Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Estimation of fracture toughness (K_{IC}) using Charpy impact test for Al6061T6 and Al7075T6 alloys subjected to corrosion

S. Sunil Kumar [a,b,*], Neelakantha V. Londe [b], K. Dilip Kumar [c], Mohammed Ibrahim Kittur [d]

[a] Department of Mechanical Engineering, A J Institute of Engineering and Technology, Mangalore, Karnataka, India
[b] Department of Mechanical Engineering, Mangalore Institute of Technology and Engineering, Moodabidri, Karnataka, India
[c] Department of Mechanical Engineering, Shree Devi Institute of Technology, Mangalore, Karnataka, India
[d] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

A R T I C L E I N F O

Article history:
Received 22 November 2020
Accepted 11 January 2021
Available online xxxx

Keywords:
Fracture toughness
Impact strength
Aluminum alloys
Corrosion
Salt spray

A B S T R A C T

Fracture Toughness (K_{IC}) is an important material property in fracture mechanics. There are numerous literatures that suggest the use of relationship between the fracture toughness (K_{IC}) and impact strength (CVN). In this investigation, the relationship between K_{IC} and CVN was used to determine the fracture toughness of high strength, low density Al6061T6 and Al7075T6 aluminum alloys. Accelerated corrosion was performed on these alloys using salt spray in a closed chamber for 250 h and 500 h. Pitting corrosion followed with exfoliation corrosion was noticed after prolonged exposure time which were responsible for the deterioration of mechanical properties. The experimentation results in degradation of yield strength, tensile strength, and impact strength with increase in exposure time. The yield and the impact test results were considered to estimate fracture toughness using the relations proposed by Rolfe and Barsom, Weld Research Council (WRC) and Robert and Newton. The K_{IC} results were validated analytically using Compact Tension (CT) and Single Edge Notched Bend (SENB) specimens. The results show that, K_{IC} decreases with increase in exposure time for all the combinations considered. Further, it was relatively observed that Al7075T6 is more susceptible to corrosion than Al6061T6.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Smart and Sustainable Developments in Materials, Manufacturing and Energy Engineering.

1. Introduction

Aluminum alloys are potential replacement for conventional high strength metallic materials from decades. Their peculiar metallurgical properties of precipitation and dispersion permit their use in wide range of applications specially in components of aircraft and space shuttles to storage vessels [1]. 7075 T6 and 6061 T6 are precipitation hardened aluminum alloys with high strength and ductility that promotes their use in automobiles, aviation and marine applications. Al6061 is predominantly used in transportation and sports applications [2]. The composition of these alloys compel them to be used in corrosive environment. Though these alloys are corrosion resistant, the continuous and concentrated exposure would affect the surface leading to pitting and exfoliation corrosion of passive layers. It is reported in the literature that 7075 is more prone to pitting, intergranular attacks, and hydrogen embrittlement [3–7]. The extended exposure to corrosive atmosphere will cause degradation in mechanical and fracture properties [8]. Accelerated corrosion by salt spray on aluminum alloys accelerates the exfoliation of passive layers and thus deteriorates their mechanical strength, fatigue life, and fracture toughness particularly under impact loads and vibration shocks [9–17]. The use of CT and SENB specimens is recommended to determine the fracture toughness which involves the evaluation of constraint issues [18–22]. The complexity of testing conditions has promoted the researchers to find alternative methods to estimate fracture toughness by using alternate specimen geometry and mathematical equations. The use of Circumferentially Cracked Round Bar (CCRB) specimen which is circumferentially 'V' grooved and pre-cracked under controlled reversible bending load, followed by tensile loading is suggested as an alternative to conventional CT and SENB specimens to determine the fracture toughness and fatigue crack growth rate [23]. The literatures [24–30] influence the use of standard correlation equations of

* Corresponding author.
E-mail addresses: sunilgooch@gmail.com, sunilkumar@ajiet.edu.in, sunilsansitha@gmail.com (S. Sunil Kumar).

https://doi.org/10.1016/j.matpr.2021.01.298
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Smart and Sustainable Developments in Materials, Manufacturing and Energy Engineering.

fracture toughness $K_{IC}$with Charpy impact strength CVN. Teran et al. [26] highlights the K_{IC} – CVNrelations by Rolfe-Barsom [28], Welding Research Council (WRC) – 1981 [29] and Robert-Newton [30], which require the data of Charpy impact strength and material's yield strength in tension to estimate fracture toughness K_{IC}. The stress concentration factor $K_t$at the root of 'V' notch responses for stress raisers which are comparatively greater than that for other geometrical discontinuities. These stress raisers influence the crack to initiate and propagate at faster rate [31]. Therefore, impact toughness obtained from 'V' notched impact specimens can be undeniably correlated to obtain fracture toughness of the material. The research has motivated to investigate the effect of accelerated salt spray on fracture toughness of Al6061T6 and Al7075T6 aluminum alloys by using the K_{IC} – CVNrelations. The results are validated analytically by CT and SENB specimen geometry by considering the yield stress as the critical stress at crack tip to estimate linear elastic plane strain fracture toughness as per the standards suggested by A H Priest [32] and ASTM E399 [33].

2. Experimental program

2.1. Materials and methods

Aluminum alloys Al6061T6 and Al7075T6 aluminum alloys purchased from Hindalco Industries Limited' (Aditya Birla Group) were considered to investigate the effect of salt spray corrosion on impact strength and fracture toughness. Table 1 shows the chemical composition of the alloys.

The tensile and impact test specimens were machined following ASTM E8 [34] and ASTM E 23 [35] as shown in the Fig. 1(a) and (b) respectively.

2.2. Salt spray corrosion

The test specimens were exposed to accelerated salt spray as per ASTM B117 [36]. The chemical composition of salt water contained 5% NaCl (sodium chloride) with pH ranging from 6.5 to 7.2. Five parts by mass of sodium chloride was dissolved in 80 parts of distilled water. The specimens were immersed continuously at temperature of 35 °C. The rate of salt spray in the chamber was maintained between 1.0 and 2.0 ml/hr. The exposure time was maintained as 250 h and 500 h.

3. Results and discussion

3.1. Optical microscopy

It was observed from the regular inspection that, inhomogeneous white and grey patches were formed at the end of 250 h of corrosion (Fig. 2(a, c)). The prolonged exposure resulted in pitting which visibly became larger and began to coalescence and propagate below the surface resulting exfoliation of the superficial layers [17]. Clearly visible pits and exfoliation was noticed in both the alloys as shown in the Fig. 2(b, d).

3.2. Tensile and impact test

The effect of salt spray corrosion on tensile properties was investigated on both alloys at 250 and 500 h of exposure with reference to the as-received sample. Fig. 3(a) and (b) represents the stress–strain curves for the respective alloys of 6061 and 7075. It was observed that yield strength and tensile strength decreases with exposure time in both the alloys. For Al6061, at 500 h of exposure a 29% decrease in yield strength and 19% decrease in tensile strength was observed. For Al7075, at 500 h of exposure a 28% decrease in yield strength and 33% decrease in tensile strength was observed. There was significant decrease in elongation at yield and elongation at break with increase in exposure time. The Charpy impact test was conducted to examine the influence of salt spray. The impact strength CVN show decreasing trend with increase in exposure hours. The data of yield strength $\boldsymbol{\sigma_{ys}}$ and the impact strength CVN were used to estimate the fracture toughness $\mathbf{K_{IC}}$.The variations of $\boldsymbol{\sigma_{ys}}$ and CVN with corrosion duration are shown in Fig. 4(a) and (b) respectively (Table 2. Table 3).

4. Estimation of fracture toughness by K_{IC} - CVN relations

The linear elastic plane strain fracture toughness is estimated using the relationship between K_{IC} and CVN. According to Rolfe-Barsom [28], K_{IC} can be estimated using CVN as:

$$\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 = 0.64\left(\frac{CVN}{\sigma_{ys}} - 0.01\right) \quad (1)$$

According to Welding Research Council (WRC) – 1981, [29],

$$\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 = 0.54\left(\frac{CVN}{\sigma_{ys}} - 0.02\right) \quad (2)$$

According to Roberts R and Newton C, at WRC in 1984 [30],

$$K_{IC} = 0.804\sigma_{ys}\left(\frac{CVN}{\sigma_{ys}} - 0.0098\right) \quad (3)$$

where K_{IC} represents fracture toughness in $Pa\sqrt{m}$, CVN is impact strength in J/m^2, and σ_{ys} is yield stress (tension) in N/m^2

To analyse the variation of fracture toughness using the relationship between K_{IC} and CVN proposed by Rolfe –Barsom, WRC, and Robert-Newton The variation of fracture toughness with exposure time is plotted as shown in Fig. 5. The magnitude of K_{IC} for Al7075 decreases significantly after 250 h of exposure in all the three cases. The overall decrease of K_{IC}at the end of 500 h of exposure for Al6061 is 31.65%, 30.21% and 30.47% and for A7075 the K_{IC}decreases by 28.4%, 30.66%, and 28.4%.

4.1. Analytical validation of fracture toughness using CT and SENB specimens

The fracture toughness values obtained from Rolfe-Barsom (Eqn. (1)) and Robert-Newton (Eqn. (3)) were identical when compared with the values of WRC (Eqn. (2)). Analytical computation was done using the CT and SENB (Fig. 6.) in accordance with the standards of ASTM E 399 to estimate linear elastic plane strain fracture toughness K_{IC} [33].

Table 1
Chemical composition of Al6061T6 and Al7075T6.

	Zn	Mg	Cu	Fe	Si	Mn	Cr	Ti	Al
Al7075T6	5.4	2.5	1.6	0.4	0.35	0.1	0.23	0.021	remaining
Al6061T6	0.09	1	0.3	0.45	0.6	0.11	0.24	0.041	remaining

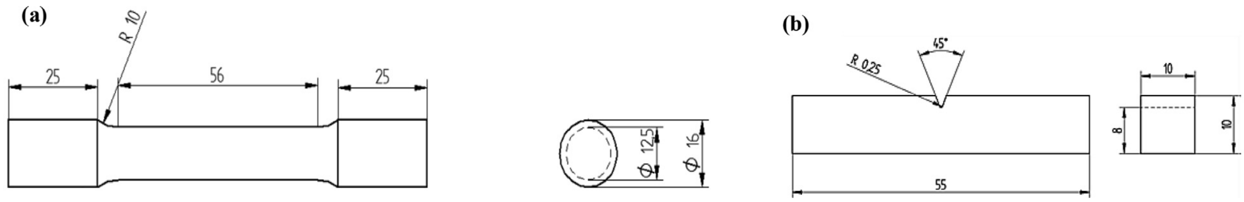

Fig. 1. (a) Dimensions of Tensile test specimen (mm) following ASTM E8; (b) Dimensions of Impact test specimen (mm) following ASTM E23.

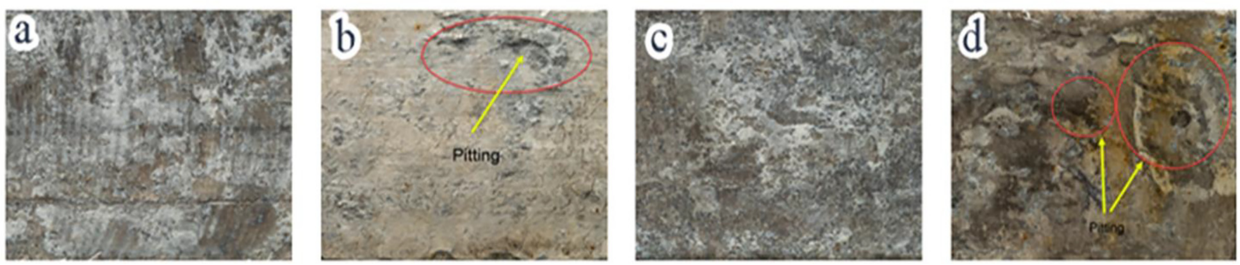

Fig. 2. Optical images of surfaces of Al6061 and Al7075 respectively (a, c): 250 h' exposure; (b, d): 500 h' exposure.

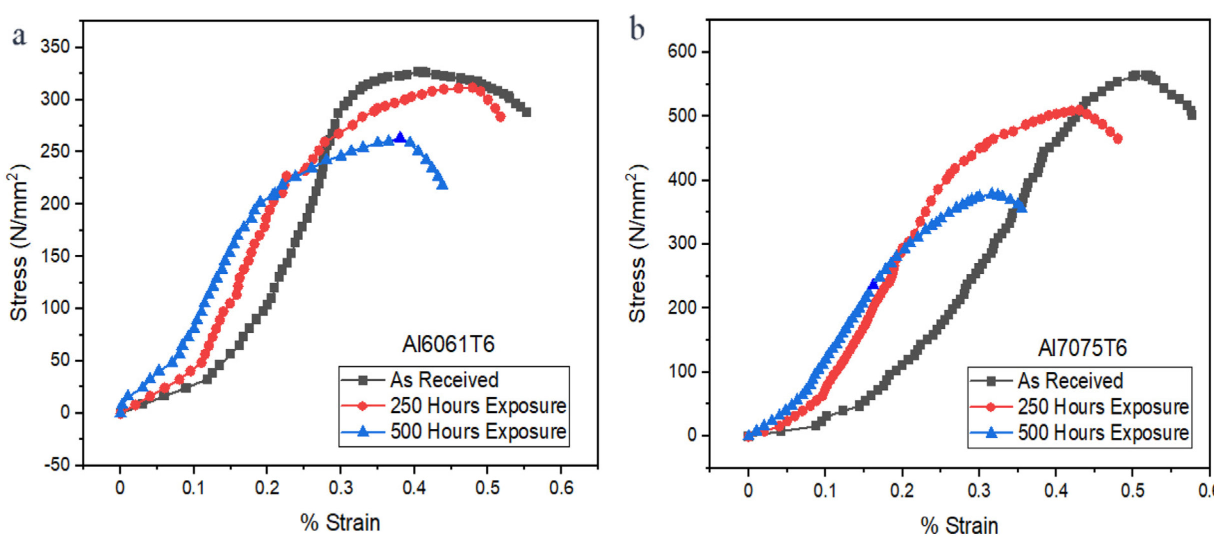

Fig. 3. Stress – Strain Curves for (a) Al6061T6; (b) Al7075T6.

The yield stress obtained by the tensile test was considered as the critical stress at the crack tip and the critical load '*P*' was calculated based on Priest equations [32] for CT and SENB specimens as shown in Eqn. (4) and Eqn. (5).

$$\sigma_{ys} = \frac{2P(2W+a)}{B(W-a)^2} \quad (4)$$

$$\sigma_{ys} = \frac{3PS}{2B(W-a)^2} \quad (5)$$

For, CT and SENB specimens K_{IC} is estimated using the following equations:

$$K_{IC} = \frac{P}{B\sqrt{W}} f\left(\frac{a}{W}\right) \quad (6)$$

$$where f\left(\frac{a}{W}\right) = \frac{\left(2+\frac{a}{W}\right)\left[0.886 + 4.64\frac{a}{W} - 13.32\left(\frac{a}{W}\right)^2 + 14.72\left(\frac{a}{W}\right)^3 - 5.6\left(\frac{a}{W}\right)^4\right]}{\left(1-\frac{a}{W}\right)^{\frac{3}{2}}} \quad (7)$$

For $\frac{a}{W}$ as 0.5, $f\left(\frac{a}{W}\right)$ = 9.6590

$$K_{IC} = \frac{PS}{BW^{\frac{3}{2}}} f\left(\frac{a}{W}\right) \quad (8)$$

$$where f\left(\frac{a}{W}\right) = 3\sqrt{\frac{a}{W}} \times \frac{\left(1.99-\frac{a}{W}\right)\left(1-\frac{a}{W}\right)\left[2.15 - 3.93\frac{a}{W} + 2.7\left(\frac{a}{W}\right)^2\right]}{2\left(1+2\frac{a}{W}\right)\left(1-\frac{a}{W}\right)^{\frac{3}{2}}} \quad (9)$$

For $\frac{a}{W}$ as 0.5, $f\left(\frac{a}{W}\right)$ = 2.6522

The fracture toughness for Al6061T6 and Al7075T6 alloys estimated using Eqn.6. and Eqn. 7. is tabulated as shown in Table 4.

The K_{IC} shows a decreasing trend in both the alloys for CT and SENB specimens and the variations are shown in Fig. 7.

It is observed from the Fig. 7 that, the magnitude of K_{IC} for Al7075 decreases significantly after 250 h of exposure in both the

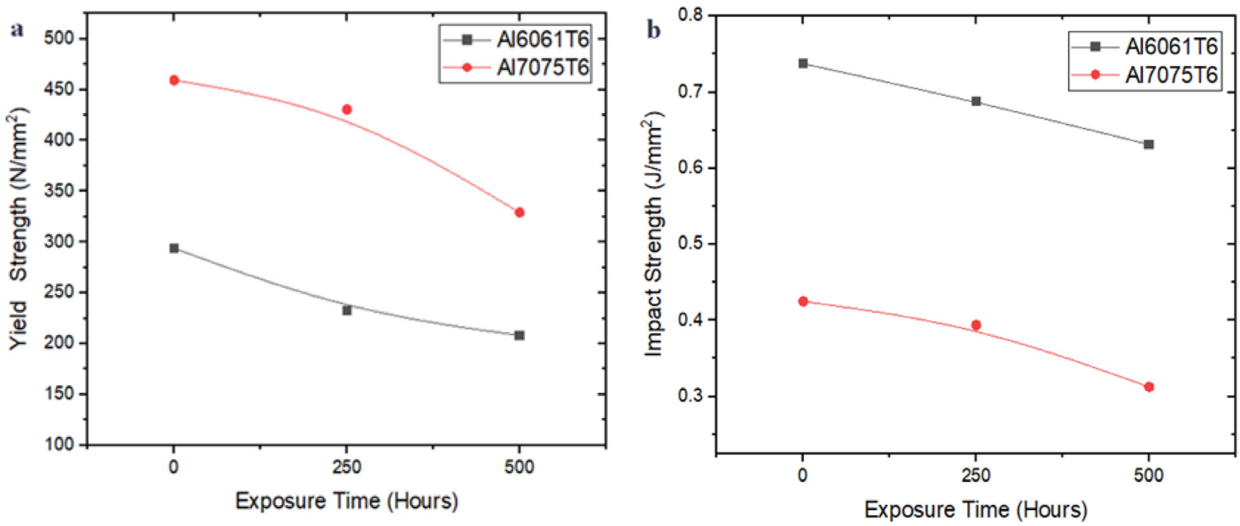

Fig. 4. Variation of (a) Yield Strength; (b) Impact Strength with Exposure Hours.

Table 2
Fracture Toughness $K_{IC}$for Al6061T6 from K_{IC} - *CVN* relations.

Exposure Hours	Yield Strength$\sigma_{ys}(\times 10^6 \frac{N}{m^2})$	Impact Energy (J)	Impact StrengthCVN ($\frac{J}{m^2}$)	Fracture Toughness$K_{IC}MPa\sqrt{m}$.		
				Rolfe-Barsom(Eqn. 1.)	WRC(Eqn. 2.)	Robert-Newton(Eqn. 3.)
0	293.84	59	737,500	20.35	28.56	20.17
250	232.10	55	687,500	15.58	22.35	15.43
500	208.24	50.5	631,250	13.91	19.93	13.78

Table 3
Fracture Toughness $K_{IC}$for Al7075T6 from K_{IC} - *CVN* relations.

Exposure Hours	Yield Strength$\sigma_{ys}(\times 10^6 \frac{N}{m^2})$	Impact Energy (J)	Impact StrengthCVN ($\frac{J}{m^2}$)	Fracture Toughness$K_{IC}MPa\sqrt{m}$.		
				Rolfe-Barsom(Eqn. 1.)	WRC(Eqn.2.)	Robert-Newton(Eqn.3.)
0	459.3	34	425,000	35.00	46.61	34.78
250	430.35	31.5	393,750	32.81	43.68	32.61
500	329.26	25	312,500	25.06	32.61	24.90

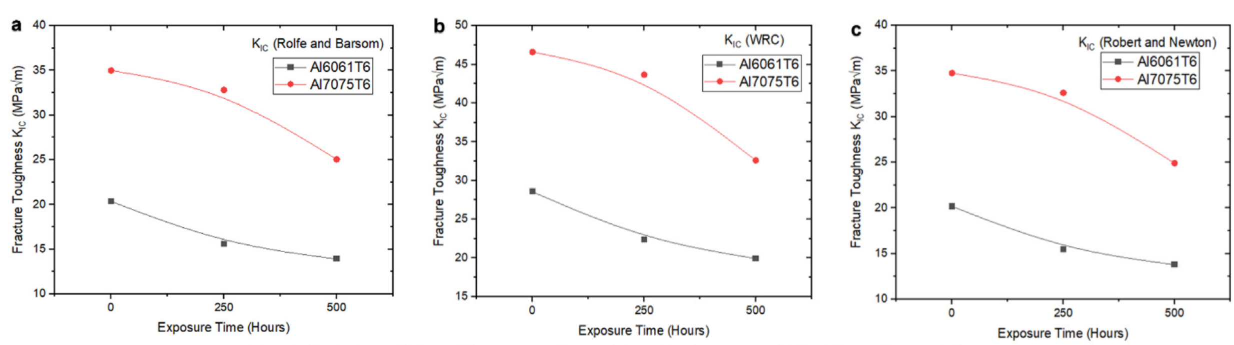

Fig. 5. Variation of K_{IC} with exposure hours (a) Rolfe –Barsom; (b) WRC; (c) Robert-Newton.

cases. The overall decrease in K_{IC}at the end of 500 h of exposure for Al6061T6 is 29.13%, and 29.11% and for A7075T6, the fracture toughness decreases by 28.31%, and 28.29% for CT and SENB specimens respectively. The analytically obtained K_{IC} values are compared with the values obtained from K_{IC} – CVN relations as shown in Fig. 8.

From Fig. 8 it is observed that, the K_{IC} of both the alloys decreases with increase in exposure duration for all the cases. Collectively it can be stated that, there is significant decrease in fracture toughness which results in pre-mature failure. It is also evident from the comparison (Fig. 8) that the stress raisers at the root of 'V' notch of impact specimen are critically equivalent to the stress at the crack tip in CT and SENB specimens [26]. The fracture toughness K_{IC} of K_{IC} – CVN relationship obtained from Rolfe-Barsom (Eqn.1.) and Robert-Newton (Eqn.3.) are nearly equal to the values obtained using CT and SENB specimens. However, the K_{IC} results obtained from WRC (Eqn.2.) are not in agreement with the other cases considered.

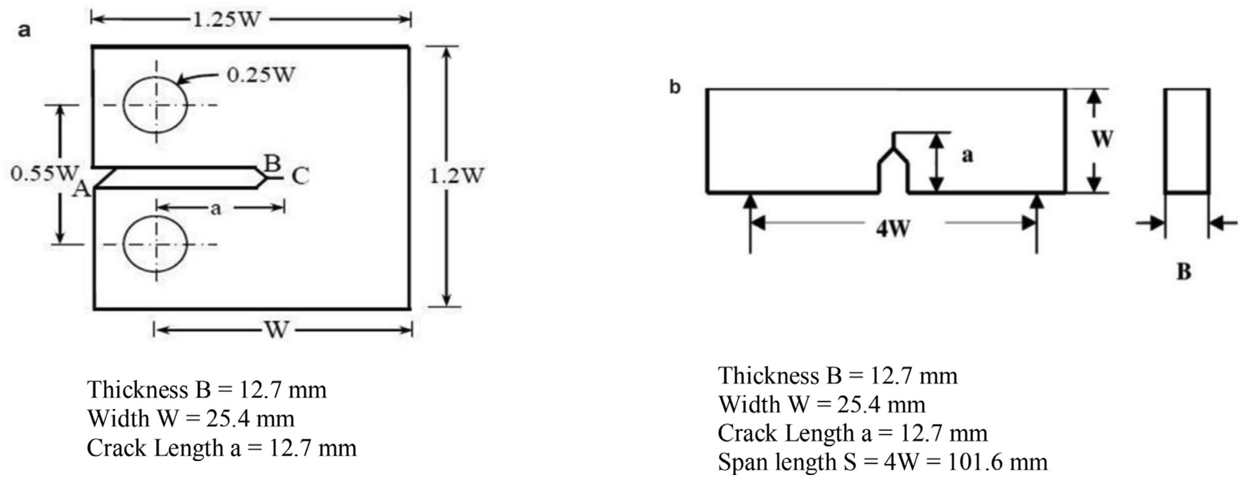

Fig. 6. Standard dimensions of (a) CT specimen and (b) SENB specimen following ASTM E 399 [33].

Table 4
Fracture Toughness for Al6061T6 K_{IC} in accordance with CT and SENB standards.

Exposure Hours	Al6061T6				Al7075T6			
	CT		SENB		CT		SENB	
	Load P from Eqn.4(N)	Fracture Toughness$K_{IC}MPa\sqrt{m}$	Load P from Eqn.5(N)	Fracture Toughness$K_{IC}MPa\sqrt{m}$	Load P from Eqn.4(N)	Fracture Toughness$K_{IC}MPa\sqrt{m}$	Load P from Eqn.5(N)	Fracture Toughness$K_{IC}MPa\sqrt{m}$
0	4739	22.62	3949	20.78	7408.	35.35	6173	32.48
250	3744	17.86	3119	16.41	6941	33.12	5784	30.43
500	3359	16.03	2799	14.73	5311	25.34	4426	23.29

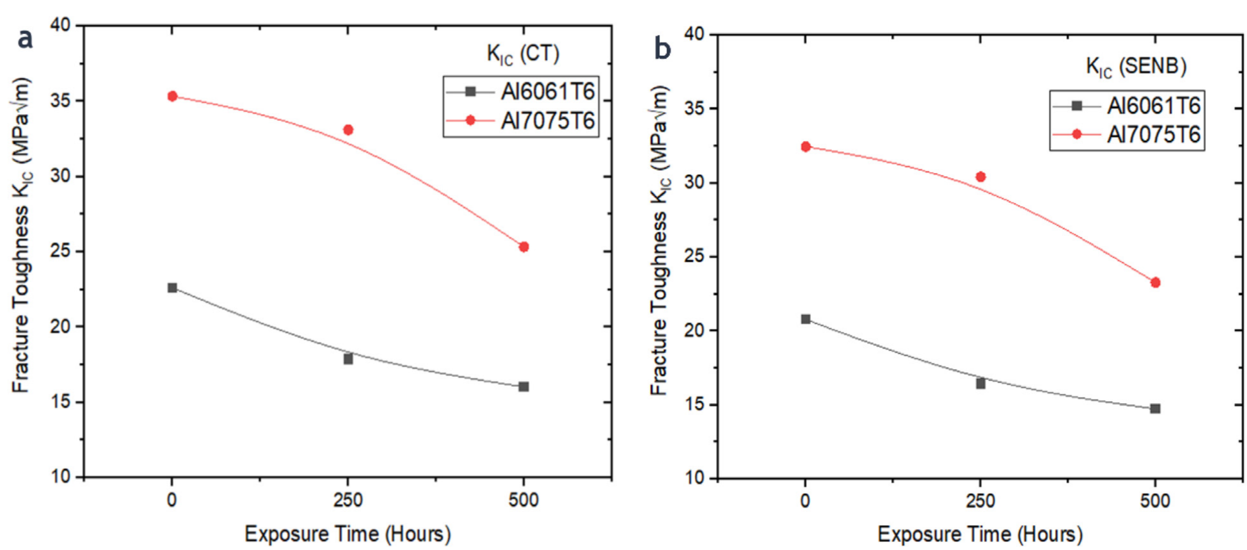

Fig. 7. Variation of $K_{IC}$for Al6061T6 and Al7075 by the standards of (a) CT and (b) SENB.

5. Conclusions

In this investigation, Al6061T6 and Al7075T6 aluminum alloys were exposed to accelerated salt spray for the durations of 250 and 500 h and following conclusions were drawn,

- The tensile and yield strength of the alloys decreases with increase in exposure duration. The salt spray has significant effect on mechanical behaviour occurring due to exfoliation of passive layers and formation of pits.

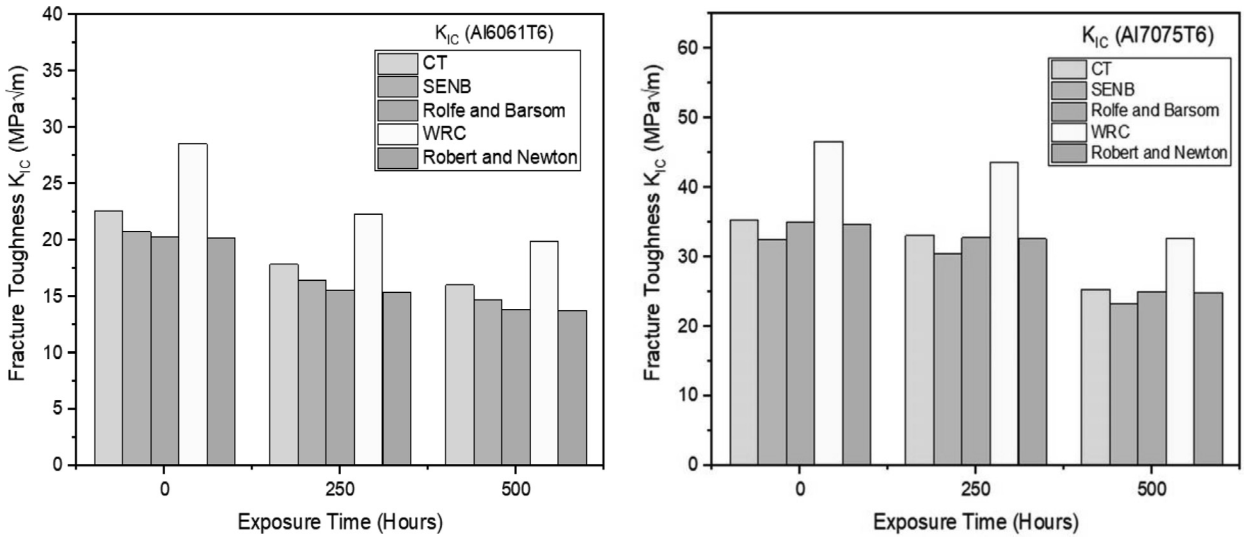

Fig. 8. Comparison of K_{IC} of K_{IC} – CVN correlations with CT and SENB standards for (a) Al6061T6; (b) Al7075T6 alloys.

- There is a considerable decrease in impact strength of the alloys and there is consequent reduction in fracture toughness in accordance with the K_{IC} – CVN relations.
- The analytical results obtained from CT and SENB specimens are in agreement with the K_{IC} – CVN equations proposed by Rolfe – Barsom, WRC and Robert-Newton and can be used to estimate linear elastic plane strain fracture toughnessK_{IC}.

CRediT authorship contribution statement

S. Sunil Kumar: Conceptualization, Formal analysis, Investigation, Methodology, Writing - original draft. **Neelakantha V. Londe:** Conceptualization, Supervision. **K. Dilip Kumar:** Conceptualization, Supervision. **Mohammed Ibrahim Kittur:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J.A. Nock, H.Y. Hunsicker, High-strength aluminum alloys, JOM 15 (3) (1963) 216–224.
[2] H. Jafari, H. Mansouri, M. Honarpisheh, Investigation of residual stress distribution of dissimilar Al-7075-T6 and Al-6061-T6 in the friction stir welding process strengthened with SiO2 nanoparticles, J. Manuf. Processes 43 (2019) 145–153.
[3] N. Murer, R.G. Buchheit, Stochastic modeling of pitting corrosion in aluminum alloys, Corros. Sci. 69 (2013) 139–148.
[4] W. Tian, S. Li, X. Chen, J. Liu, Y.u. Mei, Intergranular corrosion of spark plasma sintering assembled bimodal grain sized AA7075 aluminum alloys, Corros. Sci. 107 (2016) 211–224.
[5] W. Tian, S. Li, B.o. Wang, J. Liu, Y.u. Mei, Pitting corrosion of naturally aged AA 7075 aluminum alloys with bimodal grain size, Corros. Sci. 113 (2016) 1–16.
[6] H. Torbati-Sarraf, S.A. Torbati-Sarraf, N. Chawla, A. Poursaee, A comparative study of corrosion behavior of an additively manufactured Al-6061 RAM2 with extruded Al-6061 T6, Corros. Sci. 174 (2020) 108838.
[7] S.-S. Wang, I.-W. Huang, L.i. Yang, J.-T. Jiang, J.-F. Chen, S.-L. Dai, D.N. Seidman, G.S. Frankel, L. Zhen, Effect of Cu content and aging conditions on pitting corrosion damage of 7xxx series aluminum alloys, J. Electrochem. Soc. 162 (4) (2015) C150–C160.
[8] NECŞULESCU, Daniela Alina. "The effects of corrosion on the mechanical properties of aluminium alloy 7075-T6." UPB Sci. Bull. 73 (2011) 223-229.
[9] U. Zupanc, J. Grum, Effect of pitting corrosion on fatigue performance of shot-peened aluminium alloy 7075–T651, J. Mater. Process. Technol. 210 (9) (2010) 1197–1202.
[10] Giuseppe Silva, Barbara Rivolta, Riccardo Gerosa, U. Derudi, Study of the SCC behavior of 7075 aluminum alloy after one-step aging at 163 C, J. Mater. Eng. Perform. 22 (1) (2013) 210–214.
[11] Pantelakis, Sp G., P.G. Daglaras, Ch Alk Apostolopoulos. "Tensile and energy density properties of 2024, 6013, 8090 and 2091 aircraft aluminum alloy after corrosion exposure." Theor. Appl. Fract. Mech. 33, no. 2 (2000) 117-134.
[12] Nikolaos D. Alexopoulos, Wolfgang Dietzel, Effect of corrosion-induced hydrogen embrittlement and its degradation impact on tensile properties and fracture toughness of (Al-Cu-Mg) 2024 alloy, Procedia Struct. Integrsity 2 (2016) (2016) 573–580.
[13] Weiwei Song, Holly J. Martin, Ayesha Hicks, Denver Seely, Christopher A. Walton, William B. Lawrimore II, Paul T. Wang, M.F. Horstemeyer, Corrosion behaviour of extruded AM30 magnesium alloy under salt-spray and immersion environments, Corros. Sci. 78 (2014) 353–368.
[14] M.P. Papadopoulos, C. Alk Apostolopoulos, A.D. Zervaki, G.N. Haidemenopoulos, Corrosion of exposed rebars, associated mechanical degradation and correlation with accelerated corrosion tests, Constr. Build. Mater. 25 (8) (2011) 3367–3374.
[15] L. Calabrese, E. Proverbio, G. Di Bella, G. Galtieri, C. Borsellino, Failure behaviour of SPR joints after salt spray test, Eng. Struct. 82 (2015) 33–43.
[16] S. Sunil Kumar, Neelakantha V. Londe, K. Dilip Kumar, Md Ibrahim Kittur, A review on deterioration of mechanical behaviour of high strength materials under corrosive environment, IOP Conf. Ser. Mater. Sci. Eng. 376 (1) (2018) 012106.
[17] Abdessamad Brahami, Jamel Fajoui, Benattou Bouchouicha, Exfoliation corrosion impact on microstructure, mechanical properties, and fatigue crack growth of aeronautical aluminum alloy, J. Fail. Anal. Prev. 20 (1) (2020) 197–207.
[18] Mahammad Sharif Bhudihal, Md Ibrahim Kittur, Krishnaraja G. Kodancha, Relationship between J-integral and CTOD for different materials–A FE Study, J. Mater. Sci. Surface Eng. 3 (4) (2015) 303–307.
[19] Kittur, Md Ibrahim, Krishnaraja G. Kodancha, C.R. Rajashekar. "Study of Constraint Issues in Elasto-Plastic Fracture Analysis Using Experimental and Finite Element Simulation." In Turbo Expo: Power for Land, Sea, and Air, vol. 50923, p. V07AT31A009. American Society of Mechanical Engineers, 2017.
[20] S.K. Kudari, K.G. Kodancha, 3D Stress intensity factor and T-stresses (T11 and T33) formulations for a compact tension specimen, Frattura ed Integrità Strutturale 11 (39) (2017) 216–225.
[21] S.K. Kudari, K.G. Kodancha, On the relationship between J-integral and CTOD for CT and SENB specimens, Frattura ed Integrita Strutturale 2 (6) (2008) 3–10.
[22] MS Sham Prasad, C.S. Venkatesha, T. Jayaraju, Experimental methods of determining fracture toughness of fiber reinforced polymer composites under various loading conditions, J. Min. Mater. Charact. Eng. 10 (13) (2011) 1263.
[23] V.L. Neelakantha, T. Jayaraju, Padmayya Naik, Dilip Kumar, C.R. Rajashekar, Determination of fracture toughness and fatigue crack growth rate using circumferentially cracked round bar specimens of Al2014T651, Aerosp. Sci. Technol. 47 (2015) 92–97.
[24] A.P. Korchagin, K.A. Kuznetsov, A.O. Murashov, A.N. Yudin, S.V. Demkin, Relationship between impact strength and stress intensity factor K 1c for steels used in manufacturing petrochemical equipment, Chem. Pet. Eng. 51 (9–10) (2016) 630–635.

[25] Zeng Chen, Jianhua Pan, Ting Jin, Zhanyong Hong, Wu. Yucheng, Estimation of fracture toughness of 16MnDR steel using Master Curve method and Charpy V-notch impact energy, Theor. Appl. Fract. Mech. 96 (2018) 443–451.
[26] G. Terán, S. Capula-Colindres, D. Angeles-Herrera, J.C. Velázquez, M.J. Fernández-Cueto, Estimation of fracture toughness KIC from Charpy impact test data in T-welded connections repaired by grinding and wet welding, Eng. Fract. Mech. 153 (2016) 351–359.
[27] H.F. Li, Q.Q. Duan, P. Zhang, X.H. Zhou, B. Wang, Z.F. Zhang, The quantitative relationship between fracture toughness and impact toughness in high-strength steels, Eng. Fract. Mech. 211 (2019) 362–370.
[28] J.M. Barsom, S.T. Rolfe, Fracture and Fatigue Control in Structures, 3rd ed., Prentice Hall, Englewood Cliffs, New Jersey, 1999.
[29] R. Roberts, C. Newton. Interpretive report on small scale test correlations with KIC data, WRC Bulletin, Welding Research Council, New York N.Y.; February 1981. p. 265.
[30] R. Roberts, C. Newton, Report on small-scale test correlations with KIC data, Weld Res Council Bull (1984) 299.
[31] S. Sunil Kumar, Neelakantha V. Londe, Prem Kumar Naik, A.S. Saviraj, Effect of geometric discontinuity on stress concentration factor of Al6061T6 alloy under bending load, Mater. Today Proc. 4 (10) (2017) 11039–11043.
[32] A.H. Priest. Experimental methods for fracture toughness measurement. J. Strain Analysis, 10(4), 1(1975) 225-232.
[33] ASTM E 399 – "Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness KIC of Metallic Materials", (2017).
[34] ASTM E 8 "Standard Test Methods for Tension Testing of Metallic Materials", (2016).
[35] ASTM E 23 "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials", (2018).
[36] ASTM B117 – 11 "Standard Practice for Operating Salt Spray (Fog) Apparatus", (2011).