SYNTHESIS AND CHARACTERIZATION OF Al-6061/FLY-ASH/ZrO_2 METAL MATRIX COMPOSITES (MMCs) PROCESSED BY STIR CASTING METHOD

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Abstract: - The present work has been carried out to investigate the effect of adding Zirconium oxide and Fly ash in Al-6061 to form a metal matrix composite. The composite has been produced by stir casting process. The volume fractions of both the reinforcing constituents have been varied. Hardness and Impact strength tests have been performed on the prepared samples. The results are showing the improvement in mechanical properties of the composite by the addition of these constituents.

Index Terms: Aluminium 6061, Fly-ash, Zirconium oxide, Metal Matrix Composite (MMCs), Stir casting.

INTRODUCTION:-

Composites are just a combination of materials in such a way that the resulting materials have desired properties. Nowadays composite materials are widely used for many number of applications like engineering structures, aerospace, marine application, sports and so on.[1] Composites are one of the most advanced and adaptable engineering materials. A fast progress in the field of material science and technology has given birth to these fascinating and wonderful materials. Composites are heterogeneous in nature. [5] Aluminum metal matrix composites (Al MMCs) are being considered as advanced materials for its light weight, high strength, high specific modulus, excellent wear resistance and low co-efficient of thermal expansion compared to conventional metals and alloys. [3] Beinias et al. used aluminium with fly-ash as reinforcement and concluded that with the addition of fly-ash brittleness and corrosion increases as it forms porosity. [2] Sudarshan and M. K. Surappa has synthesized A356 Al-fly-ash particle composites. They studied the mechanical properties and dry sliding wear and come into brief idea that the damping capacity of the composite increases with the increase in the volume fraction of fly-ash. [6] Malhotra et al. investigated the effect of reinforcement (Zirconia+ Fly-ash) on the mechanical properties of Al-6061 composites samples, processed by stir casting techniques. The composites were prepared with fixed percentage of Fly-ash (10%) & with varying percentages of Zirconia (5% & 10%) by weight fraction. The Hardness and ultimate tensile strength were improved, when compared with the unreinforced alloy whereas elongation decreased as compared to unreinforced aluminium. [5]

EXPERIMENTAL:-

In this work Al-6061 is used as a matrix and Fly-ash and Zirconium oxide as reinforcement.

Aluminium 6061: It is a precipitation of hardening aluminium alloy having a density of 2.70 g/cm^3. Its major alloying elements are magnesium and silicon. It is the most commonly used alloy of aluminium. It exhibits good weldability and has good mechanical properties. [8]

Table 1: Chemical Composition of Al-6061[8]

Components	**Amount (% wt.)**
Silicon	0.4 – 0.8
Iron	0 – 0.7
Copper	0.15 – 0.40
Manganese	0 – 0.15
Magnesium	0.8 – 1.2
Chromium	0.04 – 0.35
Zinc	0 – 0.25
Titanium	0 – 0.15
Others	0.15 (No more than 0.05 % each)
Aluminium	95.85 – 98.56

Fly-ash: It is one of the residues generated during the combustion of coal in coal fired plants. Fly-ash is a waste by-product material which must be disposed off or recycled. [9]

Table 2: Chemical Composition of Fly-ash [9]

Components	Amount (% wt.)
SiO_2	67.2
Al_2O_3	29.6
Fe_2O_3	0.1
CaO	1.4
MgO	1.7

Zirconium Oxide: It is also called as zirconium dioxide or zirconia. It is a white colored crystalline oxide of zirconium. [7]

Table 3: Chemical Composition of Zirconium oxide [11]

Components	Amount (% wt.)
ZrO_2	99.6
SiO_2	≤ 0.3
CaO	0.2
MgO	< 0.1
Fe_2O_3	< 0.1
Al_2O_3	< 0.1
TiO_2	< 0.1

Figure 1: Fly-ash

Figure 2: Zirconium oxide

EXPERIMENTAL PROCEDURE:-

The Metal matrix composite samples are prepared by stir casting method. A measured quantity of Al-6061 is taken in the graphite crucible and put in the casting furnace for melting. When the temperature of the furnace reaches 830 ^oC, measured quantity of preheated reinforcement in the melt is added. The reinforcement is preheated at a temperature of 200 ^oC for 2 hrs. The melt is then stirred at a stirrer speed of 400 rpm at 750 ^oC for 4 minutes. The molten mixture is further heated upto a temperature of 830 ^oC and then poured into the prepared green sand mould of required shape. The melt is then allowed to solidify.

Table 4: Composition of Metal Matrix Composites (% wt.)

Sample Name	Al-6061 (% wt.)	Zirconium Oxide (% wt.)	Fly-ash (% wt.)
S1	100	0	0
SF1	95	0	5
SF2	90	0	10
SZ1	95	5	0
SFZ5	90	5	5
SZF	85	5	10
SZ2	90	10	0
SFZ	85	10	5
SFZ10	80	10	10

TESTING OF PROPERTIES:-

The testing of the prepared samples is performed in Thapar University, Patiala. The following tests were conducted on the metal matrix composite.

1) Hardness Test
   a) Rockwell Hardness Test
   b) Vickers Microhardness Test
2) Charpy Impact Test

The specimens for both Rockwell hardness and Vickers micro-hardness test are machined to dimensions 20 mm X 20 mm X 10 mm. The surfaces of the specimens are finished by using emery paper of grades 180, 320, 800 and 1000. The specimens for Charpy impact test are machined as per ASTM E23-02a standard. The dimensions of the specimens are 55 mm X 10 mm X 10 mm with a notch of 45 ^{o} with 2 mm depth at the centre of one side.

RESULTS AND DISCUSSION:-

Rockwell Hardness Test:

Rockwell hardness tester (Make: AVERY 6402) is used to determine the macro-hardness of the MMC specimens as per ASTM E18–11 standards. The load applied is 100 Kgf for a period of 10 secs. For each specimen 6 readings are taken and then their mean is taken as a final result.

Table 5: Results of Rockwell Hardness Test

Samples	Rockwell Hardness Number (HRB)						Mean Hardness
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	
S1	65	65	65.5	64	66	65	65.08
SF1	67	68	66	67	69	67.5	67.42
SF2	71.5	70	71	70	71	71.5	70.83
SZ1	70	69	71.5	70	68	70	69.75
SFZ5	73	74	72	73	73	72	72.83
SZF	76	75	74	75	74	75	74.83
SZ2	71	70.5	72	71	72	72.5	71.5
SFZ	76	75	76	74	75	77.5	75.58
SFZ10	80	78.5	79	78	80	79	79.08

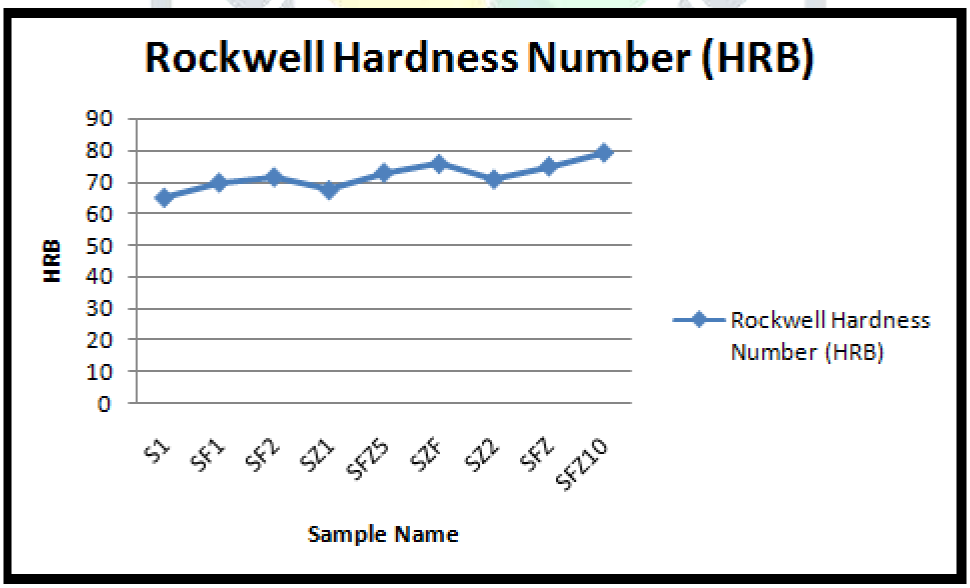

Figure 3: Variation of Rockwell Hardness Number with variation in the % vol. of Fly-ash & ZrO_2

With increase in the amount of Fly-ash content in Al-6061 the Rockwell hardness increases. The increase noticed in the Rockwell hardness is 2.34 HRB with increase in Fly-ash from 0 to 5 % vol. and increase noticed is 5.75 HRB with increase in Fly-ash from 0 to 10 % vol. With increase in the amount of Zirconium oxide content in Al-6061 from 0 to 5 % vol. fraction the Rockwell hardness increases and it increases slightly with further increase in the amount of Zirconium oxide from 5 to 10 % vol. The increase noticed in the Rockwell hardness is 4.67 HRB with increase in Zirconium oxide from 0 to 5 % vol. and increase noticed is 1.75 HRB with further increase in Zirconium oxide from 5 to 10 % vol.

Vickers Microhardness Test:

Vickers micro hardness testing machine (Make: Mitutoyo MVK - H0) is used to determine the micro-hardness of the MMC specimens as per ASTM E 384 standard. The Load applied is 100 gms for a period of 10 secs. For each specimen 3 readings have been taken to calculate the Vickers hardness number and then their average is considered. The Vickers hardness is calculated by using the formula: [10]

$$HV = \frac{2\,L\,\mathrm{Sin}\,(\Theta/2)}{d^2}$$

L = Force (Load) in kilograms
d = diagonal length of the impression in mm

Table 6: Results of Vickers Hardness

Samples	Average Length of Diagonals (µm)			Mean	Vickers Hardness (HV)
	Reading 1	Reading 2	Reading 3		
S1	2.75	2.77	2.73	2.75	24.52
SF1	2.66	2.62	2.67	2.65	26.4
SF2	2.49	2.51	2.50	2.50	29.67
SZ1	2.66	2.64	2.65	2.65	26.40
SFZ5	2.475	2.48	2.485	2.48	30.15
SZF	2.265	2.275	2.28	2.27	35.98
SZ2	2.605	2.595	2.52	2.57	28.07
SFZ	2.33	2.32	2.31	2.32	34.45
SFZ10	2.22	2.21	2.20	2.21	37.96

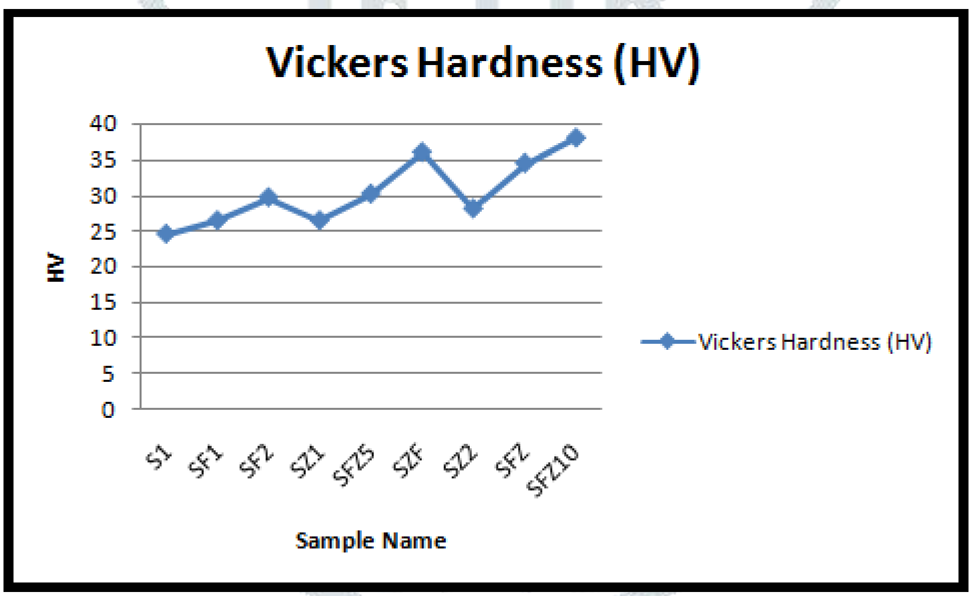

Figure 4: Variation of Vickers Hardness with variation in the % vol. of Fly-ash & ZrO_2

With increase in the Fly-ash content in Al-6061 the Vickers Hardness increases. The increase noticed in the Vickers hardness is 1.88 HV with increase in Fly-ash from 0 to 5 % vol. and the increase noticed is 5.15 HV with increase in the amount of Fly-ash from 0 to 10 % vol. With increase in the amount of Zirconium oxide content in Al-6061 the Vickers hardness increases. The increase noticed in the Vickers hardness is 1.88 HV with increase in Zirconium oxide from 0 to 5 % vol. fraction and increase noticed is 3.55 HV with increase in Zirconium oxide from 0 to 10 % vol. fraction.

Charpy Impact Test:

Charpy Impact Test Machine (Make: ALFRED J.AMSLER & Co.) is used to determine the impact toughness of the MMC specimens as per ASTM E23-02a standard. This test determines the energy absorbed by the MMC during the fracture. The pendulum of the impact machine is raised to a known height and then allowed to fall under gravity. The pendulum impacts and breaks the specimen and rises to some height. The difference in the initial and final height is directly proportional to the energy absorbed. The total energy absorbed is determined by

$\Gamma_{Total} = mg\,(h_o - h_f)$ [4]
Where, Γ_{Total} = Total energy absorbed
m = mass of the pendulum
g = gravitational acceleration
h_o = Initial height of the pendulum
h_f = Final height of the pendulum

Table 7: Results of Charpy Impact Test

Samples	Difference in height ($h_o - h_f$)			Mean of ($h_o - h_f$)	Energy Absorbed (Joules)
	Trial 1	Trial 2	Trial 3		
S1	11	11.1	10.9	11	107.91
SF1	13.8	13.7	13.9	13.8	135.38
SF2	10.8	10.7	10.9	10.8	105.95
SZ1	12.1	12.1	12.1	12.1	118.7
SFZ5	13.9	14.1	14.1	14.03	137.63
SZF	14.6	14.7	14.6	14.63	143.52
SZ2	13.7	13.6	13.5	13.6	133.42
SFZ	14.1	14.3	14.1	14.17	139.01
SFZ10	15	14.9	14.8	14.9	146.17

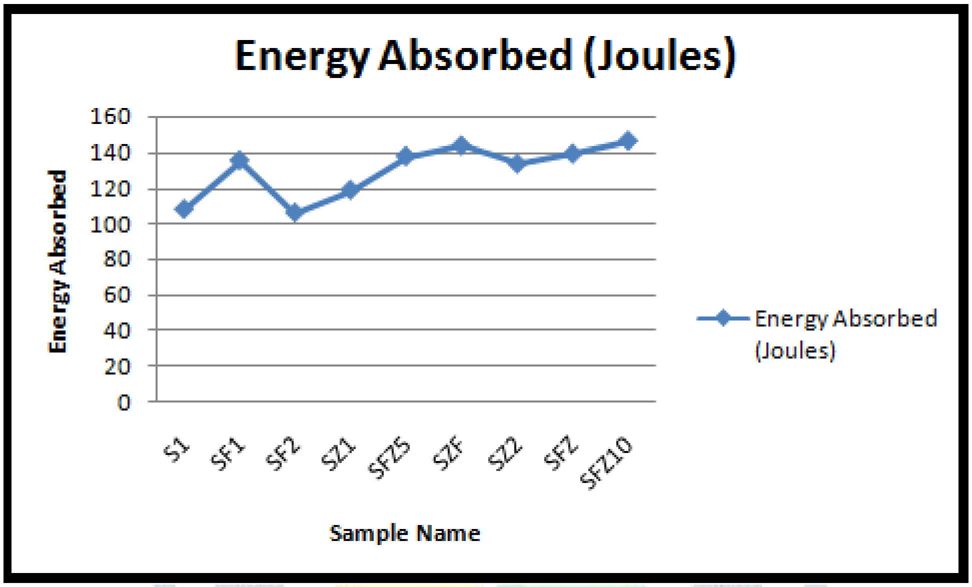

Figure 5: Variation of Energy absorbed with variation in the % vol. of Fly-ash & ZrO_2

With increase in the amount of Fly-ash content in Al-6061 from 0 to 5 % vol. the Energy absorbed increases but it decreases with further increase in the amount of Fly-ash from 5 to 10 % vol. The increase noticed in the Energy absorbed is 27.47 Joules with increase in Fly-ash from 0 to 5 % vol. and decrease noticed is 29.43 Joules with further increase in Fly-ash from 5 to 10 % vol. With increase in the amount of Zirconium oxide content in Al-6061 the Energy absorbed increases. The increase noticed in the Energy absorbed is 10.79 Joules with increase in Zirconium oxide from 0 to 5 % vol. and increase noticed is 25.51 Joules with increase in Zirconium oxide from 0 to 10 % vol.

CONCLUSIONS:

The conclusions drawn from the present investigation are as follows:

1) The Al-6061/Fly-ash/Zirconium oxide MMCs have been successfully fabricated by stir casting method.
2) Both macro-hardness and micro-hardness of the MMCs increases with the increase in the % wt. of reinforcement particles.
3) The impact toughness of the MMCs increases with the increase in the amount of reinforcement.

The results confirmed that the Al-6061/Fly-ash/ZrO_2 reinforced composite is superior to the base alloy Al-6061 in comparison of Hardness and impact strength.

SCOPE OF FUTURE WORK:

1) This work can be further extended by varying the volume fraction of the reinforcement added.
2) By using different method of production of MMC's like squeeze casting, powder processing etc.

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