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Review of Experimental Fracture Toughness (K_{IC}) of Aluminium Alloy and Aluminium MMCs

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Abstract

This paper gives technical review of different methods of fracture toughness testing, experimental evaluation in reference to both the linear elastic fracture mechanics (LEFM) and the elastic-plastic fracture mechanics (EPFM). Fracture toughness using single edge notch bend (SENB) as per ASTM E-1820 and compact tension (CT) specimens as per ASTM-E399 were widely used whereas indentation techniques as per ASTM E1820-09e1, circumferential notched tensile (CNT), circumferential cracked round bar (CCRB) are on the other hand getting popular for their ease. The material chosen for this study is restricted to aluminium matrix, particulate reinforced composites especially silicon carbide. The fracture toughness testing methods considered in this paper are single edge notch bend (SENB), circumferential cracked round bar (CCRB); circumferential notched tensile (CNT) and Vickers's indentation techniques. For the particulate composites, results of the above said testing methods are presented and discussed. From the literature, fracture toughness of aluminium alloy vary from 14 to 28 MPa√m and for the aluminium matrix particulate composite fracture toughness was found to be less than 28 MPa√m for various fracture toughness test methods [1].

Keywords: fracture toughness, compact tension (CT) specimen, single edge notched bend (SENB) specimen, circumferentially cracked round bar (CCRB), circumferential notched tensile (CNT) specimens, indentation fracture toughness

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INTRODUCTION

Metal matrix composites (MMCs) are used in structural applications, and in applications requiring wear resistance, thermal management, and weight savings. Both continuously and discontinuously reinforced MMCs are used in structural applications. [1,2] By far the most common commercial MMCs are based on Aluminum alloys reinforced with silicon carbide (SiCp), alumina (Al_2O_3), carbon, or graphite.

Discontinuously reinforced MMCs are much less expensive to fabricate than continuously reinforced composites. The properties of discontinuously reinforced composites are nearly isotropic, whereas the properties of composites with continuous aligned reinforcements are highly anisotropic. Thus, in applications requiring isotropic properties, less expensive, discontinuously reinforced composites can outperform continuous fiber reinforced composites. Typically, ceramics and graphitic materials are used as reinforcement phases in discontinuously reinforced MMCs.

Aluminum alloy is widely used for construction of aircraft structures, such as wings and fuselages. There are two

different cracks being investigated in aircraft wings; hairline cracks around fastener holes in the internal wing structure, and cracks at the edges of the vertical web of the feet. If the high loads being applied to the fasteners during assembly, are not adequately accounted for, they will combine with the stresses arising from the interference fit, potentially leading to cracking. The particular type of Aluminum alloy used will also affect this joint behavior where a balance has to be achieved between stiffness, strength and fracture toughness.
Mechanical characterization such as tensile strength and elongation experiments by using universal testing machine (UTM) of Al/SiC has been conducted for varying mass fraction of SiCp with Aluminum. [3–5]

Tribological behavior of Al/SiC [6] and Aluminum graphite[7] using pin on disc wear apparatus, fracture toughness, [8] tensile fracture behavior [9] on compact tension (CT) test specimen, fatigue behavior of a silicon carbide composite, [10–12] fatigue behavior at elevated temperature, [13,14] fatigue crack growth, [15–18] high-cycle fatigue behavior [19, 20] of Al/SiC was studied by the different authors and most of the authors compared their results with the unreinforced Aluminum alloy.

Research has to be carried on the Aluminum matrix discontinuously reinforced particulate composites in the area of fracture and fatigue in order to improve the strength and fracture characteristics of the material to avoid the cracking.

Main objective of this review paper is to investigate the different methods in finding the fracture toughness which includes the American Society for Testing and Materials (ASTM) standard methods and recent advances in fracture toughness testing methods which were used for testing of Aluminum alloys and some of Aluminum matrix particulate reinforced composites.

MATERIALS

Materials chosen for the study are discontinuously reinforced MMCs which have advantage that they are nearly isotropic. Typically, ceramics and graphitic materials are used as reinforcement phases in discontinuously reinforced MMCs. Silicon carbide, Al_2O_3, boron carbide (B_4C), and graphite are common reinforcements for Aluminum matrices. Aluminum matrix particulate reinforced composite is characterized by an improved combination of thermal, physical and mechanical properties. But these improved properties can be achieved with loss of ductility.

The ductility of MMC is decreased by the addition of ceramic reinforcement compared to unreinforced alloy. This review article concentrates only on the methods of fracture toughness testing, material selection will be restricted to Aluminum matrix discontinuously reinforced MMCs. Materials chosen in this article are Aluminum matrix with silicon carbide + zirconium silicate particulates, [21] fly ash[22], silicon carbide [23] etc.

PROCESSING

From the literature it is identified that some methods, advanced shear technology, stir casting were developed to produce the MMCs such as Al/SiC and Aluminum graphite. [24–26] A novel process has been developed at Brunel Centre for advanced solidification technology (BCAST), Brunel University, by utilizing the MCAST (Melt Conditioning by Advanced Shear Technology) process, [24] in which the liquid undergoes a high-shear stress and a high intensity of turbulence inside a specially designed twin screw machine.

The basic function of the twin screws is to break up the agglomerates and clusters embedded in the liquid melt under a high-shear stress and disperse the particles uniformly under the high intensity of turbulence.

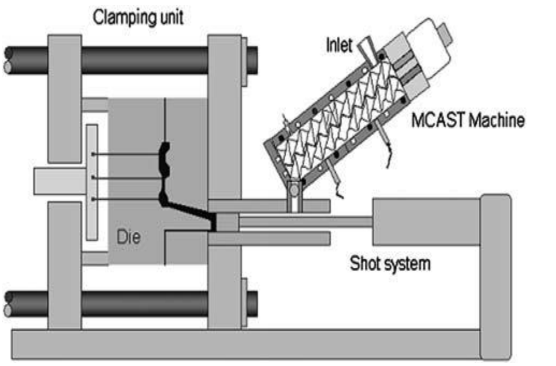

Fig. 1: *Schematic Illustration of the MC-HPDC Process.* [24]

The MCAST machine as shown in Figure 1 was operated above liquid temperature in the range between 600 and 620°C. The rotation speed of the twin screws was 800 rpm and the shearing time was varied between 60 and 240 sec.

After the predetermined shearing time, the high quality composite slurry was transferred to the high pressure die casting (HPDC) machine with a 280 T clamping force, to produce standard tensile test samples. [24] Using which improved material properties were obtained for the MMC. [24, 25]

Aluminum, silicon carbide, zirconium silicate particulate MMC can be processed using stir casting [21] technique and processing of Aluminum fly ash composites (fly ash particulates (25–45 μm) can be done through liquid metallurgy route. [22]

EXPERIMENTATION

Fracture Toughness by Single Edge Notch Bend (SENB) Specimen

Fracture toughness K_{IC} of the single edge notch bend specimen shown in Figure 2 was prepared as per ASTM C393-62 and fracture toughness K_{IC} was determined as per ASTM-D790 standard testing procedure. [21]

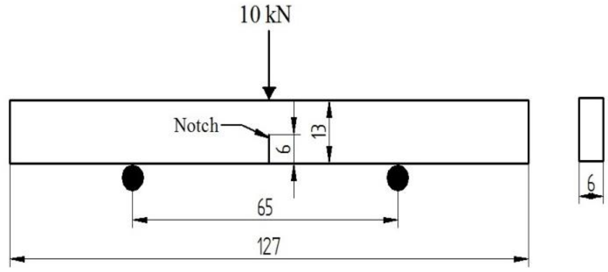

Fig. 2: *SENB Specimen.*

Experiments were conducted for following five different weight ratios of Aluminum, silicon carbide and zirconium silicate particulate MMC. [21]

Casting 1: Al356+0%SiC+8%$ZrSiO_4$
Casting 2: Al356+6%SiC+2%$ZrSiO_4$
Casting 3: Al356+2%SiC+6%$ZrSiO_4$
Casting 4: Al356+4%SiC+4%$ZrSiO_4$
Casting 5: Al356+8%SiC+0%$ZrSiO_4$

Similar type of experiments had been conducted by different authors using SENB on Aluminum and fly ash composites, [22] double cleavage drilled compression (DCDC), [27] three point bend on Japanese low activation ferrite steel, JLF-1, [28] Aluminum silicon carbide MMC. [29]

Fracture Toughness by Round Bar

Circumferentially cracked round bar (CCRB) specimens were used to determine the fracture toughness. The test material is made up of 6082-T6 Aluminum alloy [30] and Aluminum 2011-T6. [31] The specimen dimensions were as follows; D: 12 mm, total length of the specimen L: 238 mm, notch angle α: 60°, mean notch root radius ρ: 0.185 mm. [30]

The pre-cracking of the specimen at the root of V-notch was achieved using R.R. Moore rotating beam fatigue testing machine

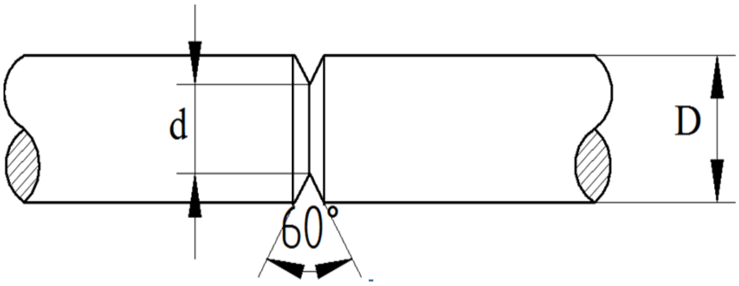

Fig. 3: *Schematic of Circumferentially Notched Round Bar.* [30]

The tensile test of each pre-cracked CCRB specimen was performed on a 400 kN universal testing machine at room temperature. The maximum tensile load at fracture was recorded for each test specimen. After the test the average fatigue crack length propagated at the notch root in each specimen was measured.

K stands for the stress intensity factor (SIF) at the crack tip at mode I (tensile) loading condition. Unstable crack propagation occurs when K attains a critical value and the component fails. In LEFM the critical SIF characterize the fracture toughness.

i) Neelakantha *et al.* used Eq. (1) for calculating SIF of a CCRB specimen under tensile load which is as follows. [30]

$K_I = \{0.932P\sqrt{D}\}/(d^2\sqrt{\pi})$ Eq. (1)

for $1.2 \leq D/d \leq 2.1$

Where P = Maximum tensile load.
d = Diameter of round bar at V-notch root.
D = Diameter of round bar at un-notched sections.

ii) Neelakantha *et al.* used following Eq. (2) for determination of stress intensity factor for CCRB in tension. [30]

$K_I = (2P/\pi d_i^2)\sqrt{[\pi d_i(1–D)]}\{f(D)\}$ Eq. (2)

where D = (d_i/d_o) and $f(D)=\{1+0.5D+0.375D^2–0.363D^3+0.731D^4\}$.
P = Maximum tensile load.
d_i = Diameter of round bar at V-notch root.
d_o = Diameter of round bar at un-notched sections.

iii) Fracture toughness (K_{Ic}) of alloys can be calculated at the onset of fracture of CCRB specimens by using Eq. (3). [30].
$K_{I\,C} = \{P/(D)^{3/2}\}[1.72(D/d)–1.27]$

Eq. (3)
For $0.48 < (D/d) < 0.86$

Fracture Toughness by Circumferential Notched Tensile (CNT) Specimens
Circumferential notch tensile (CNT) specimens were prepared for the evaluation of fracture toughness of Al6063-silicon carbide particulate composite. [23]

The CNT specimens, shown in Figure 4, were machined with a gauge length L = 30 mm, specimen diameter D = 6 mm, notch diameter d = 4.5 mm and notch angle α = 6 0°. Using universal testing machine (UTM) specimens were subjected to tensile loading to fracture.

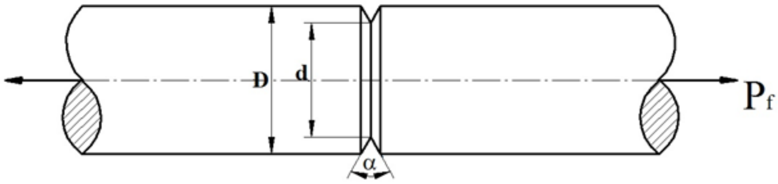

Fig. 4: *Schematic Representation of the Circumferential Notched Tensile Specimen.*

The fracture load (P_f) obtained from the CNT specimens' to evaluate the fracture toughness: [32]

$K_{1C} = P_f/(D)^{3/2}[1.72(D/d)−1.27]$ Eq. (4)

Where; *D* and *d* are, respectively, the specimen diameter and the diameter of the notched section. The achievement of the plane strain condition and, by extension, the reliability of the circumferentially notched tensile (CNT) testing method, was evaluated using the relations in accordance with Nath and Das: [33]

$D \geq (K_{1C}/\sigma_y)^2$ Eq. (5)

A minimum of two repeat tests were performed for each treatment condition and the results obtained were highly consistent at the difference was not more than 2%.

Fracture Toughness by Indentation Techniques

The Indentation Fracture (IF) method is considered to be an alternative technique to single edge-pre-cracked beam (SEPB) methods. [34] Compared with other methods, the advantages of the indentation methods include the small size of the test specimen, the ease of the specimen preparation, and the simplicity of the test. Materials used are alumina-silicon carbide. Composites were prepared and resulting samples were of disc shape with 20 mm diameter and 3 mm height.

Hardness was measured by means of Vickers method using 5 kg loading and holding time was 10 sec. The hardness was calculated using Eq. (6).

$HV = 1.8544F/a^2$ Eq. (6)

Where F: indentation load in kgf.

A: half of the diagonal length measured from the center of the indent in mm.

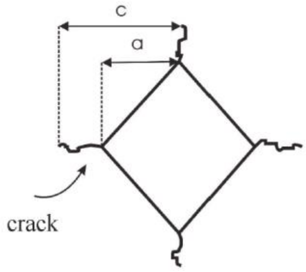

Fig. 5: *Vickers Indentation Mark [35].*

The corresponding units of HV are then kilograms-force per square millimeter (kgf/mm²). To calculate Vickers hardness number using SI units one needs to convert the force applied from kilogram-force to newtons by multiplying by 9.81 (standard gravity) and dividing by a factor of 1000 to get the answer in GPa.

Fracture toughness was measured using indentation method from crack lengths. The 2–3 indents for each material were performed. The length of cracks was measured by scanning electron microscope (SEM). From the length of the indentation cracks fracture toughness was calculated by applying the Eq. (7): [36, 37]

$K_{IC} = \eta(E/HV)^{0.5}(F/c^{1.5})$ Eq. (7)

Where:

K_{IC} [MPa√m]: Fracture toughness.

η: Shape factor (0.016 ± 0.004) based on a fit to experimental data using independent fracture toughness measurements. [38, 39]

E: Young´s modulus, GPa.
HV: Hardness, GPa. [34]
F: Indentation load, N.
c: Length of the surface trace of the half penny crack measured from the center of the indent, μm.

Fracture Toughness by Compact Tension (CT) Specimen

The fracture toughness experiments have been carried out on A356-SiCp using compact tension (CT) specimens. [40] CT specimens of various weight fractions of SiCp are tested for their fracture toughness values. The specimen as depicted in Figure 6 preparation and experiments were carried out according to ASTM-E 399 standard.

The crack propagation testing was conducted for the composite material having 10 and 20% SiCp [40] and Al 6061-40%SiCp. [18]

A procedure of tensile loading of the CT specimens is as follows. In a computer controlled universal testing machine (UTM) CT specimen is fixed in fixture. Precaution is taken to fix the test specimen in such a way that load is applied axially. The data regarding load verses displacement have been recorded during tensile loading of the specimen until fracture.

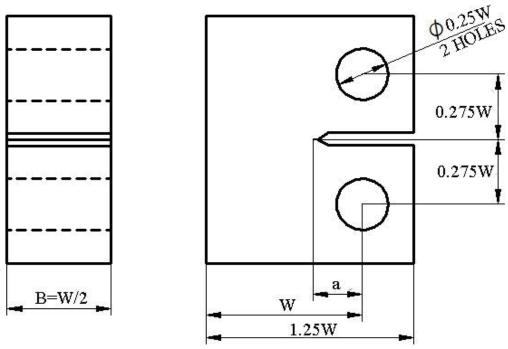

Fig. 6: Compact Specimen for KIc Testing. [41]

By drawing a line with 95% of the slope to the load displacement curve critical load P_q is obtained. The ratio of maximum load P_m to the critical load P_q should not exceed 1.10, then the value of K_q will be equal to K_{Ic}. If P_m/P_Q does exceed 1.10, then the test is not a size-independent K_{Ic} test because it is then possible that K_Q bears no relation to K_{Ic}.

The standard test method for determining fracture toughness (K_{Ic}) of a metallic material is elaborated in hand book of ASTM-E399[42]. From the P_q value and the measured crack length for each test, conditional fracture toughness K_q is calculated using the Eq. (8):

$$K_q = \left(\frac{P_q}{B\sqrt{w}}\right) f\left(\frac{a}{w}\right) \qquad \text{Eq. (8)}$$

Where, $$f\left(\frac{a}{w}\right) = \frac{\left(2+\frac{a}{w}\right)\left(0.886+4.64\frac{a}{w}-13.32\frac{a^2}{w^2}+14.72\frac{a^3}{w^3}-5.6\frac{a^4}{w^4}\right)}{\left(1-\frac{a}{w}\right)^{3/2}}$$

a = crack length, mm.
B = specimen thickness, mm.
w = width of the specimen, mm.

The following conditions are also to be fulfilled to consider, the calculated value K_{Ic} as a fracture toughness of the material [42–45].

$$a \geq 2.5\left(\frac{K_{Ic}}{\sigma_y}\right)^2 \qquad \text{Eq. (9)}$$

$$B \geq 2.5\left(\frac{K_{Ic}}{\sigma_y}\right)^2 \quad \text{Eq. (10)}$$

$$w \geq 5.0\left(\frac{K_{Ic}}{\sigma_y}\right)^2 \quad \text{Eq. (11)}$$

RESULTS AND DISCUSSION

Fracture Toughness by SENB Specimen

A356 alloy matrix hybrid composites reinforced with zirconium silicate and silicon carbide particles has been successfully synthesized by the stir casting method. The results of the experiment are listed in Table 1.

Table 1: *Fracture Toughness of Al-SiC-$ZrSiO_4$ Particulate MMC[21].*

Sl No.	Composition	K_{IC} MPa√m
1.	A356+8%SiC+0%$ZrSiO_4$	15
2.	A356+4%SiC+4%$ZrSiO_4$	17
3.	A356+2%SiC+6%$ZrSiO_4$	18
4.	A356+6%SiC+2%$ZrSiO_4$	18
5.	A356+0%SiC+8%$ZrSiO_4$	15

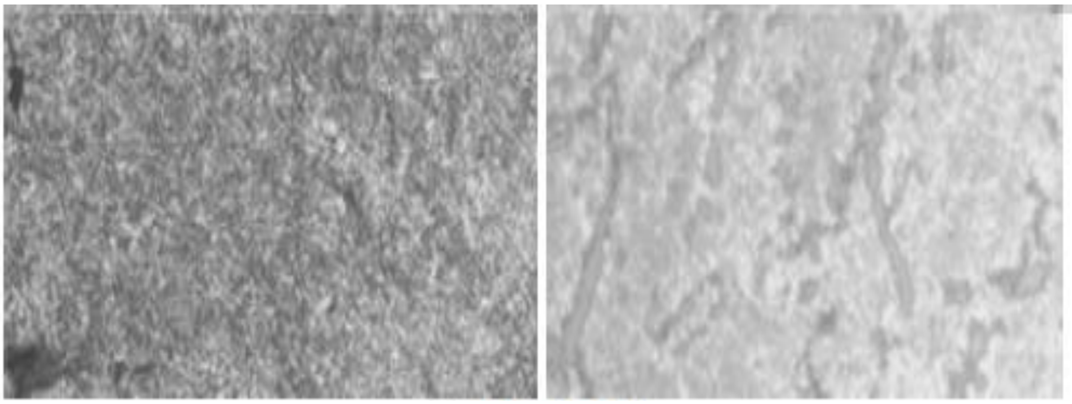

Fig. 7: *Microstructure of Al356+2%SiC+6%ZrSiO4.*

From the Figure 7 it is observed that homogenous distribution of the reinforcement SiCp and $ZrSiO_4$ particles in the cast composite. The fracture toughness was observed to improve significantly with the increase in the addition of the reinforcement SiCp and $ZrSiO_4$ particles in the A356 matrix. There is a considerable increase in the fracture toughness value for the combination of 6% SiC+2% $ZrSiO_4$ and 4% SiC+4% $ZrSiO_4$.

Elastic plastic fracture toughness J_{IC} tests and fatigue crack growth rate (FCGR) were conducted on BiSS 50 KN servo hydraulic universal testing machine by using SENB as per ASTM E-1820. The fracture toughness of the A6061 with Fly Ash (FA) composition was listed in Table 2 which shows decrease in the addition of the reinforcement particles 5%FA, 10%FA particles in the A6061 matrix[22].

Here the fracture toughness of Aluminum fly ash metal matrix composites A6061 was evaluated by using EPFM principle.[22]

Table 2: *Fracture Toughness of Al-Fly Ash Particulate MMC [22].*

Sl No.	Composition	a/W	F(a/W)	K_{IC} MPa√m	Elastic Plastic Fracture Toughness J_{IC}
1.	A6061	0.4	3.07	18.21	20.9
2.	A6061+5% FA	0.4	3.81	13.77	16.5
3.	A6061+10% FA	0.4	3.20	14.27	10.9

The fracture toughness of A6061 fly ash composites varied between 13 and 14 MPa√m as compared to 18 MPa√m for the re melted base alloy A6061 as listed in Table 2. The Elastic plastic fracture toughness J_Q for the base alloy A6061 = 20.93kJ/m^2 and for A6061-5% fly ash is 16.52 kJ/m^2 and A6061-10%FA is 10.90 kJ/m^2. This decrease in the fracture toughness of the composites is due to weak interface between the fly ash reinforcement and Aluminum alloy matrix which acts as small micro cracks. The nature of failure of the fractured surfaces of the Al-Fly ash composite was studied under scanning electron microscope (SEM).

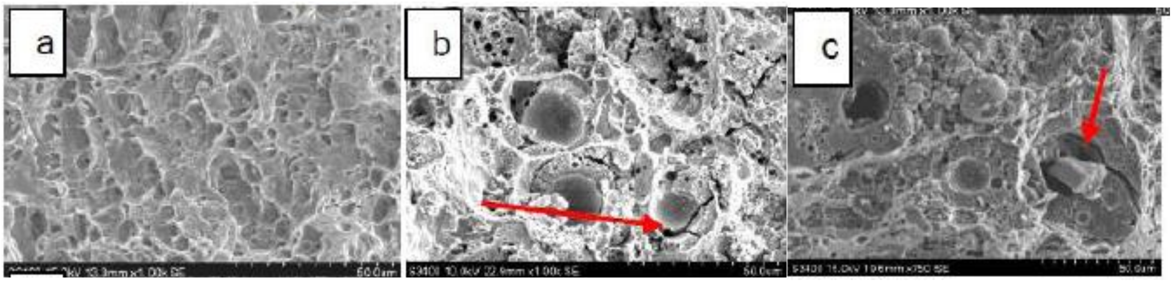

Fig. 8: *Fracture Surface of **(a)** Al6061 Base Alloy, **(b)** Al6061-5%FA and **(c)** Al6061-10%FA.*

The SEM study reveals the presence of micro crack and casting defects such as voids, porosity were generated in the specimen as shown in SEM micrograph Figure 8. These defects are due to non-uniform sizes of reinforcing particles, and their distributions in the matrix material. It is essential to get particles uniformly throughout the casting during particulate composite production.

Fracture Toughness by Round Bar

The tensile test of each pre-cracked circumferentially cracked round bar (CCRB) specimen was performed on a 400 kN Universal testing machine at room temperature. Table 3 shows the experimental observations of fatigue crack length, diameter of the specimen at the notch root and maximum load in tensile test for each specimen. The plane-strain fracture toughness of A6082-T6 alloy tested using CCRB specimen geometry was found to be in a range of 19.63 to 25.74 MPa√m. The fracture toughness K_{IC} values using mode-I loading condition were calculated using Eq. (1–3).

Table 3: *Fracture Toughness of A6082-T6 Alloy [30].*

Sl No.	a_f (mm)	d (mm)	P_{max} (kN)	K_{IC} MPa√m Eq. (1)	K_{IC} MPa√m Eq. (2)	K_{IC} MPa√m Eq. (3)
1.	0.08	9.84	33.00	19.63	20.54	20.77
2.	0.14	9.72	32.25	19.66	20.76	20.94

3.	0.22	9.56	31.50	19.85	21.18	21.90
4.	0.32	9.35	30.75	20.26	21.87	21.93
5.	0.42	9.16	30.00	20.62	22.45	22.44
6.	0.40	9.21	29.50	20.03	21.75	21.79
7.	0.63	8.74	29.00	21.87	24.05	24.08
8.	0.74	8.52	28.00	21.89	24.10	24.25
9.	0.94	8.11	25.00	21.89	24.10	24.25
10.	1.17	7.66	23.75	23.32	25.49	25.74

Results of the Eq. (1–3) are in agreement with each other with a maximum deviation of 9.73%. The plane-strain fracture toughness of A6082-T6 alloy is found to be varying from 19.63 to 25.74 MPa√m.

Fracture Toughness by Circumferential Notched Tensile (CNT) Specimens

Fracture toughness of the as-cast and age-hardened A6063-SiCp composite for 3, 6, 9, 12% SiC will be determined using a universal testing machine (UTM) using circumferential notched tensile (CNT) specimens. The plane strain fracture toughness condition was met with the specimen diameter D = 6 mm using Eq. (5) which will validate the K_{IC} values evaluated from experiment. The variation of fracture toughness for the as-cast and age-hardened A6063-SiC composites are presented in Figure 9 and the fracture toughness values given in Table 4.

***Table 4:** Fracture Toughness of A6063-SiC [23].*

Sl No.	Volume Percent % SiC	K_{IC} MPa√m	
		As-Cast	Age Hardened
1.	0	6.64	7.57
2.	3	6.61	7.60
3.	6	6.59	7.65
4.	9	5.63	7.80
5.	12	6.71	8.20

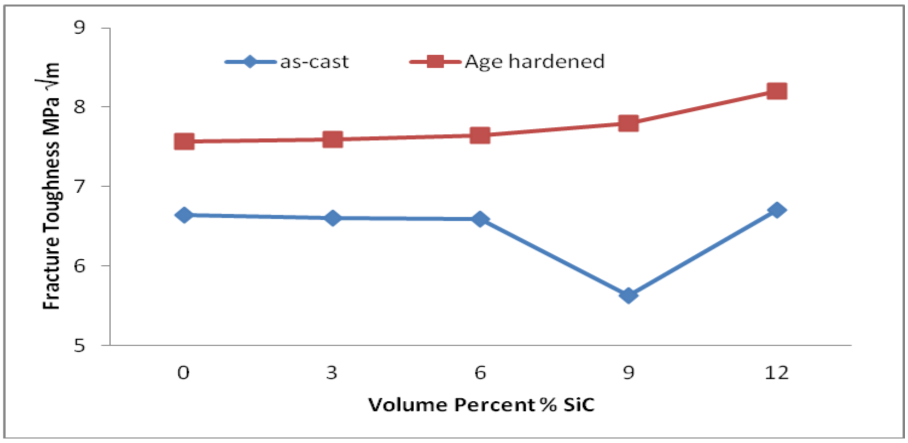

***Fig. 9:** Variation of Fracture Toughness (K_{1C}) with Increase in vol% SiC in the As-Cast and Age-Hardened Composites.*

From the results it is observed that fracture toughness improved significantly: for as-cast K_{IC} = 6.64 to 6.71 MPa√m, and for age-hardened K_{IC} = 7.57 to 8.20 MPa√m with increases as high as 22% achieved for the 12 vol% SiC reinforcement. The improvement might be due to the presence and distribution of fine coherent Mg_2Si precipitates formed in the A6063 matrix during ageing.

Fracture Toughness by Indentation Techniques

Fracture toughness was measured using Vickers indentation method from crack lengths. The 2–3 indents for each material were performed.

The Vickers's hardness value was calculated using Eq. (6). The length of cracks was measured by scanning electron microscope (SEM). From the length of the indentation cracks fracture toughness was calculated by applying the Anstis´ Eq. (7).

Fracture toughness of the different Al_2O_3-based composites fabricated here is tested using Vickers indentation technique and listed in Table 5.

Table 5: *Vickers Hardness and Fracture Toughness of Different Al_2O_3 Based Composites.* [35]

Sl No	Reinforced Metal	HV GPa	K_{IC} MPa√m
1.	Al_2O_3	20.97	3.2
2.	Al	18.62	4.1
3.	Co	18.61	4.3
4.	Fe_2Al	18.78	5.2
5.	Ti_3Al	16.10	7.3
6.	Zr_3Al	18.12	7.0

From Table 5 and Figure 10 it can be observed that in all the composite cases the fracture toughness of monolithic Al_2O_3 was improved considerably, principally in composites reinforced with Ni and Ti and in all composites reinforced with intermetallic phases.

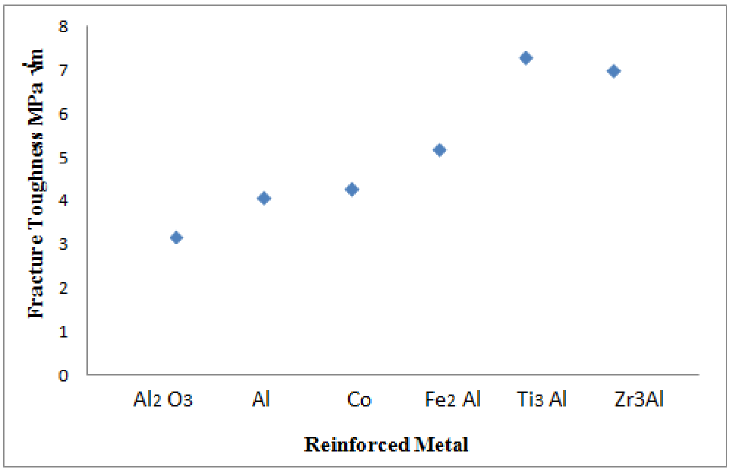

Fig. 10: *Fracture Toughness Values Measured for All the Composites Investigated.* [35]

For the case of Al_2O_3/inter-metallics systems: the use of inter-metallics as reinforcement in Al_2O_3 gives an appreciable enhancement in the fracture toughness, this is due to the good ductility, low density and chemical compatibility of inter-metallics with alumina.

Fracture Toughness by Compact Tension (CT) Specimen

Specimens of MMC materials can be successfully pre-cracked with controlled crack lengths by means of compressive fatigue loading to initiate the crack followed by tensile fatigue to complete the process. Pre-cracking with compressive fatigue only may influence the test results. Fracture toughness tests were performed on Al-SiCp pre-cracked compact tension (CT) specimen using testing machine for different weight fractions and the results of the experiment are tabulated in the Table 6.

Table 6: *Fracture Toughness of Al-SiCp Composites*[18].

Sl No.	Composition	K_{IC} MPa√m
1.	A356+10%SiCp [40]	19.4
2.	A356+20%SiCp [40]	24.1
3.	A6061+40%SiCp [18]	8.90

Test results met practically all the ASTM-E399 criteria for the calculation of plane strain fracture toughness of the material. A valid K_{IC} value of the SiCp/Al composite was established as K_{IC} = 8.9 MPa√m. [18]

Comparison

Comparisons of fracture toughness of Al/SiCp MMC using different fracture toughness testing methods were discussed below:

Compared to SiCp and ZrSiO4 particles flyash particles are of non-uniform sizes and weak in strength. These reasons may affect the fracture toughness values.

Using compact tension (CT) specimen fracture toughness of the Al/SiC particulate MMC was found to vary from 8.9 to 24 MPa√m whereas using circumferentially notched tensile (CNT) specimen fracture toughness was found to vary from 6.64 to 6.71 MPa√m for as-cast condition; and 7.57 to 8.2 MPa√m for age hardened condition.

Except 12% SiCp, the fracture toughness of as-cast Al/SiCp was observed to decrease with an increase in volume percent of SiCp. This decrement was due to increased sites (particles, particle/matrix interfaces, and particle clusters) for crack nucleation.

The fracture toughness of the Al-SiCp MMC was increased as high as 22% for the 12% SiCp reinforcement after the ageing treatment. The improvement in fracture toughness of the particulate composite was due to ageing in which Mg_2Si precipitates in the Al matrix.

In this review paper it was investigated the different methods in finding the fracture toughness which includes the American society for testing and materials (ASTM) standard methods and recent advances in fracture toughness testing methods which were getting popular for their ease. The material chosen for this study is restricted to Aluminum matrix, particulate reinforced (especially Silicon Carbide) composites which are nearly isotropic for its low density and also outstanding combination of thermal, physical and mechanical properties.

CONCLUSIONS

1. This paper gave technical review of different experimental methods of

evaluation of fracture toughness of Aluminum matrix particulate reinforced composites.
2. Fracture toughness using SENB and CT Specimens were widely used whereas indentation techniques, CNT, CCRB are on the other hand getting popular for their ease.
3. Fracture toughness of Aluminum matrix particulate composite decreases with increase in volume percentage of the reinforcement that might be due to increased particle clusters, particulate cracking, interfacial cracking or particle de-bonding.
4. Fracture toughness of Al-SiCp composite is varying from 5 to 9 MPa√m, fracture toughness of Al-Fly ash particulate composite is varying from 10 to 16 MPa√m, fracture toughness of Al-SiC-$ZrSiO_4$ particulate composite is varying from 15 to 18 MPa√m.
5. Fracture toughness of Al/SiC particulate composite increase at 12% after age hardening that may be due to Mg_2Si precipitation during ageing.
6. Fracture toughness of Aluminum alloy vary from 14 to 28 MPa√m and for the Aluminum matrix particulate composite was found to be less than 28 MPa√m for various fracture toughness test methods. [1]

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