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# Experimental Determination and Analysis of Fracture Toughness of MMC

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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. 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 and mechanical properties of Aluminium, Zirconium Silicate and Silicon Carbide Metal Matrix Composite (MMC). Here we have used the Aluminium alloy of grade 356 with addition of varying weight percentage composition of Zirconium Silicate and Silicon Carbide particles by stir casting technique. 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. The mechanical properties were tested under laboratory conditions. The change in physical and mechanical properties was taken in to consideration. For the achievement of the above, an experimental set up was prepared to facilitate the preparation of the required specimen. The experiments were carried out to study the effect of variation of the percentage composition to predict the mechanical properties as well as to measure the micro hardness.***

**Keywords:** Al 356, 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 saw 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 the various tests.
- The micro structural observations to evaluate the quality of the castings i.e., base alloy with Silicon Carbide and Zirconium Silicate (Al356+Sic+ZrSio4).
- Tests are conducted to evaluate the Fracture toughness and mechanical properties such as tensile, hardness and compression.
- Finite element (FE) simulation to validate the results.

## 3. Experimental Set-Up

### 3.1 Selection of Materials:

**a) Matrix Material**

**Figure 1:** Ingot Structure of Al 356

**Table 1:** Chemical composition and mechanical properties of matrix material Al356

| Element | Si | Fe | Cu | Mn | Mg |
|---|---|---|---|---|---|
| Wt% | 7.5% | 0.2% | 0.25% | 0.35% | 0.45% |

| Element | Ni | Zn | Ti | Pb | Aluminium |
|---|---|---|---|---|---|
| Wt% | 0.1% | 0.35% | 0.2% | 0.1% | Rem |

### b) Reinforcement Materials

**Figure 2:** Zirconium Silicate Fig 3: Silicon carbide

### 3.2 Fabrication by Stir Casting

- Aluminum (Al356) 3kg was melted in the furnace to a temperature of $850^0$c
- 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 | Al356 (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: 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%$ZrSiO_4$

## 4. Experimental Details

### 4.1 Fracture Toughness

The measurement of valid plane strain fracture toughness, (KIC)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 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 | M 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 6.1, which satisfied the requirements of ASTM D5045-99.

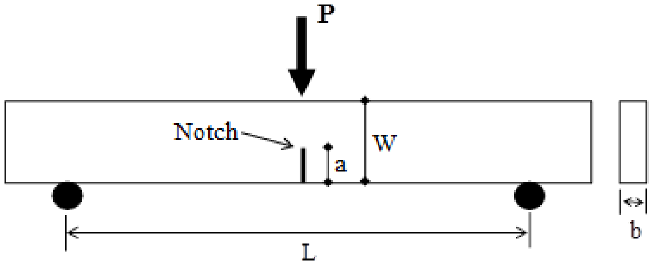



**Figure 3:** SENB specimen

**Figure 5:** Fracture Test Specimens

### 4.4 Tensile test:

Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area.

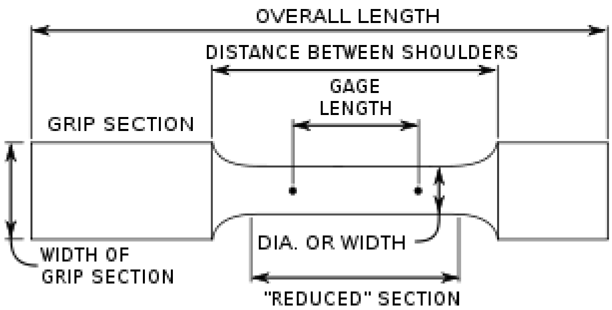



**Figure 6:** Tensile Specimen

**Figure 7:** Specimens for Tensile test

### 4.5 Hardness test

The hardness of the specimens was measured using a standard Brinell hardness testing machine. The hardness tests were conducted in accordance with the ASTM E10 standards

**Figure 8:** Hardness test specimens

### 4.6 Compression test

Compression test was carried out using a standard 10-ton capacity universal testing machine. The tests were conducted according to ASTM E9 at room temperature

**Figure 9:** Compression test specimens

### 4.7 Microstructure

The optical metallurgical microscope (model: NIKON Epiphot 200) was used for microstructure characterization of the Al356 matrix alloy reinforced with SiC and $ZrSio_4$ to study the effect of reinforcement on the matrix. The specimens for optical microscopy were prepared according to ASTM E3 standards. The samples were first subjected to grinding and polishing followed by etching. Grinding and polishing after usual grinding and machining, the specimens were rough polished using 100, 200, 400, 600, 800 and 1200 grit silicon carbide papers.

### 4.8 Finite element analysis

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 figure 1.10. In this study the three point bending test is performed experimentally and then repeated with FE technique.

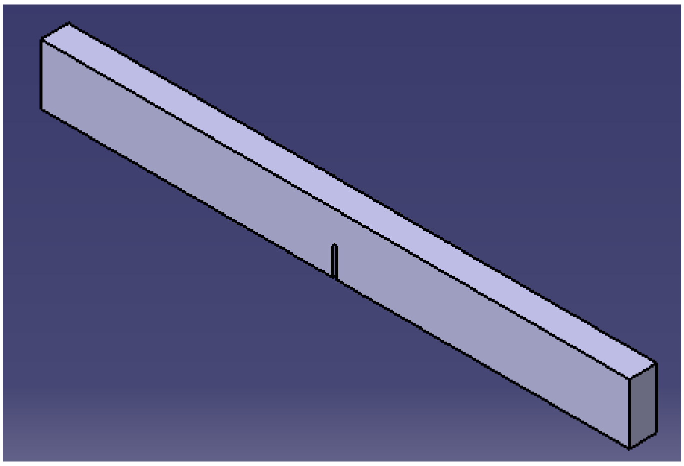


**Figure 10:** SENB specimen model

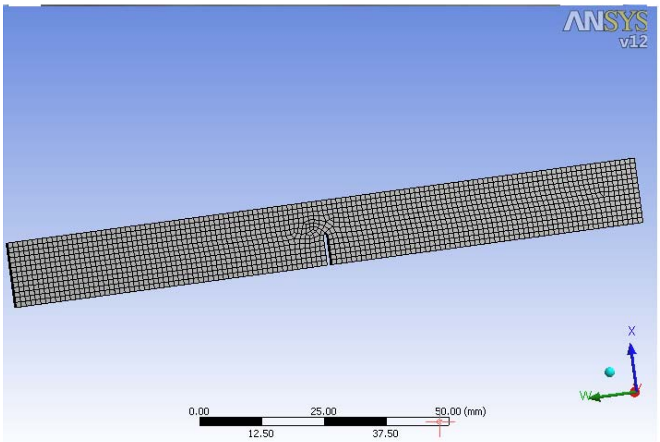



**Figure 11:** Meshed Model

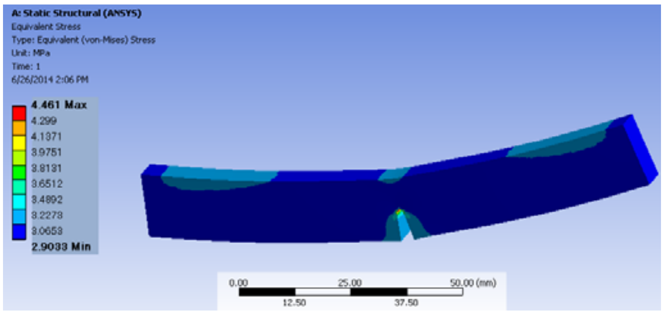



**Figure 12:** Stress distribution from finite element simulations

## 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.

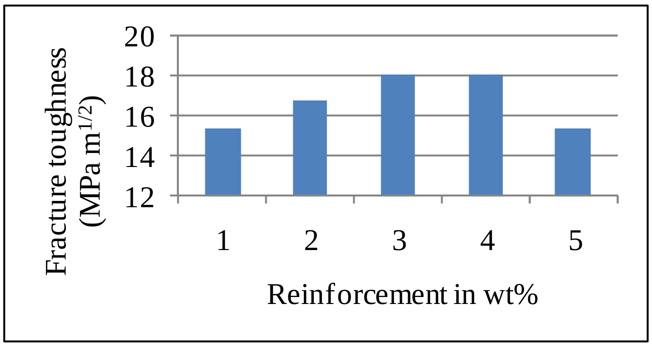



**Figure 13:** Variation of Fracture toughness with different Wt% reinforcement

### 5.2 Tensile Test Results

The average values of the ultimate tensile strength, yield strength, and % elongation obtained from the tensile test are summarized in table 7.2. It is observed that the tensile strength and yield strength are increased with an increase weight percent of both SiC and $ZrSiO_4$. The increase was more significant for the Al cast with 6%SiC+2%$ZrSiO_4$ and 2%SiC+6%$ZrSiO_4$. The increase in tensile strength is due to the presence of the hard and higher modulus SiC and $ZrSiO_4$ particles embedded in the Al (356) matrix, which act as a barrier to resist plastic flow when the composite is subjected to strain from an applied load. Also, the decreased interparticle spacing, due to the increasing weight percent of SiC and $ZrSiO_4$reinforcement, creates increased resistance to dislocation motion, which contributes to the enhanced strength of the composites.

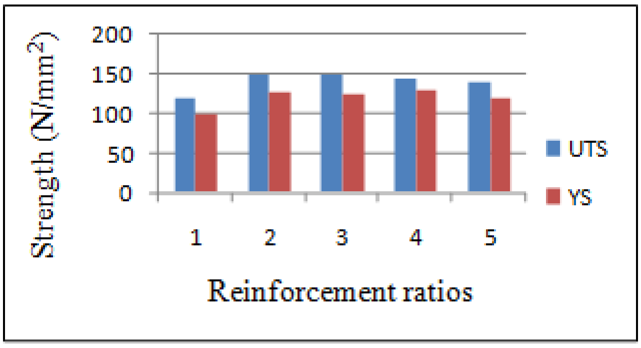



**Figure 14:** Variation of tensile strength and yield strength

From the above figure it can be noticed that the tensile property of the composite is less for zircon sand alone and silicon carbide alone reinforcement. The resultant graph shows that the tensile properties are high in case of the hybrid composite for both zirconium silicate and silicon carbide as the reinforcement. From the above graph it can be concluded that the tensile properties are high for the hybrid composites compared to the composites with zircon alone as reinforcement and silicon carbide alone as the reinforcement.

### 5.4 Compression Test Results

The compression strength of the matrix alloy reinforced with SiC and $ZrSiO_4$ is shown in Fig 7.4. It can be observed from the fig below that the composition with 0%SiC+8%$ZrSiO_4$ and 2%SiC+6%$ZrSiO_4$ have high compression strength.

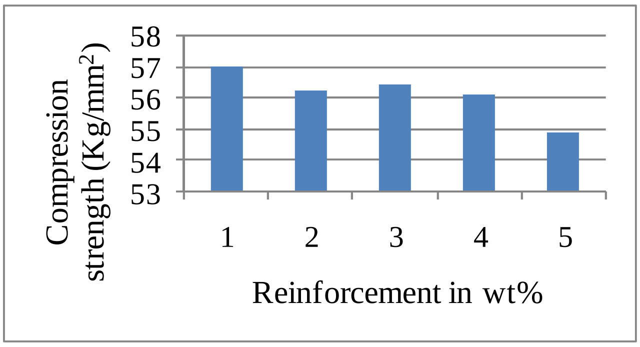



**Figure 15:** Compression strength for different wt% reinforcement

### 5.3 Hardness Test Results

The presence of reinforcement particles in the matrix could impede the movement of dislocations since these particles are stronger than the matrix in which they are embedded. it has been observed that the hardness values are high for the matrix with weight percent reinforcement of 2%SiC+6%$ZrSiO_4$ and 4%SiC+4%$ZrSiO_4$. This is also due to high proportion of the hard and brittle phase of the zircon sand in the alloy. The zircon sand addition to the matrix alloy results to elastic and plastic incompatibility due to differences in the coefficient of thermal expansion in the hard reinforcing and soft matrix alloy, which causes high dislocation density. The high dislocation density also contributed to high hardness value.

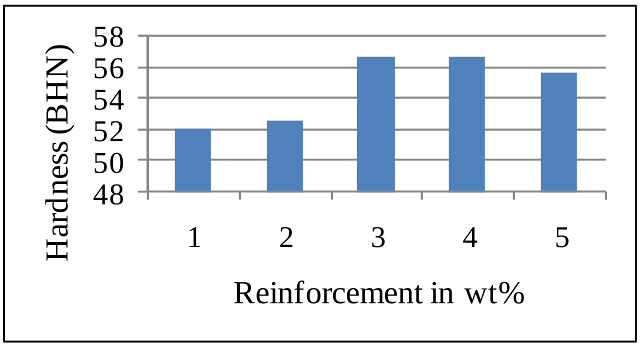
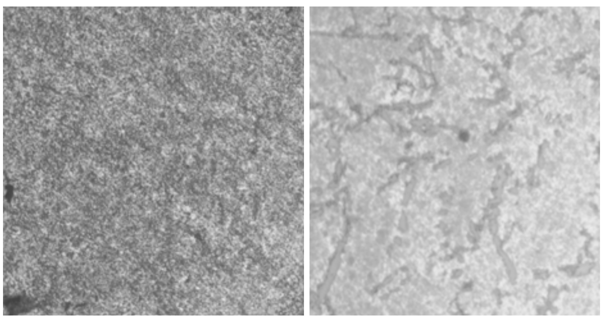



**Figure 16:** Hardness value for different wt% reinforcement

### 5.4 Microstructure



**100X 500X**
**Figure 17:** Microstructure of Al356+2%SiC+6%$ZrSiO_4$

It can be observed that there is a reasonably homogenous distribution of the reinforcement particles in the cast composite, due to which there is considerable increase in properties.

## 6. Conclusion

Aluminum based metal matrix composites are the most promising materials for the future automotive, aerospace and other applications. Al 356 alloy matrix hybrid composites reinforced with Zirconium Silicate and Silicon Carbide particles has been successfully synthesized by the stir casting method.

1. 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.
2. The result shows the increasing hardness with the increase in the reinforcement weight fractions. The presence of hard reinforcement particles in the matrix could impede the movement of dislocations since these particles are stronger than the matrix in which they are embedded.
3. The ultimate tensile strength and the yield strength of the composite are more in presence of both the reinforcement than compared to the alloy in presence of single reinforcement. The increase in the strength can be attributed to homogeneity of the reinforcement particles in the matrix alloy.
4. Microstructure reveals a reasonably homogeneous distribution of SiC and $ZrSiO_4$ particles in the cast composite. It was found that the particles showed a strong tendency to accumulate in the colonies which froze in the last stage of solidification.

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