

Characterization of Strength of Aluminum (Al 6063-T6) After Corrosion

PK Dash^{1,*}, G Ram Vishal², Vinod L³, Mahendra MA⁴, Prashant Manvi⁵

Abstract

Aluminum are frequently used as light weight structure in various nautical design. One of them is the ship structure design where sever environment of saline water influences the damage of the structure and one among them is pitting. In this paper, an experimental verification of strength and impact of corrosion effect on Al-6063-T6 aluminum was presented. The specimens were exposed to saline water for various duration like 500 hrs, 750 hrs and 1000 hrs and tensile strength and yield strength was examined. The low velocity impact like 1 J, 2 J and 3 J were used to make the damage on the specimens. Further, specimen's residual strength was examined. Also, the strength reduction was verified through a mathematical formulation developed on the basis of residual strength model. The environmental exposed specimen's data are compared with without exposed specimens and influence of environments are scaled. The theoretical results are almost matched with experimental results only with a difference of 2% approximately All observed results are presented in tables and figures for compared.

Keywords: Corrosion, Tensile strength, Residual Strength, Potential Difference, Influence time.

INTRODUCTION

Aluminum is dominated for long duration as a prime material in most of the light weight design like aerospace structural design, marine ship hull design, locomotive design etc. From age of duralumin to new modern high performance graded aluminum materials has caused a tremendous impact over design. It has found its application on fuselage, wings and all other associated components and all other associated structures and components in aircraft design and successfully put its importance in commercial and cargo air craft used in military. The cost of fabrication, design skill, evaluated performance properties, and recognized production methods and well developed facilities, are some of the attributions for continued confidence in aluminum alloys. These also ensure their application in significant quantities for light weight design especially in aerospace and ship structure.

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Corrosion presents a serious cause of structural degradation in aging aircrafts. The Corrosion has severe effects over the materials and discloses problems like different types of damages like micro to macro crack development over the materials. Different international organization arranged conferences and forms the inspection committees for evaluation related to corrosion effect damage. Mostly affected materials are in aircraft and ship which faces adverse environments during their operation. Corrosion-induced structural degradation data are usually limited to those obtained under accelerated laboratory conditions corresponding to out-door or marine environments. Through the data, the corrosion vulnerability of Aluminum is investigated by evaluation of weight reduction and

mapping the complexity and kind of corrosion attack. In aluminum the corrosion effect happened through oxidation process and reduction of strength has been reported. One of the leading process is pitting. Sometime fungus effect also so severe that it reduces the material strength to very low values. Exposing to various corrosive environment requires monitoring and proper evaluation. Number of test method has been used by researchers and out of that energy density determination or mechanical properties evaluation are some of the testing process.

Research should be conducted based on the facts and authenticity of a resource that has been recognized. So far a wide spread research findings are reported in journals, conference or open forum discussion as aluminum is a lightest metal with high strength and has been used suitably on design of light weight structures namely aerospace, automobile, marine, chemical, production, civil and mechanical construction. Attraction is more towards aluminum because of machinability, accountable mechanical properties, high durability and easy to handle. They also possess excellent damage tolerance.

Numerous committees and international conferences have been organized to contemplate the problem of material strength in aged aircrafts and ship structures, which are the most significant issues is "corrosion". From cited literatures it reveals that the normal sea water and with additional conditions like temperature salinity percentage and exposure duration the oxidation percentage is increased which tends towards the reduction of the mechanical properties of the materials [1, 2, 3, 4]. Also, the mechanical behavior like tensile, compressive, shear, fatigue and wear resistance are subject theme of research before selecting the material for design [5, 6, 7, 8, 9, 10, 11, 12]. In some cases, both properties and environments are simultaneously investigated to know the accelerated damage of the materials of aluminum family [13, 14]. Including to above conditions, now the popularity is focused on aluminum metal matrix composite, which has been found wide application in aerospace and transportation industry [15, 16, 17, 18]. Presently, sizable research are focused to computational and analytical evaluation of corrosion damage in usable aluminum alloys [19, 20, 21, 22, 23]. Including to corrosion, role of temperature also an influential parameter on applicability of aluminum as an aerospace design material and vigorously studied by number of researchers [24, 25, 26, 27, 28]. The interference of corrosion with time periods and with damage has shown some extended cracking either it is single, or it is multiple cracking developments which are the cause of some catastrophic failure in structures. Present work is carried out about the effect of saline water in mechanical properties of Aircraft graded aluminum alloy (6063-T6) after different duration of exposure. The results are analyzed and presented through figures and tables.

Corrosion

Corrosion engineering is a specialist in disseminating information, while many oxidation-reduction (redox) reactions are extremely important and beneficial and the redox reactions involved in corrosion are in form of destructive. In this process, the metal usually donates the electrons and oxidized, while the passive part gains electrons, becoming reduced and named as oxidation-reduction (redox) reaction. For corrosion to occur three conditions should occur simultaneously.

- The anodized effect
- An electron conductor between the anode and cathode.
- An electrolyte.

The corrosion impact on aircraft is related to following factors:

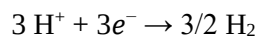
- Miss matching of materials at components design like aluminum spar attached to composite skin
- The metal fasteners used in skin to the spars.
- Exposure to hot and cold environments at saline locality like inside the sea (Sea planes) or near to the sea exposed area.
- Except to above causes, there is some time favorable anode cathode followed in design criteria as required weight, acceptable strength and operational performance.

- Sometime sealant and metal reaction extend the corrosion on used body which generally depends on coatings and sealants
- All above causes have extended to various forms of corrosion.

Engineers often take their specific environment into effect and try to understand the types of possible corrosion when designing metal components and structures. There are several types of corrosion, depending on the metal, corrosive agent, geometry, and environment so as *general corrosion, pitting galvanic stress, crevice, inter-granular, filiform, exfoliation, cavitation, erosion, microbiological, etc.* The Corrosion Products in general form are $2\text{Al} + 6\text{H}_2\text{O} \rightarrow 2\text{Al}(\text{OH})_3 + 3\text{H}_2$ and the corrosion product is aluminum hydroxide $\text{Al}(\text{OH})_3$, commonly called alumina. After calcination at 1000°C , the mass loss can reach 60%.

TESTING METHODS

Corrosion behavior of metal or alloys are related to their variable use conditions which in other ways affected the mechanical properties and strength of the materials. Before design it necessary to be analyzed and proper space on the design should be given. Corrosion behavior varies with respect to its usability, service conditions and some more environmental encounter and also varies in categories. Testing methods for identifying corrosion effects are varied like volume losses due to reaction with medium and hydrogen losses, weight changes and salt spray testing, etc. The standard testing media should be followed during testing and solution should strictly adhere to standard practice been used by other researchers. Also as corrosion requires time and some cases it requires so much time to start and purely depend on solubility medium, metal's affinity for reaction, and shape of corrosion and history. Laboratory method are simulated as par required conditions of application. Special precaution on measurement are followed for assessing the corrosion effects. Most cases the brine solution has been used as the medium which followed in this paper. A reaction mechanism of aluminum is shown below:



Also, the weight loss or gain is one of the parameter for corrosion test method. All the specimens are initially weighed and then exposed to environments. Only uniformity is noted with respect to volume of hydrogen release from test specimens.

Again, changes in mechanical properties can be accumulated for validation of corrosion. Prepared specimens are under gone for mechanical properties evaluation before and after exposing to corrosive environments. Residual stiffness degradation method is followed to evaluate the strength degradation. The residual strength of the damaged specimens can be found out by the residual stiffness degradation methods. The formula to find the residual strength is as follows.

The ratio of residual stiffness to the initial stiffness can be expressed as

$$\frac{E_r}{E_0} = 1 - \frac{\Delta E_C}{E_{C0}} \quad (1)$$

Where

$$\Delta E_C = E_{C0} - E_r \text{ and } E_{C0} = E_0$$

Elastic modulus degradation can be expressed a

$$\frac{\Delta E_C}{E_{C0}} = \frac{\Delta S}{S_0} \quad (2)$$

Expressing $\frac{\Delta S}{S_0}$ in terms of stress the

$$\frac{\sigma_r}{\sigma_u} = 1 - \frac{\Delta E}{E_0} \quad (3)$$

Converting in terms of modulus degradation, then

$$\frac{\sigma_r}{\sigma_u} = \frac{\Delta E_{range}}{E_0} = \frac{E_r}{E_0} \quad (4)$$

Where

$$\Delta E_{Range} = E_0 - E_r$$

$$E_r = \left(\frac{\sigma_r}{\sigma_u} \right) E_0 \quad (5)$$

$$\Delta S = \left(1 - \frac{E_r}{E_0} \right) S_0 \quad (6)$$

$$\Delta \sigma = \frac{\Delta S}{Area} \quad (7)$$

$$\sigma_r = \sigma_u - \Delta \sigma \quad (8)$$

Where σ_r = residual strength

Experiments

In this research, the following method has been used for experimental verification of corrosion related degradation of Al 6053-T6 material.

Specimen Preparation

Materials

Aluminum alloy 6063–T6 was used in this study. The properties of the aluminum alloy are given in Tables 1 to 4 for reference. The 6063 alloy is heat treatable, and have moderately high strength coupled with good corrosion resistance. The unique feature of this material is easy to weld, extrude and molded to design requirements. So, the materials have wide application in aircraft structures like fuselages, wings and surface design of homebuilt aircraft instead of defense or commercial applications.

Table 1. Chemical composition (wt%) of aluminum alloy 6063:

Composition	Al	Cu	Cr	Fe	Mg	Mn	Si	Ti	Zn	Sn
Weight %	98.268	0.166	0.17	0.491	0.370	0.068	0.442	0.015	0.129	0.053

Table 2. Physical properties of aluminum alloy 6063

Physical properties	Metric	English
Density	2.7 g/cc	0.0975 lb/in ³

Table 3. Mechanical Properties of aluminum alloy 6063

Mechanical Properties	Metric	FPS	Ultimate bearing strength	434 MPa	62900
Hardness, Brinell	73	73	Bearing yield strength	276 MPa	40000
Hardness, Knoop	96	96	Poisson's ratio	0.33	0.33
Hardness, Vickers	83	83	Fatigue strength	68.9 MPa	10000
Ultimate tensile strength	241 MPa	35000	Machinability	50%	50%
Tensile yield strength	214 MPa	31000	Shear modulus	25.8 GPa	3740
Elongation at break	12%	12%	Shear strength	152 MPa	22000
Modulus of elasticity	68.9 GPa	10000 ksi			

Table 4. Electrical properties of aluminum alloy 606

Electrical properties	metric	English
Electrical resistivity	3.32 e-006 ohm-cm	3.32e-006 ohm-cm

Homogeneity Check-up

The specimens prepared by above process were undergone through homogeneity check-up. In this, the dimension of the specimens, edges of the specimens and orientation of the specimens were properly checked. Also, the thickness of the specimens was kept constant throughout the surface for the entire program, if any variations are found the specimen were rejected before testing.

Chemical Composition Test

Chemical composition test was conducted to identify the alloying elements. The result revealed the number of alloying elements and ensured the alloy was aluminum alloy 6063.

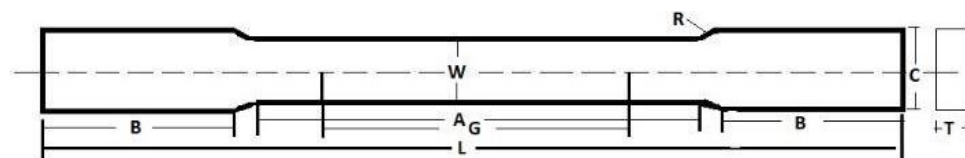
Specimen Preparation

A simple cutting machine was used for the shaping of the specimens. The ASTM standard B 557-M has been followed on tensile specimen preparation. The specimen dimensions and specimen configurations are shown in Figure 1. The cross-sectional area of the specimen was smallest at the center of the reduced section to ensure fracture within in the gauge length, A small taper was permitted in the reduced section of each of the specimens for this reason.

After proper verification of the specimens, the all specimens are examined in two sub groups as virgin samples and environmental treated samples.

Environmental Exposure

Two different solutions used for environmental exposure and details are explained in following paragraphs.



Where,
 L-overall length-200 mm
 A-length of reduced section-57 mm
 B-length of grip section-50 mm
 C-width of grip section-20 mm
 G-gage length-50 mm
 W-width-12.5 mm
 T-thickness-6 mm
 R-radius of fillet-2.5 mm

Figure 1. Dimensions of Tensile Specimens.

Solution 1

Solution 1 was prepared by dissolving the following salts: 3889.0 g (555.6 g/L) of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 405.6 g (57.9 g/L) of CaCl_2 (anhydrous) and 14.8 g (2.1 g/L) $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$. In water above mentioned solution is mixed for preparing solution I. A diluted mixer is kept in a container with evaporation protection.

Solution 1I

The Solution 2 was prepared by dissolving the following salts. 486.2 g (69.5 g/L) of KCl, 140.7 g (20.1 g/L) of NaHCO_3 , 70.4 g (10.0 g/L) of KBr, 19.0 g (2.7 g/L) of H_3BO_3 , and 2.1 g (0.3 g/L) NaF in water and was diluted to a total Volume of 7.0 L. This was stored in well stoppered glass containers.

Sea Water Preparation: The substitute sea water was prepared by the following procedure. In a container with 9L of water, the composition of 245.34 g of sodium chloride and 40.94 g of anhydrous sodium sulphate was dissolved with the above solution, 200 mL of solution 1 was added slowly and followed with vigorous stirring. Then 100 mL of solution 2 was also added. The above mixture is diluted in 10-liter normal water. The pH of the solution is maintained to 8.2 by addition of 0.1 N Sodium Hydroxide mixture. The specimen was immersed in the substitute ocean water for different duration (500, 750 and 1000 hours). The environmental exposed specimen and without environmental effected specimens are kept separately and shown in Figure 2.



Figure 2. Aluminum alloy 6063 tensile test specimen without damage.

Corrosion Test: To overcome the effect of the high ionic strength of the ocean water, the standards are made with artificial ocean water that does not contain any fluoride, to match the background of the samples. Accordance to ASTM D1141-98, the specimen preparation, testing procedure are strictly followed. The entire process is followed for preparation of the solution similar to sea water with significant concentration of inorganic salts with proper percentage and the standard is maintained with mean value because of concentration of salinity variation at different location of ocean bed. Thus the gross concentration is taken as equivalent concentration of sea. The details of sea water preparation are explained below.

Tensile Test

All the tensile properties are evaluated using a servo hydraulic Universal testing machine with capacity 20000 kg hydraulic driven machine with proper follow up of ASTM standard. Ultimate tensile strength and stress-strain values were determined through failure of sample. The specimens are prepared referring ASTM B557-10. The specimens are grouped into two categories, i.e., without environmental exposure as called virgin and with environmental exposure as called corroded specimens. The exposure of specimens to corrosive environments (saline water) are strictly restricted to fixed duration. The specimens are shown in Figure 2, 3 and 4. The specimens were fixed at top and bottom end of the fixtures of the machine. Gradually load was applied as testing recommendation of ASTM Standard until the sample was failed into two parts. The test series included the following data. 1. The tensile data for virgin specimens without environmental exposure as the reference data, 2. Tensile data for environmental exposed specimens after schedule exposure to saline environments, 3. Impact test data for test specimens under 1 J, 2 J and 3 J impact damage and residual tensile strength after above impact damage, 4. Tensile data for corroded specimens with impact damage of 1 J, 2 J and 3 J and residual tensile strength after corrosion with impact damage and 5. Effect of corrosive damage on other tensile properties after and before impact damage of specimens.



Figure 3. Aluminum alloy 6063 tensile test specimen with 1J damage.



Figure 4. Aluminum alloy 6063 tensile test specimen with 2J damage.

All above findings are concentrated for determination of stress strain value, as well as characteristic parameters like ultimate tensile strength, Poisson's ratio, elastic modulus and differential of original strength with respect to corrosive strength. Tables and figures of above measurements are shown for ready reference.

Drop Impact Test

Drop Impact test was preferred to make low energy impact damage on the specimen. A low impact damage is selected with 1 J, 2 J and 3 J values. A pendulum with 1 kg wt. is dropped from rest and impact value was estimated using formula:

$$PE = mgh$$

Dropping of the mass upon the specimen created a low energy impact damage. The damaged specimen is shown in the Figures 3 and 4.

Corrosion Monitoring

An indigenous developed method, i.e., the *Potential difference method* was used for corrosion study. This is one of the method to know the level of corrosion in the corroded material. The discontinuities produced in the material due to corrosion resists in the current flow were monitored on the material. The discontinuities due to corrosion establishes a potential difference. The potential difference is compared between the virgin specimen and the corroded specimen and the rate of corrosion was calculated.

RESULTS AND DISCUSSION

The corrosion behavior of aluminum alloy in sea water was discussed and results were analyzed. The effect of damage along with the corrosion and exposure duration were studied. The results and discussions are as followed.

A systematic way of evaluation of material original strength, effect of impact damage and damage due to corrosive environment (saline water) are carried out in present work. Gradual decrement in tensile properties due to corrosion is found. Though cited literature noted that there is reasonable influence of corrosion in aluminum material but current study reported the sizable reduction on mechanical strength of material after exposed to above mentioned environments. The detail tensile properties are mentioned in Tables 1–4 before exposed to corrosive environments. In Table 5, and in Figures from 5–23 all observations are noted about the corrosion rated degradation of Al-6063.

Table 5. Tensile Properties of Al 6063 Aluminum alloy after different hours of Saline Environment Exposure.

Types of Specimens	Virgin (0 hrs)	500 hrs exposed	750 hrs exposed	1000 hrs exposed
Yield Strength (MPa)	147.662	143.65	139.34	137.56
Ultimate Strength (MPa)	196.27	190.733	186.56	184.75

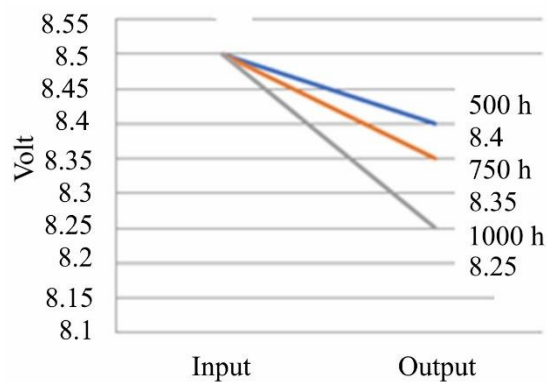


Figure 5. Potential Difference of Corroded Specimen.

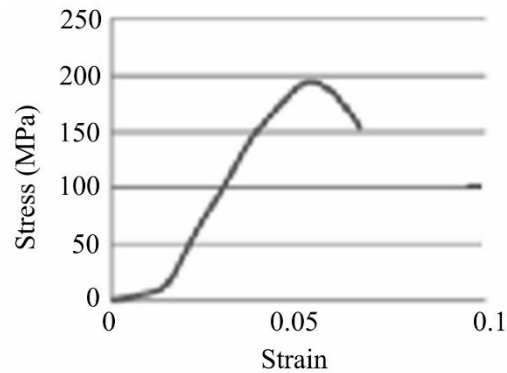


Figure 6. Stress-strain diagram for the virgin specimen.

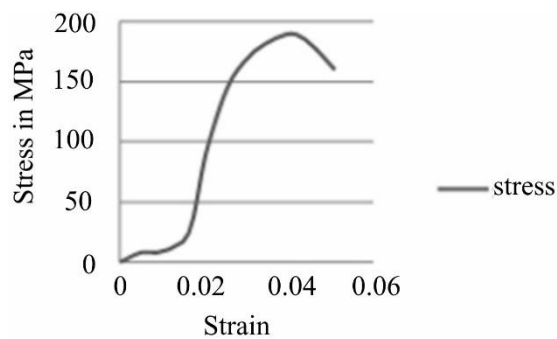


Figure 7. Stress strain diagram of corroded specimen after 500 hours duration.

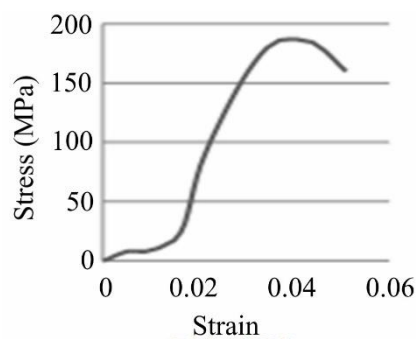


Figure 8. Stress strain diagram of corroded specimen after 750 hours.

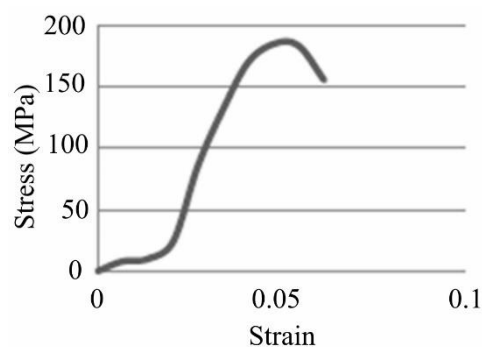


Figure 9. Stress-strain diagram of corroded specimen after 1000 hrs duration.

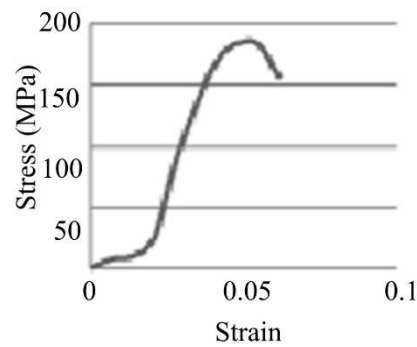


Figure 10. Stress strain diagram of virgin specimen with 1J impact damage.

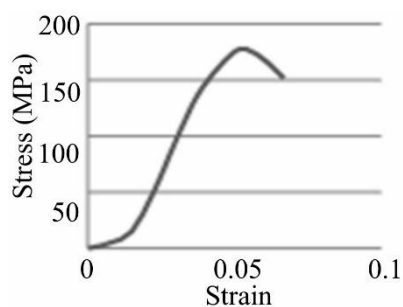


Figure 11. Stress-strain diagram of virgin Specimen with 2J Impact Damage.

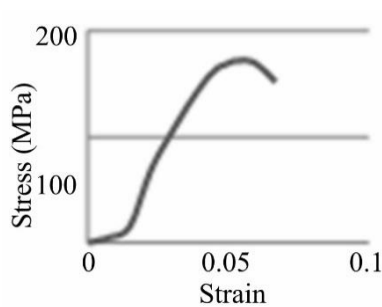


Figure 12. Stress-strain diagram of virgin specimen with 3J impact damage.

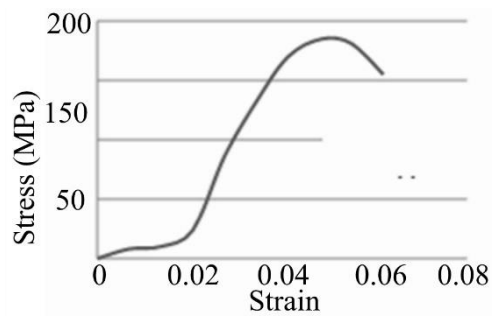


Figure 13. Stress-strain diagram of corroded specimen with 1J impact damage after 500 hours duration.

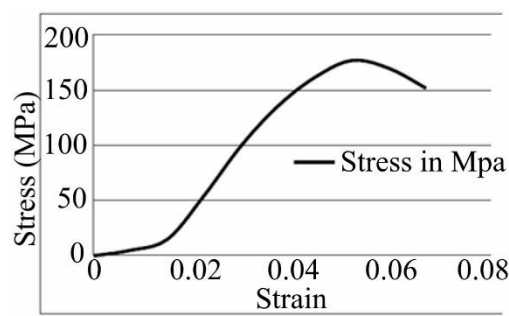


Figure 14. Stress-strain diagram of corroded specimen with 2J impact damage after 500 hours duration.

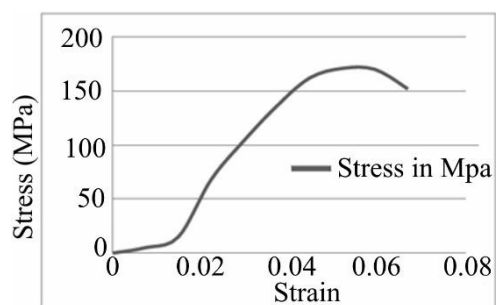


Figure 15. Stress-strain diagram of corroded specimen with 3J impact damage after 500 hours duration.

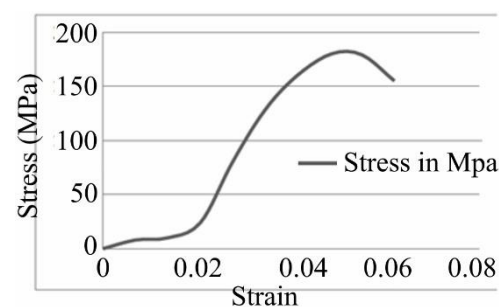


Figure 16. Stress-strain diagram of corroded specimen with 1J impact damage after 750 hours duration.

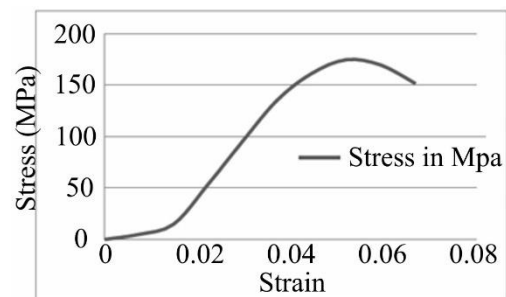


Figure 17. Stress-strain diagram of corroded specimen with 2J impact damage after 750 hours duration.

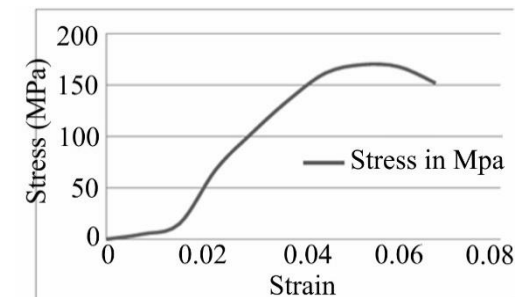


Figure 18. Stress-strain diagram of corroded specimen with 3J impact damage after 750 hours duration.

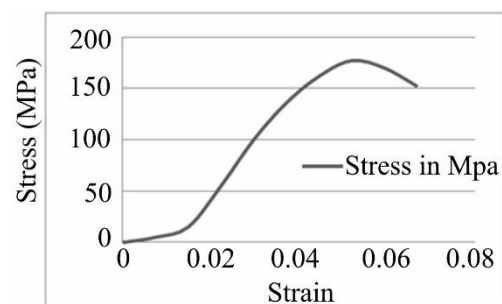


Figure 19. Stress-strain diagram of corroded specimen with 1J impact damage after 1000 hours duration.

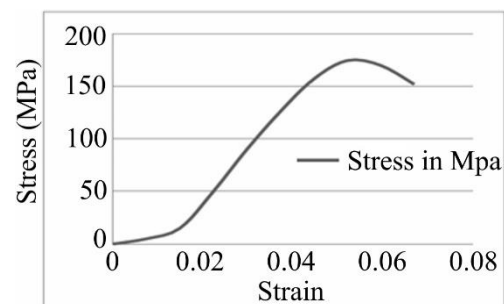


Figure 20. Stress-strain diagram of corroded specimen with 2J impact damage after 1000 hours duration.

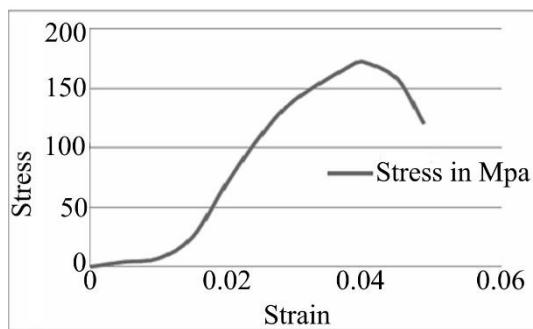


Figure 21. Stress-strain diagram of corroded specimen with 3J impact damage after 1000 hours duration.

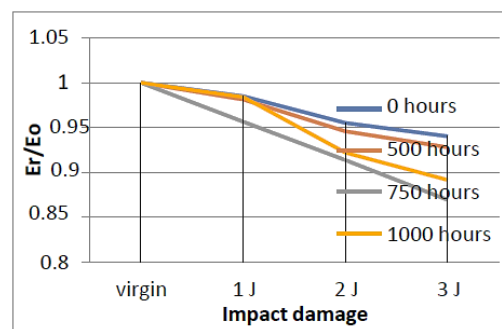


Figure 22. Ratio of tensile modulus after damage for virgin and corroded specimens.

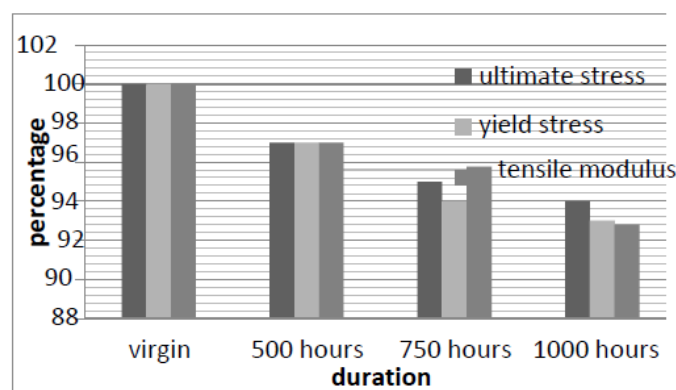


Figure 23. Comparison of tensile properties of virgin and corroded specimen.

Tensile Properties

The stress strain data of corroded specimens are obtained and compared with virgin samples. The impact properties are obtained and a residual model is formulated for the evaluation. It is found that the material is slightly prone to environmental assisted strength reduction and more effective if it is exposed in some saver corrosive environments. Notable cause of material strength reduction is scaled in following headings.

- Stress corrosion,
- Chemical effects of the environments, and
- Duration of exposure.

All these properties are evaluated in form of stress-strain reduction, yield and ultimate strength decrees and elastic modulus changes. There is a gradual decrease in the tensile behavior of aluminum alloy 6063 due to corrosion. Weight loss measurement shows a very little amount of weight decrement which ensured that the corrosion took place at a very low rate. Due to the slow rate of corrosion the mechanical properties of the aluminum alloy decreased slowly. It revealed that the corrosion resistance of the aluminum alloy in the sea water environment is good.

Influence of Time

The time of exposure of the material is another impact parameter on degradation of material strength and durability. The material response to corrosive environment has been noticed. A time rate on effect of strength degradation has been carried out and noted that the strength reduction is completely a phenomena of duration of exposure. The detail of experimental results are presented in Table 6 and Figures 22 and 23. Also Table 7 highlights the effect of comparative reduction of aluminum ultimate strength with respect to virgin sample. It indicates that the corrosive exposure duration is also a parametric effect on total strength reduction. Reported behavior is consistent with the experimental

observation of the progressive building of a protective oxide layer on the materials surface. In building of said film has been found to follow power time functions. The rate of effect during exposure decreases at very low rates or it totally ceases with respect to time. Drop of elongation to failure and energy density fitted well by the exponential time functions. The degradation of tensile properties due to corrosion are represented in terms of percentage in Figures 22 & 23.

Table 6. Tensile Properties of Al 6063 Aluminum after Impact Damage

Types of Specimens	Virgin			500 hrs exposed			750 hrs exposed			1000 hrs exposed		
Impact Damage (J)	1	2	3	1	2	3	1	2	3	1	2	3
Yield Strength (MPa)	140.372	136.31	134.31	134.33	132.42	131.65	132.67	131.53	129.12	130.19	128.0	126.46
Ultimate Strength (MPa)	182.36	178.341	172.075	181.53	177.21	171.43	180.31	175.28	170.83	177.34	174.57	169.67

Table 7. Comparison of residual tensile strength

Impact Damage in Joules	Virgin Residual UTS in MPa (0 hrs effect)			Residual UTS in MPa 500 hrs effect			Residual UTS in MPa 750 hrs effect			Residual UTS in MPa 1000 hrs effect		
	EXPT	Theo.	Deviation	EXPT	Theo.	Deviation	EXPT	Theo.	Deviation	EXPT	Theo.	Deviation
1	182.36	193.15	5.5	181.53	187.18	3.01	180.31	182.3	1.09	177.34	180.4	1.47
2	178.34	180.98	1.45	177.21	180.37	1.75	175.28	174.56	0.05	174.57	174.89	0.05
3	172.07	175.03	1.7	171.43	176.99	3.15	170.83	165.84	2.09	169.67	171.83	1.25

Influence of Damage

Corrosion damage is often found on metallic structural components subjected to operational conditions and loading behavior. The corrosion is more aggravated when a damage surface is exposed to it. This happens because of more exposed area and other one is reduction of resistance strength. The impact damage on material caused the degradation of mechanical properties and further reflected when exposed to saline water. A comparative view and data are shown in Table 6 and in Figures 22 and 23. It is find that the duration of exposure has aggravated the damage effects as shown in Table 7. The exposure to saline water may enter into the crack developed during the impact damage and effect to surface strength reduction. Also, it has been find that the corrosion of saline water reduce the tensile modulus and yield strength of the material and overall influence to structural integrity of the material. An electrical potential method has been used on damaged specimen to evaluate the corrosion effect and results are shown in Figure 5.

Stress-Strain Relation

A comparative stress-strain results of virgin and corroded specimens are shown in Figures 6–21. Sizable effect of corrosion has been observed in comparison to virgin sample and noted as corrosion reduce the mechanical properties of the material. The degradation of tensile properties due to corrosion effect depends on exposure to corrosion duration and corrosion rate. Tensile properties degradation depends upon the corrosion rate. As the corrosion rate is less, the tensile properties decrement is also gradual. As we increase the energy level of damage the curve shows slight non-linearity.

The first linear region of the diagram is referred to the uncracked-elastic range of behavior. The slope of this portion of the diagram is known as the uncracked flexural stiffness, and is the product of the modulus of elasticity of the specimen and the gross moment of inertia ($E_c \cdot I_g$).

The second linear region is the cracked-elastic range of behavior. When damage occurs, the contribution of the specimen in the tension zone is greatly reduced, thus resulting in a shallower slope

of the diagram. The slope of this region is referred to as the cracked flexural stiffness, and is defined as the product of the modulus of elasticity of the concrete and the effective moment of inertia ($E_c \cdot I_e$). The two linear portions of the moment-curvature diagrams are not strongly dependent on the properties of the specimen. When we compare the elastic modulus of the specimens before and after corrosion, it shows a gradual decrement in tensile modulus due to corrosion, Figure 22.

The final (post yield) portion of the moment-curvature, Figure 6 to Figure 21 is characterized by nonlinear behavior with large deflections and little or no increase in moment. In this range, the specimen is considered to have structurally failed after the initial yielding of the specimen. The flexural behavior of the specimen in this loading range is highly dependent on the properties of the specimen, namely the yield strength and ultimate strength. The ductility of a flexural member is also affected by the properties of the specimen. curvature ductility is the ability of a flexural member to deflect (i.e. energy dissipation) before experiencing failure, and can be determined by comparing the curvature at yield to the curvature at rupture.

In contrast, there does appear to be a correlation between the yield strength of the specimen and curvature ductility of the beam. It is apparent that the higher the yield strength of the reinforcing bar, the less ductile the beam. The high yield strength of the specimen results in higher stresses. The result is that the specimen without corrosion undergoes large strain and fails in compression before the specimen is able to undergo significant plastic deformation (i.e. energy dissipation).

Potential Difference and Corrosion Effect

After the corrosion the direct current was applied through the specimens to study the corrosion effects. There established a potential difference in the specimens due to this direct current. The established potential difference on the corroded specimens were measured. This is shown in Figure 5. Effect of corrosion changes the material integrity and resistance properties of aluminum material character. Resistance due to the disintegration of molecules differs for different duration. The Voltage drop is measured very small after the corrosion of different duration. The corrosion rate is slow for currently tested material in sea water and attribute to less effective in potential properties as observed in tested duration. Due to this slow rate of corrosion, there appears a gradual decrement in tensile properties of the aluminum alloy.

Residual Strength Degradation Method

Residual stiffness degradation method predicts the residual strength through formulae given in. The residual strength decrement was found through this formula and also experimentally. The calculated deviation of the result in both the ways are tabulated in Table 7. The deviation is very less as observed in Figures 22 & 23.

CONCLUSION

Based on the experimental observation, the following conclusions are drawn.

- The reduction in mechanical properties due to corrosion and corrosion assisted damage is found to be significant. It is noted that the corrosion lowers the mechanical properties and it varies with the duration of immersion.
- The corrosion in a sea water atmosphere occurs very gradually. Corrosion induced degradation of mechanical properties occur gradually.
- Yield and ultimate tensile stress decreased permanently at a decreased rate. Tensile ductility decreases exponentially to extremely low values.
- There is a appreciable decrement in yield and tensile stresses when the specimens are exposed to the solution under long duration.
- Chemical reaction increases with exposure timing and results in little weight decrement. Weight decrement revealed corrosion took place at low rate.

- Corrosion assisted damage causes an appreciable reduction in mechanical properties. Ultimate tensile strength decreases with increasing damage.
- Potential difference between the two ends of the specimen ensures the corrosion of the material. Potential difference between the virgin and corroded specimens shows the corrosion took place at a slow rate.
- The weight loss tests revealed that the alloy exhibited a low corrosion rate, indicating the beneficial use of this alloy in marine environment.
- Established potential difference of the corroded specimen was less. It revealed the corrosion took place at a slow rate. It also revealed that the tensile properties degradation due to corrosion also gradual.

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