Machining of Aluminium Metal Matrix Composites

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Abstract— Metal Matrix Composites (MMC) have become a large leading material in composite field and particle reinforced aluminium MMCs have received considerable attention due to their excellent engineering properties. These materials are known as the difficult-to-machine materials, because of the hardness and abrasive nature of reinforcement element like alumina, silicon carbide particles. One of the most common problems encountered in drilling is that the continuous chips curl up on the body of the tool, which might damage the drilled hole. In process we are taking 6061 grade of Aluminium and adding some of the reinforcement materials like Graphite (Gr) and Alumina (Al2O3) to improve the properties of Aluminium. Here we are adding the Graphite (Gr) and Alumina (Al2O3) to Aluminium 6061 in different percentages .Graphite (Gr) is added for the purpose of smoothness, so that we can get a smooth surface finish and machining is made easier. Alumina (Al2O3) is added to improve the strength of the aluminium. The sample pieces are going to run some of the tests to find the hardness, impact strength. By using of some tests we can gather the information about the changes in property of the aluminium metal matrix composites.

Keywords— Metal Matrix Composites (MMC), Reinforced aluminium, Silicon carbide particles, Alumina (Al2O3), Graphite (Gr), Aluminium 6061.

INTRODUCTION

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons com mon examples include materials which are stronger, lighter or less expensive when compared to traditional materials. Composites are made up of individual materials referred to as constituent materials. There are two main categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

Many commercially produced composites use a polymer matrix material often called a resin solution. There are many different polymers available depending upon the starting raw ingredients. There are several broad categories, each with numer ous variations (Surappa, 2003). The most common are known as polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, polypropylene, PEEK, and others. The reinforcement materials are often fibres but also commonly ground minerals. The various methods described below have been developed to reduce the resin content of the final product, or the fibre content is increased. As a rule of thumb, lay up results in a product containing 60% resin and 40% fibre, whereas vacuum infusion gives a final product with 40% resin and 60% fibre content. The strength of the product is greatly dependent on this ratio.

METAL MATRIX COMPOSITES

A metal matrix composite (MMCs) 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 MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminu m matrix to synthesize composites showing low density and high strength.

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement (Rosso, 2006). In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD) Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

ALUMINIUM MATRIX COMPOSITES (AMCs)

In AMCs one of the constituent is aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction.

The major advantages of AMCs compared to unreinforced materials are as follows:

II. Greater strength

III. Improved stiffness

IV. Reduced density(weigh)

PRIMARY PROCESSING OF AMCs

Primary processes for manufacturing of AMCs at industrial scale can be classified into two main groups.

[1] Solid state processes.
[2] Liquid state processes.

Solid State Processes

Powder blending and consolidation (PM processing)

Blending of Aluminium alloy powder with ceramic short fibre/whisker particle is versatile technique for the production of AMCs. Blending can be carried out dry or in liquid suspension. Blending is usually followed by cold compaction, canning, degassing and high temperature consolidation stage such as hot isostatic pressing (HIP) or extrusion. PM processed AMCs, contain oxide particles in the form of plate-like particles of few tens of nm thick and in volume fractions ranging from 0.05 to 0.5 depending on powder history and processing conditions. These fine oxide particles tends to act as a dispersion-strengthening agent and often has strong influence on the matrix properties particularly during heat treatment.

Diffusion bonding

MFAMCs are mainly produced by the diffusion bonding (foil-fibre-foil) route or by the evaporation of relatively thick layers of aluminium on the surface of the fibre. 6061 Al-boron fibre composites have been produced by diffusion bonding via the foil-fibre-foil process. However, the process is more commonly used to produce Ti based fibre reinforced composites ,The process is cumbersome and obtaining high fibre volume fraction and homogeneous fibre distribution is difficult. The process is not suitable to produce complex shapes and components.

Liquid state processing

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 simple st 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 .Subsequently several aluminium companies further refined and modified the processes which are currently employed to manufactur e a variety of AMCs on commercial scale.

Microstructural in homogeneities can cause notably particle agglomeration and sedimentation in the melt and subsequently during solidification. In homogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification. Generally it is possible to incorporate upto 30% ceramic particles in the size range 5 to 100μm in a variety of molten aluminium alloys. The melt–ceramic particle slurry 11 may be transferred directly to a shaped mould prior to complete solidification or it may be allowed to sol idify in billet or rod shape so that it can be reheated to the slurry form for further processing by technique such as die casting, and investment casting .The process is not suitable for the incorporation of sub-micron size ceramic particles or whiskers. Another variant of stir casting process is compo-casting. Here, ceramic particles are incorporated into the alloy in the semi-solid state.

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REASON FOR CHOOSING 6061

Condition	Tensile strength (PSI)	Shear strength (PSI)	Yield strength (PSI)	Elongation (%)	Brinell hardness
Al 6061	45000	30000	40000	17	95
Al 6063	27000	17000	21000	12	60

Comparison of Al 6061 and Al 6063

Reason for choosing Al 6061

Fig. 1. Al 6061 is slightly (~30%) Stronger in tensile yield compared to Al 6063.
Fig. 2. The Al 6061 would absorb more energy when subjected to a shock load.
Fig. 3. It is more corrosion resistant than Al 6063.
Fig. 4. This means that Al 6061 is superior in mechanical properties to Al 6063.

REINFORCEMENT SPECIFICATIONS

Since this hybrid metal matrix composites the number of reinforcements used here is more than one. One reinforcement improves the strength and another one to improve the ease of machinability of the composite material that is being manufactur ed. The two reinforcements are,

[1] Alumina (Al_2O_3)
[2] Graphite (Gr)

Reinforcement details

Reinforcement	Hardness (GPa)	Grain size (µm)	Density (g/cm^3)
Al_2O_3	77-93	20	3.9-4.1
Gr	7-11	75–80	2.09–2.23

MANUFACTURING METHODOLOGY

There is a variety of manufacturing processes available for discontinuous metal matrix composites; stir casting is generally accepted as a particularly promising route, currently practiced commercially. 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. 6061 the alloy has an excellent combination of mechanical properties in the cast condition. This Aluminium alloy is maintained at a temperature of 700°c. Then reinforcements were added in the liquid me lt and the slurry was consciously stirred using a stirrer. The two blade Stirrer was designed in order to produce the adequate homogenous particle distribution throughout the matrix material. The Argon gas was supplied into the near the crucible during the stirring to avoid the formation of oxide layer on the surface of matrix melt. The Stirring speed 450 -475 rpm was maintained throughout work. The mixture is allowed to solidify in the steel die.

SPECIMEN PREPARATION

In this project we are using aluminium 6061 as the major component and we also add the reinforcement materials like alumina and graphite in the correct ratios as mentioned in the percentage ratio chart. Here the aluminium is cut into small pieces and they are dropped into the furnace and they are maintained at a temperature of 700°C with the help of control unit. Aluminium 6061 and the reinforcement materials are calculated on the basis of 700gms. The reinforcement materials Alumina and Graphite are added and they are stirred well up to 5mins in the in the furnace with help of the stirrer weight calculation of different composites with their percentage.

Weight calculation of different composites with their percentage

Specimen number	Al-6061 (Grams)	Alumina (Grams)	Graphite (Grams)
S1	658 (94%)	42 (6%)	-
S2	651 (93%)	42 (6%)	7 (1%)
S3	644 (92%)	42 (6%)	14 (2%)

ROCKWELL HARDNESS TEST

Rockwell hardness test is to check the hardness of the composite material, these tests are done to check the mechanical property of the composite material. In Rockwell hardness test for aluminium alloy scale B is used and ball indenter is used in the experiment. Diamond indenter is only used foe iron products.

Scale Used: B (For Aluminium alloys)

Type of indenter: 1/16 inch diameter ball indenter

IMPACT TEST – CHARPY

Impact test is done in the composite material to check the impact strength of the composite material, here charpy test is done to check the impact strength of the material. The specimen is to machine in the shape of 9mm thickness and 65mm of height, and a notch should be taken at the Centre of the specimen up to 5mm depth.

Formula used

Cross section area = L × (b – depth of notch)

$$\text{To find impact strength} = \frac{300(\text{for Al}) - \text{scale value}}{\text{Cross section area}}$$

RESULTS AND DISCUSSION

HARDNESS TEST RESULTS

Hardness test serves an important need in industry even though they do not measure a unique quality that can be termed hardness. The tests are empirical, based on experiments and observation, rather than the fundamental theory. Hardness is the one of essential property of a material that supports it to resist plastic deformation, penetration, indentation, and scratching.

Hardness values for specimen 1, 2, and 3

Specimen number	Values taken in specimen	Average value (Hardness value)
S1 **(Al (94%), Al2O3 (6%))**	**49 , 52 , 54**	**52**
S2 **(Al (93%), Al2O3 (6%), Gr (1%))**	**48 , 50 , 52**	**50**
S3 **(Al (92%), Al2O3 (6%), Gr (2%))**	**46 , 49 , 50**	**48**

Comparison of Hardness Value

IMPACT TEST RESULTS

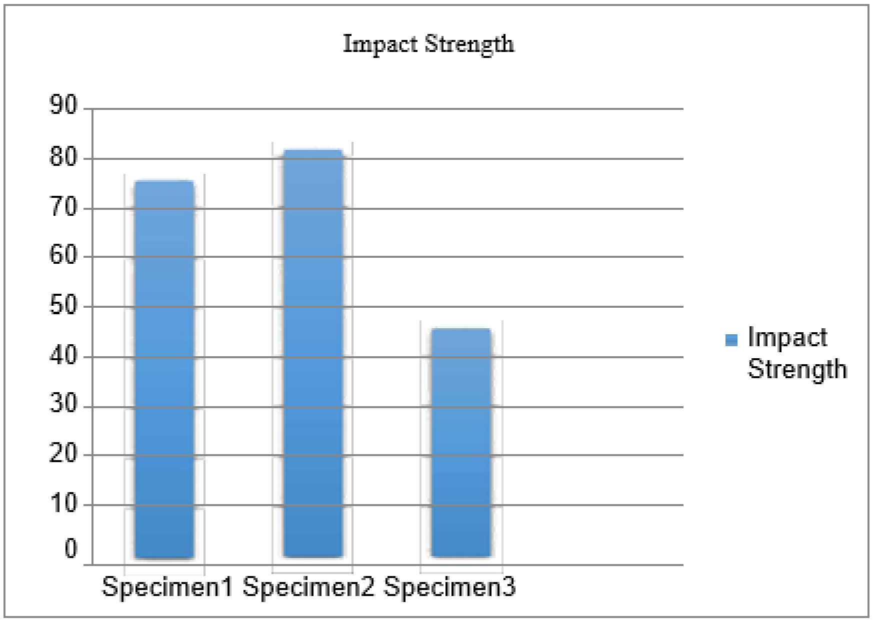
Impact test is done in the composite material to check the impact strength of the composite material, here charpy test is done to check the impact strength of the material. The sample with 6% reinforcement of Alumina and 1% graphite is found as the optimal composite and the impact strength of this sample at cast condition, along with the unreinforced material is tabulated and compared below in table

SPECIMEN NUMBER	COMPOSITION (%)	IMPACT STRENGTH
SPECIMEN 1	(Al (94%), Al2O3 (6%))	76
SPECIMEN 2	(Al (93%), Al2O3 (6%), Gr (1%))	82

SPECIMEN 3	(Al (92%), Al2O3 (6%), Gr (2%))	46

Impact strength of Specimen 1, 2, 3

Comparison of Impact Strength



CONCLUSION

The following conclusions were drawn from the aluminium matrix composites after conducting the experiments and analysing the resulting data, they are as follows. When machining of Al_2O_3-Gr particulate reinforced with Al 6061 based MMC, HSS drill bits were used for present study and machining of MMC is carried out. Chips produced by HSS drills were in powdered form of alumina reinforced composite and in graphitic composite results in both continuous and partially broken form. Thus graphitic composite material possessed good machining properties due to the presence of graphite reinforcement in the Al-Al2O3 material.

From the impact test results, it can be seen that addition of graphite reinforcement up to 2% decreases the impact strength of the material, but addition of graphite up to 1% which increases the impact strength up to $6N/m^2$. And also addition of graphite above 1% reduces the impact strength. This shows that the presence of graphite up to 1% can increase the impact strength.

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