A Review on Manufacturing of Composite Materials by Electromagnetic Stir Casting Method

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Abstract **- Composite materials are engineered from two or more materials with significantly different physical or chemical properties. These properties remain separate and distinct at the macroscopic or microscopic scale within the finished structure. These are high density and high strength materials which are used in almost all aspects of the industrial and commercial fields in aircraft, ships, common vehicles, etc. This paper presents a brief review of various explorations on manufacturing of metal matrix composites (MMC's) by stir casting methods.**

Keywords: **Composite materials, Metal Matrix Composites, Stir casting method.**

I. INTRODUCTION

A composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Composite is a multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realized. This is termed as the principle of combined action [7].

Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever increasing demand of modern technology, composites are most promising material of recent interest. The composite industry has begun to recognize that the commercial application of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. Thus the shift of composite applications from aircraft industry to other commercial uses has become prominent in recent years. Among the various classes of composites, this paper deals with Metal Matrix composites and their manufacturing by stir casting method. The present paper discusses about electromagnetic stir casting processes and the various researches conducted on it for the manufacturing of MMC's.

II. MANUFACTURING OF MMC'S

The MMC's manufacturing can be broken into various types such as solid and liquid. The solid state method involves powder blending and consolidation (powder metallurgy) method. Powdered metal and discontinuous reinforcement are mixed and then bonded through a process of compaction, degassing, and thermo-mechanical treatment. Another method called as Foil Diffusion Bonding Method utilized layers of metal foil. These layers are sandwiched between long fibers, and then pressed through to form a matrix [4].

The Liquid state method has various processes such as Electroplating / Electroforming, Stir casting, Squeeze casting, Spray Deposition and Reactive Processing. The Electroplating involves a solution containing metal ions loaded with reinforcing particles; next sentence is co-deposited forming a composite material. The stir casting method involves discontinuous reinforcement being stirred into molten metal, which is then allowed to solidify. In the Squeeze casting method, molten metal is injected into a mould with fibers preplaced inside it. While, in Spray deposition, molten metal is sprayed onto a continuous fiber substrate and in reactive processing a chemical reaction occurs, with one of the reactants forming the matrix and the other the reinforcement [2].

III. STUDIES ON MMC'S

A few researchers such as H. K. Moffatt in 1990 investigated that alternating magnetic field applied to a conductor, whether solid or fluid, will induce electric current in the conductor, and hence a Lorentz force distribution. This Lorentz force is in general rotational, and if the conductor is fluid, it is set in motion. Thus the magnetic field acts as a nonintrusive stirring device and it can, in principle, be engineered to provide any desired pattern of stirring. Stirring may also be affected through the interaction of a steady current distribution driven through a fluid and the associated magnetic field. When the field frequency is high, the Lorentz force is confined to a thin electromagnetic boundary layer, and the net effect of the magnetic field is to induce either a tangential velocity or a tangential stress just inside the boundary layer. The distribution of velocity or stress is related to the structure of the applied field. Symmetric configurations may lead to patterns of stirring in which the streamlines lie on toroidal surfaces; more generally, however, the streamline pattern is chaotic. If electrically conducting particles are suspended in a non – conducting fluid being subjected to same type of alternating magnetic field, some problem in stirring arises. Current is now induced in the particles, and each particle experiences a force and a couple. When several particles are in suspension, the movement of each is influenced by the presence of the others, and a problem somewhat analogous to the problem of interacting point vortices arises. Figure 1 shows qualitative sketch of continuous casting process for steel. For a suspension of conducting particles, inhomogeneity of the field leads to inhomogeneity of the concentration of particles and a bulk flow is induced [1].

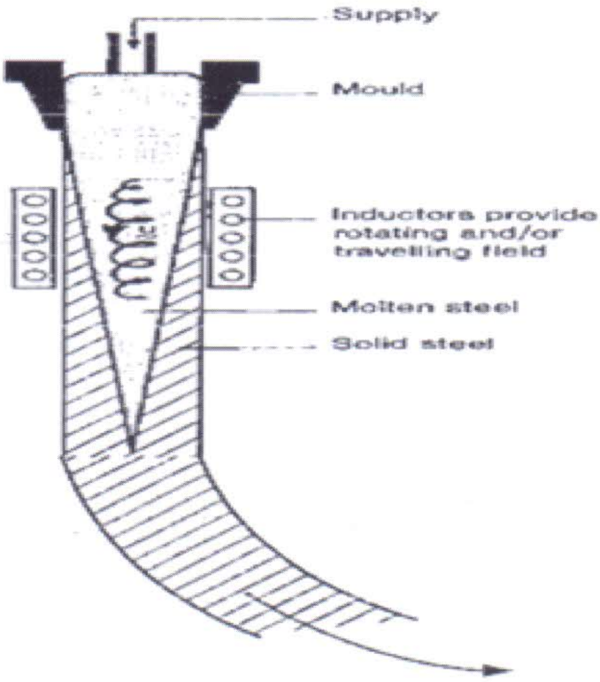

Fig.1 Qualitative sketch of continuous casting process for steel [1]

Eiichi Takeuchi et al. in 1994 investigated that continuous casting process is near perfection in terms of productivity and quality; for its further advancement from the viewpoint of both economy and technology so that it may prove a truly viable production process towards the coming century. Attention is now focused on the applied MHD technology. A typical example of Nippon Steel's applied MHD technology is the control of molten steel flow in the mold by electromagnetic stirring and braking. Author featured in his research that these flow control techniques are described from an MHD point of view. In particular, simulation experiment and numerical analysis clarify the interference between the steel flow as discharged from the immersion nozzle and that as driven by electromagnetic force, as well as the relationship between the flow field and the electromagnetic field that changes with electric boundary conditions. Also introduced are some of the characteristic metallurgical benefits of electromagnetic stirring and braking confirmed by plant tests. Further, description is made of the technique of controlling the initial solidification of steel in the mold by an alternating-current magnetic field that has been attracting increasing attention in recent years, as per to the results of simulation and steel casting tests. The oscillation mark depth decreased with increasing magnetic flux density of electromagnetic force applied as shown in fig. 2 [2].

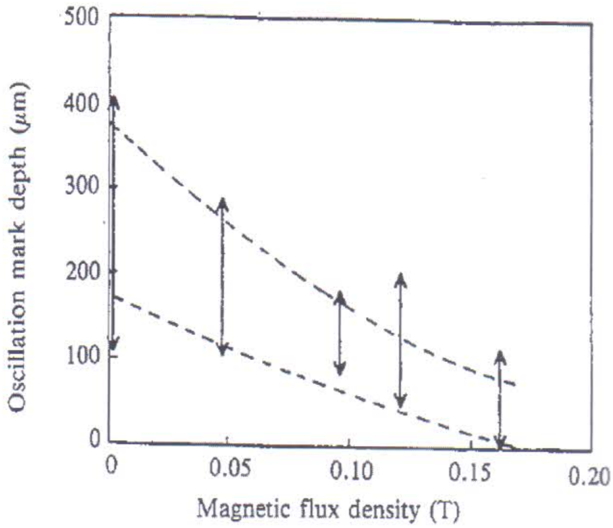

Fig. 2 Reduction in oscillation mark depth with increasing magnetic flux density [2]

N. Ei-Kaddah et al. in 1999 investigated for electromagnetic stirring which is widely used in continuous casting of steel as a means to improve homogeneity of cast slabs. Industrial experiments have shown that stirrer design and operating conditions have a strong influence on the metallurgical quality of the cast slab. Author examined the effects of the stirrer current and field frequency on the flow in horizontal electromagnetic stirring of steel slab. The stirrer current and frequency were found to affect the primary horizontal flow in the vertical section converted by the stirrer to have a significant effect on the upward flow in the force free region above the edge of the stirrer. It was also found that the flow was quite turbulent in the region. Facing the stirrer and turbulence mixing diminishes rapidly beyond the edges of the stirrer. It has also been demonstrated that through the changes in the stirrer current and or field frequency, it is possible to modify the magnitude and distribution of turbulence characteristics of the induced flow [3].

D. Brabazon et al. in 2002 carried out a comprehensive study to establish the effects of controlled stirring during solidification on the microstructure and mechanical properties of Aluminium alloys, in comparison to conventionally gravity chill cast materials. A novel device comprising a grooved reaction bonded Silicon Nitride rod rotating in a tube-like crucible was used to process Aluminium alloys in the mushy state. The stir casting device was specially designed to enable rheumatic study of the alloys in this condition. A factorial design of experiments was used to determine the effect of the process variables such as shear rate, shear time (t_s), and volume fraction solid during shear (f_s) on microstructure and the static and dynamic mechanical properties of the stir cast alloy. Investigation of the microstructure consisted of computer-aided image analysis of the primary phase morphology. A more globular primary phase was achieved at low values of f_s, but this was not the optimum morphology for mechanical properties. In all cases, improved mechanical properties and reduced porosity were obtained in the stir cast condition in comparison with conventional casting and in comparison with previous work on stir casting. Comparison with alloy commercially casted via electromagnetic stirring showed that it had superior mechanical properties. It is proposed that the mechanical stir casting process be considered as an alternative to gravity die casting in cases where very simple and thick walled shapes are required. Temperature versus fraction solid graphs, as determined for the two alloys, may be seen in figure 3. Processing should occur between the coherency point and the eutectic point in order for the dendritic structure to be modified by the shearing action. Using the coherency point determined by the two thermocouple method, processing temperature ranges of 54°C and 37°C for Al – 4% Si and A356 respectively were found [4].

Marcela B. Goldschmit, et al. in 2003 demonstrated in

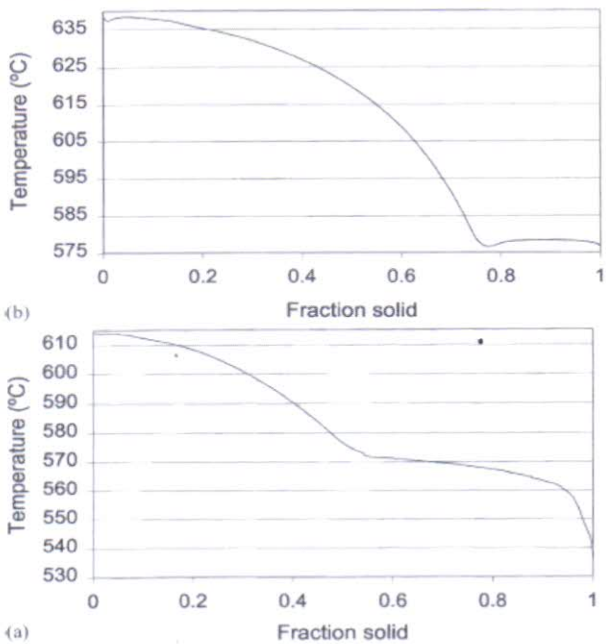

Fig. 3 Temperature vs. fraction solid for (a) A356; and (b) Al – 4% Si, at a cooling rate, after solidification, of 0.06°C s−1 [4]

their study how the numerical models contribute to the understanding of design and optimization of the continuous casting process. Three different physical mechanisms used to move the liquid steel were analyzed: gravity force, electromagnetic forces and the stirring by inert gas injection.

The optimization of the mechanisms provides high quality castings. [5].

S. Milind et al. in 2004 presented about design and analysis of a linear type Electromagnetic stirrer. Electro Magnetic Stirring of metallic alloys is mainly used to refine the grain structure of casting. This technique results in increased homogeneity of the cast alloys. In his paper a design oriented approach to a linear electromagnetic stirrer is presented. A mathematical model of such a stirrer is proposed to obtain electromagnetic field solution. The field solution is obtained from the finite element model. The influence of current and its frequency, axial force and its variation with radius have been investigated. Experimental results obtained from a prototype are presented and concludes that the paper does not consider the Magneto Hydro Dynamics aspect of the molten metal. The field solution obtained from analytical and simulation models are found to be matching quite well. They concluded that lower excitation frequencies give rise to uniform field (H) and linear currents (J). Hence with this lower employed frequency, gentle stirring of the charge (Molten Metal) in the stirrer is achieved. Also at lower frequencies, the current density is barely noticeable. The uniform magnetic field and linear current density in the molten metal will result in axial and radial forces. These axial and radial forces will be proportional to the radius. The radial forces have no average while the axial forces average in the direction of phases sequences [6].

Z.Yang et al. in 2005 investigated the possibility of replacing mechanical stirring system with Electromagnetic Stirring system for Aluminium rheo die – casting. The electromagnetic stirring was carried out under the different stirring cooling conditions. It was found that in the early period of solidification, the dendrite breakages led to a fine primary phase. When dendrites grew coarsely, the effect of ripening on grain size overwhelmed that of dendrite breakage. It was also found that the high cooling rate favored large nucleation rate, and led to a fine primary phase. But high cooling rate also made the growth rate of the dendrite arm, which prevented the dendrite arm from being sheared off. Therefore there were a suitable stirring time and suitable cooling rate to obtain rheo die-casting structure. Semisolid A356 Aluminum alloy was successfully manufactured with short time EMS. The static particle size and the shape factor based on 2D microanalysis were plotted in fig. 4. It was found that the holding time that has an unidentified effect on the grain size as well as on the shape factor [7].

Weimin MAO et al. in 2006 investigated the effects of pouring temperature, short electromagnetic stirring with low strength and then soaking treatment on the microstructure of AlSi7Mg alloy. The results show that if AlSi7Mg alloy is poured at 630°C or 650°C and meanwhile stirred by an electromagnetic field at a low power for a short time, the pouring process can be easily controlled and most solidified primary α-Al grains become spherical with only a few of them are rosette-like. Weak electromagnetic stirring makes the temperature field more homogeneous and makes the primary α-Al grains disperse in a larger region, which leads to the spherical microstructure of primary α-Al grains. When the AlSi7Mg alloy is soaked or reheated at the semisolid state, the primary α-Al grains ripen further and they become more spherical, which is favorable to the semi-solid forming of AlSi7Mg alloy [8].

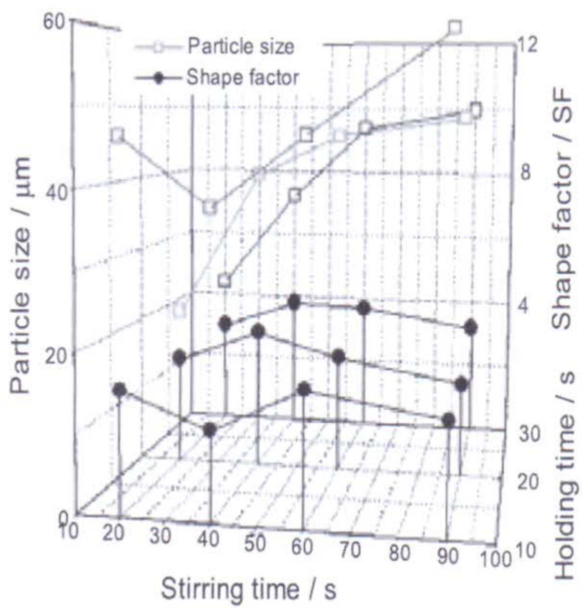

Fig. 4 Plots of the particle size, shape factor of primary phase obtained with EMS casting as a function of stirring time and holding time. [7]

ZHANG, Zhifeng et al. in 2006 investigated the semi-solid Al alloy billet obtained with high quality by imposing a multiple magnetic field from the outside of a copper mold in the continuous casting. AlSi6Mg2 alloy designed for semi-solid metal processing was continuously cast through a submerged entry nozzle under various conditions. Effects of multiple magnetic fields on meniscus motion, temperature distribution and billet quality were examined. The experimental results showed that meniscus disturbance caused by electromagnetic stirring could be controlled effectively and the surface quality of semi-solid Al alloy billet was improved greatly. A fine globular microstructure across the transverse section of the billet was achieved by optimizing the distribution of multiple magnetic fields. Figure5 shows the comparison of cooling curves under the conditions without and with MMF. It is noted that when only the commercial frequency magnetic field is imposed, the temperature difference between the outer and central part across the transverse section of the billet is large, and also the temperature near the billet surface decreases quickly and string time is very short [9].

C.G. Kang et al. in 2007 gave a setup for horizontal electromagnetic stir casting for A356 Aluminium alloy. The core of electromagnetic stirrer can be fixed in the position of coils. The selection of inner and outer diameter of the stirrer is important. The inner diameter of electromagnetic stirrer should be designed to fit the volume of products and the outer diameter, which is related to the number of rolling up the coils to meet the electromagnetic stirring force. Electromagnetic stirring coil windings are subject to wear during operation. Wear causes a progressive degradation of the insulation properties of the coils causing loss of ground insulation. In addition, accidental events (like insufficient water cooling, steel overflows etc) can damage the materials, causing significance of electromagnetic stirring performance. The cooling water inside the coil can prevent the damage to coil from the radiation of heat being rapidly generated during electromagnetic stirring [10].

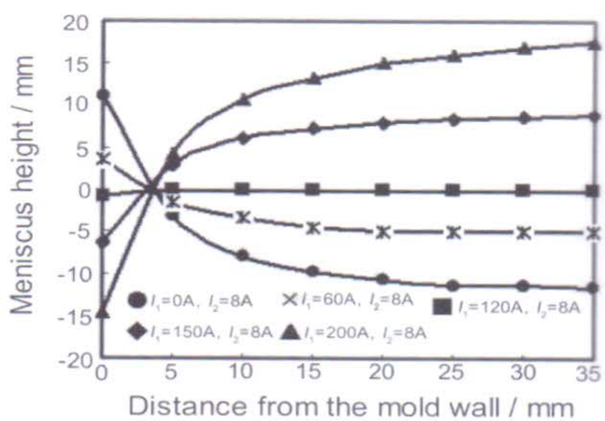

Fig. 5 Cooling curves under imposing multiple magnetic field [9]

T W Kim et al. in 2008 demonstrated the forming process of a semi-solid material with a solid fraction of about 45 per cent after the primary α-Al particle in the semi-solid material. The particles are globularized during solidification by electromagnetically stirring the molten metal poured out into the sleeve. By rheological forming experiments incorporating electromagnetic stirring on Al6061 alloy, the process parameters were optimized to be of 0.3 m/s of forming velocity, 45MPa of forming pressure, 10 s of stirring time, and 30 A of stirring current to get the best quality. The product exhibited the highest tensile strength of 312.8MPa and elongation of 4.51 per cent at positions where the pressure was directly applied to the material and overlapping occurred [11].

Karel Stranskya et al. in 2009 investigated that Electro Magnetic Stirring suppresses the growth of columnar crystals of billets and reduces the tendency to cracking during casting at low temperatures. A caster was used for the testing of two induction stirrers. One on the actual mould and the other beneath the mould to determine the effect of EMS on the formation of the structure of non alloy steel. As part of these tests, certain parts of the billets had been cast without the use of stirrers and other parts underwent alternate switching on and off of the stirrers for as many as nine combinations of modes. Samples were taken from the sections of these billets, fine-ground and etched in order to make the dendritic structure visible. The mode with the highest efficiency was when both stirrers ran simultaneously. The growth of the columnar crystals, which pointed inward, was limited to one fourth to one third of the length of the case when there was no stirring. Experimental research was also confronted with results acquired from the application of the models of the temperature field and chemical heterogeneity and the physical-similarity theory. Statistical monitoring of the quality of Concast billets has proven that stirring significantly reduces the occurrence of defects like cracks in this case [12].

Guanglei ZHU et al. in 2009 investigated a new method for producing semisolid slurry using annular electromagnetic stirring (A-EMS) to refine and spheroidize the grains. Experimental work was undertaken to investigate the effects of cooling rate, stirring power and stirring time on the solidification behavior of A357 alloy using A-EMS. It was found that increasing the cooling rate and stirring power gave rise to substantial grain refinement. It could be attributed to the increase of effective nucleation rate caused by the extremely uniform temperature and composition fields in the bulk liquid during the initial stage of solidification. Results showed that a fully grain refined spherical structure could be obtained using proper processing conditions within 10 s [13].

Y. X. Jin *et al. in 2009* investigated the microstructure and corrosion behavior of misch metal modified AZ91D magnesium alloy in the presence or absence of a rotating electromagnetic field. The study suggests that the size and volume fraction of the β (Mg17Al12) phase in the alloy decreases as magnetic field intensity increases. The immersion test results show that the mass loss for the alloy solidified in the absence of a magnetic field is always larger than that for the alloy solidified under magnetic field. The electrochemical corrosion experiments indicate that the corrosion potential of the alloys increases from −1.56 to −1.51 V, while the corrosion current density decreases from 6.31 to 1.58 mA and the charge transfer resistance increases from 3.17 to 11.32 kΩ as the excitation voltage increases from 0 to 120 V. The enhancement of the corrosion resistance is attributed to the grain refinement, and to the volume fraction reduction of the β (Mg17Al12) phase under a rotating electromagnetic field [14].

G.B. Veerish Kumar et al. in 2010 investigated that the Aluminium based composites are increasingly being used in the transport, aerospace, marine, automobile and mineral processing industries, owing to their improved strength, stiffness and wear resistance properties. The widely used reinforcing materials for these composites are silicon carbide, Aluminium oxide and graphite in the form of particles or whiskers. The ceramic particles reinforced Aluminium composites are termed as new generation material. Particle reinforced composites have a better plastic forming capability than that of the whisker or fiber reinforced ones. They are also known for excellent heat and wear resistance applications. The author aimed to present the experimental results of the studies conducted regarding hardness, tensile strength and wear resistance properties of Al6061-SiC and Al7075-Al_2O_3 composites. The composites are prepared using the liquid metallurgy technique, in which 2-6 wt. % age of particulates was dispersed in the base matrix. The obtained cast composites of Al6061-SiC and Al7075-Al_2O_3 and the castings of the base alloys were carefully machined to prepare the test specimens for density, hardness, mechanical, tribological tests and as well as for micro structural studies as per ASTM standards. The SiC and Al_2O_3 resulted in improving the hardness and density of the respective composites. Further, the increased percentage of these reinforcements contributed in increased hardness of the composites as shown in figure 6. The microphotographs of the composites studied revealed the uniform distribution of the particles in the matrix system. The dispersed SiC in Al6061 alloy and Al_2O_3 in Al7075 alloy contributed in enhancing the tensile strength of the composites as shown in figure 7. [15].

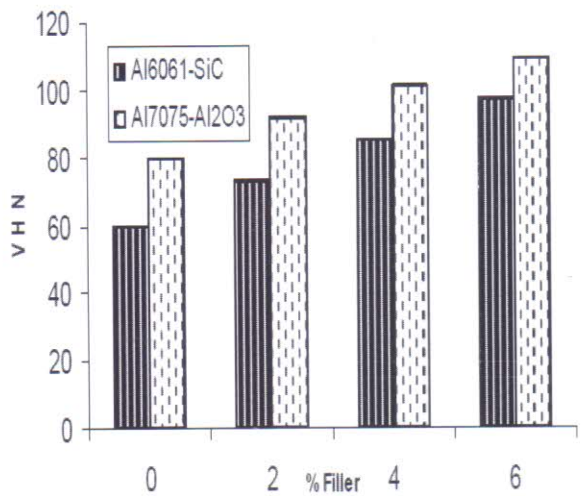

Fig. 6 Microhardness of Al6061-SiC and Al7075-Al2O3 composites. [15]

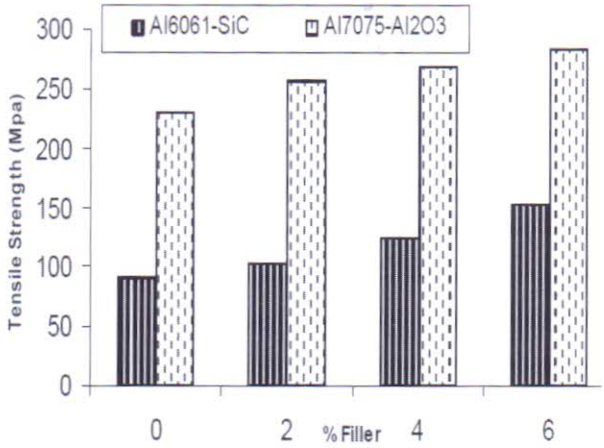

Fig. 7 Variation in Tensile Strength with increasing %' age particulate content.

IV. CONCLUSION

The conclusions on the basis of above literature review are listed below:

1. The phenomenon of electromagnetic field acts as a non intrusive stirring mechanism.
2. Liquid metallurgy technique (Electromagnetic stirring) can be successfully adopted for the preparation of $Al7075-Al_2O_3$ composite.
3. The refined microstructures with uniform distribution of particles are obtained for the composite developed through electromagnetic stir casting method.
4. The Mechanical properties like (Tensile strength, Hardness, Impact strength and wear resistance) enhances for the composite developed through electromagnetic stir casting method.
5. XRD & DTA analysis can also be included on the samples of above developed composite.

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