VARIATION OF MECHANICAL PROPERTIES (HARDNESS & MICROSTRUCTURE) OF Al6061/(Al_2O_3 AND FLY-ASH), HYBRID METAL MATRIX COMPOSITE PRODUCED BY STIR CASTING

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ABSTRACT

The present work deals with the variation of mechanical properties (hardness & microstructure) of al6061/(al_2o_3 and fly-ash), hybrid metal matrix composite using aluminum alloy Al 6061 as matrix and alumina, fly-ash as a reinforcing material prepared by stir casting technique. The alumina and fly-ash amounts varied as 10, 15, and 20 percent by volume.

The mechanical properties like hardness, microstructure have been investigated. On addition by volume percent of alumina and fly-ash, the effect on mechanical properties has been studied. The properties hardness increases with Al_2O_3 and Fly-Ash. The change in these properties is moderate for 10 percent addition of alumina and fly-ash and marginal changes with 15 and 20 percent.

INTRODUCTION

Humans have been using composite materials for thousands of years. We take the example of mud bricks. A cake of dried mud is easy to break by bending, which puts a tension force on edge, but makes a good strong wall, where all are compressive forces. A piece of straw, on the other hand, has high strength when you try to stretch it but almost none when you crumple it up. But if you embed pieces of straw in a block of mud and let it dry hard, the resulting mud brick resists both tearing and squeezing and makes an excellent building material. Put more technically, it has both good tensile and compressive strength.

Another well-known composite is concrete. Here aggregate (small stones or gravel) is bound together by cement. Concrete has very good strength under compression force, and it can be made stronger under tension by adding metal rods, wires, mesh or cables to the composite (so creating reinforced concrete). A composite material is a system composed of a mixture or combination of two or more macro constituents of different form or material composition and that are essentially insoluble in each other. The constituent that is present in greater quantity in the composite is termed as matrix. It encloses the other constituent and essentially protects them chemically and thermally. The normal view is that the properties of the matrix are improved on incorporating another constituent to produce a composite. The second constituent referred as

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reinforcing phase or reinforcement, as it enhances or reinforces the mechanical properties of the matrix. [1]

CLASSIFICATION OF COMPOSITE

Composites are of following types:

1. Polymer matrix composites.
2. Ceramic matrix composites.
3. Metal matrix composites

1. POLYMER MATRIX COMPOSITES:

Polymer-matrix composites consist of high-strength fibers, carbon glass, or other materials in a matrix of thermosetting or thermoplastic polymers. The fibers provide high strength at a very low weight, and the matrix holds the fibers in place. Throughout history, people have capitalized on the synergistic effect of combining dissimilar materials, first with adobe (twigs embedded in clay) and later with steel-reinforced concrete. The human body, which embeds a skeleton of bones in flesh and muscles, is perhaps the most astounding example of combined dissimilar materials.

The most outstanding characteristic of polymer-matrix composites is the materials' ability to replace lightweight, high-strength metals or wood with an even lighter-weight and higher-strength alternative. In the transportation sector (aerospace, automobiles, and railroad cars), this property permits lower fuel consumption and/or increased payload; sporting goods and biomedical devices also place a premium on low weight and high strength. Polymer-matrix composites' resistance to corrosion is widening their appeal in the construction industry (bridges, scrubber towers, and wastewater tanks). In addition, composites' vibration-dampening properties protect athletes from tennis elbow and enable fishermen to cast with increased accuracy. Polymer-matrix composites provide other benefits as well: In manufacturing, they permit parts consolidation, flexibility of design, and lower assembly costs, and in the military, their transparency to radar is valuable for strealth applications. Because of their high cost, relatively price-insensitive markets such as military and civilian aerospace and sporting goods have led the development of polymer-matrix composites. However, since 1991, the market has experienced a substantial increase in the growth rate for use in transportation and construction, with these two markets dominating the field while other markets have relatively or absolutely declined. No other material surpasses PMCs in light weight and good mechanical properties. PMCs' continued growth faces no technical limits; drawbacks stem only from its often higher cost and its role as a newcomer in many applications where it confronts entrenched technologies. Process development and experience of use will overcome both these impediments. [2]

2 CERAMIC MATRIX COMPOSITE:

The class of materials known as ceramic matrix composites, or CMCs, shows considerable promise for providing fracture-toughness values similar to those for metals such as cast iron. Two kinds of damage-tolerant ceramic-ceramic composites are being developed. One incorporates a continuous reinforcing phase, such as a fiber; the other, a discontinuous reinforcement, such as whiskers. The major difference between the two is in their failure behavior. Continuous-fiber-reinforced materials do not fail catastrophically. After matrix failure, the fiber can still support a load. A fibrous failure is similar to that which occurs in wood. Incorporating whiskers into a ceramic matrix improves resistance to crack growth, making the composite less sensitive to flaws. These materials are commonly described as being flaw tolerant. However, once a crack begins to propagate, failure is catastrophic. Of particular importance to the technology of toughened ceramics has been the development of high-temperature silicon carbide reinforcements. Although other reinforcement materials are available, such as glass and carbon fiber, metal whiskers, and alumina-based products, this discussion focuses on SiC-based products because they are more applicable to high-temperature use.

3. METAL MATRIX COMPOSITES

Metal matrix composites are the engineered material having the combination of two or more materials in which the tailored properties are achieved. In the past decade, the need for lighter materials with high specific strength coupled with major advances in processing, has led to the development of numerous composite materials as a serious competitor to traditional engineering alloy of particular interest in aerospace and defence industry. [3]

The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties. Numerous metals have been used as matrices. The most important have been aluminum, titanium, magnesium and copper alloys and super alloys. The most important MMC systems are:

- Aluminum

Continuous fibers: alumina , silicon carbide, graphite
Discontinuous fibers: alumina-silica, alumina
Whiskers: silicon carbide
Particulates: boron carbide, silicon carbide

- Magnesium matrix

Continuous fibers: alumina, graphite
Whiskers: silicon carbide
Particulates: boron carbide, silicon carbide

- Titanium matrix

Continuous fibers: coated boron, silicon carbide
Particulates: titanium carbide

- Copper matrix

Continuous fibers: graphite, silicon carbide
Wires: niobium-titanium, niobium-tin
Particulates: boron carbide, titanium carbide, silicon carbide

- Super-alloy matrix

Wires: tungsten

REINFORCEMENTS:

Numerous materials in different shapes are being used as reinforcement for MMCs and they can divide into five major categories:

- Continuous fibres
- Discontinuous fibres
- Whiskers
- Particulates
- Wires

With the exception of wires, which are metals, reinforcement generally are ceramics. Key continuous fibers include boron, graphite (carbon), alumina and silicon carbide Boron fibers are made by chemical vapor deposition (CVD) of this material on a tungsten core. To retard reactions that can take place between boron and metals at high temperature, fiber coatings of materials such as silicon carbide or boron carbide are sometimes used. A CVD process, using a tungsten or carbon core, also makes silicon carbide monofilaments. A Japanese multifilament yarn, designated as SiC by its manufacturer, is also commercially available. This material however, made by pyrolysis of organometallic precursor fibers, is far from pure SiC and its properties differ significantly from those of monofilament SiC. [5]

Continuous alumina fibres are available from several suppliers. Graphite fibers are made from two precursor materials, polyacrilonitrile (PAN) and petroleum pitch. Efforts to make graphite fibers from coal based pitch are under way. Graphite fibers with a wide range of strengths and moduli are available.

The particulate reinforcements have been classified as the by-products from other technologies SiO_2, Al_2O_3, alumina silicate, graphite, and are readily available or are naturally renewable at affordable cost. e.g., coconut shell char, mica palm-kernel shell char, and zircon. Further, the potential nature of these filer materials is attractive. For example, SiC has good thermal and chemical stability, both during synthesis and under severe service conditions, strengths, cost and availability. The specific applications of these composites include engine blocks, pistons, brake-system components, seals, solid lubricants, wear- and abrasion- resistant structures, electro mechanic contacts, and chassis components. [5]

Aluminum Oxide (Al_2O_3)

Alumina is the most cost effective and widely used material in the family of engineering ceramics. The raw materials from which this high performance technical grade ceramic is made are readily available and equitably priced, resulting in worthy value for the cost in fabricated alumina shapes. With an exceptional combination of properties and an attractive price, it is no surprise that fine grain technical grade alumina has a very wide range of applications.

Key Properties

- Hard, wear-resistant.
- Tremendous dielectric properties from DC to GHz frequencies.
- Provide Resistance to strong acid and alkali attack at elevated temperatures.
- Good thermal conductivity.
- Excellent size and shape capability.
- High strength and stiffness.

Typical Uses

- Gas laser tubes.
- Wear pads.
- High voltage insulators.
- Furnace liner tubes.
- Laboratory instrument tubes holders.
- Instrumentation parts for thermal property test.
- Abrasion resistant tube.
- Thermometry sensors.

Fly-Ash and Chemical composition:

Fly ash, also known as "pulverised fuel ash" in the United Kingdom, is a coal combustion product composed of fine particles that are driven out of the boiler with the flue gases. Ash that falls in the bottom of the boiler is called bottom ash. In modern coal-fired power plants, fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys. Together with bottom ash removed from the bottom of the boiler, it is known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline), aluminium oxide (Al_2O_3) and calcium oxide (CaO), the main mineral compounds in coal-bearing rock strata.

Constituents depend upon the specific coal bed makeup but may include one or more of the following elements or substances found in trace concentrations (up to hundreds ppm): arsenic, beryllium, boron, cadmium, chromium, hexavalent chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with very small concentrations of dioxins and PAH compounds.

Component	Bituminous	Subbituminous	Lignite
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	5-35	20-30	20-25
Fe_2O_3 (%)	10-40	4-10	4-15
CaO (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

PROCESSING TECHNIQUES

The fabrication of metal matrix materials may be considered in two stages: the fabrication of the composite material from base metal and fiber reinforcement and the subsequent fabrication of laminates from the composite material. In some cases, the two steps occur simultaneously depending on the final material product desired and the method of fabrication used in the process. The choice of methods used to fabricate a composite material depends on the mechanical and chemical properties of the fiber and matrix, the fiber length and size, the fiber packing, and the desired fiber configuration. Furthermore, it is necessary to know the thermodynamics and kinematics of possible fiber matrix reactions and service temperatures to which the composites are subjected. A short overview of some of the methods used to fabricate aluminum matrix composites (AMCs) are discussed below.

SOLID STATE PROCESSING

Different solid state processing techniques can be used for preparing composites. Few of these techniques are:

- Powder metallurgy technique
- Diffusion bonding
- Step pressing
- Hot-die molding
- Super plastic forming
- Hot isostatic pressing

LIQUID STATE PROCESSING

In liquid state processing of composite, liquid metal is combined with reinforcing phase and solidified in a mould. Few of these techniques are:

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- Squeeze casting
- Infiltration casting
- Investment casting
- Pressure casting
- Stir casting

EXPERIMENTAL DETAIL

In the present work aluminum based alumina and silicon-carbide reinforced particulate metal matrix was prepared. The material used and procedure for its casting is explained as follow:

MATERIAL USED:

A metal matrix composite of Al 6061 aluminum alloy reinforced with Al_2O_3 and SiC was prepared by varying composition of alumina and silicon carbide. Aluminum alloy Al 6061 with composition given in table 3.1 has been used as matrix.

Elements	**Sn**	**Si**	**Zn**	**Cr**	**Mn**	**Mg**	**Cu**	**Fe**	**Ti**	**Pb**	**Ni**	**Al**
Al 6061	**0.025**	**0.79**	**0.07**	**0.045**	**0.17**	**0.98**	**0.19**	**0.6**	**0.03**	**0.024**	**0.03**	**Rest**

PREPARATION OF COMPOSITE

The process for composite casting is shown in fig. The Matrix alloy used in the study is Al-Mg-Si-Fe-Cu-Mn wrought alloy matrix (6061) reinforced with Al_2O_3 and Fly-Ash. Commercial Al-6061 (Al-97.04%, Mg-0.98, Si-0.79, Fe-0.6, Cu-0.19, Mn-0.17) alloy reinforced with 10, 15& 20 % by vol. The Matrix alloy was first melted in a graphite crucible in a electric furnace and before mixing, the Al_2O_3 and Fly-Ash particles were preheated at 300°C for 1 hour to make the surface of Al_2O_3 and Fly-Ash particle oxidized. The furnace temperature was first raised above the liquidus temperature to melt the alloy completely at 750°C and was then cooled down just below the liquidus temperature (700˚C) to keep the slurry in a semi solid state. The stir made of stainless steel attached with graphite blade was made to move at a rate of 200 rpm up to 15 minutes. The mixing was done for a short time period of 1 to 1.5 minutes. The composite slurry was reheated to a fully liquid state and the automatic mechanical mixing was done for about 30 minutes at stirring rate of 250 rpm. In this experiment, the molten composite was transferred from the crucible into the mould.

RESULTS

HARDNESS TEST:

The hardness was measured on Brinell Hardness Testing machine using a 40mm diameter indenter and 15.625 Kg load was applied for 25 second. The B.H.N was calculated from the standard formula. The average of 5 readings has been reported in the results.

$$BHN = \frac{2F}{\pi D(D - \sqrt{D2 - d2})}$$

Where

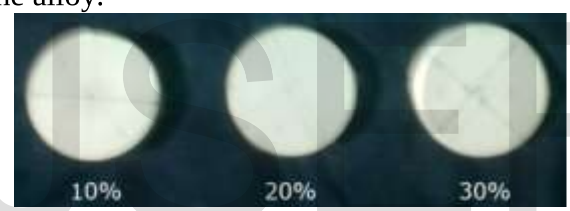
F is the load applied in Kg

D is the diameter of indenter in mm.

D is the diameter of impression in mm.

HARDNESS

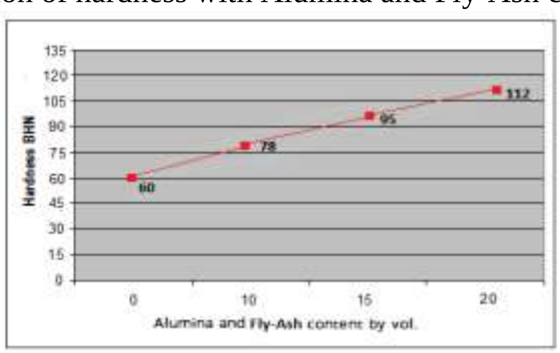
The hardness of Al 6061 base alloy is as low as 60BHN and with 10% addition of alumina and fly-ash it increases upto 78BHN and further with 15% and 20% addition of alumina and fly-ash it reaches at 95BHN and 112BHN. The variation of hardness with alumina and fly-ash content is shown in fig, the hardness of the composite increases with increase in vol. percent of alumina and fly-ash reinforced in the alloy.



Hardness Specimens of different composition

Composition	BHN
Al 6061 base alloy	60
Al 6061 +10%alumina and Fly-Ash	78
Al 6061 +15%alumina and Fly-Ash	95
Al 6061 +20%alumina and Fly-Ash	112

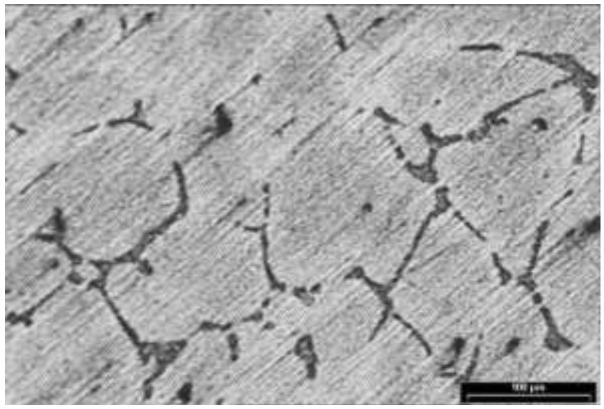
Variation of hardness with Alumina and Fly-Ash content



variation of hardness with alumina and Fly-Ash content.

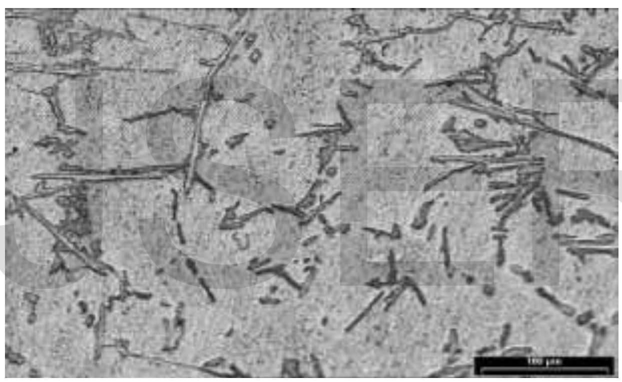
MICROSTRUCTURE

1. 10% Alumina and Fly-Ash is mixed with Al6061



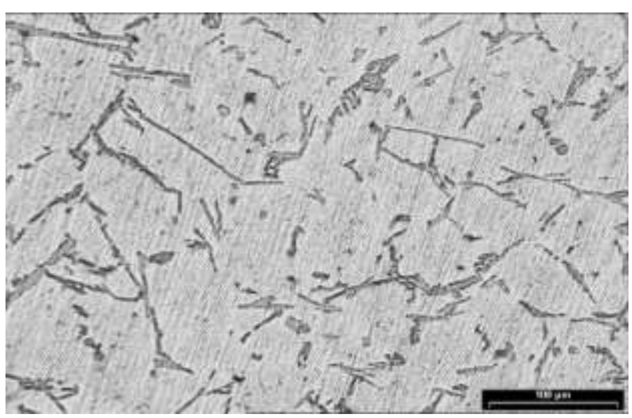
Sample 1 100 X
optical micrograph Al6061 with 10% alumina and Fly-Ash content.

2. 15% Alumina and Fly-Ash is mixed with Al6061



Sample 2 100 X
optical micrograph Al6061 with 15% alumina and Fly-Ash content.

3. 20% Alumina and Fly-Ash is mixed with Al6061



Sample 3 100 X
optical micrograph Al6061 with 20% alumina and Fly-Ash content.

DISCUSSION

The hardness of the composite increases with the addition of alumina and fly-ash. Hardness of the Al 6061 base alloy is 60 BHN, with the addition of 10% alumina and silicon-carbide it increases to 78 BHN and with addition of 15% and 20% it increases to 95 BHN and 112 BHN. The hardness of the Composite increases because hard nature of particles. With the 10% addition of particles the hardness increases by 18 BHN and with 15% and 20% it increases by 35 BHN and 52 BHN. This increase in hardness is attributed of the hard nature of particles as compared to base alloy. The result show the average value of hardness there are variations in the hardness observed for same surface of composite, this may be due to the difference in the distribution of the alumina and fly-ash particles as observed from optical micrograph.

The second reason for increase in hardness may be due to the presence of the interfacial gaps between the matrix and the reinforcement, which is unable to transfer the load from the matrix to reinforcing phase as can be seen from the optical micrograph.

CONCLUSIONS

The conclusions drawn from the present investigation are as follows:

1. The result confirmed that stir formed Al6061 with Al_2O_3/Fly-Ash reinforced composites is clearly superior to base Al6061 in the comparison of Hardness.
2. The mismatch between reinforcement and matrix leads to a large stress concentration near particulate and matrix in that region fails prematurely under application of load.
3. With the increase in vol. fraction a strong tendency of clustering of particulates [as is evident from the optical micrograph] leads to a very inefficient load transfer mechanism causing low strain to failure.
4. The hardness of aluminum alloy Al 6061 is 60 BHN. There is increase in hardness from 60 to 122 BHN, on addition of 10%, 15% and 20% alumina and silicon-carbide by vol. respectively. This increase in hardness is attributed of the hard nature of particles as compared to base alloy.

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