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Microstructure and Mechanical Properties of Aluminium Metal Matrix Composites

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***Abstract**— Over the last thirty years, composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineering materials market ranging from everyday products to applications in automobile and aerospace engineering. While composite has already proven their worth as weight-saving materials, the current challenge is to make the is to make them cost effective. The efforts to produced economically attractive composite component have resulted in several innovative manufacturing techniques currently being used in the composite industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing and even program management for composites to become competitive with metals.*

Keywords— Composite Materials Automobile, Aerospace, Weight-Saving, Cost Effective

I. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains it separate chemical, physical and mechanical properties. The two constituents are reinforcement and matrix. The main advantages of composite materials are their reinforcement and matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing a weight reduction in finished part.

The reinforcement phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger and stiffer than the matrix. The reinforcement is usually a fibre or a particulate. Particulate composite has dimensions that are approximately equal in all directions. They may be spherical, platelets or any other regular or irregular geometry. Particulate composite tends to be much weaker and less stiff than continuous fibre composites, but they are usually much less expensive. Particulate reinforced composite usually contains less reinforcement (up to 40-50 volume percent) due to processing difficulties and brittleness. Continuous fibre have long aspect ratios, while discontinuous fibres have short aspect ratios. Continuous fibre composites normally have preferred orientation, while discontinuous fibres generally have a random orientation.

The continuous phase is the matrix, which is polymer, metal or ceramic. Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility and ceramics have high strength and stiffness but are brittle. The matrix (continuous phase) performs several critical functions, including maintaining the fibres in the proper orientation and spacing and protection them from abrasion and the environment. In polymer and metal matrix composites that form a strong bond between the fibre and the matrix, the matrix transmits theload from the matrix to fibres through shear loading at the interface. In ceramic matrix composites, the objective is often to increase the toughness rather than the strength and stiffness; therefore, a low interfacial bond is desirable.

Fig. 1: Composite parts for bio prosthesis parts

Fig. 2: Carbon fibre for turbines

II. OBJECTIVE

The objective of this study is to apply the knowledge acquired by testing the composite materials in different areas of mechanical engineering; to obtain the Al matrix composites of different reinforcement concentration of alumina via electromagnetic stir casting; to machine the casted material to feasible test specimen sizes and to study the results and graphs of tests conducted on specimen such as hardness test with aging, wear test and microscopic analysis.

III. METHODOLOGY

Electromagnetic Stir Casting

Electric fields are formed by charged particles such as protons and electrons. These charged particles can set in motion and pull on each other with the electrostatic force. They follow the same rule as magnets. Opposite charges attract and like charges repel each other. When these charges are in motion along a wire, an electrical current is formed. This current is what runs electrical appliances and electrical motors. When a wire conducting, current is positioned in a magnetic field, a force is induced on the conductor. This force is the basis for the electric motor. The force is given by the equation: $F = I \times L \times B$, where F is force, B is the magnetic field strength, L is the length of the conductor, and I is the current. The force on a conductor in a magnetic field can be turned into a torque by running current through a loop of wire in a magnetic field inside the electric motor. $\tau = r \times F$ A torque τ is a rotational force that is expressed by another cross product. In this equation, F is the force applied and r is the distance from the pivot point where the force is applied. Without any changes, the coil of wire will be in motion, but it won 't spin. It will stop once the torque has changed from the maximum value to zero. Electromagnetic stirring is produced by the Lorentz force generated by an a.c. inductor. Unlike electromagnetic casting where stirring occurs near the surface region, however, electromagnetic stirrers are designed to deliberately produce melt convection deep in the liquid pool near the solidification front. Thus, lower-frequency magnetic fields are used to allow the Lorentz force to penetrate deeply into the molten-metal pool.

Two types of electromagnetic stirrers are commonly used in practice: the linear stirrer and rotary stirrer. A linear stirrer operates basically the same way as an induction furnace. The design entails the placement of a stack of coils around the casting metal to generate a primary motion that recirculates along the casting direction. A rotary stirrer is basically an electric motor. It uses a rotating magnetic field to produce a swirling flow in the liquid pool. The two modes may be applied either individually or in a combined fashion and stirring may be employed in various stages of solidification processes (i.e., in mould, below mould, and at the final stage of solidification). Possibly one of the most important inspirations for applying electromagnetic stirring during solidification processing moves toward from the sympathetic that a strong melt flow will generate strong shear stresses and the shear stresses will shed away the newly formed dendrites near the solidification front. The newly produced dendrite wreckage is then elated into the bulk liquid pool of higher temperature by convection. A little of the dendrites are remitted and vanish while others stay alive and are elated back to the solidifying region. These surviving broken dendrites then form additional nucleation sites upon which further grain growth occurs, in that way ensuing in grain refinement in the final casting products. This basic grain multiplication mechanism induced by strong electromagnetic stirring. Out-of-the-way from refining internal structures, electromagnetic stirring also has the advantages of homogenizing alloy elements, reducing porosity and segregation, and minimizing internal cracks.

Electromagnetic Stir Casting Set Up

Electromagnetic stir casting set-up mostly consists a furnace and a stirring assembly. In wide-ranging, the solidification syntheses of metal matrix composites engage producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix.

The electromagnetic stirrer employees the principle of a linear motor and be different from the conventional mechanical and decompression types since it is a noncontact stirrer in which no part touches the molten metal. As shown in Figure 1, magnetic coil of motor generates a moving magnetic field, if a 3 phase AC voltage is applied to the motor. Electric power force is produced in the molten metal owing to the action of the magnetic field (magnetic flux) and resulting induction current to flow according Fleming ‘s right hand rule.

This current then acts with the magnetic field of the inductor to persuade electromagnetic force (F) in the molten metal according to Fleming's left hand rule. As this thrust stir in the direction of the moving magnetic field, the molten metal also stir. In other words, a stirring action is applied. In addition, when this thrust has components in inthe vertical direction and the horizontal direction, the molten metal flows diagonally upwards and results in auniform temperature in both the top and bottom layers of the molten metal.

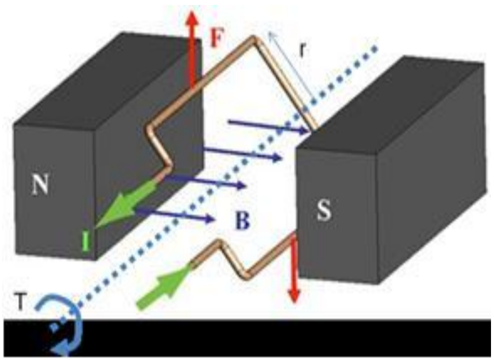

Fig. 3: Electromagnetic Process

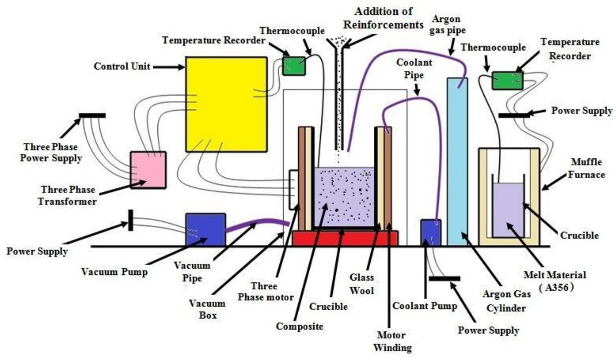

Fig. 4: Electromagnetic Stir-Casting Setup

Brinell Hardness Test

In the experiment, Brinell hardness test was used in attempt to examine the relation of the deformation of metal specimen to the hardness property of a metal. Using a hardened steel ball fixed unto a Brinell Hardness Test machine demonstrated in the experimental setup diagram. The specimen was mounted unto the machine and the machine was loaded with equivalent loads as indicated by the experimental procedure. The results were measured by help of a microscope, recorded, and tabulated. The results were used to plot graphical curves using the Microsoft excel spreadsheet package. The analysis and discussion of the results was done in relation to the present theory. Deductions were made, conclusion derived from discussion of the analysed results and recommendations put forward in response to errors encountered during the experiment. The Objectives of the experiment was to examine deformation of metal specimen when hardened steel specimen is pressed into it under different normal loads and to use the indentations to determine the properties of a metal.

$$BHN = \frac{Applied\ load\ in\ Kg}{Area\ of\ impression\ or\ indentation\ of\ steel\ ball\ in\ m^2}$$

$$BHN = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}}$$

Eqn. 1: Relation for Calculating BHN

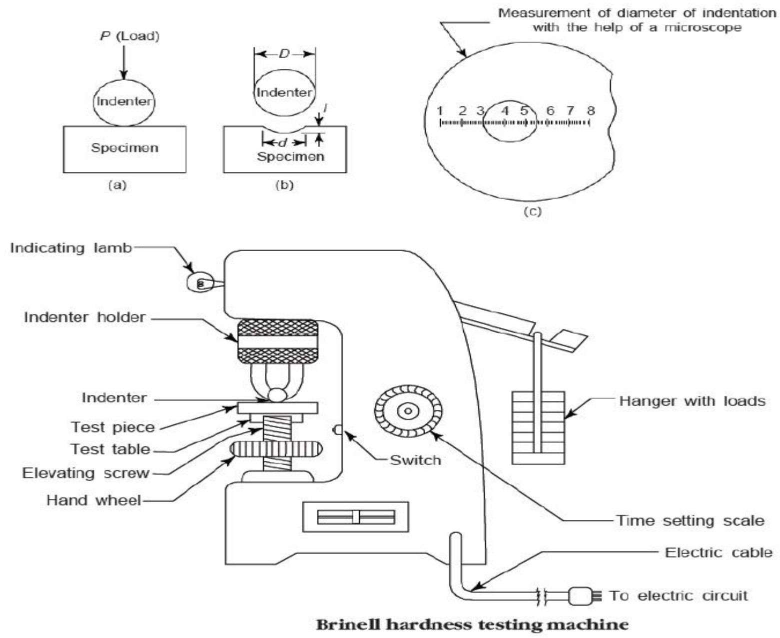

Fig. 5: Brinell Hardness Testing Machine

Wear Test

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact. As the wear is a surface removal phenomenon and occurs mostly at outer surfaces, it is more appropriate and economical to make surface modification of existing alloys than using the wear resistant alloys. This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials are tested in pairs under nominally non-abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described.

Heat Treatment with Aging

Basic construction metals tend to physically transform over time due to natural environmental conditions. The texture and colour of the metal surface changes with an oxide layer forming on it in the initial stages. Soon this layer converts to a hydroxide layer. Later this hydroxide layer combines with other elements in the atmosphere and finally the metal surface gains a stable mineral composition that is very resistant to any further alteration. This weathering or aging process can be clearly seen in natural aluminium, copper and copper alloys, lead, steel and zinc. Aging has been extensively studied and many companies are working towards perfecting the ability to accelerate and increase the weathering or aging process to bring the metal surface to a desired texture and colour. The aging process used by several companies is simply an extended heat-treatment process. This process is important for strengthening heat treatment of alloys containing Al, Cu, Mg, and Ni. The different aging techniques are Artificial Aging and Natural Aging. Artificial aging is the treatment of a metal alloy at elevated temperatures so as to accelerate the changes in the properties of an alloy as a result of the casting and forging process. Generally, the chemical properties of newly cast and forged metals naturally change and settle very slowly at room temperature. Artificial aging will speed up this change more rapidly at higher temperatures. This process ensures quality and accuracy in close tolerance specifications. It also helps manufacturers make machine-ready parts available much more quickly to machinists and distributors. Aging that occurs at room temperature is referred as natural aging.

IV. TESTING AND RESULTS

Hardness Test

Five samples of aluminium composite were used each having different percentage of Al_2O_3 i.e. 0%, 2%, 4%, 8% and 10%.

Table 1: Hardness before Aging

Al_2O_3 Concentration	BHN (Kg/mm^2)
0%	90.54
2%	113.105
4%	127.03
8%	127.03
10%	143.33

Table 2: Hardness after Aging

Al_2O_3 Concentration	Time Interval (hours)				
	0.5	1	1.5	2	2.5
0%	113.09	113.09	143.33	143.33	143.33
2%	127.03	143.33	143.33	143.33	143.33
4%	143.33	143.33	143.33	162.55	162.55
8%	143.33	143.33	162.55	185.39	185.39
10%	143.33	162.55	162.55	185.39	212.97

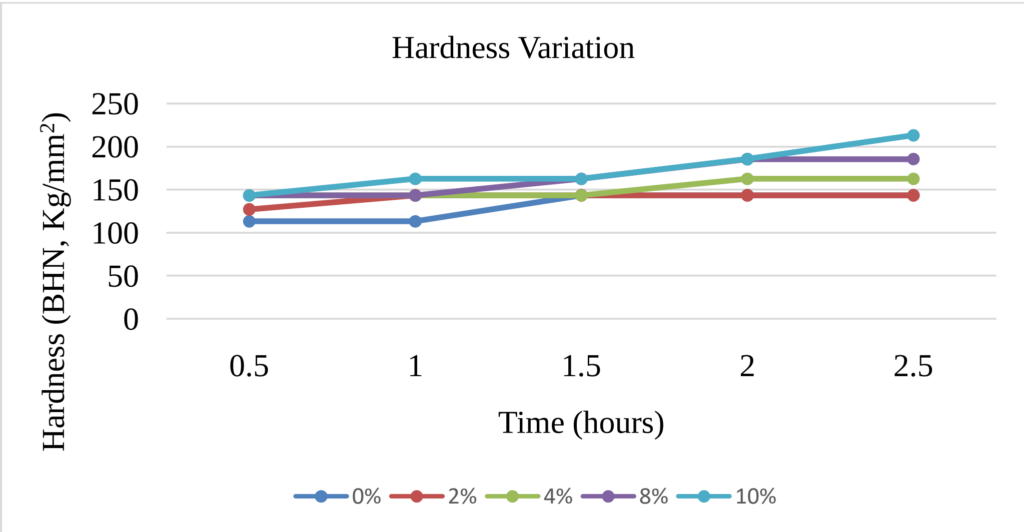

Fig. 6: Hardness number v/s filler concentration

Wear Test-Pin on Disc (ASTM G99 standard)

Table 3: Wear Test Results for 2 Kg at 500 rpm

Al_2O_3 concentration	Initial Weight	Final Weight	Wear Loss
0%	8.7383	8.7226	0.0137
2%	9.8297	9.8196	0.0101
4%	9.9547	9.9454	0.0093
8%	10.3611	10.3440	0.0082
10%	8.0595	8.0486	0.0076

Table 4: Wear Test Results for 4 Kg at 500 rpm

Al_2O_3 concentration	Initial Weight	Final Weight	Wear Loss
0%	8.7226	8.7069	0.0157
2%	9.8196	9.8668	0.0128
4%	9.9454	9.935	0.0104
8%	10.3440	10.3344	0.0096
10%	8.0486	8.0397	0.0089

Table 5: Wear Test Results for 6 Kg at 500 rpm

Al_2O_3 concentration	Initial Weight	Final Weight	Wear Loss
0%	8.7069	8.6886	0.0183
2%	9.8668	9.8526	0.0142
4%	9.935	9.9227	0.0123
8%	10.3344	10.3225	0.0119
10%	8.0397	8.0292	0.0105

Table 6: Wear Test Results for 2 Kg at 700 rpm

Al_2O_3 concentration	Initial Weight	Final Weight	Wear Loss
0%	8.6886	8.674	0.0146
2%	9.8526	9.8413	0.0113
4%	9.9227	9.912	0.0107
8%	10.3225	10.3133	0.0092
10%	8.0292	8.0208	0.0084

Table 7: Wear Test Results for 4 Kg at 700 rpm

Al_2O_3 concentration	Initial Weight	Final Weight	Wear Loss
0%	8.674	8.6567	0.0173
2%	9.8413	9.8264	0.0149
4%	9.912	9.8999	0.0121
8%	10.3133	10.3025	0.0108
10%	8.0208	8.0112	0.0096

Table 8: Wear Test Results for 6 Kg at 700 rpm

Al_2O_3 concentration	Initial Weight	Final Weight	Wear Loss
0%	8.6567	8.6375	0.0192
2%	9.8264	9.8096	0.0168
4%	9.8999	9.8852	0.0147
8%	10.3025	10.2899	0.0126
10%	8.0112	7.9993	0.0119

With the help of the results so obtained graphs were plotted for wear loss vs filler concentration for both the speed as shown in below figures. It is observed that for aluminium composite with maximum Al_2O_3 concentration the wear loss is minimum. The graphs show a linear decrease in the wear loss as the reinforcement concentration increases. The experiment has been done keeping the speed constant and varying the load. It can also be seen that as the speed increases the wear loss is more.

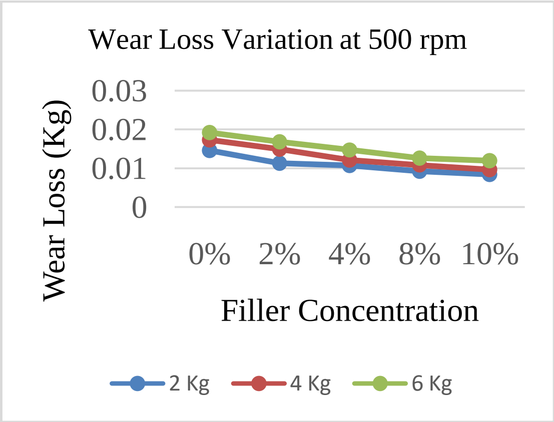

Fig. 7: Wear loss at 500 rpm for varying filler concentration and load

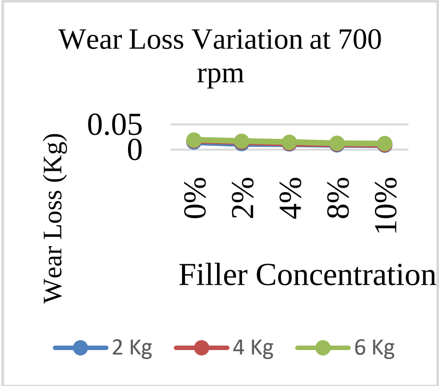

Fig.8: Wear loss at 700 rpm for varying filler concentration and load

V. DISCUSSIONS AND CONCLUSIONS

Hardness test without or before aging showed increased in BHN with increase in Al_2O_3. Hardness also increased in the same pattern after aging, with increase in time duration.

Wear test indicated the reduction in the material removal when subjected to wear with increased Al_2O_3 concentration which suggested that the material got harder with varying concentration. This can be seen from the wear loss values.

Thus we can conclude that the addition of Al_2O_3 in varied concentrations up to 10% enhanced and gave the required properties that could help in the manufacturing of various products. The maximum extent to which this concentration can be added could also be studied to know the upper limit because in that range further properties can be enhanced for high temperature and load condition applications.

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