Quantitative Analysis of Microstructure Deformation in Accelerated Creep Fenomena of Ferritic SA-213 T22 and Austenitic SA-213 TP304H Material

Cukup Mulyana, Ahmad Taufik, Agus Jodi Gunawan, R.E. Sirregar
Universitas Padjadjaran
email korespondensi: c.mulyana55@yahoo.com, a.taufik@atsolusi.co.id, rustam@phys.ac.id

Abstract

The failure of critical component in fossil fired power plant which operated in creep range (high stress, high temperature and in the long term) depends on its microstructure characteristics. Ferritic low carbon steel (2.25Cr-1Mo) and Austenitic stainless alloy (18Cr-8Ni) is used as a boiler tube in the secondary superheater outlet header to deliver steam before entering the Boiler. The failure tube is happened in a form of rupture, resulting trip that disrupts the continuity of the electrical generation. The research in quantification microstructure deformation has been done in predicting the remaining life of the tube through interrupted accelerated creep test. For Austenitic Stainless Alloy (18Cr-8Ni), creep test was done in 550°C with the stress 424,5 MPa and for Ferritic Low Carbon Steel (2.25Cr-1Mo) in 570°C with the stress 189 MPa. Interrupted accelerated creep test was done by stopping the observation in condition 60%, 70%, 80% and 90% of remaining life, the creep test fracture was done before. Then the micro hardness test, photo micro, SEM and EDS was taken. Refers to ASTM E122, microstructure parameter was calculated. The result indicated that there is consistency of increasing of grain size number, micro hardness, and the length of crack or void number per unit area with the decreasing of remaining life. While morphology of grain (stated in parameter α=LV/LH) relatively constant) for austenitic. But for ferritic the change of morphology shown significant. The quantification of microstructure can be use for predicting remaining life in power plant, refinery or chemical industry. The result is hopefully more accurate than Larson Miller Method or Replica Insitu Method with is used in a large number for predicting remaining life in industry now.

Keywords :*accelerated creep, Parameter Larson-Miller, quantification of microstructure, boiler tube, ferritic and austenitic*

Introduction

Critical component in fossil-fueled power plants have a tendency to fail more than in the other components. Failure is generally caused by creep phenomenon due to the material operated on high temperature, pressure and long period operation time [1]. Critical component in boiler tube is generally made of ferritic steel SA-213 T22-213 and Austenitic SA-213 TP304H.

To prevent the unpredictable failures that disturb production of power electricity, continuous inspection and monitoring should be done. To predict the remaining life, the general method used is replica insitu or accelerated creep test of the new material, then plotted in Larrson Miler curve that is commonly used in industry to predict the remaining life [2]. The results replica is compared to the microstructure map, the problem, result of interpretation is often subjective [3]. While the Larson Miller method predict the remaining life with a very wide range because of the nature of the logarithmic function of the PLM parameter so it tends to be less accurate.

In this paper it is carried out a quantitative analysis of the microstructure of accelerated creep test and the results were stopped before fracture adapted to the desired level of damage. Further the microstructure of the sample is tested by photomicro, SEM and EDS. Microstructure parameter such as diameter of grain boundary, the number of crack, morphology of material was observed and it is used to predict the remaining life of the sample. This method is still in the early stages even if it had been equipped with the observation that many will be very useful for application in high temperature industrial plants, oil refineries and chemical industry.

MATERIALS AND METHODS

Materials

Sample was obtained from the secondary super heater outlet header boiler in Suralaya Power Plant. The sample in a form of tube serves to flow the temperature and high-pressure steam used to rotate the turbine. The material used is the Ferritic SA-213 T22 and Austenitic SA-213 TP304H. The test results of chemical composition of this material can be seen in the table:

TABLE 1. Chemical composition of SA-213 T22

/	Mn	P	S	Si	Ni	Cr	Mo
0,18	0,46	0,01	0,02	0,23	0,11	2,22	0,89

With the inner diameter is 48.27 mm and outer diameter is 58.13 mm, while the hardness is 138 HB.

TABLE 2. Chemical composition of SA-213 TP304H

/	Mn	P	S	Si	Ni	Cr	Mo
0,08	0,81	0,02	0,01	0,49	10,27	18,67	0,11

With the inner diameter is 48.27 mm and outer diameter is 57.1 mm, while the hardness is 150 HB.

Both of materials are steel group which is resistant to high temperatures and pressure. TP304H SA-213 material has excellent corrosion resistance

Sample Preparation

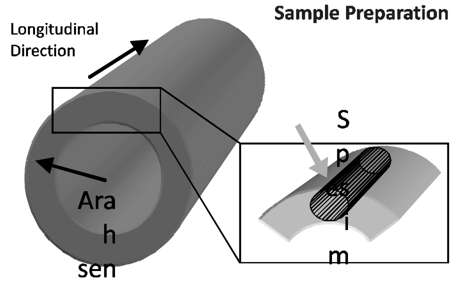


FIGURE 1. Samples slice in longitudinal direction

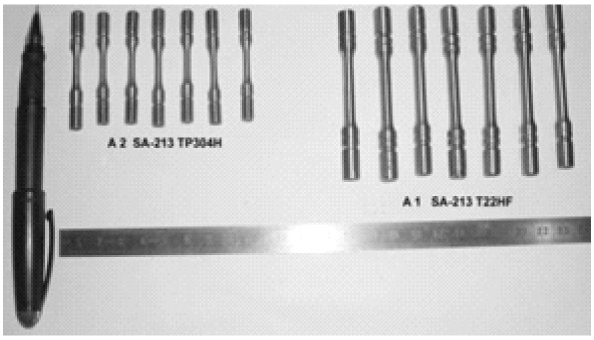


FIGURE 2. The creep and tensile test stress sample for high temperature condition

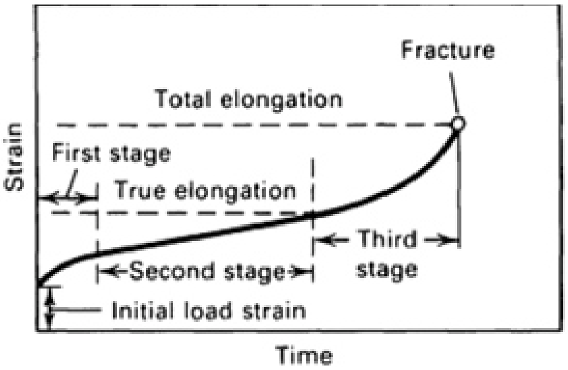


FIGURE 1. Creep curved, Strain ε versus time $t^{(2)}$

METHOD

The steps for this research are:

a. Sample preparation, high temperature tensile test to get UTS to predict the load that will be given in the creep test
b. Accelerated creep fracture test in B2 TKS-BPPT. Done by giving different loads and temperatures. Then the fracture time was measured as well as the strain as a function of time. It will be used to get a creep curve and to predict remaining life using Larson Miler method.
c. Accelerated interrupted creep test, it is done by stopping test before the material was fracture. The test was stopped at 60%, 70%, 80% and 90% of the fracture time.
d. The microstructure was examined with SEM, photo micro test and micro hardness (HV). It is used to observe the microstructure deformation adjusted on the level of damage to the operating time has been set previously.
e. The parameters obtained from the microstructure test is grain size number, the average grain diameter, the length of crack or the number of void.
f. Then the microstructure parameters are analyzed as a function of percentage of the damage, in order to obtain the relationship between microstructure quantification and of the level of damage

Equations

$\sigma = F/A$ ... (1)

Where σ : Tensile Stress, F = Force and A = Cross Section Area

$\sigma = Ee$ ... (2)

Where : E : Young Modulus, e : Strain

$\varepsilon = f(t,\sigma,T)$ ... (3)

Where : time (hour) and T : (°C)

$$PLM = T\ (C_1 + \log t_r)\ 10^{-3} \ldots (4)$$

At high temperature strength of a material decreases slowly with increasing operation time. Therefore creep testing is conducted to determine the thermal and mechanics resistance of a material is a function of temperature, stress and time, This resistance is determined by creep curve from the accelerated creep. The interrupted creep test is also conducted to get the level of the damage of material, using a microscope optics the microstructure is observed and then it is used to predict the remaining life of material.

RESULT AND DISCUSSION

Tensile Test at High Temperature

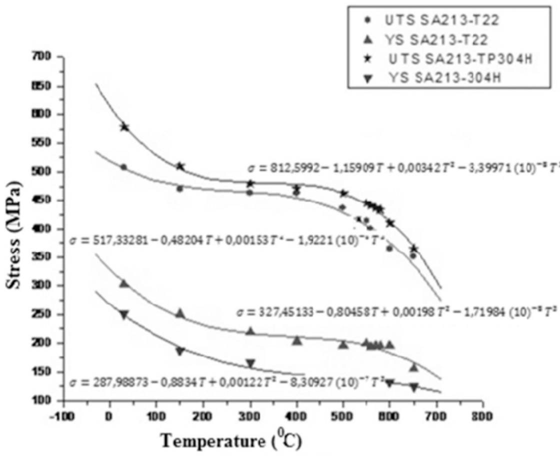


FIGURE 2. Graphic of UTS and yields stress as a function temperature of material SA-213 T22 and SA-213 TP304H

Analysis:

In FIGURE 2 UTS it is change rapidly in the temperature of 520°C - 600°C, while UTS of SA-213 T22 decreased faster than the SA-213 TP304H after passing the temperature 570°C-580°C. This temperature become limit for the creep test of material SA-213 T22. If the creep test is given above 580°C, the sample will rupture because of the damage of the microstructure, and it takes place quickly. This temperature should be avoided in the operation of the power plant. But for the material SA-213 TP304H temperature is still in the safe, the limits of temperature is higher than 600°C.

Result of Acclerated Creep Test

Creep Curve of SA-213 T22

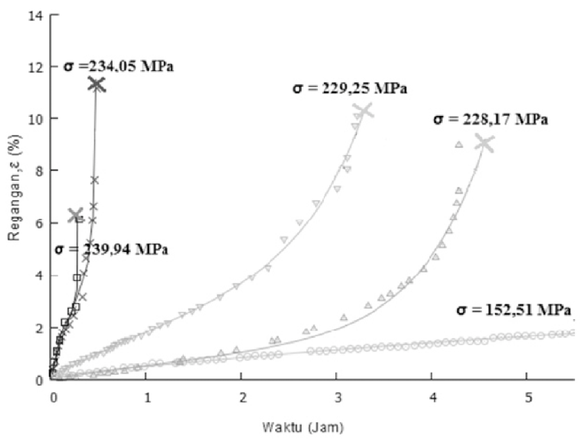


FIGURE 3. Creep curve of material SA-213 T22 from accelerated creep test, strain Vs time (hour) for constant temperature

Analysis:

At a constant temperature 580°C function of creep strain Vs time is:

For σ = 152,51 *Mpa* and t_r = 31,8 hours with

$$\frac{d\varepsilon}{dt} = 0{,}39\%\ \textit{perhour}$$

$\varepsilon(t) = 3{,}86694 - 3{,}7265 exp(-0{,}10312t)$............(5)

For σ = 228,17 *MPa* and t_r = 4,3 hours with

$$\frac{d\varepsilon}{dt} = 0{,}66\%\ \textit{perhour}$$

$\varepsilon(t) = 2{,}3647142 - 2{,}3339271\, exp(-0{,}2220950t)$

$+ (0{,}00910771) \exp(1{,}4755t)$............................(6)

For σ = 229,25 *MPa* and t_r = 3,2 hourswith

$$\frac{d\varepsilon}{dt} = 1{,}6\%\ \textit{per hour}$$

$\varepsilon(t) = 6{,}71438 - 6{,}64162\exp(-0{,}264556t)$

$+ 0{,}0422109 exp(1{,}52336t)$..............................(7)

For σ = 234,05 *MPa* and t_r = 0,48 hours with

$$\frac{d\varepsilon}{dt} = 13{,}3\%\ \textit{per hour}$$

$\varepsilon(t) = 53{,}7465 - 53{,}5012 exp(0{,}201392t)$

$+ (1{,}48265e - 7)\, exp(36{,}1565t)$.........................(8)

For σ = 239,94 *MPa* and t_r = 0,3 hours with

$$\frac{d\varepsilon}{dt} = \textit{tidak mengalami creep tahap II}$$

$\varepsilon(t) = 3{,}13583 - 3{,}26988 exp(-7{,}58039t)$

$+ (1{,}8096e - 9)\, exp(71{,}1672t)$..........................(9)

Predicting Remaining Life

Larrson Miller Curve from SA-213 T22

Figure 4 is specimen from accelerated creep test using for predicting life of material by Lars on Miller curve.

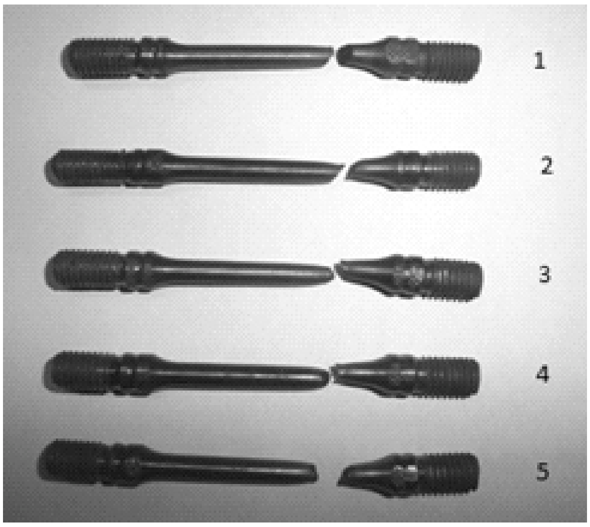


FIGURE 4. Accelerated creep sample test after fracture of SA-213 T22 for predicting remaining life

TABLE 3. PLM calculated from accelarated creep test, temperature and rupture time of material SA-213 T22.

In predicting remaining life, internal nominal stress pipe should be calculated, using hoop stress in equation 4.9 below.

$$\sigma_r = \frac{P_r\ (D_0 - B_r)}{2\ B_r} \quad \text{...(10)}$$

where, P_r = Operation pressure = 166,01 kg/cm2 = 16,28002 Mpa

D_0 = outside tube diameter= 52 mm
B_r = width of tube =12,12 mm

Nominal stress is σ_r = 26,784 MPa. Using safety factor 1,6, stress use for predicting is 41, 069 MPa. By interpolating this stress to Larson miler curve, it is obtained the PLM 20,913, with predicted time rupture is t_r = 129.653 hours.

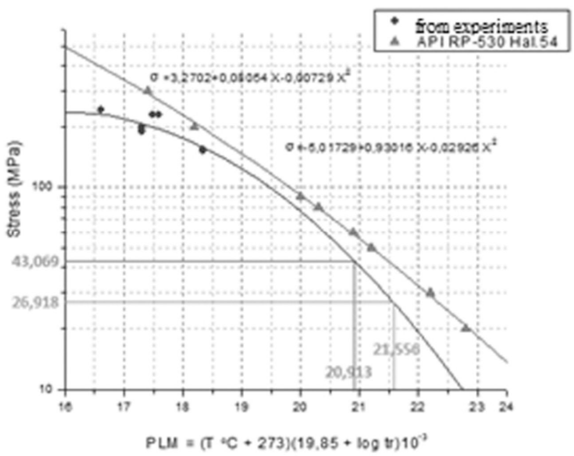


FIGURE 5. Predicting remaining life of SA-213 T22 from Larrson Miller curve with

Creep Curve of SA-213 TP304H

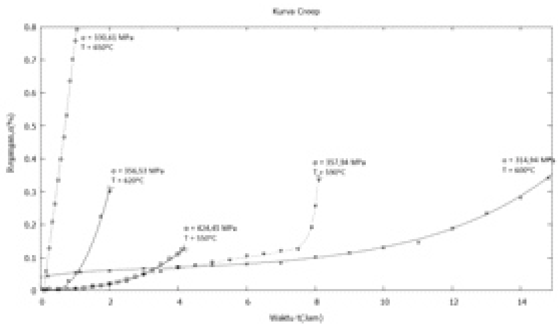


FIGURE 6. Creep curve of material SA-213 TP304H from accelerated creep test, strain Vs time (hour)

For σ = 314,94 MPa and T = 600°C t_r =14 hours with

$$\frac{d\varepsilon}{dt} = 0{,}013\%\ per\ hour$$

{Ã▓♫▟	Temperature (°C)	Stress σ (Mpa)	Rupture time (hour)	PLM
1	550	190,17	10,59	17,303
2	580	188,33	5,9	17,305
3	570	189,82	3,45	17,313
4	560	189,58	1,95	17,307
5	580	229,25	3,2	17,491
6	580	228,17	4,3	17,600
7	580	234,05	0,48	16,788
8	580	152,51	31,8	18,342
9	580	239,94	0,3	16,614

$$\varepsilon(t) = 0{,}0567109 - 0{,}0216159 exp(-0{,}934664t)$$

$$+ 0{,}004593\ exp(0{,}279769t) \qquad (11)$$

For σ = 357,94 *MPa* and *t*=590 °C t_r = 8,1 hours with

$$\frac{d\varepsilon}{dt} = 0{,}2\%\ per\ hour$$

$$\varepsilon(t)\ 0{,}0360679 - 0{,}378513\ exp(-0{,}062867t)$$

$$+ (1{,}75135e-20)\ exp(5{,}41908t) \qquad (12)$$

For σ = 424,25 *MPa* and *t*=550 °C t_r = 4,1 hours with

$$\frac{d\varepsilon}{dt} = 0{,}16\%\ per\ hour$$

$$\varepsilon(t) = 0{,}0814985 - 0{,}152726\ exp(-0{,}20625t)$$

$$+ 0{,}0742619\ exp(0{,}407135t) \qquad (13)$$

For σ = 356,53 *MPa* and *t*=620 °C t_r = 2,3 hours with

$$\frac{d\varepsilon}{dt} = 0{,}5\%\ per\ hour$$

$$\varepsilon(t)\ 35{,}136 - 54{,}8072\ exp(0{,}0457788t)$$

$$+ 19{,}6815\ exp(0{,}124187t) \qquad (14)$$

For σ = 330,61 *MPa* and *t*=650 °C t_r = 1,05 hours with

$$\frac{d\varepsilon}{dt} = do\ not\ passing\ secondary\ stage$$

$$\varepsilon(t) = 0{,}661025 - 1{,}24835\ exp(-0{,}234656t)$$

$$+ 1{,}84113 exp(0{,}268689t) \qquad (15)$$

Predicting Remaining Life

Larrson Miller Curve from SA-213 TP304H

TABLE 4. PLM calculated from accelarated creep test, temperature and rupture time of material SA-213 TP304H

{Ã▓♫ le	Temperature (°C)	Stress σ (Mpa)	Rupture time (hour)	PLM (C=15,3)
1	600	314,9	14,8	14,440
2	550	424,4	4,1	13,154
3	650	330,6	1,05	14,206
4	620	356,5309	2,3	14,048
5	590	357,9388	8,1	14,048

Using equation 10 above the nominal stress of internal tube of material SA-213 TP304H is 71,940 MPa as shown in FIGURE 7 in Larrson Miller curve of material SA-213 TP304H.

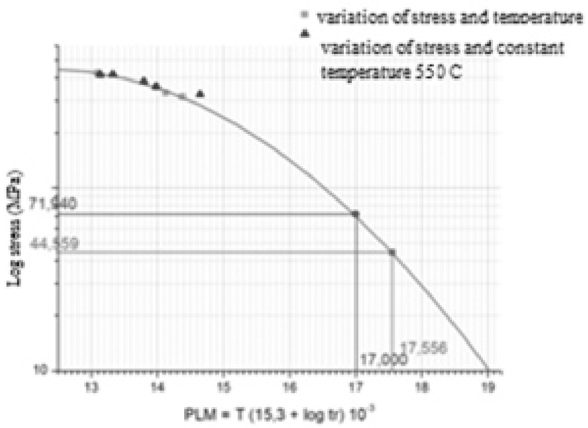


FIGURE 7. Predicting remaining life of SA-213 TP304H from Larrson Miller curve with

By interpolating nominal stress 71.940 MPa to the Larrson Miller curve in figure 7, the PLM is17.00. Substituting temperature 550°C to equation 4, the time rupture is 252831 hours.

Interrupted Accelerated Creep Test for Determining The Remaining Life Using Microstructure Quantitative Analysis

Interrupted accelerated creep test has been done for stress 189 MPa with temperature 570°C. Reference for the test is taken from creep rupture test with rupture time 3.54 hours. The Interrupted test has design for 60%, 70%, 80% and 90% level of the damage. This test was done for material SA-213 T22 and SA-213 TP304H . The specimen after tested shown in figure 8.

FIGURE 8. Specimen after interrupted accelerated creep test

After the test the sample was cut in longitudinal and then it is polished to take microstructure photo using microscope optics. Figure 9 is the photo from microstructure with magnification 200X.

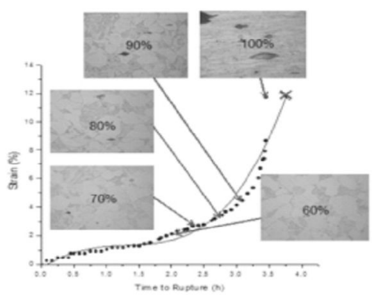


FIGURE 9. Creep curve completed with microstructure of 60%, 70% ,80%,90% and100% damage level for material SA-213 T22

Interrupted creep test is also conducted for material SA-213 TP304H with level stress 424.29 MPa and temperature 550°C. The curve creep shown in figure 10. This graph is taken from the creep test for 4.1 hours time rupture. The level of damage for the interrupted creep test is design for 60%, 70%, 80% and 90%. The microstructure for each damage level is attach in the graph.

Microstructure quantification has been done for some microscopic parameter such as grain size number (G). Morphology expressed by ratio of length of vertical and length of horizontal the grain, void number per unit area for SA-213 T22 and length of crack for SA-213 TP304H.

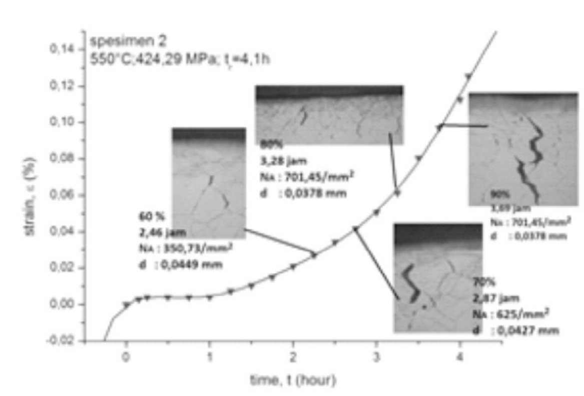


FIGURE 10. Creep curve completed with microstructure of 60%, 70% ,80%,90% and100% damage level for material SA-213 TP304H

Finally diameter average of grain which is calculated by Planimetric Jeffries Method, 3 Junction Method and Heyn Method. The result of parameter microstructure quantification as a function of degree of failure or damage level showed in table 5.

TABLE 5. Parameter microscopic of microstructure for 60%, 70%, 80%, 90% and 100% failure damage for material SA-213 T22.

[illegible] of failure (%)	100	90	80	70	60
Operation time (Hour)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]-hardness Vickers (HC)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] area [/mm²]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 6. Parameter microscopic of microstructure for 60%, 70%, 80%, 90% and 100% failure damage for material SA-213 T22.

[illegible] (%)	100	90	80	70	60
Operation time (Hour)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]-hardness Vickers (HC)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Number Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] of LV/LH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] area [/mm²]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Average of Grain [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

From table 5 and 6 it is plotted microstructure parameter versus level of damage as shown in figure 11, 12 for grain diameter.

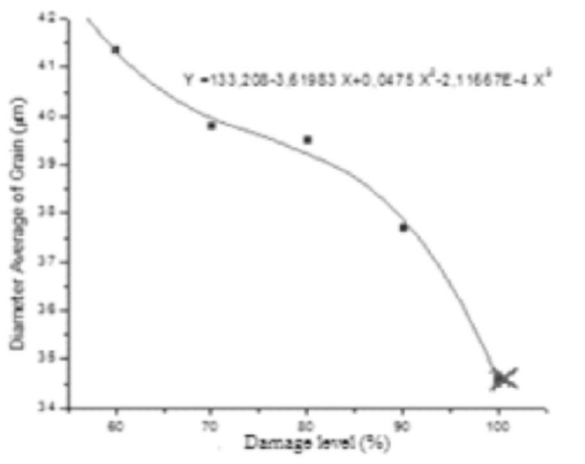


FIGURE 11. Diameter average of grain versus damage level from interrupted accelerated creep test of material SA-213 T22

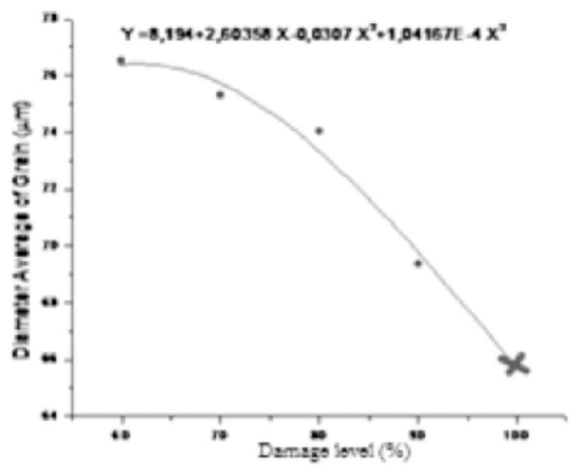


FIGURE 12. Diameter average of grain versus damage level from interrupted accelerated creep test of material SA-213 TP304H

From the graph above grain boundary decreasing as the level of the damage increasing.

The number of void as a function of level of the damage for material SA-213 T22 is plotted in figure 13. It is shown that the number of the void is increasing when the level of damage is increasing also. For material SA-213 TP304H the number of crack as a function of damage level is shown in figure 14. The same as before the length of crack increase when the level of damage increase.

Micro hardness for material SA-213 T22 and material SA-213 TP304H, is taken after the microstructure photo is got. From figure 15 and 16 shown micro hardness of material increase as the level of the damage increase. This phenomena happened for both material SA-213 T22 and SA-213 TP304H.

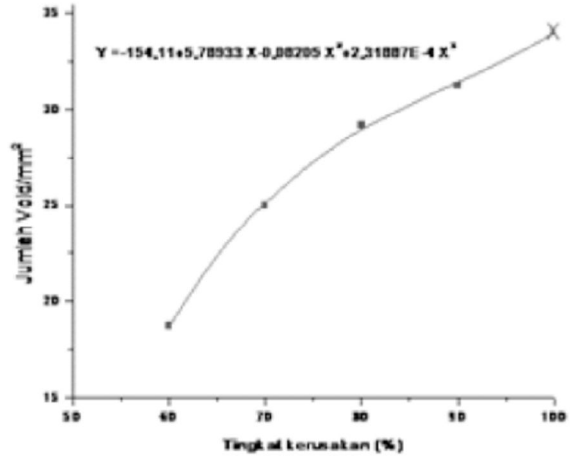


FIGURE 13. Number of void versus level of the damage for material SA-213 T22

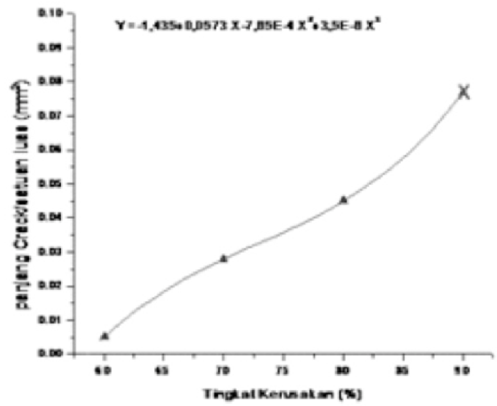


FIGURE 14. Number of void versus level of the damage for material SA-213 TP304H

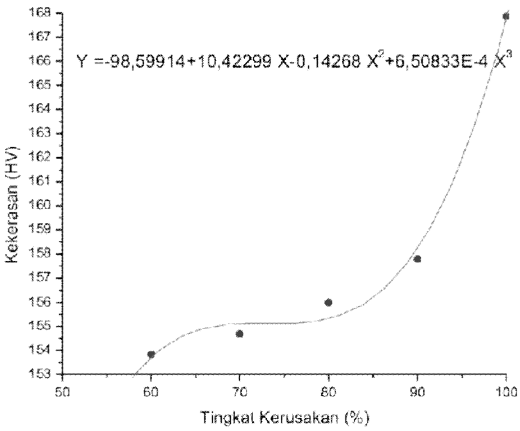
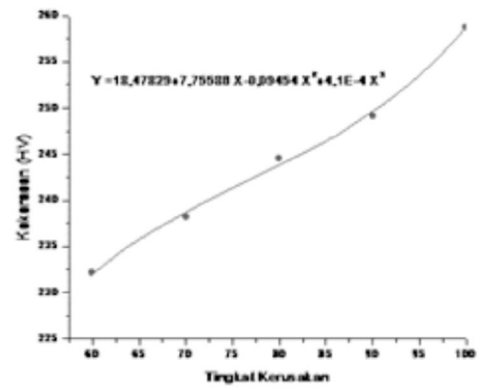


FIGURE 15. Micro hardness (HV) terhadap tingkat kerusakan untuk spesimen uji creep tanpa putus untuk material SA-213 T22



untuk spesimen uji creep tanpa putus untuk material SA-213 TP304H

SEM test for determining crack propagation

Specimen from accelerated creep test of material SA-213 T22 in temperature 570°C and stress 190 MPa. The result can be seen in figure 17. The surface of the crack is observed under scanning electron microscope. From the photo it can be seen the crack propagation as the pattern combination of intergranular and transgranular crack propagation, as shown in figure 18.

FIGURE 17. Sample from accelerated creep test of material SA-213 T22 observed under SEM.

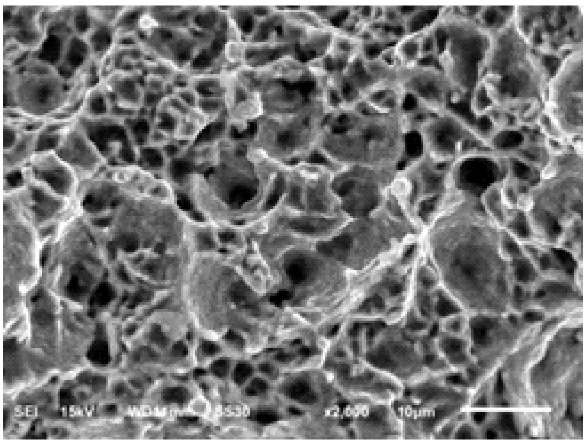


FIGURE 18. Result of SEM for material SA-213 T22 in stress 190 MPa and temperature 570°C

Specimen from accelerated creep test of material SA-213 TP304H in temperature 550°C and stress 424.44 MPa. The result can be seen in figure 17. The surface of the crack is observed under scanning electron microscope. From the photo it can be seen the crack propagation as the pattern dominated by intergranular crack propagation and in a small part shown transgranular crack propagation, as shown in figure 19

GAMBAR 19. Sample from accelerated creep test of material SA-213 TP304H observed under SEM

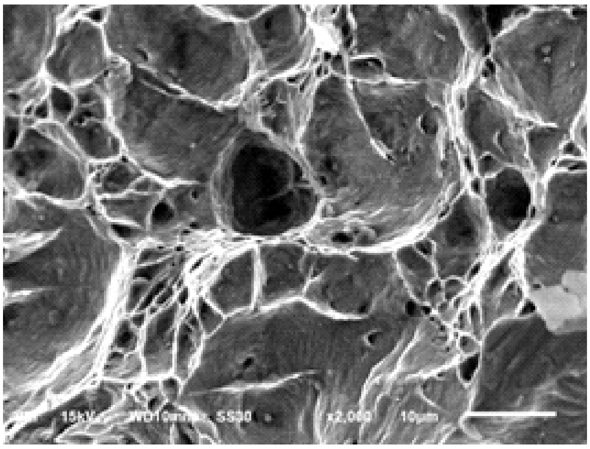


FIGURE 20. Result of SEM for material SA-213 TP304H in stress 424.44 MPa and temperature 550°C

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