Metal matrix composites processing techniques using recycled aluminium alloy

C Bulei [1], M P Todor[1] and I Kiss[2]

[1]University Politehnica Timisoara, Doctoral School, Timisoara / Hunedoara, Romania
[2]University Politehnica Timisoara, Faculty of Engineering Hunedoara, Department of Engineering and Management, Hunedoara, Romania

E–mail: imre.kiss@fih.upt.ro

Abstract. Among the weight–efficient materials used in the transport industry are the composite materials with metal matrix (Metal Matrix Composites), the aluminium alloy matrix (Aluminium Matrix Composites) being an important category. From the manufacturing process, the low cost method and uniform distribution of reinforcement particulate in aluminium is a demanding challenge in this area. Among various manufacturing methods stir casting is generally accepted as a promising route because of low cost, little damage to reinforcement and stir cast components are not restricted by its size and shape. It also possesses advantages like simplicity, flexibility and applicability to large quantity production. At the same time, aluminium offers intelligent and practical solutions to recovering for recycling. This paper presents an overview of the relatively low cost stir casting technique, for use in the production of silicon carbide/aluminium alloy metal matrix composites, using recycled aluminium.

1. Introduction

Worldwide is manifested a great interest in producing lightweight parts with different technologies. Metal matrix composites have been attracting growing interest too [1–2]. In the past few years, materials has shifted from monolithic to composite materials, adjusting to the global need for reduced weight, low cost, quality, and high performance in structural materials [1–5]. In this sense, among the lightweight materials used in the transport industry (road, rail or aviation) are the composite materials with metal matrix (Metal Matrix Composites) which have good mechanical and tribological characteristics (friction, wear resistance) improved by reinforcing of metallic alloys with particulate reinforcement, short or very short fibres (whiskers) [1–5]. The need for advanced engineering materials in the areas of aerospace and automotive industries had led to a rapid development of metal matrix composites [1–5].

For applications in the top industries, affordable cost is also an essential factor [1,2]. Apart from the emerging economical processing techniques that combine quality and ease of operations, researchers are, at the same time, turning to particulate–reinforced aluminium–metal matrix composites [1–5]. Therefore, aluminium alloy matrix (Aluminium Matrix Composites) constitute an important category of design and weight–efficient materials and their processing has the vast development in the various research on advanced materials to overtake the need of low cost, light–weight and high–technological properties [1,2]. Their relatively low cost and isotropic properties especially in those applications not requiring extreme loading or thermal conditions [1]. Also, the processing problems and commercial difficulties associated with continuously reinforced Aluminium Matrix Composites are contributory to the recent interest in their particulate composites (commonly ceramic such as SiC) [1–5].

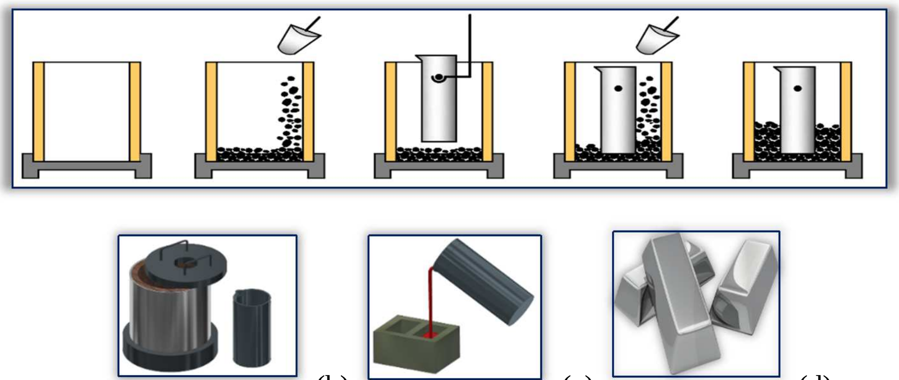
Like all composites, aluminium–matrix composites properties can be tailored, their behaviour and properties being be predicted and the factors such as properties, structural arrangement and the interaction between the constituents are of much importance [1–5]. Various processing techniques for the fabrication of Aluminium matrix composites, testing of their mechanical properties are available. Several processing techniques like ultrasonic assisted casting, powder metallurgy, stir casting are being used for the production of Aluminium matrix composites [3,5–12]. The selection of the manufacturing methods available for Aluminium Matrix Composites depends on many technological or cost factors [1]. Solid state fabrication methods are the process, in which the Metal Matrix Composites are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure [2,4]. Solid phase processes (such as powder metallurgy) are expensive because it needs expensive starting materials such as powder or the matrix [5–7]. Liquid phase process (casting process) involves a liquid state fabrication technique which requires the incorporation of reinforcing phase (discontinuous form) into a molten matrix metal (continuous form) to obtain a uniform distribution through stirring. It is generally less expensive than solid phase process [3,5,8,9].

The major disadvantage of metal matrix composites usually lies in the relatively high cost of fabrication and of the reinforcement materials [1,2,4,5]. The cost–effective processing of composite materials is, therefore, an essential element for expanding their applications. The increasing demand for lightweight and high performance materials is likely to increase the need for Aluminium matrix composites [2,4]. The availability of a wide variety of reinforcing materials and the development of new processing techniques are recently being used for the production of Aluminium matrix composites are attracting interest in composite materials. The study of metal matrix composites has become attractive to researchers interested in both scientific and industrial applications [1–9,12]. In this paper, the Stir Casting method used for Aluminium Matrix Composites manufacturing is presented and discussed. The method starts from the specially recycled aluminium alloy.

2. Recycled aluminium for matrix

Aluminium is the most expensive recycled product and recycling of aluminium is economic: it uses less energy and recycling is self–sustained due to the high value of the aluminium used. In other words, it is worth recycling it from all points of view: it is easy to carry, recyclable, infinitely reusable, it does not rust. For this reason, aluminium is rarely lost.

Recycling is the reprocessing of materials in new products [1]. Thus, in order to carry out the recycling process of collected non–ferrous metal waste, aluminium waste melting facilities are



(a) (b) (c) (d)

Figure 1. Micro station for melting of aluminium wastes from the beverage cans: (a) preparing for melting; (b) the melting aggregate; (c) ingots casting; (d) aluminium ingots.

required. This enables cost efficiency and faster recycling of waste from aluminium [1]. In this direction we propose a micro station for melting of aluminium wastes from the beverage cans (Figure 1). Research refers to a process for obtaining secondary aluminium from waste, by directly melting it into an experimental aggregate.

A lot of charcoal briquettes are placed around the crucible until they are filled. The charcoal is ignited and when the crucible is hot, the aluminium cans are introduced. Melting takes place at a temperature of 680–750°C. Thus, small ingots or secondary aluminium chips are obtained.

3. Manufacturing and forming methods

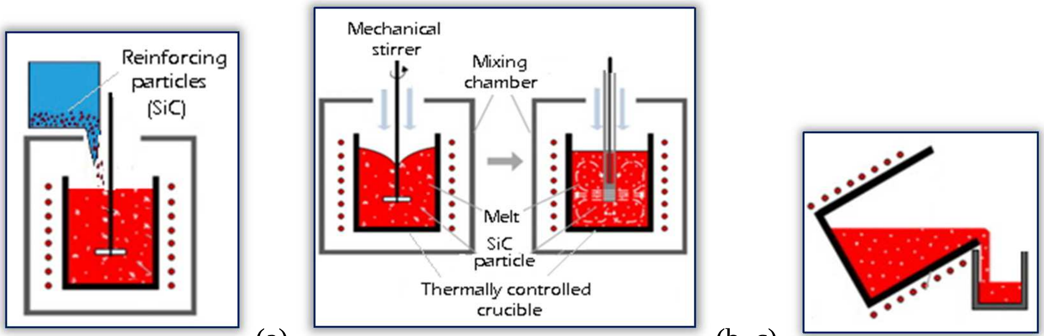
Aluminium Matrix Composites and their processing have the vast development in the current materials research to overtake the need of low cost, light weight and to exhibits high mechanical properties and improved strength to weight ratio. Having in view that the manufacturing methods determine the microstructure and interfacial bond condition between reinforcement and matrix, the low cost processing method and uniform distribution of reinforcement particulate in aluminium is a demanding challenge in this area [5–9,12]. The wettability of reinforcement – defined as the ability of a liquid to spread on a solid surface – is one of the major challenge has been studied which is a key factor for uniform property of the Aluminium Matrix Composites [3,5,9]. Recently there are several grades of aluminium and different reinforcement material are in use to develop Aluminium Matrix Composites but choosing low cost reinforcement and optimum process is a considerable factor [1–5]. The manufacturing methods available for Aluminium Matrix Composites can be classified into three types. They are:

- solid phase processes (such as powder metallurgy) [5,6,7],
- liquid phase processes (such as stir casting, infiltration of liquid alloy matrix into the composite's reinforcements) 3,5,8,9], and
- in situ processes and semi–solid methods (such as rheocasting and compocasting) [5,10–12].

The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of microstructural integrity desired [2–5]. Solid phase process such as powder metallurgy, is expensive because it needs expensive starting materials such as powder or foil matrix etc. Liquid phase process (casting process) is generally less expensive than solid phase process [3,5,8]. In the casting process, high temperature melt is used. High temperature often promotes the chemical reaction between the melt and the reinforcements. The reaction leads to the degradation or disappearance of the reinforcements. The expected properties of the composite would not be obtained if this reaction occurs. So in order to obtain metal matrix composite with good characteristics special techniques are required [2–5,8].

Among the various methods, stir casting route is simple, less expensive, and used for mass production [2–5,8]. Stir casting is a primary process of composite production whereby the reinforcement ingredient material is incorporated into the molten metal by stirring. Stir casting process was used as a production technique to produce aluminium based silicon carbide particulate metal matrix composites [2–5,8]. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. Among various manufacturing methods stir casting is generally accepted as a promising route because of low cost, little damage to reinforcement and stir cast components are not restricted by its size and shape [2–5,8]. It also possesses advantages like simplicity, flexibility and applicability to large quantity production. Stir casting process setup is shown in Figure 2.

In a stir casting process, the reinforcing phases (usually in powder form) are distributed into molten aluminium by mechanical stirring [2–5,8]. The distribution of the particles in the molten matrix also 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. To create and maintain a good distribution of the reinforcement material in molten matrix a vortex method is used. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mould casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement [2–5,8].



(a) (b–c) (d)

Figure 2. Stir Casting: (a) the incorporation of reinforcing phase into metallic matrix; (b–c) the stir casting setup; (d) casting of the metal matrix composites.

Stir casting is a unique and prominent technique for the development of reinforced aluminium matrix composite materials. This technique is utilized as a result of its simple process and ability to overcome the problem of expensive processing method which has restricted the widespread application of metal matrix composite which are considered potential material candidate for various structural and non–structural applications in the various industries [1–5]. The development of this promising technique evolved as a result of modern technological advancement in material application and the demand for lightweight materials with improved mechanical and thermal properties. This process involves a liquid state fabrication technique which requires the incorporation of reinforcing phase (discontinuous form) into a molten matrix metal (continuous form) to obtain a uniform distribution through stirring. Literature survey indicate that various properties of stir cast reinforced aluminium matrix composite materials depends upon fabrication method, volume fraction, shape, size of particles and distribution and properties of constituents. [2–5,8]

Liquid state fabrication of aluminium matrix composite materials involves incorporation of dispersed phase into a molten aluminium matrix, followed by its solidification [2–5,8]. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Manufacturing methods used for production of aluminium matrix composites should ensure uniform distribution of reinforcement in matrix. The non–uniform distribution is due to density differences between the reinforcement particles and the matrix alloy melt [2–5,8]. The distribution of reinforcement is influenced during several stages including:

— distribution in the liquid as a result of mixing,
— distribution in the liquid after mixing, but before solidification.

For obtaining composite materials by Stir Casting method, one should be aware of the following factors which influence manufacture: [2–5,8]

— assuring the field of temperature (above lichidus temperature or under lichidus temperature);
— introducing of granular particles into the metallic melts;
— preparing the granular particles (by preheating before using);
— assuring the environment (pressurized/vacuum or in inert environment);
— preparing for mechanical mixing (using of different forms of impellers/blades);
— establishing of rotation speed for achieving superior yields of embedding of granular particles.

The liquid state fabrication of aluminium matrix composite materials has two major problems: [2,8]

— first, the introduction and dispersion of the SiC particles in the liquid aluminum is difficult because the casting and solidification allows particles to sink due to their higher density resulting in non–uniform particle distribution;

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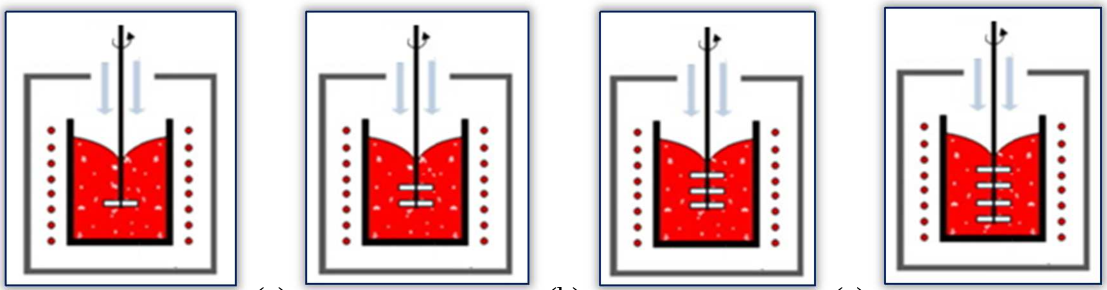
— second, the ceramic particles are generally poorly wetted by the liquid metal matrix resulting in a poor bonding force between the matrix and reinforcement. The previously mentioned casting problems appear significantly in processing of fine reinforcement particles.

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 and mixing [2–5,8]. Many factors and parameters can improve the dispersion of SiC particles in the aluminium matrix. These factors include the mechanical stirrer used, the stirring speed and time, the melt temperature. Manufacturing methods should also ensure proper wettability of reinforcement in matrix. 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 [2–5,8]. An interesting recent development in stir casting can be the multi–impeller mixing–vortex process. In this process, the matrix material and the reinforced particles are better mixed due to the use of multi–impellers attached to the mechanical stirrer (Figure 3). Therefore, the resulting microstructure has been found to be more uniform than that processed with conventional stirring.



(a) (b) (c) (d)

Figure 3. Stir Casting in the multi–impeller mixing–vortex process (1–4 impellers).

The Al–SiC composites are prepared mainly by powder metallurgy, squeeze casting, metal injection moulding and stir casting [2–5]. The most important techniques in this field are powder metallurgy and stir casting. The powder metallurgy method has the advantage of better matrix–particle bonding, easier control of matrix structure, and uniform dispersion of the reinforcement, while stir casting is generally accepted due to its simplicity, low cost of processing, manufacturing of intricate components, and near–net shape component [2–9].

Obtaining in liquid state of composite materials, when granular particles remain in contact with melted alloy of matrix for a long time and locally can result in a reaction between the two. Stir Casting Vortex method is a suitable technology for these composite materials [2–5,8]. With Stir Casting Vortex method, granular particles are embedded in melted matrix using different technologies followed by mechanical mixing or pressing and casting, resulting a composite material. In the case of Stir Casting Vortex method the reinforcement is introduced in the created vortex of liquid metallic material by mechanical mixing [2–5,8]. Reinforcement is uniformly distributed in melt, then the composite material resulted can be casted. In this process, a strong bond between matrix and reinforcement is achieved at high obtaining temperatures.

4. Concluding remarks

The developed aluminium metal matrix composites is considered to be a promising material for the high temperature applications. These metal matrix composites are important engineering materials due to their excellent mechanical properties such as higher strength to weight ratio, good wear resistance and improved hardness, low density and low coefficient of thermal expansion. A key challenge in the processing these composites is to homogeneously distribute the reinforcement phases to achieve a defect–free microstructure. The relatively low material cost and suitability for automatic processing has made the particulate–reinforced composite preferable to the fibre–reinforced composite for automotive applications.

Concluding, stir casting is characterized by the following features:

- the technology is relatively simple and low cost, being the easiest and cheapest processing route to produce discontinuous, reinforced composites;
- particles, short fibers or whiskers can be used as reinforcing components by introducing into the molten alloy matrix, like aluminium. But, the content of dispersed phase is limited (usually not more than 30 vol.%).
- distribution of dispersed phase throughout the matrix is not perfectly homogeneous, being local clusters of the dispersed particles or may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrix phase. But, the distribution of dispersed phase may be improved if the matrix is in semi–solid condition (rheocasting).
- the major disadvantage of aluminium matrix composites usually lies in the relatively high cost of fabrication and of the reinforcement materials.
- among various reinforcements, particles are the most common and cheapest reinforcement. While continuous fiber reinforcement Aluminium Matrix Composites provide the most effective strengthening (in a given direction), particle reinforced Aluminum Matrix Composites are more attractive due to their cost–effectiveness, isotropic properties, and their ability to be processed using similar technologies which are used for the monolithic materials. Among various reinforcements silicon carbide reinforcements are inexpensive.

The major advantage of the stir casting method is its applicability to large quantity production. 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 aluminium based composites and remains one of the simplest ways of their production. However, it suffers from poor incorporation and distribution of the reinforcement particles in the metallic matrix. These problems become especially significant as there reinforcement size decreases due to the reduced wettability of the particles with the melt. Development of new technologies for addition of reinforced particles into the metallic melts which would result in more uniform distribution and effective incorporation of the reinforcement particles into the matrix alloy is therefore valuable.

Therefore, the aluminium metal matrix composites have taken the place of the other engineering materials and can be a real substitute for the heavy materials. Among all materials, composite materials have the potential to replace widely used steel and aluminium, and many times with better performance.

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