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Effect of Temperature on Fatigue Transition life and Strength of Aluminum alloy

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ABSTRACT

Two different temperatures (room temperature and 200^{o}C) 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.

تأثير درجة الحرارة على العمر الانتقالي الكلالي و المقاومة لسبيكة الالمنيوم

الخلاصة

تم استخدام درجتين مختلفتين (درجة حرارة الغرفة و 200 ^{o}C) في التجارب لسبيكة الالمنيوم 1100 ، لكي يتم تحليل تأثير درجة الحرارة. اذ تم بناء منحنيات العمر (S-N) لسعة الأجهاد عند عمر الكلال لهاتين الدرجتين. تم ملاحظة نقطة انتقال العمر لهذين المنحنيين و تبين انه لا تأثير مهم لدرجة الحرارة على هذه النقطة. مقاومة الكلال تحت عدد من الدورات يقل كلما زادت درجة الحرارة.

INTRODUCTION

Material properties are dependent on the temperature. These properties decrease with increasing temperature. It should be expected that fatigue properties are also affected by the temperature. The effect of a high temperature on mechanical and fatigue properties can be associated with transformations of material structure due to diffusion processes, aging, dislocation, restructuring (softening), and recrystallization.

Al- alkawi, et.al [1] studied the effect of fatigue-creep of 2024-T4 Aluminum alloy under 150^{o}C . The results indicated that the life time decreases due to fatigue –creep interaction as compared to creep alone in about 77% and in about 80% as compared with fatigue alone.

B.Reggiani, et.al[2] investigated the effects of process parameters on the creep-fatigue behavior of hot-work steel for aluminum extrusion die. The results showed that the test could indeed physically simulate the cyclic loading on the

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hollow die during extrusion and reveal all the mechanism of creep-fatigue interaction.

Fournier Benjamin [3] ,tested 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 can be observed in the present loading conditions.

C. Stocker, et.al [4] studied mechanical behavior of RR1000, which was tested at 650^{o}C under cyclic loading. The results showed that the precipitation state is very stable at 650^{o}C and only minor differences exist in the isolation arrangements formed under pure fatigue and creep - fatigue interaction.

Huifeng Jiang and Xuedong Chen [5] studied a new life prediction for 1.25 Cr 0.5 Mo steel at 520^{o}C and 540^{o}C. The predicted lives are compared with the tested ones and a good agreement is found between them.

F. Djavanroodi ,[6] proposed a model for predicting creep - fatigue interaction life of superalloy materials at high temperature . It is shown that this model give good agreement with the experimental results.

Tae-Won Kim [7] presented a creep-fatigue interaction lifetime prediction. The effects of the levels of strain range and strain hold time together with frequency characteristics of fatigue behavior on the lifetime were investigated.

MATERIAL USED AND MECHANICAL PROPERTIES

The investigation was performed on (1100) Aluminum alloy with a Chemical composition in (wt %) listed in Table (1). The aluminum alloy used in this work is one of the most versatile, economic and attractive mechanic material with aboard range of applications from low strength, highly ductile house hold foil to the most advanced engineering applications [8].

Table (1) Chemical composition of 1100 Al. alloy, (wt%)

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

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

Table (2): the mechanical properties of 1100 Al. alloy

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

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

$$\sigma = \frac{32*125.7*P(N)}{\pi\, d^3} \quad N/mm^2)\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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 (2a):

Figure (1): PUNN Rotary fatigue bending machine

EXPERIMENTAL RESULTS

Roughness results

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

Table (2): surface roughness results of 5 specimens

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

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

Table (3): basic S-N fatigue results

Stress (Mpa)	Specimen number	Number of cycles(N_i)
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.

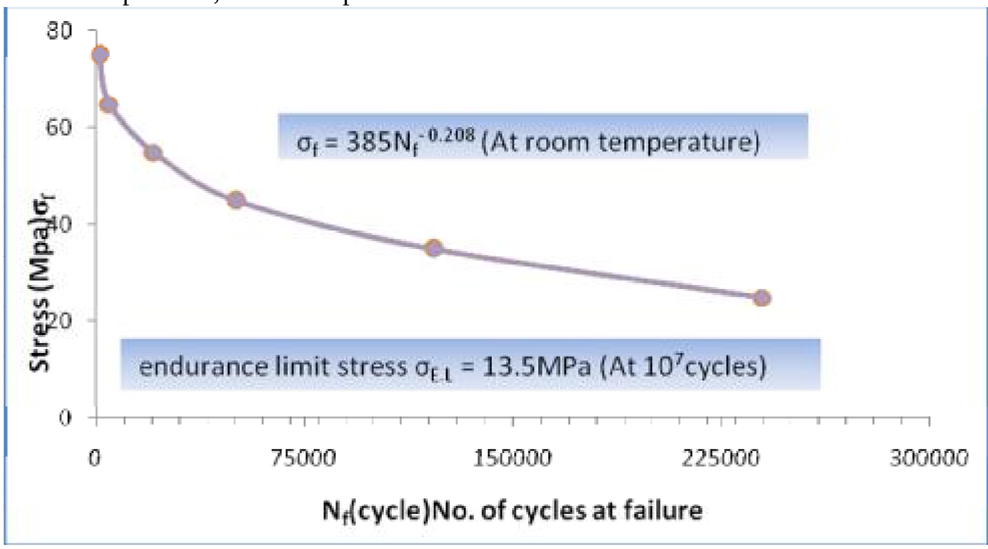


Figure (2a): basic S-N curve for 1100 Al alloy

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

Table (4) S-N fatigue results at high temperature 200°C

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

The variation of stress and number of cycles at 200°C temperature is shown in Figure (2b)

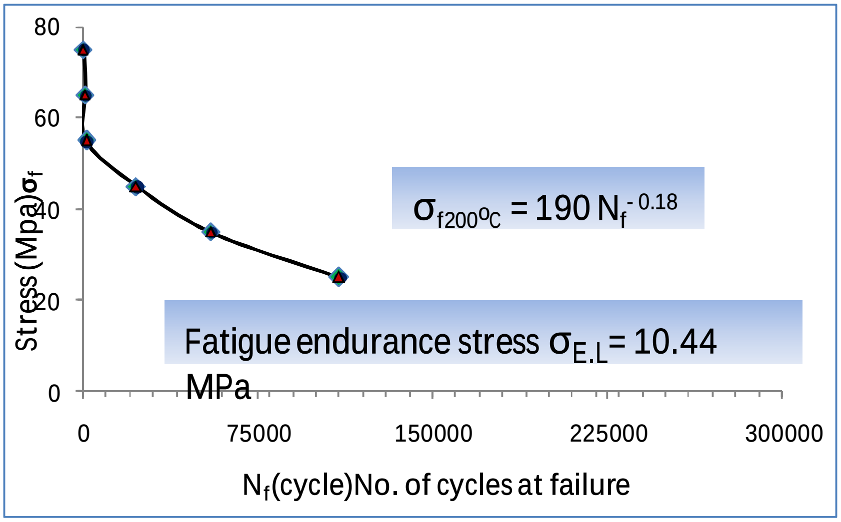


Figure (2b): The S-N curve at 200° C

DISCUSSION

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]

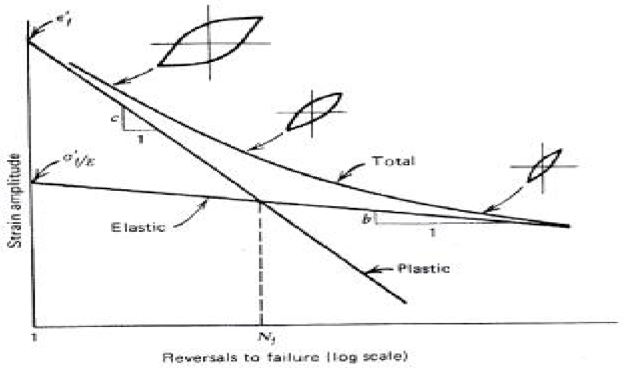


Figure (3) Strain-Life Curve [9]

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 fatigue life and fatigue strength of 1100 Al-alloy decreases with increasing temperature. The reduction percentage in fatigue strength at 10^7 cycles was observed as 22.6% due to raising temperature from RT to 200°C. at room temperature and 200°C the transition point was observed at the 1% strain [10].

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).

Table (5) Comparison of experimental transition lives between two different metals at 0.1% strain

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

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).

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.

Table (6) fatigue strength reduction

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

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 200°C. 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]

EFFECT OF TEMPERATURE ON CUMULATIVE FATIGUE LIFE

Table (7) gives the fatigue life of specimens under dry and 200°C temperature.

Table (7): Experimental comparison of fatigue lives at room temperature and 200°C

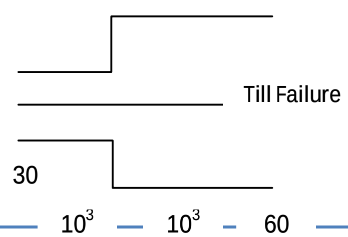
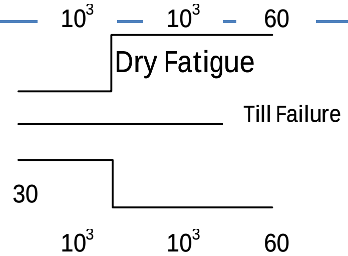
Specimen No.	Applied stress (MPa)	Test program	Cycles	
C_1	30 – 60		12600	
C_2	30 – 60		14800	
C_3	30 – 60		17000	Life reduction %
C_4	30 – 60		6000	52.38
C_5	30 – 60		4800	67.56
C_6	30 – 60		5000	70.58

Table (7) shows a decrease in fatigue life at 200° C. One reason is the formation of surface oxide at high temperature which formed cracks and propagate at high growth compared with dry fatigue. Another reason is the weaking of grain boundaries at high temperatures leading to faster crack growth [10]

At 200°C

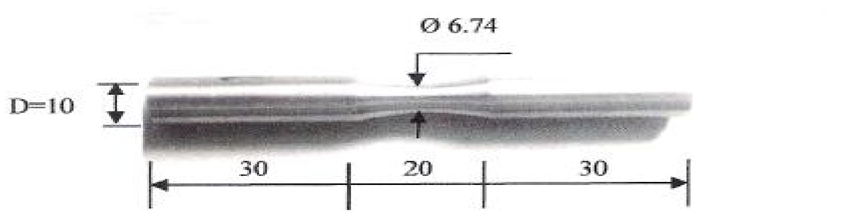


Figure (2): geometry of fatigue creep interaction specimens; dimensions in millimeter according to (DIN 50113) used standard specification

CONCLUSIONS

1. The fatigue strength was reduced by 22.6% at 200°C compared to the fatigue strength at room temperature.
2. Fatigue strength and fatigue life at a given stress amplitude are inversely proportional with temperature.
3. No significant effect of temperature on the transition life.
4. An average life reduction percentage was observed as 63.5% for cumulative fatigue damage compared with that at room temperature.

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