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EVALUATION OF CREEP-FATIGUE LIFE AND STRENGTH FOR AA7001-T6 UNDER CONSTANT AMPLITUDE LOADING

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Aluminum alloys were widely used in the construction, automotive, marine, and aviation industries due to their low specific strength, ease of manufacture, and low weight. The fatigue behavior of aluminum alloys at different temperatures is investigated. Thanks to the rapid development of armament in recent years, 7XXX ultra-high strength aluminum alloys are now used more frequently because of their non-corrosive qualities and low weight. Aluminum alloy 7001-T6 behavior is examined at the Company State for Engineering, Rehabilitation, and Inspection (SIER) in Iraq, where chemical analysis of the AA7001 is supported. Most engineering components that operate at high temperatures will eventually fail from fatigue strain, creep damage is a time-dependent process that is primarily influenced by the history of stress and temperature applied to the component. When the two damaging factors combine their effects, This study used AA7001-T6 to conduct experiments on mechanical characteristics (UTS, YS, E, and ductility) and the interaction between creep and fatigue at four distinct temperatures: room temperature (25, 150, 280, and 330) °C, the UTS, YS, and E were lowered by 37.2, 37.2, and 24) %, respectively, as compared to the result at room temperature, but the ductility increased by 28.27 %. It has been noted that rising temperatures cause mechanical and fatigue characteristics to decline. Experimental S-N fatigue test findings showed a significant loss of fatigue strength, After 10^7 cycles, the endurance fatigue limit was reduced from 208 MPa at (RT) to 184 MPa at 330 °C, an 11.5 % reduction. Overall, it can be said that AA7001-T6 demonstrates a significant drop in mechanical and fatigue properties at high temperatures

Keywords: AA7001-T6, AA7001-T6 mechanical properties, creep-fatigue Interaction, various temperature, fatigue life, S-N curve, strength for AA7001-T6

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1. Introduction

Materials are now more effective than they were decades ago, and new forms have significantly advanced science and technology. Without the application of increasingly effective materials, advances in physics and technology are challenging. Researchers are always learning about, investigating, and experimenting with new, cutting-edge materials in the field of technology. Additionally, the requisite scientific investigation into the aspects influencing and improving mechanical qualities has been conducted [1]. The strongest forging alloys are commercial heat treatable aluminum alloys from the 7xxx class, which have the maximum strength among them. It also has a passable resistance to corrosion. Aircraft manufacturing companies have a significant demand for this alloy for structural components and other highly stressed applications [2]. In numerous significant applications, aluminum alloys are frequently used. Numerous parts constructed of aluminum alloys are put through various sorts of loading systems, which in many cases cause wear and eventually reduce the estimated life of the parts. Here, it has become increasingly important to enhance these alloys' mechanical characteristics. Actually, this has been accomplished by a number of studies in this field. By combining several nanomaterial's in specific ratios, With the anticipated increase in aluminum use in various applications where high strength and low weight are required, improving wear resistance is now urgently needed [3]. One of the aluminum alloys with silicon and magnesium is called A6061. Plates, circular bars, and pipes are the most common shapes of A6061. Light structures, machine parts, rail transit parts, and airplane structures are all frequently made with it [4].The fatigue lifespan and tensile strength of aluminum alloys are affected by temperature. At higher and ambient temperatures, a cast aluminum (Al) alloy's tensile response, resistance to low-cycle fatigue (LCF), and creep behavior are being researched. Between 25 °C and 300 °C, the temperature range with the lowest % elongation of fracture is 100 °C. The coefficient of fatigue strength decreases as the temperature increases to 100 °C, whereas the exponent of fatigue power increases. As expected, the coefficient and exponent of fatigue ductility reach their ideal values, and the creep resistance decreases as the temperature increases from 200 °C to 300 °C [5]. Yield tensile strength, ultimate tensile strength, and E elastic modulus are a few of the most crucial mechanical characteristics. At room temperature, the majority of metallic materials' mechanical properties are studied [6]. Therefore, this research on the development of mechanical properties, and other materials must be tested at controlled or higher temperatures to determine their mechanical properties. Many mechanical qualities are influenced by different elevated temperatures.

2. Literature review and problem statement

The paper [7] it is shown to better understand crack nucleation, the goal of this work was to characterize the fretted damage zones to discover fretting fatigue in the aluminum alloy 7075 T6. The results indicate that fretting degradation involves the material's microstructure. The critical information needed to understand fretting damage deformation, the transition from pit to crack, and crack dispersion appears to be preserved in the microstructure changes between the thicknesses (1.6 and 4.06 mm) of aluminum alloy 7075-T6. [8] investigated the behavior of an aluminum-magnesium alloy of the type 5052-H32 using strain rates of 0.0083 0.16 s^{-1} and temperatures ranging from ambient temperature to 300 °C finding the tensile characteristics of an aluminum-manganese alloy of type 5052 in warm temperatures. The data shows that the material's uniaxial tensile elongation rises with higher temperatures but falls with increased strain rates. Warm temperatures seem to boost the formability of this material because the ideal forming conditions were found at 300 °C and 0.0083 s^{-1}. According to the results, strain rate sensitivity affects how easily a material may be shaped at high temperatures. High-temperature tests were done on the tensile characteristics of the aluminum-manganese alloy 5052 type. This study's [9] the goal of this study was to determine how the aluminum alloy 2024-T4 will react to rotational bending loading with a stress ratio of R=−1 in terms of the development of fatigue damage. Three distinct temperatures were used for the experiments: RT (room temperature), 250 °C, and 2000 °C. The results of the current version were compared to those of the trial effects and the maximum fatigue damage version in order to evaluate fatigue life at expanded temperatures using a method that considers damage at various load levels. [10] In this study, the effects of temperature fatigue on the fatigue behavior of the 2017-T4 aluminum alloy were investigated in this study on a continuous and changing basis. Fatigue experiments were performed for five applied stresses (350, 275, 200, 175, and 150 MPa) that were totally reliant on the control tensile behavior at normal load constant temperature and daily load growth temperature. The most common temperatures were room temperature (25 °C) and 100 °C. Although the ascending temperatures for one control program were (RT, 500, 1,000, and 1,500) °C, When compared to the other constant fatigue features, the continuous fatigue qualities of rising temperatures are the worst. In this source [11] the fatigue stress-existence (S-N) conduct of E319 solid aluminum alloy was examined using traditional fatigue techniques. At the temperatures examined, it was determined that fatigue at 20 kHz, 5 to 10 in air, lasts several times longer than fatigue at 75 Hz (20, 150, and 250 °C). The influence of the environment on the ratio of rising in fatigue crack causes the variation in fatigue nature between 20 kHz and 75 kHz. Temperature, environment, and frequency effects on the S-N action of E319 solid aluminum alloy may all be predicted using a widely used updated environmental superposition model. It is necessary to examine the implications for the environment [12]. This paper's mathematical model can be utilized to reduce the cost and time of trials. When the applied stress was similar to (540 MPa), the Fatigue Life Reduction Factor (FLRF) rose with increasing testing temperature, peaking at (43.963 %) at (225 °C) when compared to room temperature. The study of behavior is accurate and real-time when fatigue life is anticipated using traditional experimental methods. The stress-life curves were calculated at various temperatures (25, 75, 125, 175, and 225 °C) under various temperatures and under constant loading amplitude circumstances, the influence of fatigue life behavior of aluminum alloy AA 7075. When it was discovered that raising the testing temperature resulted in shorter fatigue life cycles, a generalized suggested model (a mathematical expression) was devised to anticipate the fatigue life of the aluminum alloy AA 7075 at various temperatures. [13] in this study using axial and torsional formed specimens that were subjected to absolute reverse tension-compression and torsional fatigue tests. the fatigue characteristics of a 7075 aluminum alloy were investigated The S-N curve is used to illustrate the findings of tension-compression fatigue testing, and the Basquin equation is used to elucidate the fatigue details. The fatigue statistics obtained under axial loading are translated based on fatigue design to forecast torsional fatigue lifestyles using common failure criteria to produce comparable shear stress. This article [14] uses finite element modeling to determine the fatigue life of aluminum 2024-T351 under uniaxial loads at room and high temperatures. Monotonic tensile and cyclic tests at 100 and 200 degrees Celsius were performed with an MTS 810 servo-hydraulic and an MTS 653 high-temperature furnace at a frequency of 10 Hz and a load ratio of 0.1. Yield strength rose by(8 %) at (100 °C), whereas ultimate strength increased by 2.32 MPa. The yield strength was 1.61 MPa lower at 200 °C than at room temperature, and the ultimate strength was 25 % lower. The overall fatigue life was shortened as a result of increased fracture initiation and propagation caused by mechanical and microstructural features at higher temperatures. The experimental and finite element results were found to be quite close. In this study [15], the electrical potential drop technique (EPD) under constant load amplitude was used to diagnose fatigue fractures. Using flat fatigue specimens manufactured from aluminum alloy 7075-T6, the potential drop electrical circuit was developed, assembled, and tested. The investigations showed that the electrical potential drop circuit could detect the fatigue fracture during the test and that the crack length findings were accurate when compared to real lengths for fatigue long cracks. After measuring crack length at 20 % of total fatigue life, the majority of fractures were identified, resulting in residual fatigue life of >70 %. Long cracks and fracture propagation are the two most common types of fracture. The purpose of this study is the mechanical properties, extracting the S-N curve, and the influence of various elevated temperatures on tensile and fatigue properties was investigated on AA7001-T6. the reduction percentages in UTS, YS, and E were recorded to be 37 %, 37.2 %, and 24 %, respectively, while the ductility rose by 8.27 % and the endurance fatigue limit was 208 MPa; at 330 °C, it dropped to 184 MPa, a loss of 11.5 %.

3. The aim and objectives of the study

The aim of this study is to identifying the influence of various elevated temperatures on tensile and fatigue properties investigated for AA 7001-T6.

To achieve this aim, the following objectives are accomplished:

– to measure the mechanical properties (Ultimate strength, yield strength, Ductility, and Young's modulus);

– to find the S-N curve for the creep-fatigue interaction at various elevated temperatures (25, 150, 280, and 330) °C for Aluminum alloy 7001-T6.

4. Materials and methods of the study

The chemical composition of the aluminum alloy is presented in Table 1. Chemical analysis of the AA7001 is supported out at (The Company State for Engineering, Rehabilitation and Inspection (SIER) in Iraq

Table 1

Chemical composition of 7001-0 Al alloy examined at the state company for standard and measured in wt %

Elements wt %.	Zn	Si	Fe	Cu	Mn	Mg	Cr
Standard [16]	6.88	0.35	0.4	1.62.6	0.2	2.63.4	0.180.35
Experimental	6.1	0.33	0.4	1.85	0.18	3.1	0.27

Using a material tensile test apparatus, the tensile test is conducted (WDW-50). To assess the mechanical properties of a product according to the ASTM standard (A370-11), the tensile test sample is made in a circular form, as shown in Fig. 1.

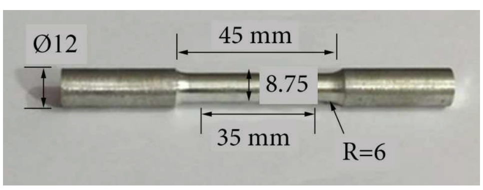


Fig. 1. Tensile test sample measurements in (mm)

Utilizing the (Schenck product) type, fatigue tests have been conducted. And the fatigue test device is a rotating bending type.

As shown in equation (1), the applied bending stress b is computed from the applied load P [17]

$$\sigma_b\left(\frac{\text{N}}{\text{mm}^2}(\text{MPa})\right)=\frac{32(N)(125.7)\text{mm}}{\pi d^3}, \qquad (1)$$

when σ_b is the stress value measured by (N/mm^2), P the load value (measured by Newton (N) applied to the sample), d is the minimum diameter of the fatigue specimen and equals 6.74 mm.

The arm of applied force P is 125.7 mm.

The fatigue sample's basic dimensions are depicted in the Fig. 2.

Fatigue specimen test all fatigue tests with constant and varied amplitude were carried out on a rotating bending fatigue testing rig. A force was given to the specimen from the right side, perpendicular to the specimen's axis, resulting in a bending moment. As a result, as the specimen rotates, the surface is exposed to tensile and compressive forces. As shown in Fig. 3 depicts the entire system Elevated temperature fatigue test (furnace and digital board).

A fatigue test at extreme temperatures is required for a system that heats the medium surrounding the fatigue sample. The electric furnace has dimensions of 100*120*140 mm. The fatigue test grips are linked to the furnace, which is controlled by a digital control circuit board. The furnace is made of 6 mm thick steel plate. To control the temperature, an electrical heater with thermocouple type (K) is installed within the furnace (2000 W).

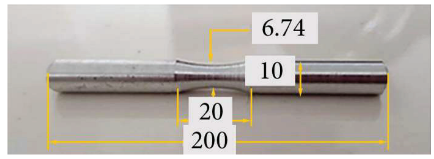
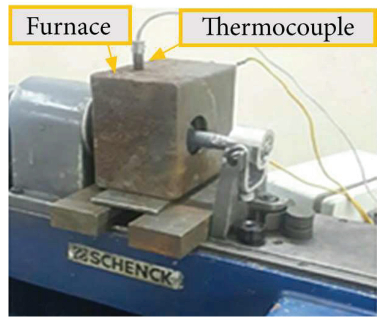


Fig. 2. Dimensions of fatigue specimen



a

b

Fig. 3. Furnace attached to fatigue machine with control board: *a* – furnace; *b* – digital electrical control board

5. Results of research of mechanical properties and creep-fatigue interaction of various elevated temperatures

5. 1. Mechanical properties measurement

The results of the research on the mechanical properties in Table 2 show a significant reduction in mechanical properties. The tensile tests were performed to measure the mechanical properties (Ultimate strength, Yield strength, Ductility, and Young's modulus) of AA7001-T6 under room temperature and at three various high temperatures. At temperature level 330 °C, there is a reduction percentage in mechanical properties of about 37 % for UTS,37.32 % for YS, 24 % for E, and 28.57 % in ductility when compared to the lab-air (25 °C) results.

The term "creep" indicates the permanent, time-dependent deformation that occurs when a material is exposed to a high temperature under a constant load or applied stress. Creep occurred at operating temperatures (0.3 to 0.5) T melting ATM (absolute melting temperature) [19]. When the temperature of the aluminum alloy increases, the alloy expands and this is denoted by thermal expansion all mechanical properties are changed due to the thermal expansion. In general, increasing the operating temperature leads to reducing the mechanical properties as shown in Fig. 4.

It is clear that all mechanical properties are reduced while ductility is increased as illustrated in Fig. 5.

Table 2

Mechanical properties of 7001 Al alloy tested compared with the standard

Condition	UTS (MPa)	Ys (MPa)	E(GPa)	Ductility
Standard(RT) [18]	676	627	(69–73)	9
Exp(25 °C)	668	618	71	10
Exp(150 °C)	602	572	67	11.5
Exp(280 °C)	533	500	60	12.7
Exp(330 °C)	421	388	54	14

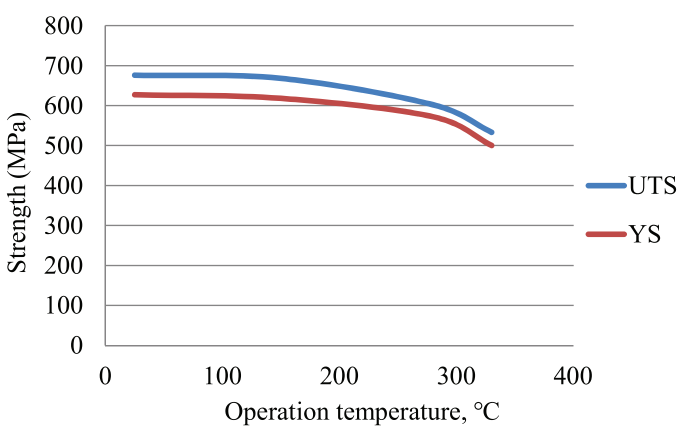


Fig. 4. The amount of reduction in strength

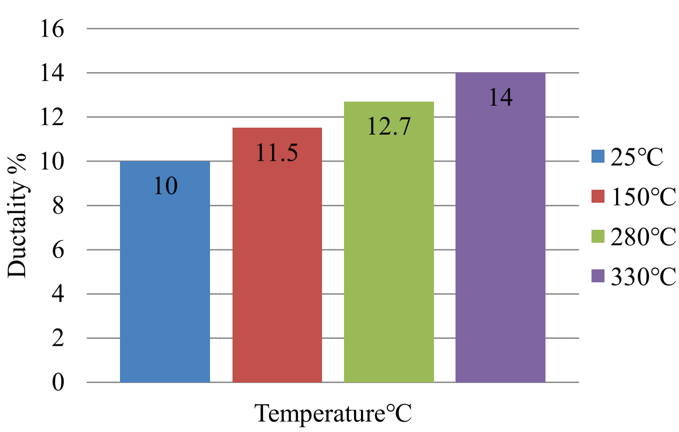


Fig. 5. The values of the ductility for as received due to elevated temperature

To explain the process of beam heated uniformly from (RT), to final temperature. The elongation of the beam due to temperature change is T–T_0 may be described by the equations

$$\alpha\left(T-T_0\right)L=\Delta L_T, \tag{2}$$

where L is the beam length, α is material thermal coefficient. The total elongation of abeam due to uniform tensile stress (σ) and temperature is

$$\Delta L_{total}=\alpha\left(T-T_0\right)L+\frac{\sigma L}{E}. \tag{3}$$

The total elongation is higher in the case of tensile and elevated temperature interaction compared to tensile only. This results in effects on the signification of the tensile properties and fatigue behavior. Mechanical and fatigue-creep behavior of AA 5085 and AA 6061-T651 were investing acted (RT) and 250 C. The experimental results showed that the mechanical properties and fatigue behavior were significantly reduced compared to the room temperature results [20].

5. 2. Creep-fatigue interaction of various elevated temperatures

The fatigue property results. The rotating bending fatigue test was performed to establish the S-N curves for the four results of Creep-fatigue testing of AA7001-T6 in the air (RT) and various high temperatures are listed in Table 3. To understand the development in fatigue life of A7001-T6 alloy.

The fatigue test was conducted under constant fatigue stresses R=–1 at room temperature (RT). The results are listed in Table 3, and the S-N curve is shown in Fig. 6.

It is clear that a significant reduction in fatigue life and strength. The outcome results explain the Creep-fatigue behavior resulting from increasing the deformation or plastic strain when the operating temperature increases [12]. Generally, the dislocation due to the Creep occurring in aluminum alloys at 250–350 C leads to weakening of the mechanical and fatigue properties as the service temperature rises. The S-N curves or fatigue life curves are plotted according to Basque formula in power law $\left(\sigma_f=AN_f^{\alpha}\right)$. Table 4 lists the Basque equations for four case.

The endurance fatigue limit property decreased as the temperature increased and it is found that the lab-air endurance limit is higher than that of Creep-fatigue interaction samples. At all temperatures, the endurance fatigue limit data demonstrates a comparable endurance connection. The fatigue strength (endurance fatigue limit) is extremely closely connected to the tensile strength at high temperatures, with a downward slope of the curve that is generally steeper than at lab-air temperature. Creep has a significant impact on the endurance fatigue limit as well as mechanical characteristics at high temperatures [21]. The S-N curve equation were obtained based on the application of Basquin formula $\left(\sigma f=AN_f^{\propto}\right)$ using the experimental data obtained. It is clear form Tables 3, 4 that the values of (R^2) are so closed to unity and this explain that the Basquin formula is well described the experimental results due to the (R^2) values (correlation factor) which evaluated and measure of fit goodness [22]. The variation of endurance fatigue limit with elevated temperature can be described by Fig. 7.

Increasing the operating temperature leads to reducing the fatigue strength due to high temperature (creep) [23] studied the fatigue creep interaction of AA6061 using 300 °C and they compared the results of fatigue life with (25 °C). It was concluded that the fatigue life and strength are significantly decreased due to creep at 300 C. This large decline in fatigue life is coming from the large expansion of AA6061 under high temperatures.

Table 3

Constant creep-fatigue interaction results

Condition	Spec. No.	Applied Stress (MPa)	Nf cycles	Spec. No.	Applied Stress (MPa)	Nf cycles	Spec. No.	Applied Stress (MPa)	Nf cycles
Lab-air (25 °C)	1	516 (0.75UTS)	18600	4	447 (0.65UTS)	74800	7	378.5 (0.55UTS)	190800
	2		22500	5		82800	8		225800
	3		24600	6		66000	9		244000
150 °C	01	516 (0.75UTS)	10200	13	447 (0.65UTS)	56600	16	378.5 (0.55UTS)	144800
	11		16400	14		70200	17		126500
	12		12000	15		51000	18		133000
280 °C	91	516 (0.75UTS)	9800	22	447 (0.65UTS)	42000	25	378.5 (0.55UTS)	111000
	20		10200	23		30600	26		102800
	21		8800	24		36500	27		114800
330 °C	82	516 (0.75UTS)	5500	31	447 (0.65UTS)	21800	34	378.5 (0.55UTS)	82800
	29		4200	32		19900	35		77000
	30		6000	33		24500	36		65800

Table 4

Fatigue life equation at four different temperatures

Condition	Basquin equation	R^2 correlation factor	Endurance fatigue limit at 10^7 cycle (MPa)
lab-air (25 °C)	$\sigma_f = 1798N_f^{-0.13384}$	0.99394	208
150 °C	$\sigma_f = 1735N_f^{-0.13381}$	0.95449	201
280 °C	$\sigma_f = 1661N_f^{-0.13262}$	0.99071	196
330 °C	$\sigma_f = 1403N_f^{-0.12597}$	0.99252	184

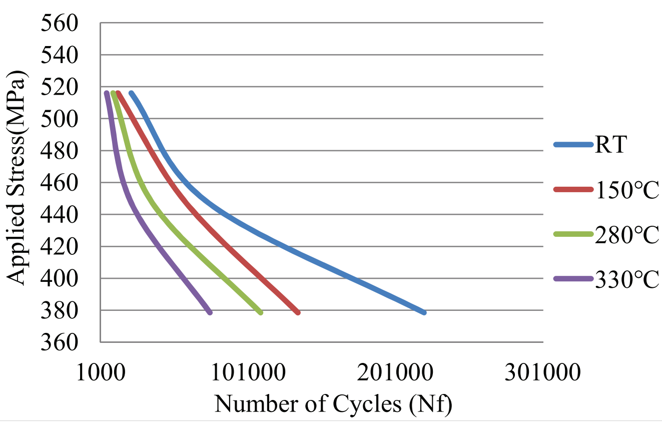


Fig. 6. The S-N curve of AA7001-T6

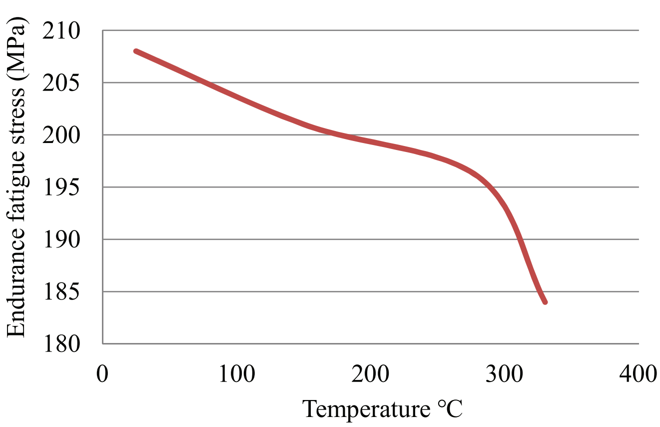


Fig. 7. Endurance fatigue limite versus elevated temperatures

6. Discussion of the results of the study of Mechanical Properties study and Creep-fatigue interaction of various elevated temperature

The interpretation can be made by analyzing the results (Fig. 4–7). The aluminum alloy has undergone stress and heating. This study used the material AA7001-T6 to conduct experiments on mechanical properties (UTS, YS, E, and ductility) and the interaction between creep and fatigue at four different temperatures. The results showed that the UTS, YS, and E were lower than the results at room temperature, but the ductility increased.

Overall, it can be claimed that AA7001-T6 exhibits a considerable loss of mechanical and fatigue capabilities at high temperatures.

This study supports the impact on the mechanical properties of AA7001-T6 at three different high temperatures as well as at room temperature (Ultimate strength, Yield strength, Ductility, and Young's modulus) as demonstrated by a notable loss in mechanical characteristics. If mechanical characteristics are reduced by a certain percentage at 330 °C.

The permanent, time-dependent deformation that happens when a material is exposed to high temperatures while being continuously loaded or under stress is referred to as "creep" operating Temperatures (absolute melting temperature).

The limitations of this research are that the specifications appear at high temperatures. The defects can be eliminated by performing a treatment with one of the methods shot penning or a laser.

This study can be developed by improving the mechanical properties of aluminum experimentally, because fatigue

Life takes a long time ,among other topics that could be the subject of future research, may be related to the study's shortcomings.

7. Conclusions

1. Tensile and high temperature at 330 °C were combined to measurement the mechanical properties of AA 7001-T6; the reduction percentages in UTS, YS, and E were recorded to be 37 %, 37.2 %, and 24 %, respectively, while the ductility rose by 28.27 %.

2. The interplay between creep fatigue and fatigue strength did have a significant impact on both. At RT (25 °C), the endurance fatigue limit was 208 MPa; at 330 °C, it dropped to 184 Mpa, a loss of 11.5 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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