Fabrication of Aluminum Based Hybrid Metal Matrix Composite Using Stircasting Technique

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Abstract**—**Aluminum composites are widely used in automobile industries, aerospace and hi-tech applications due to their great mechanical properties, low density and better resistance against corrosion and wear as compared with conventional metals and alloys. Better mechanical properties of composites make them very useful for various applications in many areas from technological point of view. The aim involved in fabricating aluminum based metal matrix composite by stir casting technique is to provide relative low production cost. Present study is focused on the fabrication of aluminum based hybrid metal matrix composites reinforced with boron carbide, graphite by stir casting technique. Tensile strength and microstructure examination of the metal matrix was performed on the samples obtained by stir casting technique.

Keywords— **Composites, Metal Matrix Composite, HMMC, Stir casting, Reinforcement.**

I. Introduction

In the current situation, due to emerging trends and the ever-changing technology, it is necessary to bring together innovative material which comprises required properties [1]. In recent years, automobile and aeronautical industry consumes composite materials for their structural and non-structural applications due to their superior mechanical and thermo physical properties [2], [3]. However, composite materials are not firsthand. They have been used since ancient times for the production of orthodox weapons like Mongolian bows, Damask sword and Japanese sabers [4]. In Indian history “Iron Pillar of Delhi” is historic example of composite material [5]. However, wood is also a natural composite material made of polymer-cellulose fibers. Therefore, concept of composite is not a human invention at all [6].

Composite materials are different from conventional materials [4]. Reinforcement materials in the form of fibers or particles are inserted in weaker material (i.e. matrix material) for the development of composite material. The resulting composite shows transitional properties that better than matrix material but inferior than reinforcement material [4]. Table 1 shows industry specific applications of composite materials. It is evident from the Table 1 that composite materials are useful for the specific purpose of different industries. There are sufficient literatures available where researchers have used or developed composite materials for specific applications [7]-[11]. There are three types of matrix materials such as polymer matrix, mineral matrix and metal matrix [12]. Similarly, there are three types of reinforcement materials such as particulate, discontinuous fiber and continuous fiber reinforcement [12], [13]. Selection of reinforcement material depends on the end-application and fabrication process [13]. Comparison between polymer matrix with metal matrix composite on the basis of industrial applicability shows very appalling scenario about metal matrix composites [13]. Few problems obstruct industrial acceptability of metal matrix composites. However, aluminum metal matrix composite has fair amount of applications in industries [13]-[18]. Table 2 shows applications of AMMCs in automobile industries. Further, it explains the need of specific reinforcement material to meet required property of the composite material for definite applications in automobile industry. The problems that obstruct the industrial acceptability of metal matrix composite could be resolved if following requirements are satisfied. The requirements are; (i) uniform distribution of reinforcement material [19], [20], (ii) maximization of wettability [21], [22], (iii) minimization of porosity [23],[24] and (iv) chemical reaction [1], [25]. Some problems persist even after the fabrication, which requires essential focus i.e. high abrasive wear of material during usage, machinability issues and corrosion resistance. The parameter optimization related to mentioned problems might reduce the problem intensity.

II. Literature Review

The process for manufacturing of MMCs generally depends on the types of reinforcement. Researchers have used different methods to fabricate MMCs i.e. vapour deposition, liquid-state, solid-state, semi-solid state, and in-situ fabrication technique [26]-[28]. Other than liquid state methods, all require expensive set-ups and are difficult to absorb in general industrial purpose [29].

The liquid state method is more convenient than others because of the following reasons: cheaper, simpler, flexible, and most economical [13], [26], [30]-[32], no limitation of shape, size and production quantity [33], [34]. Surappa [27] and Taha [13] compared stir casting with the other fabrication processes based on different parameters. Specifically, Surappa [27] compared based on range of shape, size, material yield, damage to reinforcement and cost [35]. It is apparent from the Table 3 that in all aspects stir casting is better than the other processes. Lower cost of stir casting process compared to other processes makes stir casting a viable process for mass production at industrial scale [36]-[41].

TABLE I

INDUSTRY SPECIFIC APPLICATIONS OF COMPOSITE MATERIALS [4].

Industries							
Electrical and electronics	Insulation for electrical construction	Cable tracks	Supports for circuit breakers	Supports for printed circuits	Antennas	Wind turbines	Tops of television towers
Road transport	Wheels, shields, radiator grills	Transmission shafts	Suspension springs	Chassis	Suspension arms	Cabins, seats	Body components
Rail transport	Fronts of locomotives	Wagons	Doors	Ventilation housings	Structural parts	seats	Interior panels
Maritime transport	Hovercrafts	Rescue crafts	Patrol boats	Antimine ships	Racing sailboats	Canoes	Trawlers
Cable transport	Aerial tramways	Gondola lifts	-	-	-	-	-
Air transport	Gliders	light aircraft and drones	vertical and horizontal tail plane	wing boxes	fuselages	aircraft brake disks	helicopter components
Space transport	Bodies	Tanks	Nozzles	Heat shields			
Sports and leisure	Tennis and squash rackets	Skis	Windsurf and skate boards	Bows and arrows	Javelins	Protection helmets	Bicycles

TABLE III

DIFFERENT ALUMINUM MATRIX COMPOSITES FOR VARIOUS COMPONENTS USED IN AUTOMOBILE INDUSTRIES (PRASAD AND ASTHANA 2004).

Manufacturer	**Component**	**Composite**
Duralcan, Martin Mariett, Lanxide	Pistons	Al/SiCp
Nissan	Connecting rod	Al/SiCw
Toyota	Piston rings	Al/Al_2O_3 & Al/ Boria
Honda	Engine blocks	Al/Al_2O_3
Zollner	Pistons	Al/fiberfrax
GKN, Duralcan	Propeller shaft	Al/SiCp
Dupont, Chryslers	Connecting rod	Al/Al_2O_3
Lotus Elise, Volkswagon, Chrysler, Duralcan, Lanxide	Brake rotors	Al/SiCp

Stirring helps in two ways (i) maintain particles in suspension state, and (ii) transfer the particles into the melt [23], [39]. Pressure difference due to a vortex formed during stir casting helps in particle distribution into the melt [38], [42]. Naher, Brabazon [43] optimized stirring parameters like impeller type, impeller blade angle and stirring speed for homogeneous distribution of particles. The mixture of glycerol and water mimics the viscous aluminum melt used during the experiments. SiC particles added as reinforcement into a mixture. Four or three bladed impellers with a blade angle of 60˚ and turbine bladed impeller considered good for homogeneous distribution [44]. However, melting temperature and holding temperature has a significant effect on wettability and particle distribution [45]. Temperature of melt should stay relatively higher than melting temperature of matrix material so that the viscosity of melt remains low. Lower viscosity increases the chances of homogeneous distribution and particle retention [26]. It is essential to shatter the gas layer to gain superior wettability between liquid metal and reinforcement [23], [46]. Mechanical stirring can overcome the surface tension to improve the wettability [23]. However, vigorous stirring is useless [43]. Fig. 1 illustrates an increment in the height of the liquid solution because of air entrapment [43]. Prabu, Karunamoorthy [1] examined the stirring speed and stirring time to improve particle distribution and hardness of Al-SiC composite.

Stirring speed 600 RPM and stirring time 10 min are optimum parameters for homogeneous particle distribution and better hardness of Al-SiC composite [1]. However, these parameters are adverse for porosity in Al-SiC composite [1]. Speed higher than 600 RPM depreciates the hardness of the composite while stirring time higher than 10 min ineffective in hardness improvement. The binding forces breaks, that hold mass of metal atoms together [47] which, result in gas bridge and droplets formation due to high stirring speed [47], [48].

Hashim, Looney [23] evaluated the stir casting process to resolve the problems of uniform distribution, porosity and wettability in aluminum matrix composite. Researchers have listed the significant parameters i.e. holding temperature [26], stirring speed [37], [49], [50], impeller size [51] and the impeller position [43]. Ghosh, Ray [49] investigated the effect of parameters like stirring speed, impeller diameter, impeller position and holding temperature on wettability of Al_2O_3(Alumina) in Al-Mg alloy. This study concludes that wettability improves between Al_2O_3 and Al-Mg alloy because of stirring speed (i.e. 960 RPM), impeller height (i.e. 0.81 (h/H)), impeller diameter (i.e. 0.63 (d/D)), and holding temperature (i.e. between 605 ˚C to 615 ˚C). Agarwala and Dixit [26] used bottom poring technique to decrease the time of pouring that may increase particle incorporation in the melt and for avoiding the impurities on the surface of the melt [52].

III. Experimental Setup

Experimental setup was developed for stircasting of aluminum based MMC as shown in fig. 1 because unavailability of top opening furnace in concern institutes. Without top opening furnace, it is not possible to stir the molten metal. Fig. 2 shows Experimental equipment's, procedure and materials.

Fig. 1 Top opening furnace with stirrer

Fig. 2 Experimental procedure, equipments and materials

IV. Experimental Procedure

- Ball mill was used to mix graphite, boron carbide and titanium approximately for 5 minutes to get uniform mixture of reinforcement.
- Preheating of Graphite, Boron carbide, Titanium, and Magnesium above 600 ^{o}C to reduce porosity and better wettability between the matrix and reinforcement components.
- Aluminum was melted above 850 ^{o}C in a graphite crucible in top opening furnace.
- Flux and Degasser added in melted aluminum to remove the impurities and remove any entrapped gas in the melt.
- Preheated reinforcement components were added in the metal slurry and then stirred by using motorized stirrer at 650 rpm for 12 minutes.
- Casting mould was pre heated about 400 ^{o}C for better casting.
- Mg was added at the last stage of stirring before pouring the molten slurry to improve flow ability.
- Melt degassed to remove gases that entrapped while stirring of melt.
- The molten metal poured within few minutes of addition of Mg in preheated mould and allowed to cool.
- Stir casted metal matrix specimen was used to measure Porosity and UTS.

V. Tests and Results

Different tests were performed on the specimens for the evaluation of Aluminum based HMMC fabricated by stircasting method.

A. Microscopic images

Microscope images helps in finding the distribution of reinforcement particles in the Aluminum base material. Fig. 3 shows the specimen used for Microscopic observation for uniform particle distribution detection. Microscopic image as in fig. 4 shows uniform distribution of reinforcement.

Fig. 3 Specimen for uniform particle distribution

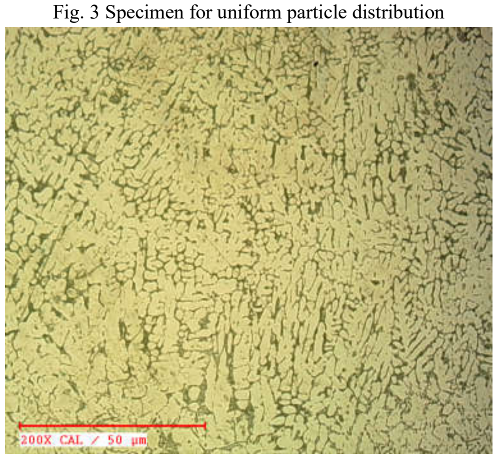

Fig. 4 Microscopic image with uniform particle distribution

B. UTS

UTS test generally conducted to find the tensile strength of the specimen. UTS test was performed on the circular specimen as shown in fig. 5 prepared from the fabricated Aluminum metal matrix composite. Tensile strength of the specimen was found as 350 Mpa.

Fig. 5 UTS test specimen of HMMC

C. *Optical Spectrometer Test*

Optical Spectrometer test usually conducted to identify elements and their percentage present in the test sample. To confirm firm presence of reinforcement material in the Hybrid MMC Spectrometer test was carried out on raw aluminum material and Hybrid MMC material after stir casting. Optical Spectrometry test result for raw aluminum and Hybrid MMC included in table 3. Comparison of both results shows firm presence of added reinforcement material Boron Carbide and Graphite. Results also indicate presence of Mg and Ti added for improvement of fluidity and wettability.

TABLE IIIII

SPECTROMETRY TEST REPORT OF ALUMINUM AND ALUMINUM BASED HYBRID MMC

Element	**Aluminum**	**Hybrid MMC**
% Si	0.45	0.42
% Fe	0.44	0.445
% Cu	0.009	0.001
% Mn	0.41	0.04
% Mg	--	1.237
% Zn	0.02	0.012
% Ti	0.013	0.085
% Cr	0.007	0.007
% Ni	0.007	0.007
% Pb	0.036	0.36
% Sn	0.001	0.001
% C	--	1.402
% B	--	6.102
% Al	98.96	90.205

VI. CONCLUSIONS

- Aluminium based hybrid Metal Matrix Composite specimen with boron carbide and graphite as reinforcement fabricated via stircasting technique.
- Different tests were performed on the specimens to evaluate the fabricated material during experiment.
- Optical Spectrometer Test results reveal the firm presence of reinforcement components and other agents like Mg and Ti.
- Degassing and fluxing helps to reduce porosity during stir casting. Flow ability improves by addition of Mg during stir casting.

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