April 2013

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Recommended Citation

GUPTA, RAHUL (2013) "ULTRASONIC ASSISTED CASTING OF ALUMINUM MATRIX COMPOSITE,"
International Journal of Applied Research in Mechanical Engineering: Vol. 2: Iss. 4, Article 5.

DOI: 10.47893/IJARME.2013.1094

Available at: <https://www.interscience.in/ijarme/vol2/iss4/5>

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ULTRASONIC ASSISTED CASTING OF ALUMINUM MATRIX COMPOSITE

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Abstract- In this study, we have investigated the effect of ultrasonic stirring in aluminium matrix composite (A359 + 20 vol % SiC) with the reinforcement of 1 mole % of carbon black. Melting experiments were performed by employing four different conditions. These were – carbon black addition accompanied with mechanical stirring, carbon black addition accompanied with ultrasonic stirring, ultrasonic stirring but no carbon black addition and control specimen (without ultrasonic stirring and no carbon black addition). Hardness comparisons between the samples casted at different condition were made. Sample which was ultrasonically treated (UST) and carbon inoculated had higher hardness than a sample which was neither ultrasonically treated nor carbon black inoculated and the samples which was either ultrasonically treated or carbon inoculated. Microstructure study revealed that a sample which was ultrasonically treated had fine dendrite structure and more uniform distribution of SiC particles than the other samples. Porosity was observed with those samples which were not ultrasonically treated. Al_4SiC_4 particles were observed but Al_4C_3 particles weren't observed.

Keywords – Aluminum alloy A359, Carbon black, SiC, Ultrasonic stirring.

I. INTRODUCTION

Aluminium matrix composites (AMCs) provide benefit such as ductility, fracture toughness, and fatigue resistance. Properties of aluminium matrix composites can be tailored to the demand of different industrial applications by suitable combinations of matrix, reinforcement and processing route. In particle reinforced composites, the reinforcement particles influence the solidification process in various ways, through their settling in the melt, through chemical reaction with the matrix and as a result of the particle pushing that occurs by the impingement of the solidification growth front on these particles. In addition, the particles can also be act as nucleation site under favourable conditions. [1]

Small particles in the melt always have the tendency to aggregate together to decrease the free energy of the whole system. Clusters of small particles are easily formed in the particulate reinforced metal matrix composites [2]. Mechanical stirring is capable only for breaking up large clusters but cannot provide shear stress larger enough to break up smaller clusters of particles.

Thereby, some clusters still exist in the matrix metal after mechanical stirring. Furthermore, oxide inclusions are easily formed on the surface of the molten aluminium, and these oxide inclusions can enter into the melt during the vigorous mechanical stirring [4]. Moreover, gases are inevitably entrained in the oxide inclusions, which form the porosity in the metal after solidification.[2,3].

Ultrasonic stirring has been extensively used in the purifying, degassing, and refinement of metallic melt.

Ultrasonic fields in a liquid gives rise to nonlinear effects such as cavitations and acoustic streaming. Acoustic streaming is a turbulence which occurs near obstacles as a result of energy loss in sound waves. Cavitations, or the formation of small cavities in the liquid, occur as a result of the tensile stress produced by an acoustic wave in the rarefaction phase. These cavities collapse under the action of compressing stresses during the compression half-period, producing high intensity shock waves in the fluid [5-6].

II. EXPERIMENTAL METHODOLOGY

To fabricate samples, 250gms of aluminium composite (A359 + 20 Vol % SiC) were melted in clay graphite crucible at 750°C in an electrical resistance furnace.

The experimental set up is illustrated in Fig 1. Chemical composition of alloy A359 was given below (Table I).

When the composite melted completely, slag appeared on the top of molten metal was removed and 1 mole % of carbon black, density is 0.0945gm/cm^3 - 0.1gm/cm^3 , average particle size is 42nm and 99.9% metal basis purity (Alfa Aesar, USA), was wrapped in aluminium foil and added into the melt. For proper mixing of carbon black, automatic mechanical stirring was done for 15

Table. I. Chemical composition of A 359

Alloy	Cu	Mg	Mn	Si	Fe	Zn	Ti	Others	Al
Wt%	0.2	0.5-0.7	0.1	8.5-9.5	0.2	0.1	0.2	0.2	Balance

Figure1. Schematic of the ultrasonic vibration assisted

minutes to allow reaction between melt and carbon black. After this, ultrasonic probe, made of Ti-6Al-4V titanium alloy, coated with zirconia and cured at 250°C temperature for 5 minutes so that during ultrasonic stirring liquid metal couldn't stick to probe, inserted into the molten metal and ultrasonic stirring was done for 3 minutes. During ultrasonic stirring air was supplied to transducer to keep it cool. After ultrasonic stirring, crucible quickly removed from the furnace and molten metal poured into the mould made up of mild steel and was preheated to 600°C.

The power of the ultrasonic generator was 1.5 kW, the frequency was 20 kHz and amplitude was 62μm (100%). A developed cavitation generated by ultrasonic vibration in the melt can be evaluated by the values of ultrasonic intensity. The ultrasonic intensity I is defined by [2]:

$$I = \frac{1}{2} \rho c (2\pi f A)^2 \quad (1)$$

Where ρ is the liquid density, c is the speed of sound in the liquid, f is the frequency and A is the amplitude.

High intensity ultrasonic vibration requires $I \geq 100 \text{ Wcm}^{-2}$. Moreover, the fully developed cavitation occurs in the molten aluminium alloys when $I \geq 80 \text{ Wcm}^{-2}$ [2]. In our experiment, speed of sound for molten aluminium alloys $c = 4.3 \times 10^3 \text{ m/s}$ [2], where $\rho = 2.685 \text{ g/cm}^3$. On putting these values in above equation, intensity came out 10.5 kw/cm^2 .

Metallographic samples were sectioned from the cast bars and polished using different grades of emery papers like 320, 800, 1200, and 1500 and at the end cloth polishing was done with magnesium oxide. For etching, Poulton etchant was used. The composition of Poulton etchant is: 12 part HCl(c), 6 part HNO₃(c), 1 part HF (48%) and 1 part water. Microstructures were examined either under Leica DMI 5000 M optical microscope or under Cambridge scanning electron microscope equipped with EDX. EDX analysis was performed to identify elements. Hardness measurements were performed by using

Leitz Vickers Hardness testing machine under an applied load of 5Kg.

In the present study, melting experiments were performed by employing three different conditions. These were – carbon black addition accompanied with mechanical stirring, carbon black addition accompanied with ultrasonic stirring and control specimen (without ultrasonic stirring and no carbon black addition).

III. RESULTS AND DISCUSSION

The particles of carbon black are amorphous in nature [7]. In molten metal processing, the reinforcing particles are mixed directly into the liquid melt and exposure times are relatively long. As a result, the reinforcing particles may react with the liquid metal. The main reaction between liquid aluminium and SiC is:

There is also the possibility of forming a ternary compound [8].

Reaction between carbon black and liquid aluminium

At 750°C, the free energy of formation of Al₄C₃ is - 168KJ/mol [9].

Fig 2 (a) is a microstructure of as received material which reveals that there is uniform distribution of SiC. Mean size of SiC particles is 19μm. Fig 2 (b) is a microstructure of the sample which has not been ultrasonically treated reveals that there is a coarse dendrite formation and SiC particles are segregated at the dendrite boundaries of aluminum. Fig 2 (c) is a microstructure of a sample which has been ultrasonically treated reveals that there is no dendrite formation and grains are fine in size and globular in shape. SiC particles distribute uniformly throughout the matrix than that of non ultrasonically treated because during ultrasonic treatment of a melt nucleation of crystals occur due to (1) undercooling of the melt by cavitation, (2) probe has a greater cooling effect on the melt, from which crystal separate and distribute into the melt and (3) wall of the crucible [10]. Refinement of crystal is due to melts vibration and large acoustic streaming occurs in the melt which makes the nucleation promoted and fine dendrite crystallizes. In fact, action of grain refinement is a result of Clausius- Clapyron equation (5) which shows that the effect of sound waves induced by ultrasonic is totally inadequate to cause a phase change from liquid to solid [11].

$$\frac{dT_m}{dP} = \frac{T_m(V_L - V_S)}{\Delta H} \quad (5)$$

Where, T_m is the freezing point, P is the pressure, V_L and V_S are the specific volume of liquid phase and solid phase and ΔH is the latent heat of freezing.

Fig. 2 (d) is a microstructure of a sample which was only carbon black inoculated reveals that the size of grains is smaller as compare to Fig 2 (b). Inoculants are generally used to refine the grain size because they provide addition nuclei which increase frequency of heterogeneous nucleation [7]. Fig 2 (e) is a microstructure of a sample which was ultrasonically treated and carbon black inoculated reveals that there is fine grain size and SiC particles are more uniformly distributed due to the combined effect of cavitation and acoustic streaming.

Figure 2. Optical micrograph of composite under various processing conditions- (a) As received, (b) without ultrasonically treated and carbon inoculated, (c) ultrasonically treated and no carbon inoculated, (d) without ultrasonically treated but 1 mole % carbon black inoculated, (e) Ultrasonically treated and 1 mole % carbon black inoculate.

Particles clustering were observed in those castings which have not been ultrasonically treated. If the ratio of the thermal conductivity of the particles to that of the liquid is greater than one, this will lead to entrapment. Liquid aluminium has thermal conductivity of 105W/mK, and value of SiC are in the range 60-200W/mK [8]. Due to cavitation effect, SiC particles were uniformly distributed in those samples which were ultrasonically treated.

Porosity was observed in those samples which were not ultrasonically treated because of the absence of ultrasonic degassing effect. Ultrasonic degassing has three stages: (1) nucleation of cavitation bubbles on nuclei and growth of the bubbles due to the transformation of gases from the surrounding melt to the bubbles, (2) coalescence of bubbles to form large bubbles, and (3) float of large bubbles to the surface of the molten metal and escape the bubbles at the top melt surface. [12] In SEM image shown in Fig 3, fine particles appear between SiC particles are Al_4SiC_4 which is confirmed by its EDS analysis. XRD analysis, shown in Fig 4, also confirms the presence of Al_4SiC_4 particles. There are three peaks of Al_4SiC_4 out of which one overlap with the peak of Al. Peaks of SiC, Al and Si are also obtained but the peak of aluminium carbide has not been identified.

Element	Weight%	Atomic%
C K	14.84	28.35
Mg K	0.37	0.35
Al K	59.93	50.98
Si K	24.86	20.32

Figure 3. SEM and EDS analysis of 1 mole % carbon black inoculated

Figure 4. XRD Pattern of carbon inoculated sample

During casting, addition of carbon black was also a problem as carbon black particles were rejected out from the melt due to large density difference. In the casting which was not ultrasonically treated, rejection was around 60%. Due to ultrasonic stirring, this rejection of carbon black was around 49%. To decrease rejection, powder of carbon black and aluminum alloy were added in the ratio 1: 10 respectively and milled for 30 minutes for proper mixing.

Hardness analysis, shown in Fig 5, reveals that hardness of an unprocessed sample (B) is higher than the hardness of as received sample (A) due to SiC particles agglomeration at the boundaries of aluminium dendrites which resist plastic deformation.. Hardness of a sample which was only ultrasonically treated (C) is higher than that which were not ultrasonically treated (B,D). Hardness of a sample which was only carbon black inoculated (D) is higher than the sample which was neither ultrasonically treated nor carbon black inoculated (B). Hardness of a sample which was ultrasonically treated and carbon black inoculated (E) is the highest among all the samples.

Figure 5. Comparison of Hardness

IV. CONCLUSIONS

1. Ultrasonic stirring prevents SiC agglomeration and reduce porosity levels.
2. Combined effect of ultrasonic stirring and carbon inoculation improve hardness.
3. Al_4C_3 carbide could not be detected but Al_4SiC_4 particles are identified by EDS and XRD analysis.

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