CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW OF LITERATURE

Rajan et al (2007) studied the effect of three different stir casting routes on the structure and properties of fine fly ash particles reinforced Al-7Si-0.35Mg alloy composite is evaluated. Among liquid metal stir casting, compo casting (semi solid processing), modified compo casting and modified compo casting followed by squeeze casting routes evaluated, the latter has resulted in a well-dispersed and relatively agglomerate and porosity free fly ash particle dispersed composites. Interfacial reactions between the fly ash particle and the matrix leading to the formation of MgAl$_2$O$_4$ spinel and iron intermetallics are more in liquid metal stir cast composites than in compo cast composites.

Harish Garg et al (2012) observed based on the literature review, the machining of hybrid AMMCs (Al/SiC/Gr and Al/Si10Mg/Fly ash/Gr) is discussed. These hybrid MMCs can easily be machined by EDM and a good surface quality can be obtained by controlling the machining parameters. These AMMCs with multiple reinforcements are finding increased applications because of improved mechanical and tribological properties and hence are better substitutes for single reinforced composites. These materials are developed for bushes, bearings and cylinder liners in cast aluminium engine blocks. The problems encountered during
machining of hybrid MMCs and their amendments by the use of EDM are discussed.

Surappa (2003) studied Aluminium Matrix Composites (AMCs) refer to the class of lightweight high performance aluminium centric material systems. The reinforcement in AMCs could be in the form of continuous/discontinuous fibers, whisker or particulates, in volume fractions ranging from a few percent to 70%. Properties of AMCs can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route. Presently, several grades of AMCs are manufactured by different routes. Three decades of intensive research have provided a wealth of new scientific knowledge on the intrinsic and extrinsic effects of ceramic reinforcement vis-a-vis physical, mechanical, thermo-mechanical and tribological properties of AMCs. In the last few years, AMCs has been utilized in high-tech structural and functional applications including aerospace, defense, automotive, and thermal management areas, as well as in sports and recreation. It is interesting to note that research on particle-reinforced cast AMCs took root in India during the 1970’s, attained industrial maturity in the developed world and is currently in the process of joining the mainstream materials. This paper presents an overview of AMC material systems on aspects relating to processing, microstructure, properties and applications.

Fazlur Rahman et al (2012) presented the necessity for the design of efficient load bearing materials together with superior functional properties, high strength and stiffness that can be tailored for specific applications where monolithic materials and conventional alloys that cannot be used, has given impetus to the development of modern composites. The development of composite technology spanning several
decades has given rise to an exotic class of materials whose characteristics could be tailored for specific applications to enhance mechanical and other properties besides, incorporating easy machinability by conventional machining methods using conventional tools. This paper deals with the charting of a strategy for the application of aluminium metal matrix composites citing the specific reasons for selecting the particular material system to its functionality as a worthy candidate meriting its applications. A brief review of the modern composites is followed by a general discussion and logical choice of a particular material system that has gained wide acceptance. With this knowledge as the basis, the materials engineer is well placed to create innovative designs that are having vast improvement over its predecessor designs and achieve not only fast effective gains, but also material enhanced properties.

Mohsen Ostad Shabani et al (2012) evaluated the mechanical properties of A356 matrix reinforced with B₄C particulates were first experimentally investigated and then a combination of artificial neural network (ANN) and finite element technique was implemented in order to model the mechanical properties including yield stress, UTS, hardness and elongation percentage. Micro-structural characterization revealed that the B₄C particles were distributed between the dendrite branches. The strain-hardening behaviour and elongation to fracture of the composite materials appeared very different from that of un-reinforced Al alloy. It was noted that the elastic constant, strain hardening and UTS of the MMCs is higher than that of the un-reinforced Al alloy and increase with increasing of B₄C content. It is also revealed that predictions of ANN are consistent with experimental measurements for A356 composite and considerable savings in terms of cost and time could be obtained by using neural network
models. The results of this research were used in solidification codes of the SUT CAST software.

Jiang et al (2006) attained the Steel matrix composite locally reinforced with in situ TiB$_2$-TiC particulates was successfully fabricated utilizing the self-propagating high-temperature synthesis (SHS) reaction of the Al-Ti-B$_4$C system during casting. Microstructure characterization of the composites reveals that the microstructure is made up of two types of TiB$_2$ and TiC particulates concerning particulate size and distribution and white Fe-rich regions. Moreover, the results show that the hardness and wear resistance of the composites are higher than those of the steel matrix.

Toptan et al (2012) presented the AlSi$_9$Cu$_3$Mg alloy matrix composites reinforced with 15 and 19 vol.% B$_4$C were produced by squeeze casting route at 850$^\circ$C under low vacuum. Titanium containing flux (K$_2$TiF$_6$) was used to promote the wetting between B$_4$C and liquid aluminium metal. It was found, from the micro structural observations, that the wetting improved by the formation of a thin Ti-rich reaction layer. In order to investigate the wear properties, the samples were subjected to reciprocating wear tests against AISI 4140 pin under dry sliding conditions. The effect of B$_4$C volume fraction, sliding velocity, applied load and sliding distance on the reciprocal dry wear behaviour of composites was studied using general full factorial experimental design. The effects of factors and interactions on the coefficient of friction (COF) and the wear rate values of both composite specimens and counter materials were studied. Worn surfaces and wear debris were characterized using Field Emission Gun Scanning Electron Microscope (FEG-SEM), Energy Dispersive Ray Spectroscopy (EDS), Optical Microscope (OM) and X-Ray Diffraction (XRD). From micro structural investigations, wear
mechanism was suggested as a combination of adhesive, abrasive and delaminating wear.

Shorowordi et al (2003) observed the aluminium metal matrix composites containing reinforcing particles of B₄C, SiC and Al₂O₃ (0-20 vol.%) were processed. The stir-casting manufacturing route followed by hot extrusion was utilized, being one of the cost-effective industrial methods. A clear interfacial reaction product/layer was found at Al-SiC interface for composites held for a relatively long processing time (>30 minutes). No reaction product was observed at Al- B₄C and Al-Al₂O₃ interfaces at the resolution limit of the SEM used. On the other hand, two secondary phases (alumina and another phase containing aluminium, boron and carbon) were found in the aluminium matrix away from the interface in Al- B₄C composites. From the fracture surface analysis, B₄C reinforced Al composite seemed to exhibit a better interface bonding compared to the other two composites.

Ali Mazahery & Mohsen Ostad Shabani (2012) presented the sliding wear tests were carried out on different sizes and volume fractions of coated B₄C particles reinforced 2024 aluminium alloy composites fabricated by a squeeze casting method. The micro structural examination showed that the B₄C distributions were generally homogeneous in the matrix while some particle clustering was observed at relatively high particle containing composites. As compared to the 2024 Al matrix alloy, the hardness of the composites was found to be greater. It is observed that the wear resistance of the composites was significantly higher than that of the unreinforced aluminium alloy, and increased with increasing B₄C particles content and size. The hard B₄C particles act as a protrusion over the matrix, carries a major portion of the applied load and protect the abrasives from penetration into the specimen surface. The combination of
rough and smooth regions is distinguished on the worn surface of the composites. The depth and number of grooves in composites decreased with increasing volume fraction of B₄C particles, and the worn surfaces of composites were relatively smooth.

Guo et al (2012) obtained the Laser welding of AA1100-16 vol.% B₄C metal-matrix composites was explored in the study. It was found that most B₄C particles were decomposed and that needle-like AlB₂ and Al₃BC phases were substantially formed during the welding process without filler. Consequently, a joint efficiency of 63% was obtained. The addition of Ti with 150 µm thick foil increased the joint efficiency to 75% due to the decrease of needle-like phase formations. On the other hand, the addition of Ti with filler wire did not show significant tensile property improvement due to the Ti segregation and microstructure in homogeneity in the weld zone. The fracture surfaces of laser welded joints were investigated to understand the fracture mechanisms.

Alaneme & Aluko (2012) studied the double stir casting processing parameters utilized in this work is in accordance with Charge calculations following standard procedures were utilized to estimate the amount of the Al (6063) scrap billets and silicon carbide required to produce 3, 6, 9 and 12 vol.% SiC reinforcements in the composite. The borax which serves as a wetting agent was dehydrated by heating at 250°C for 20 minutes, after which it was mixed with specified amounts of SiC in a ratio of 1:2. The Al (6063) 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. 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 and dehydrated borax mixture was added into 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 melt temperature. After manual stirring, the composite slurry was reheated and maintained at a temperature of 750°C ± 10°C (above the liquidus temperature) and then mechanical stirring was performed. The stirring operation was performed for 20 minutes at an average stirring rate of 300 rpm. Casting was then performed on prepared sand moulds at a pouring temperature of 720°C.

Ravi Shankar Raman & Assem Mishra (2012) observed that the modification has been carried out in the mechanical properties of Al based alloy by varying amount of different constituent in Al alloys. The process through Sand Casting and Ferrous Casting is done on different Al based alloy [Al-6Si-4Cu, Al-10Si-5Cu, Al-14Si-6Cu], And the research inspects how the mechanical properties of Al alloy improve by varying amount of each constituent and also by different types of casting. Each Al-based alloy out of two is cast by different processes (Sand Casting and Ferrous Casting) and selected one by one from each phase of comparison of properties among related casting. After selecting three different Al alloy composition from different casting processes, the researcher further evaluates the properties of each Al-alloy by comparing each other.

Wahab et al (2009) retained the preparation and characterization of aluminium metal matrix composites reinforced with aluminium nitride was carried out. A graphite crucible and a stainless steel permanent mould were used to prepare the samples. An optimum stirring speed was determined for a fixed stirring time before cast in the permanent mould. Morphology of the composite and particle distribution were investigated by optical microscopy. The reinforcing particles were clearly shown present at the edges and around grains of silicon primary, silicon needles and inter-
metallic compound of FeMg₃Si₆Al₈. The result of hardness test was 44 Hv for Al-Si matrix and increased to 89 Hv for an Al-Si composite reinforced with 5% wt.% AlN powder. The higher values in hardness indicated that the AlN particles contributed to the increase of hardness of the matrix.

Reddy et al (2009) observed by this paper describes an attempt to enhance the wear properties of hypereutectic cast aluminium-silicon alloys produced by semi-solid metal (SSM) processing technique. The rheological experiments on SSM slurries were performed under continuous cooling condition from liquidus temperature. The wear characteristics of the alloy under investigation were studied using a pin on flat wear system over a range of normal load (10–40 N) at constant average sliding speed (0.2 m/s) against cast iron and stainless steel counter surface. Stir cast alloy showed a lesser weight loss compared to conventional cast alloy. Stir cast and conventional cast alloys showed a higher weight loss against the stainless steel as compared to that against a cast iron counter surface. Optical microscopy of the conventional cast and stir cast hypereutectic alloy has shown that stir casting causes refinement of primary silicon particles and modification of eutectic silicon compared to conventional cast alloy. The scanning electron microscopy of wear surfaces was carried out to investigate the mode of wear.

Gopalakrishnan & Murugan (2012) learned the Metal matrix composite (MMC) focuses primarily on improving specific strength, high temperature and wear resistance application. Aluminium matrix reinforced with titanium carbide (Al-TiCp) has good potential. The main challenge is to produce this composite in a cost effective way to meet the above requirements. In this study Al-TiCp castings with different volume fraction of TiC were produced in an argon atmosphere by an enhanced stir casting
method. The specific strength of the composite has increased with a higher % of TiC addition. Dry sliding wear behavior of AMC was analyzed with the help of a pin on disc wear and friction monitor. The present analyses reveal the improved specific strength as well as wear resistance.

El-Sabbagh et al (2012) studied the Rolling of wrought aluminium matrix composites with hard phase-reinforcements such as SiC, is interesting to produce sheets for engineering constructions due to their light weight combined with good strength and wear resistance. In this work, the hot rolling behaviour is studied for stir-cast composites with a matrix of Al 6061 and Al 6082 alloys and fine SiCp particulates with a size of 15 µm and 8 µm and volume fraction up to 30%. For composite casting, optimum casting procedures and materials pre-treatment has been applied for successful insertion of particles into the melt, better particles/matrix wetting and particle distribution, minimized SiC/Al reaction. From thermo-mechanical simulation, step rolling is defined to be suitable at a strain rate of 1 s⁻¹ rate for each step, using intermediate heat treatment at 450°C for a period of 10 sec to 1 hour. Generally, the quality of rolled product was improved with improving casting quality. Successive hot rolling resulted in decreasing void and the agglomeration clusters and hence enhanced mechanical properties are achieved. The flow behaviour under rolling of Al-particulate metal matrix composites, PMMCs, is analysed and the product is characterized for its mechanical properties.

Naher et al (2004) observed the Examination of the liquid and semi-solid stir casting method to produce Al-SiC composites were the focus of this study. A significant part of the work consisted of the design, construction and validation of a specialised quick quench compo caster for this high temperature processing method. Stainless steel was chosen as the
main crucible and stirrer material. The machine consisted of a four 45° flat bladed stirrer and a crucible in a resistance heated furnace chamber. A linear actuator was integrated to this rig to allow the crucible to be quickly extracted from the furnace for quenching. Stirring speed ranging from 200 to 500 rpm and different shear periods were investigated. Ten percentage volumes of 30 µm sized SiC particles were used. The main research challenge was to get a uniform distribution of SiC in the aluminium matrix. In the compo casting experiments it was found that the uniformity of SiC particles in the aluminium matrix were dependent on shear rate, shear period, cooling rate and volume fraction of primary solid. The quick quench compo caster system was successful in producing cast MMC samples. The use of clean heat-treated SiC particles and the quick quench method was sufficient to produce homogeneous composites. Castings from the liquids condition were found to result in poor incorporation of SiC particles whereas castings from the semi-solid condition were found to produce a uniform distribution of SiC particles. However, quicker solidification, after cessation of mixing, was found to improve the uniformity of the SiC distribution significantly. Characterization of the MMC samples produced included microstructure recording and image analysis thereof. The matrix phase size, morphology and distribution of SiC particles throughout the stir castings were examined.

Samson Oluropo Adeosun et al (2011) prepared the processes that have been utilized to improve the tensile strength and hardness of aluminium alloys, some of which include elemental and particle additions, since work hardening cannot be used to improve strength and hardness of 1xxx wrought aluminium alloys. This work examines the possibility of introducing secondary processing of transverse rolling after the initial
primary rolling to strengthen and hardened wrought aluminium alloy. The effects of transverse and longitudinal rolling on the tensile strength and hardness of AA1230 aluminium alloy worked at ambient temperature (32°C) have been studied. Samples were rolled in longitudinal and transverse directions from a thickness of 1.55 mm to 0.45 mm in 3-7 passes in two-high irreversible mill. The samples rolled in transverse direction have hardness and tensile strength which are superior to samples rolled in the longitudinal direction. The resultant crystals in transverse directions were elongated in the rolling direction and agglomerate into larger crystals in this direction.

Hajjari & Divandari (2008) earned the 2024 aluminium alloy, conventionally is used for wrought products. If this alloy is subjected to cast process, a large number of shrinkage porosities will be produced within its microstructure due to its long solidification range. Therefore, in order to see the effect of pressure on the microstructure and reduction of shrinkage porosities of this type of alloy, the effect of squeeze pressure on the microstructure and tensile properties of the alloy was investigated in this research. The results showed that squeeze casting caused the refinement of the microstructure and reduction in the DAS of the cast structure, possibly due to increasing the cooling rate. Increasing the squeeze pressure also led to the formation of finer microstructure. Furthermore, higher pressures decreased the percentage of porosity and increased the density of the cast alloy. The ultimate tensile strengths of the squeezed cast samples improved when the squeeze pressure increased.

Yanfei Bai & Haidong Zhao (2010) studied the contribution, the effect of the micro structural characteristics of tensile properties and fracture behaviour of partial squeeze added slow shot die-cast A356 alloy die casting in the as-cast and T6 heat-treated conditions were studied.
The results show that, inferior tensile properties of the casting partial squeeze part were caused by the heterogeneity of $\alpha$-Al cells with fragment, rosette, angular and globular shapes, while finer dendrites with smaller secondary dendrite arm spacing and more rounded silicon particles corresponded to higher tensile properties. After T6 treatment, tensile properties increased significantly due to the spheroidization of silicon particle and consequently the reduction of stress concentration at the silicon/eutectic matrix interface. Differences observed in the tensile fracture path were attributed to micro structural changes as well as morphological aspects of silicon phase.

Chee Fai Tan & Mohamad (2009) presented an experimental study on the precipitation of aluminium alloy 6061-T6 to determine the effect of artificial ageing on the hardness of aluminium alloy 6061-T6. The precipitation hardening is a thermal treatment, which consists of a heat treatment, quenching and artificial ageing process. The experimental study is focused on artificial ageing upon which the temperature varies between 175°C to 420°C at different time periods. The Vickers hardness test is used to evaluate the hardness of aluminium alloy 6061-T6 before and after ageing process. The optimum ageing time and temperature is determined at the end of this experiment to obtain a reduction in energy and total cost. The study leads to the conclusion that the optimum aged was achieved between 175°C to 195°C with 2 to 6 hours of ageing time. The contribution of short time ageing is comparable to that of longer ageing time from previous studies.

Montoya Davila et al (2007) observed the effect of particle size distribution on the superficial hardness of Al/SiCp composites prepared by pressure less infiltration, as well as on the micro hardness and fracture
toughness (K\text{IC}) of particulate silicon carbide (SiCp) was investigated. Performed with 0.6 volume fraction of SiC powders (10, 68 and 140 μm) with monomodal, bimodal and trimodal distribution were infiltrated with the alloy Al-15.52 Mg-13.62 Si (wt.%) in argon followed by nitrogen at 1100°C for 60 min. Results show that density behaves linearly with increase in particle-size-distribution whilst superficial hardness, microhardness and fracture toughness exhibit all a parabolic behavior. Superficial hardness behavior can be explained by the combined effect of work-hardening in the alloy matrix and particle-to-particle impingement. Due to the highly covalent nature of SiC, the parabolic response shown by microhardness and K\text{IC} cannot be attributed to a dislocation mechanism as in strain-hardening.

Peng Yu et al (2008) inverted the alumina reinforced Al-Cu alloy matrix composite was prepared by reaction sintering of Al and CuO powders. Precipitation hardening by further aging the composite at 250°C was studied. In situ formed micron-sized alumina particles were present in the Al (Cu) matrix of the un-aged composite, while additional nanometer-sized Al\textsubscript{2}Cu rods were obtained in the matrix of the aged composite. Both hardness and bending strength were enhanced after the composite was aged. In the bending test, the sample was plastically deformed before fracture. Micro-structural analysis revealed that the size of dimples found in the fracture mouth of the un-aged composite was micron-sized, and that in the aged composite was much smaller. It was evident that when the composite was subjected to stress, micron-sized alumina particles were responsible for the formation of cracks in the un-aged sample, while in the aged sample, Al\textsubscript{2}Cu nanorods were the dominant nucleation sites for crack growth.
Adel Mahamood Hassan et al (2009) prepared the potential of using feed forward, back propagation neural network in prediction of some physical properties and hardness of aluminium-copper/silicon carbide composites synthesized by compo casting method has been studied in the present work. Two input vectors were used in the construction of proposed network; namely the weight percentage of the copper and volume fraction of the reinforced particles. Density, porosity and hardness were the three outputs developed for the proposed network. Effects of addition of copper as alloying element and silicon carbide as reinforcement particles to Al-4 wt.% Mg metal matrix have been investigated by using artificial neural networks. The maximum absolute, relative error for predicting values does not exceed 5.99%. Therefore, by using ANN outputs, satisfactory results can be estimated rather than measured and hence reduce testing time and cost.

Hui-Hui Fu et al (2004) observed the purpose of this study is to investigate the wear properties of Saffil/Al, Saffil/Al$_2$O$_3$/Al and Saffil/SiC/Al hybrid metal matrix composites (MMCs) fabricated by the squeeze casting method. Wear tests were done on a pin-on-disc friction and wear tester under both dry and lubricated conditions. The wear properties of the three composites were evaluated in many respects. The effects of Saffil fibers, Al$_2$O$_3$ particles and SiC particles on the wear behaviour of the composites were elucidated. Wear mechanisms were analyzed by observing the worn surfaces of the composites. The variation of the coefficient of friction (COF) during the wear process was recorded by using a computer. Under dry sliding condition, Saffil/SiC/Al showed the best wear resistance under high temperature and high load, while the wear resistances of Saffil/Al and saffil/Al$_2$O$_3$/Al were very similar. Under dry sliding condition, the dominant wear mechanism was abrasive wear under
mild load and room temperature, and the dominant wear mechanism changed to adhesive wear as load or temperature increased. Molten wear occurred at high temperature. Compared with the dry sliding condition, all three composites showed excellent wear resistance when lubricated by liquid paraffin. Under lubricated condition, Saffil/Al showed the best wear resistance among them, and its COF value was the smallest. The dominant wear mechanism of the composites under lubricated condition was microploughing, but micro cracks also occurred to them to different extents.

Uthayakumar et al (2013) fabricated the Hybrid metal matrix composites consist of a metal or an alloy matrix with strongly embedded multiple hard reinforcements to enhance the wear resistance properties. This research study emphasizes on the dry sliding wear behaviour of aluminium reinforced with 5% SiC and 5% B₄C hybrid composite using a pin on disc tribometer. Wear performance of the hybrid composites was evaluated over a load range of 20-100 N, at the sliding velocities from 1 to 5 m/s. Detailed metallurgical examination and energy dispersive analysis were carried out to assess the effect of SiC and B₄C particles on the wear mechanisms. The Focused Ion Beam (FIB) technique is used to characterize the Tribo layers that have been formed at the worn surfaces of composites. The experimental results show that the hybrid composites retain the wear resistance properties up to 60 N loads and sliding speed ranges 1-4 m/s. The enhancement of wear resistance with small amount of SiC and B₄C is achieved by the cooperating effect of reinforcement particles.

Hayrettin Ahlatci et al (2006) investigated dry sliding metal-metal and metal-abrasive wear behaviours of the aluminium matrix hybrid composites produced by the pressure infiltration technique. These
composites were reinforced with 37 vol.% Al₂O₃ and 25 vol.% SiC particles and contained up to 8 wt.% Mg in their matrixes. While matrix hardness and compression strength increased, amount of porosity and impact toughness decreased with increasing Mg content of the matrix. Metal-metal and metal-abrasive wear tests revealed that wear resistance of the composites increased with increasing Mg addition. On the other hand, abrasive resistance decreased with increasing test temperature, especially above 200°C.

Wang et al (2011) retained Al₂O₃ fiber (Al₂O₃f) and SiCₚ hybrid MMCs were manufactured in a squeeze casting method and investigated for their mechanical and wear properties at elevated temperatures of 100°C and 150°C. The pin specimens had different ratios of fiber to particle content but their total weight fraction was constant at 20 wt.%. Dry sliding wear tests were conducted with a pin-on-disc friction and wear tester. The morphologies of the worn surfaces were examined using a scanning electron microscope (SEM) to observe the wear characteristics and investigate the wear mechanism. An optical microscope (OM) was used to examine the precipitations of the MMCs after wear tests under different temperatures. The grown precipitations improved the hardness of the matrix material during the wear tests at 150°C. Thus, the wear resistance was enhanced at 150°C due to the precipitation strengthening of the FeSiAl₅. Furthermore, the test results revealed that the wear resistance of normal (N) MMCs was superior to that of planer random (PR) MMCs as the PR-fibers were easily pulled out whole from the worn surface. The results of this investigation showed that the wear resistance of dry sliding wear decreased as the SiCₚ content increased at 100°C and 150°C, independently of the fiber orientation.
Wang et al (2010) discussed this study investigates the room temperature sliding wear behavior of Al$_2$O$_{3f}$ and SiC$_p$ reinforced aluminium matrix hybrid composites under both the dry and lubricant conditions. The effects of fiber orientation of the Al$_2$O$_{3f}$ and the hybrid ratio of the Al$_2$O$_{3f}$ volume fraction of SiC$_p$ volume fraction on the wear behaviors are discussed in details. The composite specimens with different fiber orientations and hybrid ratios were fabricated by the squeeze casting method. The tests were carried out using a pin-on-disc friction and wear tester by sliding the pin specimens at a constant speed of 0.36 m/s (570 rpm) against a steel counter disc. The scanning electron microscope (SEM) images of the worn surfaces and debris were analyzed to understand the modes of wear. The results of dry sliding tests showed that the F20P0 unhybrid composites with normal (N)-orientation of fibers had better wear behaviours than those with planer random (PR)-orientation of fibers. However, for hybrid composites, the wear behavior was better for PR-orientation of fibers. On the contrary, the lubricant wear behaviours of F20P0 unhybrid composites with PR-orientation of fibers were superior to those with N-orientation of fibers while the hybrid composites exhibited the reverse lubricant wear behaviours.

Soleymani et al (2012) reported in this study, a self-lubricating and wear resistant surface hybrid Al-base composite reinforced with a mixture of SiC and MoS$_2$ particles has been successfully fabricated by Friction Stir Processing (FSP). Microstructure, hardness and dry sliding wear behavior of the hybrid composite have been investigated and compared with those of the base metal and Al/SiC and Al/MoS$_2$ composites. Micro-structural analyses of the hybrid composite showed a uniform distribution of reinforcing particles inside the processed zone and a good bonding between surface processed layer and base material.
The tribological studies showed that surface hybrid composite has the highest wear resistance in comparison to other samples. Moreover, dominant wear mechanisms operating in dry sliding conditions of samples were studied. The results indicated that light delamination and light abrasion mechanisms operated simultaneously during wear of the hybrid composite. The wear mechanisms confirmed that the formation of hybrid composite on the surface could significantly reduce the wear damages and improve the wear resistance of the alloy.

Urena et al (2009) observed that dry sliding wear of an AA 6061 alloy reinforced with both modified SiC particles and metal coated carbon fibres has been studied. Sic particles were used to increase the hardness of the composite while short carbon fibers are supposed to act as a solid lubricant. SiC particles were coated with a silica layer deposited through a sol-gel procedure to increase the process ability of the composite and to enhance the particle-matrix interfacial resistance. The metallic coatings on carbon fibers were made of copper or nickel phosphorus which was deposited through an electrolysis process. The metallic coatings favoured the wetting of the fibers during processing and then dissolved in the aluminium matrix forming intermetallic compounds that increased its hardness. Wear behavior of AA 6061-20%SiC and AA 6061-20%SiC-2%C was compared with that of the composites with the same reinforcement content but using coated particles and fibers. The influence that the modification of the matrix because of the incorporation of coatings on the reinforcements had on the mild wear behavior was investigated. The wear resistance of the composites increased when carbon fibers were added as secondary reinforcement and when coated reinforcements were used.

Suresha et al (2010) prepared the AMCs with multiple reinforcements are finding increased applications because of improved
mechanical and tribological properties and hence are better substitutes for single reinforced composites. Few investigations have been reported on the tribological behavior of these composites with % reinforcement above 10%. The present study focuses on the influence of addition of graphite particulates as a second reinforcement on the tribological behavior of aluminium matrix composites reinforced with SiC particulates. Dry sliding wear tests have been performed to study the influence of Gr particulates, load, sliding speed and sliding distance on the wear of hybrid composite specimens with combined % reinforcement of 2.5%, 5%, 7.5% and 10% with equal weight % of SiC and Gr particulates. Experiments are also conducted on composites with % reinforcement of SiC similar to hybrid composites for the sake of comparison. Parametric studies based on DOE techniques indicate that the wear of hybrid composites decreases from 0.0234 g to 0.0221 g as the % reinforcement increases from 3% to 7.5%. But the wear has a tendency to increase beyond % reinforcement of 7.5% as its value is 0.0225 g at % reinforcement of 10%. This trend is absent in case of composites reinforced with SiC alone. The values of wear of these composites are 0.0323 g, 0.0252 g and 0.0223 g, respectively, at % reinforcement of 3%, 7.5% and 10% clearly indicating that hybrid composites exhibit better wear characteristics compared to composites reinforced with SiC alone. Load and sliding distance show a positive influence on wear implying increase of wear with increase of either load or sliding distance or both. Whereas speed shows a negative influence on wear indicating decrease of wear with increase of speed. Interactions among load, sliding speed and sliding distance are noticed in hybrid composites and this may be attributed to the addition of Gr particulates. Such interactions are not present in composite reinforced with SiC alone. Mathematical models are formulated to predict the wear of the composites.
Naplocha & Granat (2008) analysed the Tribological behavior of Al/Saffil/C hybrid composites with various amounts of graphite and alumina fibers, produced by the squeeze casting method was studied. Preforms with about 6.5-15.0% (all the percentages v/v) of Al$_2$O$_3$ fibers (Saffil) and 1.5-12.0% of graphite were infiltrated under the pressure of 75 MPa. The effects of the applied load, form of graphite, and the reinforcement volume fraction of dry sliding friction were investigated using reciprocating movement. Comparison of the wear losses for the monolithic Al-Si7 matrix and its composites revealed that alumina fibers improved this property, but the addition of graphite improved seizure resistance. The composites reinforced with graphite fibers were less sensitive to the applied load than both the matrix and the composites reinforced with graphite flakes. During microscopic observation crushed graphite fibers and segments of alumina fibers embedded in the matrix on the wear surface were frequently observed. In the case of the composite with flake graphite, weak layers of the matrix broke and delaminated above a graphite pocket. This produced cavities of graphite, which were subsequently mixed with debris and, as the wear test was continued, these holes joined together along the direction of the counterpart movement.

Ravindran et al (2012) studied the wear and sliding friction response of a hybrid aluminium metal matrix composite reinforced with hard ceramic (5 wt. % of SiC) and soft solid lubricant (0, 5 and 10 wt. % of graphite) fabricated by powder metallurgy was investigated. The influence of the percentages of reinforcement, load, sliding speed and sliding distance on both the wear and friction coefficient were studied using the pin-on-disc method with tests based on the DOE. ANOVA was used to investigate the influence of the parameters on both the wear rate and the coefficient of friction. The hardness of the composites decreases as
the % of graphite (Gr) increases. The wear and friction coefficient were mainly influenced by both the sliding distance and the load applied. The morphology of the worn out surfaces and the wear debris was analyzed to understand the wear mechanisms. The wear resistance of the hybrid composite containing 5 wt. % SiC and 5 wt. % graphite is superior to that of the graphite free composites and the other hybrid composites. This study reveals that the addition of both and reinforcement like SiC and soft reinforcement like graphite improves the wear resistance of aluminium composites significantly.

Basavarajappa et al (2007) observed in recent years, more attention is being paid to the structure of both the surface and the subsurface of a material being subjected to wear. Surface and subsurface deformation can cause a considerable change in the microstructure of the material leading to a change in its properties. The present study investigates the influence of sliding speed on dry sliding wear behavior and the extent of subsurface deformation in aluminium metal matrix composites, namely Al 2219/15SiCp and Al 2219/15SiCp-3graphite all fabricated by the liquid metallurgy route. Dry sliding wear tests were conducted using a pin-on-disc machine. The subsurface deformation was assessed as a measure of variation in micro-hardness along the depth normal to the cross-section of the worn surface. The results reveal that with increasing sliding speeds in the mild wear region the degree of subsurface deformation was also increasing. The graphite composite exhibited a less degree of subsurface deformation in comparison to the graphite free composite.

Mahagundappa et al (2007) discussed in this technical paper describes the abrasive wear rate of as-cast and heat-treated Al (6061) alloy reinforced with 9% by weight of SiC particulate and 0, 1, 3 and 5% by
weight of E-glass fiber subjected to different ageing durations. The liquid melts technique route is used to produce the castings. Castings were machined to the ASTM standards and T6 heat-treatment process is carried out. All the specimens were artificially aged to different durations like 1, 3, 5 and 7 hr at a temperature of 175°C. Wear tests were performed on various composites in both the heat-treated and as-cast conditions using pin-on-disc machine. In each test the wear rates of the hybrid composites were found to decrease with increase in ageing durations. However, in both as-cast and heat-treated hybrid composites, the wear rate increased with increase in the sliding distance.

Saini et al (2012) said the AMMCs are new generation engineering materials that possess superior physical and mechanical properties compared to non-reinforced alloys. This makes them attractive for a wider range of applications in automotive, aerospace and defense industries. The reinforcements in AMMCs are very hard and abrasive in nature. Thus, they pose a limitation to their economic conventional machining. Production of complex shapes in such materials by traditional methods is also difficult. In view of high tool wear and high cost of tooling with conventional machining, unconventional material removal processes offer an attractive alternative. Many unconventional machining processes, have found widespread applications in industry. The machining characterization of AMMCs material is necessary for high quality-cost effective product development. This paper presents a review of non conventional machining process and year wise research work done on AMMCs. The paper also discusses the future trend of research work in the same area.

Pragya Shandilya et al (2012) discussed the present study has been made to optimize the process parameters during machining of
SiCp/6061 AMMCs by wire electrical discharge machining (WEDM) using response surface methodology (RSM). Four input process parameters of WEDM (namely servo voltage \( V \), pulse-on time \( TON \), pulse-off time \( TOFF \) and wire feed rate \( WF \) were chosen as variables to study the process performance in terms of cutting width \( kerf \). The ANOVA was carried out to study the effect of process parameters on process performance. In addition, mathematical models have also been developed for response parameter. Properties of the machined surface have been examined by the scanning electron microscopic (SEM).

Biing Hwa Yan et al (2000) inverted this study investigates the feasibility and optimization of a rotary EDM with ball burnishing for inspecting the machinability of \( \text{Al}_2\text{O}_3/6061\text{Al} \) composite using the Taguchi method. Three \( \text{ZrO}_2 \) balls attached as additional components behind the electrode tool offer immediate burnishing following EDM. Three observed values (machining rate, surface roughness and improvement of surface roughness) are adopted to verify the optimization of the machining technique. In addition, six independent parameters are chosen as variables for evaluating the Taguchi method; these variables are categorized into two groups: (1) electrical parameters, i.e. peak current, pulse duration and non-load voltage; and (2) non-electrical parameters, i.e. flushing pressure of dielectric, rotational speed of the electrode and residual height of the hump. Experimental results indicated a feasible technique for applying rotary EDM with ball burnishing in machining the \( \text{Al}_2\text{O}_3/6061\text{Al} \) composite. Optimization of this technique is also discussed.

Sanjeev Kumar et al (2009) reported that the last decade has seen an increasing interest in the novel applications of the EDM process, with particular emphasis on the potential of this process for surface modification. Besides erosion of work material during machining, the
intrinsic nature of the process results in the removal of any tool material also. Formation of the plasma channel consisting of material vapours from the eroding work material and tool electrode; and pyrolysis of the dielectric affect the surface composition after machining and consequently, its properties. Deliberate material transfer may be carried out under specific machining conditions by using either composite electrodes or by dispersing metallic powders in the dielectric or both. This paper presents a review of the phenomenon of surface modification by electric discharge machining and future trends of its applications.

Ho & Newman (2003) fabricated that EDM is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. The non-contact machining technique has been continuously evolving from a mere tool and dies making process to a micro-scale application machining alternative attracting a significant amount of research interests. In recent years, EDM researchers have explored a number of ways to improve the sparking efficiency, including some unique experimental concepts that depart from the EDM traditional sparking phenomenon. Despite a range of different approaches, this new research shares the same objectives of achieving more efficient metal removal coupled with a reduction in tool wear and improved surface quality. This paper reviewed the research work carried out from the inception to the development of die-sinking EDM within the past decade. It reports on the EDM research relating to improving performance measures, optimizing the process variables, monitoring and control the sparking process, simplifying the electrode design and manufacture. A range of EDM applications is highlighted together with the development of hybrid
machining processes. The final part of the paper discusses these developments and outlines the trends in future EDM research.

Sushant Dhar et al (2007) said the AMC is hard to machine due to the presence of hard and brittle ceramic reinforcements. EDM is an important process for machining such materials. The present work evaluated the effect of current \((c)\), pulse-on time \((p)\) and air gap voltage \((v)\) on MRR, TWR, ROC on electric discharge machining of Al-4Cu-6Sialloy-10 wt. % SiC\(_P\) composites. The experiments were performed in a systematic manner with three successive trials using a PS LEADER ZNCEDM machine and a cylindrical brass electrode of 30 mm diameter. Three factors, three levels full factorial design were adopted for analyzing the results. Second order, the non-linear mathematical model has been developed for establishing the relationship between machining parameters. ANOVA has been performed to verify the fit and adequacy of the developed mathematical models.

Biing Hwa Yan et al (2005) fabricated the Alumina particle reinforced 6061 AMCs (Al\(_2\)O\(_3\)p/6061Al) have excellent physical and chemical properties than those of a traditional metal; however, their poor machinability lead to worse surface quality and serious cutting tool wear. In this study, WEDM was adopted in machining Al\(_2\)O\(_3\)p/6061Al composite. In the experiments, machining parameters of pulse-on time were changed to explore their effects on machining performance, including the cutting speed, the width of the slit and surface roughness. Moreover, the wire electrode is easily broken during the machining Al\(_2\)O\(_3\)p/6061Al composite, so this work comprehensively investigates into the locations of the broken wire and the reason of wire breaking. The experimental results indicate that the cutting speed, the surface roughness and the width of the slit of cutting test material significantly depend on the volume fraction of
reinforcement (Al$_2$O$_3$ particles). Furthermore, bands on the machined surface for cutting 20 vol. % Al$_2$O$_3$/6061Al composite are easily formed, basically due to some embedded reinforcing Al$_2$O$_3$ particles on the surface of 6061 aluminium matrix, interrupt the machining process. Test results reveal that in machining Al$_2$O$_3$/6061Al composites a very low wire tension, a high flushing rate and a high wire speed are required to prevent wire breakage; an appropriate servo voltage, a short pulse-on time, and a short pulse-off time, which are normally associated with a high cutting speed, have little effect on the surface roughness.

Nihat Tosun et al (2004) investigated the effect and optimization of machining parameters on the kerf (cutting width) and MRR in WEDM operations. The experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. The settings of machining parameters were determined by using the Taguchi experimental design method. The level of importance of the machining parameters on the cutting kerf and MRR is determined by using ANOVA. The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. The variation of kerf and MRR with machining parameters is mathematically modelled by using regression analysis method. The optimal search for machining parameters for the objective of minimum kerf together with maximum MRR is performed by using the established mathematical models.

Mohan et al (2004) analysed the machining characteristics of SiC/6025 Al composites using rotary electro-discharge machining (EDM) with a tube electrode were investigated in this study. Brass was used as the electrode material to EDM SiC/6025 Al composites. Three observed values: material removal rates (MRR), electrode wear rate (EWR) and surface roughness (SR) are adopted to evaluate the machinability.
Peak current, polarity, volume fraction of SiC reinforced particles, pulse duration, hole diameter of the tube electrode, and speed of electrode rotation were used as the input variables to assess the machinability. Peak currents of EDM drilling were confirmed to have positive effects on the MRR, EWR and SR. The MRR, EWR and SR were more with positive polarity of the electrode than at negative. Increase in volume percentage of SiC resulted in a decrease in MRR and the increase in EWR. The pulse duration had an inverse effect with MRR, EWR and SR. The decrease in the hole diameter and increase in speed of the rotating tube electrode resulted in an increase in MRR and the decrease in EWR and SR. In comparison, the electrode hole diameter and rotational speed have a major effect on MRR, EWR and SR. The optimum machining parameter for maximum MRR, minimum EWR and better surface roughness were found out using genetic algorithm.

Muller & Monaghan (2000) reported that the Particle Reinforced Metal Matrix Composites (PRMMC’s) have proved to be extremely difficult to machine using conventional manufacturing processes due to heavy tool wear caused by the presence of the hard reinforcement. This paper presents details and results of an investigation into the machinability of SiC particle reinforced aluminium matrix composites using non-conventional machining processes such as (EDM), laser cutting and Abrasive Water Jet (AWJ). The surface integrity of the composite material for these different machining processes are examined and compared. The influence of the ceramic particle reinforcement of the machining process was analyzed by tests performed on samples of the non-reinforced matrix material.

Norliana Mohd Abbas et al (2007) discovered that EDM is one of the earliest non-traditional machining processes. EDM process is based
on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporising. The electrode and the work piece must have electrical conductivity in order to generate the spark. There are various types of products which can be produced using EDM such as dies and moulds. Parts for aerospace, automotive industry and surgical components can be finished by EDM. This paper reviews the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, EDM, in water and modelling technique in predicting EDM performances.

Narender Singh et al (2004) observed that optimization of process parameters is the key step in the Taguchi methods to achieve high quality without cost inflation. Optimization of multiple response characteristics is more complex compared to optimization of single performance characteristics. The multi-response optimization of the process parameters viz., MRR, TWR, ROC and SR on EDM of Al-10%SiCP as cast metal matrix composites using OA with gray relational analysis is reported. The optimization of the process was performed in the following steps:

a. Normalizing the experimental results of MRR, TWR, T, ROC and SR for all the trials.

b. Performing the grey relational generating and to calculate the grey relational coefficient.

c. Calculating the grey relational grade by averaging the grey relational coefficient.
d. Performing statistical ANOVA for the input parameters with the grey relational grade and to find which parameter significantly affects the process.

e. Selecting the optimal levels of process parameters.

Rozenek et al (2001) reported the experimental investigations of the effect of machining parameters (discharge current, pulse-on time, pulse-off time, voltage) on the machining feed rate and surface roughness during wire electrical discharge machining (WEDM) of metal matrix composite AlSi₇Mg/SiC and AlSi₇Mg/Al₂O₃. Generally, the machining characteristics of WEDM MMCs are similar to those which occur in the base material (AlSi₇Mg aluminium alloy). The machining feed rate of WEDM cutting composites significantly depends on the kind of reinforcement. The maximum cutting speeds of AlSi₇Mg/SiC and AlSi₇Mg/Al₂O₃ composites are approximately 3 times and 6.5 times lower than the cutting speed of aluminium alloy, respectively.

Che Chung Wang & Biing Hwa Yan (2000) reported that their work optimizes the blind-hole drilling of Al₂O₃/6061Al composite using rotary EDM by using Taguchi methodology. Experimental results confirm that the revised copper electrode with an eccentric through-hole has the optimum performance for machining from various aspects. Three observed values, MRR, EWR and SR, verify the optimization of the machining technique. In addition, seven independent parameters are chosen as variables in evaluating the Taguchi method and are categorized into two groups: (1) electrical parameters, e.g., polarity, peak current, pulse duration and powder supply voltage and (2) non-electrical parameters, e.g., rotational speed of the electrode, injection flushing pressure of the dielectric fluid and the number of eccentric through-holes in the electrode.
Moreover, analysis of the Taguchi method reveals that the electrical group has a more significant effect than the non-electrical group on the machining characteristics. Furthermore, either the polarity or the peak current most prominently affects the MRR, SR or EWR amongst all of the parameters, whereas none of the non-electrical group has an equal effect. Also derived herein are semi-empirical equations that contain all of the machining characteristics.

Ashok Kumar Mishra et al (2012) reported the tribological behaviour of aluminium alloy Al-6061 reinforced with silicon carbide particles (10% & 15% weight percentage of SiCp) fabricated by stir casting process was investigated. The wear and frictional properties of the MMCs was studied by performing dry sliding wear test using a pin-on-disc wear tester. Experiments were conducted based on the plan of experiments generated through Taguchi’s technique. A L9 OA was selected for analysis of the data. An investigation to find the influence of applied load, sliding speed and sliding distance on wear rate, as well as the coefficient of friction during wearing process was carried out using ANOVA and regression equation for each response were developed for both 10% & 15% SiC reinforced Al-6061MMCs. The objective of the model was chosen as “smaller the better” characteristics to analyze the dry sliding wear resistance. Results showed that sliding distance has the highest influence followed by a load and sliding speed. Finally, confirmation tests were carried out to verify the experimental results and SEM were done on wear surfaces.

Vijian & Arunachalam (2006) found the ability to produce near net shape components with good surface finish is made possible by means of squeeze casting, a hybrid metal forming process combining features of both casting and forging in a single operation. The primary objective of
this paper was to analyze the influence of the process parameters on surface roughness in squeeze casting of LM6 aluminium alloy using Taguchi method. In Taguchi method, a three level OA has been used to determine the S/N ratio. ANOVA and the ‘F’-test values are used to determine the most significant process parameters affecting the surface roughness. The results indicated that the squeeze pressure and the die preheating temperature are the recognized parameters to cause appreciable improvement in the surface finish of the squeeze cast components.

2.2 SUMMARY OF LITERATURE REVIEW

It was observed from the review of available literature following gaps are identified:

A lot of work has been done on aluminium based metal matrix composites with different types of reinforcements, different sizes and manufactured techniques either by stir casting technique and then subjected to study the mechanical and machining properties. Alloy composition and its condition influence the wear rate. With increase in wt % of reinforcement in the matrix the wear resistance of composite increase. The hardness will also increase with increase in wt % of reinforcement.

The investigations of several researchers have been thoroughly studied and their conclusive findings have been recorded concerning the processing and machining of composites through various routes. Electro Discharge Machining is considered for the composite production. Machining parameters affecting quality characteristics in the machining process is thoroughly studied. Productivity is constantly a matter of concern with a high level of accuracy for any process; rather it is the driver
of economic growth of industry. Therefore, it is always desirable to have machining with maximum MRR, minimal TWR and minimum surface roughness along with better circularity.

A major research work has been reported on alloy LM 25 by taking different reinforcements such as SiC, Fe3O4, Al2O3, B4C etc., but none of them had made attempt for Al alloy LM 25 and Boron carbide and Graphite as reinforcement. Now from last few decades’ interest has been increased on composites containing low density and low cost reinforcement. Such reinforced composites are likely to overcome the cost barrier for wide spread applications in automotive and aerospace applications and also control environmental conditions.

In this thesis, the combination of boron carbide and graphite reinforcement and matrix is Al alloy LM 25 was used with the help of simple and cheaper technique called stir casting technique. Al alloy LM 25 studied the effect of all these combinations on optical microscope and behaviour such as tensile, hardness, wear and EDM.