International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 6 June 2023, pp: 31-40 www.ijaem.net ISSN: 2395-5252

Synthesis of Aluminium Based Metal Matrix Hybrid Composites

[1]Hashir Shafi, [2]Neeraj Kumar, [3]Beenu
[1]M.Tech Scholar, Dept. of Mech. Engineering, PKGCET PANIPAT, Haryana, India.
[2]Assistant Prof., Dept. of Mech. Engineering, PKGCET Panipat, Haryana, India

----
Date of Submission: 01-06-2023 Date of Acceptance: 10-06-2023

ABSTRACT: Aluminium metal matrix composites are highly sought after in the automotive, aviation, and aerospace industries, and many researchers are looking into improved property combinations. Due to their reduced density and superior mechanical properties, aluminium alloys are frequently used in the automotive and aviation industries. Relative to other metals and alloys, they have a low thermal coefficient of expansion. The main problems encountered in the production of aluminium metal matrix composites—wettability, dispersion, agglomeration and particles, matrix interface debonding—make the process difficult and expensive.

For the production of AMMCs, which are the subject of this work, various solid state methods (friction stir processing, powder metallurgy, squeeze casting, stir casting, liquid infiltration), liquid state techniques (squeeze casting, stir casting, liquid infiltration), and deposition processes (Compo casting, spary deposition) have been developed. The best stir casting machine was discovered. Several studies conducted over the last 20 years have identified a method for the manufacture of AMMCs. In essence, this study provides an overview of the fabrication techniques for aluminium metal matrix composites now in use and also makes a recommendation for the least expensive technique for producing aluminium based metal matrix composites (AMMC).

I. INTRODUCTION:

A more sophisticated material known as a composite is made up of two phases: the matrix and the reinforcement. Composites were developed to meet the greater demand for better engineering materials [1].

The matrix phase of composites is made up of metal components. This continuous phase of the composite functions as a binder to enclose the phase of reinforcement [2]. The matrix material distributes and transfers the loads into the dispersion phase of the reinforcement material. The matrix is an entirely continuous monolithic material into which the reinforcement is incorporated [2, 3]. The matrix phase inserts a support in the reinforcement and uses lighter metals like aluminium, titanium, magnesium, etc.

Alloys and pure aluminium are used as the matrix in composites made of aluminium composite. The tribological and mechanical properties of the matrix material are strengthened by embedding reinforcement materials like B_4C, SiC, graphite, etc [4]

Using reinforcement as support. In MMCs, reinforcing materials like as graphite, alumina, silicon carbide, and boron carbide are used in the form of particles, long fibres, and short fibres [7].

Aluminum metal matrix composite because of its low cost, elevated strength-to-weight index, elevated wear resistance, is utilised in structural uses together with the aerospace as well as the automobile industry [10].

1.1 Engineering Materials

A large variety of materials are available for making engineering components. Most of them come under the classes given below and are influenced by the atomic bonding of that material. The major groupings are revealed in the Table 1.1.

Table 1.1 Classification Of Materials

Metals	Polymeric
• Ferrous metals and alloys • Nonferrous metals and alloys	• Thermoplastic plastics • Thermoset plastics • Elastomers

Ceramics	**Composites**
• Carbides	• Reinforced Plastics
• Oxides	• Metal matrix composites
• Graphites	• Polymer matrix composites
• Glasses	• Ceramic matrix composites
• Diamond	

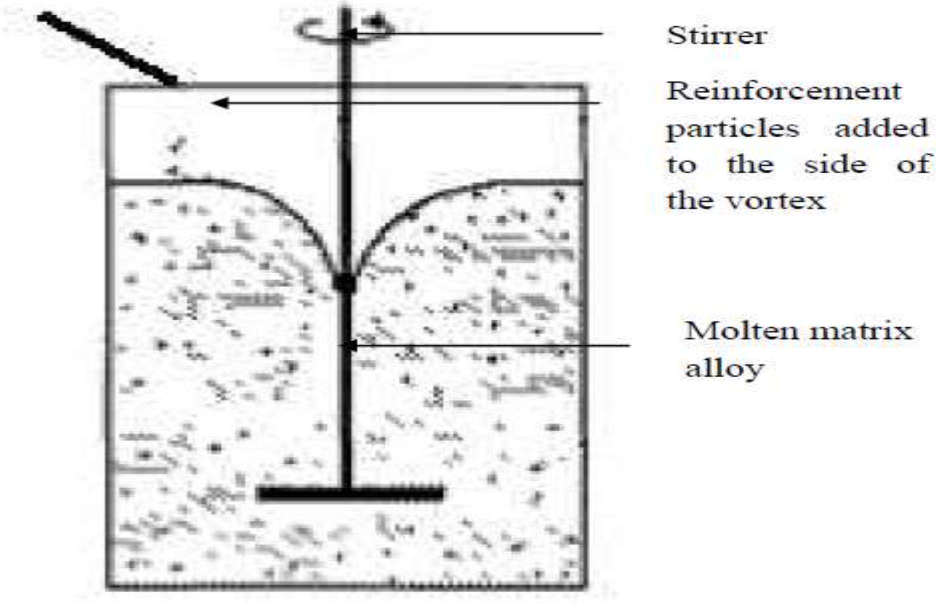
II. ALUMINIUM METAL MATRIX COMPOSITE FABRICATION METHODS

There are generally two methods employed for the fabrication of Aluminum metal matrix composites :
2.1. Liquid phase procedures, and
2.2. Solid state procedures

2.1 Liquid State Fabrication Process

In general, there exist three liquid route fabrication techniques or casting routes to casting that are presently in use for practice: the stir casting, the liquid metal infiltration method as well as the squeeze casting. Poor meltability as well as an elevated propensity for reactions to chemicals of the fortification with the liquid (metal) are two main issues that restricts the use of this elevated temperature procedural technique. Nevertheless, there exits several methods applied in the control of this phenomenon. Usually, this kind of method of fabrication is conducted in the circumstance of vacuum. Alternatively an inert gas atmosphere may be employed to lessen the liquid metal oxidation.

For the stir casting technique, incorporation of the particulates of ceramics is done in a molten matrix by employing several methods, subsequently pressing or mixing. This is followed by casting of the final MMC. A matrix-reinforcement strong bond is attained in this procedure through the employment of elevated temperatures, and frequently, alloying the matrix using an interactive element with the fortification to create a moved stage that enhances the melting occurring in-between the matrix as well as the fortification material. Variations exist in the stir casting approaches. Two forms of variations are expressed as follows. In a variation, stirring of the liquid metal is actualized for a complete liquid state , for instance, through the vortex approach. The second form is a state of partial solidification with the example being the compocasting approach. For the vortex approach, the production of the fortification is made into a vortex that is produced by stirring the liquid metal (Balasivanahaprabu 2006). Figure 1.1 showcases the diagram of the vortex approach from a schematic perspective.



(Source: Davis 1993)

Figure 2.1 Schematic diagram of producing MMC slurry using vortex method

Squeeze infiltration is the most successful form for MMC production (Sree Manu et al. 2015). In this technique, the molten metal is forced-infiltrated into fibre bundles or preformed, expelling all absorbed and trapped gases. This method involves placing a preheated preform of reinforcement into a preheated die, filling the die with molten matrix metal, squeezing the molten metal into the preform using a hydraulic press with a preheated ram, holding the pressure during solidification, releasing the pressure and ejecting the resulting composite. Figure 1.2 shows squeeze casting schematically.

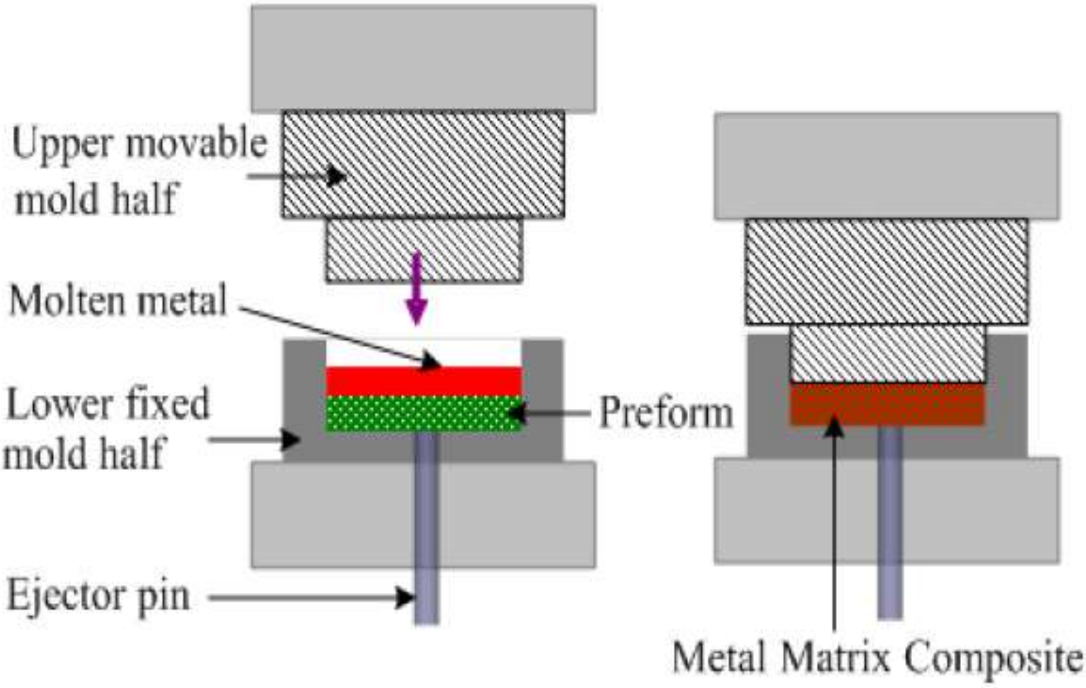


Figure 2.2 Squeeze casting process

2.2 Solid State Fabrication Process

Solid state processes are generally used to obtain the highest mechanical properties in MMCs, particularly in discontinuous AMMCs. This is because segregation effects and brittle reaction product formation are at a minimum for these processes, especially when compared with liquid state processes.

2.2.1 Powder Metallurgy

Powder Metallurgy (PM) is the common method for fabricating discontinuously reinforced AMMC. In this process, after blending the matrix alloy powder with reinforcement material and binder, the resulting mixture is fed into a mould of the desired shape. Cold isostatic pressing is utilized to obtain a green compact. The main difficulties encountered in this process are the removal of the binder used to hold the powder particles together.

The organic binders often leave residual contamination that causes deterioration of the mechanical properties of the composites.To ease the bonding of powder particles, the compact is heated to less than the melting point temperature but high enough to develop significant solid state diffusion (sintering) Sometimes, it becomes necessary to maintain the consolidation temperature slightly above the solidus to minimize deformation stress and to avoid the damage of particles or whiskers. The consolidated composites are subsequently extruded or forged into the desired shape. Figure 1.3 shows a schematic diagram of powder metallurgy technique (Radha et al. 2015)

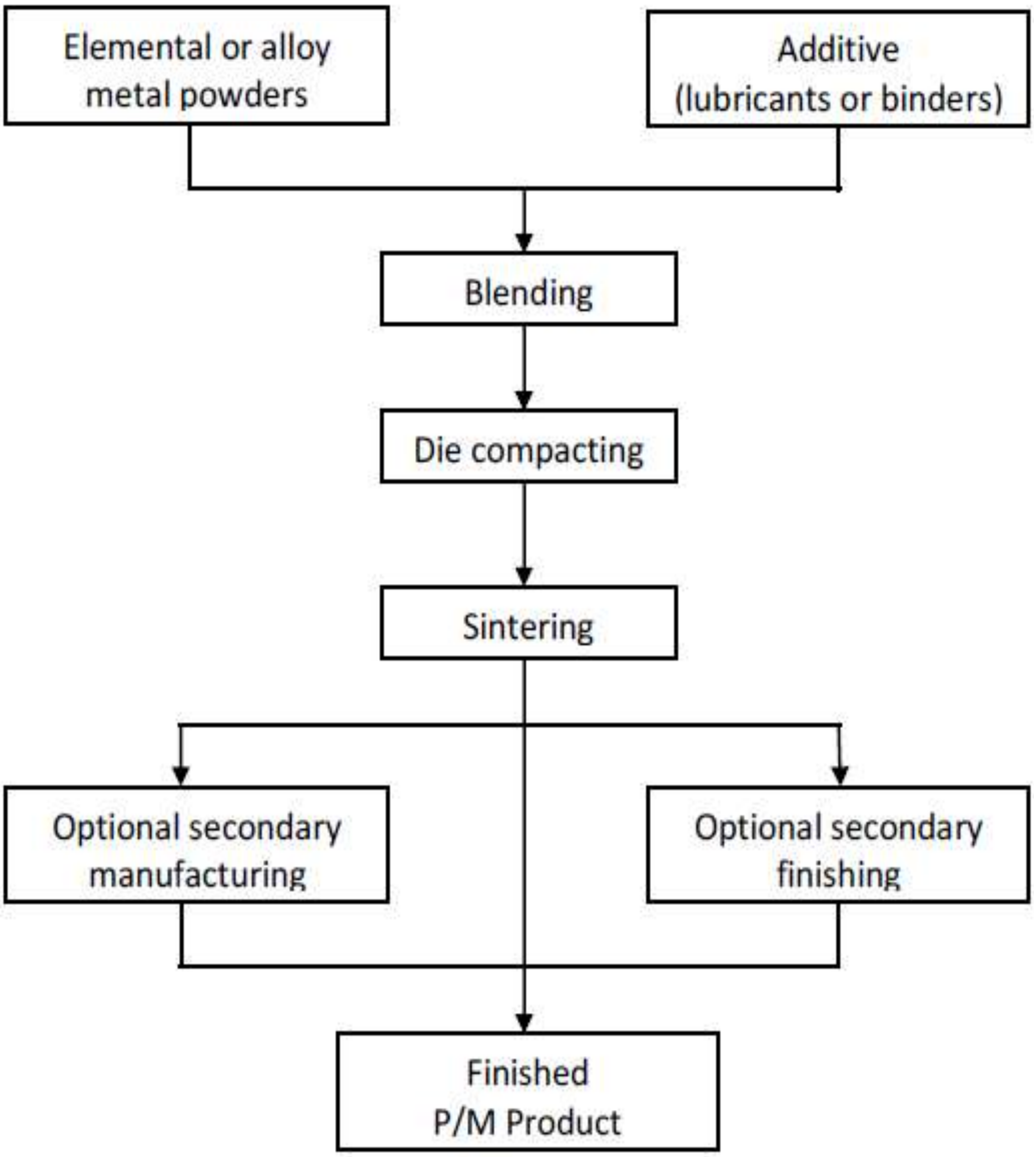


Figure 2.1.1 Flow chart of the powder metallurgy process

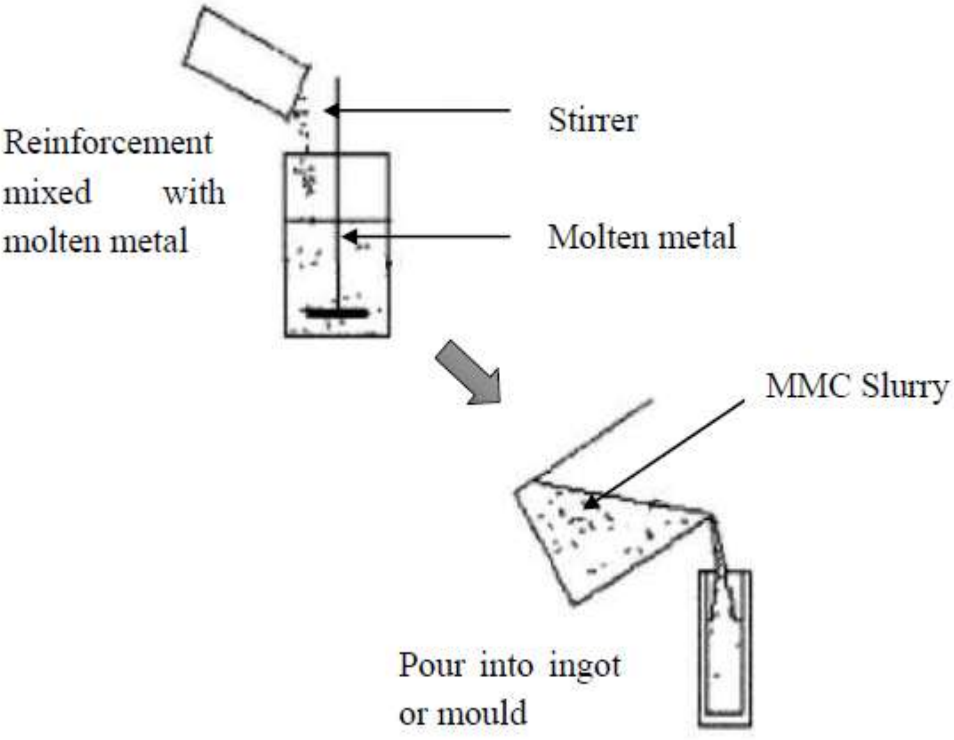
2.1.1 Spray Casting

Another method of manufacturing AMMCs are spray casting or spray deposition method. This method also can be used on unreinforced materials. In this process, a controlled stream of molten metal is produced. The stream is converted to a spray of molten droplets in an inert atmosphere, for example in nitrogen gas. The size of the droplets is approximately 205-40µm in diameter. The droplets are impacted onto a collecting surface, and allowed to coalesce. It is possible to add solid particles such as metal and ceramic to the atomised metal stream. The advantage of this process is the short contact time between the liquid matrix and reinforcement that will reduce chemical reactions. However, the production cost of this process is very high.

2.1.2 Stir Casting Fabrication Method

Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted, and currently practiced commercially. Its advantages are in its simplicity, flexibility and applicability to large scale production and because in principle it allows a conventional metal processing route to be used, and its low cost. (Mazahery et al. 2012) This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production ,because it allows very large sized components to be fabricated, and is able to sustain high productivity rates.

General, stir casting of AMMCs involves producing a melt of the selected matrix material, followed by the introduction of a reinforcing material into the melt, obtaining a suitable dispersion through stirring. The next step is the solidification of the melt containing suspended particles to obtain the desired distribution of the dispersed phase in the cast matrix. The schematic diagram of this process is shown in Figure 1.4. In aluminum composites produced by this method, particle distribution will change significantly depending on process parameters during both the melt and the solidification stages of the process. The addition of particles to the melt drastically changes the viscosity of the melt, and this has implications for casting processes (Mohanakumar et al. 2014). It is important that solidification occurs before appreciable settling has been allowed to take place.



(Source: Davis 1993)

Figure 2.1.2 Schematic diagram of stir casting process

The process is generally earned out at two different ranges of temperature of the melt, beyond the liquidus temperature or at the melt temperature maintained within the partially solid range of the alloy. The technique involving the latter range of temperature is called the compocasting process, and it is very effective in making cast composites with higher particle content. The reinforcement particles are added gradually while stirring continues at a constant rate.To get good incorporation, the addition rate needs to be reduced with a decrease in the size of the particles. Most previous researches used the matrix metal alloy in the ingot form or extruded bar. As a starting point, the ingot is generally melted to above the liquidus temperature, for example to 50°C above the liquidus temperature.

A slurry prepared from raw material composite melt may be prepared in a graphite crucible, silicon carbide crucible, alumina crucible, or concrete crucible. To keep the melt as clean as possible, the ingot is melted under a cover of an inert gas such as nitrogen, or in a vacuum chamber or in a pressure chamber. This also helps to minimize the oxidation of the molten metal, or reduce porosity (Shabani et al. 2012 and Mazahery et al. 2013). The most significant requirement when using a stir casting technique is continuous stirring of the melt with a motor driven agitator to prevent settling of particles. If the particles are more dense than the host alloy, they will naturally sink to the bottom of the melt. This means that some method of stirring the melt must be introduced before casting to ensure that the particles are properly distributed throughout the casting. Some of the stirrers which are normally used are shown in Figure 1.5. Degassing liquid aluminum alloy is a usual step in the casting procedure. When reinforcement materials are incorporated into a melt in air, the molten compound must be treated to remove the dissolved gases. Although various out-gassing treatments are available (based on nitrogen gas, chlorine or vacuum treatment), it is difficult to reach a very low hydrogen content corresponding to the saturation of solid aluminum alloys. At the end of the degassing step, the formation of bubbles is enhanced by an injection of nitrogen gas. However, the application of vacuum to the molten mixture of metal and particles during the mixing step can reduce the atmospheric gasses available for introduction into the melt, and also tend to draw dissolved, entrapped and adsorbed gasses out of the melt during mixing.

Wettability can be defined as the ability of a liquid to spread on a solid surface. Wettability also describes the extent of interface contact between the liquid and the solid. Consider a drop of liquid resting on a solid substrate. The composites produced by liquid metallurgy techniques generally show excellent bonding between ceramic and molten matrix when reactive elements are added to induce wettability. For example, the addition of magnesium, calcium, titanium, or zirconium to the melt may promote wetting by reducing the surface tension of the melt, decreasing the solid-liquid interfacial energy of the melt, or reducing wettability by chemical reaction. It has been found that for aluminum-based composites, magnesium has a greater effect in incorporating reinforcement particles in the melt, and improving their distribution, than other elements tested including cerium, lithium, zirconium and titanium, bismuth, lead, zinc, and copper. The addition of magnesium to molten aluminum has been found to be successful in promoting wetting of alumina, and indeed it is thought that magnesium is suitable with most reinforcements. Magnesium is a powerful surfactant. The addition of magnesium to an aluminum melt improves wetting because of the lower surface tension of magnesium (0.599 Nm-1) compared with that of pure aluminum (0.76 Nm-1). The addition of 3 wt % magnesium to aluminum reduces its surface tension from 0.76 to 0.62 Nm-1 at 720°C. The reduction is very sharp for the initial 1 wt.% magnesium addition. For example, with 1 wt % magnesium, the surface tension of an aluminum alloy has been found to drop from 860 to 650 dyncm-1. Magnesium can also reduce the solid-liquid interfacial energy by aiding the reaction at the surface of the reinforcement particles and forming a new compound at the interface.

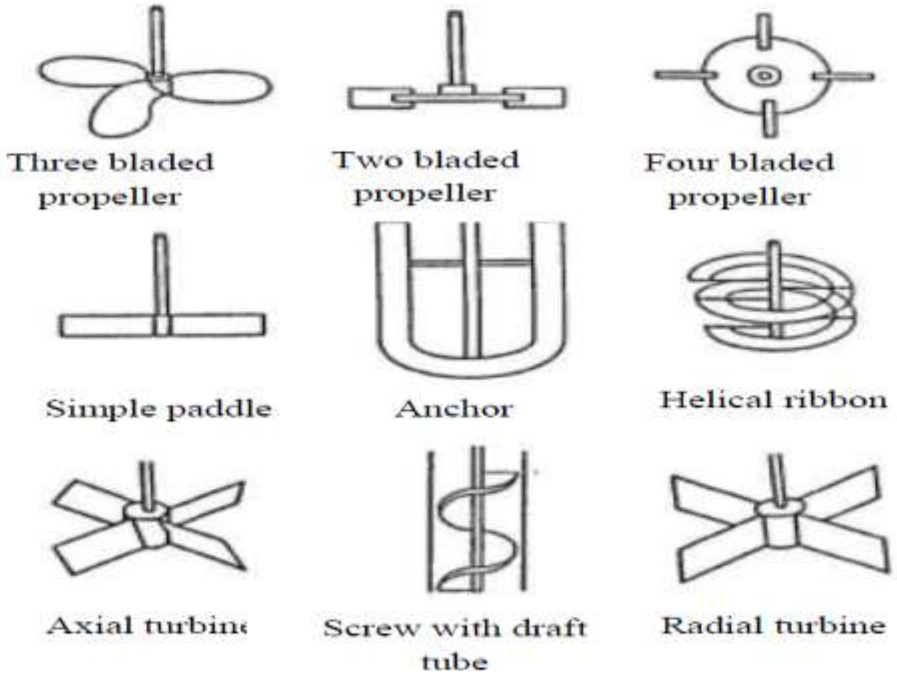


Figure 2.2.2 Several types of stirrer

Dispersion by stirring with the help of a mechanical stirrer has widely been used for this method. This external force is used to mix a non-wet table ceramic phase into a melt, and also to create a homogeneous suspension in the melt. The uniformity of particle dispersion in a melt before solidification is controlled by the dynamics of the particle movement in agitated vessels (Shabani et al. 2011). The composite slurry may be agitated using various types of mechanical stirrer such as graphite stirrer and steel stirrer coated with ceramic, four bladed alumina spray-coated stirrer or alumina stirrer. The vortex method is the most frequently used since any stirring of a melt naturally results in the formation of a vortex. Ceramic particles are introduced through the side of a vortex which is created in the melt with a mechanical impeller at different agitation speeds such as at 100-1500 rpm. Particles have, for example been continuously stirred after being incorporated into the melt, for 5-45 minutes. Some foundries use a slowly rotating propeller for continuous stirring (Li-naguan et al. 2011).

Introducing reinforcement particles to the stirred molten matrix sometimes will entrap not only the particles but also other impurities such as metal oxide and slag, which are formed on the surface of the melt. During pouring, air envelopes may form between particles, which can alter the interface properties between particles and the melt, retarding the wettability between them. In the case where the temperature of the particles added are not the same as the temperature of the molten slurry, the viscosity of the slurry increases very rapidly. The development of a vortex during stirring has been found to be helpful for transferring the particles into the matrix melt. In this method, the reinforcement particles are added to the top of the stirred liquid, and are drawn toward the center of the vortex. In other words, the vortices formed tend to concentrate particles added to the surface at the center of the mould. A pressure difference between the inner and the outer surfaces of the melt sucks the particles into the liquid.

However, air bubbles are also sucked by the same mechanism into the liquid metal, resulting in high porosity in the cast product. However, vigorously stirred melts will also entrap gas, which is extremely difficult to remove as the viscosity of the slurry increases. Slag that forms on the surface of the aluminium melt will also entrap the reinforcement particle and result in slag or particle clusters that lead to poor dispersion. It is important therefore that the matrix materials be as clean as possible. An inert cover gas such as dry argon can help to prevent atmospheric contamination of the melt. It has been possible to reduce the extent of porosity by the use of vacuum.

The melt particle slurry prepared by stirring will have to be transported to a die or casting bay either by using a slurry pump or by being held in a ladle. During the holding, the slurry must be stirred continuously if the holding time is long enough to allow considerable settling, leading to a nonuniform distribution of the particles in the cast components. The settling rate is a function of volume fraction of particles in the slurry. The utilization of fine particles with large volume fraction will reduce the settling. If a mixture of fine and coarse particles is used in slurry, the coarse ones will settle faster than the fine particles. In a large mass of liquid such as the furnace or crucible, there may be thermal current flowing around the melt, which helps to keep the particles in suspension.

However, if the melt is not continuously stirred, it is important to remember to stir it immediately before pouring, whether or not it was stirred while melting and holding. The particle distribution or homogeneity will be maintained if their settling has been controlled. After the incorporation of the particle into the melt is completed (in the case in which the stirring action was performed in semi-solid condition), the slurry needs to be remelted to a temperature above the liquidus before being poured into the mould. The remelted temperature used is about 700°C for 1-5 minutes. The composite slurry is then poured into a mould. The mould may be of steel, copper, graphite or cast iron. Normally, the mould is preheated to about 300^{o}C. In some cases, the casting is solidified under pressure to prevent porosity. The viscosity of the melt particles slurry is higher than that of the base alloy, and this may offer greater resistance to flow in the mould cavity.

III. CHARACTERIZATION OF COMPOSITES

3.1 Density

Mass can be thinly distributed as in a pillow, or tightly packed as in a block of lead. The space the mass occupies is its volume, and the mass per unit of volume is its density. Mass (m) is a fundamental measure of the amount of matter.

3.2 Hardness

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load) and a given indenter, the smaller the indentation, the harder the material. Indentation hardness value is obtained by measuring the depth or the area of the indentation using one of over twelve different test methods.

The Brinell hardness test method as used to determine Brinell hardness, is defined in ASTM E10. Most commonly, it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g. castings and forgings. Brinell testing often uses a very high test load (3000 kgf) and a 10mm wide indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured across at least two diameters – usually at right angles to each other and these result averaged (d). A chart is then used to convert the averaged diameter measurement to a Brinell hardness number. Test forces range from 500 to 3000kgf.

A Brinell hardness result measures the permanent width of indentation produced by a carbide indenter applied to a test specimen at a given load, for a given length of time. Typically, an indentation is made with a Brinell hardness testing machine and then measured for indentation diameter in a second step with a specially designed Brinell microscope or optical system. The resulting measurement is converted to a Brinell value using the Brinell formula or a conversion chart based on the formula. Most typically, a Brinell test will use 3000kgf load with a 10mm ball. If the sample material is aluminum, the test is most frequently performed with a 0.5kgfload and 10mm ball. Brinell test loads can range from 3000kgf down to 0.1kgf. Ball indenter diameters can range from 1mm to 10mm. Generally, the lower loads and ball diameters are used for convenience in “combination” testers, like Rockwell units, that have a small load capacity. The test standard specifies a time of 5 to 30 seconds, although shorter times can be used if it is known that the shorter time does not affect the result. There are other conditions that must be met for testing on a round specimen, spacing of indentations, minimum thickness of test specimens, etc.

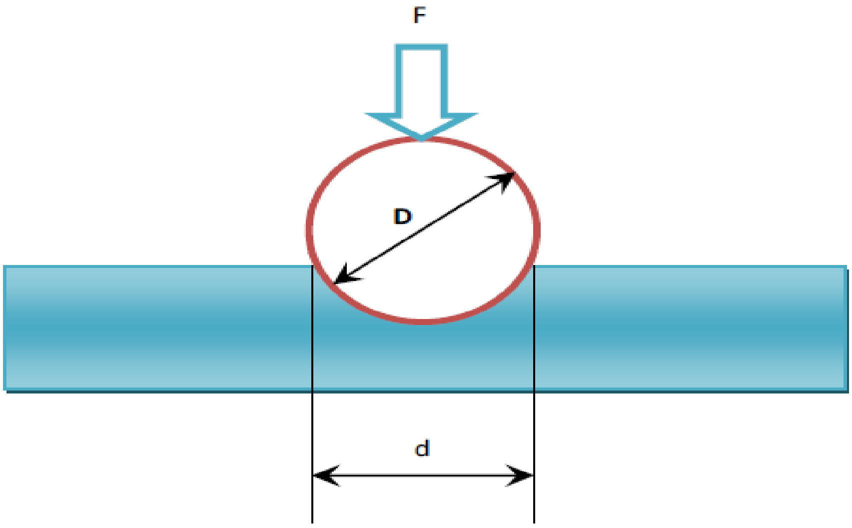


Figure 1.6 Schematic diagram of Brinell hardness test

$$HB = \frac{2F}{\pi D(D-\sqrt{D}-d)}$$

Test Method Illustration
D = Ball diameter
d = impression diameter
F = load
HB =Brinell result

Typically, the greatest source of error in Brinell testing is the measurement of the indentation. Two types of technological remedies for countering Brinell measurement error problems have been developed over the years. Automatic optical Brinell scopes use computers and image analysis to read the indentations in a consistent manner. This standardization helps eliminate operator subjectivity, and so operators are less-prone to automatically view in-tolerance results when the sample’s result may be out-of-tolerance.

IV. CONCLUSION

Researchers have developed a variety of methods for creating composites made of an aluminium metal matrix, thus it is essential that we look for methods that are both inexpensive and simple to utilise when creating composites. Following the analysis of numerous studies. In the papers, we learn that the liquid state fabrication approach is a good methodology, and that it has been determined to be the best in it. Additionally, we learn that the researchers employed roughly 90% matrix alloys. The research report demonstrates that we can improve the mechanical and tribological properties of the metal matrix composite by employing various techniques. This article is a great resource for learning how to create composites with an aluminium metal matrix.

- The optimum method for producing MMC is stir casting, and stirring temperature, time rate, and speed were discovered to be crucial factors in tensile strength.
- The percentage of reinforcement has a significant impact on every composite property.

REFERENCE

[1]. Jinzhi Liao, Ming-Jen Tan, A simple approach to prepare Al/CNT composite: Spread–Dispersion (SD) method, Materials letters 65 (2011) 2742-2744.

[2]. V. Pradeep, N. Mathiazhagan and S. Mathiyazhag, "Experimental investigation of mwcnt on aluminium – silicon carbide composites", Journal of Chemical and Pharmaceutical Sciences, Special Issue, vol. 6, **(2015)**, pp. 122-126.

[3]. B. Rebba and N. Ramanaiah, "Studies on Mechanical Properties of 2024 Al – B4C Composites", Advanced Materials Manufacturing & Characterization, vol. 4, no. 1, **(2014)**, pp. 42-46.

[4]. S. Jerome, B. Ravisankar, P. Kumar Mahato and S. Natarajan, "Synthesis and evaluation of mechanical and high temperature tribological properties of in-situ Al–TiC composites", Tribology International, vol. 43, **(2010)**, pp. 2029-2036.

[5]. A. E. Karantzalis, S. M. Wyatt and A. R. Kennedy, "The mechanical properties of Al–TiC metal matrix composites fabricated by a flux-casting technique", Mater Sci Engg., vol. 237, **(1997)**, pp. 200-6.

[6]. Dong H. Nam , Seung I. Cha , Byung K. Lim , Hoon M. Park , Do S. Han , Soon H.Hong 'Synergistic strengthening by load transfer mechanism and grain refinement of CNT/Al–Cu composites' sciVerse Science direct 50 (2012) 2417-2423.

[7]. Y. Birol, "Grain refining efficiency of Al–Ti–C alloys", Journal of alloys and Compounds, vol. 422, no. 1-2, **(2006)**, pp. 128-131.

[8]. S. Cruz, R. Pilar, M. Cabeza, M. Lieblich and P. Merinob, "Effect of the TiC particle size on the extrusion of 7075 aluminium matrix composite", ECCM16 – proceedings of the 16th european conference on composite materials, Spain, **(2014)** June 22-26.

[9]. A. R. Kennedy and S. M. Wyatt, "Characterizing particle–matrix interfacial bonding in particulate Al–TiC MMCs produced by different methods", Composites Part A: applied science and manufacturing, vol. 32, **(2001)**,pp. 555-559.

[10]. B. Deshmanya and Gk. Purohit, "Development of Mathematical Model to Predict Micro-Hardness of Al7075/Al2O3 Composites Produced by Stir-Casting", Journal of Engineering Science and Technology-Review, vol. 5, no. 1, **(2012)**, pp. 44-50.

[11]. M. T. Abou El-Khair Daoud and A. N. Abdel-Azim, "Microstructure and Wear Behavior of squeeze cast 7075 Al-Al2O3 Particle Composites", Proceedings of the 14th International Offshore and Polar Engineering Conference, Toulon, **(2004)** May 23-28, pp. 252.

[12]. R. Kumar Bhushan, S. Kumar and S. Das, "Fabrication and characterization of 7075 Al alloy reinforced with SiC particulates", The International Journal of Advanced Manufacturing Technology, vol. 65, no. 5-8, **(2013)** March, pp. 611-624.

[13]. O. Carvalho, G. Miranda, D. Soares, F.S. Silva, CNT-reinforced aluminum composites: processing and mechanical properties, clencia & Technologia Materials 25(2013) 75-78.

[14]. S. Khorasani, S. Heshmati-Manesh, H. Abdizadeh, Improvement of mechanical properties in aluminum/CNTs nanocomposites by addition of mechanically activated graphite, Composite part A 68(2015) 177-183.

[15]. T. Miyajima and Y. Iwai, "Effects of reinforcements on sliding wear behavior of aluminum matrix composites", Wear 255, **(2003)**, pp. 606-616.

[16]. Chunfeng Deng, XueXi Zhang, Dezun Wang, Qiang Lin, Aibin Li, Preparation and characterization of carbon nanotubes/aluminum matrix composites, Materials Letters 61(2007) 1725-1728.

[17]. R. Tyagi, “Synthesis and tribological characterization of in situ cast Al–TiC composites”, Wear, vol. 259, **(2005)**, pp. 569-576.

[18]. Sónia Simões, Filomena Viana, Marcos A.L. Reis, Manuel. Vieira, Improved dispersion of carbon nanotubes in aluminum nanocomposites, Composite Structure 108(2014) 992-1000.

[19]. Hansang Kwon , Miyazaki Takamichi , Akira Kawasaki , Marc Leparoux, Investigation of the interfacial phases formed between carbon nanotubes and aluminum in a bulk material, Materials chemistry and physics 138(2013) 787-793.

[20]. S.E. Shin, Y.J. Ko , D.H. Bae, Mechanical and thermal properties of nanocarbonreinforced aluminum matrix composites at elevated temperatures, composites part B 106(2016) 66-73.

[21]. Christopher R. Bradbury , Jaana-Kateriina Gomon , Lauri Kollo , Hansang Kwon, Marc Leparoux, Hardness of Multi Wall Carbon Nanotubes reinforced aluminium matrix composites, Journals of alloys and compounds 585(2014) 362-367.

[22]. H.J. Choi, B.H. Min, J.H. Shin, D.H. Bae, Strengthening in nanostructured 2024 aluminum alloy and its composites containing carbon nanotubes, Composites : part A 42 (2011) 1438-1444.

[23]. Mohamed T.Z. Hassan, Amal M.K. Esawi, Sayed Metwalli ‘Effect of carbon nanotube damage on the mechanical properties of aluminium–carbon nanotube composites’ Journal of alloys and compounds 607(2014) 215-222.

[24]. Devanshu Singla, Kaza Amulya, Qasim Murtaza, CNT reinforced aluminium matrix composite-a review, Mater. Today Proc. 2 (2015) 2886–2895.

[25]. B.N. Sarada, P.L. Srinivasa Murthy, G. Ugrasen, Hardness and wear characteristics of Hybrid Aluminium Metal Matrix Composites produced by stir casting technique, Mater. Today Proc. 2 (2015) 2878-2885.

[26]. M. Vamsi Krishna, Anthony M. Xavior, An investigation on the mechanical properties of hybrid metal matrix composites, Procedia Eng. 97 (2014) 918–924.

[27]. Atul Kumar, Sudhir Kumar & Rohit garg, Production & characterization of Al2024-SiCp Metal matrix composite using stir casting, Trans stellar 6(2015) 1-8.

[28]. Meysam, Toozandehjani, Khamirul Amin, Matori*, Farhad, Ostovan , Sidek, Abdul Aziz , Md Shuhazely, Mamat , Arshin, Oskoueian, Carbon Nanotubes Reinforced Aluminum Matrix Composites – A Review of Processing Techniques, Pertanika Journal of Scholarly Research Reviews (2017)3(1).