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# FATIGUE BEHAVIOR OF ALUMUNIUM ALLOYS AT ELEVATED TEMPERATURES

*Ахмед Салім Мустафа.* **Поведінка втомленості алюмінієвих сплавів при підвищених температурах.** Розглянуто поведінку втомленості алюмінієвого сплаву при підвищеній температурі. Втомленість матеріалу є основною причиною режиму відмови чи виходу з ладу обладнання, що працює за умов циклічних навантажень. Тому важливо дослідити поведінку втоми елементів машинного обладнання при підвищеній температурі з урахуванням того, що алюмінієвий сплав широко застосовується в промисловості: автомобільній, аерокосмічній, в промисловому виготовленні мініатюр та ін. через його корозійну стійкість та легку вагу. Поведінка втомленості алюмінієвого сплаву 2024-Т4 досліджується при кімнатній і підвищених температурах. Встановлено, що коефіцієнт міцності від втомленості алюмінієвого сплаву 2024-Т4 при підвищеній температурі складає 1,2...1,4 порівняно з втомленістю за відсутності корозійного середовища.
*Ключові слова*: відсутність корозійного середовища, підвищена втомлюваність, алюміній.

*Ахмед Салим Мустафа.* **Усталостное поведение алюминиевых сплавов при повышенных температурах.** Рассмотрено усталостное поведение алюминиевого сплава при повышенной температуре. Усталость материала является основной причиной режима отказа и выхода из строя оборудования, работающего в условиях циклических нагрузок. Поэтому важным является исследование усталостного поведения конструктивных элементов машинного оборудования при повышенной температуре, с учетом широкого использования алюминиевого сплава в промышленности: автомобильной, аэрокосмической, в промышленном изготовлении миниатюр и др., благодаря его коррозионно-стойким характеристикам и легкому весу. Исследовано усталостное поведение алюминиевого сплава 2024-Т4 при комнатной и повышенных температурах. Установлено, что коэффициент усталостной прочности алюминиевого сплава 2024-Т4 при повышенной температуре составляет 1,2...1,4 по сравнению с усталостью при отсутствии коррозионной среды.
*Ключевые слова*: отсутствие коррозионной среды, повышенная усталость, алюминий.

*Ahmed Mustaffa Saleem.* **Fatigue behavior of aluminum alloys at elevated temperatures.** The fatigue behavior of aluminum alloy at elevated temperature is studied. Fatigue failure is a major failure mode of malfunction where the cyclic load is applied toa machine element. Hence, it is important to know the fatigue behavior of the machine element at elevated temperature, as aluminum alloy is widely used in industry, namely, in aerospace, automobile and miniatures industries etc., because of its non-corrosive properties and light weight. The fatigue behavior of 2024-T4 Aluminum alloy is investigated under ambient as well as elevated temperatures and it is observed that the fatigue strength coefficient of 2024-T4 Aluminum alloy at elevated temperature makes up 1,2...1,4 compared with dry fatigue strength.
*Keywords*: dry fatigue, increased fatiguability, aluminum.

## Literature Survey

H. Moa and S. Mahadevan [1], derived probabilistic model for the reliability analysis of the creep and fatigue of materials based on experimental data and a linear damage accumulation rule was used. The main conclusions related to that the scatter of different random variables on the creep fatigue life is very important. Bilal M. Ayuub Etal [2], studied the fatigue behavior of material structures subjected to fatigue loadings under the effect of sea water waves and sea environment. The objective of this paper was to develop reliability based methods for determining the fatigue life of structural details associated with conventional displacement type surface monohull ships based on the *S-N* approach and on the assumption that the fatigue damage accumulation is a linear phenomenon (i.e; that follows Miner's rule). T. Hanlon, E. D. Tabahnikova, and S. Suresh [3], studied the stress — life fatigue behavior and fatigue crack growth characteristics of pure Ni were studied as a function of grain size. This study concluded that the fatigue resistance of engineering structures by recourse to grain refinement down to the Nano crystalline regime. Levon Minnetyan [4], studied damage progression sequence during different degradation stages was made. This study showed that the number of cycles to failure at different temperatures using computational simulation data in the assessment of damage tolerance. Ali F. Hamide Al — amiri [5], studied the fatigue behavior of Aluminum alloy at elevated temperature was investigated using random cyclic loading at zero mean stress. The results showed that the mechanical and fatigue properties are decreased at elevated temperature compared with the results of dry fatigue. Svjetlana Stekovic [6], investigated high strength nickel – base super alloys have been used under dry and elevated fatigue (high temperature). The focus of this work was on a study of the low cycle fatigue and thermo-mechanical fatigue behavior of a polycrystalline. The main conclusions were that the presence of the coatings was, in most cases, detrimental to low cycle fatigue lives of the super alloys at 500 °C while the coatings do improve the low cycle fatigue lives of the super alloys at 900 °C.

**Experimental Work Material**

Aluminum alloy was under discussion the average of chemical composition for three specimens comparing them with the standard specification as shown in table 1.Tensile test machine of a maximum capacity (1000 kN) was used to determine the mechanical properties of the material under the standard Germany specification on (DIN 5025) and compared with the standard specification as shown in table 2.The standard material specification for Aluminum 2024 alloy hiss given in table 3.

*Table 1*

*Experimental chemical composition for 2024-T4 Aluminum-alloy*

| Element | Cu | Fe | Mg | Ni | Mn | Zn | Si | Al |
|---|---|---|---|---|---|---|---|---|
| % wt | 4 | 0,28 | 0,244 | 0,1 | 0,43 | 0.43 | 0,12 | 94,396 |

*Table 2*

*Experimental mechanical properties*

| AL-alloy | $\sigma_y$, MPa | $\sigma_{ult}$, MPa | Elongation, % | Hardness, HB |
|---|---|---|---|---|
| 2024 | 352 | 502 | 15,4 | 117 |
| G | μ | Average of (3) specimens | | |
| 26,86 | 0,29 | | | |

*Table 3*

*Standard material specification 2024-T4 Aluminum-alloy [3], [4]*

| Chemical composition, % w | |
|---|---|
| Al 92,05; Cu 4,5; Mn 0,6; Cr 0,1; Mg 1,5; Zn 0,25; Si 0,5; Fe 0,5 | |
| Physical properties | |
| Melting Range, °C | 502...638 |
| Density, kN/m$^3$, 20 °C | 1,366 |
| Thermal Expansion, 1/°C·10$^{-6}$ | 24,66 (20...300 °C) |
| Mechanical properties – temperature = HT | |
| Tensile strength, *MN*/mm$^2$ | 482,3 |
| Yield strength, *MN*/mm$^2$ | 344,5 |
| Elongation, % | 18 |
| Hardness (Brinell) | 120 |
| Elastic modulus (Gpa.) / tension | 69,3 |

**Test Rig**

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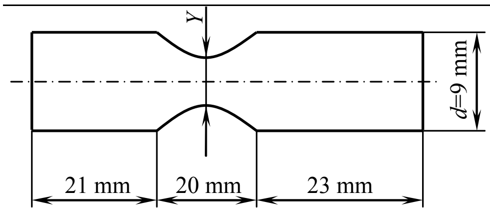


*Fig. 1. Dimension of rotating bending fatigue test specimens*

Rotating bending test machine: A cantilever type, load controlled type machine of constant load ratio of (–1). The specimen is subjected to an applied load at its free end perpendicular to its axis while rotating. This will develop a bending moment calculated by the following equations:

$$\sigma_b = MY / I \,, \qquad (1)$$

$$\sigma_b = PL / (\pi d^3 / 32) \,, \qquad (2)$$

where $L$ — the arm of the applied force ($L$=125,7 mm);
$\sigma_b$ — bending stress;
$Y$ — radius of the specimen ($Y=d/2$);
$I$ — moment of inertia ($I=\pi d^4/64$);
The specimen dimensions are given at figure (1).

**Experimental Results and Discussion**

Table 4 shows the *S-N* curve fatigue data for specimens tested reversed bending and ($R$=–1, stress ratio) at room temperatures.

*Table 4*

*S–N curve fatigue data for 2024-T4 Aluminum-alloy at room temperatures*

| $\sigma_b$ (bending stress), MPa | Life to failure (cycles) $N_f$ | | |
|---|---|---|---|
| | Group One | Group Two | Group Three |
| 140 | $9{,}4\cdot10^6$ | $8{,}2\cdot10^6$ | $10{,}1\cdot10^6$ |
| 160 | $3{,}5\cdot10^6$ | $4\cdot10^6$ | $3{,}7\cdot10^6$ |
| 170 | $2{,}65\cdot10^6$ | $3{,}01\cdot10^6$ | $2{,}88\cdot10^6$ |
| 180 | $1{,}94\cdot10^6$ | $1{,}77\cdot10^6$ | $1{,}82\cdot10^6$ |
| 200 | $9{,}25\cdot10^5$ | $8{,}88\cdot10^5$ | $9{,}2\cdot10^5$ |
| 250 | $3{,}2\cdot10^4$ | $3{,}07\cdot10^4$ | $2{,}92\cdot10^4$ |
| 300 | $4{,}2\cdot10^3$ | $4\cdot10^3$ | $3{,}87\cdot10^3$ |

Figure 2 shows the relation between bending stress at failure and number of cycle to failure.

The equation of life of the *S-N* curve in figure 2 may be written as

$$\sigma_f = 1479 N_f^{-0{,}147} \,, \qquad (3)$$

where $R$ — Stress ratio;
$\sigma_f$ — Fatigue stress;
$N_f$ — Fatigue Life;
$S$ — Stress Range;
$N$ — Number of Cycle.

Similarly 21 specimens were tested under elevated temperature at 180 °C at the same condition as given in table 4. The results are listed in table 5.

*Table 5*

*S-N curve fatigue data for 2024-T4 Aluminum-alloy at (180 °C)*

| $\sigma_b$ (bending stress) or stress at failure, MPa | Life to failure (cycles) $N_f$ | | |
|---|---|---|---|
| | Group Four | Group Five | Group Six |
| 140 | $5{,}2\cdot10^6$ | $4{,}45\cdot10^6$ | $4{,}9\cdot10^6$ |
| 160 | $1{,}1\cdot10^6$ | $0{,}9\cdot10^6$ | $1{,}07\cdot10^6$ |
| 170 | $8{,}1\cdot10^5$ | $9{,}02\cdot10^5$ | $8{,}4\cdot10^5$ |
| 180 | $5\cdot10^6$ | $4{,}45\cdot10^5$ | $5{,}07\cdot10^5$ |

| | | | |
|---|---|---|---|
| 200 | $1{,}2\cdot10^5$ | $1{,}09\cdot10^5$ | $1{,}7\cdot10^5$ |
| 250 | $1{,}2\cdot10^4$ | $1{,}09\cdot10^4$ | $1{,}11\cdot10^4$ |
| 300 | $1{,}2\cdot10^3$ | $0{,}9\cdot10^3$ | $0{,}85\cdot10^3$ |

Figure (3) shows the behavior of the AL-alloy under high temperatures.

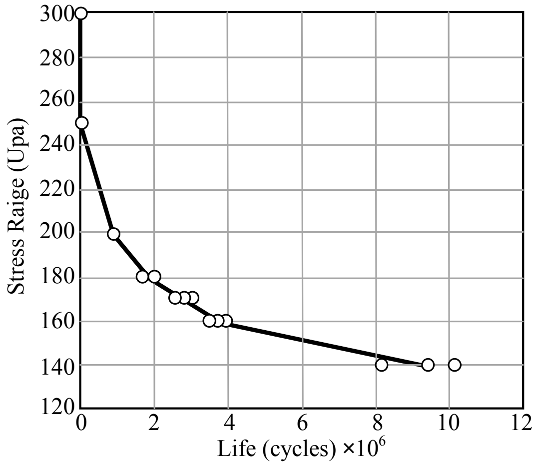


*Fig. 2. S-N curve for 2024 Aluminum-alloy material for dry fatigue*

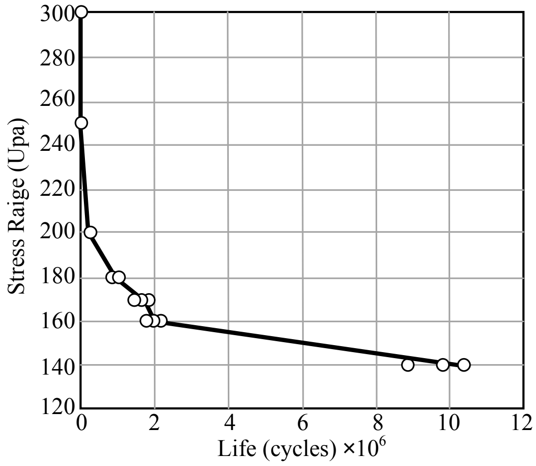


*Fig. 3. S-N curve for 2024 Aluminum-alloy material for elevated temperature fatigue*

The equation of the *S-N* curve life in figure 3 may be written as

$$\sigma_f = 524 N_f^{-0{,}0858}. \tag{4}$$

Figure 4 shows a comparison between the *S-N* curve for dry fatigue and elevated temperature.

Al-Kaisee [7], studied the 2024 AL-alloy material and a comparison between the published result and the current result is given at figure 5.

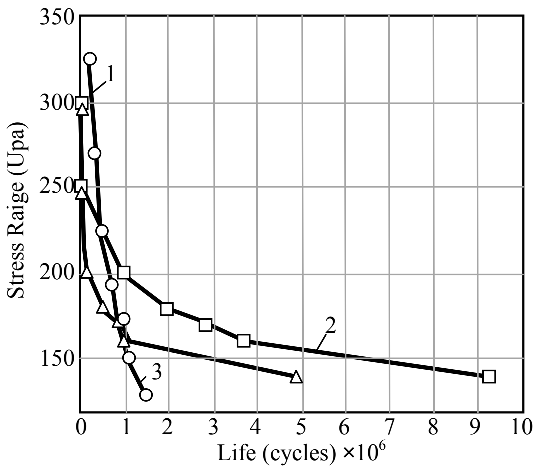


*Fig. 4. Comparison between the S-N curve for dry and elevated temperature fatigue: 1 — Al-Kaissee result; 2 — Ounent result (Dry fatigue); 3 — Ounent result (elebted fatigue)*

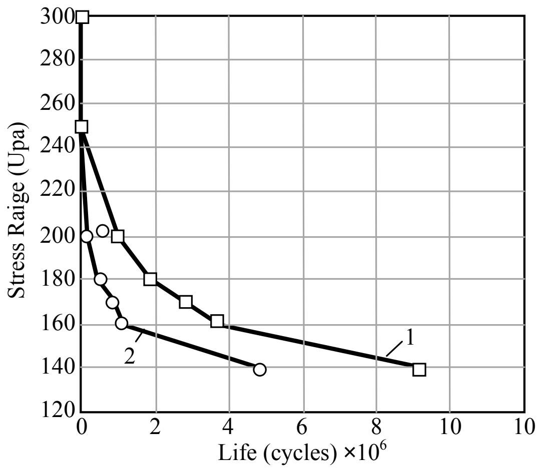


*Fig. 5. Comparison between present results and AL-Kaisee results: 1 — S-N for fatigue; 2 — S-N at elevated temperature*

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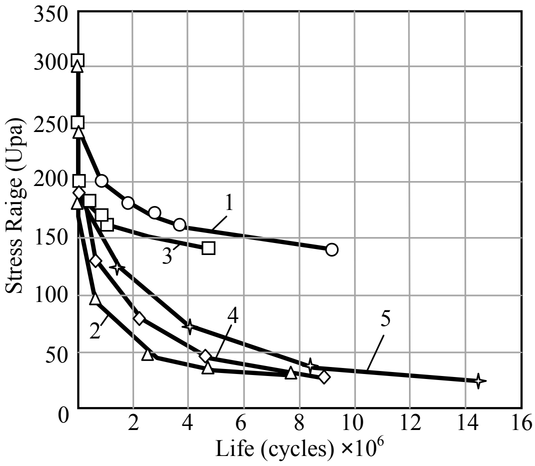


*Fig. 6. Comparison between present results and AL-Amiri, Yaseen , and AL-Naimy Results: 1 — Ounent result (Dry fatigue); 2 — Yassen result; 3 — Ounent result (elevated temperature); 4 — AL-Amiri result; 5 — AL-Naimy result*

AL-Amiri [5], Yaseen [8], and AL-Naimy [9], studied the 2024 AL-alloy material and a comparison between the published result and the current result is given in figure 6.

**Conclusion.**

In this study the fatigue life cycle of the for Aluminum-alloy 2024-T4 is carried out for three group of materials with the different stress range, this specimen have been tested at ambient and elevated temperature that is 180 °C; it was observed that the life cycles are significantly reduced at elevated temperature when compared to specimen tested at room (ambient) temperature within the same applied stress range, The equations were developed for fatigue life for Aluminum-alloy 2024-T4 at room temperature and elevated temperature, It is observed that the fatigue strength under elevated temperature is reduced when compared to ambient temperature by a factor 1,2...1,4:

— The fatigue behavior of the Aluminum-alloy 2024-T4 of dry fatigue at constant amplitude load may be described by the following formula:

$$\sigma_f = 1479 N_f^{-0,147}.$$

— While the behavior of the Aluminum-alloy under 180 $^o$C may be taken the formula:

$$\sigma_f = 524 N_f^{-0,0858}.$$

— The fatigue strength under elevated temperature is reduced by a factor of 1,2...1,4 compared with the strength at dry fatigue.

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