Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

First Engineering Scientific Conference
College of Engineering –University of Diyala
22-23 December. 2010, pp. 127-137

# LOW CYCLE FATIGUE BEHAVIOR OF ALUMINUM ALLOYS AA2024-T6 AND AA7020-T6

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**ABSTRACT:-** In this study low cycle fatigue tests were performed in two aluminum alloys with different chemical composition, namely AA2024-T6 and AA7020-T6 under same heat treatment, using standard round specimens. The tests undertaken in strain control with strain ratio $R_e$ = -1.The low cycle fatigue results are used for characterization of the cyclic plastic response and the fatigue life of the alloys. This study revealed that the strength and the different chemical composition have a significant effect on transition fatigue life. The degree of the compatibility and precipitation of elements zinc (Zn) and copper (Cu) on their parent metal lead to obtain higher fatigue properties value in alloy AA7020-T6 than alloy AA2024-T6. Moreover, the cyclic deformation behavior seems to be influenced by the strength and the different chemical composition

***Keywords:-*** Low cycle fatigue, chemical composition, heat treatment**.**

## INTRODUCTION

Age hardened aluminum alloys are of great technological importance. In particular for ground transport systems, when relatively high strength, good corrosion resistance and high toughness are required in conjunction with good formability and weld ability of aluminum alloys with Cu and Zn as alloying elements AA2024-T6 and AA7020-T6 aluminum alloys are used, which have many applications on aircraft fittings, gears and shafts, hydraulic valves, nuts, pistons, worm gears, couplings and fastening devices (1-3). One of the essential goals in the fatigue process study is the prediction of the fatigue life of a structure or machine component subjected to a given stress–time history, to allow this prediction complete information about the response and behavior of the material subjected to cyclic loading is necessary (4, 5). For ductile metals under periodic plastic loading, materials often fail within a limited number of life cycles, e.g. below about $10^3$ - $10^4$ cycles; this phenomenon is often called the Low Cycle Fatigue (LCF) in a broad sense. Within this regime, the failure mechanism is governed by plastic damage, which is characterized by microstructure deterioration such as micro-void nucleation, growth and coalescence and micro-crack initiation and propagation (6). So the low cycle fatigue (LCF) became an important design consideration in industrial integrity analysis of components operating at high temperatures, when repeated thermal stresses are generated as a result of temperature gradient which occurs on heating and cooling during start up and shut downs occurs and thermal transient condition. LCF resulting from start up and shut down under essentially strain controlled conditions, since the surface region is constrained by bulk of the component (5, 7). The cyclic stress – strain path can be dependent on the material microstructure (8). Fatigue cracks frequently initiated from intensively stress concentration regions, increasing volume fraction and particular sizes result in early crack initiation (9). Aging resulted in the formation of second phase with associated reduction in the toughness and LCF lives of the alloy (10).

Fatigue life was found to decrease with increase in the duration of hold time in both tension and compression and it is increased and decreased according the type of heat treatments (11, 12).

The present work intends to analyze the microstructure influence, namely the different content on the aluminum alloys response to cyclic deformation behavior. For this purpose low cycle fatigue (LCF) tests were performed in two AA2024-T6 and AA7020-T6 alloys under same heat treatment. In addition the stress and strain fatigue life relation of the alloys will also be obtained.

## MATERIALS AND EXPERIMENTAL PROCEDURES

The tested materials were aluminum alloys with a T6 heat treatment, namely the AA2024-T6 and AA7020-T6 alloys. The T6 heat treatment corresponds to a conversion of heat-treatable material to the age-hardened condition by solution treatment, quenching and artificial age-hardening. The chemical composition is shown in Table (1) has been examined in Nsier's company in Baghdad and their mechanical properties in Table (2) in Sulymania technical college. An axial tensile test has been made using 4 samples for each alloy, and they were prepared according ASTM E660 Fig. (1).Tensile tests were performed on tensile test machine (Universal Material tester type WP 300 with 50 KN) to obtain monotonic stress –

strain (S –e) curve and then forming true stress – strain (σ – ε) curve to find the total strain and the load that which applied in fatigue test.

Low-cycle fatigue tests were performed in a fatigue testing machine WP140 with 300 N, interfaced to a computer for machine control and data acquisition. The tests were undertaken, in agreement with ASTM E606 standard, using 12 samples for each alloy with 8 mm diameter round specimens and 106 mm long gauge sections shown in Fig. (2), were obtained from extruded round rods with 25 mm diameter and their surfaces were mechanically polished after machining.

The samples were cyclically loaded under strain control with nominal strain ratio $R_e$ = -1 fully reversed stress. The cyclic-strain curves were determined theoretically using equation (1) and (2) [5] for comparisons with the monotonic stress-strain curves were also experimentally determined.

$$k' = \frac{\sigma'_f}{\left(\varepsilon'_f\right)^{n'}} \quad \text{………..…. (1)}$$

$$n' = \frac{b}{c} \quad \text{……………….. (2)}$$

Where: $\sigma'_f$ is the fatigue strength coefficient, $\varepsilon'_f$ the fatigue ductility coefficient, $k'$ the cyclic strength coefficient, $n'$ the cyclic strain hardening exponent, (b) the fatigue strength exponent usually varying between -0.04 to -0.15 for metals, and (c ) the fatigue ductility exponent usually varying between -0.3 to -1.0 for metals.

## RESULTS AND DISCUSSION

### Material Response to Tension

The basic stress-strain curve characterizes the plastic stress-strain response of the material for the major part of the fatigue life, and is one of its most important fatigue characteristics. The strain hardening exponent (*n*) and the strength coefficient (*k*) were determined as shown in Table (3) by plotting the stable stress amplitude against the axial plastic strain amplitude on a logarithmic scale for both alloys are superimposed as shown in Fig. (3) for comparison, which it shows that the value of (n) and (k) of the alloy AA7020-T6 more than of the alloy AA2024-T6, this means the high movement dislocation that produced from internal strain about precipitation atoms was occurred, and provide more grain boundaries to prevent crack propagation than in alloy AA2024-T6. This indicates the compatibility of solute atoms zinc (Zn) with the parent metal atoms in alloy AA7020-T6 more than the copper (Cu) atoms in alloy AA2024-T6, and also indicates that the grain size in alloy AA7020-T6 finer than in alloy AA2024-T6, this belong that the fine grains reduce localized strain along slip bands, decreasing the amount of irreversible slip, and provide more grain boundaries to aid in transcrystalline crack arrest and deflection, thus reducing fatigue crack growth and increasing strength (14).

## Material Response to Cyclic Deformation

The correlated cyclic stress-strain curves for both alloys are plotted in Fig.4 and 5 and their parameters are indicated in Table 4. The monotonic curves are also superimposed in the figure for comparison.

For the alloy AA7020-T6, as the monotonic curve lies below the cyclic curve, cyclic hardening occurs at low axial strain up to 1.8%, while for strain amplitude higher than 1.8% the alloy cyclically softens. This means the alloy AA7020-T6 has mixed behavior and their strain hardening exponent value shown in Fig.3 proofed that. Typically, metals with a high monotonic strain hardening exponent ($n > 0.2$) will cyclically harden whereas those with a low monotonic strain hardening exponent ($n < 0.1$) will cyclically soften and for intermediate strain hardening exponent ( $0.1 \le n \le 0.2$ ) a metals will be mixed [5, 12].

The elastic limit for the stress strain curve was increased from the monotonic yield stress ($\sigma_y$) value of 441 MPa to the cyclic yield ($\sigma_c$) value on ($\sigma_c$ = 470 MPa) as shown in Fig. 4. As expected from the strain hardening exponent value in Fig.3, alloy AA2024-T6 presents a cyclically soften because the monotonic curve lies above the cyclic curve as shown in Fig. 5. Furthermore, for this alloy, the cyclic yield strength approximately is equal to the monotonic value.

## Strain-Fatigue Life Relationship

Fig. 6 and 7 depicts, as a log-log plot, the total strain amplitude versus life in reversals ($2N$) for alloy AA2024-T6 and AA7020-T6 respectively. In addition to the total strain amplitude; the half-life values of elastic and plastic strain amplitude are also plotted.

As expected due to the lower monotonic properties as illustrated in Fig. 3, when compared to alloy AA2024-T6, alloy AA7020-T6 has higher fatigue properties for high strain amplitude ($2N \le 1000$), but lower fatigue resistance for strain amplitudes less than approximately 5.1% as shown in Fig 7. The transition life ($2N_t$) can be determined from these figures. It is defined as the life where the total strain amplitude consists of equal elastic and plastic components, this imply, the life at which the elastic and plastic curves intersect [4]. The transition life was found to be about 20100 and 780 cycles for alloys AA2024-T6, AA7020-T6 respectively as shown in Fig. 6 and 7. Therefore, for higher lives the fatigue resistance of these alloys will be determined by their strength.

The fatigue ductility and strength properties of the alloys were obtained from Fig. 6 and 7, and are given in Table 5., it is indicated that the fatigue ductility and strength properties of the alloy AA7020-T6 recorded larger than the fatigue ductility and strength properties of the alloy AA2024-T6; this implies the chemical composition and strength of the two alloys has significant effect on their fatigue properties under the same heat treatment condition. Therefore, the strain – fatigue life of the analyzed alloys, will be expressed by application of Morrow's equation is for alloys AA2024-T6 and AA7020-T6 respectively using their fatigue parameters of Table 5.

$$\frac{\Delta\varepsilon}{2} = \frac{420}{71000}(2N)^{-0.06} + 0.11(2N)^{-0.5} \quad \ldots\ldots\ldots.. (3)$$

$$\frac{\Delta\varepsilon}{2} = \frac{3672}{72000}(2N)^{-0.071} + 0.48(2N)^{-0.69} \quad \ldots\ldots... (4)$$

## CONCLUSIONS

From the Low cycle fatigue behavior of aluminum alloys AA2024-T6 and AA7020-T6 with different chemical composition and under same heat treatment condition, the following concluding notes can be written:

1. The compatibility and precipitation of element zinc (Zn) with its parent metal in alloy AA7020-T6 better than copper (Cu) in alloy AA2024-T6 under same heat treatment, lead to give high strength and large fatigue properties value.
2. The cyclic parameters were theoretically determined and compared with the monotonic parameters were experimentally determined. The alloy AA7020-T6 cyclic hardening occurs at low axial strain up to 1.8%, while for strain amplitude higher than 1.8% the alloy cyclically softens, whereas the alloy AA2024-T6 cyclically hardens.
3. The transition fatigue life was found experimentally to be about 780 and 20100 cycles for alloys AA7020-T6 and AA2024T6 respectively.
4. The ductility and strength properties of both alloys were experimentally determined under same heat treatment, it was found that these properties significantly affected by the chemical composition and the strength of the alloy.
5. The values of (b) and (c) of the two alloys are within the standard value.

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**Table(1):** The chemical composition of the two aluminum alloys (wt %).

| Alloy | Zn | Si | Cu | Fe | Mn | Mg | Ti | Al |
|---|---|---|---|---|---|---|---|---|
| 2024 | 0.09 | 0.43 | 4.31 | 0.32 | 0.62 | 1.45 | 0.12 | Balance |
| 7020 | 4.28 | 0.14 | 0.15 | 0.39 | 0.09 | 1.04 | 0.042 | Balance |

**Table (2):** Monotonic mechanical properties of the T6 heat treated aluminum alloys**.**

| Aluminum alloy | 2024 | 7020 |
|---|---|---|
| Tensile strength, $\sigma_u$ (MPa) | 420 | 565 |
| Yield strength, $\sigma_y$ (MPa) | 360 | 441 |
| Elongation, $\varepsilon_t$ (%) | 12.3 | 10 |
| Young's modulus, *E* (GPa) | 71 | 72 |

**Table( 3):** The monotonic strain hardening exponent and strength coefficient values.

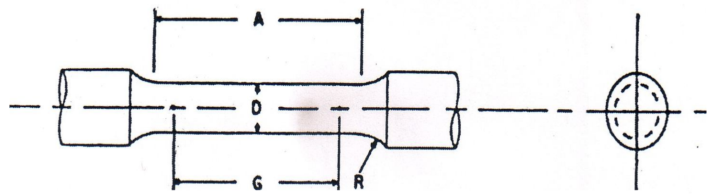
| Aluminum alloys | AA2024-T6 | AA7020-T6 |
|---|---|---|
| The strain hardening exponent (*n*) | 0.093 | 0.14 |
| the strength coefficient (*k*), (MPa) | 700 | 840 |

**Table(4):** Cyclic stress-plastic strain curve parameters.

| Aluminum alloy | AA2024-T6 | AA7020-T6 |
|---|---|---|
| Cyclic hardening coefficient, *k´ (MPa)* | 700 | 3952 |
| Cyclic hardening exponent, *n´* | 0.11 | 0.1 |

**Table (5):** Strength and ductility fatigue parameters.

| Aluminum alloy | AA2024-T6 | AA7020-T6 |
|---|---|---|
| Fatigue strength exponent, b | -0.06 | -0.071 |
| Fatigue strength coefficient, $\sigma_f{}'$ (MPa) | 420 | 3672 |
| Fatigue ductility exponent, c | -0.5 | -0.69 |
| Fatigue ductility coefficient, $\varepsilon_f{}'$ | 0.11 | 0.48 |




G: Gauge length (30 mm), D: diameter (6.0 mm ±0.1), R: radius of fillet (6 mm), A: length of reduced section (36 mm).

**Fig. (1):** Geometry of the specimens used in tensile test [13].

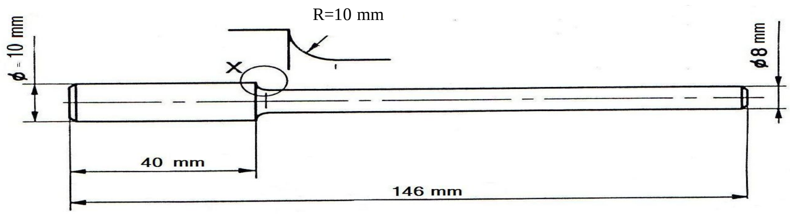



**Fig.(2):** Geometry of the specimens used in the Low cycle fatigue test [13].

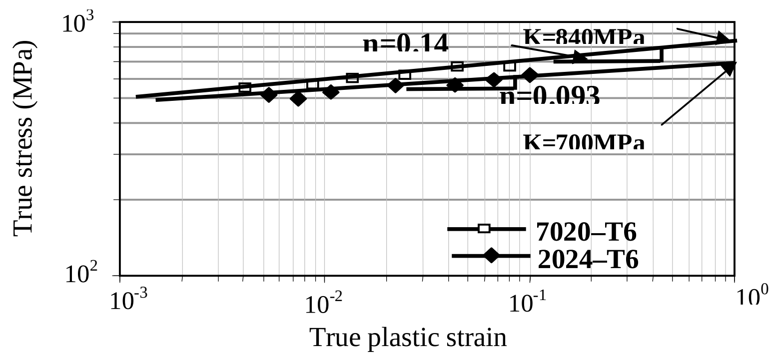



**Fig.( 3):** Monotonic stress-plastic strain curve parameters.

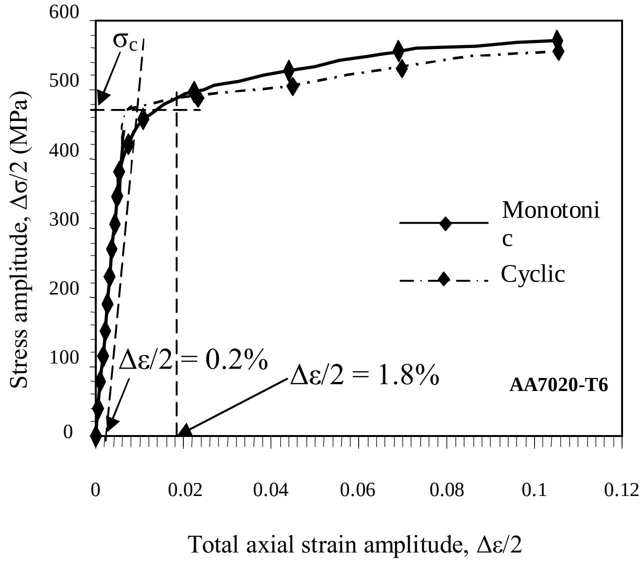



**Fig.(4):** Monotonic and cyclic stress-strain curves: (a) alloy AA7020-T6.

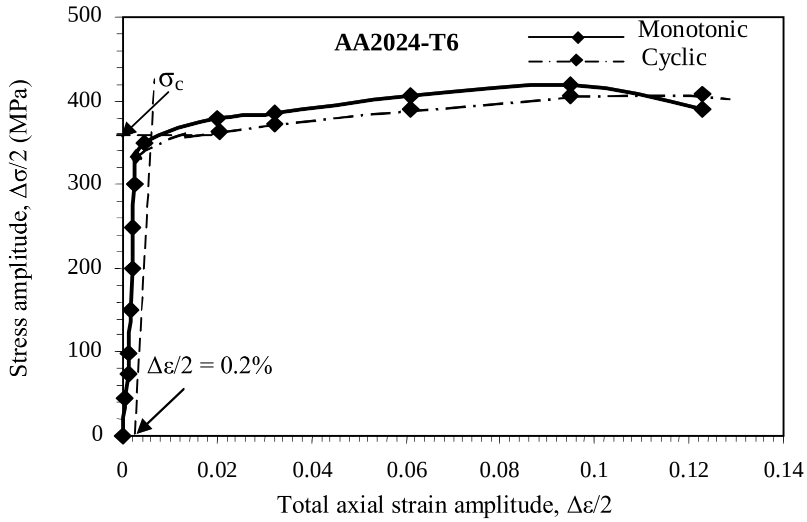



**Fig.( 5):** Monotonic and cyclic stress-strain curves: alloy AA2024-T6.

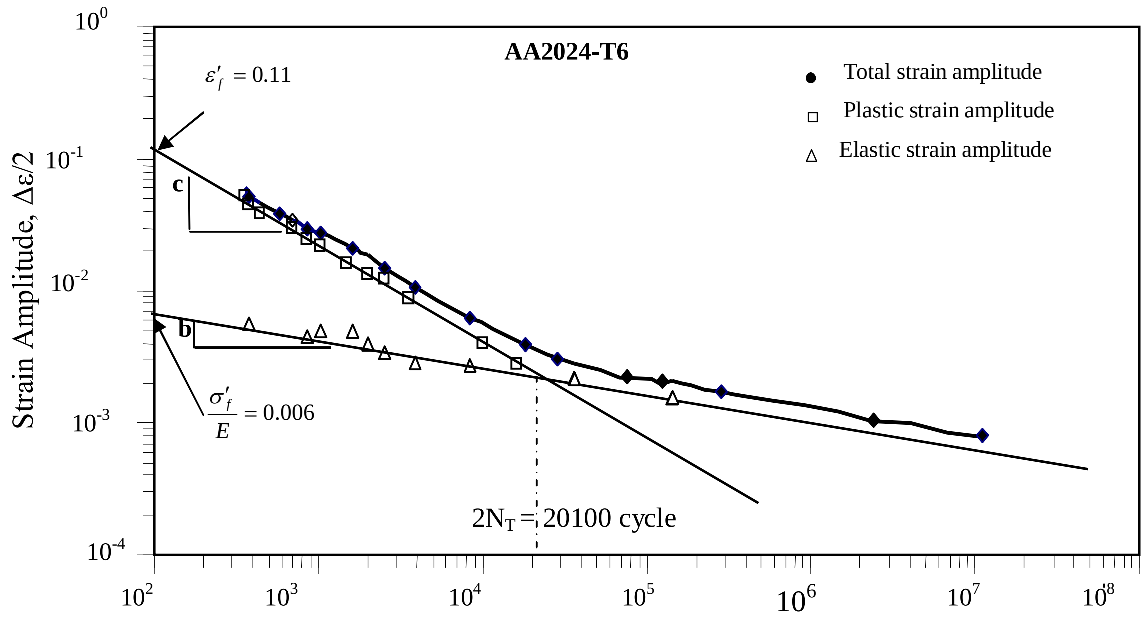



**Fig.( 6):** Total strain –fatigue life curve of alloy AA2024-T6.

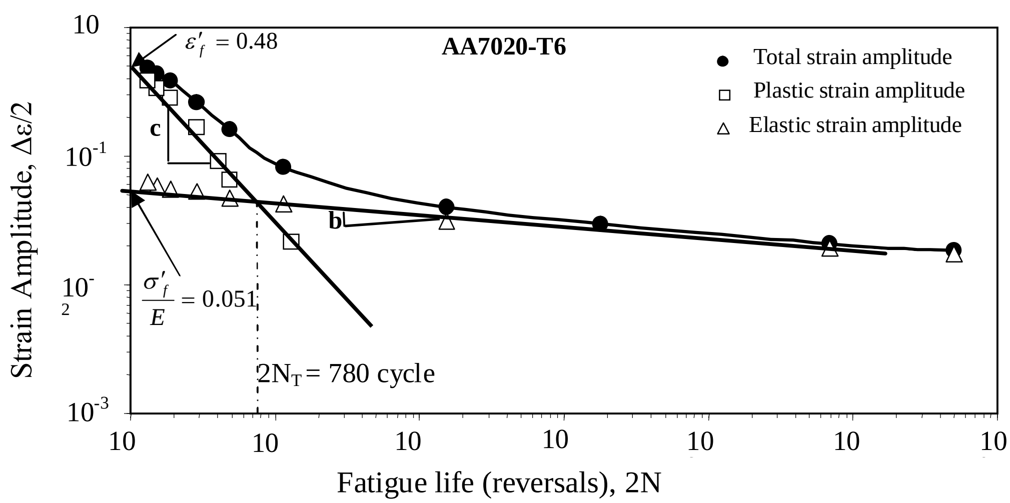



**Fig.(7):** Total strain –fatigue life curve of alloy AA7020-T6**.**

# سلوك الكلال الدوري المنخفض لنوعيين من السبائك ألمنيوم AA2024-T6 و AA7020-T6

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**الخلاصة**

كيمياوية مختلفة (AA2024-T6) و (AA7020-T6) و كليهما نفس المعاملة الحرارية, و بأستخدام عينات دائرية قياسية. الدراسة تم تحت سيطرة الأنفعال (معدل الأنفعال = -1). النتائج المستخلصة من هذا البحث تم الأستفادة منها لتحديد استجابة المعدن للدورات اللدنة و مغرفة عمر الكلال لهذه السبيكتين.

قوة السبيكة و المركبات الكيمياوية المختلفة المضافة لها تأثير مباشر على عمر الكلال. درجة و نسبة (Zn) و (Cu) تؤدي الى الوصول الى خصائص كلال اعلى في السبيكة (AA7020-T6) من السبيكة (AA2024-T6), فلهذا سلوك الفشل الدورات يكون مرتبطا بقوة السبيكة و المركبات الكيمياوية المختلفة المضافة.