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# Elevated Temperature Corrosion of Mechanical Properties and Fatigue Life of 7025 Aluminum Alloy

**Mohammed H. Alwan [a], Hussain J. M. Al-Alkawi [b*], Ghada A. Aziz [c]**
[a, c] Electromechanical Engineering Dept., University of Technology-Iraq, Alsina'a Street, P.O. Box 10066, Baghdad, Iraq.
[b] Department of Aeronautical Engineering Techniques, Bilad Alrafidain University College, Diyala, Iraq.
*Corresponding author Email: mailto:Alalkawi2012@yahoo.com

## HIGHLIGHTS

- All mechanical and fatigue properties were reduced due to corrosion - elevated temperature interaction for AA 7025.
- The experimental results showed that the Ultimate Tensile Strength (UTS) and Yield stress (YS) of AA 7025 reduced by 8.7% and 19.35% respectively when subjected to tensile and corrosion - elevated temperature test.
- Fatigue life and strength of AA 7025 significantly reduced under the application of corrosion and elevated temperature together.

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## ABSTRACT

Aluminum alloys are widely used in aircraft industry where good corrosion resistance, light weight and high strength are the primary requirements.
In the present study, attempts have been made to extend the application of mechanical and fatigue properties of AA7025 in laboratory with corrosive environment of media and combined corrosive at elevated temperature (ET) 150$^0$C. The experimental results and analysis of corrosion and corrosion - elevated temperature mechanical and fatigue behavior of the samples showed that the 3.5%NaCl corrosive media and corrosion - elevated temperature (ET) greatly decrease the properties mentioned. The Ultimate Tensile Strength (UTS) and Yield stress YS of AA 7025 reduced by 5.3% and 14.83% respectively due to combine corrosion and elevated temperature but these properties reduce by 8.7% and 19.35% respectively due to combined actions corrosion (ET). The Brinell hardness also reduced by 4.2% and 11.26% due to corrosion only and corrosion and (ET). Ductility was increased by 10.5% and 16.25% for corrosion and corrosion (ET). The environment and elevated temperature – corrosion have significant effect on reduction the fatigue life and strength of AA 7025. It's clear that the combine corrosion and (ET) combination reduce safely of the mechanical properties compared with the corrosion only and room temperature conditions.

## 1. Introduction

Aluminum alloys are lightweight materials and they are not very strong materials in its pure form. Different elements are added to enhance its mechanical and fatigue properties such as zinc, silicon, copper, magnesium etc. The aluminum alloys can work efficiently even in extreme environmental conditions due to their good mechanical properties, (strength and ductility), good corrosion resistance, better weldability. Aluminum alloys are widely used in many applications of industries like aerospace, and automobiles.

The corrosion plays a major role in reduction of the mechanical and fatigue properties of aluminum alloys. The main cause of corrosion of aluminum alloys is the usage of these alloys in the environment in which they are chemically unstable [1].

Corrosion in general has the overall effect in reducing the strength of a structure, and if not detected, could progress to a state that eliminates the possibility of damage tolerant crack growth, resulting instead in catastrophic failure. Significant effort is placed upon minimizing the effect of corrosion in aircraft structure and the corrosion fatigue effect can be diminished.

The environment (corrosion and elevated temperature) is very harmful due to localized electrochemical reaction of corrosion pits formation and the interaction of corrosion with creep (elevated temperature) is proved to be an important factor in designing the component and structures subjected to cycling loads [2].

Mishra R. K [3] investigated the conditions of the fins of the heat exchangers so these exchangers face extreme environment and fatigue loading, therefore they go through corrosion – fatigue. The applied bending fatigue stress were 120, 150 and 180



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2412-0758/University of Technology-Iraq, Baghdad, Iraq

(MPa). The corrosion solution was aqueous of NaCl. It was found that the corrosion due to NaCl has significantly reduce the mechanical properties and fatigue life. The reduction percentage in (UTS), (YS), and ductility was found to 4.4%, 9.17% and 37.5 respectively. These loads applied to uncorroded and corroded specimens. They found that the fatigue life is roughly reduced from 20% to 65%, approximately 30% to 80% and 15% to 75% cycles at the above stress applied respectively.

Sayan Sarkar et al [4] obtained corrosion conduct of new HEAs AlCoFeNiTiV0.9Sm0.1 and AlCoFeNiV0.9Sm0.1, produced with the aid of laser based additive production, which offers excessive freedom of layout, fast prototyping, and rapid quenching prices which can be perfect for lots commercial programs. These alloys have been examined in corrosive syngas environment at elevated temperatures to explore their applicability in such harsh environments. Phase evaluation outcomes indicated the presence of a single FCC section in these HEAs with no predominant floor cracks after enduring such corrosive atmospheres. Also, these alloys exhibited right corrosion resistance as found out by means of electrochemical trying out methods. CALPHAD and DFT simulations have been also carried out to reveal the phase balance and crystal systems.

Alalkawi H.J.M et al [5] concluded that the corrosion-fatigue happens by the combined actions of cyclic loading and corrosive surroundings. The result of shot peening on accumulative corrosion-fatigue lifetime of 1100-H12 Al alloy was investigated. Before fatigue testing, specimens were submerged in 3.5% NaCl resolution for 71 days. Constant fatigue tests were performed with and without corrosive surroundings. They obtained the constant fatigue life was considerably reduced because of corrosive surroundings and therefore the endurance fatigue limit was reduced by 13% compared with dry fatigue. It was found that the CFLIF% (Cumulative Fatigue Life Improvement Factor) was regarding (2-6) because of shot peening surface treatment.

Shrnoos R. M. [6] studied the mechanical and fatigue properties of AA6061 – T6 under stress ratio (R= -1) and combined corrosion with elevated temperature (ET). The results revealed that the mechanical and fatigue properties were significantly reduced, But the shot peening process improved this reduction.

In the current work, an effort has been made to study the effect of pre-corrosion of the mechanical properties and fatigue life of AA7025 under the interaction of elevated temperature -fatigue at constant cycling loading. In the first group of experimental work, samples of tensile are subjected to tensile to investigate the influence of 60 days corrosion (3.5%NaCl) on the mechanical properties UTS, YS and ductility. While the second set, tensile test is carried out to obtain the mechanical properties under elevated temperature (150$^0$C). The results obtained from the first and second group are compared with the dry properties at room temperature (RT). The third set is performed to determine the fatigue life of dry (RT), corrosion – fatigue and corroded specimens subjected to elevated temperature (150$^0$C) - fatigue interaction.

Our goal is to know the effect of 3.5% NaCl corrosion only and corrosion with (ET) on mechanical and fatigue properties of AA7025. Comparison between the above properties with different conditions of testing is made.

## 2. Experimental work

### 2.1 Material and methods

The AA7025 which adopted in this work is used mainly for manufacturing the fins of heat exchangers in ships, air conditions, aircrafts and automobile. Chemical analysis of the AA7025 is listed in Table 1.

### 2.2 Tensile tests

The tensile test was carried out using Tinius Olsen K1000 tensile test machine with a capacity of 1000KN (College of Engineering, University of AL-Mustansiriya).

The experimentation was done at a constant rate of 1 mm/min till failure. In order to achieve the elevated temperature – tensile testing a small furnace was attached to the tensile test rig. Inside the furnace there is an electrical heater that was fixed with K-type thermocouple to control the temperature of the furnace.

The tensile specimen was a circular shape of dimensions shown in Figure 1 according to standard ASTM(E8/E8M) [8].

### 2.3 Hardness test (HB)

Hardness examination was carried out using the ems-51 hardness tester and it is performed in accordance to the standard ASTM E10-2017 [9].

### 2.4 Fatigue test

A circular shape specimen of dimensions shown in Figure 2 were taken according to standard DIN50113.

The fatigue tests were performed on dry, corroded and corroded – elevated temperature (150$^0$c) interaction. The fatigue machine which is used to done fatigue test of 1425 rpm (24Hz). The stress ratio was taken to be R= -1. The applied load was taken from (150 – 90) MPa. Three specimens were taken for each of dry, fatigue corroded and fatigue corroded – elevated temperature fatigue interaction. The average value of three results was adopted to compare between the three mentioned groups.

### 2.5 Corrosion test

Tensile and fatigue specimens involved polished to about 1μm roughness to minimize possible fractures from material or machining discontinuities. The specimens were corroded prior to tensile and fatigue testing through submersion in container containing 3.5% NaCl.

The NaCl solution was mixed in large quantities with water by ratio for 60 days. Testing was completed in a laboratory environment (20-30$^0$C, 25-35% relative humidity). The corrosion test was done according to (ASTM G48) specification.

**Table 1:** Chemical compositions of AA7025 Wt.%

| Element | AL | Zn | Mg | Mn | Mn | Fe | Cr | Cu | Ti |
|---|---|---|---|---|---|---|---|---|---|
| Standard [7] | 92.60 | 4.13 | 1.32 | 0.60 | 0.37 | 0.31 | 0.28 | 0.17 | 0.11 |
| Experimental | Balance | 3.87 | 1.27 | 0.55 | 0.29 | 0.30 | 0.26 | 0.14 | 0.10 |

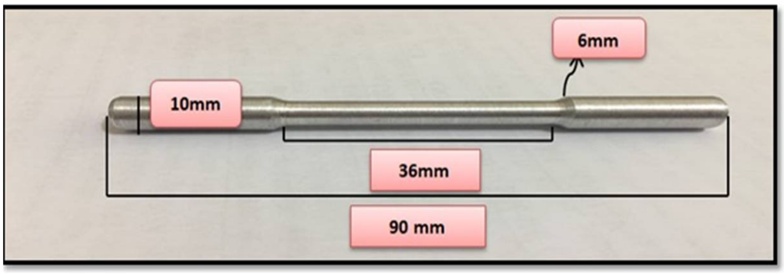


**Figure 1:** Tensile test specimen (according to standard ASTM(E8/E8M), all dimensions in mm

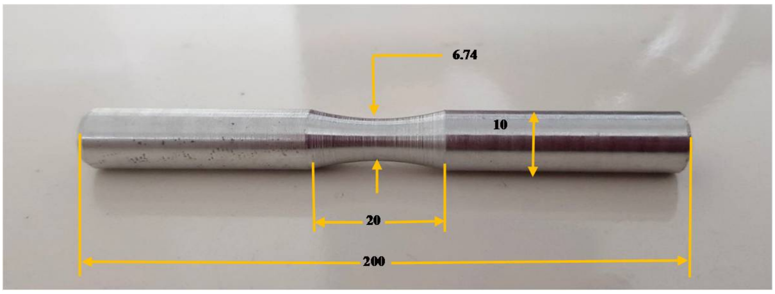


**Figure 2:** Fatigue test specimen, all dimensions in mm

## 3. Results and discussion

Mechanical properties of AA7025 are illustrated in Table 2.

Table 2 shows that the effect of 60 days 3.5% NaCl corrosion and elevated temperature (150$^0$C) on the ultimate tensile strength (UTS), Yield stress (YS), Brinell hardness HB and ductility of AA7025. It has been observed that all the mechanical properties except ductility are initially decreased while the ductility is increased.

The highest values of UTS and YS are observed in the case of as-received showing (264 MPa) for UTS and (155 MPa) for YS. While these values are reduced to be (250 MPa) for 60 days - 3.5% NaCl corrosion and (132 MPa) due to corrosion with elevated temperature as shown in Figure 3.

The reduction percentage obtained in (UTS) due to 3.5% NaCl corrosion is recorded to be 5.3% and 8.7% for 3.5% NaCl corrosion elevated temperature. The yield stress (YS) is reduced by 14.83% and 19.35% due to 3.5% NaCl corrosion and 3.5% NaCl corrosion with elevated temperature respectively compared with (RT) results. The hardness of corrosion samples and 3.5% NaCl corrosion - elevated temperature samples is reduced from 71 to 68 and 71 to 63 respectively. The reasons for the reduction in mechanical properties are the presence of pitting corrosion which played a larger role in reducing the mechanical, hardness and fatigue life as compared to as – received specimens. Corrosion pits were identified as crack origins in all corroded samples of AA7025.

Comparing the mechanical properties of tensile test at (RT) and corrosion with the results corrosion - elevated temperature when considering the same AA7025 alloy showing that the corrosion –high temperature results have the less values, except the ductility as shown in Figures 4 and 5.

There are many factors effecting the corrosion – fatigue of metals, such as concentration of corrosion solution PH valve, load frequency and temperature.

Examined the corrosion fatigue under wt.% $CaCl_2$ and wt.% NaCl. They found that the fatigue strength reduction was 0.77 and 0.85 in comparison with (RT) test [10].

Tested stainless steels corroded with light water under temperatures 70$^0$C to 320$^0$C. They concluded that the mechanical and fatigue properties are significantly reduced compared with that of air. Since corrosion pits generated by electrochemical reaction, may grow to other sizes with the neighboring pits as shown in Figure 6 [11].

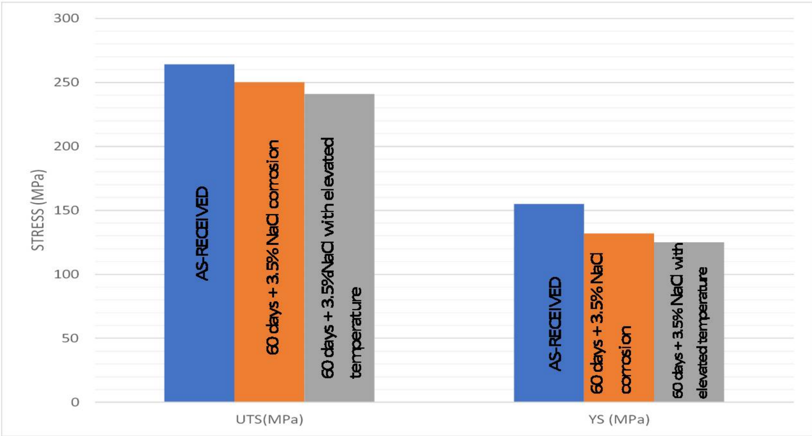


**Figure 3:** UTS and YS under three conditions of testing

**Table 2:** Mechanical properties of AA7025 at three conditions of testing

| Condition | UTS(MPa) | YS(MPa) | HB | Ductility |
|---|---|---|---|---|
| As received | 264 | 155 | 71 | 17 |
| 60 days+ 3.5% NaCl corrosion | 250 | 132 | 68 | 19 |
| 60 days+3.5% NaCl corrosion + elevated temperature | 241 | 125 | 63 | 20.3 |

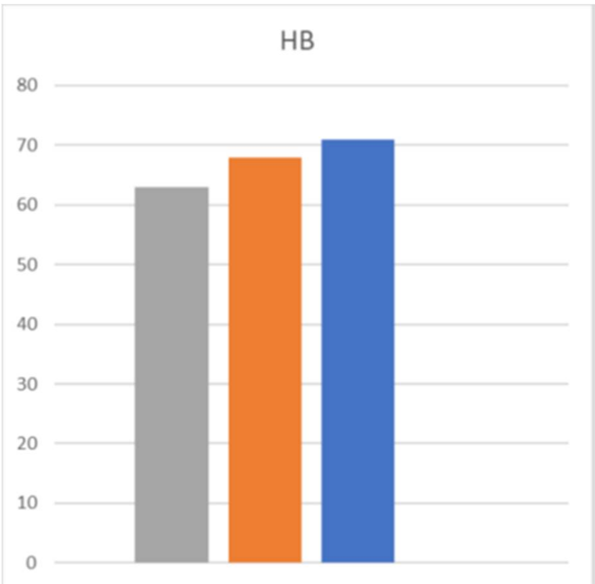


**Figure 4:** HB for three cases of testing

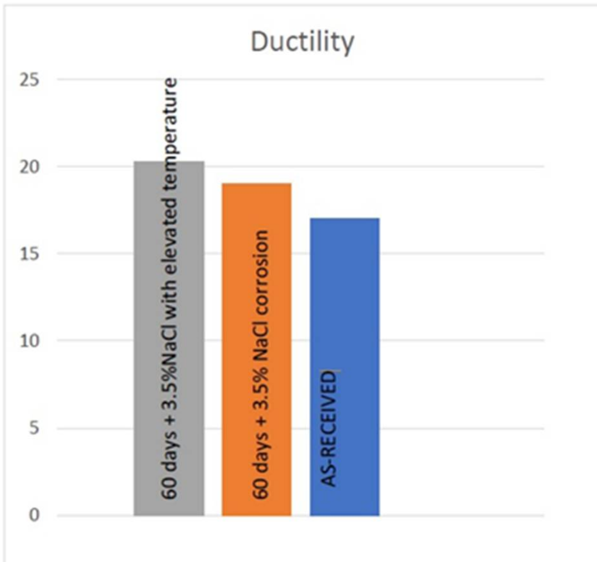


**Figure 5:** Ductility of as– received, 3.5% NaCl corrosion and corrosion- elevated temperature

## 3.1 Fatigue test results

Fatigue results having three different cases, dry fatigue at (RT) 3.5% NaCl corrosion – fatigue and corrosion fatigue -elevated temperature.

For constant stress levels are adopted for each case i.e., 100,120,150 and 200 MPa and three tests are carried out at each stress level. The results of the above three cases are tabulated in Table 3.

where $б_f$ is the applied stress at failure, A and $\alpha$ are material constants. The Basquin equations for the three cases are given in Table 4 with ($R^2$), correlation factor which represents and measure of goodness of fit [12].

The Basquin equations indicated that results obtained from fatigue experimental work are well described by power law formula.

The values of ($R^2$) are closed to unity (relatively high) and this mean that the Basquin equation is well applied to the fatigue data.

The Basquin equation for three cases adopted in this study are plotted as shown in Figure 7.

**Figure 6:** Container of 3.5% NaCl aqueous solution and samples after corroded by 3.5% NaCl

**Table 3:** S-N curve results for three cases of testing

| Dry – fatigue at (RT) | | |
|---|---|---|
| Stress at failure (б$_f$) MPa | $N_f$ cycle | $N_f$ av |
| 0.378 (UTS) = 100 | 282000, 305700, 310600 | 299433 |
| 0.454 (UTS) = 120 | 212000, 225000, 207000 | 214667 |
| 0.568 (UTS) = 150 | 125000, 133600, 140800 | 133133 |
| 0.757 (UTS) = 200 | 88600, 79800, 84000 | 84133 |
| **3.5% NaCl corrosion – fatigue** | | |
| Stress at failure (б$_f$) MPa | $N_f$ cycle | $N_f$ av |
| 0.378 (UTS) = 100 | 240600, 258000, 274800 | 257800 |
| 0.454 (UTS) = 120 | 190000, 181500, 175000 | 182167 |
| 0.568 (UTS) = 150 | 101600, 98800, 107000 | 102467 |
| 0.757 (UTS) = 200 | 74600, 51800, 62600 | 63000 |
| **corrosion fatigue -elevated temperature** | | |
| Stress at failure (б$_f$) MPa | $N_f$ cycle | $N_f$ av |
| 0.378 (UTS) = 100 | 218000, 201000, 192000 | 203667 |
| 0.454 (UTS) = 120 | 132500, 141800, 135000 | 136433 |
| 0.568 (UTS) = 150 | 78600, 58000, 65800 | 67467 |
| 0.757 (UTS) = 200 | 31600, 42500, 39800 | 37967 |

**Table 4:** Basquin equation for three cases with ($R^2$)

| **Condition** | **$R^2$Correlation factor** | **Basquin equation бf = A.Nfα** |
|---|---|---|
| Dry-Fatigue | 0.996354 | б$_f$=87454*$N_f^{-0.537}$ |
| Corrosion-Fatigue | 0.992848 | б$_f$=38701*$N_f^{-0.478}$ |
| Corrosion Fatigue -elevated temperature | 0.99158 | б$_f$=13203*$N_f^{-0.399}$ |

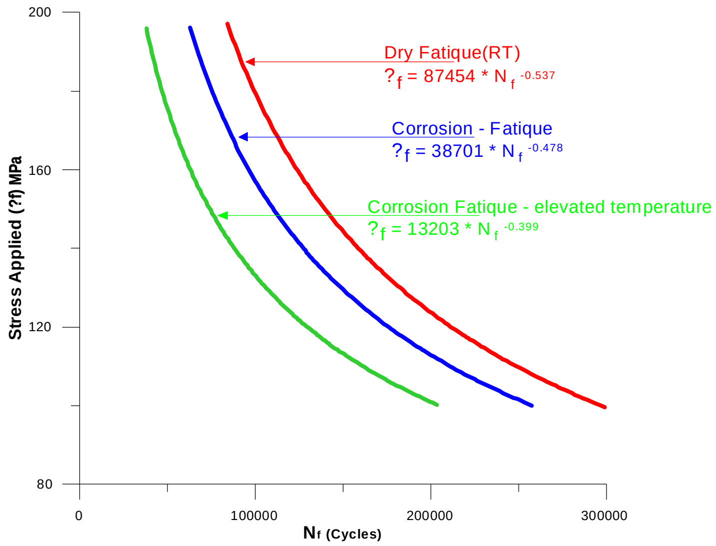


**Figure 7:** S-N curve for three cases of testing

**Table 5:** Fatigue strength of three cases of testing at $10^7$ cycles

| Dry fatigue (RT) | Corrosion - fatigue | Corrosion – fatigue + elevated temperature |
|---|---|---|
| Fatigue strength at $10^7$ cycles (MPa) | | |
| 76.3 | 61.3 | 53.3 |

The above results, Table 3, are plotted by relationship between stress at failure ($\sigma_f$) and Number of cycle ($N_f$) in power law (Basquin equation $\sigma_f = A.\ N_f^{\alpha}$) given in Table 4. It is clear that Figure 7, the fatigue life of (RT) shows the longer life while the corrosion – fatigue with elevated temperature ($150^0$C) shows highly poor performance due to pitting and over ageing condition. The fatigue strength of the three-condition mentioned in Figure 7 at $10^7$ cycles is given in Table 5.

Table 5 indicates that the fatigue strength of corrosion fatigue reduces by 19.65% while it reduces to 30.14% for corrosion fatigue with elevated temperature ($150^0$C). There is a drastic decrease in fatigue strength for both fatigue corrosion and fatigue corrosion elevated temperature cases which were over aged compared to dry (RT) case.

## 4. Conclusions

In the current work, the effects of the corrosion of 3.5% NaCl solution and elevated temperature on mechanical and fatigue properties. The contributions of this investigation are as follows:

1) It is found that there is a significant reduction in mechanical and fatigue properties due to corrosion – fatigue and corrosion – fatigue elevated temperature for AA7025.
2) The average hardness of the dry sample was measured to be (71 HB) while it reduced to 68 for corrosion and to 63 for corrosion + elevated temperature.
3) Maximum fatigue life and strength were observed in dry sample and minimum was observed in corrosion fatigue elevated temperature. The maximum reduction percentage in fatigue strength was recorded to 30.14% at corrosion fatigue elevated temperature while minimum percentage was reported to be 19.65% for corrosion fatigue case.

The corrosion plays a significant rule on mechanical and fatigue properties. Corrosion accelerated the crack growth leading to reduction in mechanical and fatigue strength and life. While corrosion with (ET) severely accelerated the crack, growth resulted in low mechanical and fatigue behavior. Corrosion pits extended along the crack growth path generating defects and stress concentration around the sample crack.

### Author contribution

All authors contributed equally to this work.

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### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

### Conflicts of interest

The authors declare that there is no conflict of interest.

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