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Evaluation of Mechanical Properties of Al 6061, Fly Ash Reinforced With E-Glass Fiber Composites

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Abstract: *The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. Metal Matrix Composites (MMCs) possess significantly improved properties. Among the MMC's aluminium composites are predominant in use due to their low weight and high strength. In this project the Tensile test, compression and Hardness test results of Aluminium 6061 Reinforced with E- Glass Fibre and Fly ash composite is studied. Also microstructure of the specimen is analysed. The reinforced composites were manufactured by Stir Casting process. Each fabrication carries the E-glass reinforcement content varied from 0% to 6% with incremental steps of 2% and Fly ash of 0% to 15% with incremental steps of 5%. The casted composite specimens are prepared according to ASTM standards by facing and turning operations to conduct tensile, hardness and compressive test. Microstructure of the composites was observed to study the bonding of E-Glass and Fly ash with AL6061. Mechanical tests were carried out on specimens from each composition and it is observed that reinforcement enhances the mechanical properties of Aluminium 6061 Composites.*
Keywords*: composite, stir casting, aluminum 6061, reinforcement, hardness test, tensile test, compression test.*

I. Introduction

The basic idea is that continuous fiber reinforced composite has better strength but the processing methods is highly expensive which hinders their adoption. The continuous fiber reinforced composites do not allow secondary forming such as rolling, forging and extrusion. As results of these limitations new efforts on the research of discontinuous reinforcements have been used. At early stages of development of metal matrix composite emphasis was given on the preparation of fiber reinforced composite only. But due to the high cost associated with the process of production, anisotropic properties of the resultant composite and difficulties associated with the fabrication process, production of this type of composites has been limited.

The aluminum metal matrix composites are produced either by casting route or by power metallurgy. The former has the advantages of producing the composites as lower cost of production and possibility of producing larger components. However, the inherent difficulties of casting route are non-wettability of ceramic particles by liquid aluminum and most of the research work carried out on aluminum based composite materials involves silicon carbide as its reinforcing material. Therefore it is essential to look for the possibilities of fabricating aluminum based composite materials using waste or recycling materials like fly ash.

Most of energy needs in the century is relied on the fossil fuels. Combustion of coal energy produces waste by product, i.e., fly ash in abundance. The disposal of this fly ash is a major challenging task .In this work, an attempt has been made to fabricate a hybrid composite material from commercial pure material and waste product. Short e-glass fibers are used as commercially pure material and fly ash as waste product. Aluminum 6061 is used as matrix material for the fabrication of Al-e-glass-fly ash hybrid composite material.

The most conventional method of production of composites is by stir casting method, where the liquid aluminium is stirred with an impeller and ceramic particles are incorporated into composite by stirring of the liquid metals. Addition of Mg into the liquid metal reduces the surface tension and there by avoids the rejection of the particles from the melts. Without addition of Mg recovery of the particles into the melt is quite low. Hence 0.5% Mg is generally added into the Al melts before incorporation of the particles. The present investigation has been focused on utilization of waste fly ash in useful manner by dispersing it in aluminium matrix to produce composite. In the present work, fly-ash which mainly consists of refractory oxides like silica, alumina, and iron oxides, was used as the reinforcing phase and to increase the wet ability magnesium was added. Composites were produced with different percentages of reinforcing phase. Further, these composites were characterized with the help of, Microstructure analysis. Mechanical properties of the composites were also evaluated.

II. Metal Matrix Composites

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. Conventional monolithic materials have limitations with respect to achievable combinations of strength, stiffness, and density. In order to overcome these shortcomings and to meet the ever-increasing engineering demands of modern technology, metal matrix composites are gaining importance. In recent years, discontinuously reinforced aluminium based metal matrix composites have attracted worldwide attention as a result of their potential to replace their monolithic counterparts primarily in automobile and energy sector.

TECHNIQUES FOR METAL MATRIX COMPOSITES

- **Liquid metallurgy route**

Liquid state processes include stir casting or compo casting, infiltration, spray casting and in situ (reactive) processing. The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of micro structural integrity desired.

- **Stir casting:**

This involves incorporation of ceramic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. Lloyd (1999) has reports that vortex-mixing technique for the preparation of ceramic particle dispersed aluminium matrix composites was originally developed by Surappa&Rohatgi (1981) at the Indian Institute of Science, Bangalore. Subsequently several aluminium companies further refined and modified the process which are currently employed to manufacture a variety of aluminium metal matrix composites on commercial scale.

FLY ASH

Fly ash is one of the residues generated in the combustion of coal. It is an industrial byproduct recovered from the flue gas of coal burning electric power plants. Depending upon the source and makeup of the coal being burned, the components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of silica (silicon dioxide, SiO_2) (both amorphous and crystalline) 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 1 μm to 100 μm with a specific surface area, typically between 250 and $600 m^2/kg$. The specific gravity of fly ash vary in the range of 0.6-2.8 gm/cc. Coal fly ash has many uses including as a cement additive, in masonry blocks, as a concrete admixture, as a material in lightweight alloys, as a concrete aggregate, in flow able fill materials, in roadway/runway construction, in structural fill materials, as roofing granules, and in grouting. The largest application of fly ash is in the cement and concrete industry, though, creative new uses for fly ash are being actively sought like use of fly ash for the fabrication of MMCs.

E-GLASS FIBER:

E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fibre forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fibreglass.

E-glass accounts for 90% of the glass fibre market and is used mainly in a polyester matrix. The 'E' in E-glass stands for 'electrical' and was intended to indicate that the material had low electrical conductivity. The major driver, however, for its command of the market is due to the fact that it is the cheapest glass fibre and is therefore the preferred material in general purpose products. Continuous and chopped E-glass are widely used in product manufacture. Its advantages are relatively low cost combined with high tensile strength and modulus, with individual filament strengths around 3500 MPa and modulus around 80GPa. Elongation-to-break is nearly 5%. Two types are available one contains boron, the other boron free. The ultimate use temperature of E-glass is around 500^oC. The maximum service temperature for the composite will, however, be dictated by the matrix material.

The corrosion resistance of E-glass without boron is approximately seven times the corrosion resistance of the boron-containing E-glasses. Boron free E-glasses have approximately a 10% higher dielectric constant than boron containing E- glasses when measured at room temperature making them less suitable for electronic circuit boards and aerospace applications.

STIR CASTING ROUTE

The aluminium 6061,E-Glassfiber & fly ash metal matrix composite was prepared by stir casting route. For this we took 500gm of commercial aluminium 6061 and desired amount of fly ash and E-Glass fibre particles. The fly ash and E-glass particles were preheated at 500^{o}C for about 20 minutes in preheating furnace to remove moisture. Meanwhile Commercial aluminium 6061 was melted in casting furnace. The melt temperature was raised up to 950^{o}C and it took about 30 minutes for complete melting of the AL6061 alloy. Exo-chloroethane tablets were added to the molten metal to degasify the soluble gases that are present. The preheated Reinforcements such as E-glass and Fly ash were added to the molten metal. The melt temperature was maintained at 900^{o}C during addition of fly ash and E-Glass fibre particles with AL6061.Then the melt was stirred with the help of a mild steel turbine stirrer. The stirring speed was maintained at ~480rpm. Each stirring was done for about 2-4 minutes. The melt with reinforced particulates were poured into the permanent metallic mould. The pouring temperature was maintained at 850^{o}C.The melt was then allowed to solidify in the moulds. The composites were made with a different amount of fly-ash (i.e.5, 10, 15%wt), & E-glass fibre (i.e.2, 4, 6 %wt) Magnesium was added to increase the bonding between materials.

Stir Casting Machine

FACTORIAL DESIGN TO TEST ALL POSSIBLE COMBINATIONS

Total experiments = 9

BASE METAL	E-GLASS %	FLYASH %
AL 6061	2	5
AL 6061	4	5
AL 6061	6	5
AL 6061	2	10
AL 6061	4	10
AL 6061	6	10
AL 6061	2	15
AL 6061	4	15
AL 6061	6	15

MECHANICAL PROPERTIES OBSERVATION

- **Hardness**

Bulk hardness measurements were carried out on the base metal and composite samples by using standard Brinell hardness test. Brinell hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 1000kgs and indenter was a steel ball of 10 mm diameter.

- **Tensile test**

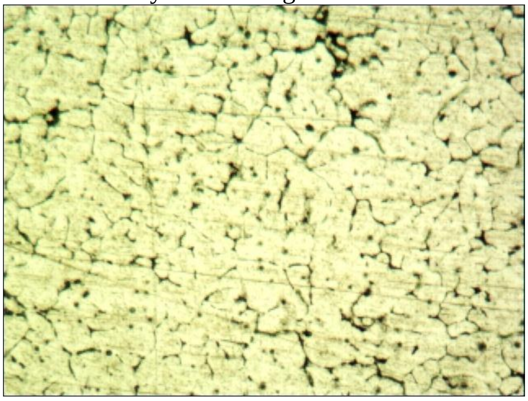
The tensile testing of the composite was done, on Instron testing machine. The sample rate was 9.103pts/sec and cross-head speed 5.0 mm/min. Standard specimens with 30mm gauge length were used to evaluate ultimate tensile strength. The comparison of the properties of the composite material was made with the commercially available pure Al6061.

- **Compressive Test**

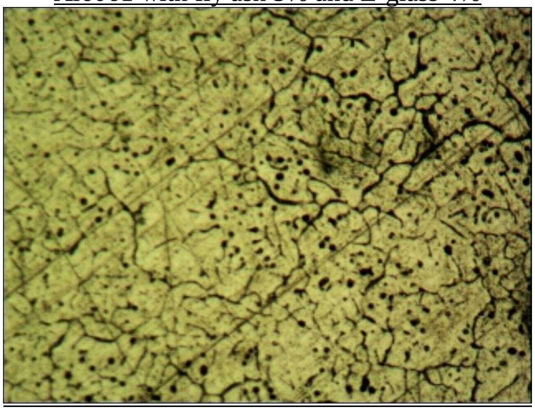
The compressive testing of the composite was done, on Computerized Universal Testing machine. Standard specimen with gauge length of 60mm was taken for evaluation of compressive strength. The comparison of the properties of the composite material was made with the commercially available pure Al6061.

MICROSTRUCTURE

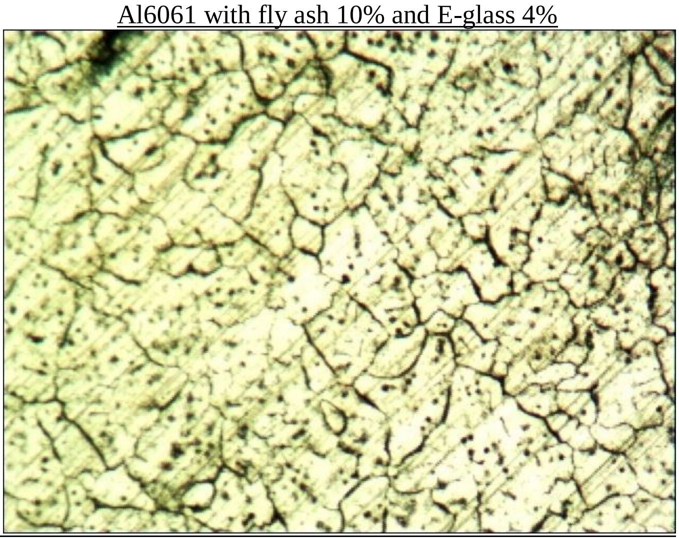
Microstructure (100x zoom) of al6061 with fly ash and E-glass fiber are as follows.



Al6061 with fly ash 5% and E-glass 4%



Al6061 with fly ash 10% and E-glass 4%



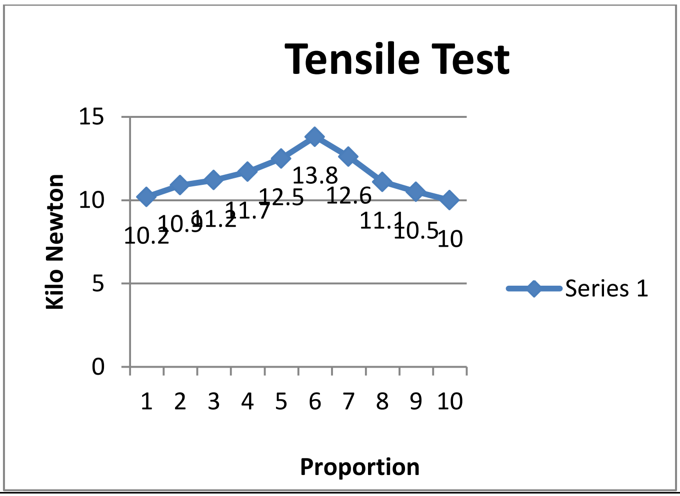
Al6061 with fly ash 15% and E-glass 4%

SI.NO	SAMPLE DESIGNATIONS	U.T.S (KN)
1	Aluminum 6061	10.2
2	Al+2% E-glass +5% Fly ash	10.9
3	Al+4% E-glass +5% Fly ash	11.2
4	Al+6% E-glass +5% Fly ash	11.7
5	Al+2% E-glass +10% Fly ash	12.5
6	Al+4% E-glass +10% Fly ash	13.8
7	Al+6% E-glass +10% Fly ash	12.6
8	Al+2% E-glass +15% Fly ash	11.1
9	Al+4% E-glass +15% Fly ash	10.5
10	Al+6% E-glass +15% Fly ash	10.0

III. Results

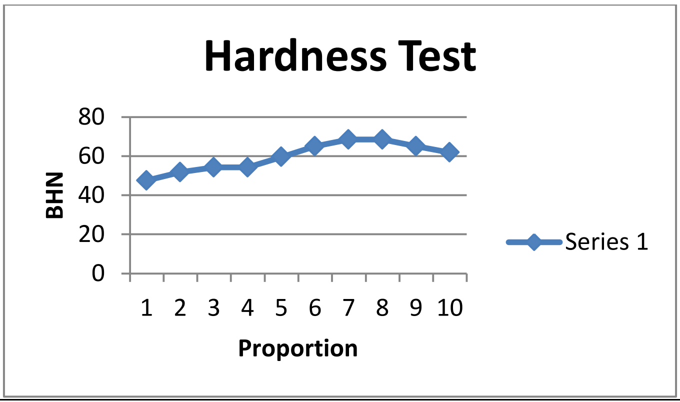
- **Tensile**

This indicates that the fly ash addition leads to improvement in the ultimate tensile strength. From the table it is clear that the tensile properties of the composite has been increased. Thus the strengthening of composite can be due to dispersion strengthening as well as due to particle reinforcement. Dispersion strengthening is due to the incorporation of very fine particles, which help to restrict the movement of dislocations, whereas in particle strengthening, load sharing is the mechanism.



- **Hardness**

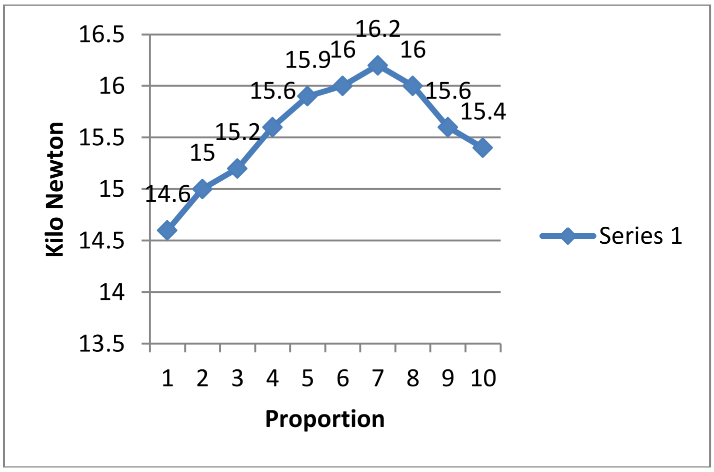
SI.NO	SAMPLE DESIGNATIONS	HARDNESS(BHN)
1	Aluminum 6061	47.53
2	Al+2% E-glass +5% Fly ash	51.78
3	Al+4% E-glass +5% Fly ash	54.25
4	Al+6% E-glass +5% Fly ash	54.25
5	Al+2% E-glass +10% Fly ash	59.54
6	Al+4% E-glass +10% Fly ash	64.99
7	Al+6% E-glass +10% Fly ash	68.48
8	Al+2% E-glass +15% Fly ash	68.48
9	Al+4% E-glass +15% Fly ash	64.99
10	Al+6% E-glass +15% Fly ash	61.84



The above table shows that incorporation of fly ash and E-Glass Fibre particles in Aluminium matrix causes reasonable increase in hardness. The strengthening of the composite can be due to dispersion strengthening as well as due to particle reinforcement. Thus, fly ash as filler in Al casting reduces cost, decreases density and increase hardness which are needed in various industries like automotive etc.

- **Compression**

SI.NO	SAMPLE DESIGNATIONS	C.S (KN)
1	Aluminium 6061	14.6
2	Al+2% E-glass +5% Fly ash	15.0
3	Al+4% E-glass +5% Fly ash	15.2
4	Al+6% E-glass +5% Fly ash	15.6
5	Al+2% E-glass +10% Fly ash	15.9
6	Al+4% E-glass +10% Fly ash	16.0
7	Al+6% E-glass +10% Fly ash	16.2
8	Al+2% E-glass +15% Fly ash	16.0
9	Al+4% E-glass +15% Fly ash	15.6
10	Al+6% E-glass +15% Fly ash	15.4



Compression Test

IV. Conclusions

The following conclusion may be drawn from the present work:

- From the study it is concluded that we can use fly ash for the production of composites and can turn industrial waste into industrial wealth. This can also solve the problem of storage and disposal of fly ash.
- Fly ash up-to 15% by weight can be successfully added to commercially aluminium 6061 with E-Glass fiber by stir casting route to produce composites.
- Addition of magnesium improves the wet ability of fly ash with aluminium melt and thus increases the retention of the fly ash in the composite
- Hardness of commercial aluminium 6061 is increased from 47.53BHN to 68.48BHN with addition of fly ash,E-Glass fiber and magnesium.
- The Ultimate tensile strength has improved with increase in proportion of composite till 6% E-Glass and 10% Fly ash.
- The Compressive strength has also improved with increase in proportion of composite till 6% E-Glass and 10% Fly ash.
- The microstructure analysis shows the proper bonding of materials.

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