RESEARCH ARTICLE OPEN ACCESS

Studies On Fracture Toughness Behavior of Hybrid Aluminum Metal Matrix Composites

Arun C Dixit U[1], Mamatha.Y.P[2], Balu Vijay S N[3], Shivashankar R[4]
[1,2,3,4]*Department Of Mechanical Engineering, Vidyavardhaka College Of Engineering, Mysuru -02*

ABSTRACT
The limited mechanical properties of Al and its alloys adversely affect its applications in automobile and aerospace industries. This remains one of the major concern in the fabrication to suit its application in recent days. The main aim of the present work is to improve the fracture toughness of the Al matrix composite . A composite with Al 6061 alloy as matrix and Zirconium Oxide as reinforcement is fabricated by stir casting process. The specimens were prepared according to ASTM standards and fracture toughness, tensile and hardness tests were performed and the properties were investigated. Zirconium oxide is selected as a reinforcement because of its ability to influence the microstructure of the Al 6061 alloy to improve the fracture toughness. The fracture toughness is highest at 6% reinforcement of ZrO_2 and hardness is found to be more at 4% reinforcement.
Keywords: Fracture Toughness, Zirconium Oxide, Al 6061, SENB, Stir Casting, Metal Matrix Composite.

I. INTRODUCTION

Aerospace applications are the original driving force for metal matrix composite development. This is due to the quest for weight reduction for improved performance and payload capabilities combined with high value placed on weight savings. In the automotive market, properties of interest to the automotive engineer include increased stiffness, wear resistance, improved cycle fatigue resistance and fracture toughness. Weight saving is also important in automotive applications for achieving performance. In commercial and industrial sector, improved performance is highly valued. As a result, many materials that gain favour in aerospace and automotive industries are also applied in this sector. Metal matrix composites gives the solution to the contemporary problems, considering the factors like cost effectiveness and hostile environmental conditions.

II. METHODOLOGY

The main objective of this work is to fabricate Al6061-ZrO_2 metal matrix composite by stir casting process, to prepare specimens and investigate tensile, hardness and fracture toughness properties according to ASTM standards. Finally analysing the microstructure of the composite.

III. MATERIAL SELECTION

Matrix Material- Al 6061

Table 1 Composition of Al6061 alloy

Manganese	0.15%
Iron	0.70%
Copper	0.15-0.40%
Magnesium	0.15%
Silicon	0.4-0.8%
Zinc	0.25%
Chromium	0.4-0.35%
Aluminium	0.05-0.15%
Others	95.8-98.6%

Table 2 Composition of Al 6061 & ZrO_2 for specimen preparation

S.No	Reinforcement %
Specimen 1	As Cast Al 6061
Specimen 2	2%
Specimen 3	4%
Specimen 4	6%
Specimen 5	8%
Specimen 6	10%

Fabrication By Stir Casting

The quantities of zirconium oxide were taken in a crucible and was heated to a temperature of 400^o C for 15 mins. Al 6061 was heated in the furnace at a temperature of 900^oC.The molten material was stirred with a stirrer speed of 220 rpm to create vortex , then the heated reinforcements were added and stirred. The composites were cast using conventional methods.

Fig 2 Stir Casting Apparatus

Specimens for Investigation

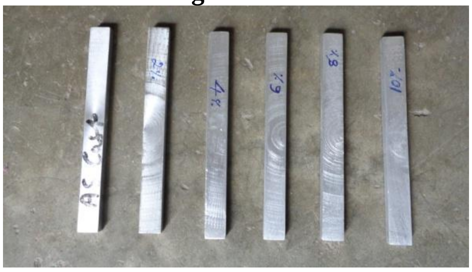

Fig 3 Fracture Test Specimens

Fig 4 Tensile Test Specimens

Fig 5 Hardness Test Specimens

Fig 3, 4, 5 shows the specimens prepared for fracture, tensile and hardness test according to ASTM E 1820-13, E 8, E 10.

IV. TESTING FRACTURE TEST

The Fracture toughness is determined as per ASTM-E1820-13. The specimens were tested with a span length of 65mm using three point bending with 10 ton capacity of computer controlled UTM. The rate of loading was kept at 1mm/min. The total span of the specimens was 65 mm. The single edge notch bend (SENB) specimens were used to determine the fracture toughness.[2] The experimental setup is as shown in fig.6.

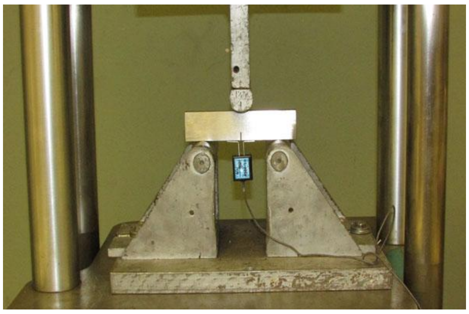

Fig. 6 Three Point Bending Fracture Test Method

Tensile Test

Tensile Test was carried out on a computerized UTM according to ASTM E8.The experimental setup is as shown in figure 8.

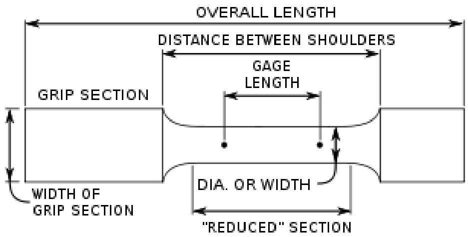

Fig.7 Tensile Test Specimen

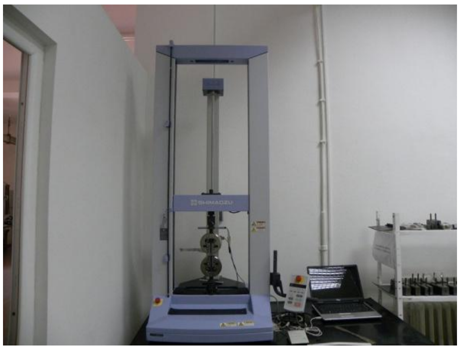

Fig 8 Universal Testing Machine to perform Tensile Tests.

Hardness Test

Hardness test was done with standard Brinell Hardness Testing Machine. Test was perfomed according to ASTM E10.

Fig 9 Brinell Hardness Testing Machine

Microstructure Study and Analysis

Microstructure is the microscopic definition of each constituents in the material. Precisely, it's the study of crystalline structure , composition, size, interaction, orientation and eventually their effect on macroscopic behavior in terms of toughness, hardness, tensile and compressive strength and corrosive resistance

V. RESULTS AND DISCUSSION

Tensile Test Results

Table 3 Tensile and Yield Strength for various wt.% of reinforcenment

Specimen	Tensile Strength in N/mm^2	Yield Strength N/mm^2
As cast Al 6061	147.65	134.61
2%	124.058	108.376
4%	126.772	113.896
6%	104.233	92.934
8%	96.686	87.975
10%	96.775	89.228

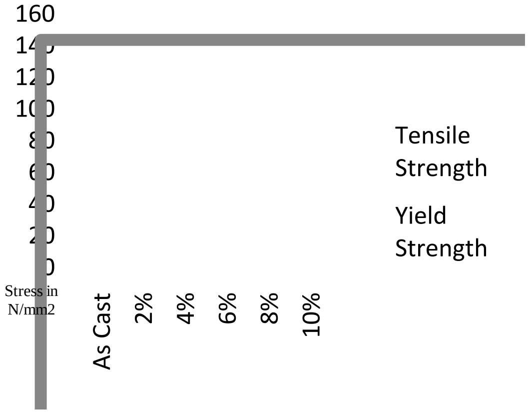

Fig 10 Variation of Tensile and Yield Strength for different composition of ZrO_2

Specimen	Brinell Hardness
As Cast	70.2
2%	76.3
4%	80.4
6%	65.5
8%	68.8
10%	67.5

It can be seen that there is a decrease in both tensile and yield strength of the composite as the weight fraction of the reinforcement is increased. This decrease is more pronounced at the Al6061+6%ZrO_2 composition. When Zirconia is under tensile or compressive strain by external force, its structure will be changing from tetragonal phase to mono-clinic phase, and it is similar with "Martensitic transformation" which is caused by steel quenching. The unique phenomenon which is utilizing phase transformation to absorb energy and increase ceramic toughness, is called "Stress-induced phase transformation". Also the decrease in molecular spacing, because of increased weight of ZrO_2 causes resistance to dislocations. Thus, we can witness the reduction in the tensile properties of the composite.

VI. FRACTURE TEST RESULTS

Table 4 Fracture Toughness for various wt.% of reinforcenment

Specimens	Fracture Toughness Mpa√m
As cast Al 6061	25.64
2%	21.37
4%	22.79
6%	31.01
8%	18.521
10%	18.28

Composition of Al-ZrO_2 Composite

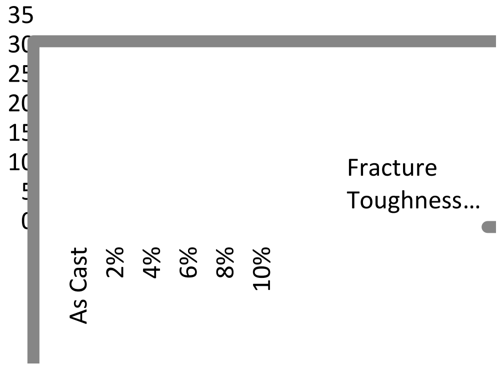

Fig 11 Variation of Fracture Toughness for different composition of ZrO_2

From the graph, it can be seen that the fracture toughness decreases with 2% ZrO_2 and reaches the peak value at 6% ZrO_2 and the fracture toughness value decreases with further increase in the reinforcement percentage. Due to the phase transformation and ability of the zirconia to influence the microstructure of the matrix material, by making them finer, brittleness is overcome.

VII. HARDNESS TEST RESULTS

Table 3 Brinnel Hardness for various wt.% of reinforcenment

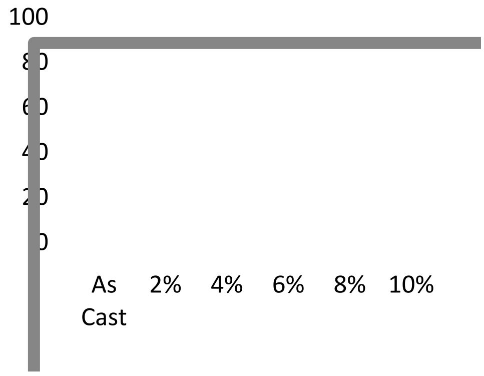

Fig 12 Variation of Brinell Hardness for different composition of ZrO_2

From the above graph it can be seen that the brinell hardness is increased with the increase in percentage of reinforcement and reaches its maximum value at 4%.And with further increase in the reinforcement, the hardness tends to decrease. At room temperature, the mechanical strength & fracture toughness for Zirconia (ZrO_2) is the most powerful within all ceramic materials; therefore it has another appellation "Ceramic Steel". The Vickers Hardness is about 1400HV.

VIII. MICROSTRUCTURE ANALYSIS

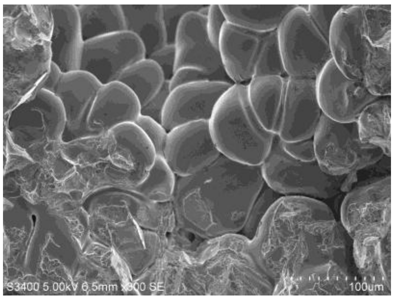

Fig 13 Microstructure of Al 6061 as cast ×300

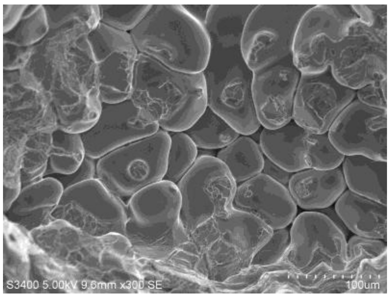

Fig 14 Microstructure of 6% ZrO_2 ×300

The homogenous distribution is achieved by the shearing forced caused by stirring which also averts settling of particles. Homogenous distribution leads to better wear and mechanical properties. The collection of particles in some places is evident in cooling case, this is because of porosity associated with it. Porosity is formed due to entrapment of moisture and air.

IX. CONCLUSION

Aluminum metal matrix composite materials are the most potential materials for future automotive, aerospace and other sophisticated applications. Al 6061 matrix composites reinforced with Zirconium Oxide has been successfully produced by the stir casting method.

1. The results from the work manifests that there is increase in the fracture toughness in the presence of zirconium oxide in the matrix alloy. The composite with 6% ZrO_2 reinforcement has shown highest value of fracture toughness.
2. The result shows the increase in hardness for 4% weight fraction of zirconium oxide. The hard reinforcement particles in the matrix will obstruct the movement of dislocations ,as these particles are harder than the matrix.
3. The yield strength and the ultimate strength of the composite is reduced as the weight fraction of ZrO_2 is increased in the matrix.
4. Microstructure shows reasonable homogeneous distribution of ZrO_2 particles in the composite.

REFERENCES

[1]. Anthony Kelly, Karl Zweben, " Comprehensive composite materials: design and application", Elsevier, volume 6, ISBN-0-08-043724-9.
[2]. Shivaraja H. B & B. S. Praveen Kumar, "Experimental Determination and Analysis of Fracture Toughness of MMC", International Journal of Science and Research (IJSR),2012.I.S.
[3]. K.B. Girisha, Dr. H.C.Chittappa, "Preparation, Characterisation of Wear Study of Al 356.1 Reinforced with Zirconium Nano Particles ",
[4]. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 8, August 2013
[5]. Jacobs and C.P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.
[6]. K. Elissa, "Title of paper if known," unpublished.
[7]. R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.
[8]. Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740-741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
[9]. M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.
[10]. P.O Babalola1, C.A Bolu1, A.O Inegbenebor1 and K.M Odunfa,
[11]. "Development of Aluminium Matrix Composites: A review" Online International Journal of Engineering and Technology Research, pp.1-11, Vol 2, 2014