International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 10, Issue 5 (May 2014), PP.68-74

Tensile Behavior of Aluminium Alloy 6063 - T6 In Sea Water

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Abstract:- Sea water, by virtue of its chloride content, is a most efficient electrolyte. The Omni-presence of oxygen in marine atmospheres, sea spray increases the aggressiveness of salt attack. The differential concentration of oxygen dissolved in a droplet of salt spray creates a cell in which attack is concentrated where the oxygen concentration is lowest. The sea environment is the most structurally hostile environment within which aircraft operate. The structural components are being exposed to salt spray continuously during its operation and it experiences heavy loading during landing. Corrosion also leads to crack propagation when subjected to loading. Corrosion along with damage leads to the failure of structural components prematurely and presents a serious problem in the aging aircraft. This requires a different approach to the maintenance of structural components subjected to corrosion and repetitive loads.

This paper studies the effect of corrosion and low impact damage on aluminium alloy 6063- T6. The 6063 aluminium alloy that was used for the study was heat treated and soaked in seawater prepared per ASTM D1141 for different intervals of time between 0hours and 1000hours. Corroded specimens were subjected to low impact damage. The result shows a gradual degradation in mechanical properties of the alloy due to corrosion and damage.

Keywords:- Sea Water, Corrosion, tensile strength, impact damage, Al Alloy 6063 – T6, ASTM D1141

I. INTRODUCTION

Corrosion by sea water, *aqueous corrosion*, is an electrochemical process, and all metals and alloys when in contact with sea water have a specific electrical potential (or corrosion potential) at a specific level of sea water acidity or alkalinity - the pH[2]. Most corrosion resistant metals rely on an oxide film to provide protection against corrosion. If the oxide is tightly adherent, stable and self healing, as on many stainless steels and titanium, then the metal will be highly resistant or immune to corrosion. If the film is loose, powdery, easily damaged and non self repairing, such as rust on steel, then corrosion will continue unchecked. Even so, the most stable oxides may be attacked when aggressive concentrations of hydrochloric acid are formed in chloride environments. Many different types of destructive attack can occur to structures, ships and other equipment used in sea water service. The term 'aqueous corrosion' describes the majority of the most troublesome problems encountered in contact with sea water, but atmospheric corrosion of metals exposed on or near coastlines, and hot salt corrosion in engines operating at sea or taking in salt-laden air are equally problematical and like aqueous corrosion require a systematic approach to eliminate or manage them. Hosni Ezuber et al[2] studied the corrosion behaviour of aluminium alloy in sea water and corrosion monitoring was done by done by using potentiodynamic polarization technique. They found the weight loss was less which revealed the corrosion attack took place at a low rate. They found that the immersion corrosion of aluminium alloys appeared to be controlled by oxygen diffusion through the corrosion layer. Wu.X.R [3] et al analysed the basic characteristics of corrosion cracking of a loading-carrying frame on X-type aircraft. They studied the mechanism of corrosion cracking through experimental simulation. They concluded that temperature, humidity and the tightness of contact between frame metal and rubber fuel tank were the most influential factors for the cacking. D.L. DuQuesnay [4] et al investigated the growth behaviour of fatigue cracks initiated from the corrosion pits of aluminium alloy 7075-T6511 tested in laboratory subjected to the aircraft spectrum loading. They suggested that the size of the deepest corrosion pit in the area of corrosion damage on an aircraft, or similar structure, can be used as the *metric* for predicting fatigue life. Their investigation have shown that artificially produced pitting corrosion gives a severe reduction in the fatigue life of laboratory specimens when subjected to transport aircraft spectrum loading in laboratory air.Margery E.Hoffman[5] et al studied the effects of corrosion on structural issues related to naval aviation. Their study demanded a paradigm shift to our approach to designing, maintaining metallic aircraft structure. They found corrosion assisted fatigue resulted in premature ending of components. Frederic menan[6] et al studied the interactions between mechanical, environmental and micro structural parameters during corrosion fatigue crack growth in the aluminium alloy 2024. The corrosion fatigue crack growth behaviour of alloy 2024-T351 under alternate immersion in 3.5% NaCl solution differs significantly from the behaviour under permanent immersion.W.B. Wan Nik [7] et al studied the behaviour of different types of aluminium subjected to aqueous corrosion in salt spray chamber and normal seawater container. They found that the corrosion rate tends to be increased by decreasing temperature, pH, and flow velocity and by increasing dissolved oxygen. The potentiodynamic polarization curves suggested a cathodic character for the inhibition process in seawater.

Corrosion is one of the main factor which causes structural degradation in aging aircrafts. Corrosion also leads to crack propagation and damage of the structural components [4-6]. The corrosion resistance of these alloys is related to the formation of an oxide (passive) film, which naturally develops on the alloy surface under normal atmospheric conditions [10,11]. The oxide film formed on the aluminium alloy surface is non-uniform, thin and non-coherent. Therefore, it imparts a certain level of protection under normal conditions. When exposed to environments containing halide ions, of which the chloride (Cl_) is the most frequently encountered in service, the oxide film breaks down at specific points leading to the formation of pits on the aluminium surface [8]. Corrosion of aluminium alloy takes place when it is exposed to the presence of electrolyte having pH between 4.5 to 8.5.

Corrosion of aluminium alloy also depends upon its purity and the alloying elements, especially its copper content. Corrosion takes place in direct proportion to the amount of the copper content. 2xxx series alloy normally have more copper content and exhibit lower corrosion resistance than other aluminium alloys. The other aluminium alloy, such as Al-Si (4xxx grade) and Al-Si-Mg (6xxx grade) show a lower resistance to localized corrosion. 1xxx series grade is the purest and it’s highly corrosion resistant. Al-Mg(5xxx grade) series alloys exhibits a fairly good resistance in sea water and chloride-containing solutions.

Corrosion resistance tests are made for the determination of tensile and energy density properties after exposure in several different types of corrosion tests. These data are used for evaluating the corrosion susceptibility of the materials by measuring weight loss and characterizing depth and type of corrosion attack. The severity of corrosion attack depends on material heat treatment procedure, corrosive environment, pH value, temperature of the solution. As it is to be expected, corrosion damage tends to degrade the yield and ultimate tensile stress. The degree of degradation depends on the exposure time. A dramatic volumetric material embrittlement was observed even after short exposure times. In this study, the corrosion behaviour of aluminium alloy 6063 was evaluated in sea water.

Table I Chemical composition (wt%) of aluminium alloy 6063

Aluminium alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Ni	Zr	Li
6063	0.5	0.35	0.1	0.1	0.75	0.1	0.1	0.1	-	-	-`

II. EXPERIMENTS

Measured tensile properties of the corroded specimens were compared with those for the uncorroded material. Corrosion process was conducted according to ASTM standard. Performed analysis gave supporting data for characterizing corrosion susceptibility.

A. *Material and Specimen*

Experiments are conducted for aluminium alloy 6063. This alloy is used in less loaded components in aircraft. They are also used in hydraulic, oil and fuel systems. Alloy 6063 is perhaps the most widely used because of its extrudability. Chemical composition of the alloy is given in the table 1.Tensile specimens were machined according to the specification ASTM B557M. Prior to the tensile test, the specimens were pre-corrodded as described below.

B. *Corrosion Process*

The different corrosion processes for the tensile specimens are as follows.

1. Exfoliation Corrosion
2. Intergranular Corrosion
3. Alternate Immersion Corrosion
4. Salt Spray Corrosion
5. Cyclic acidified salt fog Corrosion
6. Atmospheric Corrosion Test
7. Sea water Immersion Test

The method preferred in this study was Sea Water Immersion Test.

C. *Sea Water Immersion Test*

These tests were made in accordance to ASTM D1141 -98 specification [9]. This practice covered the preparation of solutions containing inorganic salts in proportions and concentrations representative of ocean water. Since the concentration of ocean water varies with sampling location, the gross concentration employed herein was an average of many reliable individual analyses. The stock solution was be prepared in two ways.

Stock Solution No. 1— The indicated amounts of the following salts were dissolved in water and diluted to a total volume of 7.0 L and stored in well stoppered glass containers.
$MgCl_2 \cdot 6H2O$ 3889.0 g (= 555.6 g/L)
$CaCl_2$ (anhydrous) 405.6 g (= 57.9 g/L)
$SrCl_2 \cdot 6H2O$ 14.8 g (= 2.1 g/L)

Stock Solution No. 2—The indicated amounts of the following salts were dissolved in water and diluted to a total volume of 7.0 L or a convenient volume and stored in well stoppered amber glass containers.
KCl 486.2 g (= 69.5 g/L)
NaHCO3 140.7 g (= 20.1 g/L)
KBr 70.4 g (= 10.0 g/L)
H3BO3 19.0 g (= 2.7 g/L)
NaF 2.1 g (= 0.3 g/L)

Preparation of Substitute Ocean Water

10.0 L of substitute ocean water was prepared by dissolving 245.34 g of sodium chloride and 40.94 g of anhydrous sodium sulphate in 8 to 9 L of water. This was added with 200 mL of Stock Solution No. 1 slowly with vigorous stirring and then 100 mL of Stock Solution No. 2. It was then diluted to 10.0 L and the pH of the solution was then adjusted to 8.2 with 0.1 *N* sodium hydroxide solution. Only a few millilitres of NaOH solution was required. The solution was used immediately after the preparation of the solution and adjustment of the pH. The specimens were immersed in this substitute solution for a duration of 500, 750, 1000 hours.

D. *Mechanical Testing:*

Specimen testing:

The servo Hydraulic Universal Testing Machine having a maximum capacity of 20000 kg was used for the experimental measurements. The machine was properly calibrated before using.

Tensile testing:

After subjecting the specimens to the corrosive environments described above, the corroded specimens were subjected to tensile tests [8]. The specimens were prepared in accordance to ASTM B557M-10. During the tensile test, the ASTM standard (B 557-M)specimens as mentioned above was striped at two fixtures of the machine and load was applied as per the ASTM standard recommends till the sample was failed into two segments. During the process, the load Vs deflection was recorded in the machine and converted into the stress strain diagram. This stress strain diagram gave the elastic modulus, Poisson's ratio and ultimate tensile strength of the specimen .The test series include the following 1) establishing the reference for uncorroded tensile specimens, 2) tensile testing of the uncorroded specimens after low impact damage(1,2,3J), 3)tensile testing of the corroded specimens after specified duration of exposure, 4)tensile testing of the corroded specimens after low impact damage(1,2,3J), 5)determination of degradation of tensile property of the specimens. Corroded specimens were damaged by dropping weight from a certain altitude. Damage was created in the specimens in the order of the energy 1, 2,3J. Corrosion of the specimens was monitored by measuring the potential difference of the specimens. All the mechanical tests are summarized in table 2.

Table II Tensile tests of Aluminium alloy 6063

Test series	Test series description	Corrosion exposure prior to tensile test	Number of tests performed
1	Tensile tests for reference material	none	5
2	Tensile tests for reference material with low impact damage (1,2,3 J)	none	15
3	Tensile test for corrosion with different exposure time	Sea water corrosion (exposure time 500,750,1000h)	15
4	Tensile tests for corroded specimen with low impact damage (1,2,3J)	Sea water corrosion (exposure time 500,750,1000h)	45

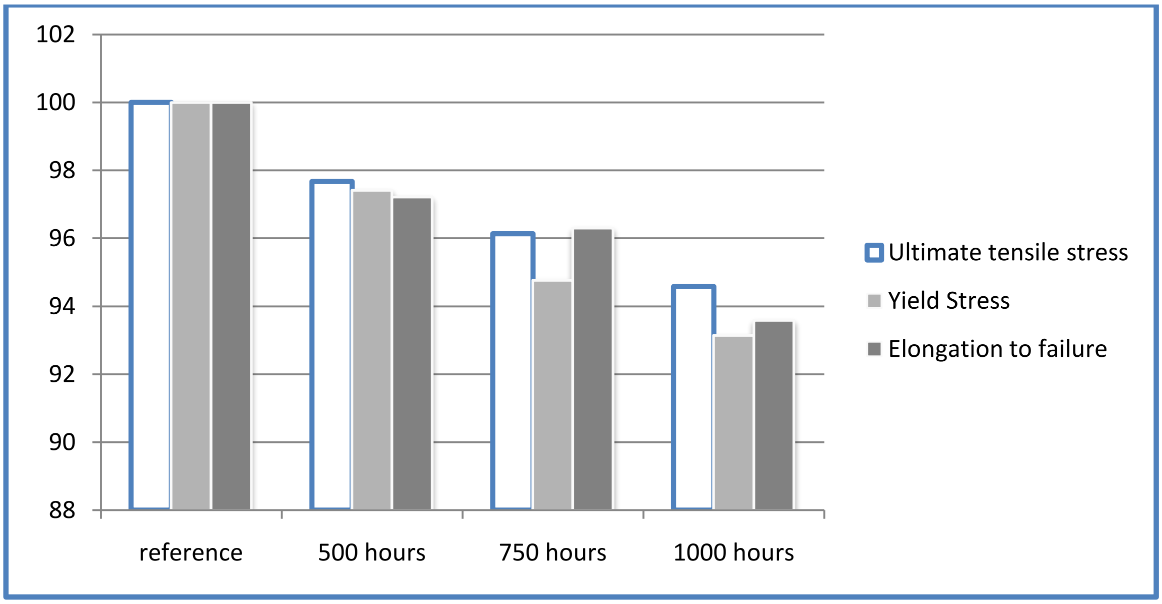

Fig 1. Tensile properties of Al 6063 alloy after removal of surface corrosion

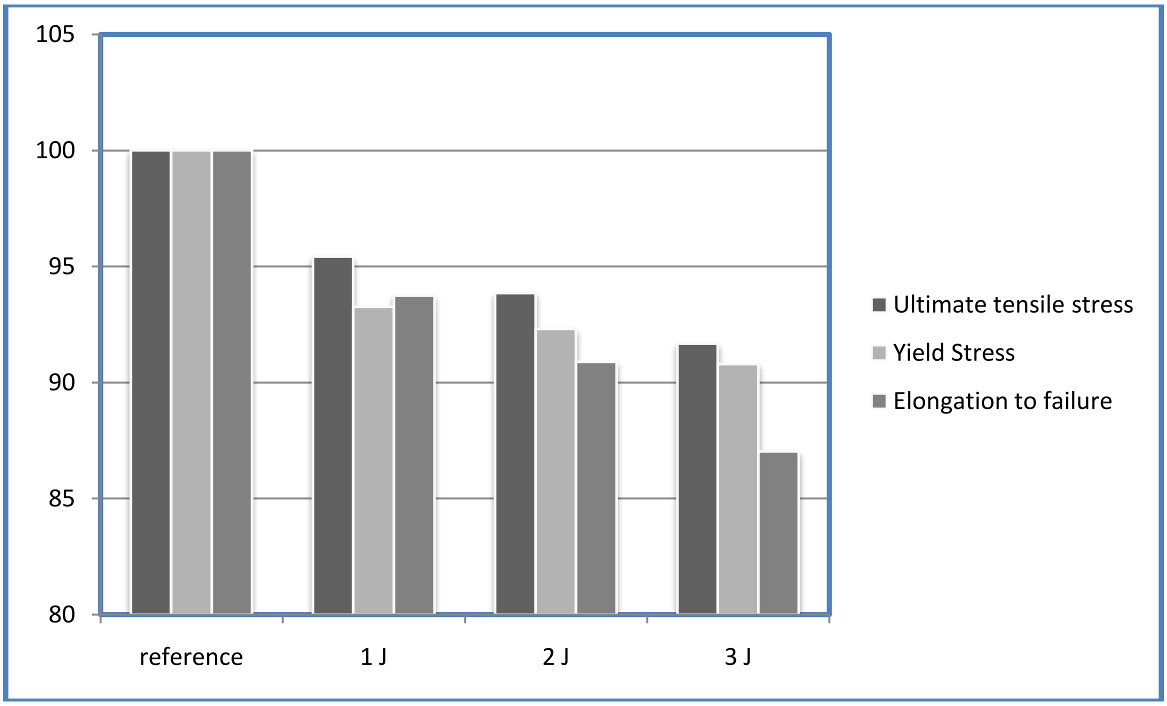

Fig 2 Tensile properties of reference specimen after low impact damage

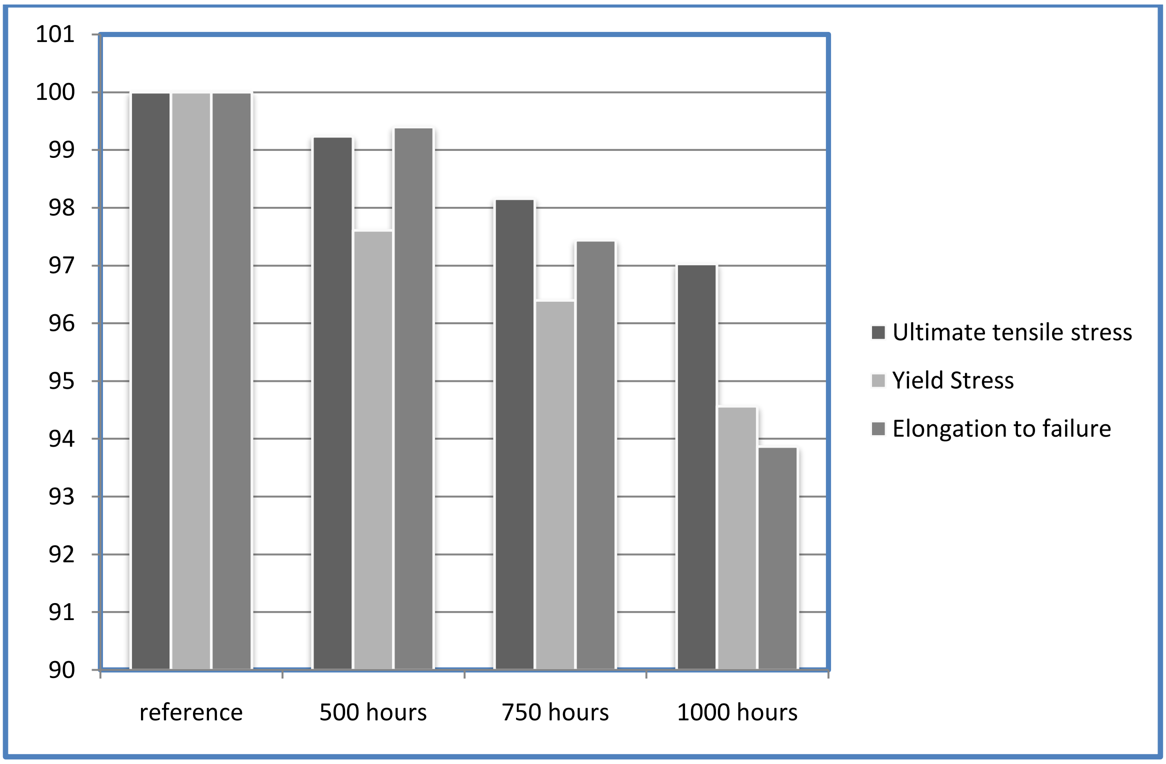

Fig 3 Tensile properties of corroded Al alloy 6063 after low impact damage of energy 1 J
Reference – Reference specimen with low impact damage of 1 J

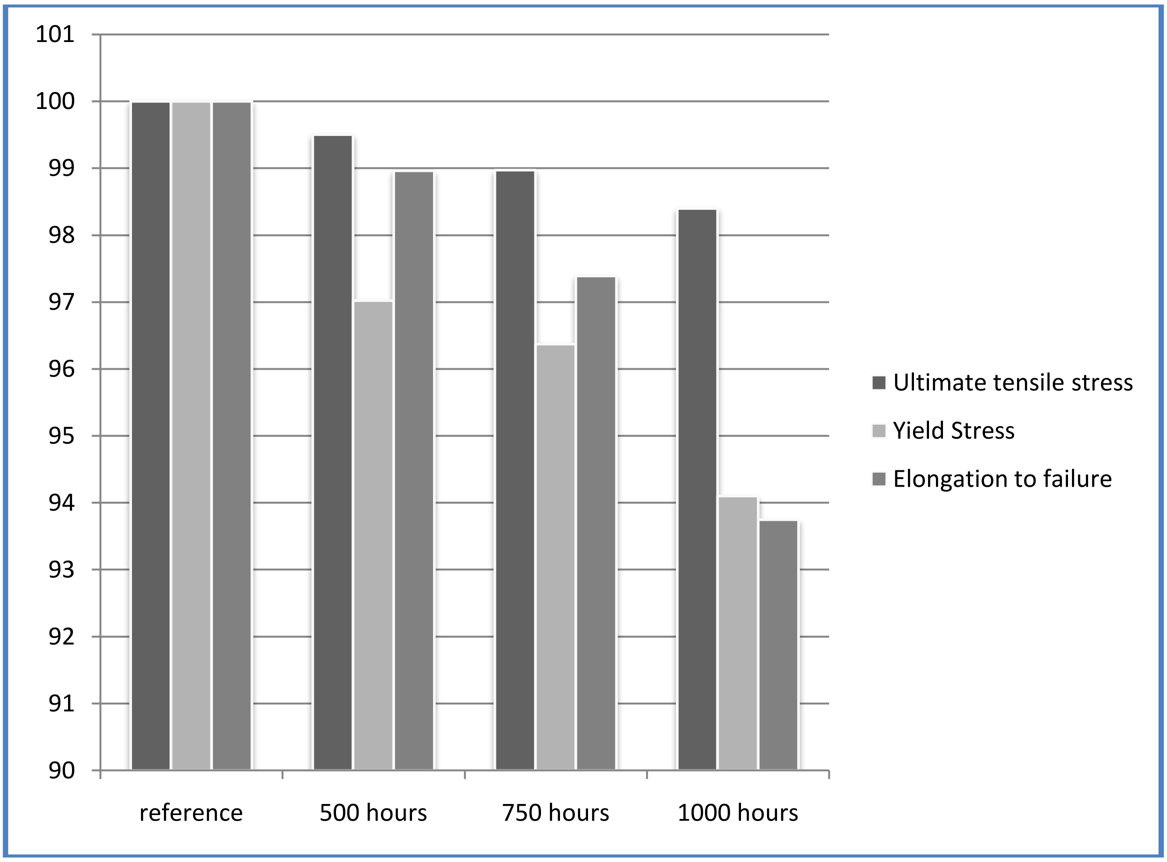

Fig 4 Tensile properties of corroded Al alloy 6063 after low impact damage of energy 2 J
Reference – reference specimen with low impact damage of 2 J

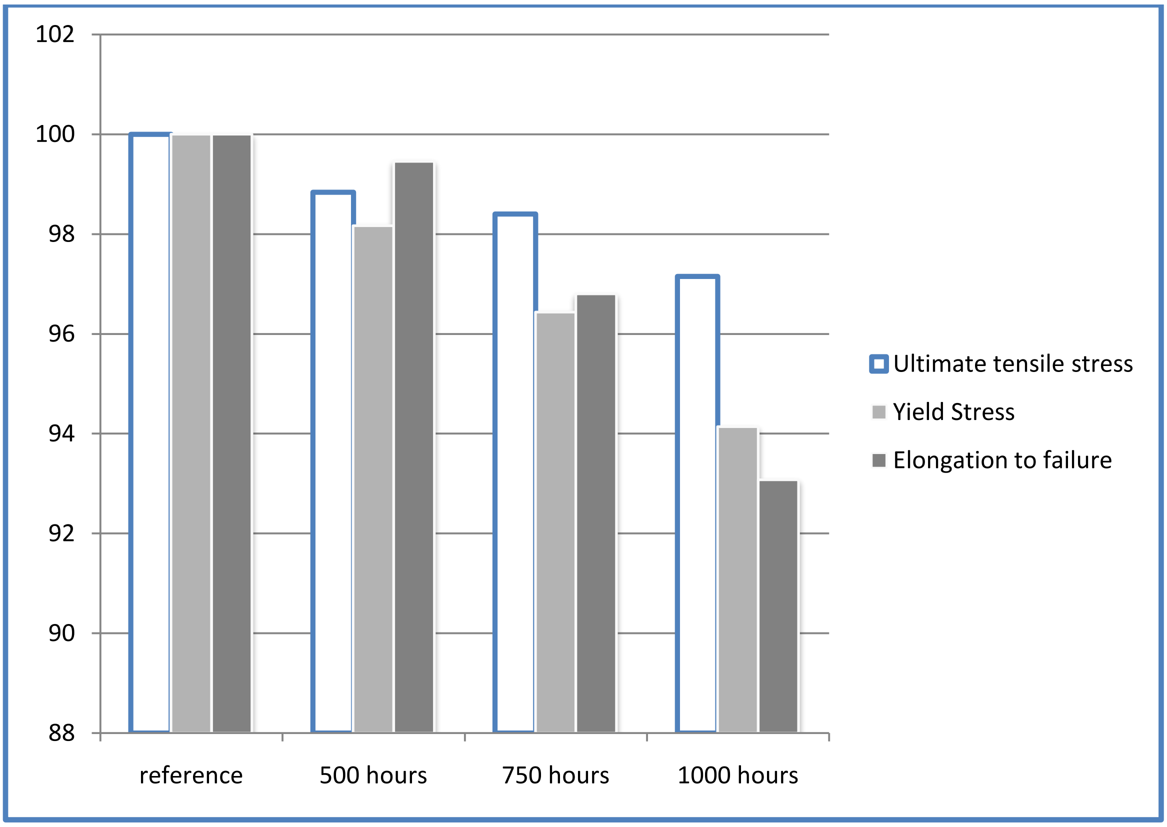

Fig 5 Tensile properties of corroded Al alloy 6063 after low impact damage of energy 3 J
Reference – reference specimen with low impact damage of 3 J

Table III Tensile properties for reference materials

Material	Yield stress (MPa)	Ultimate stress(MPa)	Elongation to failure (%)
6063 T6	**172**	**207**	**13**

III. RESULTS AND DISCUSSION

Reference material

The tensile properties of the reference specimen are listed in table III. A drop in mechanical properties is measured after corrosion and damage. The degradation in mechanical properties due to corrosion along with damage is more.

Tensile behaviour after exposure to corrosion

Fig 1 displays the tensile property degradation of aluminium alloy 6063 for the sea water immersion corrosion test. They are compared with the reference data table III. The tensile property tends to decrease due to corrosion. The reduction in ultimate and yield tensile stress due to sea water is gradual. Mechanical degradation can be related to the initiation of corrosion defects which evolute and lead to early failure of the material [11]. Possible causes of reduction can be attributed to the following events:

1. Due to stress corrosion, there occurs strength reduction
2. Due to the chemical reaction with the solution, the corrosion took place results in strength decrement
3. Increased duration of immersion in solution accelerates mechanical property degradation

Influence of time

The ultimate and tensile stresses tend to decrease with time. The influence of corrosion on the material increases with time. As the time increases the chemical reaction with the specimen increases and results in degradation of properties. Mechanical property degradation of the Aluminium alloy 6063 is shown in fig 2 - 5, it is evident that the corrosion attack tends to decrease ultimate tensile stress and yield stress. The effect of the corrosion process becomes appreciable with increasing exposure time in the corrosive solutions.

Influence of Damage

The mechanical properties are found to decrease gradually due to corrosion fig 1. The damage in the corroded specimen reveals further degradation in tensile properties fig 3 - 5. Corrosion may lead to cracks and small damage when loads are applied [4]. The effect on mechanical degradation properties due to corrosion assisted damage is remarkable. It may lead to the structural component failure if the damage is more. Corrosion damage leads to the degradation of the yield and ultimate stress.

IV. CONCLUSIONS

There is a gradual degradation of mechanical properties due to corrosion and corrosion assisted damage. Yield and ultimate stresses decreased permanently. There is a appreciable decrement in yield and tensile stresses when the specimens are exposed to the solution under long duration. Rate of chemical reaction varies with the exposure timing. Chemical reaction increases with exposure timing and results in little weight decrement. Weight decrement revealed corrosion took place at low rate.

Ultimate tensile strength decreases with the rate of increasing exposure duration. Corrosion assisted damage causes an appreciable reduction in mechanical properties. The lack of a quantitative correlation between accelerated laboratory corrosion tests and in-service corrosion attack or, atmospheric corrosion tests calls for additional investigation related to corrosion of aging aircrafts.

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