inspected by X-ray testing and metallographic examination before being treated with the post-welding heat treatment. The Welded position is shown in figure 2.

The creep strain is measured by an extensometer. Regression analysis was done. The test was done by SATEC System's creep machine model M3**.** Tests were carried out in accordance with Table 3.

Table 3. Testing point plan for the experiment.

No	Time (hour)	Temperature	Specimens
1	100	550°C 600°C 650°C	As-received As-welded
2	300		
3	1000		
4	3000		

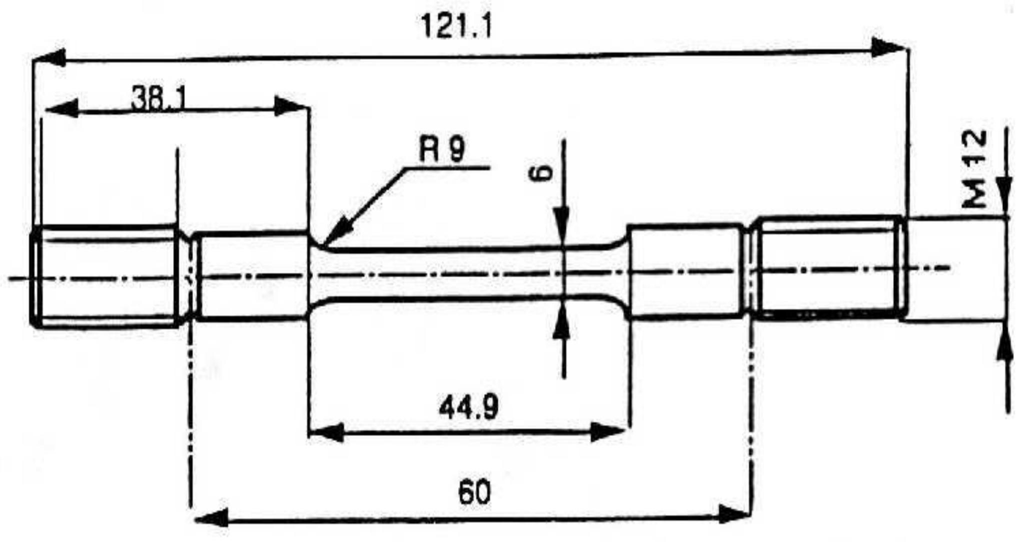

Figure 1 . Dimension of the specimen (mm).

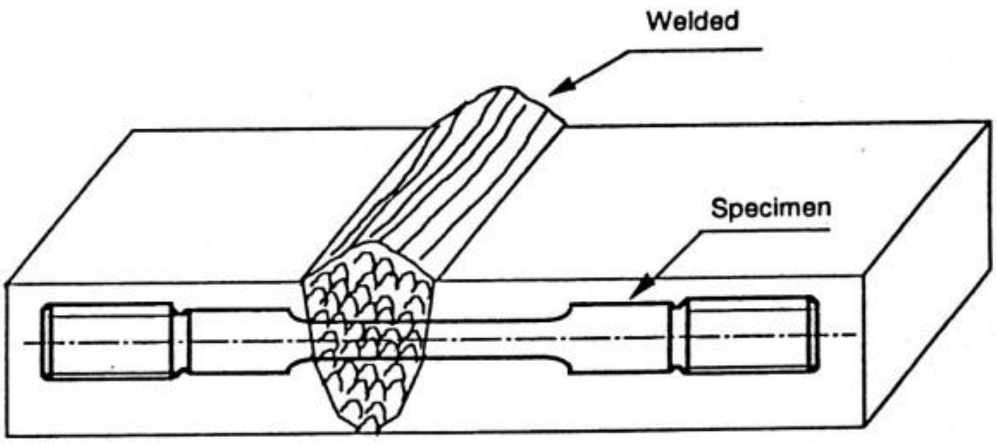

Figure 2 . Welded position on the specimen.

RESULTS AND DISCUSSIONS

Creep *Rate and Creep Rupture* Test

A represented creep curve obtained from the testing is illustrated in figure 3. The curve has a primary creep (or stage I) where the creep rate (slope of the curve) ; $\frac{d\epsilon}{dt}$ or $\dot{\epsilon}$ decreases with time, then reach essentially a steady-state (secondary creep or stage II) in which the creep rate changes little with time, and finally, the creep rate increases rapidly with time (tertiary creep or stage III) until a fracture occurs. It should be noted that the degree to which these three stages are readily distinguishable on the applied stress and temperature From the creep curve (figure 3)–can be obtained a curve between time versus creep rate. Figure 4 shows the representative creep rate curve that has a minimum value at stage II. Table 3 shows the general results of the testing, included the minimum creep rate, time to rupture, fracture elongation, and reduction of area. The same group of time as-received specimen and the as-welded specimen have the same load condition.

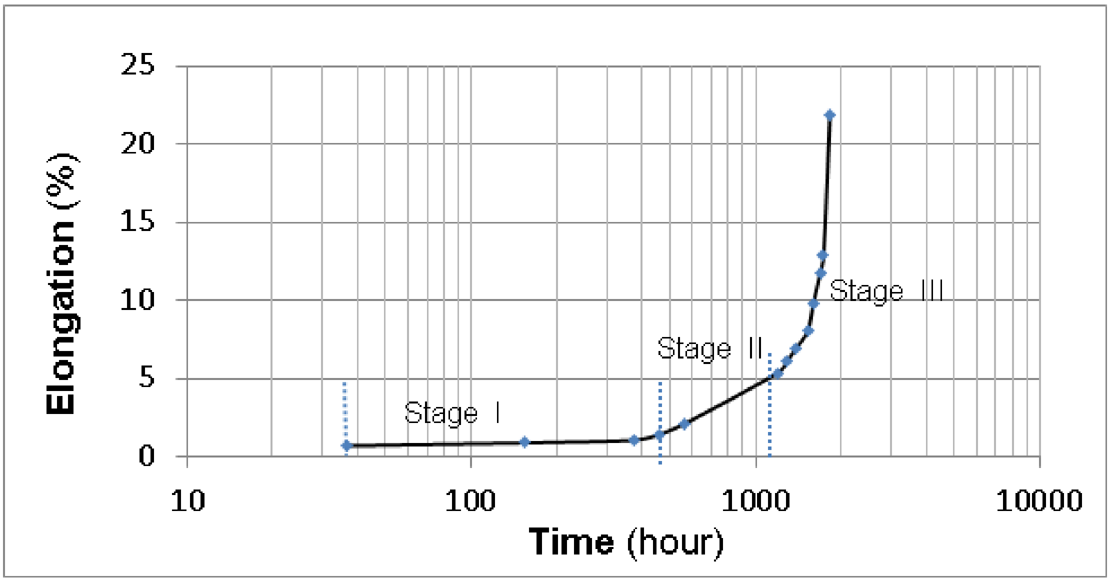

Figure 3. Representative creep curve, the data taken from D-3 specimen (650^{O}C, 43.13 N/mm^2) with 43.13 N/mm^2 of stress and 650^{O}C of temperature.

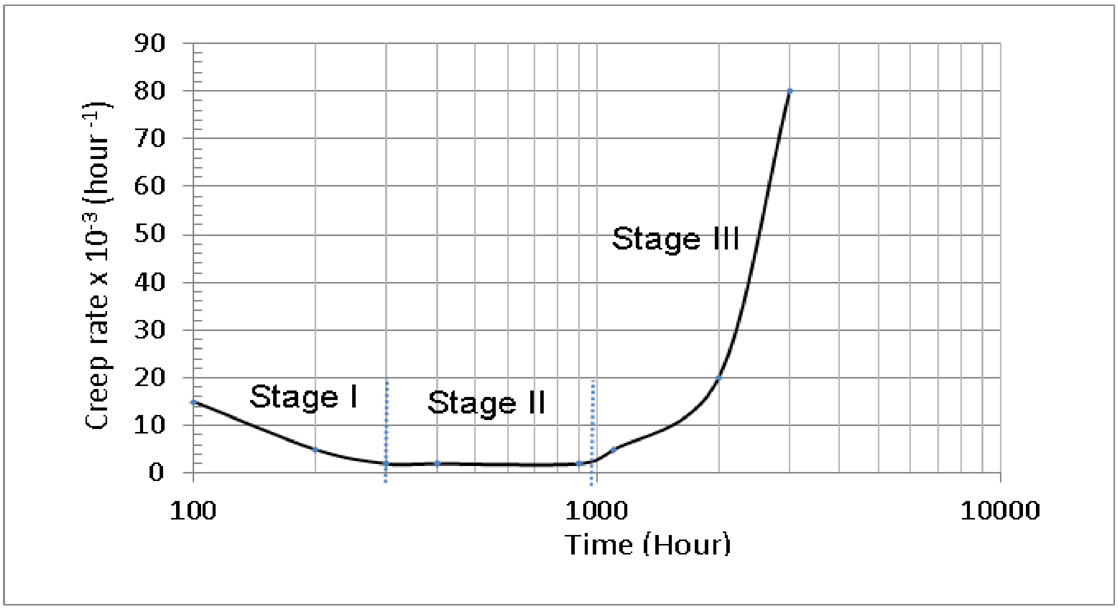

Figure 4. Creep rate curve obtained from creep curve (Using the same data as shown in figure 3.

Table 4. The minimum creep rate of the as-received and as-welded specimens.

No	Time (hour)	Minimum Creep Rate as-received	Minimum Creep Rate as-welded
1	100	100 X 10^{-3} %/hour	50 X 10^{-3} %/hour
2	300	40 X 10^{-3} %/hour	20 X 10^{-3} %/hour
3	1000	10 X 10^{-3} %/hour	10 X 10^{-3} %/hour
4	3000	5 X 10^{-3} %/hour	2 X 10^{-3} %/hour

In general, the as-welded specimen has a longer rupture time compared to the as-received specimen. It also can be seen in the minimum creep rate that the as-welded specimen has a lower minimum creep rate. The result creep rate is shown in Table 4

The Fracture elongation varies from 25 - 45 %. (Table 4) In general, the specimen tested at a higher temperature has a longer fracture elongation. Similarly, it can be seen that a higher temperature produced a smaller fractured area or a high reduction of area.

Comparison of the as-welded and as-received specimen, the as-welded specimen showed that the as-welded specimen commonly has a smaller fracture elongation and smaller reduction area for the same testing condition than an as-received specimen.

3.2. Fractography and Metallography

The specimens that have been tested under creep rupture were then analyzed by fractography and metallography. Figure 5a and 5b show the result of the metallographic examination of the as-received specimen (figure a) and the as-welded specimen (figure B). Figure 5a. A1, A2, A3 show the metallography taken from the as-received specimen based on the position from the fracture. A1 is the closest to the fracture, while A2 and A3 are located further from the fracture. Figure 5b. B1, B2, B3 show the metallography of the as-welded specimen was taken based on the position of the fracture, with B1 being the closest to the fracture, while B2 and B3 are located further.

The microstructure exhibits a ferrite-pearlite mixture. Figure (B-3) shows a different microstructure of the dendritic weld microstructure. It can be seen from the figure (A) and figure (B) that both of them shows a typical creep deformation. This is indicated by the formation of some voids within the microstructure. Figure 5a A1 and 5b B1 show the voids (see arrow). These voids indicated that the specimen was actually fractured by creep [13].

Table 5. General Test result obtained, which includes: rupture time, fracture elongation, reduction area, and minimum creep rate.

Group	Spec. Code	Temperature (°C)	Stress (N/mm^2)	Rupture Time (Hours)	Minimum Creep Rate (X10^{-3} % hour)	Reduction Area (%)
As-received 100 hours	A-1	550	183.77	97.5	103. 23	91.84
	A-2	600	110.26	140.4	99. 76	92.85
	A-3	650	73.18	113.6	85.47	94.55
As-welded 100 hours	A-1W	550	183.77	105.8	58. 40	89.44
	A-2W	600	110.26	205.0	30. 95	89.97
	A-3W	650	73.18	206.4	36. 79	91.97
As-received 300 hours	B-1	550	154.00	283.3	44. 87	93.73
	B-2	600	95.93	372.5	41. 56	91.00
	B-3	650	66.89	256.2	17. 09	93.64
As-welded 300 hours	B-1W	550	154.00	336.5	23. 61	89.44
	B-2W	600	95.93	421.5	16. 66	88.89
	B-3W	650	66.89	241.5	21. 60	91.97
As-received 1000 hours	C-1	550	139.16	975.2	18. 33	87.75
	C-2	600	80.46	1361.3	7. 00	88.89
	C-3	650	50.98	1360.5	6. 12	86.86
As-welded 1000 hours	C-1W	550	139.16	491.7	15. 30	88.89
	C-2W	600	80.46	2421.7	2. 05	85.30
	C-3W	650	50.98	998.0	3. 20	91.97
As-received 100 hours	D-1	550	110.23	3934.6	4. 09	92.98
	D-2	600	75.78	2137.0	6. 60	93.77
	D-3	650	43.13	1810.4	5. 00	94.54

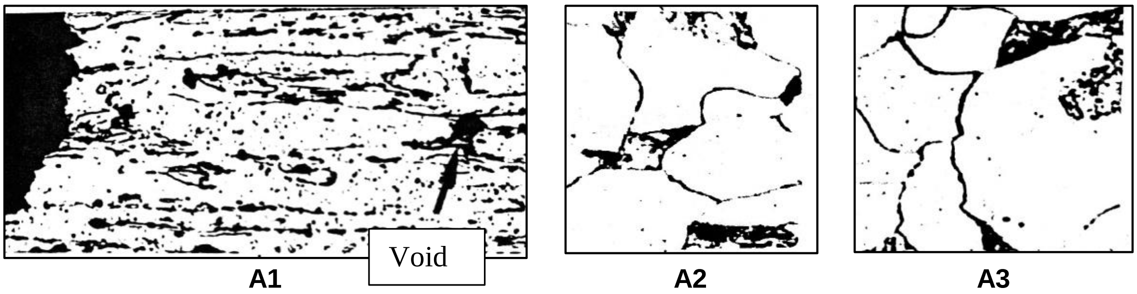

Figure 5a. Metallography of the specimen, (A) as-received.

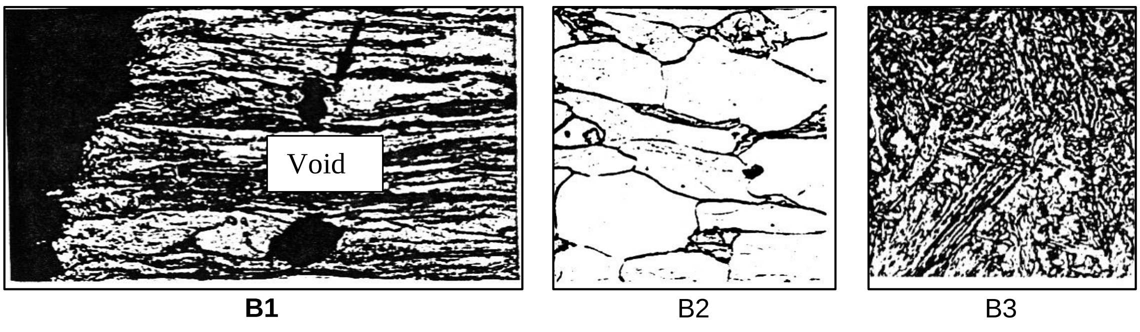

Figure 5b. Metallography of the specimen, (B) as-welded specimen.

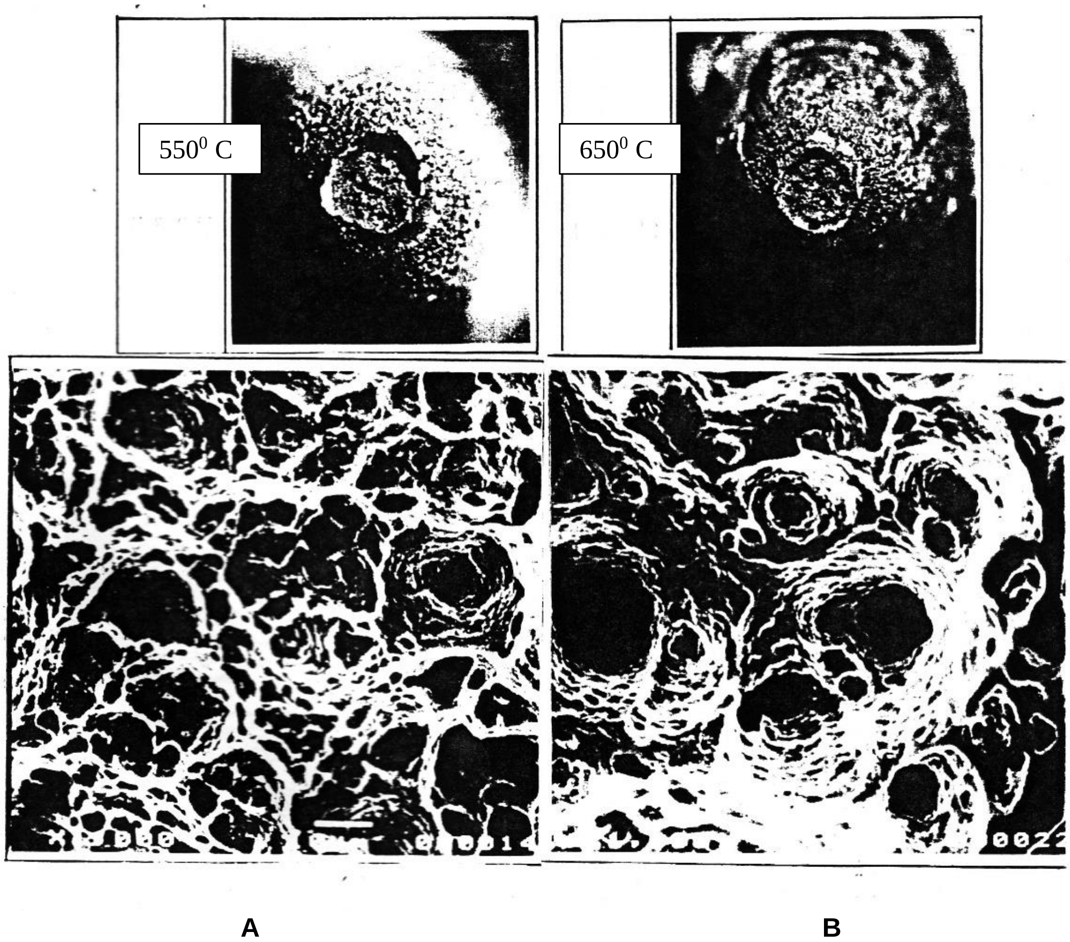

Figure 6. Macrograph of the fracture surface. Showing the typical dimple fracture. (A) Specimen tested at 550^o C. (B) Specimen tested at 650° C.

Figure 6 shows the fracture surfaces of the specimen. The upper picture is the photograph of specimen fracture, while the lower picture shows the detail of the surface of the fracture. It is clearly seen that the fracture surface has a typical dimple configuration. In figures (6a) and (6b), the dimples are seen clearly, and these dimples surface of the specimen tested at 650° C are larger than the specimen tested at 550° C. A dimple fracture refers to a type of material failure on a metal's surface that is characterized by the formation and collection of microvoids along the granular boundary of the metal [14], [15].

By observing the fractographic and metallographic results of each tested specimen, it has been found that all of the specimens have the same fracture, i.e., a typical creep voids. The difference in void dimension can not be determined clearly. The only thing that can be observed is the tendency of that voids to become larger at higher test temperatures.

Data listed in table 5 can be represented by figure 7 in that it shows the creep rupture curve. In this figure, there is no significant difference between the as-received and as-welded specimens.

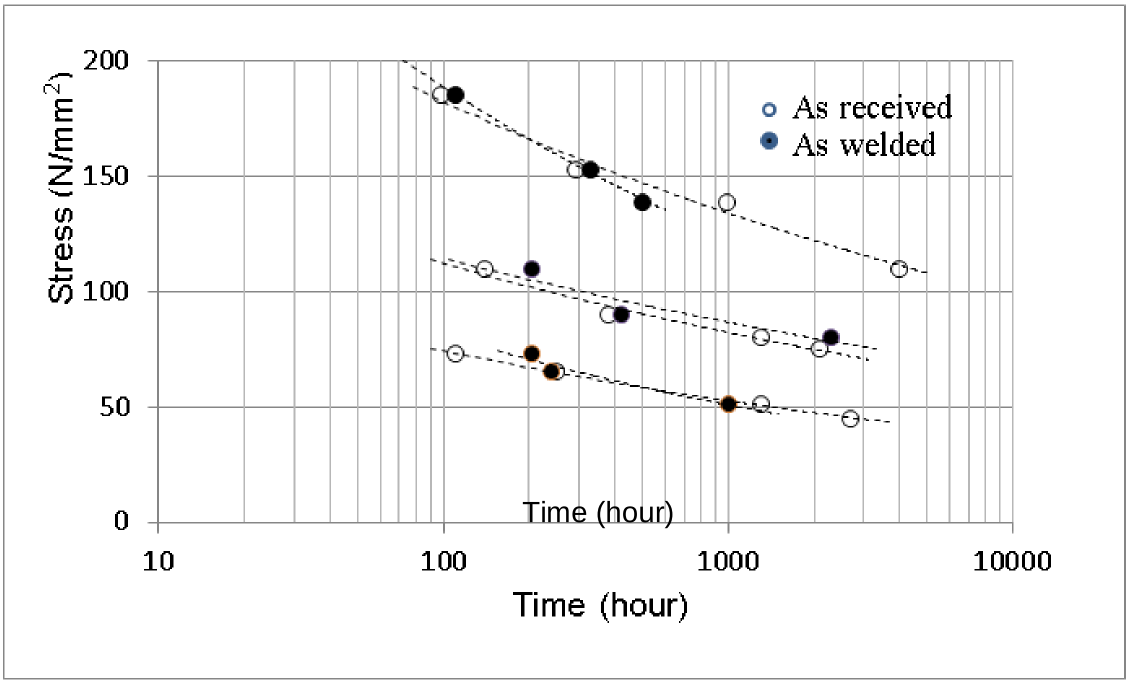

Figure 7. Stress Rupture Curve.

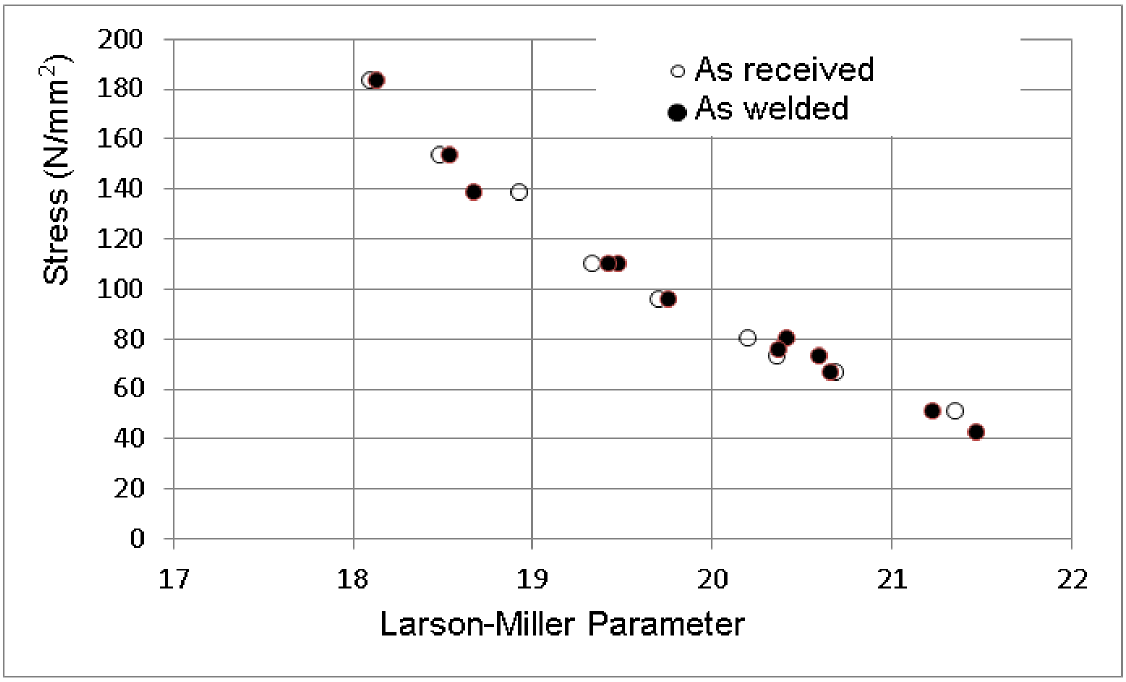

Figure 8. LMP curve of the as-received and as-welded specimen.

Data Analysis

For the purpose of regression analysis of creep rupture data, the experimental creep data were used to calculate the Larson-Miller (LM) parameter by the following equation [16]:

$$LMP = T\ (20 + \log tr).\ 10^{-3} \tag{1}$$

Where
LMP = Larson-Miller Parameter
T = test temperature in Kelvin, and
Tr = rupture time in hours (h).

Figure 8 shows the Larson-Miller parameter curve of the as-received and as-welded specimen. The regression line between LM parameter and applied stress (σ) can be given by the following equation :

For as-received specimen
$$LMP = -1.2680(\log \sigma)^2 - 0.63132 (\log \sigma) + 25.996 \quad (2)$$

and for as-welded specimen
$$LMP = -1.9242(\log \sigma)^2 + 1.7853 (\log \sigma) + 23.851 \quad (3)$$

The level of significance of the regression analysis was found to be approximately 99.5% for as-received and 99.2% for the as-welded specimen. The as-received and as-welded specimens have almost the same LMP. This means that at the same condition, the part with the weld joint has the same rupture time as the other smooth un-welded parts.

CONCLUSION

The creep and creep-rupture behavior of commercial-quality $2^{1/4}$ Cr-1 Mo steel has been characterized and analyzed at 550^0C, 600^0C, and 650^0C for periods extending up to 3 000 h. The extrapolation curve of the as-received and as-welded specimen has been obtained. The study concluded that the welding process is most likely to have no dangerous effect on parts under high-temperature working loads. The tests show that the rupture time of parts with welds and other smooth unwelded parts is almost the same under the same conditions. It is expected that this extrapolation data is useful in designing boiler and related power plant equipment.

AUTHOR INFORMATION

Coresponding Author:

hagussuhartono@yahoo.co.id
phone: +6281297282767

suprisutidjo@gmail.com
phone: +6281380920233

Author contribution:

The first author and second author have contributed equally to this work.

REFERENCES

[1] R. Viswanathan, Damage Mechanisms and Life Assessment of High Temperature Components, ASM International, Ohio, 1989.
[2] H.K. Yadav, L. Maddi, A.R. Ballal, D.R. Peshwe, V. Rao Structural and mechanical characterization of service exposed 2.25Cr-1Mo steel Trans Indian Inst Met, 70 (2017), pp. 1091-1096
[3] W.F. Lima, G. Rigueira, H.C. Furtado, M.B. Lisboa, L.H. de Almeida, Microstructure evolution and creep properties of 2.25Cr-1Mo ferrite-pearlite and ferrite-bainite steels after exposure to elevated temperatures Mater Res-IBERO-AM J Mater, 20 (2017), pp. 418-422
[4] A. Elrefaey, Y. Javadi, J.A. Francis, M.D. Callaghan, A.J. Leonard AJ. Evolution of microstructure and toughness in 2.25Cr-1Mo steel welds Int J Pres Ves Pip, 165 (2018), pp. 20-28
[5] X.M. Chen, S.H. Song, Z.C. Sun, S.J. Liu, L.Q. Weng, Z.X. Yuan Effect of microstructural features on the hot ductility of 2.25Cr–1Mo steel Mater Sci Eng A, 527 (2010), pp. 2725-2732
[6] P. Mayr, C. Schlacher, S. Mitsche, Critical issues with creep exposed ferriticmartensitic welded joints for thermal power plants, International Conference of the IIW 2011, pp. 417–425.
[7] D. Abson, J. Rothwell, Review of type IV cracking of weldments in 9–12%Cr creep strength enhanced ferritic steels, Int. Mater. Rev. 58 (8) (2013) 437–473.
[8] S. David, J. Siefert, Z. Feng, Welding and weldability of candidate ferritic alloys for future advanced ultrasupercritical fossil power plants, Sci. Technol. Weld. Join. 18 (8) (2013) 631–651.
[9] L. Li, B. Silwal, A. Deceuster, Creep rates of heat-affected zone of grade 91 pipe welds as determined by stress-relaxation test, Int. J. Press. Vessel. Pip. 146 (2016) 95–103.
[10] N. Saini, R.S. Mulik, M.M. Mahapatra, Influence of filler metals and PWHT regime on the microstructure and mechanical property relationships of CSEF steels dissimilar welded joints, Int. J. Press. Vessel. Pip. 170 (2019) 1–9
[11] L. Milović, T. Vuherer, I. Blačić, M. Vrhovac, M. Stanković, Microstructures and mechanical properties of creep

resistant steel for application at elevated temperatures, Mater. Des. 46 (2013) 660–667.
[12] H.W. Wu, T.J. Wu, R.K. Shiue, L.W. Tsay, The effect of normalizing temperature on the short-term creep rupture of the simulated HAZ in Gr. 91 steel welds, Metals 8 (2018) 1072
[13] A. Raj, N. Roy, B.N. Roy and A.K. Ray*, Life Estimation and Creep Damage Quantification High Temp. of Service Exposed Reformer Tube Mater. Proc. 2015; 34(7): 731–742
[14] W. Zhang,T. Zhang, X. Wang, H. Chen, J.Gong, Remaining creep properties and fracture behaviour of P92 steel welded joint under prior low cycle fatigue loading, Journal of Materials Research and Technology Vol. 9, Issue 4, July–August 2020, Pages 7887-7899
[15] J.S. Lee, H. Ghassemi Armaki, K. Maruyama, T. Muraki, H. Asahi, Causes of breakdown of creep strength in 9Cr-1.8W-0.5Mo-VNb steel, Mater Sci Eng A, 428 (2006), pp. 270-275

[16] H, Sakasegawa, H. Tanigawa, , Larson–Miller Constant of Heat-Resistant Steel, Metallurgical and Materials Transactions A, 2013, DO - 10.1007 /s11661-013-1631-0