

Research Article

Review on Effect of Silicon Carbide (SiC) on Stir Cast Aluminium Metal Matrix Composites

Jayashree P.K.^{*a}, Gowri Shankar M.C.^a, Achutha Kini^a, Sharma S.S.^a, and Raviraj Shetty^a^a Department of Mechanical & Manufacturing Engineering , Manipal Institute of Technology, Manipal, Manipal University, Karnataka, India

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Abstract

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 behavior of these composites were explored to a maximum extent and were reported by number of research scholars for the past 25 years. In the present study, based on the literature review, the effect of Silicon carbide on Stir cast Aluminium Metal Matrix Composites is discussed. Aluminium Metal Matrix Composites with Silicon carbide particle reinforcements are finding increased applications in aerospace, automobile, space, underwater, and transportation applications. This is mainly due to improved mechanical and tribological properties like strong, stiff, abrasion and impact resistant, and is not easily corroded. In the present scenario, a review of different researchers have been made to consolidate some of the aspects of mechanical and wear behavior of Aluminium Metal Matrix Composites reinforced with Silicon carbide particles in both untreated and precipitation hardened condition.

Key words: Aluminium alloy, Metal Matrix Composites, Silicon Carbide, Stir casting, Precipitation hardening

1. Introduction

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, and transportation applications. Aluminum based matrix composites remain the most explored metal matrix material for the development of MMCs (Surappa *et al*, 2003). When these composites reinforced with silicon carbide (SiCp) particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding non-reinforced matrix alloy systems. Among all materials, composite materials have the potential to replace widely used steel and aluminum, and many times with better performance. In AMCs one of the constituent is aluminium alloy, is termed as matrix phase. The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al₂O₃. As the addition of discontinuous reinforcement (Silicon Carbide particles) increases in aluminium matrix materials, the ductility and the fracture toughness of the composite decline so that structural applications in many engineering situations are limited. In order to improve the

mechanical properties, it is very important to understand the strengthening mechanism, including the study of interfacial structure, dislocation generation and precipitation during the aging process (D.L. McDanel *et al* 1985). It has been noted that the dislocation generation is due to the large difference between the coefficients of thermal expansion of the tungsten fibres and copper matrix, i.e. the coefficient of thermal expansion of copper matrix is about four times that of the tungsten fibres. Consequently, it has been assumed that the high dislocation density in SiC-reinforced aluminium alloy matrix composite was also caused by the difference between the thermal expansion coefficients. The coefficient of thermal expansion of aluminium alloy is about ten times that of SiC (K.K. Chawla *et al* 1972). The enhanced strength could be accounted for by a high dislocation density (Warren H. *et al* 2004).

2. Al6061-alloy Selection

The families of aluminium alloys are represented by 1XXX, 2XXX, 3XXX upto 8XXX. The 1xxx series designation concerns unalloyed aluminium materials which are distinguished according to their degree of purity. The 8xxx series designations are for miscellaneous types of alloys (i.e. Fe alloys) which cannot be grouped in the other families. The 2xxx, 6xxx and 7xxx series are heat-treatable alloys, which gain their strength by alloying but make use of precipitation hardening as the main

*Corresponding author: Jayashree P.K

mechanism. The first digit gives basic information about the principal alloying elements as shown in Table 1. The designation system also says something about the hardening of the alloys belonging to a family (R. Gitter 2008). Table 2 shows the nominal composition Wt% of Al-6061 matrix material (J.Jenix Rino, *et al* (2012) and K.M. Shorowordi *et al* (2013)). The 1xxx, 3xxx and 5xxx series are so called non-heat-treatable alloys; they gain their strength by alloying (e.g. increasing content of Mg) and work hardening. Among them Al6061 alloy is highly corrosion resistant, extricable in nature and exhibits moderate strength. It finds vast applications in the fields of construction, automotive and marine fields. They have been studied extensively because of their technological importance and their exceptional increase in strength obtained by precipitation hardening.

Table 1: Standard terminology, with key alloying elements for structural application

Alloy Designation	Detail
1XXX	99% Pure Aluminium
2XXX	Cu containing alloy
3XXX	Mn containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Mg and Si containing alloy
7XXX	Zn containing alloy
8XXX	Other alloys

Table 2 Chemical composition of Al6061 alloy

Element	Si	Mg	Cu	Cr	Fe	Ti	Zn	Mn	Al	Others
% Wt	0.4 - 0.8	0.8 - 1.20	0.15 - 0.40	0.04 - 0.35	0.70 Max	0.15 Max	0.25 Max	0.15	Rest	0.15 Max

2.1 Silicon carbide (SiC)

SiC can be used as reinforcement in the form of particulates, whiskers or fibers to improve the properties of the composite. When embedded in metal matrix composites SiC certainly improves the overall strength of the composite along with corrosion and wear resistance. Aluminum MMCs reinforced with SiC particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding un-reinforced matrix alloy systems. Silicon carbide as such, because of its high hardness, has got a number of applications such as

in cutting tools, jewellery, automobile parts, electronic circuits, structural materials, nuclear fuel particles, etc. For these reasons SiC-particulate-reinforced aluminium composites have found many applications such as brake discs, bicycle frames, aerospace and automotive industry (A.K. Vasudevan *et al* 1995 and B. Roebuck 1987).

3.0 Stir-casting or Compo casting

According to the type of reinforcement, the fabrication techniques can vary considerably. From the contributions of several researchers, some of the techniques for the development of these composites are stir casting/ Compocasting (Y.H. Seo *et al* 1999), powder metallurgy (X. Yunsheng *et al* 1998), spray atomization and co-deposition (C.G. Kang *et al* 1997), plasma spraying (Y.H. Seo *et al* 1995) and squeeze-casting (S. Zhang *et al* 1998). The above processes are most important of which, liquid metallurgy technique has been explored much in these days. This involves incorporation of ceramic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. Ceramic particles and ingot-grade aluminum are mixed and melted. The melt is stirred slightly above the liquidus temperature (600–700°C). Stir casting offers better matrix-particle bonding due to stirring action of particles into the melts shown in Fig 1. The recent research studies reported that the homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, and temperature of molten metal, preheating temperature of mould and uniform feed rate of particles. Disadvantages that may occur if process parameters are not adequately controlled include the fact that non-homogeneous particle distribution results in sedimentation and segregation (Z. Zhang *et al* 1994 and V.P. Mahesh *et al* 2011).

3.1 Stir casting procedure for Al6061/SiC MMCs

During processing of SiC particle-reinforced aluminum matrix composites, the particles are preheated at 600–800° C for 2 h in order to remove the volatile substances and to maintain the particle temperature closer to melt temperature of 750° C. Also, in SiC particles preheating leads to the artificial oxidation of the particle surface forming SiO₂ layer. This SiO₂ layer helps in improving the wettability of the particle. The Al6061 billets were charged into the furnace and melting was allowed to progress until a uniform temperature of 750° C (which is above the liquidus temperature) was attained, subsequently degassed by passing hexachloroethane (C₂Cl₆) solid degasser.

The melt was then allowed to cool to 600° C (slightly below the liquidus temperature) to a semi-solid state. At

this stage, the silicon carbide mixture was added to the melt and manual stirring of the slurry was performed for 20 minutes. An external temperature probe was utilized in all cases to monitor the temperature readings of the furnace. After the manual stirring, the composite slurry was reheated and maintained at a temperature of $750^{\circ}\text{C} \pm 10^{\circ}\text{C}$ (above the liquidus temperature) and then mechanical stirring was performed. The stirring operation was performed for 10 minutes at an average stirring rate of 400rpm. Casting was then performed on prepared sand moulds at a pouring temperature of 720°C . After effective degassing the molten metal was then poured into permanent moulds for casting (B. Veeresh Kumar et al 2010).

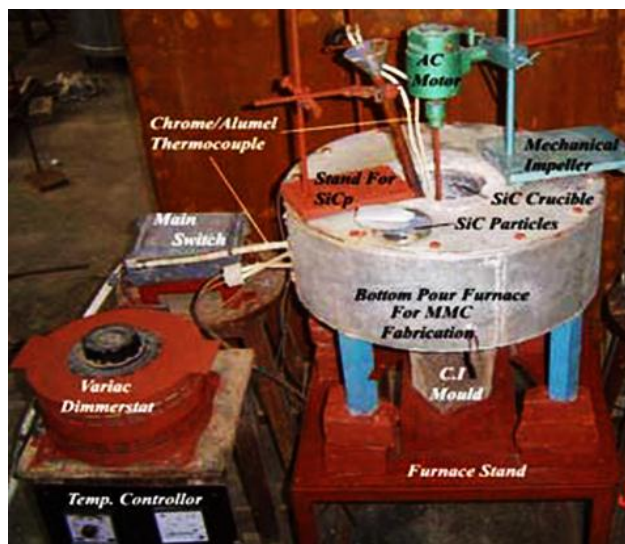


Fig 1 Metal Matrix Composites by casting route through Stir Casting method

3.2 Factors influencing preparation of MMC's

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, the wettability or bonding between these substances should be optimized and the porosity levels need to be minimized (M.K. Surappa 1997).

The distribution of reinforcement materials

One of the problems encountered in metal matrix composite processing is the settling of the reinforcement particles during melting or during casting. This arises as a result of density differences between the reinforcement particles and the matrix alloy melt. The reinforcement distribution is influenced during several stages including (a) distribution in the liquid as a result of mixing, (b) distribution in the liquid after mixing, but before solidification, and (c) redistribution as a result of solidification. Proper dispersion of the particles in a matrix is also affected by pouring rate, pouring temperature and gating systems. The method of the introduction of particles

into the matrix melt is one of the most important aspects of the casting process (L. Hashim, et al 1999). It helps in dispersing the reinforcement materials in the melt.

The vortex method is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy. In this method, after the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The stirring is continued for a few minutes before the slurry is cast.

Wettability between reinforcement material and matrix alloy

Wettability can be defined as the ability of a liquid to spread on a solid surface. It also describes the extent of intimate contact between a liquid and a solid. Successful incorporation of solid ceramic particles into casting requires that the melt should wet the solid ceramic phase. The problem of the wetting of the ceramic by molten metal is one of surface chemistry and surface tension.

The chemistry of the particle surface, including any contamination, or oxidation, the melt surface and oxide layer must be considered. The basic means used to improve wetting are (a) increasing the surface energies of the solid, (b) decreasing the surface tension of the liquid matrix alloy, and (c) decreasing the solid-liquid interfacial energy at the particles-matrix interface. The bonding force between the liquid and solid phases can be expressed in terms of contact angle referred to in the Young-Dupre equation. The magnitude of the contact angles (θ) in this equation, as shown in Fig. 3, describes the wettability, i.e. (a) $\theta = 0^{\circ}$, perfect wettability, (b) $\theta = 180^{\circ}$, no wetting, and (c) $0^{\circ} < \theta < 180^{\circ}$, partial wetting. In general, the surface of non-metallic particles is not wetted by the metallic metal, regardless of the cleaning techniques carried out. Wetting has been achieved by coating with a wettable metal. Metal coating on ceramic particles increases the overall surface energy of the solid, and improves wetting by enhancing the contacting interface to metal-metal instead of metal-ceramic. The addition of certain alloying elements can modify the matrix metal alloy by producing a transient layer between the particles and the liquid matrix. This transient layer has a low wetting angle, decreases the surface tension of the liquid,

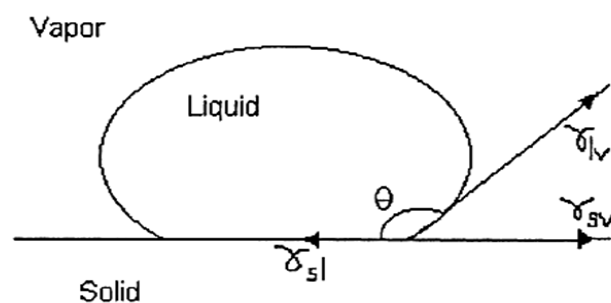


Fig. 2 Schematic diagram showing the contact angle that describes wettability

and surrounds the particles with a structure that is similar to both the particle and the matrix alloy. 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.

Porosity in cast metal matrix composites

The porosity of composite results primarily from air bubbles entering the slurry either independently or as an air envelope to the reinforcement particles. In general, porosity arises from three causes: (a) gas entrapment during mixing, (b) hydrogen evolution, and (c) shrinkage during solidification. The volume fraction of porosity, and its size and distribution in a cast metal matrix composite play an important role in controlling the material's mechanical properties. There are several strategies that have been used to minimize porosity, such as (a) compocasting in vacuum, (b) extensive inert gas bubbling through the melt, (c) casting under pressure, or (d) compressing, and extruding, or (e) rolling the materials after casting to close the pores. This kind of a composite defect can be detrimental also to the corrosion resistance of the casting. Porosity levels must, therefore, be kept to a minimum.

3.3 Precipitation hardening

Precipitation hardening is a heat treatment technique used to increase the yield strength of malleable materials, including most structural alloys of aluminium, magnesium, nickel, copper and titanium, and some stainless steels (Sidney H. Avner, 1986). It relies on changes in solid solubility with temperature to produce fine particles of an intermetallic phase, which resists the movement of dislocations, or defects in a crystal lattice. Since dislocations are often the dominant carriers of plasticity, this serves to harden the material. The impurities play the same role as the particle substances in particle-reinforced composite materials. Unlike ordinary tempering, alloys must be kept at elevated temperature for hours to allow precipitation to take place. This time delay is called aging. The precipitation-hardening process involves two basic steps: Solution treatment, and Aging. Figure-3 shows the sequence of precipitation hardening process.

Solution treatment, or Solutionizing, is the first step in the precipitation-hardening process where the alloy is heated above the solvus temperature (T_0) and soaked there until a homogeneous single phase solid solution forms. The intermetallics (θ) present at room temperature (T_1) are dissolved in this step and any segregation present in the original alloy is reduced. Now this single phase solid solution is quenched from this temperature to room temperature to form a super saturated solid solution which contains excess of solute concentration. This super saturated solid solution maintains the structure of solid solution formed at soaking temperature. The atoms do not

have time to diffuse to potential nucleation sites and thus θ precipitates do not form at room temperatures.

Aging is the second step where the supersaturated solid solution is reheated below the solvus temperature (T_2) to produce a finely dispersed precipitate as shown in Figure-3. Atoms diffuse only to short distances at this aging temperature. Because the supersaturated solid solution is not stable, the extra solute atoms diffuse to numerous nucleation sites and precipitates grow. The formation of a finely dispersed precipitate, in the alloy is the objective of the precipitation-hardening process.

For the 6061Al-alloy composites natural aging or artificial aging may be done. In natural aging for diffusion of solute atoms enough time will be provided at room temperature. However, since diffusion is hampered by lower temperature, it may take several years for enough diffusion to form the intermetallic precipitates and adequately enhance the physical properties of the alloy. In artificial aging, the intermediate aging temperature is about 200°C , by holding several specimens for different times at this aging temperature, the effect of aging time on the mechanical properties of the material can be determined. The maximum hardness and strength develops when alloy is aged at a suitable temperature which ranges between 120°C and 200°C .

4. Literature review

4.1 Preparation of composites by Stir casting Methods

The results of the several investigations regarding manufacturing of metal matrix composites reinforced with Silicon Carbide particles by stir casting technique can be summarized as follows:

(J Hashim *et al* 1999) studied the technical difficulties associated with low cost stir casting technique used in the production of silicon carbide/aluminium alloy MMCs 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 widely as an addition agent to promote the wetting of different ceramic particles, such as silicon carbide and mica. Heating silicon carbide particles to 900°C , for example, assists in removing surface impurities and in the desorption of gases, and alters the surface composition by forming an oxide layer on the surface. It has been recommended that a turbine stirrer should be placed so as to have 35% liquid below and 65% liquid above to reduce porosity level. During stir casting, stirring helps in two ways: (a) transferring particles into the liquid metal as the pressure difference between the inner and the outer surface of the melt sucks the particles into the liquid and (b) maintaining the particles in a state of suspension. The vortex method is one of the better known approaches used to create and maintain a good

distribution of the reinforcement material in the matrix alloy. (W Zhou *et al* 1997) 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 and SiC particles were observed to act as substrates for heterogeneous nucleation of Si crystals in A356, Al6061-10%SiC. (Vikram Singh *et al* 2004) reported that during manufacturing of Al6061/SiC_p composite, it was observed that, there is a loss of Mg content during stirring of MMC fabrication and hence decrease in mechanical properties. The mechanical properties of metal matrix composites after hot rolling were not significantly improved due to the presence of shrinkage cavities and particle cracking, whereas, unreinforced alloys 6061 in rolled condition has high toughness and therefore, crack arrest capability. (Umanath K *et al* 2011) investigated the effect of stir casting by preparing Al6061-SiC-Al₂O₃ Hybrid composites. It was observed that, the vortex method is one of the better known approaches 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. (Barbara Previtali *et al* 2008) studied the various factors to improve wettability between reinforcement and matrix interface.

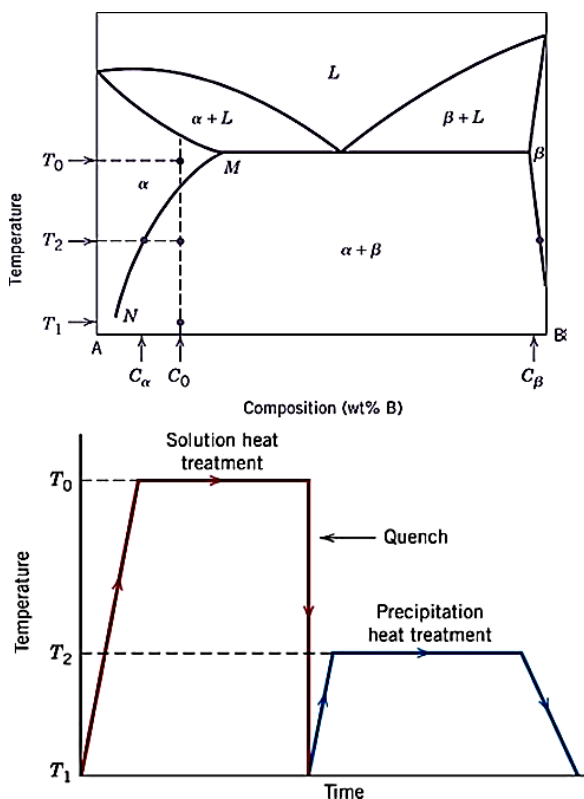


Fig 3 Phase diagram of the precipitation hardenable alloy and sequence of precipitation hardening process

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 and enhances wettability through a liquid-liquid reaction. The addition of small quantities of Mg (up to 1%) to molten aluminium, which promotes wetting, can be found particularly successful (Hashim J, Looney *et al* 2001). Transition from non-wetting to wetting occurs in SiC at high temperatures because of dissociation of surface oxides. Heat treatment of the particles before dispersion into the molten aluminium aids their transfer by causing oxide formation (Urena A *et al* 2004).

4.2 Mechanical and Physical properties

The resistance to indentation or scratch is termed as hardness. Among various instruments for measurement of hardness, Brinell's, Rockwell's and Vicker's hardness testers are significant. Theoretically, the rule of mixture of the type $H_c = V_r H_r + V_m H_m$ (suffixes 'c', 'r', and 'm' stand for composite, reinforcement and matrix respectively and v and H stand for volume fraction and hardness respectively) for composites (S.C. Sharma *et al* 2001)

Wear is the progressive loss of material due to relative motion between a surface and the contacting substance or substances (Peter J *et al* 1997). The wear damage may be in the form of micro-cracks or localized plastic deformation (U. Sanchez-Santana *et al* 2006). Wear may be classified as adhesive wear, abrasion wear, surface fatigue wear and corrosive wear. Commonly available test apparatus for measuring sliding friction and wear characteristics in which, sample geometry, applied load, sliding velocity, temperature and humidity can be controlled are Pin-on-Disc, Pin-on-Flat, Pin-on-Cylinder, Thrust washers, Pin-into-Bushing, Rectangular Flats on a Rotating Cylinder and such others.

Tensile properties dictate how the material will react to forces being applied in tension. Uniaxial tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate strength, yield strength, % elongation, % area of reduction and Young's modulus. The tensile testing is carried out by applying longitudinal or axial load at a specific extension rate to a standard tensile specimen with known dimensions (gauge length and cross sectional area perpendicular to the load direction) till failure. In general, the particle reinforced Al-MMCs are found to have higher elastic modulus, tensile and fatigue strength over monolithic alloys (P.M. Singh *et al* 1993). Increase in elastic modulus and strength of the composites are reasoned to the strong interface that transfers and distributes the load from the matrix to the reinforcement (Rang Chen *et al* 1997).

The density measurements were carried out to determine the porosity levels of the samples. The percent porosity, and its size and distribution in cast metal matrix composites play an important role in controlling the mechanical properties. Porosity in composites results primarily from air bubbles entering the slurry during the stirring period or as air envelopes to the reinforcing parti-

-cles (Ray, S *et al* 1993).

4.2.1 Untreated/As-cast condition

The results of the several investigations regarding the Mechanical and Physical properties in untreated condition of Silicon Carbide (SiC) particles reinforced with Al6061 and other aluminum alloys can be summarized as follows:

Hardness:- (B. Deuis *et al* 1996) concluded that the increase in the hardness of the composites containing hard ceramic particles not only depends on the size of reinforcement but also on the structure of the composite and good interface bonding. The particulate reinforcements such as SiC, B₄C, Al₂O₃ and aluminide. (Y Sahin *et al* 2003) investigated that, the hardness of the Al2024-SiC composites increased more or less linearly with the volume fraction of particulates in the alloy matrix due to the increasing ceramic phase of the matrix alloy. (F. M. Husking *et al* 1982 and Debdas Roy *et al* 2005) are generally referred to impart higher hardness. Moreover, these composites exhibit excellent heat and wear resistances due to the superior hardness and heat resistance characteristics of the particles that are dispersed in the matrix (Alpas AT *et al* 1992, Kulkarni MD, *et al* 1996 and Kim CK *et al* 1984). (Veeresh Kumar *et al* 2010) in the studies of Al6061-SiC, Al7075-Al₂O₃ composites concluded that higher filler content exhibits higher hardness and it can be observed that the hardness of the Al7075-Al₂O₃ composite are higher than that of the composite of Al6061-SiC and is to the fact that the matrix Al7075 and Al₂O₃ possess higher hardness (J.M. Wu *et al* 2000).

Wear resistance:- (S.Y. Yu *et al* 1997) demonstrated the effects of applied load and temperature on the dry sliding wear behavior of Al6061-SiC composites and concluded that the wear rate decreases with increased applied load. (Liang Y. N. *et al* 1995) reported that the MMCs containing SiC particles exhibit improved wear resistance. (Rupa Dasgupta *et al* 2005) reported the improvement in the hardness, mechanical and sliding wear resistance properties attained as a result of heat treatment and forming composites by adding 15 wt.% of SiC. (Ames and Alpas, *et al* 1995) have studied the tribological testing of hybrid composites with a base of aluminum alloy A356 reinforced with 20 % SiC and 3 to 10 % Gr. The tribological tests are done on tribometer with block on ring contact. The wear rate of hybrid composites is significantly lower than the wear rate of the base material without reinforcements, especially at low normal loads. (A.Wang and H.J.Rack, *et al* 1991) reported that the steady state wear rate of 7091Al matrix composite is generally independent of reinforcement geometry (particulate versus whisker) and orientation (perpendicular versus parallel) with the exception of wear at 3.6m/s where the parallelly oriented SiC composite was found to be superior. (Yoshiro Iwai *et al* 1995) found that the initial sliding distance require to achieve mild wear decreased with increasing volume fraction and also severe wear rate decrease linearly with volume fraction. (Alpas and Zhang *et al* 1994) while investigating the wear of particle

reinforced Metal Matrix Composites (MMC) under different applied load conditions identified three different wear regimes. At low load (regime I), the particles support the applied load in which the wear resistance of MMCs are in the order of magnitude better than Al-alloy. At regime II, wear rates of MMCs and Al-alloy were similar. At high load and transition to severe wear (regime III), the surface temperature exceeded the critical value. (D.P.Mondal, *et al* 1998) opinion was that the applied load affects the wear rate of alloy and composites significantly and is the most dominating factor controlling the wear behavior. The cumulative volume loss increases with increasing applied normal load and the contact surface temperature increases as the applied load increases. (Kowk and Lim, *et al* 1999) suggested that massive wear occurs if the particles are smaller than the threshold value at higher speeds. (Basavarajappa S *et al* 2007) stated that the microstructural characteristics, applied load, sliding speed and sliding distance affect the dry sliding wear and friction of MMCs. However, they conclude that, at higher normal loads (60N), severe wear and silicon carbide particles cracking and seizure of the composites occurs during dry sliding. In addition to this they have studied the tribological behaviour of hybrid composites with aluminum base Al2219 reinforced by SiC and graphite. They studied the tribological properties of hybrid composites with 5, 10 and 15 % SiC and 3 % Gr obtained with process of liquid metallurgy. The tribological tests show that wear decreases with increasing SiC content in the hybrid composite. With increasing sliding speed and normal load, wear rate of composites is growing. (Veeresh kumar G.B *et al* 2011) reported that, wear resistance of the Al6061-SiC and Al7075-Al₂O₃ composites are higher but the SiC reinforcement contributed significantly in improving the wear resistance of Al6061-SiC composites, which exhibits superior mechanical and tribological properties.

Tensile strength:- (Nikhilesh Chawla *et al* 2001) studied the effect of Al2080 alloy reinforced with silicon carbide(SiC) metal matrix composites. It was observed that, increase in volume fraction, increases the elastic modulus, work hardening rate, macroscopic yield & tensile strengths, but coupled with lower ductility. (YU Xiao-dong *et al* 2007) studied the effect of Al5210 alloy reinforced with SiC metal matrix composites with a high volume fraction (50%) and various particle sizes of 10, 28, 40 & 63µm. It was concluded that, the bending strength of SiCp/5210 Al composite with a high volume fraction (50%) increases with decreasing particle size, but the fracture toughness of increases with the increasing particle size. (Zaklina Gnjjidic *et al* 2001) investigated that, the SiC particles increases the yield strength and elastic modulus, but decreases the ultimate compressive strength and ductility of the Al7XXX base alloy.(J.R. Gomes *et al* 2005) investigated that, among many ceramic materials, SiC and Al₂O₃ are widely in use, due to their favorable combination of density, hardness and cost effectiveness. When these reinforcements are combined with Al-MMCs, the resulting material exhibits significant increase in its elastic modulus, hardness, strength and wear

resistance. (B. Roebuck *et al* 1987) concluded that, aluminum metal matrix composites (MMC) reinforced with silicon carbide (SiCp) particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding non-reinforced matrix alloy systems. (Corbin S.F *et al* 1994) observed that, the reinforcing phase in the metal matrix composites bears a significant fraction of stress, as it is generally much stiffer than the matrix. Microplasticity in MMCs that takes place at fairly low stress has been attributed to stress concentrations in the matrix at the poles of the reinforcement and/or at sharp corners of the reinforcing particles. (Mahendra Boopathi, M *et al* 2013) noticed that, Increase in area fraction of reinforcement in matrix result in improved tensile strength, yield strength and hardness. The percentage rate of elongation of the hybrid MMCs is decreased significantly with the addition of SiC and fly ash into Al2024 alloy.

Density:-(Veeresh kumar G.B *et al* 2011) reported the density of Al6061-SiC composites increases with the incorporation of the hard ceramic reinforcement into the matrix material. The experimental and theoretical densities of the composites were found to be in line with each other. There is an increase in the density of the composites compared to the base matrix. (Umanath K *et al* 2011) observed that the porosity was more pronounced around Al₂O₃ particles than the location around SiC particles due to wetting behavior of Al alloy. It is also observed from the optical micrographs that the porosity of the specimens increase with increasing volume fractions of the particulate reinforcement. (G. B. Veeresh Kumar *et al* 2010) studied the effect of Al6061-SiC and Al7075 - Al₂O₃ Metal Matrix Composites having various particle size prepared by stir casting method. It was found that, liquid metallurgy techniques were successfully adopted & uniform distribution of the particles were observed during the preparation of Al6061-SiC and Al7075-Al₂O₃ composites. Silicon carbide and aluminium oxide reinforced particles significantly improves the density of the composites with increased percentage of filler content in the Composites. The Al7075- Al₂O₃ composites exhibits higher density than that of the Al6061-SiC and can be reasoned for the higher density values of Al₂O₃. (Kenneth K. *et al* 2012) found that, the low porosity level (≤ 1.6 % porosity) can be achieved by using borax additive and two-step stir casting technique resulted in the production of Al 6063/SiCp. (Y Sahin *et al* 2003) investigated the effect of Al2024 alloy reinforced with silicon carbide (SiC) metal matrix composites of various particle sizes by molten metal mixing, because of cost effective method. Microstructural examination showed that the SiCp distributions were homogeneous and no interface porosity could be observed. Density of the composite increased almost linearly with the weight fraction of particles. It was found that, increasing amount of porosity with increasing the volume fraction, especially for low particle sizes of composites, because of the decrease in the inner-particles spacing. In other words, with increasing the volume fraction of MMCs during the

production stage, it is required that the longer particle addition time is combined with decreasing the particle size. The porosity level increased, since the contact surface area was increased. It is also reported by the early work (M. Zamzam *et al* 1993 and Kok M 1999). Further, (Miyajima *et al* 2003) reported that the density of Al2024-SiC particle composites is greater than that of Al2024-SiC whisker reinforced composites for the same amount of volume fraction. From the above the increase in density can be reasoned to the fact that the ceramic particles possess higher density. Further, the increased volume fraction of these particles contribute in increasing the density of the composites, also they have stated that the theoretical and measured density values of these composites match to each other. Additionally, the above discussions can be reasoned to the fact that the ceramic particles possess higher density. (YU Xiao-dong *et al* 2007) studied the effect of Al5210 alloy reinforced with SiC metal matrix composites with a high volume fraction and various particle size. It was concluded that, the bending strength of SiCp/5210 Al composite with a high volume fraction (50%) increases with decreasing particle size, but the fracture toughness of increases with the increasing particle size. (Mahendra Boopathi, M *et al* 2013) noticed that, since SiC and fly ash particles are having low density compared with aluminium., the experimental density values of the Al-SiC, Al-fly and Al-SiC-fly ash composites decreased linearly. The decrease in density of composites can be attributed to lower density of SiC, flyash and SiC-fly ash particles than that of the unreinforced Al. If the theoretical value closely matches with the experimental values indicates the better bonding between the interface between matrix and reinforcement. Similar results were observed by (Rao *et al.* 2010 and Gnjjidi *et al.* 2001). It is therefore, to improve the density again, apart from Al-SiC and Al-fly ash composites, the mixture of SiC and fly ash particles were added with aluminium. At higher concentration [(Al/(10%SiC+10%fly ash)], the density is about 54% improvement when compared pure aluminium (Rao, J.B *et al* 2010 and Gnjjidi, Z *et al* 2001).

4.2.2 Precipitation/Age hardened condition

The results of the several investigations regarding the Mechanical and Physical properties in Precipitation/Age hardened condition of Silicon Carbide (SiC) particles reinforced with Al6061 and other aluminum alloys can be summarized as follows:

(Rafiq A *et al* 2000) investigated the mechanical property in under aged, peak aged and overaged conditions of Al6063 alloy. The variation in time and temperature has improved the mechanical properties of Al alloy with reduction in ductility. Aging at 200° C for 6 hrs, has produced maximum fatigue fracture resistance. Scanning Electron Microscope(SEM) images investigated facet fatigue fracture surface, in under-aged alloys, whereas the peak-aged and over-aged alloy show a mixed mode of fracture, i.e. facet fracture with striation and also intergranular fracture. (J.J. Gracio *et al*, 2006) investigated the

artificial aging behaviour of Al6022-T4 alloy over a wide temperature. It was shown that 6022-T4 alloy can be substantially hardened through a short aging treatment at temperatures in excess of 200° C in a time interval of less than 2 h. The increase in hardness until the peak-aged condition and finally a decrease in hardness as the specimen becomes over-aged were observed. The under-aged and pre-peak-aged alloy exhibited a good combination of strength and strain hardening while the peak-aged alloy was characterized by maximum strength, although with a drastic reduction in strain hardening ability. The under-aged alloy view that its marginal reduction in strength is counter balanced by an increase in strain hardening ability. (G. Mrówka-Nowotnik *et al*, 2006) investigated the artificial aging behaviour of Al6082 alloy over a wide temperature for different intervals of time. It was found that Al6082 alloy aged at 190° C for 6 h exhibits the best combination of microstructure, mechanical properties and fracture toughness changes during artificial aging due to the precipitation strengthening process. (R.A. Siddiqui *et al*, 2008) investigated the effect of sea water corrosion, aging time, and aging temperature on the fatigue resistance property of Al6063 alloy over a wide temperature for different intervals of time. It was found that alloy aged for 7 to 9 hours and heat treated at temperatures between 160 and 200° C shows best precipitation hardening and has achieved a maximum fatigue resistance property. The results also showed that the brittle fracture pattern tend to occur with the increase in aging time and temperature. (F. Ozturk, *et al*, 2010) investigated that the solution treatment in the furnace at 500° C for 2 hrs, optimum temperature and duration for peak aged condition was found to be 200° C and 200 minutes to get maximum hardness and yield strength for Al6061 alloy. The presence of intermetallics, change the mechanical behaviour of material like ultimate tensile strength (321 Mpa, which is 73% higher than base alloy) and decreases the strain hardening capabilities. Overaged condition shows a reduction in the mechanical properties with an increase in aging time and temperature. (Majid Vaseghi *et al*, 2012) investigated the artificial aging behaviour of Al6082 alloy over a wide temperature for different intervals of time. It was found that for achieving the highest hardness value in solution treating, water quenching, and static ageing at 175° C for 3 h and then Equal Channel Angular Pressing (ECAP) at room temperature. According to this schedule, the hardness value increases from 86 HV (as-solution treatment) to 138 HV. (S. Rajasekaran *et al*, 2012) studied the effect of T4 (Natural aging) and T6 (Artificial aging) treatment of 6061Al-15 vol.% SiCp Composite having 23 µm particle size prepared by stir casting method. The one batch samples were solutionized at 558° C for 1 h, and then naturally aged at room temperature (T4 treatment) and other batch samples were artificially aged (T6 treatment) for various temperatures and time intervals. It was observed that T4 treatment of 6061Al 15-Vol.% SiCp, composite show that the peak hardness is reached after 500 hours of aging at room temperature. In T6 treatment, the composite is under aged at 140° C and 160° C. Peak

aging takes place at 180° C. Over aging takes place at above 200° C. Maximum peak hardness is obtained for the composite aged at 180° C for four hours. As the aging temperature increases in T6 treatment, the time to reach peak hardness decreases. (Kenneth K *et al*, 2012) investigated the production quality and age-hardening behaviour of Al 6063/SiC particulate composites having 30 µm size with different volume percentage using borax additive and stir casting process. The samples were solution-treated in the furnace at 560° C for 2 h, followed by water quenching. Thereafter, ageing was performed at temperatures of 180, 190 and 200° C for holding periods ranging 30 minutes to 360 minutes followed by water quenching. It was observed that, compared with the monolithic alloys, the aging response of the 6 and 9 vol.% SiC composites was generally poor, while the 12 vol.% SiC composites showed appreciable age-hardening response at temperatures of 180-190° C, as considerable increases in hardness were observed for both temperatures until peak hardness is attained. The distribution of the SiC particulates in the matrix of the Al6063 is fairly uniform with minimal particle clusters. (R. Ehsani *et al*, 2004) investigated the effect of aging behavior, tensile properties and fracture mechanism of Al6061/SiC composites having 16 and 22 µm size and 30 vol%, prepared by squeeze casting method. The samples were homogenized at 530° C for 3 hrs. Then, the solution heat treatment was employed for 2 h. at 557° C, followed by water quenching. Finally, all specimens were aged at 175° C at varying times. It was found that in comparison to the 6061 aluminum alloy, the precipitation kinetic was accelerated by adding the SiC reinforcement material and reduced the time for obtaining the maximum hardness by the aging heat treatment. Decreasing the SiC particle size (22 to 16 µm) improved the impact strength and stiffness, also the peak hardness was shifted to a shorter time. However, the ductility of the composite material was lower than that of the unreinforced specimen. (S. Ikeno *et al*, 2001) studied the effect of precipitation sequence in a SiC/Al6061 alloy composite material having 8 vol% and 1.1 µm particle size prepared by stir casting method. The base alloy, excess Si alloy and the composite material were solution-treated at 848 K for 1 hour, ice water quenched and subsequently the composites were aged at 150, 200, 250° C for various time intervals. It was found that, the hardness value after the solution treatment of the composite material is higher than that of the excess Si alloy & base alloy & the time to reach peak hardness was shorter than those of the other two alloys. The metastable phases in the composite material aged at 200° C suitable for best precipitation. (Zhou Zhao *et al*, 1991) investigated the effect of microstructure on the mechanical properties of an Al6061-SiC particle composite having 15% volume fraction & 3.5 & 5 µm particle sizes prepared by powder metallurgy process. The samples were solutionized at 790 K for 2 h, water quenched and subsequently the composites were aged at 425 K for 6 h. It was observed that, SiC-reinforced aluminium alloy 6061 composite has a higher strength and modulus and a lower ductility than the extruded aluminium alloy 6061. (S.O. Adeosun *et al*, 2009)

investigated the heat treatment behaviour of Al1200 alloy reinforced with silicon carbide (SiC) metal matrix composites at 430° C for 8 hours. This study has shown that addition of SiCp to wrought 1200 aluminum alloy can significantly increase its strength and elongation characteristics. Good ultimate tensile strength (UTS) of 157 MPa and 158 MPa can be obtained in as-cast and normalized samples with 40 vol % and 50 vol % of SiCp respectively, while the elongations are 13 and 15% respectively. (N.E. Bekheet *et al*, 2002) studied the effects of aging on the hardness and fatigue behavior of 2024Al alloy SiC composites having 5, 10 & 30 wt% and 49 µm particle size prepared by stir casting method. The samples were solution treated for 2 h at 500° C, then quenching in cold water followed by artificial aging at 170° C. It was observed that, the peak hardness of composites is slightly higher than that for 2024 Al alloy. The time required to attain the peak hardness is very much affected by the existence and amount of SiCp. The addition of SiCp and artificial aging greatly improves the fatigue limit of the composite. An approximately 100% increase in the fatigue limit has been achieved by adding 5 wt. % SiCp to the alloy. In addition, fatigue life could be increased by artificial aging at 170° C. (Wuhua Yuan *et al*, 2009) investigated the heat treatment processing, microstructures and mechanical properties of the SiCp/Al–Zn–Mg–Cu composites having 15–20 vol% and 5 µm particle size prepared by spray co-deposition method. The samples were solution treated at 490° C for 1h, and then aged at 120° C for 0–36 hours. It was observed that, the solution treated composites can reach the peak ageing at 120° C for 28 h and exhibit higher tensile strength. The X-Ray Diffraction (XRD) studies showed that, well-bonded strength in the interfaces between SiC and matrix alloy. (S.M.R. Mousavi Abarghouie *et al* 2010) studied the effect of aging behavior of a 2024 Al alloy-SiCp composite material having 20 vol% and 20 µm particle size prepared by stir casting method. The solution treatment of the composite sample and the unreinforced alloy was carried out at 495° C for 1, 2 and 3 h followed by aging at 191° C for various aging times between 1 and 10 h. It was observed that, the optimum soaking time and duration for solution treatment was found to be 2 h and 495°C. The peak hardness values increase with the decrease in aging temperature but with longer aging duration. The increase in the vol% of reinforcement in the composite increases the peak hardness values with reduced aging duration.

Conclusions

The exhaustive literature survey presented above reveals that extensive work has been reported to improve properties of Aluminium Metal Matrix Composites reinforced with Silicon carbide particle in both untreated and precipitation hardening condition. But, the studies carried out worldwide on welding of these composites and to conduct precipitation hardening treatment after welding of 6061Al-SiC composites has not been adequately addressed so far. A further study in this respect is needed particularly to determine and compare the properties of

welded joint in untreated and heat treated condition to improve the quality of welded joint. Present research work includes, behavior of SiC particles in Metal Matrix Composites during welding by Microstructure examination and improvement in mechanical and physical properties after precipitation hardening process.

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