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On Mechanical Response of Aluminum Alloys in Corrosive Environment

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Abstract: Al6061T6 and Al7075T6 aluminum alloys are subjected to accelerated salt spray corrosion to evaluate the amount of degradation and the effect on mechanical behavior. The specimens were stored in a closed chamber with continuous salt spray for a period of 250 hours and 500 hours, respectively. It was observed that the oxide layer was unprotective after prolonged salt spray resulting in pitting continued with exfoliation corrosion. The tensile test results show that there was a remarkable decrease in tensile properties with exposure time. A significant reduction in tensile strength, yield strength, elongation at yield, elongation at break, and overall toughness in both the alloys was observed at 500 hours. The impact strength decreased by 14.4 % and 26.47 %, Rockwell hardness (HRB) reduced by 12.2% and 20.71% for respective alloys at 500 hours of exposure. However, there was an increasing trend in elastic stiffness which attributed to decrease in ductility. Furthermore, it was comparatively observed that Al7075T6 is more susceptible to corrosion than Al6061T6.

Keywords: Aluminum alloys, pitting, corrosion, mechanical properties

1. Introduction

The advancement in technology in aircraft, spacecraft, rockets, hydrospace vehicles has motivated us to use high-strength aluminum alloys as the prime material. The metallurgical properties such as dispersion and precipitation, excellent stiffness to weight, and strength to weight ratio are the key strengths of aluminum alloys in designing advanced structures [1]. 7xxx and 6xxx series aluminum alloys are the two categories applicable in automobiles, systems, aviation,

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transportation in railways, and marine vehicles. The prime alloying elements of Al7075 are Zn, Mg, and Cu, responsible for exceptional strength, ductility, and strength. Based on the heat treatment processes, Al7075 are available as T651, T6, T73, T7351. Al7075T6 is precipitation hardened with improved strength and machinability promoting its applicability in the automotive, construction, and aerospace manufacturing industries. However, the alloy is more susceptible to pitting and film-form corrosion. Researchers have reported intergranular corrosion embrittlement of Al7075. The key alloying elements of Al6061T6 are Mg, Si, and Cu which enhance its weldability and resistance to corrosion promote its application in transportation, construction, and sports [2 - 6]. Though Al6061T6 is corrosion-resistant, its prolonged use in adverse environmental conditions such as in carbon enriched fuel tanks and marine applications leads to weakening of the passive layers resulting in pitting corrosion or crevice corrosion [7]. These hardened aluminum alloys' precipitations are also prone to stress corrosion and intergranular cracking that leads to deterioration of their mechanical properties, resulting in premature failure of materials [8,9]. Various studies were conducted to investigate the effect of hydrogen embrittlement due to corrosion on the mechanical performance of aluminum alloys [10-31]. The results reveal that degradation in performance of the high strength materials occurs when exposed to aggressive environments. Investigation of natural corrosion in aluminum alloys is a quite lengthy process. To investigate the effect of corrosion on the mechanical behavior of aluminum alloys a specific corrosion technique known as the salt spray is utilized. The literature [15, 17, 23] reveals that corrosion significantly affects the mechanical properties of high-strength aluminum alloys. The present study aims to characterize the degradation behavior of Al7075T6 and Al6061T6 as a consequence of continuous salt spray exposure on tensile, hardness, and impact behavior.

2. Experimental Program

2.1. Materials and Methods

In order to investigate the effect of corrosion Al7075T6 and Al6061T6 aluminum alloys were provided by Aditya Birla Co. India. The chemical composition in wt. % is presented in Table 1.

Table 1 - Chemical formulation of aluminum alloys in wt.%

	Zn	Mg	Cu	Fe	Si	Mn	Cr	Ti	Al
Al7075T6	5.43	2.52	1.62	0.4	0.34	0.09	0.24	0.02	remaining
Al6061T6	0.08	0.96	0.32	0.45	0.6	0.12	0.25	0.04	remaining

The aluminum alloys were purchased in the form of circular rods of diameter 20 mm and length 500 mm and the specimens for tensile, hardness, and impact test were fabricated out of these rods. Fig 1. and Fig. 2 shows the dimensions of tensile (ASTM E8 [33]) and impact test (ASTM E23 [34]) specimens. Rockwell hardness test specimens having a diameter of 16mm and thickness of 10mm were prepared according to ASTM E18-16 [35]. A set of two specimens were utilized for each test.

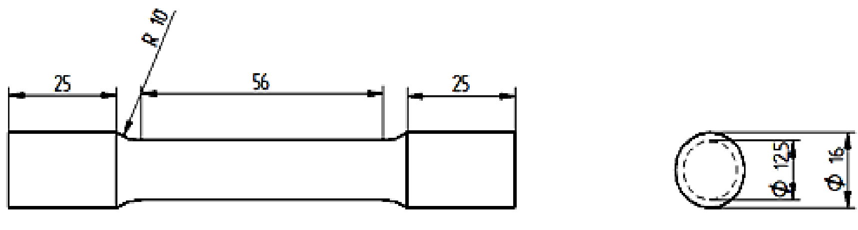

Fig. 1 - Tensile test specimen prepared following ASTM E8 (All dimensions are in mm)

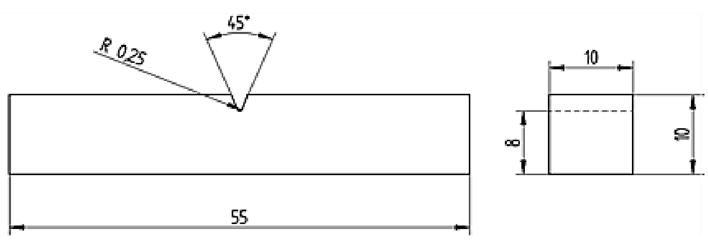

Fig. 2 - Impact test specimen prepared following ASTM E23 (All dimensions are in mm)

2.2 Accelerated Corrosion by Exposure to Salt Spray

The specimens were exposed to salt spray solution following ASTM B117 standard. The solution was prepared by mixing 5 parts (by mass) of sodium chloride (NaCl) in 80 parts of distilled water with a pH value varying between 6.5 to 7.2 at room temperature. The specimens were exposed to salt spray in a closed chamber for 250 and 500 hours at 35°C and the salt spray speed was maintained between 1.0 to 2.0 ml/hr. Specimens were regularly inspected, and corrosion growth was observed with an increased exposure time [32].

3. Results and Discussion

3.1 Tensile Test

The influence of corrosion on the mechanical behavior of Al6061T6 and Al7075T6 is investigated. The stress-strain curves of degraded and as-received specimens obtained by the uniaxial tensile test are presented in Fig. 3. The magnitude of Young's modulus, modulus of resilience, ultimate tensile strength, yield strength, elongation at yield and break, and overall toughness were obtained from the tensile test to examine the deterioration effect caused by salt spray exposure. The variation in Young's modulus for both the alloys is shown in Fig. 4.

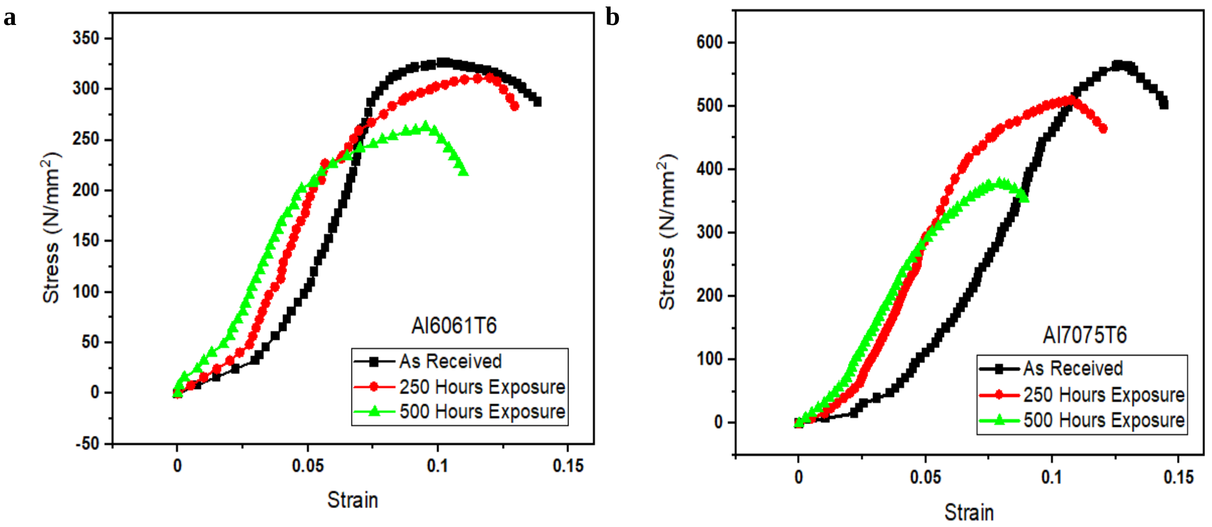

Fig. 3 - (a) Engineering stress-strain plot of (a) All6061T6; (b) Al7075T6

It is interesting to note that the stiffness (Youngs Modulus) of the aluminum alloys is increasing with an increase in the duration of corrosion. 24% and 14% of in growth are observed for 500 hours of exposure for Al6061 and Al7075, respectively. The increase in stiffness in the elastic region can be attributed to hydrogen embrittlement manifestation [29]. Yield strength (at 0.2% strain) and tensile strength were computed with respect to the specimens' nominal cross-sectional area. The gradual decrease of yield and tensile strength was observed in Al6061, whereas a sharp decrease was noticed in Al7075 after 250 hours of exposure. With the increase in exposure durations, an increase in corrosion and loss of strength in terms of tensile ductility can be observed. The decrease in strength is the consequence of mass loss due to pitting and exfoliation. The effect of exposure durations on yield strength is shown in Fig. 5(a) and tensile strength is presented in Fig. 5(b). In both the alloys it is observed that tensile strength and yield strength decrease significantly as a function of exposure time. However, it is to be noted that, Al7075 deteriorates drastically, showing a nonlinear trend after 250 hours of corrosion compared with Al6061, which offers almost a linear variation (Fig. 5).

The transformation in elongation at yield and elongation at break as a function of exposure time is presented in Fig. 6(a) and 6(b). It is evident that the ductility decreases significantly with an increase in the duration of exposure, demonstrating their susceptibility to accelerated corrosion. The amount of energy absorbed, which is a measure of overall toughness, was also estimated by integrating the area under stress-strain curves. A congruent decrease in ductility was observed with the exposure time as shown in Fig. 7(a). The overall toughness decreased by 3.8% and 27.07% for Al6061T6, and for Al7075T6, the area decreased by 5.7% and 48.5% for a respective exposure duration of 250 and 500 hours. The modulus of resilience, which is the measure of elastic strain energy, was also calculated, and the values are shown in Fig.7 - (b). There was a decreasing trend observed in both cases attributed to a decrease in energy absorption with exposure time. The retention of mechanical property as reported in Table 2 is estimated as $R = R_a/R_o$, where R_o corresponds to a value of the as-received sample and R_a represents the value after exposure. The stress and strain ratios have a decreasing trend representing the deterioration of the alloys' strength and ductility, whereas the Young Modulus increases by 24% and 14% for Al6061T6 and Al7075T6, showing the increase in stiffness before yield. The decrease in ductility and increase in stiffness is due to the absorption of hydrogen with an aggressive salt attack known as hydrogen embrittlement resulting in exfoliating corrosion [29].

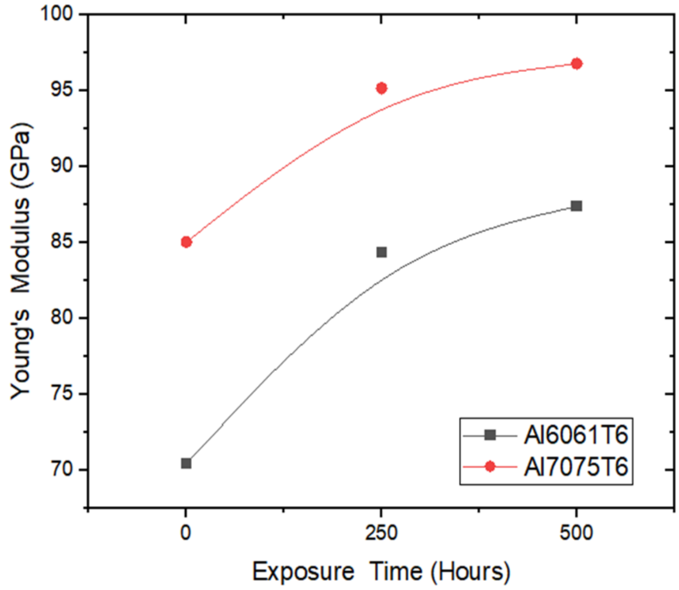

Fig. 4. Evolution of Young's Modulus with exposure time

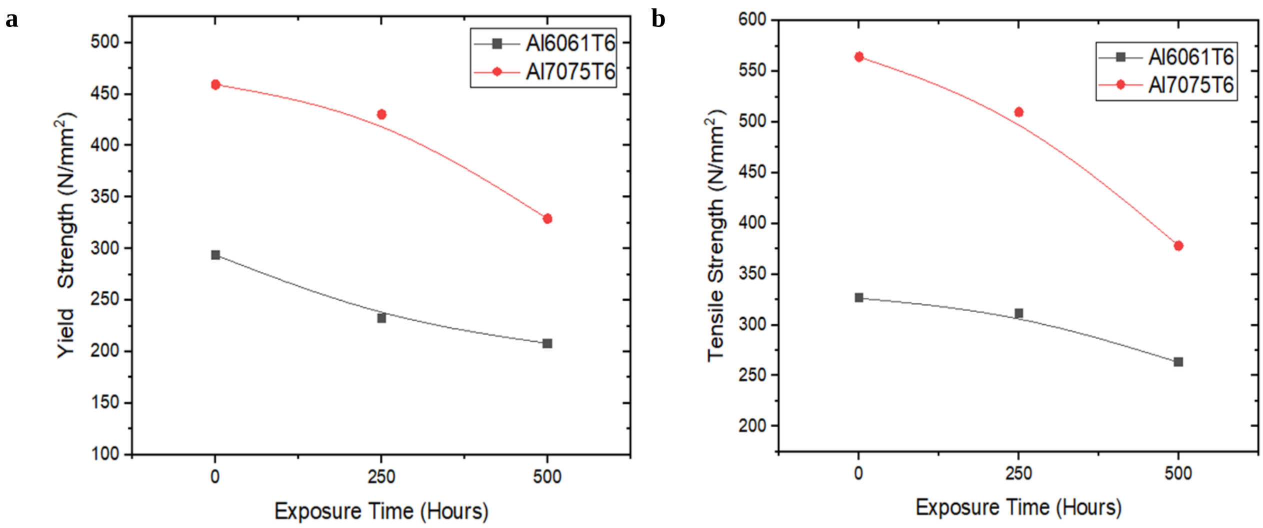

Fig. 5 - (a) Transformation in yield strength as a function of exposure durations; (b) Transformation in tensile strength as a function of exposure durations

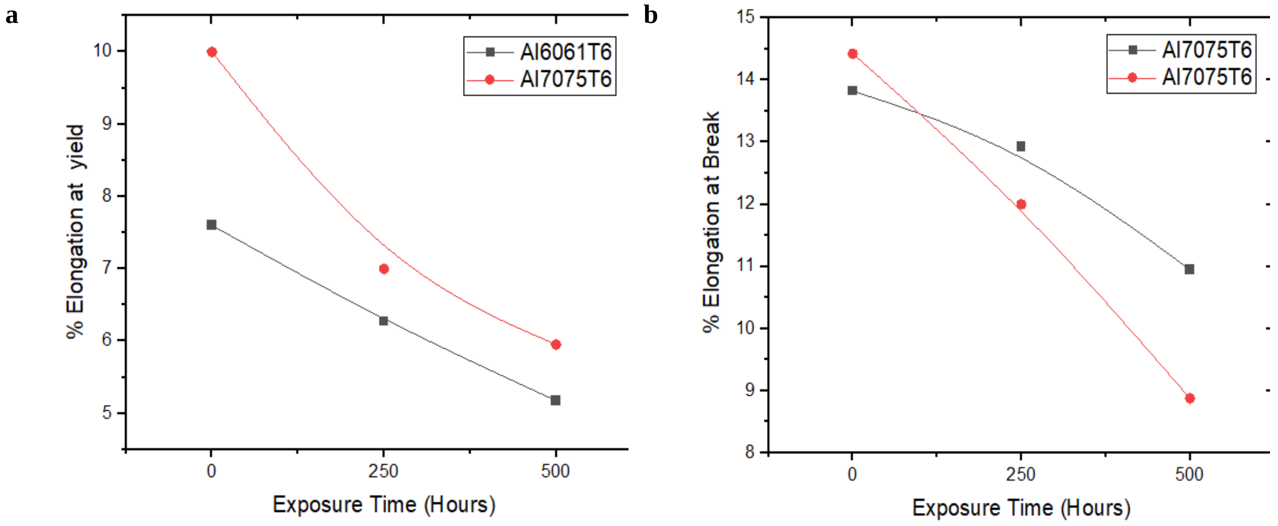

Fig. 6 - (a) Transformation in elongation at yield as a function of exposure durations; (b) Transformation in elongation at break as a function of exposure durations

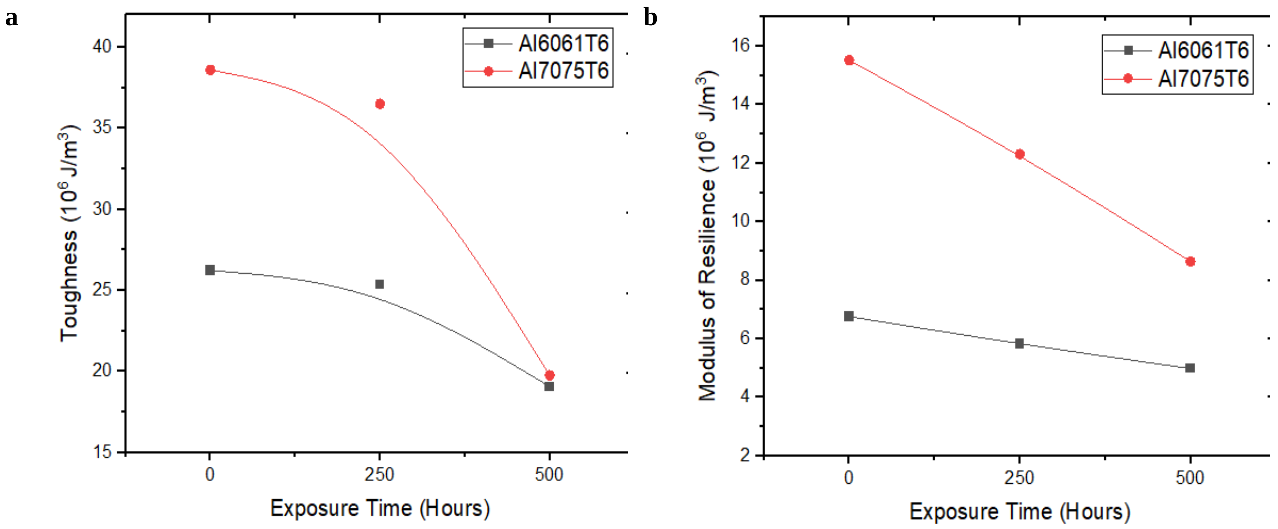

Fig. 7 - (a) Variation of Toughness with exposure time; (b) Variation of Elastic Resilience with exposure time

Table 2 - Retention of tensile properties with exposure time

Alloy	Exposure Time (Hours)	Stress at yield R_σ	Strain at yield R_ϵ	Young's Modulus R_E	Ultimate Stress Ratio R_σ	Strain at break R_ϵ	Area Under Curve R_A
	0	1	1	1	1	1	1
Al6061T6	250	0.9066	0.825	1.1976	0.9856	0.9349	0.962
	500	0.8134	0.6809	1.2411	0.7579	0.7920	0.7293
	0	1	1	1	1	1	1
Al7075T6	250	0.9389	0.7	1.1189	0.8421	0.8318	0.943
	500	0.6740	0.595	1.13815	0.6434	0.6152	0.515

3.2. Hardness Test

The Rockwell Hardness (HRB) test was done on Al6061 and Al7075 alloys to analyze the repercussion of corrosion on localized plastic deformation. The trend of variation in hardness number is represented in Fig. 8. The hardness of Al7075T6 without corrosion was 84.5 HRB, which reduced to 76.5 HRB for 250 hours and further reduced to 67HRB at 500 hours of salt spray exposure. For Al6061, the Rockwell hardness number decreased from 58.5 HRB to 54 HRB and also to 51 HRB for respective corrosion hours. The hardness decreases almost linearly as a function of exposure time. The percentage decrease in hardness of Al7075T6 at 500 hours of salt spray is 20.7%, which is considerably greater than 12.82% for Al6061T6. The reason for the increase in localized surface plastic deformation is that the extended hours of salt spray form pits on the surface that weakens the grain boundary.

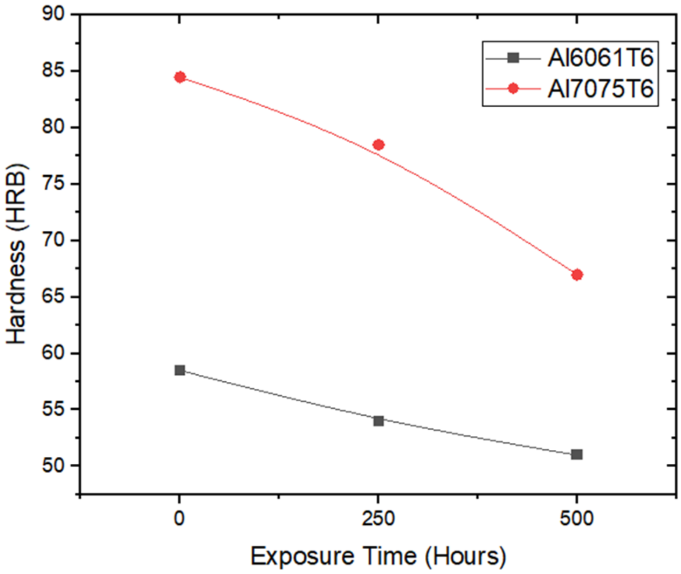

Fig. 8 - Variation of Rockwell Hardness Number (HRB) as a function of exposure time

4.2. Impact Test

The specimens of Al6061 and Al7075 for as-received samples, 250 hours, and 500 hours of corrosion exposure were tested on Charpy impact tester, and the magnitude of impact strength is shown in Fig. 9. The impact strength of Al6061 reduces by 6.8% for 250 hours of exposure and continues to decrease to 14.4% at 500 hours, whereas, for Al7075, the impact toughness deteriorates to 7.35% for 250 hours of exposure and further reduces to 26.47% for 500 hours. The decrease in impact strength correlates with the results obtained from the tensile test (Fig. 5, Fig. 6, and Fig. 7), showing a decreased decline in the material's toughness with an increase in corrosion exposure. The surface degradation after prolonged exposure results in film form corrosion and pitting corrosion, as shown in Fig. 10. Initially, the formation of white layers was observed. The continued salt spray exposure results in tiny pits that enlarge with the increase in exposure time. Both the aluminum alloys' surface is inhomogeneous with grey and white patches at 250 hours of salt spray exposure revealing the different phases of components. The grey phase would contain Al, Cu, Mn, and Si, and the white phase would include Al and Cu as major components. The difference in phases would promote pitting corrosion as indicated at 500 hours of exposure. Al7075 was degraded more with visible separation of material from the surface. The corrosion pits are formed under the surface, begin to coalescence, and propagate beneath the surface with the increase in exposure time resulting in the exfoliation of the superficial layers [29]. The corrosion process is controlled by the exfoliation of surface layers, further leading to intergranular corrosion paths. The fractography of the alloys at the edge of pits is represented in Fig. 11. It is observed that the fractured surface of uncorroded specimens is brighter and shinier, attributing to transgranular crack propagation. The fractured images at the pit edges for 250 and 500 hours of exposure are dull because of intergranular attack. The crack would initiate at corrosion pits or intergranular pre-cracks because of hydrogen embrittlement [29].

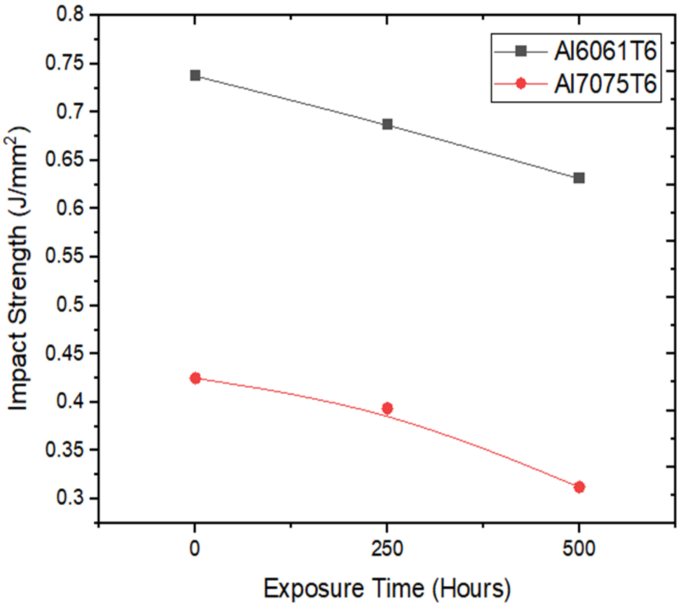

Fig. 9 - Variation of impact strength with exposure time

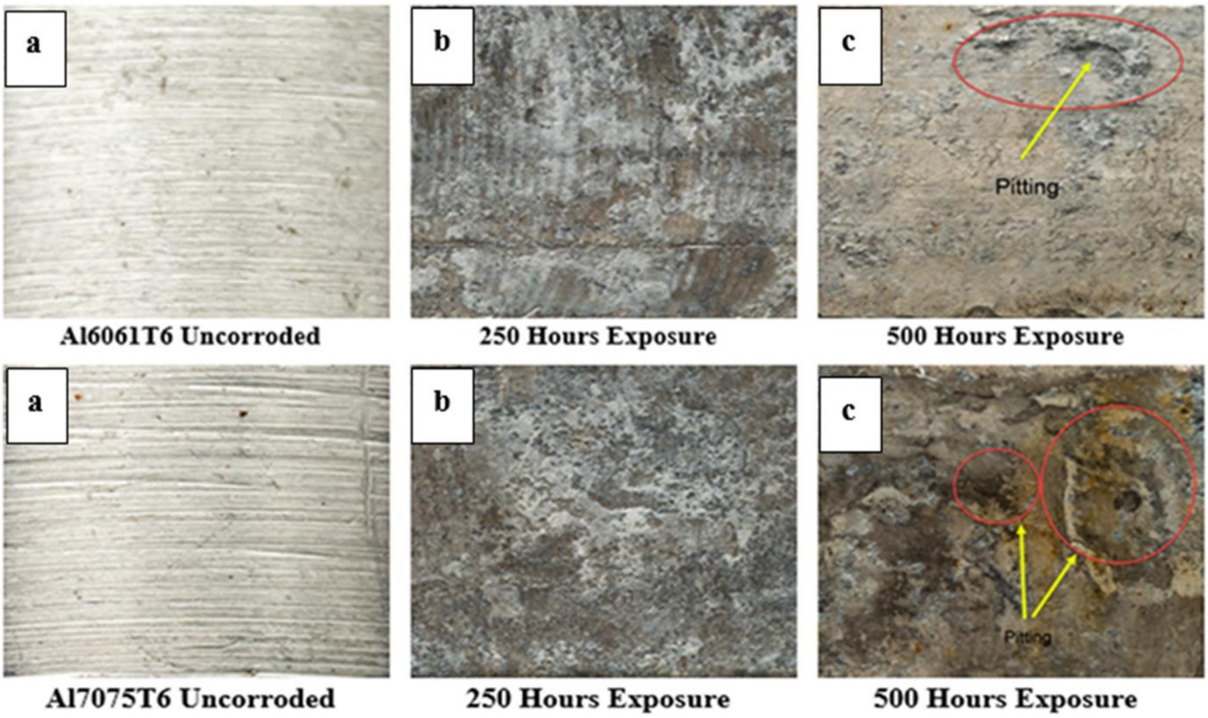

Fig. 10 - Optical surface images representing with and without corrosion of Al6061T6 and Al7075T6 (a) as-received samples; (b) 250 hours; (c) 500 hours

5. Conclusions

Al6061T6 and Al7075T6 aluminum alloys were subjected to the laboratory augment salt spray under controlled rate and temperature for 250 hours and 500 hours, and the influence of exposure time on mechanical properties was analyzed. The exposure manifested the inception of white and gray patches in the earlier stages, and prolonged exposure led to the formation of pits at 500 hours followed by an intergranular attack causing exfoliation corrosion. The experimental results on the mechanical response of Al6061T6 and Al7075T6 reveal the deterioration of load-carrying capacity corresponding to yield strength and tensile strength as a function of exposure time. A sharp decline in overall toughness and impact toughness was observed. The Rockwell hardness also showed a decreasing trend attributing to the weakening of the grain boundaries. it can be noted that Al7075T6 is more susceptible to corrosion than Al6061T6. Collectively it is evident from the current investigation that there is a significant deterioration in aluminum alloys' mechanical properties under accelerated salt spray exposure.

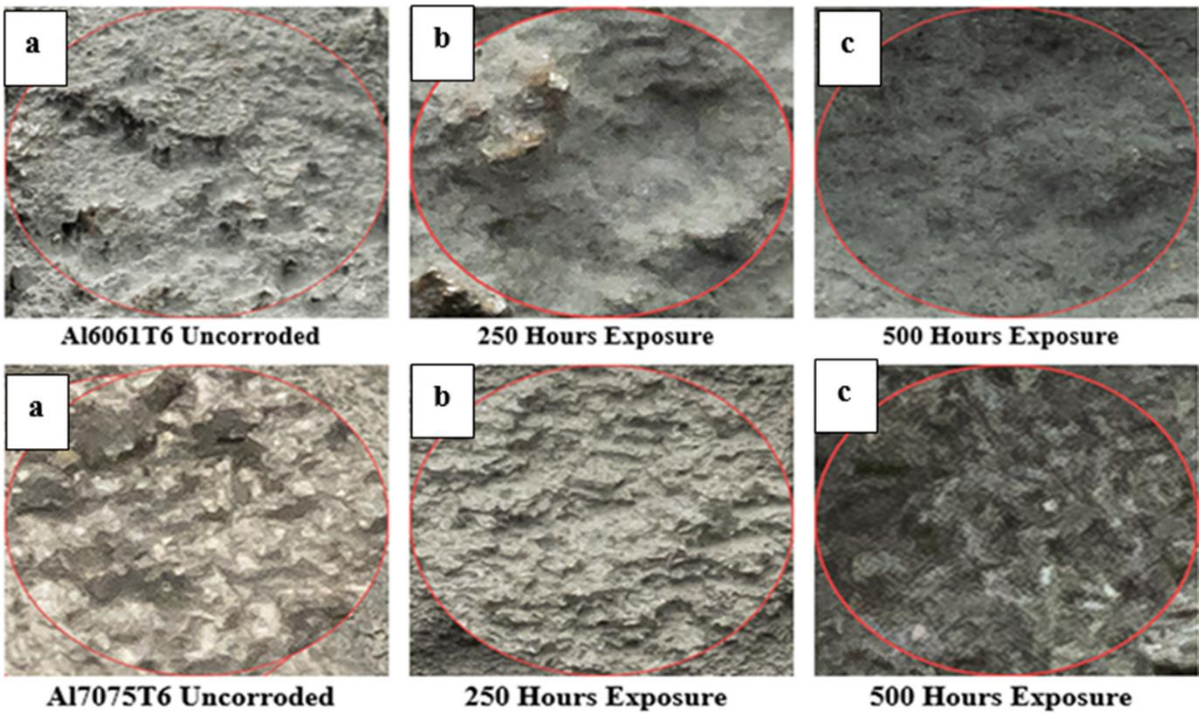

Fig. 11 - Optical surface images of fractured specimens representing with and without corrosion Al6061T6 and Al7075T6 (a) as-received samples (b) 250 hours; (c) 500 hours

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