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Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite

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Abstract:Metal Matrix Composites (MMCs) have evoked a keen interest in recent times for potential applications in aerospace and automotive industries owing to their superior strength to weight ratio and high temperature resistance. The widespread adoption of particulate metal matrix composites for engineering applications has been hindered by the high cost of producing components. Although several technical challenges exist with casting technology yet it can be used to overcome this problem. Achieving a uniform distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite material. In the present study a modest attempt has been made to develop aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two step-mixing method of stir casting technique has been adopted and subsequent property analysis has been made. Aluminium (98.41% C.P) and SiC (320-grit) has been chosen as matrix and reinforcement material respectively. Experiments have been conducted by varying weight fraction of Sic (8%, 12%, 16%, and 20%) while keeping all other parameters constant. The results indicated that the 'developed method' is quite successful to obtain uniform dispersion of reinforcement in the matrix. An increasing trend of hardness and impact strength with increase in weight percentage of SiC has been observed. The best results (maximum hardness 40.5 BHN & maximum impact strength of 32N-m.) have been obtained at 20% weight fraction of SiC. The results were further justified by comparing with other investigators.

Key Words: Metal Matrix Composites MMC's, Silicon Carbide SiC.

1. INTRODUCTION

Metal matrix composite (MMC) is engineered combination of the metal (Matrix) and hard particle/ceramic (Reinforcement) to get tailored properties. MMC's are either in use or prototyping for the space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and a variety of other applications

Like all composites, aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong, though brittle.

The melting was carried in a tilting oil-fired furnace in a range of 760 ± 10^0C. In the present study, an oil fired tilting furnace has been used. The crucible material was graphite. Diesel was used as the fuel. A forced draft fan equipped with 02 H.P 2820-rpm motor has been used for supplying the required quantity of air.

Scraps of aluminium were preheated up to a temperature of 450^0C and particles of silicon carbide up to a temperature of 1100^0C in core drying oven. Crucible used for pouring of composite slurry in the mold was also heated up to $760\ ^0$C.

3. METHODOLOGY

First of all stirring system has been developed by coupling motor with gearbox and a mild steel stirrer. All the melting was carried out in a graphite crucible in an oil-fired furnace. Scraps of aluminium were preheated at 450^0C for 3 to 4 hours before melting and mixing the SiC particles were preheated at 1100^0C for 1 to 3 hours to make their surfaces oxidized.

The furnace temperature was first raised above the liquidus to melt the alloy scraps completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed manually. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state.

After sufficient manual mixing was done, the composite slurry was reheated to a fully liquid state and then automatic mechanical mixing was carried out for about 10 minutes at a normal stirring rate of 600 rpm [6].

In the final mixing process, the furnace temperature was controlled within 760 ± 10^0C. Pouring of the composite slurry has been carried out in the sand mould prepared according to the specifications for hardness, impact and normalized displacement test specimens.

Normalized Displacement Test

Indentation was made on hardness testing machine using a 1.587 mm ball indenter and a varying load was applied for 30 seconds. Five different loads of 60, 100, 150, 187.5 and 250N have been used. The penetration depth and height of model specimen has been measured by height gauge coupled with dial indicator. The normalized displacement was calculated from following formula. The average of four readings has been reported for the results.

4. RESULTS AND DISCUSSION

4. 1 Results

Experiments have been conducted by varying weight fraction of SiC (8 %,12 %, 16% 20 %)Hardness and impact strength were recorded and tabulated. Hardness test has been conducted on each specimen using a load of 250 N and a steel ball of diameter 5 mm as indenter. Diameter of impression made by indenter has been predicted by Brinnel microscope. The corresponding values of hardness (BHN) were calculated from the standard formula.

4.2 Discussions

4.2.1 Uniform distribution of reinforcement in the matrix

when the composite has been developed without applying stirring process, particle clustering occurred in some places, and some places were identified without SiC inclusion. This was due to the fact that when the SiC particles were added into the molten alloys, they were observed to be floating on the surface, though they have a large specific density than the molten metals. This was due to high surface tension and poor wetting between the particles and the melt. In fact, wettability between most ceramic particles and liquid metals has been poor. A mechanical force can usually be applied to overcome surface tension to improve wettability.

the micrograph of composite developed with the help of manual stirring. However, for the composites, manual stirring in a completely liquid state could not solve the problem of poor wetting. Manual stirring could indeed mix the particles into the melt, but when stirring stopped, the particles tended to return to the surface. Most of these particles still stuck to

one another to remain in clusters. It is not surprising for these clusters to resurface because it might be argued that pores could exist in them to make them float. However, the fact that single particles also tended to return to the surface strongly indicates that the particles floated mainly because of the surface gas layers surrounding them

The gas layers might be the main factor for the poor wettability Firstly, gas layers can cause the buoyant migration of particles, making it difficult to incorporate the particles into the melt. Secondly, even the particles can be suspended in the melt by vigorous agitation; it has been still difficult for the particles to be wetted by the molten metals because of the gas layers. The above analysis leads to the conclusion that it was necessary to break the gas layers in order to achieve good wettability. Single particles and particle clusters can flow easily in a completely liquid melt, therefore, no large mechanical forces are actually applied to the particles during agitation, making it very difficult to break the gas layers simply by stirring in the conventional way . A two-step mixing method (as described before) was thus tried and was found to be effective.

In the first step, stirring has been carried out in a semi-solid state. In this state, primary α-Al phase exists, so agitation can apply large forces on the SiC particles through abrasion and collision between the primary α-Al nuclei and particles. This process can help to break the gas layers and perhaps oxide layers as well and to spread the liquid metal onto surfaces of the particles, thus helping to achieve good wettability. It was found that cast composites with upto 20% by weight particles could be obtained using this method. The advantages of using semisolid slurries have been usually considered to be the increase in the apparent viscosity and the prevention of the buoyant migration of particles.

In the present study, the breaking of particle– surface gas layers has been emphasized. When the gas layers were broken and the particles have been wetted, the particles will tend to sink to the bottom (due to higher specific weight) rather than float to the surface. However, this does not ensure a uniform particle distribution.

To improve the particle distribution, the second mixing step is needed, i.e., to heat the slurry to a temperature above the liquidus and then to stir the melts using an automatic device for 10 minutes at 600 rpm.

4.2.2 Hardness

As observed from figure the hardness value increases up to 20% weight fraction of SiC and beyond this weight fraction the hardness trend started decreasing. In the hardness test, severe plastic flow has been concentrated in the localized region directly below the indentation, outside of which material still behaves elastically. Directly below the indentation the density of the particles increased locally, compared to regions away from the depression. This was schematically shown in figure. Although plastic deformation itself has not been responsible for volume change, the existence of very large hydrostatic pressure under the indentation can contribute to volumetric contraction of the metal matrix.

As the indenter moves downward during the test, the pressure has been accompanied by non-uniform matrix flow along with localized increase in particle concentration, which tends to increase the resistance to deformation. Consequently, the hardness value increases due to local increase in particle concentration associated with indentation up to 20% weight fraction of SiC. Beyond this weight fraction the hardness trend started decreasing as SiC particles interact with each other leading to clustering of particles and consequently settling down. Eventually the density of SiC particles started decreasing locally thereby lowering the hardness.

5. CONCLUSIONS

The experimental study reveals following conclusions:

(a) The results of study suggest that with increase in composition of SiC, an increase in hardness, impact strength and normalized displacement have been observed.
(b) The best results has been obtained at 20% weight fraction of 320 grit size SiC particles. Maximum Hardness = 40.5 BHN & Maximum Impact Strength = 32N-m.
(b) Homogenous dispersion of SiC particles in the Al matrix shows an increasing trend in the samples prepared by without applying stirring process, with manual stirring and with 2-Step method of stir casting technique respectively.

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