A Brief Research Review for Improvement Methods the Wettability between Ceramic Reinforcement Particulate and Aluminium Matrix Composites

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Abstract. The development of new methods for addition fine ceramic powders to Al aluminium alloy melts, which would lead to more uniform distribution and effective incorporation of the reinforcement particles into the aluminium matrix alloy. Recently the materials engineering research has moved to composite materials from monolithic, adapting to the global need for lightweight, low cost, quality, and high performance advanced materials. Among the different methods, stir casting is one of the simplest ways of making aluminium matrix composites. However, it suffers from poor distribution and combination of the reinforcement ceramic particles in the metal matrix. These problems become significantly effect to reduce reinforcement size, more agglomeration and tendency with less wettability for the ceramic particles in the melt process. Many researchers have carried out different studies on the wettability between the metal matrix and dispersion phase, which includes added wettability agents, fluxes, preheating the reinforcement particles, coating the reinforcement particles, and use composting techniques. The enhancement of wettability of ceramic particles by the molten matrix alloy and the reinforcement particles distribution improvement in the solidified matrix is the main objective for many studies that will be discussed in this paper.

1. Introduction

Stir casting is the cheapest and simplest technique among different the liquid state production routes. The non-uniform distribution of the particulate is the main problem associated with this process due to gravity regulated segregation and poor wettability[1]. Achieving a uniform dispersion of reinforcement within the matrix is of utmost concern in the stir casting process, as this influences the quality and properties of the developed composites. Thus, the wettability affects the interfacial...
strength at the matrix-reinforcement joint and is also a key factor in evaluating properties of the metallic matrix composites MMCs [2]. Fig. 1 demonstrates stir casting method.

The wettability can be explained as the spreading capacity of a liquid on a solid surface, and also determines the degree of contact between the liquid and the solid. The buoyant migration can be caused by gas layers at the particles surfaces. Mechanical stirring in a semi solid state is preferred over the completely liquid state so as to promote the breakdown of the gas layer and enhance surface tension reduction. Optimal wettability can be achieved by decreasing the liquid-solid interfacial energy at the reinforcement matrix interface, decreasing the surface tension of the liquid matrix alloy, and increasing the surface energies of the solids.

The adhesion between the matrix and the reinforcement phase results in the interfacial bonding. For adhesion to take place in the course of the composites manufacture, the matrix and the reinforcement must be in a close connection with each other. During the developmental stage of composite, the matrix is often in a state wherein it has a high tendency of flowing towards the reinforcement and this behaviour is similar to that of a liquid flow. A key concept in this contact is wettability. Bonding occurs when an intimate contact is established between the matrix and the reinforcement which is due to adequate wetting of the matrix on the reinforcement particles.

Many methods have been proposed to overcome the problem of the poor wettability. Some of these techniques are complex and expensive, and other simple and cheap methods still to be found. In this review paper, the methods of the wettability improvement will be discussed.

2. Improvement methods of the wettability

The wettability of a liquid phase on solid substrate can be evaluated using the contact angle measurement of the liquid-solid joint. Meanwhile, the extent of wetting of the interface can be expressed with a contact angle range from 0-180 degree. The contact angles magnitude ($\theta$) describes the wettability in Eq.1[3], as shown in Fig. 2, whereby $\theta$=0 is perfect wettability, $0 < \theta < 180$ is partial wetting, and $\theta = 180$ isn’t wetting.

\[ \gamma_{ss} = \gamma_{sl} + \gamma_{lg} \cos \theta \]  

(Eq.1)

Where $\gamma_{ss}, \gamma_{sl}$, and $\gamma_{lg}$ represent interfacial energies between solid, liquid, and gas phase. In terms of wetting energetic, the adhesion work $W_{ad}$ is the energy required to separate a unit area (J/m$^2$) of liquid solid interface according to Eq. 2[3].

\[ W_{ad} = \frac{\gamma_{lg}}{1 + \cos \theta} \]  

(Eq.2)
The most of engineering methods are used to increase the wettability can be classified into: preheating the reinforcement particles, adding wettability agents, fluxes addition, coating the reinforcement particles, and use compocasting which will be explained in the sections below.

\[ \gamma_{ls} \]

2.1 Preheating the reinforcement particles
Essentially, the reinforcements are preheated for two reasons firstly to remove moisture and secondly to make compatible with molten Al. In order to enhance wettability with the liquid alloy or metal matrix material, it is essential to preheat the reinforcement phase.[5]. Heat treatment or calcination of ceramic particles before dispersion into the melt is significant process to get rid of unburnt carbon content, organic materials and release adsorbed gases that will be clear when the powder colour change. Miyajima and Iwai [6], have noticed the preheating of reinforcement particles which used as filler to fabricate composite that improve interfacial strength and the reinforcing particles dispersion. Shirvanimoghaddam et al 2016 studied the influence of processing temperature on the mechanical properties of Al composites which reinforced with micron sized B₄C, ZrSiO₄, and TiB₂ by using stir casting. They observed significant improvement 125% increase in the hardness and 52% in tensile strength[7].

2.2 Wettability Agents Addition
Introduction of reactive elements such as Li, Mg, Ca, Ti, Zr and P promotes the wettability of metal-ceramic systems by inducing a chemical reaction at the interface. In addition, reactive elements additions decrease the surface tension of the molten Al and the solid-liquid interfacial energy of the melt [8, 9]. The increase of wettability can be obtained in certain ceramic particles doped with elements having high affinity for oxygen. Sarkar et al [1] reported on the wetting behaviour improvement of two-phase materials using surface properties modification such as the surface tension through the introduction of magnesium to the Al melt. Furthermore, they observed that the ceramic must be subjected to a sieving process so as to prevent having clustered particles, and thereafter, the sieved particles must be pickled and preheated at a certain temperature in order to eliminate moisture and other surface contaminants. The researchers found enhancement of the mechanical properties and wear resistance in the metal matrix composites.

2.3 Fluxes Addition
Potassium fluotitanate K₂TiF₆ flux is often utilized for the purpose of improving the wetting process between Al and Boron carbide B₄C as well as to promote the doping of molten Al with the B₄C particles[10]. They further reported that the development of the Al–B₄C composites having a uniform microstructure is feasible using K₂TiF₆ flux by casting method. Dhinakaran and Moorthy showed that the enhancement of the wettability of B₄C particles in the matrix by using K₂TiF₆ flux into the molten metal has been significant. Reaction of the flux with melted interface surface of B₄C particle resulted in the formation of Ti compounds around the B₄C particle surface region. An exothermic reaction is
triggered, followed by heat evolution around the interface of the B₄C particle melt [11]. The improvement at the interface was observed by form a reaction layer containing TiC and TiB₂ at the interface which result in wettability increase and interface bonding [12]. Kennedy, AR developed LM25 Al composite by reinforcing B₄C particles of average particle size 25 μm and volume fraction of 5 and 10%. The composites were produced by die casting route, to improve the wettability K₂TiF₆ flux were added to the melt. The results showed that the improvement of mechanical properties such as the tensile and yield stress. This attribute to a strong interfacial bond between the matrix and reinforcement owing to the evolution of Titanium (Ti) layer around the particles due to the addition of flux [13].

2.4 Coating the Reinforcement Particles

Metallic coated ceramic reinforcements such as graphite, titanium dioxide TiO₂, Al oxide Al₂O₃, Silicon carbide SiC exhibit excellent wetting behaviour and enhanced adhesion when related with their uncoated counterpart. Subjecting ceramic reinforcements to coating is highly essential as it guarantees a limited chemical interaction between the reinforcement and matrix as well as improves the interfacial strength integrity. Thus, paving way for an overall mechanical properties upgrade. [14, 15]. Nickel phosphide Ni–P coated silicon nitride particles have been successfully dispersed in Al6061 alloy. Silicon nitride particle was Ni–P coated Prior its addition to a molten metal and this resulted in having an interface clear of impurities from the reaction products and also an excellent bond was formed between matrix alloy and reinforcement [16].

2.5 Compocasting Technique

Due to the high cost of fabrication involved in the utilization of techniques such as stir casting, it becomes imperative to present, an economical technique that can improve the wettability. The modified approach to the stir casting technique is termed compocasting or slurry casting which includes the casting temperature reduction and the addition of ceramic particles when the Al is in a semi-solid state [17]. Several investigators have reported on the wettability enhancement and uniform distribution of ceramic particles in the developed AMCs using compocasting technique as compared to the stir casting technique [18-20]. Elsewhere [21], results showed that the wettability behaviour and distribution of SiC particles are further enhanced by casting in semisolid state (compocasting) rather than in fully liquid state (stir casting). It also increases the hardness and the impact energy of the composites and decreases their porosity. It was observed ceramic to be floating when add to molten Al due to high surface tension that leads to poor wettability, the buoyant migration is caused by the gas layers that surround the practical’s surfaces. It is possible to break the gas layers by using mechanical stirring in semi solid state thereby reducing surface tension and improve the wettability [22]. Selvam et al. 2013, concluded the incorporation of ceramic particles into semi solid Al alloy improved the wettability [23].

3. Conclusions

Previous research studies have confirmed the strengthening of Al alloys with a dispersion of particulates, thereby strongly enhancing their tribological, mechanical, and structural applications. With a view to achieving a metal matrix composite with optimum properties, several factors must be considered, which includes having a uniformly distributed reinforcement material in the molten matrix as well as an improved wettability or bonding between the matrix and reinforcement. One of the intrinsic drawbacks that bedevil the stir casting technique is the poor wettability of the liquid Al on the reinforcement particles, thereby leading to particle segregation. Improvements of wettability can achieve by surfaces energies increase, decrease of the surface tension of the molten alloy and decrease of the liquid–solid interfacial energy at the interface of the reinforcement matrix. In order to broadly classify the existing engineering approaches suitable for wettability improvement, this paper suggests two basic methods. The first is by subjecting the reinforcement phase to a surface modification process and the melting treatment technique is the second. Surface modified reinforcements can be achieved
through particulate treatment at high temperature in order to evaluate the gas desorption and oxidation processes at the surface as well as to determine the coating compatibility of particles with additives that promote the reaction with the matrix. Melt treatment technique is often performed in order to enhance reaction at the metal-particulate interface. In order to reduce to the barest minimum any form of reinforcement degradation, the wetting reaction must be constrained during the fabrication.

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