Detailed Study and Analysis of Bonding and Interface Formation in AMC

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Abstract: Present work is to study the bonding mechanism and formed interface between matrix and reinforcement constituents. The scope of this work aims to share the overview in bonding and interfacial problems as far as Aluminium Matrix Composite (AMC) is concerned when ceramic particles are added in it. Through this study, one should get ideas of typical interfacial reactions and remedial steps to overcome problems when possible. Since wet ability of reinforcement constituents is solely responsible for appreciable interfacial bonding strength, present study includes the wet ability concept when ceramic particles are added into the aluminium matrix made by stir casting route.

***Index Terms* – AMC.**

I. Introduction

Aluminium Matrix Composite Materials (AMC's) are important classes of well established advanced materials. They are being used in many critical applications such as in aerospace and automobiles. Substantial progress in the development of AMC's has been achieved in recent decades as they opened up unlimited possibilities for modern material science & development [1]. Particle reinforced aluminium matrix composite materials (PAMC's) are the most promising because of their higher specific strength, excellent wear resistance, near isotropic properties and superior high temperature performance. All such good properties of the composites are solely depending upon the nature of frontier zone (interface) between matrix and reinforcing constituents. Bonding at frontier zone is developed from physical and chemical interaction, interfacial frictional stress and thermal stresses due to mismatch between coefficient of thermal expansion between matrix and reinforcement. Understanding and control of underlying interfacial phenomena governing transmission of thermal, electrical and mechanical properties across the whole composite might become of paramount importance when designing AMC's for particular task. Among the various production techniques available in manufacturing of PAMC, the 'stir casting' technology is considered to be a potential method because of advantages like low production cost, simplicity, flexibility and applicability to large scale production [2].

II. Processing of AMC

Processing of PAMC carried out by stir casting route. In general the stir casting process involves producing a melt of selected matrix material and stirring it to form a vortex in which the reinforcement particles are dispersed before casting. Although stir casting is generally accepted as an economical & viable process for production of PAMC's, there are however technical challenges associated with the process such as; the difficulty of achieving uniform/homogeneous distribution of reinforcement in the matrix ; poor wet ability and chemical reaction between matrix & reinforcement materials; porosity in cast MMC's [3,4].

2.1 Stir Casting of AMC

Stir casting as shown schematically in figure 1, involves stirring the melt with solid ceramic particles and then allowing the mixture to solidify. This can usually be done using fairly conventional processing equipment and can be carried out on a continuous or semi-continuous basis. A concern is to ensure that good particle *wetting* occurs. Difficulties can arise from the increase in viscosity on adding particles or, especially, fibers to a melt. However, this increase is typically only by a factor of 2 or so with up to about 20 pct. by volume particulate, provided the particles remain well-dispersed. This viscosity is sufficiently low to allow casting operations to be carried out. Microstructural in homogeneities can arise, notably particle agglomeration and sedimentation in the melt. Redistribution as a result of *particle pushing* by an advancing solidification front can also be a problem. This is reduced when solidification is rapid, both as a result of a refinement in the scale of the structure and because there is a critical growth velocity, above which solid particles should be enveloped rather than pushed. Stir casting usually involves prolonged liquid – ceramic particles contact, which can cause substantial interfacial reaction.

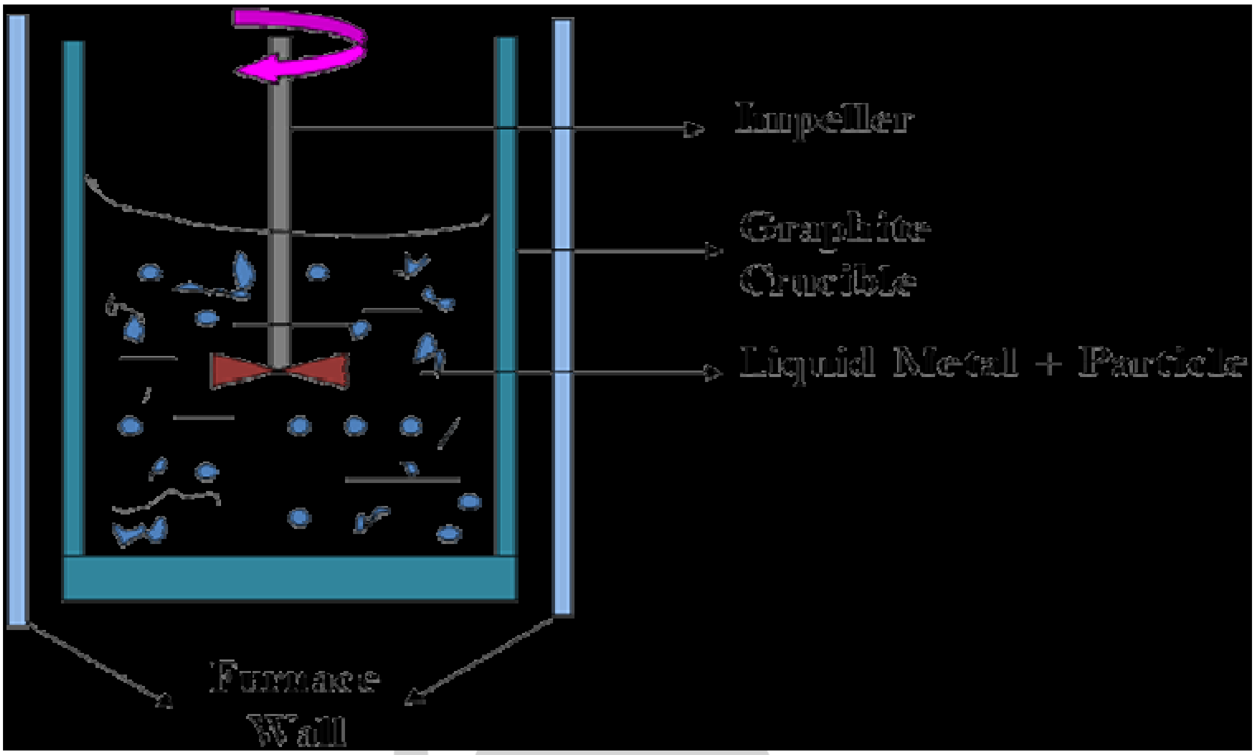

Figure 1 Line diagram of stir casting

The uniform distribution of reinforcement particles depends on many factors like vortex formation, stirrer geometry, position of stirrer, speed of stirring, volume fraction of reinforcement and viscosity of the melt. In normal practice of stir casting process, the opaque nature of molten metal and crucible poses problems in observing the process in situ, in order to study the effect of impeller geometry and position, in dispersing of reinforcement. Hence the process needs to be simulated in order to optimize the parameters that influence the process. There are four latest methods to stir the molten composite bath as:

1. Mechanical Stirring by impeller (as in figure 1),
2. Electromagnetic Stirring,
3. Ultrasonic Stirring and
4. Magneto-hydrodynamic Stirring.

Among all four techniques, mechanical stirring technique is more common and cheap. Here one impeller consisting of three or four blade rotates in melt with predetermined speed, angle and depth. Electromagnetic stirring consist of stirring of melt by eddy current, same as in induction furnace. This technique produces more uniform reinforcement distribution in short time at high expense comparatively. Ultrasonic stirring is carried out by high frequency sound waves directed towards the molten bath. Magneto-hydrodynamic stirring is most complicated and expensive technique than previous three.

2.2 Interface of AMC

After synthesis of AMC by stir cast route, frontier zone (interface) was studied. Considering physical and chemical properties of both matrix and reinforcement constituents, the actual strength and toughness desired in final AMC, a compromise has to be achieved balancing often several conflicting requirements. A weak interface will lead crack propagation followed the interface, while a strong matrix associated with strong interface will reveal crack across both matrix and reinforcements. If however the matrix is weak in comparison with both the interface and the particle strength, the failure will propagate through matrix itself. The wettability of the reinforcement materials by the liquid metallic matrix plays vital role in the bonding formation. It mainly depends on heat of formation, electronic structure of the reinforcements and the molten metal, temperature, time, atmosphere, roughness and crystallography of reinforcements. Surface roughness of the reinforcing material improves mechanical interlocking at interface through the contribution of the resulting interfacial shear strength is secondary compare to chemical bonding. Large difference between coefficient of thermal expansion between matrix and reinforcements should be avoided as they can induce internal matrix stresses and ultimately give interfacial failures.

III. Experimental Technique

The final AMC were prepared by addition of MnO_2 particles stirred by four blade stirrer (300 rpm for 3 min) along with purging N_2 gas into commercially pure aluminium. The resulting liquid metal cast into the metallic mould from resistance heating furnace. About 1 to 3 kg of commercially pure aluminium containing 99 wt. pct. of aluminium is melted in a clay graphite crucible inserted in the resistance heating furnace at the desired processing temperature (720 °C). A four blade stirrer (45° angled) is used, which is made up of 304 Austenitic Stainless Steel. The stirrer was coated with slurry of fine MnO_2 powder and dried, so that there is no significant dissolution of iron from the stirrer into the molten metal bath. MnO2 particles were preheated prior to addition into the molten bath at 200 – 250 °C. The Schematic diagram of experimental set – up is shown in figure 3.

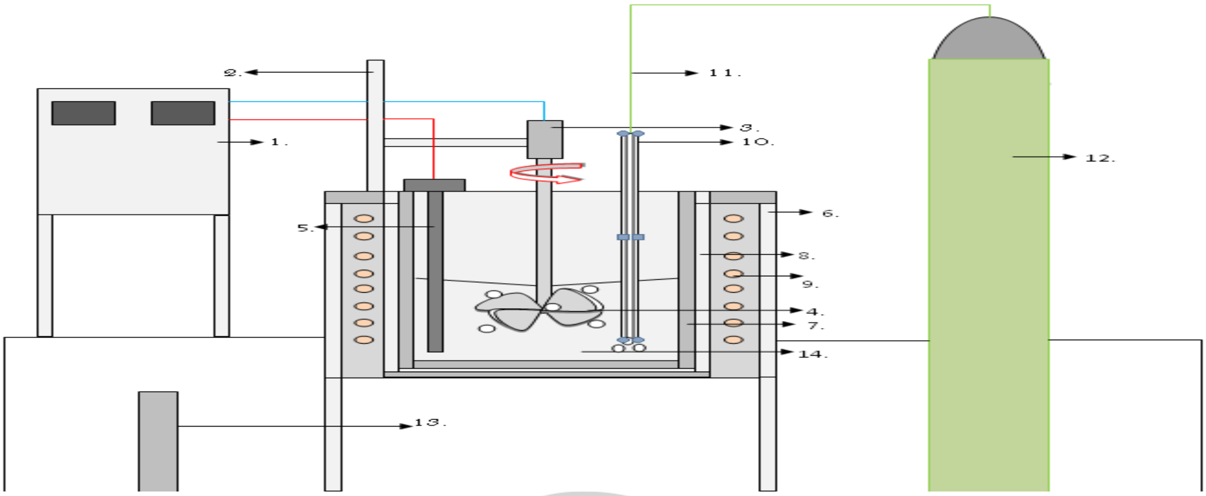

Figure 2 Experimental set – up

1. Temperature /display unit 2. Movable stirrer's stand 3. Motor for rotate stirrer 4. Turbine type stirrer 5. Chromel-Alumel thermocouple 6. Outer M.S. furnace wall 8. Thermal insulation-Asbestos 9. Kanthal wire-wounded 10. Hollow Stainless Steel pipe (N2 inlet) 11. Rubber tube,12. N2 cylinder 13. Metallic die 14. Composite melt

The speed of the stirrer is kept constant, i.e. 300 rpm, which measured by digital tachometer (Bangalore, India). The position of stirrer into the melt is also kept constant in all experiments. The temperature of the melt is measured by using digital temperature indicator connected to Chromel- Alumel thermocouple placed inside the melt. Amount of Magnesium added into the bath after MnO2 addition is (kept constant) 5 wt. pct. Finally prepared composite bath is cast into preheated (150 – 200 °C) metallic die (23x23x6 cm). The specimen for metallographic study has been prepared by standard metallographic method. Prior to etching, the resultant composite structure was observed under scanning electron microscope. The typical distribution of generated particles and various micro structural features of composite were recorded.

IV. RESULTS & DISCUSSION

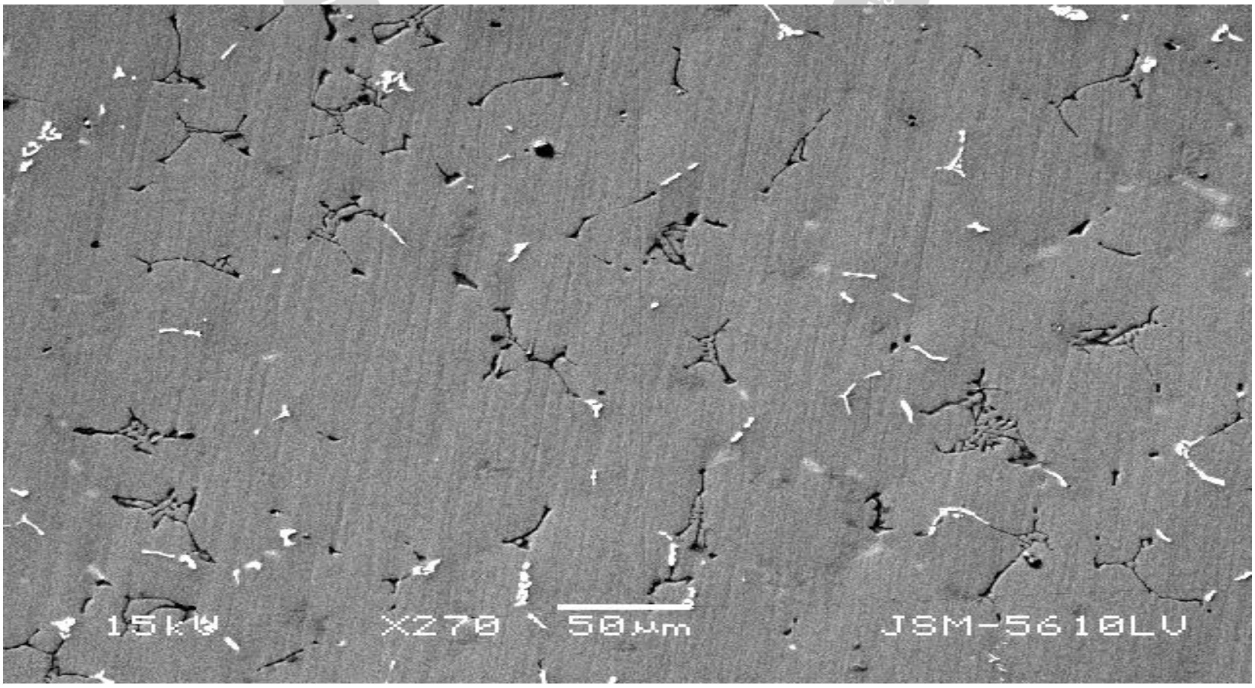

Figure 3 Scanning Electron Micrograph of Al – Mg (MnO2) composite at 270 X magnification

From this experimental study, we can see the distribution of reinforcing constituents in given matrix as shown in figure 4. This figure is the scanning electron microphotograph of resultant composite at 270 X magnification. From this microphotograph, one can be cleared that the distribution of added reinforcement particles (MnO2) as well as in – situ generated particles (Al2O3), is very uniform under above mentioned stirring speed and stirring time at processing temperature (720 °C). Figure 5 indicates the bonding and interface formation between aluminium matrix and Al2O3 – Altex particles. From figure 6, it is cleared that at some of the particle interface, the formation of brittle phase (T – phase) are present. Since these are brittle in nature, they are act as a flaw in the matrix – reinforcement bonding. Chances of initiation of the cracks from such brittle phase are likely to be more. Hence they are not acceptable in resultant structure of composites.

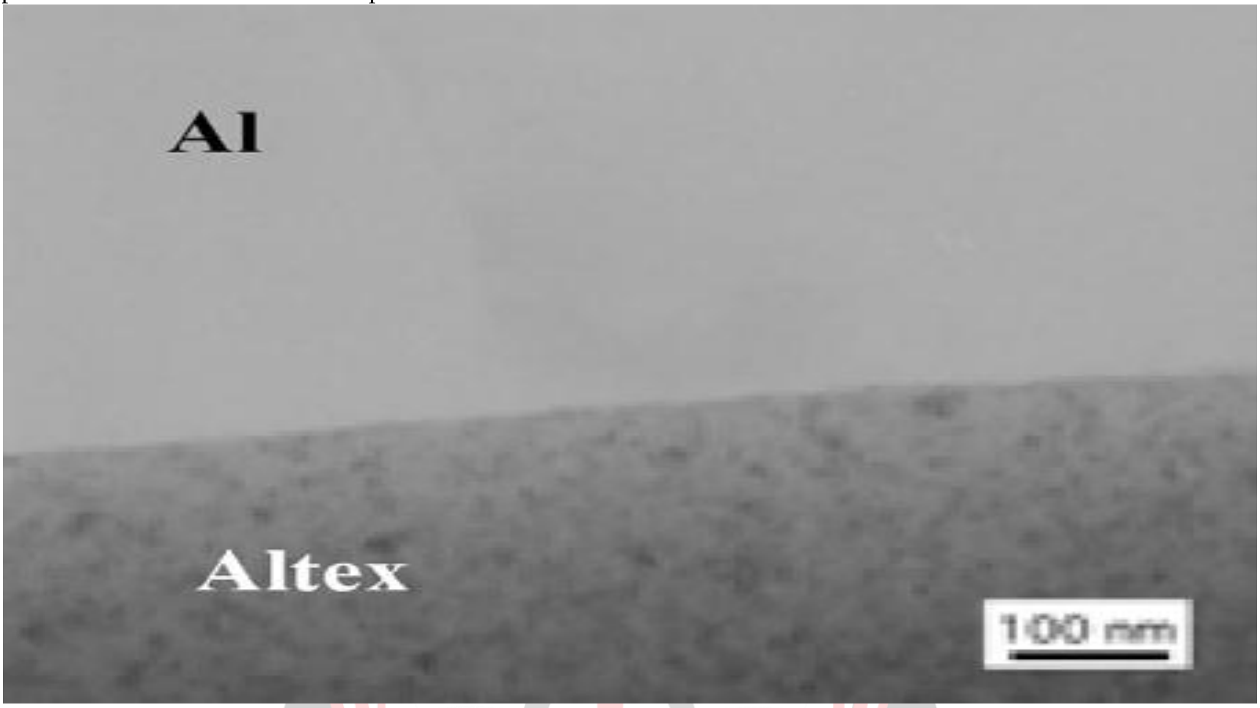

Figure 4 Formation of bonding and interface between aluminum matrix and reinforcement by addition of magnesium

SUMMARY OF WORK

Aluminium Metal matrix composites (AMC's) include a wide group of materials, which includes cermets and metallic foams, as well as more conventional particle- and fiber-reinforced metals. Depending on the types of matrix and reinforcement concerned, various techniques employed for
production of metal matrix composite material and components; these are classified according to
whether the matrix is in the liquid, solid or gaseous state when it is combined with the reinforcement. Each of these processing routes has advantages and disadvantages. In particular, some are far more expensive than others. The lowest cost routes are generally those in which particle-reinforced aluminium is produced using liquid metal handling - particularly stir-casting which is employed in present work to synthesize Al – Mg(MnO2) composite. Material produced in this way represents a substantial proportion of the AMC's in commercial use today. Study of interfacial bonding carried out in same composite at mentioned condition. At fixed positioned stirring at fixed rpm speed, formation of interface varies in thickness. Secondary phase (T – phase) which is formed at interface leads to and oxygen. Separated manganese and oxygen react with molten aluminium, which leads to formation of MnAl6 and Al2O3. Magnesium acts as intermediate agent to increase wettability of the added ceramic particles towards molten aluminium. Magnesium reacts with aluminium and manganese. This reaction leads to formation of Al – Mg – Mn intermetallic which increases the bonding. Since the nature of interface represents the life of composite materials, weightage to study the same should be more as in present approach.

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