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Evaluation of Mechanical Properties of Hybrid Aluminium-Alumina-Flyash Particulate Metal Matrix Composites

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ABSTRACT

Most of the present research work in engineering focused towards materials and its developments such as smart materials, composites, alloys etc. Among these materials composites materials are playing crucial role in engineering applications like aerospace, automobile and marine industries because of its high strength to weight ratio, low cost and easy manufacturing. Under this light, in the present work the hybrid metal matrix composites are produced using stir casting methodology by using Aluminium Alloy Al6061 as matrix and Fly ash and Alumina as reinforcements. The hybrid composites are produced with different weight percentage of fly ash (9%, 12% & 15%) and keeping 3% Alumina as constant. The mechanical tests were carried out on as cast components to evaluate the mechanical properties like tensile strength, Hardness, Impact strength and fatigue life and the results of hybrid composites are showing good trend as compared to unreinforced alloy.

Keywords *– Metal Matrix Composites (MMC), Alumina, Fly Ash, Mechanical Properties.*

1. INTRODUCTION

The particulate composite can be prepared by injecting the reinforcing particles into liquid matrix through liquid metallurgy by casting. Among the entire liquid state production routes, stir casting is the simplest and cheapest one. The only problem associated with this process is the non-uniform distribution of the particulate due to poor wet ability and gravity regulated segregation. Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. To overcome this problem magnesium is added to molten aluminium about 2% to achieve wettability. To ensure the proper mixing of particulate material a required amount of controlled vortex formation is produce during stirring operation. Fly ash was extracted from Raichur thermal plant and Al_2O_3 from locally. The magnesium removes oxygen from surface thus by eliminating gas layers and improving wettability. Hybrid Aluminium MMCs containing reinforcements such as Al_2O_3 with fly ash is available in the literatures [1-7].

2. MATERIAL SELECTION

MMC materials have a combination of different, superior properties to an unreinforced matrix which are increased strength, higher elastic modulus, and higher service, temperatures, improved wear resistance, high electrical and thermal conductivity, low coefficient of thermal expansion and environmental resistance. These properties can be attained with the proper choice of matrix and reinforcement. Composite materials consist of matrix and reinforcement. Its main function is to transfer and distribute the load to the reinforcement or fibers. This transfer of load depends on the bonding which depends on the type of matrix and reinforcement and the fabrication technique. The matrix can be selected on the basis of oxidation and corrosion resistance or other properties. Generally Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn and Si are used as the matrix material, but Al, Ti, Mg are used widely[1-7].

Reinforcement increases the strength, stiffness and the temperature resistance capacity and lowers the density of MMC. In order to achieve these properties the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix and the aspects like size, shape, surface morphology and surface defects etc. must be considered while selecting the reinforcement material.

2.1. ALUMINIUM ALLOY (AL6061)

The Aluminium alloy consists of other metals such as copper, zinc, manganese, silicon, and magnesium. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products. Cast aluminium alloys yield cost effective products due to the low melting point. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4-13%) contribute to give good casting characteristics.

In this work Aluminium alloy Al6061 is used as matrix. The Al6061 is a precipitation hardening aluminium alloy containing magnesium and silicon as its major alloying elements. Aluminium alloy 6061 is a medium to high strength heat-treatable alloy. It has very good corrosion resistance and very good weld ability although reduced strength in the weld zone. It has medium fatigue strength.

Component	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Others
Weight %	95.8 – 98.6	0.04 – 0.35	0.15 – 0.4	Max 0.7	0.8 – 1.2	Max 0.15	0.4 – 0.8	Max 0.15	Max 0.05

Table1: Chemical Composition of Al6061 alloy

2.2. ALUMINIUM OXIDE (AL_2O_3)

The chemical formula of aluminium oxide is Al_2O_3. It is commonly referred to as alumina, or corundum in its crystalline form, as well as many other names, reflecting its widespread occurrence in nature. Alumina (Al_2O_3) is the most cost effective and widely used material in the family of engineering ceramics. The raw material from which this high performance technical grade ceramic is made is readily available and reasonably priced, resulting in good value for the cost in fabricated alumina shapes. Its most significant use is in the production of aluminium metal, it is also used as an abrasive due to its hardness and as a refractory material due to its high melting point.

2.3. FLY ASH

Fly ash is one of the residues generated in the combustion of coal. It is an industrial by-product recovered from the flue gas of coal burning electric power plants. Fly ash includes substantial amounts of silica (silicon dioxide, SiO_2) and lime (calcium oxide, CaO). In general, fly ash consists of SiO_2, Al_2O_3, and Fe_2O_3 as major constituents and oxides of Mg, Ca, Na, K etc. as minor constituent. Fly ash particles are mostly spherical in shape and range from less than 1µm to 150µm with a specific surface area, typically between 250-600m^2/kg. The specific gravity of fly ash varies in the range of 0.6-2.8g/cc.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	LOI
Weight%	65.56	19.90	3.79	7.56	1.24	1.20	0.70

Table2: Chemical Composition of Fly Ash

3. EXPERIMENTATIONS

In this work, Al6061 material is used as the matrix element and Alumina and fly ash as reinforcement with varying weight percentage. The hybrid composite is produced with a different weight % like 9%, 12% & 15% of fly ash and 6 %, 9% of Al_2O_3 using stir casting technique. The experimental setup is as shown in Fig1.

Fig 1: Stir Casting Set up

The procedure followed for stir casting technique is as follows,

1. 1kg of Al6061 alloy is taken in the billet form and placed in the furnace and is melted at 750^{0}C.
2. The reinforcement such as fly ash of 9g by weight is measured and pre heated to 400-750^{0}C and maintained at that temperature for about 20mins to remove the moisture content.
3. Then other reinforcement such as alumina of 3g by weight was melted in a crucible at 750^{0}C
4. Slag should be removed using scum powder
5. The molten metal should be degassed at a temperature of 780^{0}C using solid dry hexachloro-ethane tablets. (<0.5%wt)
6. Then the molten metal was stirred to create a vortex and the weighed quantity of pre heated fly ash particle were slowly added to the molten metal maintained at >780^{0}C with continuous stirring at a speed of 350-500rpm to a time of 6-8mins
7. During stirring magnesium about >2% should be added to ensure good wet ability.
8. Then the melt with the reinforced particles were poured in to moulds the poring temperature should be maintained at 680^{0}C.
9. Then it is left for minimum 3hrs to solidify before withdrawing the specimens from the mould.

4. SEM ANALYSIS

The prepared Specimens are tested for quality before testing. Clean and neatly polished specimens are examined under SEM and the images at 2000x magnification are shown in Fig 2.1-2.4. The images show that there exists a good bonding between reinforced particles and the matrix. It is also evident that there is uniform distribution of reinforced particles along the metal matrix.

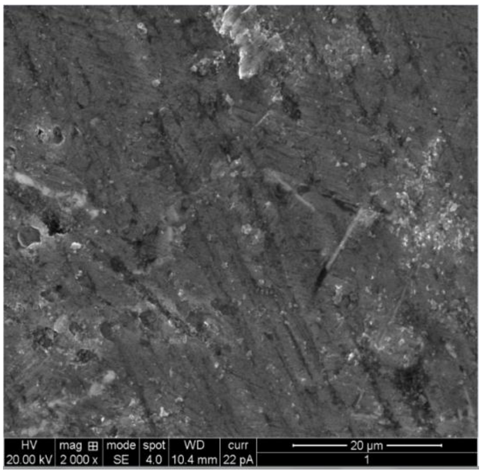

Fig 2.1: 3% Al_2O_3 + 9% Fly ash

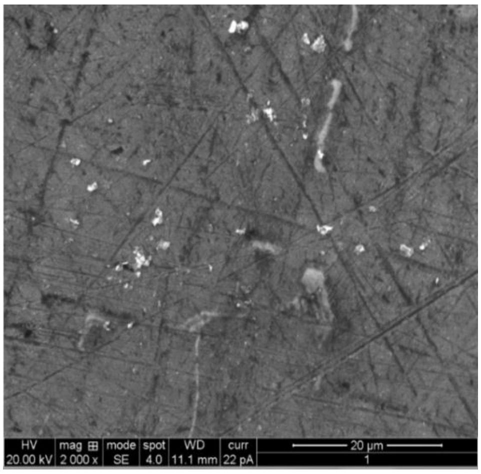

Fig 2.2: 3% Al_2O_3 + 12% Fly ash

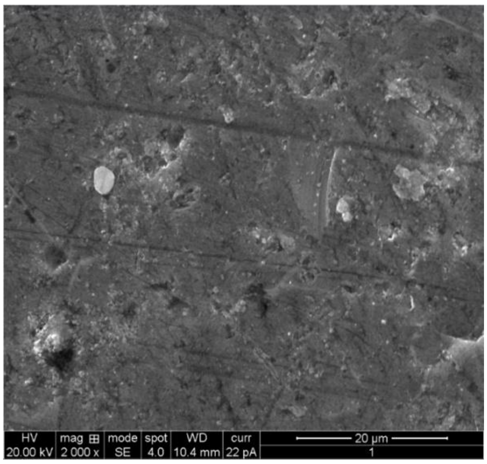

Fig 2.3: 3% Al_2O_3 + 15% Fly ash

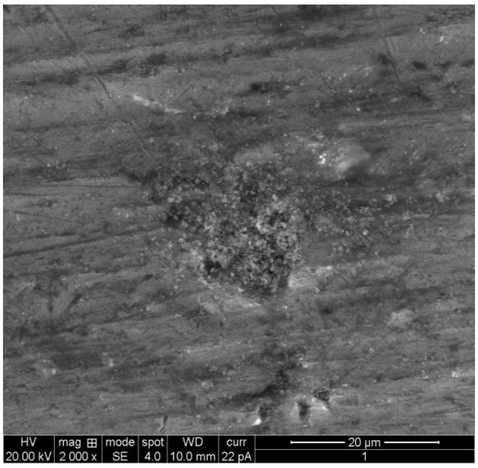

Fig 2.4: 6% Al_2O_3 + 15% Fly ash

5. MECHANICAL PROPERTIES

The Mechanical properties of the hybrid composites are evaluated from the following tests.

5.1. TENSILE STRENGTH

The tensile tests were carried out at a constant speed of 0.05mm/min in a Universal tensile testing machine of 100KN capacities. The specimen prepared as per ASTM standard E08.

5.2. HARDNESS

The Hardness test was carried out using Leitz, Brinnel hardness measuring machine with a load of 100N. The specimen prepared as per ASTM standard E8-82. The test was carried out with 10mm diameter ball indenter and with a load of 250kg. The loading time was 30secs. Three readings were taken for each specimen and mean value was considered.

5.3. IMPACT STRENGTH

The impact strength tests were carried out at room temperature using an Impact testing machine of Charpy type. The test was carried out with an initial energy of hammer 30Kg-m and with a striking velocity of 5.6m/s. The specimen is prepared according to ASTM standard E23.

5.4. FATIGUE TEST

The fatigue test was carried out by using RR Moore method. To carry out a fatigue test a specimen is prepared with ASTM standard and tested using rotating bending machine with predetermined value of loads by considering 0.5UTS,0.7UTS and 0.9UTS [7]. The failure cycles for the predetermined stress levels are observed from the test and S-N curve is plotted from these stress levels and number of cycles.

6. RESULTS AND DISCUSSION

Al-Al_2O_3-Fflyash Hybrid composite is casted and tested as per ASTM standards and the material properties are evaluated and listed below.

Sl No.	Nomenclature	Tensile Strength (N/mm2)	Hardness (BHN)	Impact Strength (J/mm2)	Fatigue Life at		
					0.9 UTS	0.7 UTS	0.5 UTS
1	Al6061 + 0% reinforcement	319.90	50	0.70	778038	853310	928551
2	Al6061 + 3% Al_2O_3 + 9%FLY ASH	378.19	54	0.68	787374	863550	939694
3	Al6061 + 3% Al_2O_3 + 12%FLY ASH	380.50	62	0.65	795933	872936	949908
4	Al6061 + 3% Al_2O_3 + 15%FLY ASH	386.99	77	0.62	799823	877203	954550

Table 3: Mechanical Properties of Al-Al_2O_3-Flyash Hybrid composite material

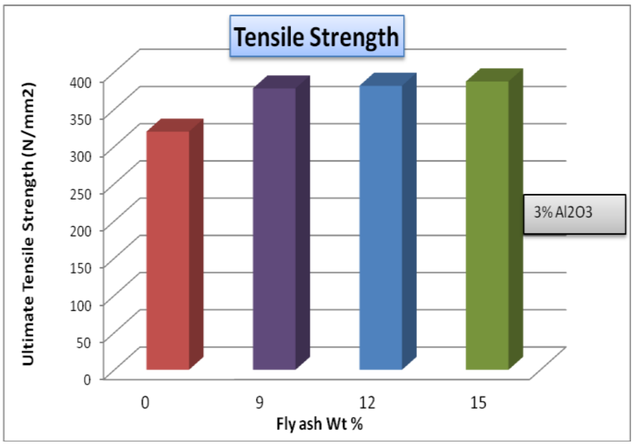

Fig 3: Tensile Strength vs Fly Ash wt %

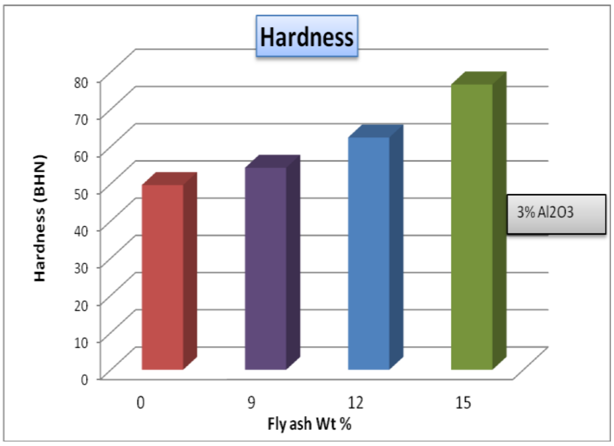

Fig 4: Hardness vs Fly Ash wt %

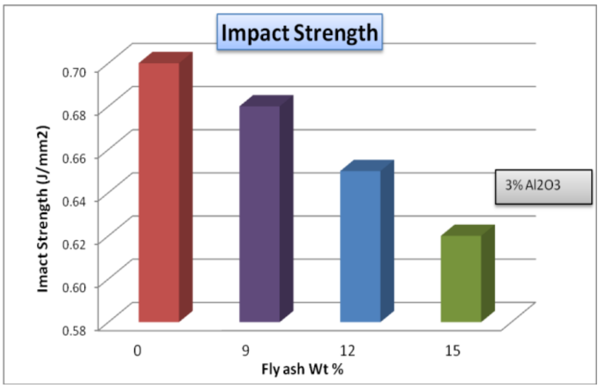

Fig 5: Impact strength vs Fly Ash wt %

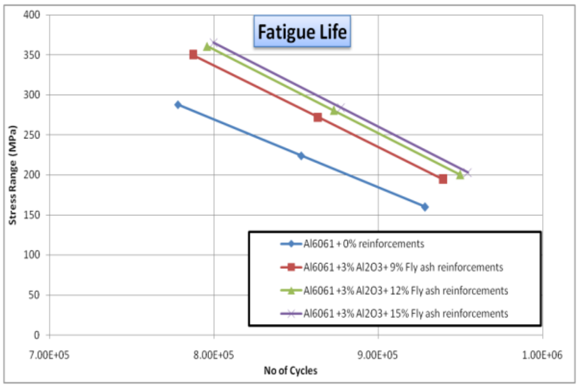

Fig 6: S-N curve for unreinforced alloy and Hybrid Composite material.

From the table 3 and Fig 3&4, it is reveals that the tensile strength and hardness of the composite material increases monotonically by significant amounts as the reinforcement's particles content increases when compared to monolithic alloy Al6061 due to the presence of the harder particles, which imparts the strength to the matrix alloy thereby enhancing the resistance to the deformation/dislocation of matrix structure this might have caused the increase in tensile strength and hardness. From Fig 6 it can be observed that the fatigue strength of the composite with 3% Al_2O_3 and 15% fly ash reinforcement is having good fatigue performance compared to the monolithic Al6061 alloy. The impact strength of the composite material is decreases with increase in fly ash as shown in Fig 4 because of increase in hardness.

6. Conclusion

From the observations made and results obtained from the experiments, we can conclude that.

- The good dispensability of Alumina and Fly ash particles in aluminum matrix which improves the mechanical properties like hardness and tensile strength. The effect is because of increase in interfacial area between matrix material and reinforcements particles leading to increase in mechanical properties appreciably.
- The fatigue property of the composites is better than the unreinforced alloy and it is observed that the fatigue behavior is same for higher reinforcements.
- The results confirmed that stir formed Al 6061 alloy with alumina and fly ash reinforced composites is clearly superior to base Al 6061 alloy in the comparison of mechanical properties.
- The fatigue life has been increased with the increase in weight percentage of fly ash and it can be seen from S-N curve when compared to monolithic alloy.

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