COMPARATIVE STUDY OF FABRICATION METHODS OF METAL MATRIX COMPOSITES BY POWDER METALLURGY & STIR CASTING METHODS

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ABSTRACT

The increasing demand for the product having minimum cost along with outstanding quality has motivated work on the way to composite materials in current years. Composite materials are very significant materials nowadays. With different fabrication processes and different reinforcement materials, properties are changes. There are two fabrication methods of composite. First is liquid state methods & second being solid state methods. Stir casting and powder metallurgy both are liquid state methods. In this study a brief comparison between stir casting and powder metallurgy.

KEYWORDS: Metal Matrix Composite, Powder metallurgy, Stir casting method, Comparative study

I. INTRODUCTION

The composite materials are basically composed of two phases with different properties, namely reinforcement and matrix. The composites are the most motivating of the engineering materials because their structure is more complex. Composites can be considered that are very strong & stiff, light in weight, giving them strength to weight & stiffness to weight ratios numerous times greater than steel or aluminum. These properties are highly required in application ranging from commercial airplane to sports apparatus. There are many mechanical properties are better than for the common engineering metals like fatigue, strength, toughness etc, and also corrosion resistance is improving in composites. [1] With composite materials, its really tough to achieve the required properties which may easily achieve by the composite as compare to metal alone. Better appearance & surface finishing can be easily obtained by some composite materials. [2] Many manufacturing methods are available for the production of Metal matrix composite. There are basically two method of making composite. 1. Liquid state Methods & 2. Solid state methods. The manufacturing route is based on the requirements, applications & which type of materials are used. [3]

II. METAL MATRIX COMPOSITE

Metal matrix composites is the combination of ceramics and metals, such as cemented carbides and other cermet’s, as well as aluminum or magnesium reinforced by strong, high stiffness fibers. [2] The metal matrix composites have various advantages over other types of composites. They are mainly as high surface durability, low sensitivity, high toughness, impact properties, thermal shocks and high electrical conductivity. [4]

III. FABRICATION METHODS OF METAL MATRIX COMPOSITES [MMC]

There are many methods of fabrication metal matrix composites but in general liquid state fabrication methods are more important. Metal matrix composites are important in industries point of view.

(a) Liquid state fabrication methods

The liquid state fabrication methods are a method in which a base metal is in a molten state & mixed with a reinforcing material to form a new composite material. The liquid state fabrication methods are easy in manufacturing. In liquid state, there are generally five fabrication methods for making composites. [4,5]

1. Stir casting
2. Infiltration
3. Gas pressure infiltration,
4. Squeeze casting infiltration
5. Pressure die infiltration.

In this study we will discuss stir casting and powder metallurgy methods for fabrication of composites as well as process parameters of both the methods.
1. Power Metallurgy

To manufacture the metal matrix composites the powder metallurgy is one of the useful methods. It’s a metal processing technology which uses the sequence of operation, as starting from the powders are compressed into the desired shapes then heated at high temperature below the melting point to causes solid state bonding of the components into a hard-rigid mass called sintering. [6]

The Matrix and reinforcement are mixed in a solid-state bonding which further overcome the problem of non-wetting between liquid metal and the reinforcement and also preventing the formation of undesirable states. [7]

Process Parameters of powder metallurgy

The main factors which effects the reinforcement in molten metal & create good interface bonding as discussed below.

Powder blending

Blending facilitates the proper shapes of powder particles, also control the distribution of reinforcement particles and porosity in compacts after compaction [8]. To reduce the agglomeration of powder particles proper blending of matrix and ceramic powder is required. The over mixing will reduce the homogeneity in particle distribution.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition type</th>
<th>Blending Speed</th>
<th>Blending time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al-Al$_2$O$_3$</td>
<td>150</td>
<td>2, 24</td>
</tr>
<tr>
<td>2</td>
<td>Al–SiC–B$_4$C</td>
<td>200</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Al-Zr based glassy reinforcement</td>
<td>150</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Al–Si/SiC</td>
<td>50</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The above table represents the blending time for Al, metal matrix composites while performing blending operations. The mixing should be done after consider the reinforcement shape and size, mixing time, volume percentage and speed. The particle size ratio (PSR) should be near to 1 which provide finer micro structure and better mechanical properties. If the value is more then 1 then this results in formation of agglomeration as due to the surface area of the matrix, which is insufficient for the uniform arrangement of the particles. [31]

The segregation is also a major concern during the blending process, which characteristics between the reinforcement particle and metal powder further minimize their surface energy. [32]

The flow characteristics of the particles can be improved by adding lubricants like zinc stearate(or)stearic acid in 0.25 to 5wt%. Particles are taken in different forms like spherical, rounded, irregular, porous and angular. The size and shape directly depend on the powder production method. The reinforcement powder particles and densities of matrix will also play an important role in blending the lighter particles remains at the top whereas the heavier particles try to comes to the bottom. [31,33]

(a) Powder compaction

The green compact is the process to apply pressurize and bond the particles to form solid bond between the powder particles. For a good solid bonding the irregular shaped particles are preferred as they give better interlocking and also high green strength. The pressure depends upon powder particle and the matrix as well the reinforcement material also the application of the lubricant, also the desired density of green compact. Compacting aluminum-based composites requires less force (about 200MPa), because high compressibility of aluminum powders. Weight percentages of reinforcement & compaction pressure are most important parameters. [9] Table 2 represents amount of compaction pressure for different materials for different applications. The different compaction methods are reported like cold, warm (or) hot isostatic pressing (HIP) [30,33] for achieving good quality of green compact with desired green strength and density.
Table-2: Compaction pressure for different MMCs [8]

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Metal Matric Composites</th>
<th>Compaction Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al/10wt% SiC–Cu</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>(3 Ni+Fe)-Al2O3</td>
<td>750</td>
</tr>
<tr>
<td>3</td>
<td>SiCp/Al-10wt%Si</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>SiCp/Al-12wt%Si</td>
<td>540-570 (Hot Pressed)</td>
</tr>
<tr>
<td>5</td>
<td>Al/SiC</td>
<td>200-300</td>
</tr>
<tr>
<td>6</td>
<td>Al/Al2O3</td>
<td>440</td>
</tr>
<tr>
<td>7</td>
<td>6711Al/SiC</td>
<td>400</td>
</tr>
<tr>
<td>8</td>
<td>Cu-graphite</td>
<td>700</td>
</tr>
<tr>
<td>9</td>
<td>Al/SiCp</td>
<td>80 ton</td>
</tr>
<tr>
<td>10</td>
<td>Al/SiCp</td>
<td>200</td>
</tr>
<tr>
<td>11</td>
<td>Al–SiC–B4C</td>
<td>150</td>
</tr>
<tr>
<td>12</td>
<td>NiFe–CNT and Ni3Fe–CNT</td>
<td>300</td>
</tr>
</tbody>
</table>

(b) Sintering temperature

The objective of the sintering is the green compact heated above the melting temperature so that matrix powder melts and reacts the other elements. So that reinforcement in powder mixture to convert to liquid between which overcomes the more refractory phase. The different researchers to gives how much sintering time and temperature has been considered in sintering process for fabrication of AlMMCs.

One of the researchers, experiment on Al as a metal and different weight % MoO3 as a reinforce materials, in this study they have concluded that sintering temperature is not more effect on hardness [9]

The two main points may arise in fabrication of MMCs. One is due to several reinforcement phase (SiC) are thermodynamically unreliable in matrix (e.g Al), which leads to interfacial reactions. The second difficulty is due to difference in thermal expansion coefficients between the ceramic reinforcement and metallic matrix. For instance, coefficient of thermal expansion for Al is 24 X 10^-6 K^-1 whilst it is only 3.8 X K10^-6 K^-1 for SiC. [10]. This causes the thermal mismatch strain over the reinforcement and matrix interface while cooling in processing of MMC. The MMC is subjected to thermal cycling, the micro structural can be accelerated leading instability. The thermal expansion behavior depends on flake orientation and its size. [10]

The sintering temperature is the main controlling factor in sintering process. The selection of sintering temperature plays a major role.

Some of the researches, studied on different metal matrix composites and they have concluded that porosity decreases with increases of sintering temperature as well as mean density & mean hardness increases with increases of sintering temperature. [11, 13]

Studied micro structure and mechanical properties of nano MgO reinforced Al matrix MMCs, and they state that at higher sintering temperatures leads to increasing wettability of matrix and reinforcement by improving the inter facial bonding between the nano MgO particles and Al matrix.[14]

One of the researchers Studied on Al based hybrid composite, they concluded that with an increase in sintering temperature from 400 to 600 °C, the sintered density of the sample increases and porosity level decreases.[15]

The sintering temperature plays a major role in the structure of the composites, at higher sintering temperatures a close compact structure is obtained due higher diffusion rates [1].

This can be clearly understood by equation (1)

\[
D = D_0 \exp \left(-\frac{Q}{RT}\right); \quad (1)
\]
where \( D \) is diffusion coefficient, \( D_0 \) is constant, \( Q \) is activation energy, \( R \) is Boltzmann’s constant and \( T \) is temperature.

(c) Sintering time

The diffusion in conventional sintering process depends on the sintering time. This can be clearly explained by equation (2) [16].

\[
r = 2.4\sqrt{Dt},
\]

(2)

where \( r \) is the radial distance, \( D \) is the diffusion coefficient and \( t \) is the diffusion time. The radial distance is directly proportional to square root of the sintering time which is responsible for the atomic diffusion leading to finer grain structure.

(d) Particle size

The size and volume percentage, distribution of reinforcement in the metallic matrix, plays a vital role in the microstructure and properties of the metal matrix composites.

Al investigate the effect of particle size on microstructures & mechanical properties on SiC reinforced pure Al composite. In this study, particle size has important effects on the microstructures and mechanical properties of the composites. The voids coexisting with the clustered and large sized SiC particles significantly decrease the density and mechanical properties of the composites. The decrease of the SiC particle size will improve the tensile strength and yield strength because of the larger interfacial surface area and larger work hardening rate, but decrease the ductility of the composites because of the smaller inter-particle spacing. [17]

Investigate on effect of SiC particle size on the physical and mechanical properties of extruded Al matrix nanocomposites. In this investigation SiC of particle size 70 nm, 10 µm and 40 µm, and Al powder of particle size 60 µm were used. Composites of Al with 5& 10 wt. % SiC were fabricated by powder metallurgy technique followed by hot extrusion. Densification and thermal conductivity of the composites decreased with increasing the weight & of SiC and increased with increasing SiC particle size. Increasing the weight % of SiC leads to higher hardness and consequently improves the compressive strength of Al–SiC composite. [18] One of the Article investigated that up to 10vol% of SiC reinforcement in 6711 Al alloy results uniform distribution of of SiC particles throughout the matrix, as the SiC percentage increases beyond 10vol% resulted cluster formation. Upto optimum percentage of reinforcement into metallic matrix gives homogeneous microstructure. [19]

This is explained with the following equation (3)

\[
\lambda = \frac{4(1-f)r}{3f}
\]

(3)

where \( f \) is the volume fraction of the reinforcement, and its radius \( r \), \( \lambda \) is the inter particle distance [16].

The strength of the composites increases with increase in volume fraction of reinforcement and decreasing as increase in particle size of the reinforcement [2]. This means that the mechanical properties of the composites like hardness, yield strength, compressive strength and elongation to fracture were higher when the particle size is fine as compared to coarse particle size of the reinforcement. The particle size of the reinforcement and matrix plays an important role, because it is difficult to force hard ceramic particles into a soft metallic matrix.

Thus, the proper selection process of selecting proper size of matrix alloy and reinforcement is really crucial point to achieve homogeneous distribution of reinforcement into metallic matrix.

The main relationship between volume fraction and particle spacing size is given by: -

\[
\lambda = d_r \left[ \frac{\pi}{6f} \right]^{1/3}
\]

(4)

where \( d_r \) represents the reinforcement size, and \( \lambda \) represents the inter-particle spacing.
From above equation relation 4, it is clear that the inter particle spacing varies inversely with the reinforcement volume fraction and directly proportional to the reinforcement size [16]

The uniformity in the distribution of the reinforcement is anticipated only when the reinforcement size \( d_r \) is not less than a critical value \( d_c \)

\[
d_r \geq d_c \tag{5}
\]

\[
d_c = d_{mr} \left[ \frac{\pi}{6V_f} \right] ^{1/3} \sqrt{R} \tag{6}
\]

In the above equation, the critical value is a function of matrix powder size \( d_{mr} \) volume fraction of reinforcement particles \( V_f \) and reduction ratio \( R \) in secondary process [20].

The reduction ratio for Extrusion process is:

\[
d_{mr} / d_f = \sqrt{R} \tag{7}
\]

where \( d_{mr} \) and \( d_f \) are original and final transverse length of the matrix powder.

2. Stir casting

Stir casting methods is a less costly methods as well as simple in manufacturing for metal matrix composites. In stir casting method, MMCs is to blend the solid reinforcement into liquid metal & then to solidify the mix into a suitable mold, while the reinforcing material is slowly being added in melted material. Before the reinforcing material is added, the matrix material is heated above its melting temperature. Stir casting method is generally used for fabrication of metal matrix composites. During the manufacturing of Metal matrix composites by stir casting methods, a variety of factors that required important consideration, which includes to achieve a homogeneous dispersion of reinforcement materials, porosity, & a good bonding between reinforcement and matrix material. [1] In stir casting process, the reinforcement materials are directly added to the molten metal & the particles are uniformly distributed by means of stirring, reinforcement material must be uniformly distributed in the matrix material to achieve the best possible characteristics. [21]

Process parameter of stir casting methods

(a) Stirrer speed & Stirring period

Stirrer speed & time both are most important parameter in the stir casting methods. Stirring speed & time effects, the molten metal flow pattern i.e Molten metal flow pattern directly depends on the stirring speed. It is an important factor to make molten metal in a uniform state. High speed stirrer improves the wetting between the metal melt & the reinforcing particles [22]. Some of the study on Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. In this article, the high silicon content aluminium alloy–silicon carbide metal matrix composite material, with 10%SiC were successfully synthesized, using different stirring speeds and stirring times & they concluded that Increase in stirring speed and stirring time resulted in better distribution of particles. The hardness test results also revealed that stirring speed and stirring time have their effect on the hardness of the composite. The uniform hardness values were achieved at 600 rpm with 10 min stirring. But beyond certain stir speed the properties degraded again. Table 3 indicates the effect on mechanical properties at different stirring speed and time on different composition.
### Table-3: Effects of Stirring speed & time on different composition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition type</th>
<th>Stirring speed (rpm)</th>
<th>Stirring time (Min.)</th>
<th>Conclusion</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>100% Al+ 0% Sic+ 0% Jute Ash 96.6% Al+ 3.4% SiC + 0% Jute Ash 99.7% Al+ 0% SiC + .9% Jute Ash</td>
<td>150</td>
<td>14</td>
<td>In this study tensile strength, wear resistance &amp; microhardness was increases with the introduction of reinforcement.</td>
<td>[23]</td>
</tr>
<tr>
<td>2.</td>
<td>Al6061 Al6061-2 wt.% Al₂O₃ Al6061-4 wt.% Al₂O₃</td>
<td>600</td>
<td>-</td>
<td>Hardness &amp; Ultimate tensile strength of Al6061 alloy increased with increasing weight fraction of aluminium oxide particles in aluminium matrix. Peak hardness of 81HV is observed for the composites had 4 wt% of Al₂O₃ particles.</td>
<td>[24]</td>
</tr>
<tr>
<td>3.</td>
<td>AA7075-TiC</td>
<td>400 to 600</td>
<td>5 to 15</td>
<td>In this investigation AA7075-TiC was melted at different temperature and stirred speed &amp; time are also different. It shows that temperature is the most significant factor affects the compressive strength.</td>
<td>[25]</td>
</tr>
<tr>
<td>4.</td>
<td>Al2020+2% SiC Al2020+4% SiC Al2020+6% SiC Al2020+8% SiC</td>
<td>1000 to 1100</td>
<td>-</td>
<td>In this experiment, it shows that addition of 2% SiC, Tensile strength is more and in 8% of SiC Hardness &amp; Impact strength are more.</td>
<td>[26]</td>
</tr>
</tbody>
</table>

(b) Pouring temperature

Poring rate, poring temperature should be sufficiently high to avoid entrapping of gases.

(c) Wetting element

The addition of different alloying increases the wettability. For example, alloying element calcium, magnesium into the aluminum melt can increases the wettability with the reinforce particles. Due to reduction in surface tension magnesium is added in liquid aluminum to increases the wettability. Wettability can be defined as the ability of a liquid to spread on a solid surface. Successful incorporation of solid ceramic particles into casting requires that the melt should wet the solid ceramic phase. [27]
(d) Reinforcement preheating

It is also a very important parameter to improve the wettability of reinforcement. If preheated the reinforcement materials, the reinforce material gets reduces the moisture and any other gases. [28]

(e) Preheating the mold

Preheating the mold is the important solution to reduces porosity. It is important parameter to remove the gases from the slurry. [29]

IV. CONCLUSION

The application increases day by day of metal matrix composites. So, we focus on developing new and less costly methods for fabrication of metal matrix composites.

In this Articles, we have discussed two method of fabrication metal matrix composites that is powder metallurgy & Stir casting, both are liquid state fabrication methods & also discuss different process parameters of these two methods.

1. In powder Metallurgy, powder compaction & particle size both are most important parameter. Which will affect the mechanical properties.
2. In stir casting methods, pouring temperature, stirring speed & wetting element are most important parameter.

Powder Metallurgy & Stir casting methods, both are very important methods for fabrication of metal matrix composites. But stir casting methods is more commonly used for fabrication of metal matrix composites due to economical, Molten metal flow is uniform as well as better distribution of particles.

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V. REFERENCES


