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Evaluation of Fracture toughness of Al 7075 Hybrid MMC by Experimental and FEA methods

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Abstract— Aluminium and its alloys have continued to maintain their mark as the matrix material most in demand for the development of Metal Matrix Composites (MMCs). This is primarily due to the broad spectrum of unique properties it offers at relatively low processing cost [1-5]. Some of the attractive property combinations of Al based matrix composites are: high specific stiffness and strength, better high temperature properties (in comparison with its monolithic alloy), thermal conductivity, and low thermal expansion. The project is associated with the study of Fracture Toughness of Aluminium, Zirconium Silicate and Silicon Carbide Metal Matrix Composite (MMC)[6-12]. Aluminium alloy of grade 7075 with addition of varying weight percentage composition of Zirconium Silicate and Silicon Carbide particles by stir casting technique was developed[13-15]. Finite element (FE) simulations for the proposed SENB geometry was carried out using ANSYS software package (v12) to investigate stress distribution around the notch and to validate the experimental results.

Index Terms— Al 7075, Silicon Carbide, Zirconium Silicate, MMC, Stir Casting, Fracture, SENB, Toughness.

1 Introduction

New and high performance particle reinforced metal matrix composites (PRMMC) are expected to satisfy many requirements for a wide range of performance-driven, and price sensitive, applications in aerospace, automobiles, bicycles, golf clubs, and in other structural applications. In general, these materials exhibit higher strength and stiffness, in addition to isotropic behavior at a lower density, when compared to the un-reinforced matrix material. PRMMC benefits from the ceramic's ability to withstand high velocity impacts, and the high toughness of the metal matrix, which helps in preventing total shattering. This contribution leads to an excellent balance between cost and mechanical properties, which are appealing for many applications. The recognition of the potential weight savings that can be achieved by using the advanced composites, which in turn means reduced cost and greater efficiency, was responsible for this growth in the technology of reinforcements, matrices and fabrication of composites. If the first two decades aw the improvements in the fabrication method, systematic study of properties and fracture mechanics was at the focal point in the 60's. Since then there has been an ever-increasing demand for new, strong, stiff and yet light-weight materials in fields such as aerospace, transportation, automobile and construction sectors. These materials have low specific gravity that makes their properties particularly superior in strength and modulus to many traditional engineering materials.

2 SCOPE AND OBJECTIVE

The aim of the project is to synthesize and characterize hybrid metal matrix composite by stir casting technique and to experimentally evaluate the fracture toughness and mechanical properties of the composite. Then finite element analysis is carried out to validate the obtained results. The objectives of the project are listed below.

- Preparation of composite casting by liquid metallurgy route.
- Preparation of specimen to required dimensions for carrying out the test.
- The micro structural observations to evaluate the quality of the castings i.e., base alloy with Silicon Carbide and Zirconium Silicate.
- Test is conducted to evaluate the Fracture toughness.
- Finite element (FE) simulation to validate the results.

3 Experimental Set-Up

3.1 Selection of Materials:
Matrix Material

Fig 1: Ingot Structure of Al 7075

Reinforcement Materials

FIG 2: ZIRCONIUM SILICATE **FIG 3: SILICON CARBIDE**

3.2 Fabrication by Stir Casting

- Aluminum (Al 7075) 3kg was melted in the furnace to a temperature of 850^0c
- Addition of scum powder.
- Formation of slag.
- Slag removal.
- After 10 mins titanium dioxide was added to remove the entrapped gases (degasification) and Stirrer was introduced.
- Stirrer was rotated at a speed of 0 to 300 rpm to create a vortex in the liquid metal.
- Reinforcement material SiC and $ZrSiO_4$ powder was added according to the required proportions to molten metal in steps while stirring.

3.3 Composition of matrix and reinforcement

Table 2. Different wt% ratios of matrix metal & Reinforcement

Samples	Al7075 (kg)	Sic (%)	$ZrSio_4$ (%)
1	3	-	8
2	3	6	2
3	3	2	6
4	3	4	4
5	3	8	-

The casting samples with different wt% reinforcements were prepared respectively as shown below.

Casting 1: Al7075+0%SiC+8%$ZrSiO_4$
Casting 2: Al7075+6%SiC+2%$ZrSiO_4$
Casting 3: Al7075+2%SiC+6%$ZrSiO_4$
Casting 4: Al7075+4%SiC+4%$ZrSiO_4$
Casting 5: Al7075+8%SiC+0%$ZrSiO_4$

4 EXPERIMENTAL DETAILS

4.1 Fracture Toughness:

The measurement of valid plane strain fracture toughness, (K_{IC}) values for particulate reinforced metal matrix composites is an important step in the process of developing useful products from these materials and increasing confidence in their properties and performance.The measurement procedure of fracture toughness is based on the principle of linear-elastic fracture mechanics (LEFM) and contains three main steps: generation of cracks in the test specimen, measurement of the load at failure stress respectively, and crack depth. In the case of ideally brittle materials, the fracture toughness is independent of the crack extension. The crack growth resistance increases with the increasing crack extension. Some structural ceramics show an increase of fracture resistance with crack extension under stable crack growth. The Single-Edge-Notched Beam (SENB) method was developed as a simple and inexpensive alternative, but the results can be influenced by the tip radius of the sawed notch.

4.2 Specimen dimensions as per ASTM standards

The Samples were cut to the dimensions as per ASTM standards ASTM C393-62 for Testing; ASTM standards are given in Table 3.

Table 3. ASTM codes for mechanical test and sample dimensions

SL No	ASTM Code	Mechanical Test	Sample Dimensions (mm)	Span Length (mm)
1	ASTM-D790	Flexural	127 x 13 x 6	65

4.3 Test for Fracture toughness:

The Fracture toughness of the specimens was determined as per ASTM-D790. The specimens (127 X 13 X 6 mm) were tested with a span length of 65mm using three point bend setup with 10 ton capacity high precision computer controlled UTM. The rate of loading was maintained at 1mm/min. The tests were performed with a load resolution of 0.5 N at a loading rate of 1 mm/min. The total span (length) of the specimens was 65 mm. The single edge notch bend (SENB) specimens were used to determine the fracture behaviour by K_{IC}, as shown in Fig 4, which satisfied the requirements of ASTM D5045-99.The Fig.5 shows the fracture toughness specimens.

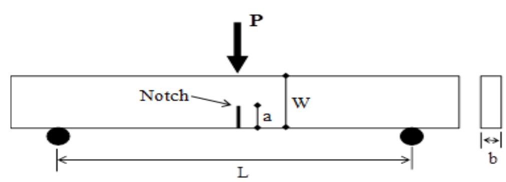

Fig 4: SENB Specimen

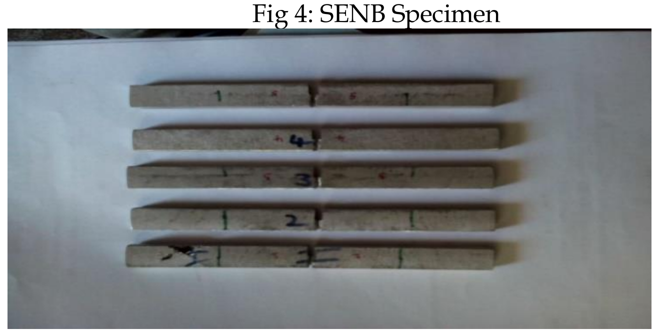

Fig 5. Fracture Test Specimens

4.4 FEA of Fracture Toughness Specimens

The study is performed on common specimen with nominal dimensions equal to 127×13×6 mm with and span S = 65 mm. In the mid span of the specimen a notch is created with length 6mm and width 1mm. The geometry of the SENB specimen was modeled in catia and is shown in Fig.6. In this study the three point bending test is performed experimentally and then repeated with FE technique.The meshing was done using quadrilateral elements and a fine mesh was obtained.

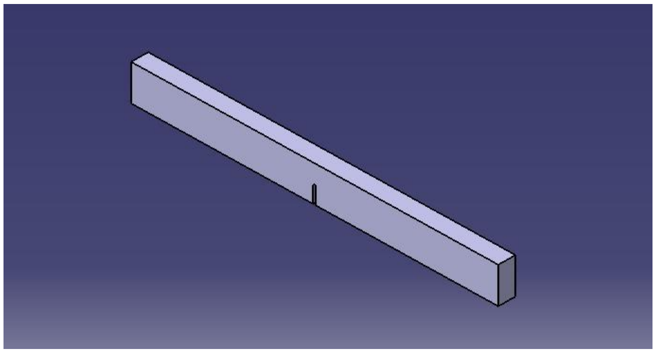

Fig 6.SENB specimen model

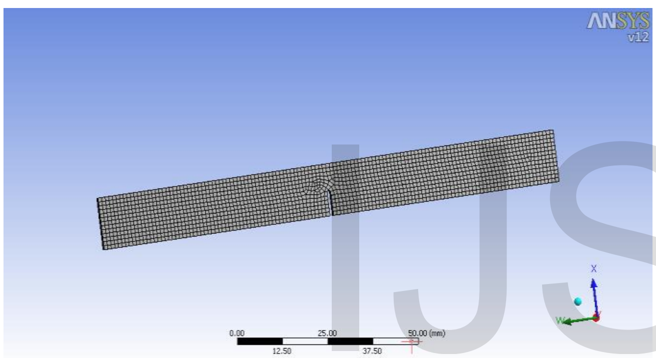

Fig 7. Meshed Model

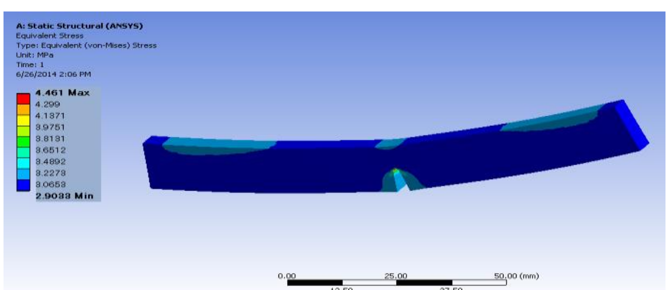

Fig.8 Stress Distribution from FEM Simulations

The following equation is used to calculate the fracture toughness, K_{IC}, of MMC:

$$K_{IC} = \frac{PL}{bW^{3/2}} f\left(\frac{a}{W}\right) \quad \text{--------------- (1)}$$

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

The stress value obtained from FEA is shown in the Fig.8. The values of the maximum load at which the specimen breaks are taken by the experimental results. Eq. (1) is used to calculate the fracture toughness of the specimen. The stress in Eq. (1) is determined using FE technique, by analyzing the SENB specimen under different loading conditions. The geometric factor of the specimen is calculated using Eq. (2) by the known dimensions of the specimen. By putting the stress values obtained by the FEA technique in Eq. (1) gives us the Fracture Toughness for all the composition of the composite. The values of fracture toughness calculated in this study are near to the general range of fracture toughness values obtained experimentally.

5 RESULTS AND DISCUSSIONS:

5.1 Fracture Toughness Results:

The fracture toughness (which is a measure of the resistance to crack propagation) was observed to improve significantly with the increase in the addition of the reinforcement particles. The improvement might be due to the presence and distribution of fine SiC and $ZrSiO_4$ particles in the Al matrix. There is a considerable increase in the fracture toughness for the combination of 6% SiC+2% $ZrSiO_4$ and 4% SiC+4% $ZrSiO_4$. The deformation and fracture behavior of the composite reveals the importance of particle size. It is well established that large particles are detrimental to fracture toughness due to their tendency towards fracture. A reduction in particle size is observed to increase the proportional limit, yield stress and the ultimate tensile stress.

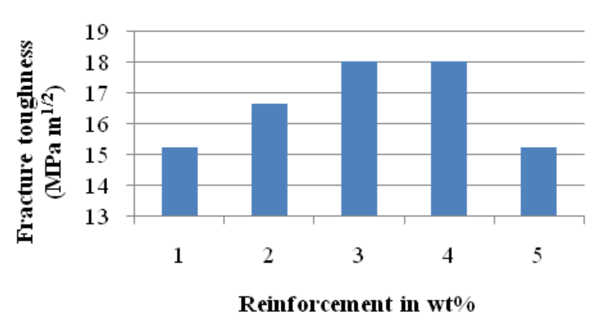

Fig 8: Variation of Fracture toughness with different Wt% reinforcement

5.2 Comparison of the Experimental and FEA results

	Al7075+ 0%Sic+ 8%Zrsio4	Al7075+ 0%Sic+ 8%Zrsio4	Al7075+ 0%Sic+ 8%Zrsio4	Al7075+ 0%Sic+ 8%Zrsio4	Al7075+ 0%Sic+ 8%Zrsio4
Fracture toughness (experimental)	15.27	16.67	18.05	18.05	15.27
Fracture toughness (FEA)	14.13	15.28	16.89	16.89	14.13

From the table its clear that the difference in the experimental and FEA results are well within the acceptable range, i.e, it is less than 5%.

6 Conclusions

- Al 7075 alloy matrix hybrid composites reinforced with Zirconium Silicate and Silicon Carbide particles has been successfully synthesized by the stir casting method.
- The results from the study reveal that there is considerable increase in the fracture toughness in the presence of both silicon carbide and zirconium silicate reinforcement in the matrix alloy. The matrix alloy with 2%SiC and 6%$ZrSiO_4$ reinforcement has shown high toughness for fracture.
- Aluminum based metal matrix composites are the most promising materials for the future automotive, aerospace and other applications.
- There is close matching in the fracture toughness values of experimental and FEA.

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