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Electromagnetic Stir Casting and its Process Parameters for the Fabrication and Refined the Grain Structure of Metal Matrix Composites – A Review

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Abstract

In numerous applications of casting, dendritic microstructure is not desirable as it results in poor mechanical properties. Enhancing the fluid flow in the mushy zone by mechanical stirring is one of the means to suppress this dendritic. Several manufacturing techniques have been invented for fabrication of metal matrix composites. One of the popular ways of generating non-dendritic microstructure is to stir the liquid metal during solidification using an electromagnetic force field. However, the main problem faced in the electro magnetic stir (EMS) casting is the selection of optimum combination of input variables for achieving the required physical, mechanical and tribological properties of composites. Therefore, in the present work an attempt has been made to review electromagnetic stir casting and its process parameters for the fabrication and refined the grain structure of metal matrix composites that possesses exceptionally good mechanical properties as well as tribological properties.

1. Introduction

Electric fields are formed by charged particles such as protons and electrons. These charged particles can set in motion and pull on each other with the electrostatic force. They follow the same rule as magnets. Opposite charges attract and like charges repel each other. When these charges are in motion along a wire, an electrical current is formed. This current is what runs electrical appliances and electrical motors [1]. When a wire conducting current is positioned in a magnetic field, a force is induced on the conductor. This force is the basis for the electric motor. The force is given by the equation:

$$F = I \times L \times B \qquad (1)$$

Where 'F' is force, 'B' is the magnetic field strength, 'L' is the length of the conductor, and 'I' is the current.

The force on a conductor in a magnetic field can be turned into a torque by running current through a loop of wire in a magnetic field inside the electric motor (as seen in Figure 1).

$$\tau = r \times F \qquad (2)$$

A torque 'τ' is a rotational force that is expressed by another cross product. In this equation, 'F' is the force applied and 'r' is the distance from the pivot point where the force is applied. Without any changes, the coil of wire will be in motion, but it won't spin. It will stop once the torque has changed from the maximum value to zero [2 –5].

Electromagnetic stirring is produced by the Lorentz force generated by an a.c. inductor. Unlike electromagnetic casting where stirring occurs near the surface region, however, electromagnetic stirrers are designed to deliberately produce melt convection deep in the liquid pool near the solidification front. Thus, lower-frequency magnetic fields are used to allow the Lorentz force to penetrate deeply into the molten-metal pool [6].

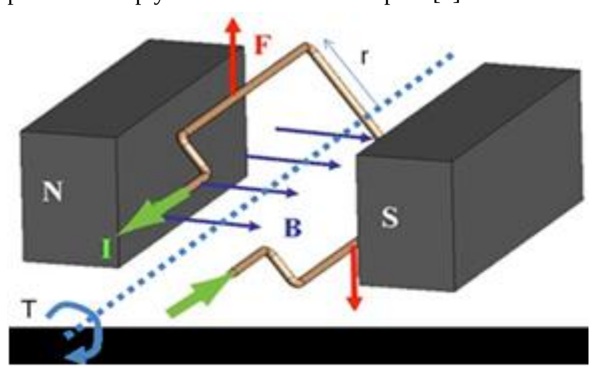

Fig: 1. Schematic Diagram of a Coil of Wire Conduction Current in a Magnetic Field

Two types of electromagnetic stirrers are commonly used in practice: the linear stirrer and rotary stirrer. A linear stirrer operates basically the same way as an induction furnace. The design entails the placement of a stack of coils around the casting metal to generate a primary motion that recirculates along the casting direction. A rotary stirrer is basically an electric motor. It uses a rotating magnetic field to produce a swirling flow in the liquid pool. The two modes may be applied either individually or in a combined fashion and stirring may be employed in various stages of solidification processes (i.e., in mold, below mold, and at the final stage of solidification). Possibly one of the most important inspirations for applying electromagnetic stirring during solidification processing moves toward from the sympathetic that a strong melt flow will generate strong shear stresses and the shear stresses will shed away the newly formed dendrites near the solidification front. The newly produced dendrite wreckage is then elated into the

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bulk liquid pool of higher temperature by convection. A little of the dendrites are remelted and vanish while others stay alive and are elated back to the solidifying region. These surviving broken dendrites then form additional nucleation sites upon which further grain growth occurs, in that way ensuing in grain refinement in the final casting products. This basic grain multiplication mechanism induced by strong electromagnetic stirring. Out-of-the-way from refining internal structures, electromagnetic stirring also has the advantages of homogenizing alloy elements, reducing porosity and segregation, and minimizing internal cracks [7-10].

2. Literature Review

Jun Zhang et al. [11] showed that, as the frequency increases, the shaping stability and the surface quality decrease due to the violent surface electromagnetic stir. The frequency effect is also correlative to the sample's size and electric conductivity. E. Liotti et al. [12] studied the effect of a pulsed electromagnetic field on dendrite fragmentation behavior based on synchrotron X-ray imaging, involving the passage of an oscillating current through a foil specimen placed in a static magnetic field. Meng-ou Tang et al. [13] developed annulus electromagnetic direct chill (A-EMDC) casting process. Two pairs of vortexes take place within the crystallizer with opposite direction in A-EMDC. The microstructure achieved by A-EMDC was globular or rosette-like, and the microstructure was homogeneous in the billet. Zhihe Dou et al. [14] investigated the influences of the additive CaF_2, different molds, mold pre-heating temperature, electromagnetic stirring, and alloying elements on CuCr respectively during the preparation of CuCr alloys by thermit-reduction electromagnetic stirring. Electromagnetic stirring can prevent the growth of dendrite crystal into refine crystal particles, as well as homogenize Cu and Cr to improve the CuCr properties: the optimal stirring time is 7 min; when the alloying elements Ni and Co are added to the reactants, elements Cu and Cr can distribute evenly but the crystal particles become thick. Yue-long Bai et al. [15] showed that the problem of inner porosity and composition segregation can be solved with the complex electromagnetic stirring technique. The ratio and index of central segregation and porosity can be reduced significantly. Zhen-duo Zhao et al. [16] showed that the AlSi7Mg alloy slurry with fine and spherical primary α-Al grains distributed homogeneously. Under the condition of low superheat pouring and week traveling-wave electromagnetic stirring, when the pouring temperature is 630°C, raising the stirring power or frequency appropriately can gain a better shape of primary α-Al grains; but if the stirring power or frequency is increased to a certain value (1.72 kW or10 Hz), the shape of primary α-Al grains cannot be obviously improved and spherical primary α-Al grains distributed homogeneously can be still obtained. M.J. Li et al. [17] proposed a model to account for the microstructure formation and grain refinement when considering the significant difference of the electrical resistivity properties of the solid and the liquid during EMV processing in the semisolid state. F.U. Bruckner et al. [18] developed a modified Czochralski technique (EMS-CZ) to pull single crystals without mechanical rotation of the crystal and the crucible by bringing forth the controlled convection in the melt solely by a rotating electromagnetic field. Crystals of copper, germanium and silicon have been grown successfully with this technique. Charles Vives [19] performed the experiments both in the absence and in the presence of electromagnetic body force fields, oriented either upward or downward, and for various degrees of heat extraction rate. It has been established that the stirring and liquid-solid-phase separation phenomena results in a decided grain refinement and, under certain conditions, in the segregation of the most part of the eutectic phase from the primary solid. Z. Liu et al. [20] indicated that the slurry with particle-like and rosette-like primary α phases can be prepared by low superheat pouring and slight electromagnetic stirring from liquid A356 alloy grain-refined, in which the pouring temperature can be suitably raised. Compared with the A356 samples without grain refining, the grain size and particle morphology of primary α phase as well as the distribution of the grain with particle-like or rosette-like along radial in the ingot in A356 are markedly improved by grain refining. W.D. Griffiths et al. [21] found the effect of electromagnetic stirring during solidification on the structure of Al-Si alloys. Guirong Li et al. [22] showed that high-frequency pulsed magnetic field accelerates heat and mass transfer processes and improves the kinetic condition of in-situ fabrication. W.D. Griffiths et al. [23] suggested that macrosegregation in the ingots was caused by the displacement of solute-enriched liquid from the mushy zone as a result of the electromagnetically stirred bulk liquid being driven into the solidification front. Zheng Liu et al. [24] manufactured the semi-solid slurry of A356 Al alloy by low superheat pouring and weak electromagnetic stirring. The results indicated that it is feasible to manufacture the slurry with particle-like primary phases by low superheat pouring and weak electromagnetic stirring, and there is an important effect of the pouring temperature (superheat temperature) on the morphology and the size of primary α-Al in A356 Al alloy. Guanglei ZHU et al. [25] investigated the effects of cooling rate, stirring power and stirring time on the solidification behavior of A357 alloy using annular electromagnetic stirring (A-EMS). It was found that increasing the cooling rate and stirring power gave rise to substantial grain refinement, which 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. S. Simlandi et al. [26] performed a numerical study to predict the transport phenomena during continuous casting of an aluminum alloy (A356) in presence of weak stirring. A set of volume averaged single phase conservation equations (mass, momentum, energy and species) is used to represent the casting process. The electromagnetic forces are incorporated in the momentum equations. P. A. Davidson et al. [27] gave a review of one-dimensional models of stirring in which the axial variation in the stirring force is ignored. In these models the magnetic body force is balanced by shear. Weiqiang Zhang et al. [28] applied electromagnetic stirring and water cooling to centrifugal casting of Al-25% Cu alloy. A full eutectic zone formed due to macro segregation of Cu caused by the centrifugal force. Both electromagnetic stirring and water cooling refined the primary grains. In addition, the equiaxed dendrites of α-Al were transformed into globular grains and the eutectic fraction in the alloy increased. Alexander A. Tzavaras et al. [29] reviewed the history of commercial electromagnetic stirring devices used to control the solidification structures of continuously cast products. Shyam Lal et al. [30] developed hybrid metal matrix composite (Al7075/7.5 % SiC/7.5 % Al2O3). The hybrid composite was prepared by inert gas assisted electromagnetic stir-casting process. T. Campanella et al. [31] studied the influence of electromagnetic stirring (EMS) on grain refinement for two copper-base solidified in a Bridgman furnace. The results were analyzed on the basis of a dendrite fragmentation criterion similar to Flemings' criterion for local remelting of the mushy zone. Sug Won Kim et al. [32] showed that the electromagnetic casting (EMC) specimens have high enthalpy, i.e., the thermal kinetic energy to form precipitates during the aging treatment process. N. Barman et al. [33] performed a numerical study to predict the effect of process parameters on transport phenomena during solidification of aluminium alloy A356 in the presence of electromagnetic stirring. It was found that increasing stirring intensity results in increase of slurry velocity and corresponding increase in the fraction of solid in the slurry. In addition, the increasing stirring intensity results uniform distribution of species and fraction of solid in the slurry. It was also found from the simulation that the distribution of solid fraction and species is dependent on cooling rate conditions. At low cooling rate, the fragmentation of dendrites from the solid/liquid interface was more. S.W. Oh et al. [34] focused on the microstructural characteristics of A6061 and A7075 wrought Al alloy slurries fabricated by an electromagnetic stirrer (EMS). Billets fabricated by electromagnetic stirrer under different conditions of stirring current, stirring time, and pouring temperatures of EMS. Lower pouring temperatures in the range (650–730 °C) led to finer primary-α Al phase grains in both A7075 and A6061 billets. Higher stirring current led to the finer primary-α Al phase. With respect to the effect of stirring time, the primary-α Al phase still appears in dendritic shape for 20 and 40 s of electromagnetic stirring time. The longer electromagnetic stirring time of 60 s led to a finer primary-α Al phase. Man Yao et al. [35] focused on the influence of mold-electromagnetic stirring (M-EMS) on mold heat transfer, for the purpose of developing a general approach to study mold heat-transfer characteristics in continuous casting of small round billets. B. A. Sivak et al. [36] analyzed and substantiated the effectiveness of improving the quality of semifinished sections and rounds cast on semi-continuous casting machines with electromagnetic stirring of the liquid phase of the crystallizing ingot in the mold and the zone in which final solidification takes place. D. A. Currey et al. [37] demonstrated that electromagnetic stirring reduced the amount of silicon segregation in the hypereutectic alloy, while in the hypoeutectic alloy stirring promoted dendrite fragmentation. In addition, the axial porosity was reduced and the core of the ingot was sounder. Electromagnetic stirring affects the solidification process by the stirring action and also by extending the time of thermal arrest. S. W. Oh et al. [38] described a rheo-forming process for the development of automobile suspension parts by using rheology material with electromagnetic stirring equipment. M. R. Bridge et al. [39] made chemical and metallographic studies of the "white band" (a zone of negative segregation) formed by the electromagnetic stirring of 127 mm square strand-cast steel billets. D. P. Cook et al. [40] showed how the method of inductances can be extended to three dimensions in order to solve Maxwell's equations for the electromagnetic field in and around the caster. Yingxin Wang et al. [41] investigated the grain-refinement effects of titanium (Ti) additions and a low-frequency electromagnetic casting (LFEC) process on the AZ31 magnesium alloy. It is shown that Ti has no effect on the formation and distribution of secondary phases in the AZ31 alloy. The results suggested that the grain size decreases with an increasing cooling rate for the AZ31 alloy; it decreases first, however, and then increases slightly for Ti-containing AZ31 alloys, indicating that the grain-refinement effect of Ti decreases with an increasing cooling rate. Yubo Zuo et al. [42] demonstrated that the Low-frequency electromagnetic casting (LFEC) process has a significant grain refining effect on aluminum alloys. D. C. Prasso et al. [43] developed a mathematical model for heat transport and solidification of aluminum in electromagnetic casting. B. A. Sivak et al. [44] found the influence of electromagnetic mixing of liquid metal in the continuous-casting machine on the quality of continuous-cast bar and bloom depends on the mixing rate. Xiang-jie Wang et al. [45] showed that when the low-frequency electromagnetic (LFE) field is turn off during the hot-top casting process, cold folding appears, and the as-cast structure becomes very coarse. Ch. Vives et al. [46] described the use of new local measurement techniques for velocity, magnetic field, current density, and phase difference, which allow experimental investigation of the flow of molten metal in industrial equipment (up to 700 °C) in the presence or absence of an induction magnetic field.

3. Electromagnetic stir casting set up

Electromagnetic stir casting set-up mostly consists a furnace and a stirring assembly. In wide-ranging, the solidification syntheses of metal matrix composites engage producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix [47-55].

The electromagnetic stirrer employees the principle of a linear motor and be different from the conventional mechanical and decompression types since it is a noncontact stirrer in which no part touches the molten metal. As shown in Figure 1, magnetic coil of motor generates a moving magnetic field, if a 3 phase AC voltage is applied to the motor. Electric power force is produced in the molten metal owing to the action of the magnetic field (magnetic flux) and resulting induction current to flow according Fleming's right hand rule [56-63].

This current then takes action with the magnetic field of the inductor to persuade electromagnetic force (F) in the molten metal according to Fleming's left hand rule. As this thrust stir in the direction of the moving magnetic field, the molten metal also stir. In other words, a stirring action is applied. In addition, when this thrust has components in in the vertical direction and the horizontal direction, the molten metal flows diagonally upwards and results in a uniform temperature in both the top and bottom layers of the molten metal [64, 65].

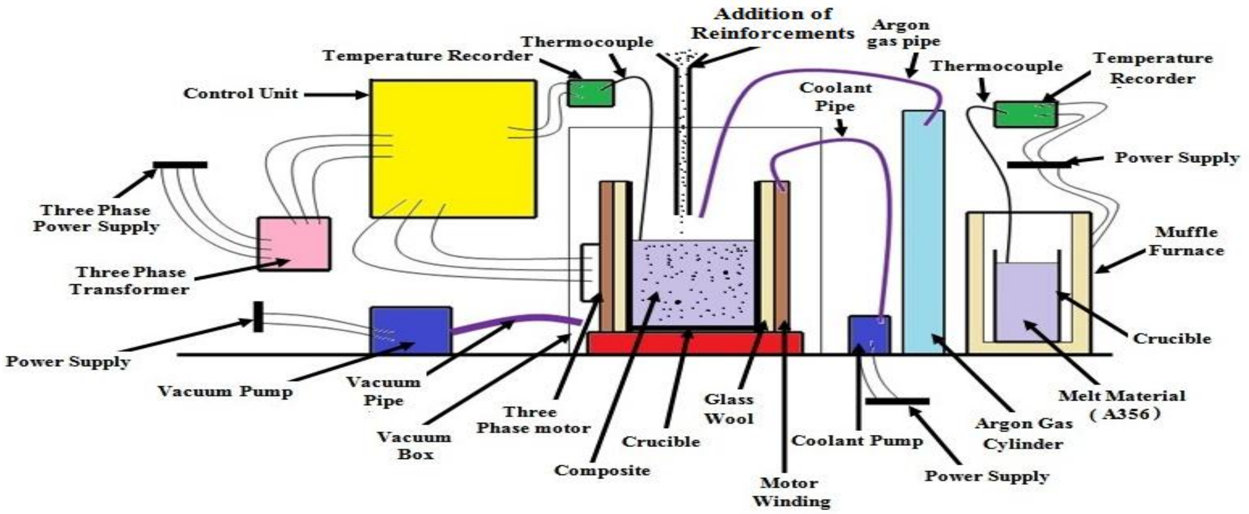

Fig: 1. Schematic View of Electromagnetic Stir Casting Set-Up

4. The Microstructure of Metal Matrix Composites Fabricated by EMS

The key features in the microstructure of a metal matrix composite material ensuing from the interface between the matrix and the reinforcement generally comprise the type, size, and distribution of reinforcing phases, matrix grain size, matrix and secondary phase interfacial characteristics microstructures defects. The mechanical properties of the composite materials are muscularly influenced by these factors.

4.1 Types of Reinforcement

Two types of reinforcing materials have been studied for metal matrix composites fabricated by electromagnetic stir casting (EMS). The first and the majority generally used are ceramic. The other is metallic/Intermetallic ceramic particles are the mainly generally used for metal matrix composites fabricated by electromagnetic stir casting (EMS). A few ordinary properties of ceramic materials make them popular for reinforcements. These properties consist of low-density and high levels of strength, hardness, thermal stability and elastic modulus. Though, they also have a number of common limitations for example low wettability, low compatibility and low ductility with an aluminum matrix. Along with the a variety of ceramic reinforcements SiC, B_4C and Al_20_3 is the most accepted because of its comparatively high wettability and its stability in a magnesium melt, as compared to other ceramics. The shape of reinforcement is one more factor upsetting the reinforcing effect. In an aluminum metal matrix composite, the largely usually used reinforcements assume a shape of particles or a mixture of these two configurations [66-68]. Metal matrix composites reinforced with ceramics generally give better mechanical properties fabricated by electromagnetic stir casting than fabricated by mechanical stir casting. To surmount the barriers of moderately high cost and the anisotropic properties related with reinforcement, some recent efforts have been made to reduce the cost by developing a new EMS [65].

4.2 Porosity and Inclusions

Porosity and inclusions are unfavorable to the mechanical properties of metal matrix composites. The porosity in a composite might take place from a number of bases in EMS. These consist of: the trap of gases during mixing of reinforcement in matrix, hydrogen growth and the shrinkage of the matrix during its solidification. The traps of gases depend mostly on the fabrication method, for example mixing and pouring of matrix. Stirring time, stirring current, stirring speed as well as the size and position of the reinforcements also considerably influence the porosity formation. Typically a quantity of water vapour is engrossed on the surface of the added reinforcement particles. Once entering the melt of matrix, the water vapour can react strongly with matrix like aluminum and magnesium (as magnesium is burning material), aluminum matrix forming Al_4C_3 and releasing hydrogen. Though, gas porosity in casting by EMS is additional sensitive to the volume fraction of the inclusions. In the Aluminum matrix composite, the occurrence of comparatively huge amounts of reinforcement particles may impose a grave porosity problem, if the reinforcement is not appropriately degassed prior to its addition to the melt matrix. Inclusion is one more main microstructural deficiency that is deleterious to metal matrix composites properties. Fabrication of metal matrix composites needs melt stirring in EMS. Some of the predictable techniques for taking away inclusions, for example reinforcement refining, reinforcement preheating be suitable for processing the metal matrix composites by EMS. It was examined that bigger inclusions are generally more damaging to the material's properties (mechanical properties and physical properties). Therefore, care must be in used to avoid the creation of inclusions in the metal matrix composites [69, 70].

Porosity (P) is the percentage of the pores volume to the total volume with the volume of a substance. It is defined by

$$P = \left(1 - \frac{V_{Theoretical}}{V_{Experimental}}\right) \times 100\,\% \quad \text{Or,} \quad P = \left(1 - \frac{\rho_{Experimental}}{\rho_{Theoretical}}\right) \times 100\,\%$$

Where, P = Porosity
V = Volume
ρ = Density

Porosity and characteristics of pores (including size, connectivity, distribution, etc.) influence the properties of materials very much. Usually, for the same material, the lower the porosity is, the less the associated pores are. As a result, the strength will be higher, the water absorption will be smaller, and the permeability and frost resistance will be better, but the thermal conductivity will be greater. The density measurements were carried out to establish the porosity levels of the samples. This was attained by comparing the experimental and theoretical densities of each volume percent reinforced composite. The experimental density of the samples was assessed by weighing the test samples. The calculated weight in each case was divided by the volume of respective samples [71].

4.3 Interfacial Characteristics

The border between the matrix and the reinforcement segment acts a key role in the processing of metal matrix composite materials. Main qualities of the interface are the strength of bonding and chemical reactions. Interfacial reactions in the aluminum metal matrix composite are mostly decided through the composition of the matrix and the reinforcement materials. An evaluation study of the interfacial reactions in magnesium based alloy composites reinforced with silicon carbide (SiC) particles has showed the effect of a matrix alloy composition on the particle/matrix interfacial phenomena. Porosity also persuades the interfacial reactions between the matrix material and the reinforcing material phases. Porosity may have enlarged the surface area and thus endorsed the reaction. The surface purity of the materials is one more issue affecting the interface chemical reactions. The constraints of the casting procedure for example melting temperature and stirring time have also been found to change the interface reactions in the aluminum metal matrix composite during fabrication via electromagnetic stir casting. According to Arrhenius law, higher temperature in electromagnetic stir casting (EMS) normally speeds up interfacial reactions. The degree of interfacial reactions can also change the microstructure. To get metal matrix composite materials with the preferred microstructure and properties, the interfacial reaction should be forbidden from side to side choosing a suitable matrix alloy, performing a suitable surface treatment of the reinforcement, and properly controlling the process parameters of electromagnetic stir casting (EMS) [72].

5 Properties of Metal Matrix Composites Fabricated by EMS

Behavior and properties of metal matrix composites from the nature and morphology can be forecasted and the factors for example structural arrangement, intrinsic properties and the interaction between the constituents are of much significance fabricated by electromagnetic stir casting (EMS). The intrinsic properties of ingredients verify the common order of properties that the metal matrix composite will exhibit. The size and shape of the each ingredient, their structural arrangement and allocation and the virtual quantity of each contribute to the overall performance of the composite. The factors that find out properties of metal matrix composites are microstructure, homogeneity, weight fraction and isotropy of the system and these are muscularly influenced by properties and proportions of the matrix and the reinforcement.

5.1 Effect of Temperature and Strain Rate

During the fabrication of aluminum metal matrix composites by electromagnetic stir casting (EMS), size of second phase in aluminum based metal matrix composite is dependable for room temperature strengthening outcome. This intermetallic has low melting point and has a tendency to expand into roughen at prominent temperature and no longer take action as a barrier for dislocations. Consequently; in aluminum based metal matrix composite, this phase demonstrates the method to the poor outstanding temperature properties. It should be prominent that temperature has an enormous result on the tensile strength at lesser strain rate, while at upper strain rate; the temperature effect is fewer significant [73-75].

5.2 Effect of Grain Size of Matrix in EMS

Properties (mechanical properties) are tremendously dependent on grain size. The yield strength can be linked with grain size by well-known Hall-Petch equation;

$$\sigma = \sigma_o + Kd^{-1/2}$$

Where 'σ' is the yield stress, 'σ_o' is the yield stress of a single crystal, 'K' is a constant and'd' is the grain size. With growing the Taylor factor the value of K increases. Strength and ductility can enhanced with decrease in grain size of matrix by controlling various parameters of electromagnetic stir casting (EMS). It is observed that intergranular fracture is detected in matrix alloy with a hefty grain size: on the other hand, intergranular fracture is narrow in aluminium based metal matrix composite with a small grain size, on behalf of that the fracture mechanism is distorted by grain refinement. This is for the cause that the critical stresses for crack propagation at grain boundaries enlarge with falling grain size [77-79].

5.3 Physical Properties

Physical properties (density) imitate the characteristics of metal matrix composites. In a metal matrix composite, the percentage of the matrix and reinforcement are stated either as the weight fraction (*w*), which is applicable to fabrication, or the volume fraction (*v*), which is usually used in property estimation. The density of metal matrix composite fabricated by EMS is attained by displacement procedure via a physical balance by density measuring kit as maintained by ASTM. Additional, the density can also be analyzed from porosity and evident sample mass values. The results of the numerous studies concerning the density of the B_4C, Al_2O_3 and SiC particle reinforced aluminum can be sum up as follows: the reinforcements Al_2O_3 and SiC increase the density of the metal matrix composites when they are added to the base matrix alloy to form the composite. When, the theoretical density values match with the experimental density values of the metal matrix composites, minimum porosity observed [80-81].

5.4 Mechanical Properties of Metal Matrix Composites Fabricated by EMS

Mechanical properties of MMCs (metal matrix composites) are fundamentally functions of the casting processes. Type of matrix, reinforcement and heat treatment persuade the mechanical properties of the metal matrix composites. The factors for example the porosity of the metal matrix composites, weight fraction of the reinforcements and their distribution, sedimentation or agglomeration of the reinforcement particles and particle size of reinforcement, influence the properties of the metal matrix composites, such as tensile strength, hardness, toughness, Young's modulus, creep resistance, and fatigue resistance [82-84].

5.4.1 Hardness

The resistance to indentation or scratch is termed as hardness. Along with a variety of apparatus for measurement of hardness, Brinell's, Rockwell's and Vicker's hardness testers are considerable. Among the variants of reinforcements, the low aspect ratio particle reinforcements are of a large amount significant in imparting the hardness of the material in which they are. The heat treated alloy and composite exhibits better hardness; though, the over-aged condition may tend to reduce the hardness significantly [82-88].

5.4.2 Tensile Strength

Aluminium metal matrix composites have higher elastic modulus, tensile and fatigue strength over massive alloys. In case of heat treatable Al-alloys and their composites, the strength of composites enhance after heat treatment by reducing the cracking tendency and improving the precipitation hardening. Before fabrication process, heat treated to an under aged condition as the materials can be shaped more easily and after fabrication, these materials are heat treated to the peak aged condition so as to provide improved mechanical properties. Along with a lot of ceramic materials, SiC, Al_2O_3 and B_4C are extensively in use, due to their positive combination of density, hardness and cost effectiveness. When these reinforcements are combined with aluminium metal matrix composites, the resulting material shows significant increase in its elastic modulus [82-88].

5.4.3 Toughness

The fracture toughness of a material is assessed in terms of crack tip parameter at the initiation of crack growth. The fracture toughness of the composite is decreases with increase in the reinforcement content and size. In the study of fracture toughness characteristics of discontinuously reinforced aluminum, the fracture behavior of ceramic-based materials with sharp well-defined fluorescence lines can be quantitatively analyzed in terms of the measured microscopic stress fields [82-88].

5.4.4 Creep

Creep is defined as the progressive deformation of a material under the action of a constant applied load. Creep does not become significant until temperatures of the order of 0.3 T_m for metals and 0.4 T_m for alloys is reached. Creep behavior in particulate reinforced MMCs is characterized by a progressively increasing creep rate (tertiary creep) over most of the creep life. The creep rate of each phase is described by a unified constitutive equation that can account for the effect of stress, strain-hardening, and temperature. The increase of creep resistance is attributed to the decrease of grain size, but a continuous decrease of grain size would increase the presence of the softer grain boundary affected zone and this in turn could result in the softening effect for the nanocrystalline solid [89, 90].

5.4.5 Fatigue

The fatigue behaviour of metal matrix composites is very important for many engineering applications concerning cyclic or dynamic loading. When the composite materials are subjected to cyclic stress amplitude, the resulting strain amplitude may change with continued cycling. Cyclic strain produces a number of damaging process which affects the microstructure and the resulting cyclic strain resistance and low-cycle fatigue. The cyclic strain amplitude reversals to the failure can be viewed as an indication of the resistance of the composites microstructure to microscopic crack formation, potential propagation and coalescence of the cracks culminating in fracture. The strains are much lower in the composite materials than they would be in the unreinforced material. This is because of the higher elastic modulus and higher proportional limit of the composite material. The presence of particulate reinforcement results in the development of localised stresses from constraints in matrix deformation around the reinforcing particles. The highly localised stresses contribute to the observed work-hardening behaviour of the composites. The concentration of the localised stresses results from constraints in matrix deformation that occur because of the significant difference in elastic modulus of the constituents of the composite, i.e. the discontinuous particulate-reinforcement and continuous phases and the continuous Aluminium alloy metal matrix. Under constant strain amplitude conditions, the MMC is inferior in the low cycle regimes where plastic strains dominate, and in the high cycle regimes, the composite is superior to the unreinforced material [91-93].

5.4.6 Ductility

Ductility is one of the significant features in the properties of metal matrix composites. The tensile elongation decreases quickly with the addition of reinforcing particles and with increased aging time in the heat treatable alloys of metal matrix composites reinforced with ceramic particle. Metal matrix deformation between closely spaced elastic particles would be highly constrained [94, 95].

5.5 Thermal Properties

5.5.1 Thermal Conductivity

Thermal conductivity is the property of a material to conduct heat. It is assessed mainly in terms of Fourier's Law for heat conduction. Heat transfer takes place at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. Correspondingly materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. Thermal conductivity of materials is temperature dependent. The reciprocal of thermal conductivity is called thermal resistivity [96, 97].

5.5.2 Thermal Expansion

Thermal expansion is the propensity of substance to change in volume in reply to a change in temperature, all the way through heat transfer of metal matrix composites. Temperature is defined as the average molecular kinetic energy of metal matrix composites. When a composite is heated, the kinetic energy of its molecules increased. As a result, the molecules start moving extra and typically maintain a greater average separation. Metal matrix composites materials which agreement with increasing temperature are curious; this effect is limited in size, and only occur inside limited temperature ranges. The degree of expansion divided by the change in temperature is called the material's coefficient of thermal expansion and usually varies with temperature [98, 99].

5.5.3 Boiling Point

The boiling point of composite is the temperature at which the vapor pressure of the liquid equals the pressure surrounding the liquid and the liquid changes into a vapor. The normal boiling point of metal matrix composites in electromagnetic stir casting (EMS) is the particular case in which the vapor pressure of the liquid equals the defined atmospheric pressure. At that temperature, the vapor pressure of the metal matrix composites becomes sufficient to overcome atmospheric pressure and allow bubbles of vapor to form inside the bulk of the liquid [100].

5.6 Electrical Properties

Electrical resistivity also known as resistivity, specific electrical resistance, or volume resistivity is an intrinsic property that enumerates how strongly a given material opposes the flow of electric current. A low resistivity points out a material that willingly allows the movement of electric charge. Electrical conductivity or specific conductance is the reciprocal of electrical resistivity, and measures a material's ability to conduct an electric current [101].

5.7 Magnetic Properties

For the metal matrix composite material, the Curie temperature (Tc), or Curie point, is the temperature where a metal matrix composite material's permanent magnetism changes to induced magnetism. The force of magnetism is determined by magnetic moments. The Curie temperature is the vital point where a metal matrix composite material's intrinsic magnetic moments change direction. Magnetic moments are permanent dipole moments within the atom which originate from electrons' angular momentum and spin. Materials have different structures of intrinsic magnetic moments that depend on temperature. At a metal matrix composite material's Curie temperature those intrinsic magnetic moments change direction.

In electromagnetism, permeability is the assess of the capability of a material to hold up the formation of a magnetic field within itself. It is the degree of magnetization that metal matrix composite material obtains in response to an applied magnetic field [102, 103].

5.8 Chemical Properties

Corrosion is the steady destruction of materials by chemical reaction with its environment. Corrosion is electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Rusting, the formation of iron oxides is a well-known example of electrochemical corrosion [104].

Many structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area more or less uniformly corroding the surface. Because corrosion is a diffusion-controlled process, it occurs on exposed surfaces [105].

6. Conclusions

This review presents the views, theoretical and experimental results obtained and conclusions made over the years by various researchers in the field of metal matrix composites. Following conclusions can be drawn from review.

1. An optimized combination of electromagnetic stir casting process parameters may be achieved to obtain better mechanical properties, if aluminum metal matrix composites are processed with a controlled gradient of reinforcing particles.
2. Processing of aluminum composites with high weight fraction of reinforcement with hard particles is actually difficult task. There is no apparent correlation between mechanical properties of the metal matrix composites, weight fraction, type of reinforcement and surface nature of reinforcements.
3. The reduced size of the reinforcement particles is believed to be effective in improving the mechanical properties and refine the grain structure of the metal matrix composites fabricated by electromagnetic stir casting (EMS).
4. It has been studied and concluded that the density of the metal matrix composites increases with the addition of the hard ceramic reinforcement like SiC and Al_2O_3, while reduces with the addition of B_4C, Fly-ash, Graphite into the matrix material.
5. The strength and hardness of the metal matrix composites were reviewed. It is discovered that as the reinforcement contents increased in the matrix material, the strength and hardness of the composites also increased. The mechanical properties were reviewed with respect to strength. It is apparent that the grain structures and properties of the reinforcements control the mechanical properties of the composites.
6. In general, the aluminum metal matrix composites are found to have higher elastic modulus, tensile and fatigue strength over monolithic alloys.
7. The fracture toughness of the metal matrix composite decreases with increase in the reinforcement content and size.
8. Creep does not become significant until temperatures of the order of 0.3 Tm for metals and 0.4 Tm for alloys is reached.
9. The Ductility (tensile elongation) decreases rapidly with the addition of reinforcing particles and with increased aging time in the heat treatable alloys.
10. Thermal properties, Electrical properties, Magnetic properties and Chemical properties are also the important aspects in the properties of metal matrix composites.

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