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Preparation of Aluminium Matrix Composite by Using Stir Casting Method

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Abstract— The "composite material" is composed of a discrete reinforcement & distributed in a continuous phase of matrix, In Aluminium matrix composite (AMC) one constitutes is aluminium which forms network i.e. matrix phase and another constitute serve as reinforcement which is generally ceramic or non metallic hard material. The basic reason of metals reinforced with hard ceramic particles or fibers are improved properties than its original material like strength, stiffness etc. Stir casting process is mainly used for manufacturing of particulate reinforced metal matrix composite (PMMC). Manufacturing of aluminum alloy based casting composite by stir casting is one of the most economical method of processing MMC. Properties of these materials depend upon many processing parameters and selection of matrix and reinforcements. This paper presents an overview of stir casting process, process parameter, & preparation of AMC material by using aluminium as matrix form and SiC, Al_2O_3, graphite as reinforcement by varying proportion.

Index Terms— Stir casting process, Aluminum Matrix composite, Reinforcement, Mixing and Agitation.

I. INTRODUCTION

Now days with the modern development need of developments of advanced engineering materials for various engineering applications goes on increasing. To meet such demands metal matrix composite is one of reliable source. Composite material is one of the reliable solutions for such requirement. In composites, materials are combined in such a way as to enable us to make better use of their parent material while minimizing to some extent the effects of their deficiencies. The simple term 'composites' gives indication of the combinations of two or more material in order to improve the properties. In the past few years, materials development has shifted from monolithic to composite materials for adjusting to the global need for reduced weight, low cost, quality, and high performance in structural materials. Driving force for the utilization of AMCs in areas of aerospace and automotive industries include performance, economic and environmental benefits[1].

In AMC one of the constituent is aluminum, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminum and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC, Al_2O_3 etc

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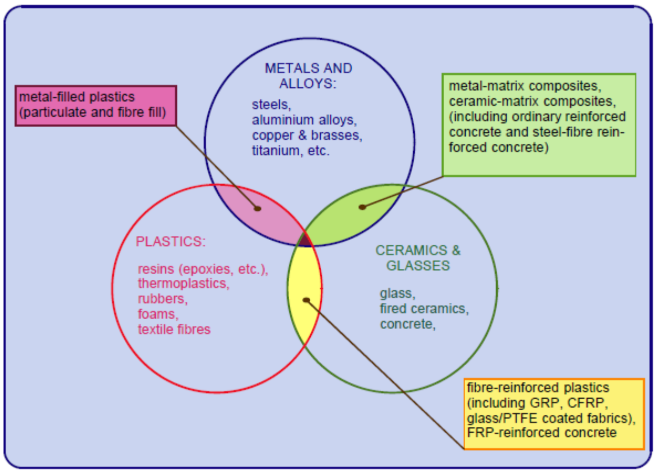

Fig1.1 Composite Material

These advantages can be used to achieve better properties. For example, elastic modulus of pure aluminium can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol. % continuous aluminum fiber. On the other hand incorporation of 60 vol% alumina fiber in pure aluminium leads to decrease in the coefficient of expansion from 24 ppm/°C to 7 ppm/°C. Similarly it is possible to process Al-9% Si-20 vol% SiCp composites having wear resistance equivalent or better than that of grey cast iron [1]. All these examples illustrate that it is possible to alter several physical properties of aluminium/aluminium alloy by adding two or three appropriate reinforcement in suitable volume fraction.

Reinforcing the matrix with whiskers, short fibers or particulates of ceramics could give a composite improved properties compared to monolithic base alloy. Further, the attractive feature is the isotropic nature of the properties. Even though the property improvements are not as high as those achievable with continuous fiber ones, they are sufficiently attractive enough for most of the intended engineering applications.[2]. The cost of the component production by solid state processing route was still high and hence large scale commercialization of wide spectrum of engineering component did not take place .

The commonly used reinforcement is silicon carbide particulates (SiCp) in cast alloy matrix (modified compositions of 356 and 357 Al alloys) and alumina particulates in wrought alloy matrix (6061/2024). Even though the possibilities of using different kinds of reinforcement in Al alloys as reinforcements, except SiCp and $A1_20_3$ others have not shown any commercial potential [2] Jokhio, Panhwar & Mukhtiar Ali investigate the effect of elemental metal such as Cu-Zn-Mg in aluminum matrix on mechanical properties of stir casting of aluminum composite materials reinforced with alpha "Al2O3" particles using stir casting they found increase in tensile strength.

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Also they found that Mg has pronounced effect on aluminum cast composites up to 2.77% Mg contents which increases wetability, reduces porosity and develops very good bonding with Al_2O_3 [3].
Preparation and characterization of aluminum metal matrix composites reinforced with aluminum nitride was carried out by M. N. Wahab, A. R. Daud and M. J. Ghazali they found considerable significant increase in hardness of the alloy matrix [4].
Cast A356/SiCp composites were produced using a conventional stir casting technique by S. Tzamtzis, N. S. Barekar, N. Hari Babu, J. Patel, B. K. Dhindaw they found a good combination of improved Ultimate Tensile Strength(UTS) and tensile elongation is obtained [5].
Experiments have been conducted by varying weight fraction of SiC, graphite and alumina (5%, 10%, 15%, 20%, 25%, and 30%), while graphite weight fraction 2%, 4%, 6%, 8% and 10% keep all other parameters constant by Dunia Abdul Saheb they found that an increasing of hardness and with increase in weight percentage of ceramic materials [6]

II. PROCESSING OF AMC

A key challenge in the processing of composites is to homogeneously distribute the reinforcement phases to achieve a defect-free microstructure. Based on the shape, the reinforcing phases in the composite can be either particles or fibers. The relatively low material cost and suitability for automatic processing has made the particulate-reinforced composite preferable to the fiber-reinforced composite for automotive applications. Primary processes for manufacturing of AMCs at industrial scale can be classified into two main groups.

A. Liquid state processes:

Liquid state processes include stir casting, compo casting and squeeze casting spray casting and in situ (reactive) processing, ultrasonic assisted casting [4].

B. Solid state processes:

Solid state process include Powder blending followed by consolidation (PM processing), high energy ball milling, friction Stir Process, diffusion bonding and vapors deposition techniques. The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of micro structural integrity desired [4].

Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production.

It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the Available routes for metal matrix composite production and allows very large sized components to be fabricated.

Table-2.1: A comparative analysis of different technique used for fabrication [4]

Method	Range of shape and size	Range of vol. fraction	Damage to reinforcement	Cost
Stir casting	wide range of shapes; Larger size; up to 500 kg	Up to 0.3	No damage	Least expansive
Squeeze casting	limited by pre form shape Up to 2cm height	Up to 0.5	severe damage	Moderate expansive
Powder metallurgy	wide range; restricted size		reinforcement fracture	Expansive
Spray casting	Limited shape, large shape	0.3-0.7		Expansive

C. Stir casting:

In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into an aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement [7].

The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. A major concern associated with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The final distribution of the particles in the solid depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification .The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added [7].
An interesting recent development in stir casting is a two-step mixing process. In this process, the matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixing process has been used in the fabrication of aluminum.
Among all the well-established metal matrix composite fabrication methods, stir casting is the most economical. For that reason, stir casting is currently the most popular commercial method of producing aluminum based composites.

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III. OBJECTIVE OF THE PAPER

The main objective of this paper is to study the operating parameter of the composite as its control the properties of the composite material. Second objective is manufacture the particulate aluminum metal matrix composite (PAMC) with varying compositions of reinforcement particles of graphite, Al2O3 and SiC by using stir casting method.

A. Composite Material:-

For composite material selection of Matrix and reinforcement are of prime importance. For this research work we had selected material as follows.

B. Matrix:-

Aluminium alloy 2000, 6000 and 7000 series are used for fabrication of the automotive parts. PAMC under study consist of matrix material of aluminium alloy Al6061 whose chemical composition is shown in the Table. An advantage of using aluminium as matrix material is casting technology is well established, and most important it is light weight material. Aluminium alloy is associated with some disadvantages such as bonding is more challenging than steel, low strength than steel and price is 200% of that of steel. But with proper reinforcement and treatment the strength can be increased to required level.

Table3.1 Chemical composition of Al (6061)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4 - 0.8	0 - 0.7	0.15 - 0.4	0.0 - 0.15	0.8- 1.2	0.04- 0.35	0.0 - 0.25	0.0 - 0.15	Bal

C. Reinforcement-

Particles of Al2O3, SiC and graphite of mesh size 320 are used as reinforcement.

SiC:-Silicon carbide particulates have attained a prime position among the various PAMC. This is due to the fact that introduction of Sic to the aluminum matrix substantially enhances the strength, the modulus, the abrasive wear resistance and thermal stability. The density of Sic (3.2g/cm) is nearer to that of aluminum alloy AA6061 (2.7g/cm3). The resistance of Sic to acids, alkalis or molten salts up to 800 degree Celsius makes it a good reinforcement candidate for aluminum based MMC. Furthermore, Sic is easily available and has good wetability with aluminum alloys. Addition of alumina particle results in good wear properties and compatibility. Addition of Silicon carbide particle results in Excellent Mechanical properties this produces a very hard and strong material.

Alumina: - Addition of alumina particle has shown increase in tensile strength and it has good compatibility with aluminium alloy.

Property	Unit	Al (6061)	Al2O3	SiC	Graphite
Density (at 20°C)	g/cm3	2.7	3.97	3.22	2.09–2.23
Melting point	˚C	650	2,288	2973	3915
Coefficient of thermal expansion	µm/m °C	23.4	7.1	4	2-6
Thermal conductivity	W/m K	166	35.6	126	85
Young's modulus	GPa	70	370	410	10

Table 3.2 Properties of Matrix and Reinforcement

Graphite: - Addition of graphite particle results in low friction of composite as it is good dry lubricant hence reduces wear and abrasion.

IV. PROCESS PARAMETER

For manufacturing of composite material by stir casting knowledge of its operating parameter are very essential. As there is various process parameters if they properly controlled can lead to the improved characteristic in composite material.

A. Stirring speed:-

Stirring speed is the important process parameter as stirring is necessary to help in promoting wetability i.e. bonding between matrix & reinforcement. Stirring speed will directly control the flow pattern of the molten metal. Parallel flow will not promote good reinforcement mixing with the matrix. Hence flow pattern should be controlled turbulence flow. Pattern of flow from inward to outward direction is best. In our project we kept speed from 300-600 rpm. As solidifying rate is faster it will increase the percentage of wetability [8].

B. Stirring temperature:-

It is an important process parameter. It is related to the melting temperature of matrix i.e. aluminium. Aluminium generally melts at 650˚C. The processing temperature is mainly influence the viscosity of Al matrix. The change of viscosity influences the particle distribution in the matrix. The viscosity of liquid decreased when increasing processing temperature with increasing holding time stirring time [8]. It also accelerates the chemical reaction b/w matrix and reinforcement. In our project in order to promote good wetability we had kept operating temperature at 630°C which keeps Al (6061) in semisolid state.

C. Reinforcement preheat temperature:-

Reinforcement was preheated at a specified 500˚C temperature 30 min in order to remove moisture or any other gases present within reinforcement. The preheating of also promotes the wetability of reinforcement with matrix [7].

D. Addition of Mg:-

Addition of Magnesium enhances the wetability. However increase the content above 1wt. % increases viscosity of slurry and hence uniform particle distribution will be difficult [6].

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E. Stirring time:-

Stirring promotes uniform distribution of the particles in the liquid and to create perfect interface bond b/w reinforcement and matrix. The stirring time b/w matrix and reinforcement is considered as important factor in the processing of composite. For uniform distribution of reinforcement in matrix in metal flow pattern should from outward to inward.

Table 4.1Uniform dispersion time for 10% SiC particles for different stirrer types and stirring speeds in glycerol/water solution of viscosity 300mPas[2]

Uniform dispersion time for 10% SiC particles for different stirrer types and stirring speeds in glycerol/water solution of viscosity 300 mPa s[a]

Stirring speed (rpm)	Blade angle (°)	Uniform dispersion time (s)		
		Three-blade stirrer	Four-blade stirrer	Turbine-blade stirrer
200	0	2700	2520	2340
	30	2520	2460	
	45	2400	2400	
	60	2100	1920	
	90	2640	2460	
250	0	1980	1800	1680
	30	1800	1800	
	45	1800	1740	
	60	1740	1680	
	90	1920	1800	
300	0	1320	1200	900
	30	1200	1140	
	45	1080	1080	
	60	900	900	
	90	1200	1200	

F. Blade Angle:-

The blade angle and number of blades are prominent factor which decides the flow pattern of the liquid metal at the time of stirring. The blade with angle 45° & 60° will give the uniform distribution. The number of blade should be 4. Blade should be 20mm above the bottom of the crucible [8].
Blade pattern drastically affect the flow pattern

G. Inert Gas:-

As aluminium melt it start reacting with environment oxygen and will produce an oxide layer at the top. This oxide layer will avoid further oxidation but along that it will difficult to brake. So such layer will be big trouble for reinforcement mixture with metal. So in order to avoid this we had used inert gas like nitrogen.

H. Preheated Temperature of Mould:-

In casting porosity is the prime defect. In order to avoid these preheating the permanent mould is good solution. It will help in removing the entrapped gases from the slurry in mould It will also enhance the mechanical properties of the cast AMC. While pouring molten metal keep the pouring rate constant to avoid bubble formation.

I. Powder Feed Rate:-

To have a good quality of casting the feed rate of powder particles must be uniform. If it is non-uniform it promotes clustering of particles at some places which in turn enhances the porosity defect and inclusion defect, so the feed rate of particles must be uniform.

V. EXPERIMENTAL SETUP AND PROCEDURE:-

Fig. 5.1 Stir Cast apparatus

This is the layout of the stir casting apparatus. It consist of conical shaped graphite crucible is used for fabrication of AMCs, as it withstands high temperature which is much more than required temperature [680°C].Along that graphite will not react with aluminum at these temperature. This crucible is placed in muffle which is made up of high ceramic alumina. Around which heating element of wound. The coil which acts as heating element is Kanthol-A1. This type of furnace is known as resistance heating furnace. It can work up to 900°C reach within 45 min. Aluminium, at liquid stage is very reactive with atmospheric oxygen. Oxide formation occurs when it comes in contact with the open air. Thus all the process of stirring is carried out in closed chamber with nitrogen gas as inert gas in order to avoid oxidation. Closed chamber is formed with help of steel sheet. This reduces heat loss and gas transfer as compare open chamber. A K type Temperature thermocouple whose working range is -200°C to 1250°C is used to record the current temperature of the liquid. Due to corrosion resistance to atmosphere EN 24 is selected as stirrer shaft material. One end of shaft is connected to 0.5 hp PMDC motor with flange coupling. While at the other end blades are welded. 4 blades are welded to the shaft at 45°C. A constant feeding rate of reinforcement particles is required to avoid coagulation and segregation of the particles. This can be achieve by using hopper . Aluminium alloy matrix will be formed in the crucible by heating aluminium alloy ingots in furnace. A stirring action is started at slow rate of 30 rpm and increases slowly in between 300 to 600 rpm with speed controller. A mixture of reinforcements (Al_2O_3 + SiC + Graphite) is to be incorporated in the metal matrix at semisolid level near 640°C. Dispersion time is to be taken as 5 minutes. After that slurry is reheated to a temperature above melting point to make sure slurry is fully liquid and then it is poured in mould.
Procedure:-

Stir casting process starts with placing empty crucible in the muffle. At first heater temperature is set to 500°C and then it is gradually increased up to 900°C. High temperature of the muffle helps to melt aluminium alloy quickly, reduces oxidation level, enhance the wetability of the reinforcement particles in the matrix metal. Aluminium alloy Al6061 is used as Matrix material. Required quantity of aluminium alloy is cut from the raw material which is in the form of round bar. Aluminium alloy is cleaned to remove dust particles, weighed and then poured in the crucible for melting. During melting nitrogen gas is used as inert gas to create the inert atmosphere around the molten matrix. Powder of alumina (Al2O3), silicon carbide (SiC) and graphite are used as reinforcement. 1% by weight of pure magnesium powder is used as wetting agent. At a time total 700 gram of molten composite was processed in the crucible. Required quantities of reinforcement powder and magnesium powder are weighed on the weighing machine. Then it is thoroughly mixed with each other with the help of blending machine for 24 hour. This mixture is kept ready 1 day before the test has to carry out. Prior to conducting the test this mixture is kept for heating in another heater.

Reinforcements are heated for half hour and at temperature of 500°C. When matrix was in the fully molten condition, Stirring is started after 2 minutes. Stirrer rpm is gradually increased from 0 to 300 RPM with the help of speed controller. Temperature of the heater is set to 630°C which is below the melting temperature of the matrix. A uniform semisolid stage of the molten matrix was achieved by stirring it at 630°C.Pouring of preheated reinforcements at the semisolid stage of the matrix enhance the wetability of the reinforcement, reduces the particle settling at the bottom of the crucible. Reinforcements are poured manually with the help of conical hopper. The flow rate of reinforcements measured was 0.5 gram per second. Dispersion time was taken as 5 minutes. After stirring 5 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make sure slurry was fully liquid. Stirrer RPM was then gradually lowered to the zero. The stir casting apparatus is manually kept side and then molten composite slurry is poured in the metallic mould. Mould is preheated at temperature 500°C before pouring of the molten slurry in the mould. This makes sure that slurry is in molten condition throughout the pouring. While pouring the slurry in the mould the flow of the slurry is kept uniform to avoid trapping of gas. Then it is quick quenched with the help of air to reduce the settling time of the particles in the matrix.

Fig. 5.2 AMC Specimen

VI. CONCLUSION

In present study the aim is study the various operating parameter of stir casting process. And to prepare AMC with help of stir casting process. For this Aluminium (6061) is selected as matrix phase while SiC, Alumina and Graphite act as reinforcement. With the help of stir casting process we had successfully manufactured AMC at less cost. While manufacturing AMC we come to know that process parameter are platy a major role for uniform distribution of reinforcement. We had some following conclusion

1) For uniform dispersion of material blade angle should be 45° or 60 ° & no of blade should be 4.
2) For good wetability we need to keep operating temperature at semisolid stage i.e. 630 for Al (6061). At full liquid condition it is difficult uniform distribution of the reinforcement in the molten metal.
3) Preheating of mould helps in reducing porosity as well as increases mechanical properties.

For further study we are going to check its mechanical properties.

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