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Ceramic Materials and Stir Cast Aluminium Matrix Composites: A Literature Review

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ABSTRACT: Aluminium is one of the lightest material among the engineering materials. It has strength to weight ratio superior to steel. By utilising numerous combinations of its advantageous properties such as strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever increasing number of structural applications. The importance of composites as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 200 are composites. These composites initially replaced cast iron and bronze alloys but owing to their poor wear and seizure resistance. They were subjected to many experiments and the wear behaviour of these composites were explored to a maximum scope and were reported by the number of researchers for the past 25 years. In the present study, based on the literature review, the ceramic materials, classifications of ceramic materials and their effect on stir cast aluminium matrix composites are discussed in quite detail. The choice of aluminium alloy and its properties are also out-lined in this paper. Aluminium matrix composites with silicon carbide particle reinforcements are finding increased applications in aerospace, automobile, space shuttle, underwater, and transportation applications. This is mainly due to improved mechanical and tribological properties. In the present scenario, a review of different researchers have been made to consolidate some of the aspects of mechanical and wear behaviour of stir cast aluminium metal matrix composites.

KEYWORDS: Aluminium alloy, Ceramic materials, AMCs, Stir casting.

I. INTRODUCTION

The possibility of taking advantage of particular properties of the constituent materials to meet specific demands is the most important motivation for the development of composites. A composite is a material that consists of constituents produced via a physical combination of pre-existing ingredient materials to obtain a new material with unique properties when compared to the monolithic material properties. The terms “matrix” and “reinforcement” are often used in composite materials. The matrix is a percolating “soft” phase (with in general excellent ductility, formability and thermal conductivity) in which are embedded the “hard” reinforcements (high stiffness and low thermal expansion). The reinforcements can be continuous or discontinuous, orientated or disorientated. The composites are classified by: (1) their matrix (polymer, ceramic, metal), (2) their reinforcement, which includes the chemical nature (oxides, carbides, and nitrides), shape (continuous fibers, short fibers, whiskers, particulates) and orientation, (3) their processing routes [1].

Metal matrix composites (MMCs) are composed of a metallic matrix (Al, Mg, Fe, Cu etc.) and a dispersed ceramic (oxides, carbides, nitrides) or metallic phase (Pb, Mo, W etc.). Ceramic reinforcements may be silicon carbide, boron carbide, alumina, silicon nitride, boron nitride etc. Although, metallic reinforcements may be tungsten, beryllium etc. Among the MMCs, aluminium matrix composites (AMCs) are used for space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications [1-4]. Aluminium is typically reinforced by Al_2O_3 , SiC, SiO_2 , BN, B_4C , AlN, TiO_2 , Si_3N_4 , TiN, ZrC, WC, TiC, TaC, AlB, ZrO_2 etc. Aluminium alloys such as the 2000, 5000, 6000 and 7000 alloy series, are most commonly utilized as matrix materials in the fabrication of MMCs for aerospace applications. In the cast alloy series, aluminium–silicon alloys such as A356 are widely used. Alumina, zirconia or silicon carbide particles are widely used as reinforcing materials for automotive applications [4, 5].

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The mechanical alloying (MA) process, using ball-milling and/or rod-milling techniques, has received much attention as a powerful tool for the fabrication of several advanced materials including equilibrium, nonequilibrium (e.g., amorphous particles, quasicrystals, nanocrystalline materials, etc.), and nanocomposite materials. In addition, it has been employed for reducing some metallic oxides by milling the oxide powders with metallic reducing agents at room temperature. The MA is a unique process in that a solid-state reaction takes place between the fresh powder surfaces of the reactant materials at room temperature. Consequently, it has been employed to produce alloys and compounds that are difficult or impossible to obtain by the conventional melting and casting techniques [6].

II. CERAMIC MATERIALS

A ceramic is an inorganic, non-metallic solid material comprising metal, non-metal or metalloid atoms primarily held in ionic and covalent bonds. Ceramic materials compromise a number of benefits in a variety of applications. They afford high wear, heat and corrosion resistance, as well as high tensile strength, volume resistivity, dielectric strength and modulus of elasticity. These materials also offer lower thermal expansion than metals or plastics, and a longer part life at original design dimensions and tolerances.

2.1 Benefits of Certain Advanced Technical Ceramics

There are several benefits of ceramic materials such as excellent mechanical and wear behaviour, good electrical and thermal properties. Some benefits of particular advanced technical ceramic materials are summarized in the following paragraphs [7]:

Aluminum Oxide (Al_2O_3): Aluminum oxide (alumina) is the pillar of advanced technical ceramics. It has noble mechanical and electrical properties, wear resistance and corrosion resistance. It has comparatively poor thermal shock resistance. It is used as an electrical insulator for a number of electrical and electronic applications, including spark plug insulators and electronic substrates. It is also used in chemical, medical and wear applications.

Zirconium Oxide (ZrO_2): Zirconium oxide has the highest fracture toughness of any advanced technical ceramic. Its toughness, mechanical properties and corrosion resistance make it perfect for medical and selected wear applications. Its thermal expansion coefficient is very close to steel, making it an ideal plunger for use in a steel bore. Its properties are derived from a very precise phase composition. Some environmental conditions can make the material unstable, causing it to lose its mechanical properties. It has relatively low hardness and high weight also limit its extensive use in wear applications.

Fused Silica (SiO_2): Fused silica is an outstanding thermal insulator and has essentially zero thermal expansion. It has good chemical resistance to molten metals but is limited by its very low strength. It is used for a number of refractory and glass applications, as well as for missiles.

Titanium Diboride (TiB_2): Titanium diboride is an electrically conducting ceramic and can be machined using electron discharge machining (EDM) technique. It is a very hard material. However, its mechanical properties are poor. Its major use is in metallurgical applications involving molten aluminum. It is also used for certain limited wear applications, such as ballistic armor to stop large diameter (>14.5 mm) projectiles.

Boron Carbide (B_4C): Boron carbide is the hardest material after diamond, giving it outstanding wear resistance. Its mechanical properties, specifically its fracture toughness, are low, limiting its application. However, it is used extensively for ballistic armor and blast nozzles. Boron carbide is also a neutron absorber, making it a principal choice for control rods and other nuclear applications.

Silicon Carbide (SiC): Silicon carbide has outstanding wear and thermal shock resistance. It has good mechanical properties, particularly at high temperatures. It is a semiconductor material with electrical resistivity in the $10^5 \Omega\text{cm}$ range. It can be processed to a very high purity. Silicon carbide is used extensively for mechanical seals because of its chemical and wear resistance.

Tungsten Carbide (WC): Tungsten carbide is generally made with high percentages of either cobalt or nickel as a second metallic phase. This ceramic metal (cermet) has wide use as cutting tools and other metal forming tools. Pure tungsten carbide can be made as an advanced technical ceramic using a high temperature hot isostatic pressing process. This material has very high hardness and wear resistance. It is mostly used for abrasive water jet nozzles. However, its weight limits its use in many applications.

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Aluminum Nitride (AlN): Aluminum nitride has a very high thermal conductivity while being an electrical insulator. This makes it a perfect material for use in electrical and thermal management conditions.

Boron Nitride (BN). Hexagonal boron nitride is a chalky white material and is often called “white graphite.” It has generally poor mechanical properties. It has outstanding high temperature resistance ($>2500^{\circ}\text{C}$) in inert atmospheres but cannot be used above 500°C in an air atmosphere. It is used as a high temperature insulator and in combination with TiB_2 in many ferrous and aluminum metallurgical applications.

Silicon Nitride (Si_3N_4): Silicon nitride has the best combination of mechanical, thermal and electrical properties of any advanced technical ceramic material. Its high strength and toughness make it the material of choice for automotive and bearing applications.

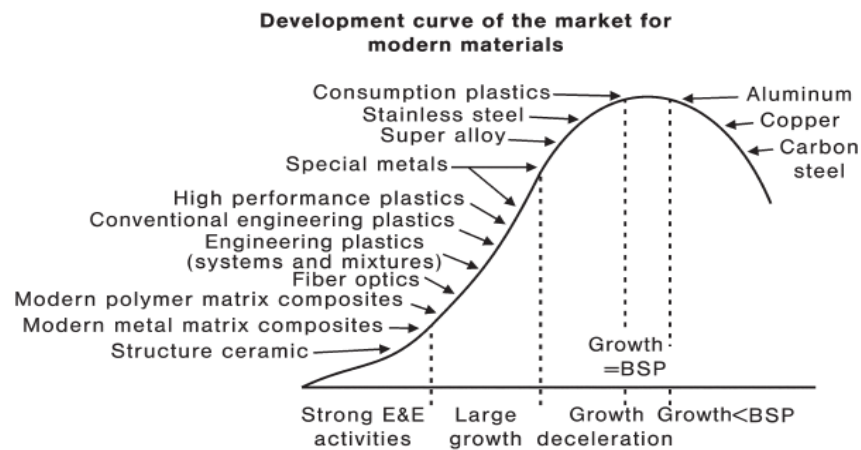


Fig. 1 Development curve of the market for modern materials[8]

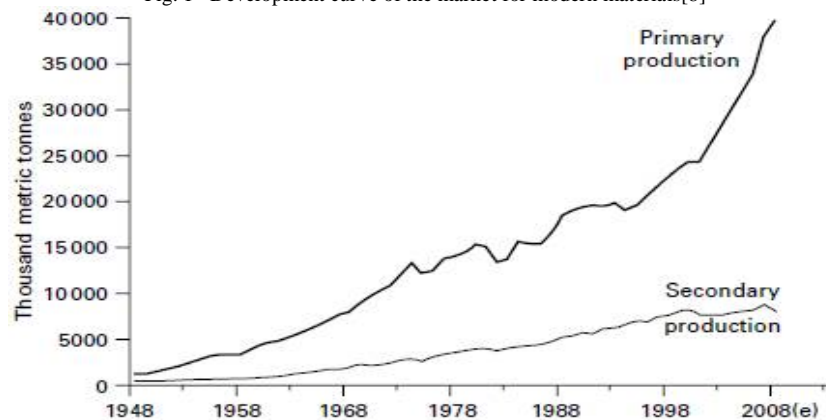
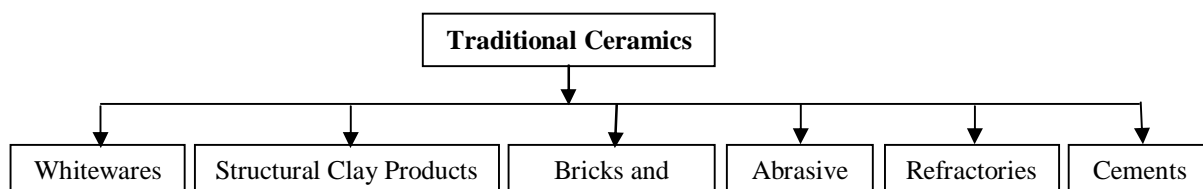


Fig. 2 World aluminium production 1948–2008 (e – estimate) (Source: USGS) [4]

2.2 Classification of Ceramic Materials

There are several classification schemes of ceramic materials, which may be ascribed to one of two main groups: application base system and composition base system. Detail classifications of ceramic materials [9] are shown in the Fig. 3.



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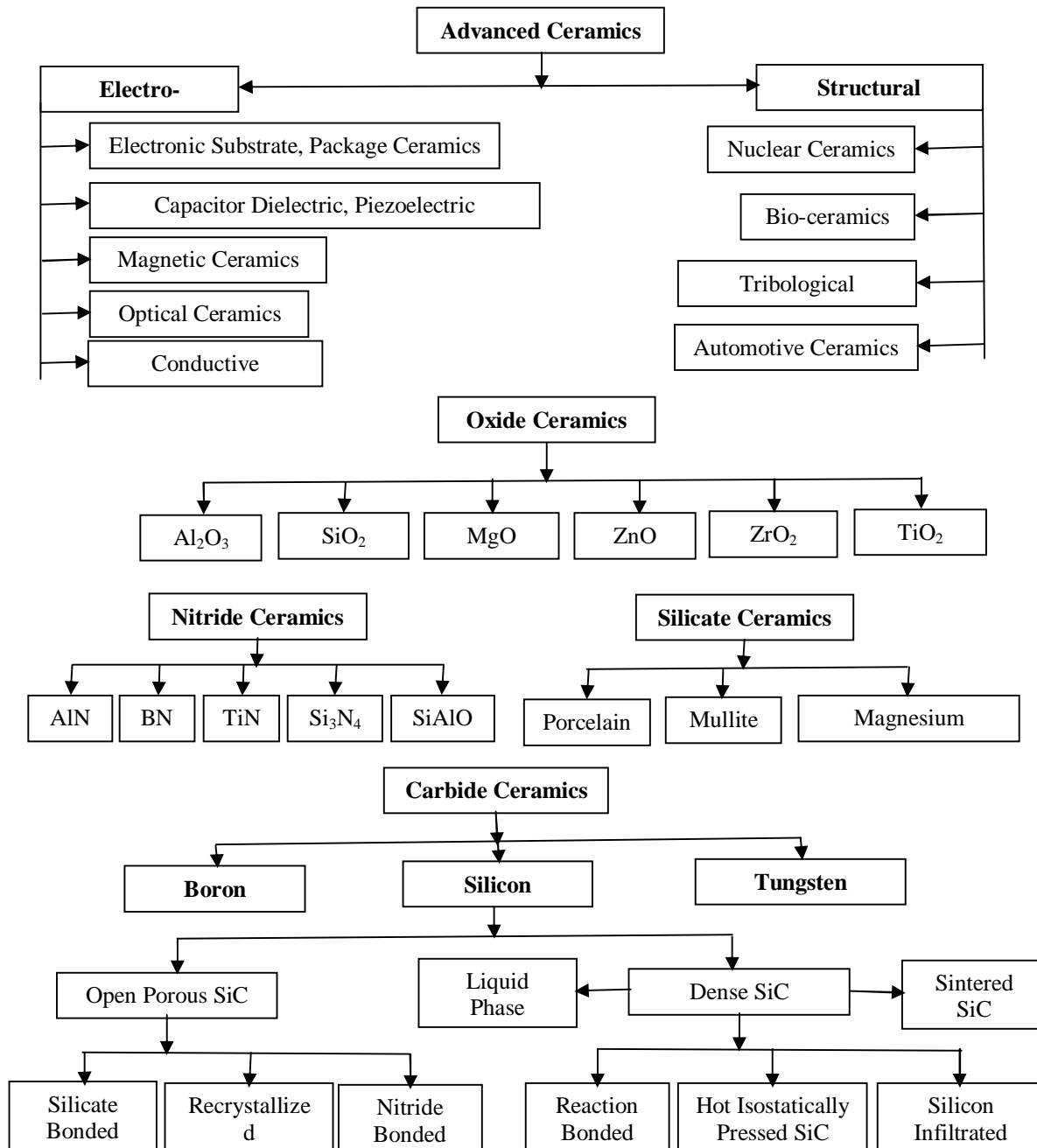


Fig. 3 Detail classification of ceramic materials

III. ALUMINIUM ALLOY SELECTION

Numerous aluminium alloy designation systems have been reported by Alam and Ansari [10]. They discussed that there are a number of available alloys to choose from to satisfy individual requirements. Once the casting method is determined, the alloy choice is limited because not all alloys can be used with all casting methods. Occasionally, the alloy that shows the best properties on paper may have production characteristics that make it less desirable on an

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overall basis than other eligible alloys. Therefore, it is best to consult with a metalcasting facility, which can advise on such factors as availability and relative cost of ingot, production costs and reproducibility of results. Service requirements also are the key consideration in alloy selection. If high strength is required, heat-treatable alloys must be used. The alloy options can be narrowed further when considering the remaining requirements, such as pressure tightness, corrosion resistance and machinability [11].

Die casting alloy selection requires evaluation not only of physical and mechanical properties, and chemical composition, but also of inherent alloy characteristics and their effect on die casting production as well as possible machining and final surface finishing. The benefits of consulting a custom die caster experienced in casting the aluminium alloy being considered are clear [12]. Among the several aluminium casting alloys, A356.0-aluminium casting alloy (7Si-0.3Mg) has been chosen [10]. This aluminium alloys is also designated by A356. The previous studies were deliberated the essential properties of A356 aluminum casting alloy. Table 1 shows the maximum chemical composition of A356 unless otherwise range is given.

Table 1 Chemical composition of aluminium alloy (A356)

Element		Quantity (weight %)			
Reference		[13]	[14]	[15]	[16]
Si		6.5-7.5	6.5-7.5	7.5	7.23
Mg		0.25-0.45	0.2-0.6	0.38	0.38
Cu		0.2	0.2	0.001	0.18
Fe		0.2	0.5	0.106	0.32
Zn		0.1	0.1	0.02	0.05
Ti		0.2	0.2		0.01
Mn		0.1	0.3		0.02
Ni			0.1	0.05	
Pb			0.1		
Sn			0.05		
Others	each	0.05			
	Total	0.15			
Aluminium		Balance	Balance	91.99	91.73

3.1 Applications of Aluminium Casting Alloys (A356)

Typical uses of A356 alloy are aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water cooled cylinder blocks etc. Other applications where excellent castability and good weldability, pressure tightness and good resistance to corrosion are required. Moreover, A356 are used in aircraft structures and engine controls, nuclear energy installations and other applications where high strength permanent mold or investment castings are required [12].

Table 2 Properties of aluminium casting alloy (A356) [17, 18]

Property	Unit	Value
Density at 20°C	g/cm ³	2.67
Heat capacity	J/gK	0.963
Thermal conductivity	W/mK	151
Melting range	°C	555-615
Ultimate tensile strength (UTS)	MPa	234
Yield tensile strength (YTS)	MPa	165
Elongation	%	2-3.5

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0.2%. Proof Stress	MPa	185
Brinell hardness number	HBN	75
Modulus of Elasticity	GPa	71
Shear strength	MPa	120
Endurance Limit	MPa	56
Specific heat	J/kg	963
Latent heat of fusion	kJ/kg	389

IV. ALUMINIUM METAL MATRIX COMPOSITES

Metal matrix composites are those which consist of metal as a matrix and ceramic materials are reinforced into it. Among the metal matrix composites, aluminium matrix composites are the lightweight material. These composites are generally used in structural applications. Aluminium metal matrix composites (AMCs) consist of nonmetallic reinforcements incorporated into an aluminium matrix. Reinforcements can be continuous or discontinuous, the most common being silicon carbide. Other reinforcements include boron carbide, alumina and graphite fibers as well as various particles, short fibers and whiskers. AMCs have better stiffness, wear resistance and thermal conductivity than base aluminium alloys. The American National Standards Institute specifies that AMCs be identified as follows: Matrix/reinforcement/volume%/form. Using this formula, A356 aluminium alloy reinforced with 20% SiC particulate would be designated as 356/SiC/20p [11]. Moreover, aluminium metal matrix composites are aluminium based alloys reinforced with up to 20% silicon carbide (SiC) particles, which are now being used for high performance die cast components. The mechanical properties of ASTM test specimens made from these materials typically exceed those of most aluminium, magnesium, zinc and bronze components produced by die casting, and match or approach many of the characteristics of iron castings and steel at lighter weight.

The anticipated properties of AMCs parts are higher stiffness and thermal conductivity, improved wear resistance, lower coefficient of thermal expansion, and higher tensile and fatigue strengths at elevated temperature, with densities within 5% of aluminium die casting alloys. These composites can also yield castings with reduced porosity. Preliminary data also indicates that less vibrational noise is generated by parts made from these composites, under certain conditions, than by identical parts made from unreinforced aluminium. Duralcan F3D.10%v/v and 20%v/v aluminium metal matrix composites reinforced with SiC ceramic powder are general purpose die casting alloys. It contains virtually no copper or nickel and are designed for use in corrosion sensitive applications. All of these composites are heat treatable [12]. Figure 5 shows broad classification of different composite materials.

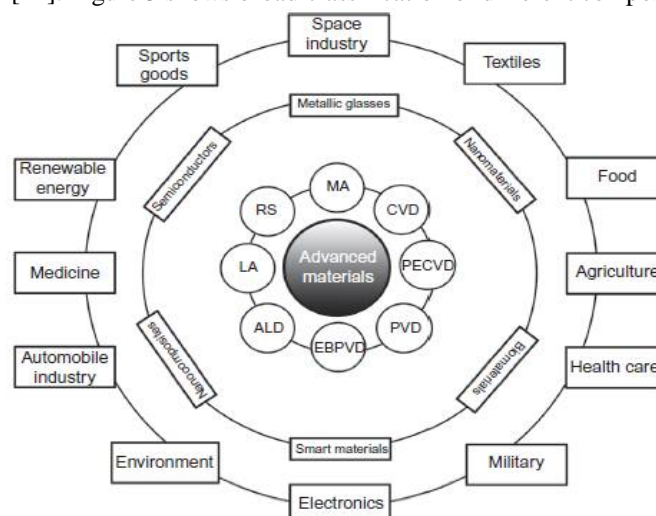


Fig. 4 Advanced materials, such as metallic glasses, nanomaterials, biomaterials, smart materials, nanocomposites, semiconductors, etc., that are used in different industrial, medical, electronic, and many other sectors are prepared by wide variety of materials processing [6]

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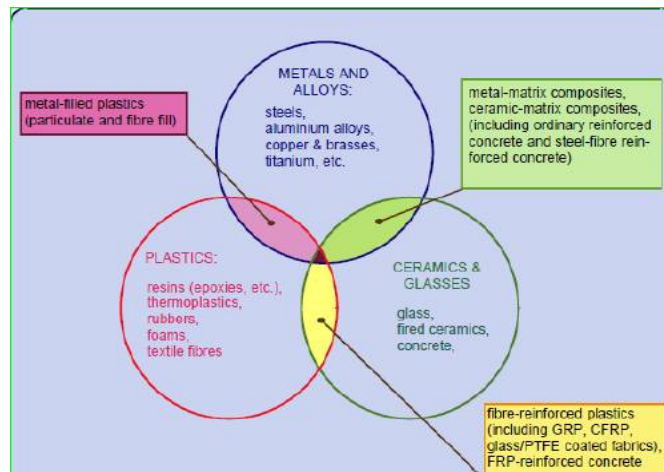


Fig. 5 Classification of composite materials [19]

4.1.1 Machining Characteristics of AMCs

Aluminium metal matrix composites are significantly more abrasive to cutting tools than all other aluminium die cast and gravity cast alloys, except for hypereutectic Al-Si alloys (those containing primary Si phases). Coarse grades of polycrystalline diamond (PCD) tools are recommended for anything more than prototype quantities of machining. With the proper tooling, AMCs can be readily turned, milled, or drilled. However, cutting speeds are lower and feed rates are higher than for unreinforced alloys [12]. General machining guidelines are described in Volume 1 of the SME Tool & Manufacturing Engineers Handbook.

4.1.2 Surface Treatment Systems of AMCs

Surface treatments are generally applied to aluminium metal matrix composites to provide a protective barrier to environmental exposure, to provide decorative finish, or to reduce the abrasiveness to a counter face material. Because of the inherently high wear resistance of the AMCs, surface treatments on these materials are generally not used to improve their wear resistance. Decorative finishes can be applied by painting, powder coat finishing, epoxy finishing and plating, using procedures similar to those used for conventional aluminium alloys. Though, conventional and hard coat anodized finishes can be applied to AMCs die castings, the results are not as cosmetically attractive as for conventional aluminium. The presence of the SiC particles results in a darker, more mottled appearance. This problem can be minimized. Even though not entirely eliminated, by using the darker, more intensely colored dyes to color the anodic coatings. Another problem often noted is that the presence of the ceramic particles produces a rougher surface, particularly after chemical etching. This, in turn, indicates to a less lustrous anodic coating than usually seen with unreinforced aluminum [12]. Recommended procedures for painting, plating and anodizing Duralcan MMCs can be obtained through Rio Tinto Alcan, 2040 Chemindela Reserve, Chicoutimi (Quebec) G7H 5B3, Canada.

4.2 Aluminium Silicon Carbide Advanced Substrate

Aluminium silicon carbide is a metal ceramic composite material consisting of silicon carbide particles dispersed in a matrix of aluminium alloy. It combines the benefits of high thermal conductivity of metal and low coefficient of thermal expansion (CTE) of ceramic. With its composite features, Al/SiC is an advanced packaging material for high technology thermal management. Al/SiC is compatible with a wide range of metallic and ceramic substrate and plating materials used in microelectronic packaging for aerospace, automotive, microwave applications. Al/SiC allows for a new packaging technology that can replace traditional WCu, Mo, BeO, Kovar, MoCu, AlN, AlSi and Al₂O₃. Other important applications of AMCs are advanced printed circuit board, microelectronic packaging, radiofrequency and microwave packaging, optoelectronic packaging [20].

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Table 3 Properties of Al/SiC composite [20]

Property	Unit	Value
Density at 20°C	g/cm ³	2.95-3.00
Thermal conductivity	W/mK	170-200
Thermal expansion coefficient	K ⁻¹	(6.5-9.5)x10 ⁻⁶
Electrical Resistivity	μΩcm	30-50
Bending strength	MPa	350-500
Elastic modulus	GPa	200-230

V. STIR CASTING PROCESS FOR FABRICATION OF AMCs

Stir casting (vortex method) is a liquid state process of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods. Its advantages lie in its simplicity, flexibility and applicability to large scale production. The primary functions of the “fillers” are to reduce cost, improve workability, and/or impart desired properties. Fillers are inert substances added to reduce the cost and/or improve its thermo-physical properties, viz., thermal conductivity, hardness, stiffness and impact strength, compressive and tensile strengths, elasticity etc. Frequently used fillers for stir casting process are Al₂O₃, SiC, B₄C, SiO₂, MgO, ZrO₂ etc. Silicon carbide also known as carborundum, is a compound of silicon and carbon with chemical formula SiC. Silicon carbides are produced with a nominal 0.0055 in. (140μm) filament diameter and are characteristically found to have high strength, modulus and density [21, 22]. Melting temperature of SiC is 2730°C. Figure 6 shows block diagram of steps involved in stir casting process for fabricating Al/SiC composites.

The vortex technique for the addition of particles to make a particulate metal matrix composite (MMC) has inclusion troubled. It is to be expected that the method would drag the oxide film down into the vortex, together with the heaps of particles supported on the film, so that the clumping of particles, now nicely and collectively packaged, wrapped in film, is probably unavoidable. The ‘clumping’ of particles observed in such MMCs survives even long periods of vigorous stirring [23]. Furthermore, the manufacture of aluminum alloy MMCs based on aluminum alloy containing SiC particles introduced under high vacuum was investigated. These authors found that under the hydrostatic tension produced by poor feeding conditions the SiC–matrix interface frequently decohered. This contrasted with the behavior of an Al-TiB₂ MMC in which the TiB₂ particles were created by a flux reaction and added to the matrix alloy without ever having been in contact with the air. These particles exhibited much better adhesion at the particle–matrix interface when subjected to tension. Relatively few pores were initiated when subjected to the hydrostatic tensile stress generated by the poor feeding [23].

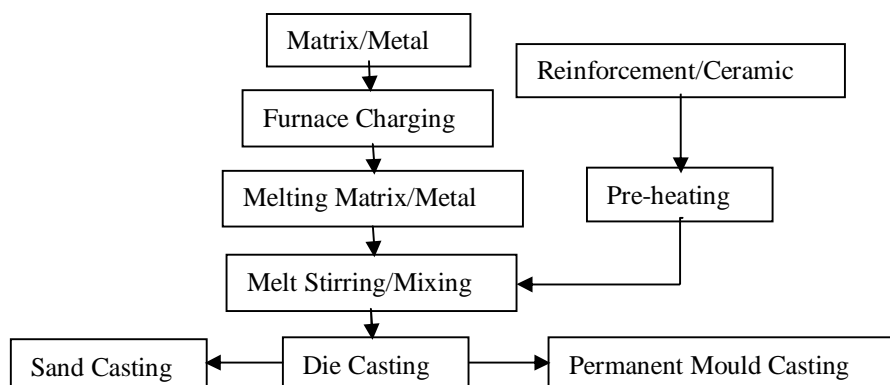


Fig. 6 Block diagram of steps involved in stir casting process

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Table 4 Comparative study of different processes to fabricate MMCs [19]

S.No.	Process	Shape	Size	Volume Fraction	Reinforcement Condition	Cost
1	Stir casting	wide range of shape	larger size up to 500 kg	up to 0.3	no damage	least expansive
2	Squeeze casting	limited by preform shape	up to 2cm height	up to 0.5	severe damage	moderate expansive
3	Spray casting	limited shape	large size	0.3-0.7	reinforcement damage	expansive
4	Powder metallurgy	wide range	restricted size		reinforcement fracture	expansive

VI. LITERATURE REVIEW

The results of the several investigations regarding manufacturing of aluminium metal matrix composites reinforced with silicon carbide particles and others ceramic materials by stir casting process are summarized in quite details. Hashim et al. [24] studied the technical difficulties associated with low cost stir casting technique used in the production of silicon carbide/aluminium alloy MMCs. They have been tried to attain a uniform distribution of reinforcement, good wettability between substances, and a low porosity material. It was observed that the composites produced by liquid metallurgy techniques show excellent bonding between the ceramic and the metal when reactive elements such as Mg, Ca, Ti, or Zr are added to induce wettability. The addition of Mg to molten aluminium to promote the wetting of alumina is particularly successful. And it has also been used extensively as an addition mediator to promote the wetting of different ceramic particles such as silicon carbide and mica. Al/SiC composites have been effectively fabricated by stir casting process at 680° C and 900° C pouring temperatures at stirring speed of 300 rpm [25]. The results have been declared that crystal size increases first and then decreases at 680° C and 900° C pouring temperatures and the maximum crystallite size was found at 30 wt. % SiC. Although, maximum and minimum crystallite sizes were determined to be practically 42 nm and 12 nm respectively, and corresponding to these, lattice strain as 0.0025 and 0.0055 correspondingly. Additionally, presence of segregation and agglomeration of SiC particles were perceived by SEM and XRD. Zhou and Xu [22] found that a two-step mixing method improves the wettability of the SiC particles and ensure a good particle distribution. Before mixing the SiC particles are to be preheated at 1100 °C for 1 to 3 hours to make their surfaces oxidized. SiC particles were perceived to act as substrates for heterogeneous nucleation of Si crystals in A356, Al6061-10% SiC. During manufacturing of Al6061/SiCp composite [26], it was observed that there is a loss of Mg content during stirring of MMCs fabrication and hence reduction in mechanical properties. The mechanical properties of MMCs after hot rolling were not significantly enhanced due to the presence of shrinkage cavities and particle cracking. Although, unreinforced alloys 6061 in rolled condition has high toughness and consequently, crack arrest capability.

Umanath and Selvamani [27] investigated the effect of stir casting by preparing Al6061-SiC-Al₂O₃ hybrid composites. It was attributed that the vortex method is one of the better known approach used to create a good distribution of the reinforcement material in the matrix. Good quality composites can be produced by this method by proper selection of the process parameters. Such as pouring temperature, stirring speed, preheating temperature of reinforcement, etc. The coating of an alumina to the blades of the stirrer is essential to prevent the migration of ferrous ions from the stirrer into the molten metal. The various factors to improve wettability between reinforcement and matrix interface have been deliberated by Barbara et al [28]. Good wettability of B₄C in aluminium (higher than that of SiC) can be found. This is attributed to the formation of a layer of liquid B₂O₃ on the B₄C particles. Due to its low melting point, B₂O₃ exists above 450° C as a liquid on the surface of B₄C. These enhances wettability through a liquid-liquid reaction. Distribution of SiC particulates in stir cast aluminium alloy metal matrix composites and its effect on mechanical properties were researched [29]. They were considered input parameters such as a stepped (3-step) cast LM6-SiCp metal matrix composites, 5, 7.5, 10, 12.5 by wt. %. They declared that hardness/micro hardness, tensile strength increase with SiC. Forgeability of stir cast MMCs was examined. Mechanical properties and forgeability of cast MMCs are different at different step of castings. Morphology indicates distribution of SiCp is not uniform throughout casting and changes

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with thickness of casting. High strength aluminium-silicon carbide composites have been fabricated through stir casting process by Alam and Ansari [30]. They were investigated that strength of the Al/SiC composites enhanced with the incorporation of SiC reinforcement up to 30 wt. % and then decreases after this percentage of reinforcement. Furthermore, pouring temperatures have less effects on strength of composites as compared to the reinforcement. Their result also illustrated that porosity increased by about 1% [31].

Vanarotti et al. [32] studies synthesis and characterization of aluminium alloy A356 and silicon carbide MMCs with fixed SiC content in the alloy at 5 weight % and 10 weight %. They predicted uniform distribution of SiC in the alloy. Their results declared that hardness improved by 28% and an enhancement in tensile strength. Naher et al [33] investigated computational and experimental analysis of particulate distribution during Al-SiC MMC fabrication. They have been considered various input parameters such as processing periods (up to 65 min), stirring speeds (50–500rpm), reinforcement sizes (13–100 μm), and two different viscosity levels (1 and 300 mPas). Computer simulations, analogue fluid simulations, volume fraction of SiC at different locations within fluids were assessed by each method and compared. Stirring speed 200 rpm for lower viscosity fluid, 300 rpm for higher viscosity fluid depicted best in order to produce uniform distributions of SiC. For uniform SiC distribution in lower viscosity system, stirring periods found to range from 14 to 170 s and for higher viscosity from 540 to more than 3920 s. Optimization of stirring parameters through numerical simulation for the preparation of AMCs by stir casting process have been sought [34]. Fluid flow in stirred crucible during stir casting are simulated using finite element method. Effects of stirring process parameters such as blade angle, rotating speed, diameter of impeller, stirrer geometry on flowing characteristics of molten matrix were investigated to achieve effective flow pattern, uniformly disperse ceramic particles in matrix. Simulation results showed that process parameters have significant effects on flow behaviour of fluid in stirred crucible for uniform particle distribution by stir casting process. Optimum processing conditions for uniform distribution of particle are multistage stirrer with speed around 1000 rpm, blade angle 30 degree to stirrer axis, d/D value of 0.55.

Semisolid processing of Al/ β -SiC composites fabricated by mechanical stir casting (MSC) and high pressure die casting have been studied by Martinez and Valencia [35]. Composites manufactured by MSC found ultimate tensile strength and yield strength enhanced by 73% and 92% respectively. Though elongation of composite deteriorated by 44% because of reinforcement effect. AMCs with SiCp were manufactured through two step-mixing [36]. They were deliberated several input parameters such as SiC (320-grit) wt. fraction of 5%, 10%, 15%, 20%, 25%, 30%, stirring speed 600 rpm, pouring temperature 760 ± 10^0 C, stirring time 10 min. They were described the best results at 25% wt SiC as maximum hardness 45.5 BHN and maximum impact strength 36 Nm. Shehata et al. [37] studied equal channel angular pressing (ECAP) of Al-SiC composites fabricated by stir casting by taking SiC (50 μm), 5%, 10% by wt., pouring temperature 750^0C . They found low porosity levels < 3.6%, ECAP technique reduced SiC particles from 50 to 3 μm , yield strength twice, maximum 245 MPa after 8 passes, four times, hardness increased 1.5 times after one ECAP pass, maximum 71 HRB after 8 passes, 3.5 times. Wear properties of Al-SiC composites with SiC (320 grit size) by wt. 5%, 10%, 20% , 25% have been explored [38]. They examined minimum wear at 20% SiC, wear rate varies linearly with normal load, average coefficient of friction decreases linearly with increasing normal load and wt. fraction of SiC. For the production of MMCs, processing parameters such as stirring speed 200 to 500 rpm, 30 micron meter sized SiC, liquid and semisolid processes, 10% SiC were investigated by Naher et al. [39]. Liquidus condition found poor incorporation of SiC while semi-solid condition found uniform distribution of SiC, quicker solidification. Subsequently, cessation of mixing improve homogeneity of SiC distribution significantly, matrix phase size and morphology.

[40] Studied thermal, hardness and microstructural characterization of Al-Si-SiCp composites. They considered Si 1, 2, 3, 4% by wt. and SiC 0.5, 1, 1.5, 2% by wt. and annealing heat treatment process. They anticipated differential thermal analysis (DTA), hardness test and microstructural analysis. Two new milling models based on the size of reinforcement materials were developed [41]. Al₂O₃-B₄C nanostructured composite powders containing 0, 5, 10 and 20 weight percentage (wt. %) of B₄C particles with two different particle sizes ($d_{50} = 49 \mu\text{m}$ and $d_{50} = 5 \mu\text{m}$) as reinforcement material were produced by mechanical milling. The milling was carried out in a planetary ball mill for 10 h with a rotating speed of 400 rpm and ball to powder ratio of 10:1. They revealed that milling time as well as reinforcement size and reinforcement content were strongly affecting the particle size and microhardness of composite powders. The results disclosed that the coarse B₄C particles accelerated the milling process due to cutting effect, while fine B₄C particles accelerated the milling process due to embedding effect. Al-A206/5 vol. % alumina_p cast composites were manufactured by semi-solid and liquid states, in two different forms: as received alumina particles and pre-synthesized composite reinforcement prepared via milling of alumina with Al and Mg powders by Tahamtan et al. [42]. The effects

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of powder addition method, reinforcing particle size and interface bonding strength on tensile properties and fracture behavior of Al-A206/5 vol. % alumina_p composites were then examined. Results declared that manufacture of Al-A206/ alumina_p composites in the semi-solid state leads to substantial enhancement in tensile properties. They have been predicted that maximum porosity of 14% when pre-synthesized 100 nanometer alumina particles processed at liquid state while minimum porosity 2% when pre-synthesized 100 nanometer alumina particles processed at semi-solid state.

The effect of graphite particles addition (from 0% to 12% in a step of 3%) on the microstructure of Al6082 metal matrix composites fabricated by conventional stir casting process have been deliberated [43]. The result of the microstructural examination disclosed that a non-uniform distribution of graphite particles takes place at all weight percentages of graphite reinforcement. An experimental research on the wear behavior of aluminium alloy LM 25 and its composites prepared by stir casting process reinforced with 7.5% SiCp 2.5% TiO₂ and 2.5% SiCp 7.5% TiO₂ is carried out to establish which component is having more effect on the fabricated composites [44]. The experiments are conducted at a constant sliding velocity of 1.04 m/s and a sliding distance of 628m over various loads of 3, 4 and 5 kg. The results were showed that the reinforcement SiC and TiO₂ have enhanced the wear resisting property of LM 25 alloy composites. The results also indicated that the three-fourth volume fraction of the TiO₂ in a 10% volume fraction of reinforcement has better wear and frictional property than the three-fourth volume fraction of SiC. Although, coefficient of friction declined with the increasing loads and particle reinforcements. Furthermore, microstructure examination disclosed that SiC and TiO₂ particulate are homogeneously distributed in the matrix. The wear surfaces are observed by SEM which indicated an abrasive wear mechanism due to hard ceramic particles exposed on the worn surface. Yar et al. [45] have been investigated aluminum alloy (A356.1) matrix composites reinforced with 1.5, 2.5 and 5 vol. % nanoparticle MgO via stir casting process at many casting temperatures, viz. 800, 850 and 950° C. Optimum amount of reinforcement and casting temperature were determined by evaluating the density, microstructure and mechanical properties of composites. The results disclosed that the composites containing 1.5 vol. % reinforcement particle manufactured at 850° C have uniform microstructure as well as enhanced mechanical properties. Md. T. Alam et al. [46] have been investigated various mechanical properties and morphology of Al/SiC nanocomposites processed through stir casting process by taking various processing parameters. They were resulted that strength, hardness increase while toughness, elongation and forgeability decrease with the incorporation of SiC nanoparticles.

VII. CONCLUSION

The exhaustive literature survey presented reveals that extensive works have been reported to improve properties of aluminium metal matrix composites reinforced with silicon carbide and others ceramic materials. However, aluminium matrix nanocomposites by double stir casting process is yet to be considered. Although, studies have been carried out worldwide on AMCs through stir casting process. Moreover, numerous benefits of stir casting process over other composite fabrication techniques are described in this review paper. From several current researches, it is clear that oxides and slag formation, segregation and agglomeration of the constituents, clustering of reinforcement particles, and wettability of reinforcement particles in molten aluminium are the major disquiet in the manufacture of aluminium metal matrix composites through stir casting process. In addition, the works openly point out that tribological behaviour, mechanical properties, corrosion performance of stir cast aluminium metal matrix composites be influenced by a number of factors like production methods, volume fraction, shape and size of reinforcement particles, the distribution of reinforcement particles, properties of ingredients and many more. Also, heat treatment process of aluminium matrix nanocomposites has not been adequately addressed so far. A further study in this respect is needed particularly to determine and compare the properties of AMCs in untreated and heat treated conditions to improve the quality of the stir cast products.

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