Effect of Temperature on Fatigue Transition Life and Strength of Aluminum Alloy

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Abstract:-Two different temperatures (room temperature and 200ºC) were used in the experiments using 1100 Aluminum alloy in order to analyze the effect of temperature. Stress amplitude versus fatigue life (S-N curves) for two different temperatures was established experimentally. The transition lives (point) of those two curves were observed and no significant effect of temperature on this point was observed. Fatigue strength at a given number of cycles decreases with increasing temperature. The endurance limit (fatigue strength at 10^7cycles) was reduced when temperature increased. For example at 10^4 cycles, fatigue strength of the material decreases from 56.68 MPa to 36.2 MPa as the temperature increases from RT to 200ºC.

Keywords:-1100 Aluminum Alloy, Fatigue Life (S-N Curves), Temperature.

I. LITERATURE REVIEW

Al- alkawi, et.al [1] investigated the effect of fatigue-creep by studying the constant amplitude fatigue (CAF) and creep separately, and then fatigue-creep interaction is introduced by testing the alloy under constant amplitude with some holding time periods through the test at high temperature (150ºC). Using 2024-T4 Aluminum alloy. The results showed that the life time of the alloy decreases due to fatigue –creep interaction as compared to creep alone in about 77% and in about 80% as compared with fatigue alone. This is the result of accumulated fatigue damage superimposed on creep damage. Creep allows more free spaces for fatigue cracks paths that accelerate failure. A theoretical model to calculate the time to failure due to fatigue-creep interaction has been proposed.

B.Reggiani, et.al[2] investigated the effects of process parameters on the creep-fatigue behavior of hot-work steel for aluminum extrusion die. Tests were performed on a Gleeble thermo mechanical simulator by heating the specimen using joule's effect and by applying cyclic loading up to 6.30 h or till specimen failure. Displacements during the tests were determined. A dwell time of 3 minutes was introduced during each of the tests to understand the creep behavior. The results showed that the test could indeed physically simulate the cyclic loading on the hollow die during extrusion and reveal all the mechanism of creep-fatigue interaction.

Fournier Benjamin [4] carried out detailed observations of fractured specimens of 9-12%Cr martensitic steel subjected to creep-fatigue loading at 823 K. Observations revealed that oxidation phenomena strongly influence the creep-fatigue lifetime whereas no creep damage (cavities) can be observed in the present loading conditions. Two main interaction mechanisms between creep, fatigue and oxidation damage were highlighted. Based on the identified mechanisms, a creep-fatigue lifetime prediction model is proposed. The crack initiation is approached by, the Tanaka and Mura model, whereas the crack propagation phase is accounted by the Tomkins formulation.

C.Stocker, et.al [5] studied mechanical behavior of a nickel-based super alloy, RR1000, which was investigated at 650ºC under cyclic and dwell loading conditions. Constitutive behavior of the alloy was described by a unified constitutive model, where both cyclic plastic and viscoplastic strains were represented by one inelastic strain. The results showed that the precipitation state is very stable at 650ºC and only minor differences exist in the isolation arrangements formed under pure fatigue and combined creep and fatigue conditions. Hence, a unified constitutive model seems to be justified in describing and predicting the constitutive behavior in both cases.

Huifeng Jiang and Xuedong Chen [6] studied a new life prediction method which was developed taking the equivalent grain boundary cavity radius as a damage parameter. This method which was applicable for stress controlled mode. It involves the effect of fatigue, static creep and cyclic creep during the fatigue-creep interaction. By employing this method, the fatigue-creep life is assessed for 1.25 Cr 0.5 Mo steel at 520ºC and 540ºC. The predicted lives are compared with the tested ones and a good agreement is found between them.

F.Djavanroodi [7] studied the current fracture mechanism concepts that were employed to predict cracking of nickel base supper alloy materials at high temperatures under low and high frequency cyclic loading. A model for predicting creep crack growth in terms of C^* and the creep uniaxial ductility was presented at low frequency, and at high frequency power law relation is used to predict the crack growth rate. When dealing with creep/fatigue interaction, a simple cumulative damage concept with fractography evidence was used to predict the crack growth rate. It is shown that these models give good agreement with the experimental results.

Tae-Won Kim [8] presented a creep-fatigue interaction lifetime prediction methodology based on continuum damage mechanics for the Ni-based super alloy under cycling loading at high temperature. The effects of the levels of strain range and strain hold time together with frequency characteristics of fatigue behavior on the lifetime were investigated.

II. MATERIAL USED AND MECHANICAL PROPERTIES

The material used in this test is aluminum alloy (1100); the Chemical composition is given in Table (1):

Cu	**Mn**	**Zn**	**Si**	**Fe**	**Al**
0.02	0.05	0.09	0.95	0.94	Rem.

Table 1: Chemical Composition of 1100 Al. alloy, wt%.

from tensile test , the mechanical properties of metal are given in Table (2):

Property	**Yield stress (Mpa)**	**Ultimate stress (Mpa)**	**Elongation %**	**Modulus of elasticity (Gpa)**	**Hardness (HB)**	**Modulus of rigidity(Gpa)**	**Poisson ratio(υ)**
Experimental	99	116	14	72	47	29	0.25
Standard	104	111	12	70	28	30	0.26

Table 2: The Mechanical Properties of 1100 Al. Alloy

III. FATIGUE TESTING MACHINE AND ITS SPECIMEN

A fatigue-testing machine of type PUNN rotating bending was used to execute all fatigue tests, with constant and variable amplitude, as illustrated in fig.(1). The specimen was subjected to an applied load form the right side of the perpendicular to the axis of specimen, developing a bending moment. Therefore the surface of specimen is under tension and compression stress when it rotates. The value of the load (P) measured by Newton (N), applied on the specimen for a known value of stress (σ) measured by (N/mm) is extracted from applying the relation below:

Where, the force arm is equal to 125.7mm and d (mm) is the minimum diameter of the specimen

$$\sigma(N/mm^2) = \frac{32X125.7\ P(N)}{\pi\ x\ d^3} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

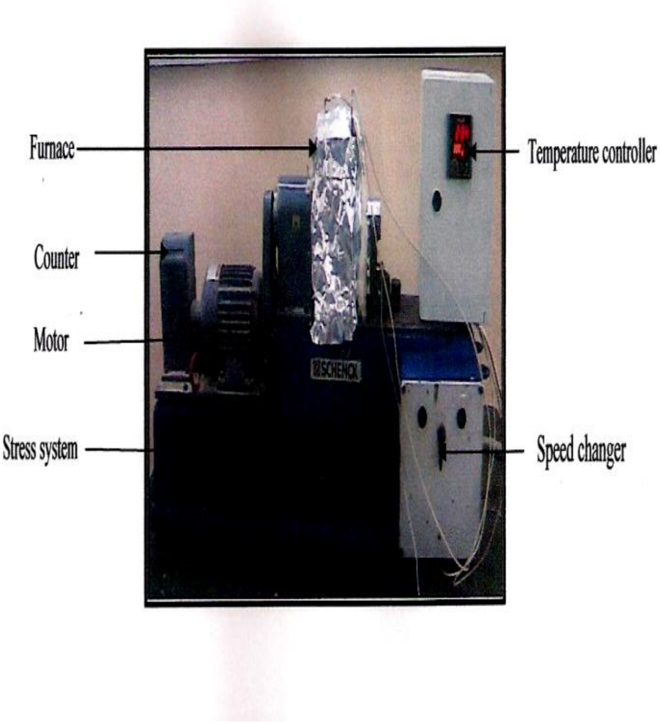

Figure 1: PUNN Rotary Fatigue Bending Machine

IV. SPECIMEN DIMENSIONS

Cylindrical hourglass specimens with minimum diameter of (6.74) mm were used in the fatigue-creep interaction test. The geometry of specimens is plotted in figure (2):

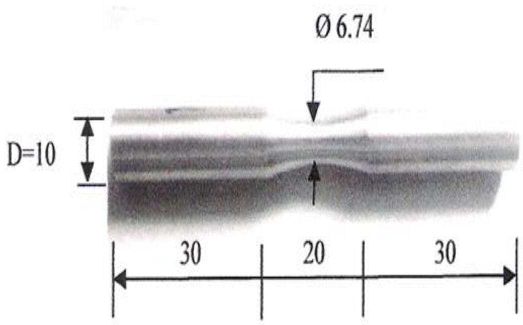

Fig. 2 Geometry of Fatigue Creep Interaction Specimens; Dimension in Millimeter According to (DIN 50113) used Standard Specification.

V. EXPERIMENTAL RESULTS

A. Roughness Results

The results of the surface roughness are given in Table (2)&(2)* where it is selected randomly:

The roughness of the samples increases after shot peening which leads to the deterioration of the fatigue strength, because the surface of the samples become prone to nucleation of cracks.

Specimen No.	**Average Roughness Ra (μm)**	**Peak Roughness Rt (μm)**
A1	0.4	1.0
A5	0.3	1.2
A7	0.25	0.9
A10	0.2	0.8
A14	0.15	0.6

Table 3 : Surface Roughness Results of 5 Specimens

The results of the surface roughness are given in Table (3)* where it is measured in the direction; this direction is the initiation of propagation transverse of cracks in the minimum diameter of specimen.

Specimen No.	Ra (μm)	Rt (μm)	Specimen No.	Ra (μm)	Rt (μm)	Specimen No.	Ra (μm)	Rt (μm)
1	0.4	1.1	**16**	0.66	2.3	**31**	0.92	2
2	0.3	1.3	**17**	0.7	2.15	**32**	0.71	2.1
3	0.25	1.25	**18**	0.55	1.7	**33**	0.62	3.1
4	0.2	1.2	**19**	0.48	1.27	**34**	0.91	1.9
5	0.11	1.7	**20**	0.38	1.8	**35**	0.87	2.11
6	0.17	1.4	**21**	0.41	1.4	**36**	0.72	2.3
7	0.32	1.72	**22**	0.76	1.7	**37**	0.58	1.8
8	0.41	1.61	**23**	0.66	2.1	**38**	0.49	1.9
9	0.5	1.41	**24**	0.52	1.9	**39**	0.82	2.1
10	0.6	2	**25**	0.61	1.7	**40**	0.92	3.1
11	0.47	1.9	**26**	0.42	1.6	**41**	0.25	1.2
12	0.7	1.72	**27**	0.61	2.2	**42**	0.39	1.5
13	0.62	1.52	**28**	0.42	1.82	**43**	0.35	1.7
14	0.58	1.61	**29**	0.63	1.9	**44**	0.57	1.2
15	0.71	2.1	**30**	0.8	2.7			

Table 4: Surface Roughness Results of 44 Specimens

The above data are the average of five readings.

Series A: 18 specimens were investigated in this series; they were used to establish the basic S-N Curve (fatigue only). The results of this series are illustrated in Table (3):

Stress (Mpa)	Specimen number	Number of cycles(N_j)
25	A_1, A_1^*, A_1^{**}	240000, 249000, 260000
35	A_2, A_2^*, A_2^{**}	122000, 130000, 128000
45	A_3, A_3^*, A_3^{**}	51000, 49000, 44000
55	A_4, A_4^*, A_4^{**}	21000, 19000, 18000
65	A_5, A_5^*, A_5^{**}	5000, 5100, 5400
75	A_6, A_6^*, A_6^{**}	1400, 1600, 2000

* Second specimen, ** Third specimen at the same stress level.

Table 5: Basic S-N Fatigue Results

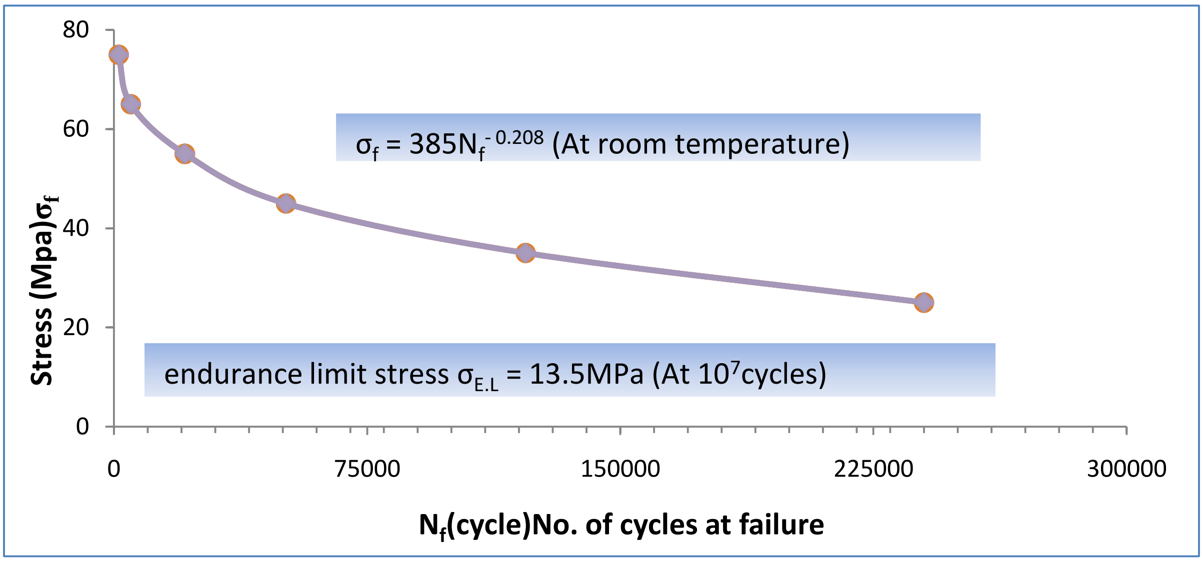

Figure 3: Basic S-N Curve for 1100 Al Alloy

Series B: This group was selected in order to investigate the fatigue at high temperatures (200°C). The result is shown in Table (4):

Stress (Mpa)	Specimen number	Number of cycle N_f
25	B_1, B_1^*, B_1^{**}	110000, 99000, 101000
35	B_2, B_2^*, B_2^{**}	55000, 49000, 52000
45	B_3, B_3^*, B_3^{**}	23000, 20000, 19000
55	B_4, B_4^*, B_4^{**}	1600, 1800, 2000
65	B_5, B_5^*, B_5^{**}	1000, 1200, 1150
75	B_6, B_6^*, B_6^{**}	190, 200, 280

Table 6: S-N Fatigue Results At High Temperature 200°C

The Variation of Stress and Number of Cycles at 200°C Temperature is Shown in Figure (2)

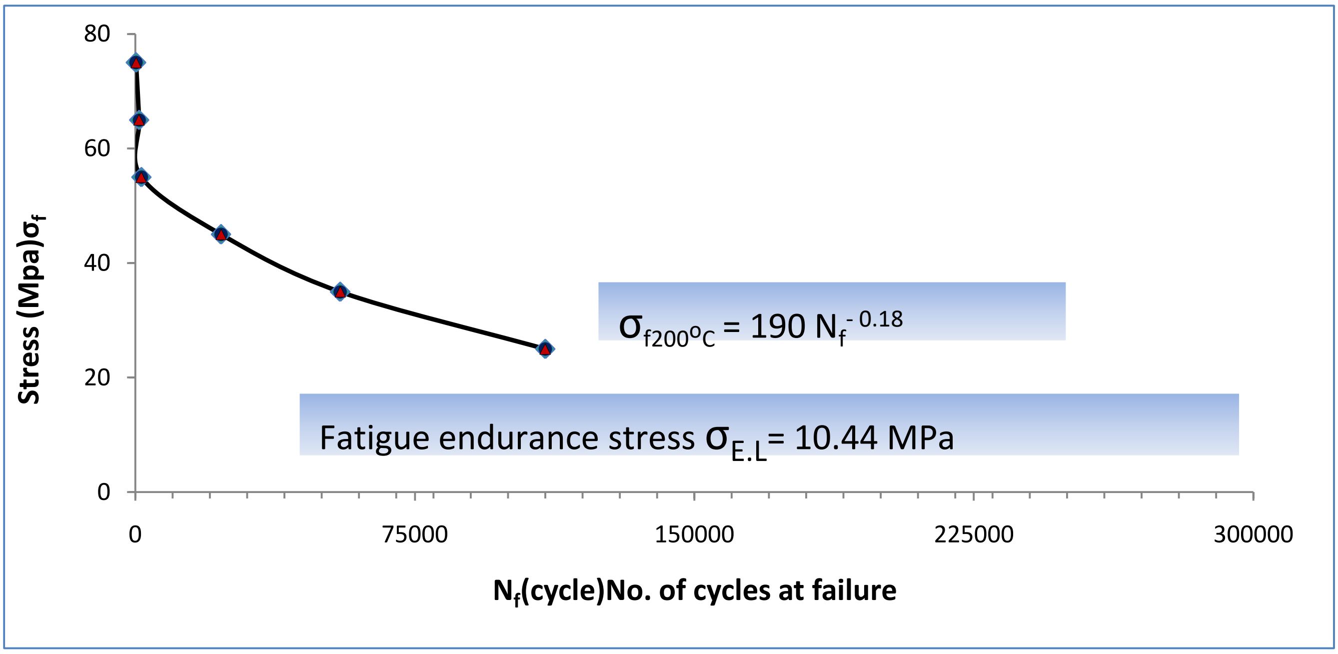

Figure 4: The S-N Curve at 200° C

VI. DISCUSSION

A. *Effect of Transition Life*

In fig.(3), the point where the elastic and plastic life lines intersect is called transition life. The transition life represents the point at which a stable hysteresis loop has equal elastic and plastic components. At lives less than the transition, plastic events dominate and at lives longer than the transition elastic events dominate. In simple words, the transition point is the way of delineating between the low and high cycle fatigue regimes.[9]

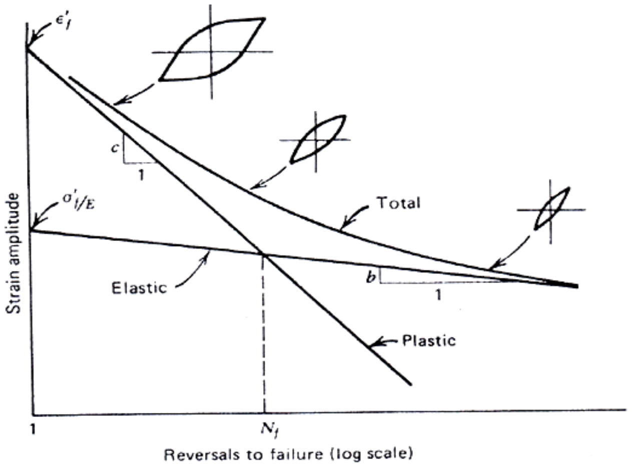

Figure 5: Strain-Life Curve [9]

Distinction is important because problems of high-cycle fatigue are usually tackled through the selection of stronger, higher UTS (ultimate tensile strength) materials or through the application of compressive surface stresses through shot peening.

The experimental transition life results for the two cases can be determined from the figure (1) and (2). From these figures, it can be seen that at 0.1% strain amplitude the number of cycles that corresponds to that point is the transition life [10]. The experimental transition lives can be seen at table (5).

Condition	Experimental data
	1100 Al alloy
RT	11908 cycles
200°C	12223 cycles
Condition	DIN35 NiCrMoV 12.5 steel [Ref.10]
RT	10390 – 10650 cycles
250°C	11630 – 13750 cycles
400°C	14750 – 16250 cycles

Table 5: Comparison of Experimental Transition Lives Between Two Different Metals At 0.1% Strain.

Orkun [10] found that the effect of temperature on the transition life is negligible i.e the difference is few in cycles as shown in table (5).

B. *Effect of Temperature on Fatigue Strength*

The endurance limit (fatigue strength at 10^7cycles) was reduced when temperature increased. Table (6) gives the percentage reduction in fatigue strength.

Condition	$\sigma_{E.L}$(MPa)	Reduction %
RT	13.5	22.6
200°C	10.44	

Table 6: Fatigue Strength Reduction

This reduction in fatigue strength may be forming cracks starts to oxidize and the propagation of these cracks become easier [11]. Another reason is the weaking of grain boundaries at high temperatures. As the grain weaken, the transgranular type of cracks changed into intergranular form. Also internal grain cracks and oxidation of fracture surface occur [12].

For example at 10^4 cycles, fatigue strength of the material decreases from 56.68 MPa to 36.2 MPa as the temperature increases from RT to 200ºC. The reason of the decrease in fatigue strength with temperature could be related with the tensile properties of the material. Tension test results have shown that the yield stress and the ultimate strength values are lower at high temperature.[1]

VII. CONCLUSIONS

- The fatigue – life equations for two different temperatures were established in the Basquin equation form as follows:

  $\sigma_{fRT} = 385N_f^{-0.208}$

  $\sigma_{f200^oC} = 190\ N_f^{-0.18}$

- Fatigue strength and fatigue life at a given stress amplitude are inversely proportional with temperature.

- No significant effect of temperature on the transition life.

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