CHAPTER 2

LITERATURE REVIEW

Aluminum matrix composites are attractive materials for structural applications in aircraft, automotive and military industries. High strength to weight ratio, environmental resistance, and high stiffness are the characteristics that encourage more researchers to develop their applications, with further improvement in the properties, particularly from the viewpoint of their ability to resist wear. It is the property of wear resistance, that lacks in them, though they possess many other advantages making them good structural materials. This chapter presents a detailed review on aluminum metal matrix composites, an in depth review on machinability studies of metal matrix composites, based on Taguchi methodology and grey relational analysis.

2.1 REVIEW OF ALUMINUM METAL MATRIX COMPOSITES

The researchers developed aluminum metal matrix composites in many commercial and industrial applications and the related valuable studies presented by the past researchers are reviewed.
This section reviews the related studies, as presented by past researchers, while developing aluminum matrix composites for many commercial and industrial applications.

It has been reported by Lim and Clegg (1997) about the development of a new process, referred to as the hybrid process which combines the advantages of both, the squeeze casting and investment casting processes for the production of Al-Si alloy metal-matrix composites. During the tensile testing of these MMC’s, they were found to have superior strength as compared to those MMCs produced by squeeze casting and investment casting individually.

Difficulties associated with attaining a uniform distribution of reinforcement, good wettability between substances, and low porosity for the production of silicone carbide aluminum alloy MMC’s, under low cost stir casting technique was studied by Hashim et al. (1999) It was found that Wettability of the reinforcement particles by the matrix alloy and especially reinforcement of ceramic particles were very difficult to wet by liquid metal.

Manna and Karthikeyan (1999) studied the properties of aluminum/SiC/fly ash hybrid metal matrix composites. The properties of these metal matrix composites like density, tensile strength, yield strength, elongation and hardness were examined. Their observations were that the density of such composites decreased, while hardness and the tensile strength increased, whereas the elongation of these composite decreased compared to unreinforced aluminum alloy.

Sliding friction and wear behaviour of aluminum alloy SiC particulate reinforced aluminum matrix composites under dry sliding wear conditions were examined by Venkataraman and Sundararajan (2000) Their
experimental observations indicated that, a strong correlation existed between the friction and wear of the mechanically mixed layers.

Compression tests on aluminum metal matrix composite reinforced with continuous unidirectional $\text{Al}_2\text{O}_3$ fibres were conducted by Gudena and Hall (2000) and the results indicated that the maximum stress of the composite increased with an increasing strain rate.

An observation regarding the sliding distance or the time for transition from severe to mild wear, in machining of fibre composites, was made by Iwai et al. (2000) it was concluded that this could be identified by two factors in Al-Si10Cu2Fe/alumina fibres composites, i) an abrupt and steep reduction in the frictional force, and ii) a change in the magnitude of displacement of pin specimen. The wear curves characterized by two distinct straight lines of different slopes, corresponded to severe and mild wear conditions. This shows that Fibre reinforcements effectively prevented the occurrence of severe wear and also aided in decreasing the time/distance required for transition from severe to mild wear. Aluminum alloy reinforced with alumina fibres could also result in an enhanced dry sliding wear resistance. Reinforcements basically inhibit plastic flow and restrict propagation of wear cracks. Both, the duration of the severe wear regime as well as the severe wear rate, decrease with an increase in the fibre volume fraction and above a certain value of volume fraction of reinforcements, composites would not exhibit severe wear.

6061Al reinforced with 10% SiC and natural graphite or electroless nickel coated graphite (0, 2, 5, 8, and 11 vol.%) made by P/M route was studied by Chu and Lin (2000). The wear results indicated that the use of the electroless nickel film significantly in lowered the wear rate of the component, although it did not produce an appreciable reduction in the wear
rate of composite with pure graphite. Similarly, friction coefficients were at relatively lower levels when electro less nickel coated graphite was used.

Self-lubricated 6061 aluminum /10%SiC / graphite hybrid composites containing 2, 5 and 8 vol. % of graphite synthesized by the semi-solid powder densification (SSPD) method, were studied by Chu and Lin (2000). Result of this wear test indicated that hardness and fracture energy decreased with an increase in the vol% of graphite, in the composite. Seizure occurred for aluminum alloy, while no seizure occurred for Al/SiC and Al/SiC/Gr composites. It was further found that the Friction coefficient decreased as the percentage of graphite addition increased, also the amount of graphite released during the wear increased with an increase in the %vol of graphite in the composite. As a result wear behaviour became more stable with an increase in the vol% of graphite

Yilmaz and Buytoz (2001) observed that wear rate of Al-0.86Mg0.46Si-0.15Cu/Alumina Composites 80 grade SiC abrasive Paper increased to 220 Grades SiC Abrasive paper. Aluminum composites with larger alumina size are more effective against abrasive wear those with smaller alumina size. In addition Particulate size and volume fraction decreased the effect of aging treatments. The Aging treatment on aluminum based MMC is more effective than graphite addition in improving the wear resistance.

A356 aluminum alloy reinforced with 10SiC/4%Graphite and 5%alumina/3%Graphite composites produced by stir casting technique were studied by Riahi and Alpas (2001). The results showed a mild wear regime range for loads (5–420 N) and sliding speeds (0.2–3.0 m/s) for both composites. They concluded that in the mild wear regime, the wear of graphitic composites was primarily controlled by the formation of the trio-layer as well as an oxidized surface layer on the contact surfaces for both types of composites.
For all the test conditions employed, Modi et al. (2001) observed that Al 2104 / alumina composites experienced lower material loss than the matrix alloy. The material loss was lower due to the work hardening of the matrix as well as the protrusion of the dispersoid phase. A higher degree of protection was offered to the matrix by the increase in the extent of protrusion of the dispersoid phase with sliding distance. The composites exhibited maximum wear loss with silicon carbide abrasive medium, while, minimum in the case of zircon, and intermediate in case of sand.

Wear resistances of Al6061 garnet composites are superior to that of unreinforced matrix alloy was an observation made by Sharma (2001). He observed that the wear resistance of composites increased with an increasing percentage of garnet (4-12 %). Further the average coefficient of friction of the Al6061 composite was found to be lower than that of the matrix alloy. It was also observed that the formation of a Mechanically Mixed Layer (MML) was responsible for the decrease in the wear-rate and the friction coefficient of the MMCs.

A356/SiC composite with Dual Particle Size (DPS) composite (47 and 120 m) showed better wear resistance than the composite having only small (47m) sized particles was an observation sighted by Bindumadhavan et al. (2001). It was deduced that in these DPS composites, larger SiC particles helped to carry a greater portion of the applied load, thereby reducing the load on the smaller SiC particles as well as on the base metal. It was further concluded that the larger SiC particles also helped in shielding the smaller SiC particles from the gouging action of the abrasive, thereby aiding the smaller particles to continue performing their wear resisting function.

Hashim et al. (2001) having chosen magnesium as a wetting agent, with continuous stirring, observed that, while slurry solidifying was
found to promote the wettability of SiC, the decreasing solidification time was also found to improve the wettability.

In 2001 ZaklinaGnjidic et al. (2001), ended up producing an Al alloy, reinforced with SiC particles composites by hot pressing and observed that by the addition of the SiC particles the yield strength and elastic modulus showed a marked increase.

Influence on the micro structure of the composite during liquid processing, by the settling of particles, was found out by Ourdjini et al. (2001). It was also observed that, at low melt temperatures, the volume fraction of particles did not affect the rate of settling, but with an increase in the melt temperature, the particles tended to settle when presented in lower volume fractions.

The correlation between macro hardness and tensile strength of particle reinforced metal matrix composites was studied by Shen and Chawla (2001). They observed that, the matrix strength appeared to play an important role in influencing the behaviour of the composite, under hardness and tensile loading conditions.

In 2001, Shen et al. (2001) indicated that there was no existing relationship between the hardness and tensile strength MMCs, they deduced that particle fracture greatly reduced the tensile strength, and that it did not significantly affect the deformation under indentation loading. It was further observed that, at very low matrix strengths, the composites exhibited similar tensile strengths but the hardness increased with an increasing particle concentration, and that the particle fracture caused by tensile testing was independent of the matrix strength.
An aluminum alloy MMC, by using a natural mineral namely sillimanite as a reinforcement through a solidification technique, was fabricated by Singh et al. (2001). The reinforcement particles were added to the matrix melt by creating a vortex with the help of a mechanical stirrer while the melt temperature was maintained between $750^\circ$C and $800^\circ$C. They observed that in the cast composite, sillimanite particles, uniformly distributed, exhibited good mechanical bonding with the matrix. Though the strength of the composite was marginally lower than that of the base alloy, it was observed that the hardness along with the wear resistance of the composite, were found to be significantly higher than that of the base alloy.

An increase in the abrasive wear rate of the composite and the matrix alloy with an increase in applied load and the abrasive size in Al-Si12Fe/SiC composites, was first observed by Singh et al. (2002). It was found that the wear resistance of the composite was superior to that of matrix alloy for finer size abrasives, while, on the contrary the trend reversed for coarser size abrasives. It was further found that the wear rate also decreased with an increase in sliding distance for composites due to work hardening of wear surface, clogging, attrition and shelling of abrasive particles.

The effect of dry sliding wear of SiC whisker, Al2O3 fibre and SiC particle reinforced with Al 2024 and ADC12 aluminum alloys, in the initial wear regime was studied by Miyajima and Iwai (2003), the fibres were larger in diameter and length than the whiskers, such that the fibres were more effective in decreasing the initial severe wear as compared to the whiskers. It was observed that the particle reinforcement effectively prevented the plastic flow and the adhesion of matrix material, as the shape of the particles has great advantage to carrying contact load as compared to whisker and fibre reinforcements.
Yang (2003) modelled the standard wear coefficients, in both the transient wear and steady-state wear of Al 6061–Al2O3/steel system. In the case of 10% alumina composite, higher wear coefficient values were observed compared to 15% alumina and 20% alumina reinforced composites, attributed to the presence of a lower volume fraction of alumina in its matrix.

On completion of their experiments, as conducted by Izciler and Muratoglu (2003) they concluded that the abrasive wear rates of the Al2124/SiC composites increased with an increasing applied load. Wear rate of the composites tested with SiC abrasive particles showed a higher value than that of the composites abraded by Al2O3 abrasive particles. The Al2O3 abrasive particles showed lesser effect on specimen surface of composites when compared to that exhibited by SiC abrasive particles due to their relatively higher hardness.

The consequence of centrifugal casting was that the SiC particles were partially clustered with some pores gathered with them, was an observation, first made by Velhinho et al. (2003) this was basically being attributed to imperfect wetting of ceramic particles by the molten aluminum alloy. Moreover, small spherical pores associated with trapped gas bubbles were observed in the matrix.

A simulation technique to study the parameters for uniform particle distribution of SiC in aluminum matrix composites for batch compocasting was developed by Naher et al. (2003) it was found that higher blade angles and lower viscosity resulted in a reduction of particulate dispersion time, and that the minimum stirring speed was dependent upon the viscosity of the matrix liquid.

An aluminum alloy composite with SiC particles by molten metal mixing and squeeze casting method was developed by Sahin (2003a). He
poured the molten mixture into a die, and on stirring under pressure the metal matrix was produced. He observed that a uniform dispersion of particles occurred in the matrix alloy and also that the density decreased with decreasing particle size.

The wear behaviour of SiC reinforced aluminum composite produced by the molten metal mixing method by means of a pin-on-disc type wear rig was studied by Sahin (2003b). He carried out abrasive tests against SiC and Al₂O₃ emery papers on a steel counter face at a fixed speed, and concluded that the wear rate increased with an increasing applied load, for abrasive size and sliding distance in the case of SiC emery paper, whereas the wear rate increased with the applied load and abrasive particle, and decreased with sliding distance for Al₂O₃ emery paper.

Al / quartz particulate composites, cast in sand moulds containing metallic and non-metallic chills respectively, were developed by Seah et al. (2003). It was observed that, all other factors being kept constant by the introduction of chills, a faster heat extraction from the molten MMC, during casting, led to an increase in the ultimate tensile strength and fracture toughness of the castings. In fracture analysis of the MMCs, cast using copper and steel chills showed ductile rupture with isolated micro-cracks and a bimodal distribution of dimples on the fracture surface. On the contrary, fracture analysis of the MMCs, cast without chills revealed brittle failure with separation of the quartz particles from the matrix.

Antonio Forn et al. (2003) suggested that de cohesion between the matrix and reinforcement involved a loss of mechanical properties. The spinel creation came about during the casting process promoting the loss of adherence between the aluminum matrix phase and the reinforced Al₂O₃ particles.
Zhu and Iizuka (2003) fabricated porous ceramics, with a framework of aluminum borate whiskers, by in situ firing ceramic powder compacts, and incorporated within an Al alloy matrix by squeeze casting. They found that the microstructures of the porous aluminum borate and the composites were isotropic and independent of the compaction and the casting direction. The hardness and the tensile strength of the Al alloy matrix composite increased with an increase in the volume fraction of porous aluminum borate with a decreasing diameter of the aluminum borate whiskers. The tensile strengths of the composite were higher than those of un-reinforced Al alloy.

Having conducted tension tests on Al-SiC composites, Soon-Jik Hong et al. (2003) showed that, the yield strength and ultimate tensile strength increased, while the fracture strain decreased due to the addition of SiC.

After having carried out wear tests with pin-on-disc, Genel et al. (2003) concluded that wear behaviour and the friction coefficient of the composites were significantly affected by the fibre volume fraction. Moreover, specific wear rate was also found to decrease with an increasing fibre volume fraction and increased with increasing load, and that the coefficients of friction, of the composites were higher than that of the unreinforced matrix alloy.

Wear tests on three types of pins made of commercial A6061 aluminum alloy matrix composites reinforced with alumina particles were carried out by Yang (2003). He observed that 10% alumina MMC had higher wear coefficient values as compared to those of 15% and 20% volume fraction of alumina particles. He further noted that due to the presence of a lower volume fraction of alumina in its matrix, the main wear mechanism of the worn pin surface confirmed adhesive wear. However, micro-cuts were found
on the pin surface at distances of around 12 meters for MMC of 15% and 20% volume fraction of alumina particles caused by the dislodged alumina particles.

Tribological tests, with pins made from new lead free centrifugally cast copper alloy graphite metal matrix composite, were carried out by Kestursatya et al. (2003), on a commonly used leaded copper alloy. The results showed that the graphite metal matrix composite had higher wear resistance than the leaded copper alloy.

High explosive under water shock waves technique was used by Raghukandan et al. (2003) to consolidate the carbon fibre reinforced aluminum composites using an axis symmetric under water assembly. The encapsulation of the fibre detritus in the aluminum matrix resulted in high hardness.

Two aluminum metal matrix composites reinforced with SiC / B₄C particles, made by stir casting followed by hot extrusion were developed by Shorowordi et al. (2004). From the pin-on-disc wear tests, he observed that, at higher sliding velocity led to lower friction coefficient for both MMCs.

An aluminum alloy - SiC composite, by compo casting technique, was developed by Akhlaghi et al. (2004). He found that the uniformity, in particle distribution, was improved by an increase in the SiC particles, at the expense of increased porosity content, by increasing the size of the particle. Peng Yu et al. (2004) found that the distribution of the alumina particles strongly depended on the rate of cooling of the sintered product.

Aluminum boron carbide composites, by two different powder consolidation routes of extrusion and sintering / hot isostatic pressing, were
fabricated by Zhang et al. (2004). He inferred that the strength of the MMCs increased with an increasing volume fraction of articulate reinforcement.

Superior abrasive wear resistance, in case of Al-Si12Cu/SiC heat-treated composite over the cast composite was observed by Sawla and Das (2004). He also noticed that the wear surface and subsurface deformation of heat treated composite showed less damage, reduced crack propagation and lower depth of deformation as compared to cast composite. This was attributed to the combined effects of the reinforcement of SiC and heat treatment, which resulted in an improved hardness and wear resistance of the composite.

Acilar and Gul’s (2004) investigation of both, 10%, and 30% SiC particle reinforced with Al-10Si composites, showed that the wear rate of composites increased with increasing sliding distance and applied load. The damage, to the surface of the composites, increased with an increase in the load, since these matrix materials did not have enough resistance and therefore volumetric wear rate of the composites were higher.

Ramesh et al. (2005) opinionated that wear coefficients were evaluated by using Archard’s and Yang’s theoretical models for Al6061–TiO₂ composites. An increase in the volume fraction of TiO₂ resulted in higher hardness and lower wear coefficient of the composites. The wear coefficient of all the Al6061–TiO₂ composites, studied, decreased at higher loads and larger sliding distances. At larger sliding distances, relatively higher rise in temperature of the sliding surfaces resulted in softening of both the matrix alloy and the composite pin surfaces leading to heavy deformation at higher sliding distances. This contributes to higher wear losses of both the matrix alloy and the composites.

2024 aluminum alloy metal matrix composites reinforced with Al₂O₃ particles were developed by Kok (2005), he found that the porosity in
the composites increased with an increase in the weight fraction and the decreasing size of $\text{Al}_2\text{O}_3$ particles. Moreover, the dispersion of the coarser size particles was more uniform while finer particles led to agglomeration of the particles and porosity, the hardness and tensile strength of the composites increased with decreasing size and increasing weight fraction of the particles.

An Al-6061 metal matrix composite reinforced with fine $\text{Al}_2\text{O}_3$ particulates, processed by equal channel angular pressing, was developed by Megumi Kawasaki et al. (2005). On closer Micro structural observations it was found that the grain size was reduced while the average particulate size remained unchanged.

The friction and wear characteristics of Al - TiC composites under dry sliding, using a pin-on-disc wear tester were investigated by Rajnesh Tyagi (2005). It was observed that the wear rate decreased linearly with an increasing volume fraction of titanium carbide, and coefficient of friction also decreased linearly with an increasing normal load and volume fraction of TiC.

Srivastava et al. (2005) found that the aluminum alloy based metal matrix composites, containing SiC as reinforcement, possessed physical and mechanical properties conducive for use in applications in the aerospace and automotive industries, while Cavaliere (2005) developed an aluminum alloy reinforced with alumina particles by the friction stir process, which showed good strength and ductility values.

A tri-modal aluminum based composite, with 10 %wt of $\text{B}_4\text{C}$, 50 %wt coarse-grained Al and the balance nano-crystalline Al, was developed by Jichun Ye et al. (2005). He found that the composite was extremely high in compressive strength but had a low ductility’s at room temperature.
The influence of dispersed alumina particles on the wear behaviour of aluminum composites in a corrosive environment was studied in detail by Sharma et al. (2006). These composites were prepared by modified pressure die casting technique. Corrosive – erosive wear experiments were carried out on a proprietary corrosion - erosion wear tester to study the wear characteristics of the composites. The results showed that the wear rate varied marginally at low speeds but increased sharply, at higher speeds. It was further found that the corrosive wear rate increased logarithmically with an increasing concentration of the corrosive medium.

Tensile tests on aluminum alloys, reinforced with different percentage volume of Al₂O₃ particles were performed by Ceschini et al. (2006). The results showed significant increase in the elasticity modulus and tensile strength in the MMCs when compared with those of the unreinforced alloys, which was evident from these tensile tests.

Al₂O₃ particles reinforced aluminum MMCs, using pressure die-casting technique, were prepared by Huseyin Sevik and Can Kurnaz (2006). The density values of the composites were increased by adding Al₂O₃ particle, while hardness of the composites was increased by increasing particle volume fraction and decreasing the particle size. It was found that the tensile strength of the composites decreased with an increasing particle volume fraction and size, while the wear rate of the composites decreased with the increasing particle volume fraction and decreasing particle size but at the same time increased proportionally to the applied load. The results also showed that the wear mechanism, for the surface of the un-reinforced alloy, was plastic deformation, whereas for the composites it was the layer deformation on the surface of the composites.

The stirring speed and stirring time, on the distribution of ceramic particles in cast metal matrix composites, using SiC reinforced in the A348
aluminum matrix, was studied by Balasivanandha (2006). They noted that, a top speed of 600 rpm and 10 minutes of stirring time, gave the best results on the properties of cast aluminum composites.

Konopka and Szafran (2006) fabricated $\text{Al}_2\text{O}_3$–Al composites by metal infiltration into porous perforations. This technique provided a homogeneous distribution of metallic phase in the ceramic matrix with higher strength and toughness.

Al-Qutub et al. (2006) observed that addition of 10 vol. %, of submicron (0.7µm) alumina particles improved the wear resistance of the 6160 aluminum alloy by up to 45% compared to the unreinforced alloy. Further increase in the alumina content improved the wear resistance, by, up to 145%. Hardness tests indicated that the hardness of the composite increased linearly with the percentage of added alumina particles.

Sevik and Kurnaz (2006) concluded that Al-Si12/alumina composites with larger alumina particles (125 m) showed better wear resistance than the composites containing smaller particles (44 m). In the case of 125 m, the particles were found to be deeply embedded in the matrix, resulting in them being very hard to pull out from the matrix, whereas in the composites with smaller particles (44 m), the depth of embedding was far less as compared to that of bigger particles and these particles could easily be taken out from their matrix.

Yalcin and Akbulut (2006) observed that both wear rate and friction coefficient of the A356 alloy decreases with increasing SiC particle content (5-20 vol.%). However, specimen reinforced with 15 and 20 vol.%SiC, when tested at 5 N applied load, showed an increase in the friction coefficient. It is believed that this increase was caused by poor interfacial bonding between the matrix and SiC particles. Poor bonding, associated with
particle segregation can cause particle transfer from the matrix to the WC ball and disc interface generating vibrations.

The abrasive wear behaviour of both, cast and aged 2124Al/SiC composites in the temperature range 20–200°C were studied by Muratoglu and Aksoy (2006). The results, of the wear test obtained, showed that the weight loss of the aged specimen was less than that of the non-aged specimen. It was also observed that better wear resistance was exhibited by the specimen when tested at room temperature, in the case of both, aged and non-aged specimen.

Kok and Ozdin (2007) observed that Al₂O₃ reinforcement significantly improved the abrasion wear resistance in the Al 2024 /alumina composites tested against different abrasives. The wear resistance of the composites was much higher than that of the unreinforced aluminum alloy. Wear volume loss of the matrix alloy and the composites almost increased linearly with an increasing sliding distance. The wear resistance of the composites increased with both increase in the Al₂O₃ particle content as well as size.

According to Das et al. (2007) abrasive wear resistance properties of Al–4.5 wt% Cu alloy improved significantly by the addition of alumina and zircon particles. Decrease in particle size improved the wear resistance property for both, alumina and zircon reinforced composites, since smaller particle reinforced composite has higher hardness and is more efficient in blunting the abrading surface. Zircon reinforced composite shows better wear resistance than alumina reinforced composite due to its superior particle-matrix bonding.

The tribological performance of electroless Ni–P coatings and optimization of tribological test parameters based on the Taguchi method
coupled with grey relational analysis, were studied by Sahoo (2007). A grey relational grade obtained from the grey relational analysis was used as performance index to study the behaviour of electroless Ni–P coating with respect to friction and wear characteristics. Grey relational analysis was done to find optimum test parameter combination that yielded minimum friction and wear characteristics.

Shafaat Ahmed et al. (2007) found that the metal matrix composites were of great interest in recent years as they could offer a better combination of properties, unattainable in conventional alloys. Al-based MMCs have been attracting a lot of attention particularly for their desirable combination of high stiffness and low specific gravity. Recently, tribological properties of Al-MMCs have also drawn much interest.

Ravi et al. (2007) investigated and optimized the influence of mixing parameters like impeller blade angle, rotating speed, direction of impeller rotation and effect of baffles on the synthesis of Al–SiC<sub>p</sub> reinforced Metal Matrix Composites (MMCs) by the stir casting technique through a water model.

The effects of slurry temperature, injection pressure, and piston velocity on the RHEO filling ability of semisolid A356 alloys produced by the RDC method, were studied by Yuelong Bail et al. (2008). It was found that the slurry temperature had an important effect on the filling ability and that it was better at higher slurry temperatures. Piston velocity and the injection pressure also had a great effect on the filling ability of the high quality die casting. Fabricated aluminum alloy composites reinforced with fly ash particles, were fabricated by Sudarshan and Surappa (2008). They studied the dry sliding wear behaviour of unreinforced alloy and composites using the pin on disc machine. It was found that the dry sliding wear resistance of Al-fly ash composite was almost similar to that of Al2O₃ and SiC reinforced Al-
They also noted that composites exhibited better wear resistance when compared to unreinforced alloy, up to a load of 80N. It was also noted that the particle size of Fly ash and its volume fraction significantly affected the wear and friction properties of composites. Significant increase in the friction coefficient was also observed when volume fraction of fly ash particles increased.

Sornakumar and Senthilkumar (2008) have developed the bronze alumina composite by stir casting method. The flank wear of the carbide tools on machining bronze - alumina composite was higher than that on machining bronze, because of the abrasive characteristics of alumina. The surface roughness of machined bronze was lower than the surface roughness of machined bronze - alumina composite.

Mohanty et al. (2008) developed aluminum - boron carbide composite with boron carbide particulate reinforcement in an aluminum matrix. From the result, it was noted that the microstructure showed the existence of porosities. The hardness and brittle fracture properties increased with higher reinforcement fractions.

Mitrovic et al. (2008) investigated aluminum metal matrix composites with multiple reinforcements, which increased their mechanical and tribological properties. Multiple reinforcements are better substitutes for single reinforced composites. The result shows that hybrid composites possess higher hardness, higher tensile strength, better wear resistance and lower coefficient of friction when compared to pure alloys.

The wear rate of Al-Si12Cu / SiC composite is less than that of the alloy and that it decreased with an increase in SiC content was noticed by Das et al. (2008). He further suggested that, the wear rate of the composite increased with increasing size of the reinforcement. The composite suffered
more wear than the alloy if the abrasive size was higher than that of reinforcement size. For sizes of the abrasive less than 60m it was found that the effect of abrasive size was insignificant, but it was found that the wear rate however increased almost linearly with applied load. Addition of SiC particle as well as heat treatment provided considerable improvement in wear resistance.

A factorial design of an experiment to develop linear equations for predicting wear rate of Al/SiC composites was made use of by Sahin and Ozdin (2008). These established equations demonstrated that 10 and 15 wt.% SiC composite exhibited higher wear resistance as compared to that of the Al2011 matrix alloy. The wear rate of the matrix and composites increased with an increasing abrasive size, applied load while it decreased with the sliding distance. Among the various parameters, abrasive size was found to be more significant for composite, followed by load. For the matrix alloy, however, the applied load was dominant, followed by the abrasive size. The interaction of load and abrasive size was found to be more significant for both alloy matrix and its composite.

Unreinforced Al 8090 alloy and Al8090/SiC composites exhibited mild wear up to 20 N but beyond 20N, the transition from mild to severe wear occurred, this was observed by Bauri and Surappa (2008). It was further noticed that these Composites exhibited much better wear resistance, in the severe wear regime in the as-extruded condition. Wear resistance of the unreinforced alloy increased due to ageing for all the test loads whereas in the case of composites, wear resistance improved due to ageing, for loads up to 20 N. but beyond 20 N, it was found that the wear resistance of the composites was lower in the peak-aged condition when compared to the extruded condition. Greater material loss due to larger surface and subsurface deformation, in peak-aged condition, was identified as the main reasons for
this. Ageing was attributed to reduction in ductility in peak-aged condition and thus attainment of subsurface plastic strain conditions for surface softening.

Uniform distribution of particles, with little agglomeration, along with some porosity in the microstructure of 2618 Al-SiC composites, made by stir casting method, was identified by Sakthivel et al. (2008). It was also observed that the hardness and tensile strength of the composites increased with a decreasing size and increasing weight fraction of the reinforcement particles.

The high temperature wear of Al6063 – TiB$_2$ composites was studied in detail by Natarajan et al. (2009). He found that the wear rate of the monolithic alloy and composites, increased slightly with the increase in temperature up to 100 $^\circ$C, however the trend was found to reverse beyond this temperature, finally leading to specimen seizure indicated by a sharp rise in wear rate up to around 200$^\circ$C, and hereafter the increase in wear rate became gradual. It was further observed that the wear rate decreased with an increase in the amount of TiB$_2$.

The effect of strontium in two A357 aluminum metal matrix composites, reinforced with fine particles of silicon carbide and alumina separately, was studied in detail by Razaghian et al. (2009). Results showed that the addition of 0.03% strontium made a modest improvement to the yield strength, ultimate tensile strength, elongation percentage values, and the scatter of these properties, but significantly improved the minimum strength and elongation results. Further results showed that the addition of higher strontium levels contributed to the overall modification of the eutectic silicon and promoted the formation of an Al–Si–Sr inter-metallic compound on the particle / matrix interface.
AA1061 alloy reinforced with Al2O3, B4C, Ti3Al and B2Ti processed by P/M technique was investigated by Rosenberger (2009). He inferred that the composites reinforced with alumina, showed the largest amount of wear among the composites, due to the fact that the size of the alumina particles was, one order in magnitude, smaller than the other reinforcements. The amount of wear for the composites reinforced with particles of Ti3Al, B2Ti and B4C were practically the same.

The dry sliding wear behaviour of aluminum alloy and aluminum alloy - SiC composite, using pin-on-disc apparatus against EN32 steel counter surface, emphasising on the parameters such as coefficient of friction, rise in temperature, wear and seizure resistance as a function of sliding distance and applied pressure was investigated by Rao et al. (2009). They observed that the wear rate of the aluminum alloy was significantly higher than that of the aluminum alloy - SiC composite and was further suppressed due to the addition of silicon carbide particles. The overall results indicated that the aluminum alloy silicon carbide particle composite could be considered as an excellent material where high strength and wear resistance were of prime importance.

The aluminum – silicon alloy properties were influenced by the shape and distribution of the eutectic silicon particles in the matrix, and also by the iron intermetallic and copper phases that occur upon solidification, this was an observation made by Mohamed et al. (2009). They also stated that the function of Fe, Mn, Cu, and Mg content was more sensitive to variations in microstructure and tensile properties of Al-Si near - eutectic alloys.

The Taguchi method was used by Kok (2010) to investigate the abrasive wear behaviour of Al2O3 particle reinforced 2024 aluminum alloy cast composite, under different testing conditions. The results indicated that reinforcement size was found to be the most influencing factor on abrasive
wear, followed by the abrasive grain size. The wear rate of the composites increased with increasing abrasive grain size and applied load while it decreased with increasing reinforcement size and sliding distance.

A mathematical model, to predict the abrasive wear rate of AA7075 aluminum alloy matrix composites reinforced with SiC particles, was developed by Kumar and Balasubramanian (2010). It was developed using the Response Surface Method (RSM). The effect of volume percentage of reinforcement, reinforcement size, applied load, sliding speed and abrasive size, on abrasive wear behaviour, was analysed and it was inferred that the size of abrasive exerted the greatest effect on abrasive wear.

The dry sliding wear behaviour of Al-Si7Mg matrix composites reinforced with graphite and 10% SiC particulate, were investigated by Suresha and Sridhara (2010). Using the Central Composite Design (CCD), they studied the effect of percentage of reinforcement, load, sliding speed and sliding distance on stir cast Al / Gr, Al/SiC composites and Al/SiC/Gr hybrid composites. The result showed that hybrid composites exhibited better wear characteristics, and that an increase in speed reduced wear, while an increase in, either, load or sliding distance, or both increased wear.

Rohatgi et al. (2010) reported that the dendrite arm space decreases with an increase in the volume fraction of the particles in A206/Silica sand composites, in the stir casting technique.

The Response Surface Model (RSM) is one of the best suited methods to deal with the engineering related problems, was an observation by Bayhan and Onel (2010). The effects of friction load, sliding distance and reinforcement content, on the wear rate and weight loss of AlSi7 Mg/SiCp composites were evaluated by using the RSM optimization procedure. Through this research, it was found that the RSM optimization procedure
was very effective in optimizing the reinforcement content and sliding distance for the minimization of wear rate and weight loss of tested composites.

A wear rate prediction model for aluminum based composites reinforced with 10 wt. % and 30 wt. % in situ aluminium diboride flakes using Taguchi’s method was developed by Sulardjaka et al. (2010). The experimental results showed that the normal load and reinforcement ratio were the major parameters influencing the specific wear rate for all samples.

The wear behavior of Al/Si$_{10}$Mg alloy reinforced with 3 wt. % graphite and 9wt. % alumina for the second phase was investigated in detail by Radhika et al. (2011). As a conclusion it was stated that the incorporation of graphite, as primary reinforcement, increased the wear resistance of composites and that the inclusion of alumina, as a secondary reinforcement, also had a significant effect on the wear behaviour.

The evaluation of aluminum alloy composites, reinforced with fly ash particles of three different size ranges 53-75, 75-103, and 103-150 μm in 3, 6, 9, and 12 wt. %, was carried out by Ravikumar et al. (2012). Pin on disc wear tests were conducted with 20, 30, and 40 N loads and sliding speeds of 2, 3, and 4 m/s, for a constant time period of 10 min. Composites reinforced with coarse fly ash particles exhibited superior wear resistance as compared to those reinforced with fine fly ash particles.

An aluminum metal matrix composite, reinforced with titanium carbide for improving the high specific strength, high temperature and wear resistance, was developed by Gopalakrishnan et al. (2013). Al/TiC castings with different volume fraction of TiC were produced in an argon atmosphere by an advanced stir casting method and the result of this study showed that
the specific strength of the composite increased with a higher percentage of TiC addition.

A hybrid composite of aluminum alloy with garnet and carbon particulate reinforcements, using chill casting technique, was developed by Anantha Prasad et al. (2014). Chills of various materials such as copper, steel, iron and silicon carbide were used in order to accelerate the solidification. Combination of dispersoids varied from 3 to 12 wt. % in steps of 3 percentages garnet and 3 percentages carbon particulates. The results confirmed that there was a positive relationship between mechanical behaviour and the dispersoids content. The copper chill cast composite with 9 wt. % garnet and 3 wt. % carbon was found to increase the mechanical properties.

Deepakumaar et al. (2014) developed Al₄SiC₄ using in-situ and incorporation of TiC particles into commercial aluminum melt through stir casting method. It was seen that the overall wear rate increased with load, both in the alloy as well as in the composite. The in-situ Al₄SiC₄ particles offered resistance to adhesive wear.

Sivakumaret al. (2014) reported that the aluminum metal matrix composites, successfully produced, using stir casting route, with up to 20 wt. % of fly ash, exhibited an increase in the hardness of Aluminum fly ash composites and that it further increased with an increase in addition of fly ash. It was further reported that in the aluminum melt, both the frictional forces and the wear rates decreased significantly with the incorporation of fly ash.
2.2 REVIEW OF MACHINING ALUMINUM METAL MATRIX COMPOSITES

The machined surface quality of composites is one of the most critical criteria affecting the actual application of the composites. In a machining operation, surface quality essentially depends more on the variables of processes rather than the characteristic features of the material. Therefore estimation of surface roughness, in accordance to the variations in the machining parameters and their minimization becomes an essential requirement.

The machining behaviour of SiC composite using PCD and Chemical Vapor deposition coated tools was investigated in detail by Andrewes et al. (2000). It was concluded that the cause of initial flank wear on both the PCD and CVD diamond tools, was due to the abrasion of the very hard SiC particles present in the work piece material. It was also noted that there was no significant crater wear formation to be seen on the rake face of the tool, owing to the low frictional coefficient and high thermal conductivity of diamond.

Drilling tests, with an aim to develop optimal drilling conditions with the help of the genetic algorithm approach, were conducted by Paulo Davim and Antonio (2001). A typically abrasive wear mechanism, owing to the presence of the hard particles in the matrix, was noticed. Moreover it was also found that the surface finish was chiefly affected by the feed rate than by the cutting speed.

Different tooling systems for the effective machining of Al/SiC/MMC, were investigated by Manna et al. (2002). In an attempt to establishing the criteria for an appropriate tooling system, they studied in
depth the influence, cutting time and length of machining, had on the tool wear along with the influence, the cutting speed, feed rate, depth of cut, and the angle of inclination of the tool holder, had on the surface finish. In order to accomplish this, uncoated and coated tungsten carbide tools were used by them. It was from this that they deduced that fixed rhombic tooling and fixed circular tooling were the most effective options for proper high speed machining with a low depth of cut. It was found that the Rotary circular tool (RCT) was superior to wear resistance with an extended tool life. But according to the inference by the authors, the surface roughness produced on using the rotary tooling system was undesirably high; Ra values obtained were in the order of 6 to 13 micron. On the other hand these values were almost 1.5 to 3 times the Ra value produced on use of fixed circular tools.

Teti (2002) reported that Metal matrix composites emerged as new materials, for the challenging functional requirements of aircraft components and at the same time found increasing applications in the automotive industry also. The main problem encountered in machining MMC was the high tool wear resulting in an uneconomical production process or in other words that makes renders commercial production most inefficient.

Performance of the PCD tool in turning MMCs, was studied by Paulo Davim (2002) they measured the power along with the distinct cutting force at the various cutting conditions during various stages of tool wear. It was seen that, for all cutting conditions, the power and specific power increased in tandem, as both, the tool cutting time and tool wear increased. It was further observed that as the cutting speed was increased, the specific power was seen to decrease up to a cutting speed of 250-350 m/min., while it increased beyond this cutting speed. The author noted that this was chiefly due a very rapid tool wear happening at cutting speeds in the range of 500-700 m/min.
Uncoated tungsten carbide fixed rhombic tools were used by Manna and Bhattacharayya (2003) in order to study the machinability aspect of Silicon carbide particulate aluminum metal matrix composite of type LM 6 Mg 15 SiC\textsubscript{p} of 23 µm during the process of turning. They conducted experiments at cutting speeds between 20 225m/min with a feed rate of 0.14 - 1 mm/rev and depth of cut 15mm in steps of 0.5 mm each. The inference was that, the feed force along with the main cutting force, were higher when subjected to low cutting speeds while decreasing as the cutting speed increased. While on the other hand, it was seen that with an increase in the feed resulted in an increased feed force and main cutting force.

An investigation into the drilling metal matrix composites of type A356/20% SiC-T6 based on the Taguchi, was conducted by Paulo Davim (2003) with an objective of establishing correlations between cutting velocity, feed and cutting time along with the evaluation of tool wear, specific cutting pressure and the hole surface roughness, by using a poly crystalline diamond tool.

A study on the machinability of Al/SiC and the influence of turning parameters on the cutting force and surface finish criteria was conducted by Manna and Bhattacharyya (2003). During the experiment the influence of turning parameters was investigated using fixed rhombic tools on the composite, which is otherwise, usually machined by costly poly crystalline diamond tool or cubic boron nitride tools.

An investigation into the hardness and residual stress properties of SiC/Al composites existing in the surface layer affected by machining was carried out by YanmingQuan et al. (2003). It was inferred that the structure of SiC/Al composites composed of a soft matrix and hard reinforcing particles, under the cutting force, the Al matrix and the SiC particles exhibited
non uniform deformation. Hence it was concluded that there will remain an extent of work-hardening and stress in the machined surface layer.

The evaluation of machining performance of MMC with PCBN and PCD tools was studied by Ding et al. (2005). In their evaluation they noted that the $R_a$ and $R_t$ values of the work piece along with the morphology of the machined surface was essentially the same and did not vary with the cutting distance. But since their study of the machining experiments was conducted for a very short period of 2.5 minutes at 400 m/min cutting speed. They found that within this period the $R_a$ and $R_t$ were almost constant.

The effect of the various cutting parameters on the surface quality and microstructure, on drilling of 2124Al/17% SiC particulate metal matrix composite, by using various drills was investigated by GulTosun and Muratoglu (2004). The influence of the type of drills, point angles of drills and ageing on the drilling performance of aluminum alloy reinforced with SiC particulates was investigated experimentally. They concluded that, considering the results from an estimate of economic factors, the TiN coated HSS drill, which is cheaper than solid carbide tools, be suggested for drilling Al/SiC.

The effect that the machining parameters such as cutting speed, feed and depth of cut had on tool wear and surface roughness when AlSiC MMC was machined, was reported by Kilickap et al. (2005). They used two types of K10 cutting tools (uncoated and TiN-coated) at different cutting speeds of (50, 100 and 150 m/min), feed rates (0.1, 0.2 and 0.3 mm/rev) and depths of cut (0.5, 1 and 1.5 mm), they observed that in dry turning condition, the tool wear was chiefly affected by the cutting speed, while it increased with an increase in the cutting speed. They also noticed that the Surface roughness was influenced by cutting speed and feed rate.
The optimum machining conditions for turning of particulate metal matrix composite were investigated by Palanikumar and Karthikeyan (2005). In this study, Carbide tools were used for turning particulate metal matrix composite instead of poly crystalline diamond tool, since it resulted in an increase in the cost of production. Effect of machining parameters on surface roughness, was evaluated and the optimal machining conditions in order to maximize the metal removal rate and minimize the surface roughness were determined.

Issues regarding the machinability of aluminum-silicon carbide (15P) metal matrix composites (MMC) in turning, by using three different grades of poly crystalline diamond (PCD) inserts, were studied by Muthukrishnan et al. (2008). Measurements of surface roughness, specific power consumed and the material removal rate could be made possibly only after the conduction of experiments at various cutting speeds, feeds and depth of cuts. It was inferred that the performance of 1600 grade PCD inserts was optimal for the desired surface finish and the specific power consumption criteria, followed by the 1500 grade PCD inserts.

2.3 REVIEW OF TAGUCHI TECHNIQUES

The Taguchi methodology of experimental design is one of the foremost conventional approaches utilised for producing high quality products at reasonably low costs. It proves to be an efficient and effective method of the designing of experiments as well as a faster way of identifying the parameters influencing the processes.

The systematic approach for identifying optimum surface roughness performance, in end-milling operations was put forward by John L. Yang & Chen (2001). There were two distinct purposes of this research. The
first one was to demonstrate a systematic procedure in using Taguchi parameter design in process control of individual milling machines. The second was to demonstrate the use of the Taguchi parameter design, in order to identify the optimum surface roughness performance with a particular combination of cutting parameters in an end milling operation. In this study, the analysis of confirmation experiments has shown that Taguchi parameter design can successfully verify the optimum cutting parameters. The authors concluded that Taguchi parameter design can provide a systematic procedure that can effectively and efficiently identify the optimum surface roughness in the process control of individual end milling machines. It also allows industry to reduce process or product variability and minimize product defects by using a relatively small number of experimental runs and costs to achieve superior-quality products.

An experimental investigation on machinability behaviour of Al-Al4C3 in-situ composites, was carried out by Ozcatalbas (2003). It was found out that the micro crack propagation, at particle-matrix interface, facilitates the fracturing through the chip cross section, and that this effect reduces the cutting force. It also showed that the homogeneous microstructure and high hardness of the composite reduced the build-up edge formation, that improves the surface roughness.

A study on influence of cutting velocity and cutting time on drilling metal-matrix composites using a drill bit, was put forward by Paulo Davim (2003). Plans of these experiments were based on Taguchi orthogonal array. The objective was to establish correlation between the cutting velocity, feed rate and cutting time, in order to evaluate the tool wear, specific cutting pressure and the hole’s surface roughness. These were obtained by multiple linear regressions.
End milling parameters, using Taguchi's Design of Experiments, were optimized by Ghani et al. (2003). This paper outlined the Taguchi optimization methodology, applied to optimize cutting parameters, in end milling, when machining hardened steel with carbide insert tool under semi finishing and finishing conditions of high speed cutting. An orthogonal array, signal to noise ratio and Pareto analysis of variance, were employed to analyse the effects of these milling parameters. It was also concluded that the Taguchi method was most suited to solve the stated problem, with minimum number of trials as compared with a full factorial design.

The process parameters in surface grinding, with graphite as the lubricant, based on the Taguchi method were analysed by Shaji and Radhakrishnan (2003). Taguchi’s tools such as orthogonal array, signal-to-noise ratio, factor effect analysis, ANOVA, etc. were used for this purpose and an optimal condition found out.

The effects of various control factors, on the quality of mould, were demonstrated by NoorulHaq et al. (2004). The manufacturing and product life time costs, in industries, were minimized by minimizing the performance variation. Taguchi’s parameter design was used to analyse and find the significant factors, affecting the compressive strength of the selected moulding sand.

The step by step methodology of using Taguchi’s Design of Experiments was illustrated by Kesavan et al. (2004). One of the major problems faced by visual display terminal users was the eye strain occurring during work. Some of the ergonomic factors, affecting eyestrain were considered by the authors for reducing eye strain and to increase productivity. This analysis used Taguchi method to optimize ergonomic factors, such as viewing angle, viewing distance and exposure time and the parameters were optimized for the minimization of the objective.
Manna and Bhattacharyya (2004) used the Taguchi method for determining significant cutting parameter settings to achieve better surface finish, during turning operation of aluminum and silicon carbide-based metal matrix composites.

An investigation on the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations was presented by NihatTosun et al. (2004). All the settings of machining parameters were determined using the Taguchi experimental design methodology. The results confirmed the validity of the Taguchi method, used, for enhancing the machining performance and optimizing the machining parameters in WEDM operations.

Paulo Davim et al. (2004) studied cutting parameters (cutting velocity and feed rate) using Taguchi techniques. The analysis of variance was performed to investigate the cutting characteristics of GFRP’S using cemented carbide drills. As a function of cutting parameters, it was possible to predict surface quality.

The surface integrity of drilled Al/17% SiC particulate MMCs by using HSS, TiN coated HSS and solid carbide drills was studied by Tasun and Muratogue (2004). Dry drilling tests at different spindle speeds, feed rates, point angles of drill and heat treatment were conducted in order to investigate the effect of various cutting parameters on surface quality and the extent of deformation in drilling. It was inferred that an increase in drill hardness and feed rate resulted in a decreased surface roughness of the drilled surface for all heat treated condition.

The machining parameters for achieving minimal surface roughness in turning of GFRP composites were optimised by Palanikumar and
Karunamoorthy (2005). This analysis focused on the utilization of Taguchi method of optimization, in order to optimize the process parameters, for achieving the minimal surface roughness in turning of composites, using coated carbide tools. The study also focused on analysing the influence of machining parameters and their interactions during machining. The results, from confirmation tests, indicated that the determined optimal combination of machining parameters satisfied the actual requirement of turning operations for machining of GFRP composites.

A review of literature on optimization of machining techniques was reported by Aggarwal et al. (2005). This review showed that the many traditional machining optimization techniques like, Lagrange’s method, geometric programming, goal programming, dynamic programming etc. had been applied successfully, in the past in order to optimize turning process variables. Taguchi technique and response surface methodology along with Fuzzy logic, genetic algorithm, and scatter search, were the latest optimization techniques, being successfully applied in industrial applications, for the optimal selection of process variables, in the area of machining. A review of the study on optimization techniques showed that there were, in particular, successful industrial applications of design of experiment-based approaches, for achieving optimum settings of process variables.

The application of the Taguchi optimization methodology, which is applied to optimize cutting parameters in drilling of glass fibre reinforced composite (GFRC) material, was showcased by Mohan et al. (2005). Analysis of variance was used to study the effect of process parameters on the machining process. An orthogonal array, signal-to-noise ratio were employed to analyse the influence of these parameters on cutting force and torque during drilling. It was concluded that the Taguchi method
could be useful in predicting thrust and torque as a function of cutting parameters and specimen parameters. The main objective of this study was to find the important factors and combination of factors influencing the machining process, to achieve low cutting thrust and torque. It was also stated that, this procedure eliminated the need for repeated experiments, and conserved the material by the conventional procedure.

The Taguchi method for Minimization of warpage and sink index in injection-moulded thermoplastic parts was used by Erzurumlu and Babur Ozcelik (2006). Orthogonal arrays of Taguchi, signal-to-noise ratio, and the analysis of variance, were utilized to find the optimal levels and the effect of process parameters on warpage and sink index. Confirmation analysis test with the optimal levels of process parameters were carried out in order to demonstrate the goodness of Taguchi method. From this study, it was concluded that Taguchi method was most suited to solve the quality problem occurring in the injection-moulded thermoplastic parts.

The wear resistance model, for three types of steels, was developed in terms of abrasive grain size, applied load and sliding distance using the Taguchi method by Sahin (2006). Wear tests were carried out using a pin-on-disc type of apparatus under different conditions. The orthogonal array, signal-to-noise (S/N) ratio and analysis of variance were employed to investigate the optimal testing parameters. The experimental results demonstrated that, the type of material was the major parameter among the controllable factors that influence the weight loss in steels. The optimal combinations of the testing parameters were determined and a good agreement between the predicted and actual wear resistance was observed within a tolerance of ±10%.

The experiments on machining of Al-TiC in-situ composite were conducted by Rai et al. (2006). They reported chip formation and cutting force
measurements during the shaping operation. High volume fraction of the TiC particles caused dis-continuous and favourable chip formation, without any build-up of edge formation. The cutting force was minimized due to the propagation of micro cracks, at particle-matrix interface. Size and morphology of the TiC particle, present in the composite, had been found to influence the surface roughness.

Multi-objective optimization of PMEDM process was performed by Kansal et al. (2007) using Taguchi technique to optimize the process parameters during machining of AISI D2 die steel using silicon suspended dielectric.

The application of Taguchi techniques, to study dry sliding wear behaviour of metal matrix composites was used by Basavarajappa et al. (2007). In this study, Aluminum metal matrix composites reinforced with SiC and graphite (Gr) particles were prepared using the liquid metallurgy route. A plan of experiments based on Taguchi technique were used to acquire the data in a controlled way. An orthogonal array and analysis of variance was employed to investigate the influence of wear parameters like, normal load, sliding speed and sliding distance on dry sliding wear of the composites. The objective was to investigate which design parameter significantly affected the dry sliding wear.

The influence of cutting parameters on thrust force, surface finish and burr formation in drilling A12219/15SiCp and A12219/15 SiCp-3gr composites, using carbide and coated carbide drilling tools, was presented by Basavarjappa et al. (2008). They inferred that feed rate had a major influence on thrust force, surface roughness and exit burr formation.

Tsao (2008) studied thrust force and surface roughness of core drill with drill parameters (grit size of diamond, thickness, feed rate and
spindle speed) in a drilling carbon fibre reinforced plastic laminate, experimentally, by using the Taguchi method. The confirmation tests demonstrated a feasible and an effective method for evaluation of drilling-induced thrust force and surface roughness (errors within 10%) in drilling of composites materials.

A studied in the use of Taguchi techniques and the response surface methodologies in order to minimize the surface roughness in machining glass fibre reinforced plastics, with a polycrystalline diamond tool was conducted by Palanikumar (2008). He conducted experiments using the Taguchi’s experimental design technique. The cutting parameters considered for these were cutting speed, feed and depth of cut. The effect of these parameters on surface roughness having been evaluated the optimum cutting condition for minimizing the surface roughness was determined. He succeeded in establishing a second-order model between the cutting parameters and surface roughness, by using the response surface methodology. These experimental results showed that, the most significant machining parameter for surface roughness was feed, followed by the cutting speed.

Anandakrishnan and Mahamani (2010) investigated machinability of the in-situ Al6061-TiB2 composites. They reported the effect of speed, feed and depth of cut on flank wear, cutting force and surface roughness. It was observed that presence of small and fine TiB2 particles had a significant influence on machinability.

2.4 REVIEW OF GREY RELATIONAL ANALYSIS

It must be understood that the performance of a manufactured product is very often characterized by a group of responses. Such responses are in general, correlated and measured by a different measurement scale.
Consequently, a grey relational analysis is required to resolve this parameter selection problem in order to optimize each response. Such a problem is regarded as a multi-response optimization problem, subjected to different response requirements. These Multiple-response design problems have been extensively studied in quality improvement and quality management literature.

Use of modified desirability functions, which measure the designer’s requirements, over a range of values of the selected quality characteristics, was made use of by Derringer and Suich (1980). They used the approach for the development of a tyre tread compound which involved four responses (abrasion index, modulus, elongation at break, and hardness) and three independent variables or factors. This method increased the complexity of the computational process and therefore could not be easily understood by engineers with limited statistical skills.

An example of the optimization of two quality characteristics: the force required to insert the tube into the connector; and the pull-force was illustrated by Byrne and Taguchi (1987). It was required that the pull-off force be as high as possible while the insertion force be as low as possible for ease of manufacturing. An informal argument was used to arrive at a compromise solution. It is important to note that engineering judgement together with past experience will often bring some uncertainty in the decision-making process. The statistical validity and robustness of the results cannot be assured using the above procedure.

A manufacturing process characterized, by five responses was discussed by Logothetis and Haigh (1988). They selected data-driven transformations for each of the five responses, in a multiple-univariate or one-at-a-time manner, ignoring possible correlations among the responses. Then using five single responses, first-order multiple regression models, tentative optimal settings were arrived at, for the controllable variables. However such
an approach increases the computational process complexity while the possible correlations among the responses may still exist. In addition to this, a factor significant in a single-response case may not be significant when considered in a multi-response case. Consequently it would be difficult to generalize their approach.

Deng (1989) proposed applications of GRA to engineering problems and proved it to be useful in dealing with poor, incomplete, and uncertain information. The GRA was used to solve the complicated interrelationships among the multiple performance characteristics effectively. From the GRA, a grey relational grade (GRG) is obtained to evaluate the multiple performance characteristics.

Engineering judgement, has until now been used primarily to optimize the multi-response problem in the Taguchi method. Phadke (1989) used the Taguchi method to study the surface defects and thickness of a wafer in the polysilicon deposition process, for a VLSI circuit manufacture. Based on the judgement of relevant experience and engineering knowledge, some trade-offs were made in his investigation to choose the optimum factor levels for this multiple quality characteristics problem. By human judgement validity of experimental results cannot be easily assured. Contradictory results could be reached by different engineers. Thus increasing uncertainty in the optimum factor levels. Phadkes’s approach can only be used by an experienced engineer.

Based on the grey system theory (Deng 1989) viable solutions, for the complicated interrelationships among the multiple responses, can be worked out. A grey relational grade is then obtained for analysing the relational degree of the multiple responses.
Tong et al. (1997) presented an approach to standardize the loss of each characteristic and set all of the standardization values between zero and one. They then gave a weight for the loss of each characteristic and summed the losses to obtain the SN ratio of total quality loss.

A goal-programming approach for optimizing three responses in an injection moulding process, involving seven process parameters at two levels, was proposed by Reddy et al. (1997). Since this method increases the complexity of the computational process, is therefore not readily understood by engineers with limited mathematical and statistical skills.

Chen (1997) addressed a multi characteristics model, based on the Signal to Noise ratio instead of quality loss function. He then used the mathematical programming technology to obtain the optimal parameter design.

Optimization of parameters for the process of electrical discharge machining, was looked into, in depth, by Lin and Lin (2002) and the findings were verified by the GRA. This study further analysed the effects of data normalization along with data integrity in the GRA in order to predict the rank of the parameter effect, in case of insufficient data derived from Taguchi method.

The use of grey relational analysis based on an orthogonal array and fuzzy-based Taguchi method, for the optimization of the electrical discharge machining process, with multiple process responses was presented by Lin et al. (2002). The objective of the study was to determine the minimum electrode wear ratio, surface roughness and maximum material removal rate.

Utilisation of orthogonal array along with grey relational analysis, for the optimisation of the multi-response characteristics of electrical
discharge machining of Al-10%SiCp composites was put forward by Narender Singh et al. (2004). A considerable improvement in the process was observed when experiments for the optimal settings were conducted. It was also found that the conversion of the multiple-response variable into a single response grey relational grade, by the application of this technique, simplified the optimization procedure.

Taguchi method was known as an off-line quality control methodology to be used in many industries. Until now, most of the applications of Taguchi method only focus on optimizing a single-response problem (Jeyapaul et al. 2005). Furthermore, due to the increasing complexity of the product design, more than one quality characteristic must be considered simultaneously to improve the production quality, thereby leading to the necessity for the development of several studies to address the multi-response problem. The related valuable studies, for optimization of multi response problems, by the past researchers, are given below.

GRA, for ascertaining of optimal drilling parameters, with the chief objective of minimization of surface roughness and burr height, were used by Tosun (2006). S/N ratio and Grey relational grade were used for determination of optimal parameters for drilling AISI 4140 steel.

The GRA, for the optimisation of the drilling process parameters, for the surface roughness and the burr height of the work piece, was used by NihatTosun (2006). In order to achieve this various drilling parameters, like feed rate, cutting speed, drill and point angles of drill, were required to be considered. In order to achieve the desired experimental design an orthogonal array was made use of Optimal machining parameters for the multi-performance characteristics (the surface roughness and the burr height), were determined by utilising the grey relational grade as obtained from the grey relational analysis. A marked improvement in the surface roughness and the
burr height, in the drilling process, was seen on conduction of these experiments. Fong and Chen (2006) obtained optimal parameters for turning of tool steel using GRG that maximised accuracy and minimised the surface roughness.

The effective optimisation of multiple quality characteristics of Nd:YAG laser welded titanium alloy plates by using Taguchi method-based Grey analysis, was demonstrated by Lung Kwang Pan (2007). The integrated numerical value, called the Grey relational grade or rank for, both, detraining the optimum settings of machine parameters, and for combining multiple quality characteristics, was successfully obtained by the adoption of the modified algorithm.

A new method utilising GRA and fuzzy clustering, to form part families was presented by Wang et al. (2008). The chief objective of this was to establish part families based on a new similarity coefficient which takes into account processing time, lot size, machine usability, etc., by using the GRA.

A multiple response optimization using grey relational analysis in drilling of SiC composites was proposed by NoorulHaq et al. (2008). Cutting speed, feed rate and point angle were considered as machining parameters. It was inferred that the responses in drilling process can be improved effectively through this approach.

Application of the Taguchi method and GRA in the optimisation of dry machining parameters, for high-purity graphite, in end milling process, was first carried out by Chorng-JyhTzeng et al. (2009). Lu et al. (2009) specifically mentioned in their report using GRA coupled with principal component analysis for the optimization of design specifics for the cutting parameters in high-speed end milling.
The use of Taguchi method along with grey relational analysis, in order to achieve the optimisation of thin-film sputtering process with multiple quality characteristics, in colour filter manufacturing, was first reported by Yu-min Chiang et al. (2009). In this work the weightage of the quality characteristics were determined by utilising the entropy measurement method.

An attempt for the optimisation of the sintering process parameters of Al-SiC (12%) alloy/fly ash composite, utilising the grey relational analysis, was made by Siddhi Jailani et al. (2010). Various experiments were conducted under varying conditions of temperature, fly ash content, and compacting pressure. Taguchi’s L9 orthogonal array was utilised in order to investigate the sintering process parameters. Optimal levels, for the parameters were established using grey relational analysis, while the significant parameter was determined by an analysis of variation. By the results of these experiments it was ascertained that the Multi-response characteristics like, density and hardness could be effectively improved by utilising the grey relational analysis.

Singh and Yeh (2012) employed grey relational analysis for the multi-objective optimization of high MRRand low Ra, for PMEDM of 6061 Al/Al2O3 aluminum matrix composite using SiC particles suspended dielectric.

2.5 RESEARCH GAP AND THE NEED FOR THIS STUDY

It can be stated that a good volume of research has been carried out on the mechanical and wear properties of aluminum metal matrix composites along with their machining characteristics, with different reinforcement materials. As per (Hu et al. 2013; Kuc and Cebulski 2012; Ravi Kumar et al. 2012) in the case of hybrid LM24 alloy composites, limited
literature is available encompassing the aspects, such as mechanical properties, wear behaviour and machining study of aluminum alloy metal matrix composites, and the experiments conducted on these. But tribological studies and optimization machining parameters for drilling and turning on LM24/Silicate/ Fly Ash Hybrid Composite under different conditions has not been reported so far. Hence in this research work, an attempt has been made to study the wear behaviour, mechanical properties and machining characteristics on LM24/Silicate/ Fly Ash Hybrid Composite.

2.6 OBJECTIVES

The objective of this research is to investigate the mechanical properties, wear characteristic and machining studies such as turning and drilling on LM24/Silicate/ Fly Ash Hybrid Composite under different conditions as numerated below:

- To fabricate an aluminum alloy with Silicate/ Fly Ash Hybrid using stir casting method.
- To study the mechanical properties of the LM24/Silicate/ Fly Ash Hybrid Composite.
- To study the tribological characteristics of LM24/Silicate/ Fly Ash Hybrid Composite.
- To single response optimization of tribological parameters for wear rate on LM24/Silicate/ Fly Ash Hybrid Composite using Taguchi technique.
- To single response optimization of machining parameters for drilling and CNC turning of LM24/24 wt. % silicate/ 4 wt. % fly ash hybrid composite using Taguchi technique.
To multi response optimization of machining parameters for drilling and CNC turning LM24/24 wt. % silicate/ 4 wt. % fly ash hybrid composite using grey relational analysis in the Taguchi method.