CHAPTER 2

LITERATURE REVIEW

Literatures on friction drilling process were available as U.S. Patents from the year 1976 to 1984. Many researchers and few Industries are using this process for hole making as well as metal joining. European automakers have been using friction drilling screws to assemble body panels and chassis made of aluminum and thin materials to make cars lighter since 1996.

Number of literature on friction drilling process as well as on process modeling and analysis and on optimisation have been collected and some of the important literature are discussed here for understanding the present scenario of the friction drilling process, applied to make holes in Aluminum Silicon Carbide (AlSiC) composites.

The literature collected have been reviewed under three categories namely,

i. Conventional methods of machining AlSiC composites

ii. Modeling, analysis and optimisation techniques

iii. Recent trends in conventional drilling and friction drilling

In addition, the motivation for the present research work along with the scope and objectives of friction drilling of AlSiC composites are discussed at the end of the chapter.
2.1 CONVENTIONAL METHODS OF MACHINING AlSiC COMPOSITES

A persistent problem with particulate metal matrix composite (PMMC) is that they are difficult to machine, due to the presence of hard abrasive particles and other reinforcing particles. The SiC particles used in PMMC are harder than tungsten carbide (WC) which are the main constituent of hard materials and harder than the majority of the cutting tool materials. Poly crystalline diamond (PCD) is recommended by many researchers for machining PMMC as its hardness is approximately three to four times than that of the SiC.

Many researchers used very hard PCD or CBN (Cubic Boron Nitride) tool materials, but some used conventional tool materials either with coating or without coating under various cutting environment for machining composites and their findings are discussed to understand the cutting mechanism applicable for AlSiC composites.

Looney et al (1992) conducted a series of turning tests with a number of different cutting-tool materials (uncoated carbide, the triple-coated carbide, and the CBN) to turn AlSiC (25% SiC) composites. They brought out two features pertaining to cutting forces from the results. The first feature is that in each case there is a progressive increase in each of the force components with increasing speed. The second feature is that the radial force component is greater than the axial (or feed) force component, at each cutting speed. These effects may be explained by the high levels of flank wear led to the production of a cutting surface rather than to a cutting edge on both the primary and secondary cutting regions of the tools. Consequently, while the depth of cut decreased with increased cutting speed due to tool wear, the effective area of contact between the tool and the work piece increased significantly, thereby increasing the frictional forces at the tool / work
piece interface. This had the effect of altering the mechanics of the cutting process leading to a rise in the various force components. The high magnitude of the radial force component compared to that of the axial force can also be explained by this change in the effective area of contact at the tool cutting surfaces.

Quigley et al (1994) have observed that the cutting mechanism applicable for AlSiC (25% SiC) composites is quite different from that of an aluminum alloy. They conducted turning tests on 5083 aluminum alloy and AlSiC composite using coated and uncoated carbide tool. After comparing the test results they concluded that the composite material tend to fail by crumbling like concrete mix rather than by shearing as in the case of ductile material and the mechanics of cutting process for AlSiC composite material was more complicated than that of brittle type materials producing discontinuous chips.

Hung et al (1996) studied the subsurface damage and machinability of AlSiC (10% SiC) composite material by conducting turning and facing tests. They reported that clustering of SiC particles was commonly found and these weakly bonded particles could be easily de-bonded and separated from the matrix. They also concluded that regardless of the cutting tool materials and cutting conditions the de-bonded particles along a machined surface can drop out and further damage it’s mating surface. Lin et al.(1998) studied the chip formation in turning AlSiC (20 % SiC) composite material using PCD tools and noticed that the addition of SiC particle reinforcement into the aluminum matrix has caused a reduction in its ductility and makes the material ideal for producing such semi-continuous chips.

Caroline et al (2000) conducted turning tests of AlSiC (25% SiC) composite and they observed that the general purpose cemented carbide inserts failed within seconds and TiN coated inserts failed within a minute.
They concluded that the PCD and the CVD (Chemical Vapor Deposited) diamond inserts performed better than the carbide inserts and were able to remove a greater amount of material. This is due to the higher hardness value of diamond tools in comparison with coated and uncoated carbide tool. Xiaoping Li and Seah (2001) studied the influence of SiC particles in the cutting mechanism of AlSiC (2.5, 5, 7.5, 10, 12 & 15% SiC) composites by turning using tungsten carbide tool. They concluded that the main mechanism of tool wear is abrasion, including two-body and three-body abrasion. In addition, they concluded that the abrasive wear of the tool is accelerated when the percentage of the reinforcement in the composite exceeds a critical value.

Yanming Quan and Bangyan Ye (2003) conducted turning tests on AlSiC (15 % SiC) composites using HSS and Carbide tools and observed that the superficial micro hardness of the machined composites was lower than that of the interior material. The reason provided by them was that the surface underwent the highest temperature during the machining and there were more machining defects in the surface layer. Forming of a Built up Edge (BUE) at low cutting speed was reported by Manna and Bhattacharayya (2003) during turning of AlSiC (15% SiC) composites with uncoated tungsten carbide (WC) fixed rhombic tools. Due to friction, high temperature and pressure, the particles of the AlSiC composites were adhering to the cutting tool materials and forming BUE. The formed BUE generated higher cutting force and poor surface finish.

Ibrahim Ciftci et al (2004) conducted turning experiments on AlSiC (8 & 16 % SiC) composite and concluded that the uncoated tool produced better surface finish ($R_a = 2.02\mu m$) at lower cutting speed (20 m/min) in comparison with poor finish (2.53 µm) at higher cutting speed (80 m/min). In addition, they noticed that the triple layer coating (TiC, Al$_2$O$_3$ and TiCN) of the cemented carbides tool was worn completely in the cutting
zone. Tamer Ozben et al (2008) discussed the machinability properties of AlSiC (5, 10, & 15% SiC) composites by turning, using TiN coated tungsten carbide tool. They observed that the surface roughness ($R_a$) values of turned composites were much higher than the traditional materials in the order of 3-4 $\mu$m. They also concluded that with the increase in the reinforcement ratio, flank wear of the tool increased.

2.1.1 Drilling Experiments with AlSiC Composites

COELHO et al (1995) conducted drilling and reaming experiments with aluminum based alloys including AlSiC (15 % SiC) composite material and observed that HSS drills produced only one hole in a 25 mm thick composite material where as both coated and uncoated cemented tungsten carbide (WC) drills produced 48 holes. But polycrystalline diamond (PCD) drills produced easily 300 holes. They also noticed that TiN coating of the WC drills did not improve the life of the tool and the coating was quickly breached in spite of offering a substantial initial advantage in abrasion resistance.

Existing coated tools, such as those coated with titanium nitride or titanium carbide which had shown advantages in the cutting of steel showed poor performance in machining AlSiC (20 % SiC) was the inference made by Durante et al (1997) after conducting turning, milling and drilling tests. They concluded that both the coated and uncoated Carbide drills had very short tool life in comparison with PCD drill which produced a drilled length of more than 12000 mm.

Basavarajappa et al (2007) conducted drilling experiments on AlSiC (15% SiC) composite and AlSiC (15% SiC and 3% Gr) graphite composite materials using coated carbide drill and multifaceted carbide drill. They noted that the surface roughness of both the materials decreased as
cutting speed is increased and the surface roughness increased as feed rate is increased. They concluded that the reason for the decreased surface roughness with increase in cutting speed was the burnishing and honing effect by the rubbing action of small SiC particles trapped between tool and work piece.

They also observed that the surface roughness obtained by using coated carbide drill is less than multifaceted carbide drill. This is due to the hard coating present over the surface of the tool which facilitates reduced built-up-edge formation. They also measured the variation in micro hardness of the machined surface and noticed that the variation is similar for both the work material but hardness values are less for graphite composite nearer to the surface when compared to AlSiC composite. This was attributed to the decrease in contact temperature due to the formation of graphite film between the tool and the work piece.

They concluded that conventional coated carbide tool performs better than multifaceted carbide drill in terms of improved surface finish and analysis of drilled surface shows the existence of micro cracks, particle pull out and shearing of particles.

2.2 MODELING, ANALYSIS AND OPTIMISATION TECHNIQUES

Researchers were applying various techniques for modeling machining processes in order to study and improve the machinability, surface finish of the work piece as well as for optimising the process parameters. While mathematical models can be used to predict performance measures, simpler empirical type equations are preferred, particularly for use by practicing engineers in a shop floor environment and for the optimisation of cutting conditions where the force, torque and power act as constraints. Some
of the modeling, analysis and optimisation technique used for process improvements are discussed in this chapter.

Lee et al (1998) modeled the drilling process using self-organized abductive networks to predict drilling performance (tool life, metal removal rate, thrust force and torque) for given process parameters (drill diameter, cutting speed and feed rate). They found out optimal drilling process parameters among the predicted values by employing simulated annealing optimisation algorithm. They conducted several drilling tests using the optimal process parameters to confirm the effectiveness of this approach and declared that the prediction error of the tool life was less than 10%.

Paulo Davim and Conceicao Anto´nio (2001) used PCD twist drill to machine AlSiC (20% SiC) and found at a constant cutting speed, the surface finish (Ra) varied between 0.25 and 1.2 \( \mu \text{m} \). The surface finish of the holes deteriorated with increasing feed rate but did not change significantly with varying cutting speed. They used experimental data to develop a numerical model based on a genetic search and the model proved to be effective in optimising the cutting conditions in drilling of particulate metal matrix composites. Pirtini and Lazoglu (2005) developed a mathematical model for drilling Aluminum (Al7039) using Carbide drills based on the mechanics and dynamics of the drilling process. The model was developed for the prediction of cutting forces and hole quality in terms of cylindricity, roundness and perpendicularity values. They also reported that the cutting forces are the main reason for the problems related to drilling in manufacturing such as form and surface errors and vibration etc.

Kug Weon Kim and Tae-Kil Ahn (2005) developed a theoretical model to predict thrust and torque without any experiment in drilling for known tool geometry, cutting condition and work material properties. They concluded that the predicted and experimental data were having good
correlation. Tash et al (2006) obtained experimental correlations between the metallurgical parameters and the machinability values for Heat-Treated 319 Alloys (drilling forces and moments as well as heat build up on the cutting tool edge) and analysed them using factorial analysis. They concluded that magnesium contributed most to the drilling forces and moments. Copper and Magnesium increase alloy hardness, improved surface finish and decrease the tendency of an alloy to built up on a cutting tool edge.

Palanikumar (2007) applied response surface methodology to model and analyze the process of turning Glass Fiber Reinforced Plastics (GFRP) composites for studying surface roughness. Influence of four important input variables such as cutting speed, feed rate, depth of cut and fiber orientation angle was analyzed and he concluded that the surface roughness increases with the increase of fiber orientation angle. Wang and Zhang (2008) developed predictive models using the ‘Unified-generalized mechanics of cutting approach’ for the thrust force and torque in drilling ASSAB 4340 high tensile steel bars. They used TiN coated HSS twist drills with modified plane rake face. They concluded that the model predictions yielded an average deviation of about 5% from the experimental results and confirmed the adequacy and predictive capability of the models.

Audy (2008) made computer-assisted modelling of drilling process using ‘Mechanics of cutting approach’ and concluded that this approach allowed to establish simpler predictive equations for forces and power in drilling. He drilled Bisalloy 360 steel with different drill geometry and tool surface coating. He confirmed that the predicted results produced statistically equal variances and mean at the 95% and higher confidence levels. Satishkumar and Asokan (2008) modified a mathematical model for CNC multi tool drilling process to incorporate non-traditional algorithms like Genetic Algorithm (GA), Simulated Annealing (SA) and Ants Colony
Optimisation (ACO). In this model, minimum production cost was taken as the objective and they concluded that minimum production cost is obtained in two stage drilling rather than single stage drilling. They also stated that the results emphasised the importance of using optimisation strategies rather than selecting the proper machining parameters using handbook recommendations.

Mustafa Kurt et al (2009) applied Taguchi methods to optimise surface finish and hole diameter accuracy in the dry drilling of Al2024 alloy using coated and uncoated HSS twist drills. They obtained minimum surface finish value as 3.58 µm and minimum hole diametric error value as 36.5403 µm by using Taguchi’s optimisation method.

Erol Kilickap et al (2011) conducted experiments for drilling AISI 1045 using TiN coated HSS tool. They modeled the drilling process using Response Surface Model (RSM) and optimised drilling process using Genetic Algorithm (GA). They reported optimum drilling parameters for the minimum surface roughness (Ra=1.89µm) value as cutting speed of 7.62 m/min, feed of 0.1mm/rev, and MQL (1). Balasubramanian and Ganapathy (2011) optimised the process parameters for Wire Electro Discharge Machining (WEDM) of Inconel 718 work material by applying integrated Grey based Taguchi method. They validated the optimised process parameters by conducting confirmation tests that showed an improvement of 0.1134 in Grey Relational Grading of the process.

Babu Aurtherson et al (2011) conducted experiments on AlSiC (10% SiC) composite material by Electrolytic in-process dressing (ELID) grinding machine using a cubic boron nitride wheel. The experiments were designed based on fractional factorial design with five factors at two levels each. They optimised machine parameter settings using Grey relation analysis and they concluded that this technique converted the
complicated multi response process into a single response Grey relational grade.

2.3 RECENT TRENDS IN CONVENTIONAL DRILLING AND FRICTION DRILLING

Drilling is one of the most commonly used machining processes in various industries and due to the increasing competitiveness in the market, cycle times of the drilling processes must be decreased along with maintaining close geometric tolerance requirements. Researchers were attempting many alternative techniques to improve drilling process and to avoid expensive tools. A promising technique among many attempted was the use of friction tool for drilling. All those research publications are discussed below.

Joshi et al (1999) established the utility of rotary carbide tools as an alternative to the stationary carbide tools in the intermittent turning of AlSiC (10% & 30% SiC) composites and found out that the cutting speed had a statistically predominant influence on the absolute magnitude of the tool flank wear. They also proposed a tool life model incorporating process and tool parameters along with proportion of reinforcement in the composite material. They concluded that the average difference between experimental and predicted data was 9.1%, considering all the runs.

Tero Stjernstoft (2004) developed a self-propelled rotary cutting tool made up of TiN coated sintered Carbide as an alternative to PCD tools, for turning AlSiC (15% SiC) composites and found out that rotary cutting tool provide higher material removal rate than conventional cemented carbide and PCD tooling. Rotary tool produced twice as good a surface as PCD tool. He also observed that the surface roughness variations in turning
AlSiC composites are small and independent of cutting speed and when turning AlSiC composites very large Built up Edge (BUE) occurred.

Influence of the cutting parameters on the quality of holes produced were studied by Nouari et al (2005) and they noticed that the uncoated drill produced holes with good dimensional accuracy while the coated drill produced holes with worse precision at lower cutting speeds (25 m/min). But at higher cutting speeds (165 m/min) coated drill gave better result compared to uncoated drill. They also concluded that similar surface finish were produced by both the coated and uncoated carbide drills while poor surface finish were produced by HSS drills on aluminum alloy (AA2024).

Miller et al (2006) conducted friction drilling experiments on Aluminum Al380 alloy using carbide tool and they analyzed the energy requirement, average power requirement, and peak power requirement for friction drilling at various spindle speeds. They justified that this analysis was useful in providing basic information of the machine requirements, such as the selection of the spindle speed and design of the fixture for work holding. They also observed that most of the energy in friction drilling converts into heat and transfers to the work piece and tool.

Miller et al (2007) studied the formation of cylindrical shaped bushing without significant radial fracture or petal formation in friction drilling of aluminum alloy Al380 using carbide tool. They concluded that the shape and quality of the bushing were improved at higher work piece temperature of 300 °C. They reported minimum tool wear after friction drilling 11,000 holes in AISI Steel work material of 1.5 mm thick using carbide tool and they also noted that the variation in diameter between hole numbers 1 and 11,000 as 0.29 mm, which was near the bottom of the bushing at a depth of 4.46 mm.
The performance of the sintered carbide friction drill was compared with the Tungsten carbide (WC) twist drill in drilling AISI-304 material by Han-Ming Chow et al (2008). They concluded that WC twist drill damaged seriously after three drilling runs but the friction drill showed very little wear after 60 runs and also produced good quality hole surface. They noticed fine grain size and compact structure on the surrounding area around drilling. Cheung et al (2008) conducted drilling experiments on Bohler M238 plastic mould steel by using TiN coated HSS drills with prior magnetic polishing treatment and unpolished sharp-coated drills. They concluded that the thrust force and the drilled hole surface roughness increased as feed rate increased.

Shin Min Lee et al (2009) friction drilled AISI 304 stainless steel and observed that surface temperature of drills increased with repeated drillings, due to the adhesion of tool to work piece, which enhanced the drill surface roughness and in turn raised the friction coefficient of the subsequent drilling. They also noticed that axial thrust force decreased with increase in number of holes made. They observed that higher the spindle speed, the greater the torque offering evidence to the linear relationship between spindle speed and torque.

A specific observation made by Miller et al (2005) for making holes in various materials including aluminum alloy 5052-H32 using carbide tool was that the maximum temperature generated in friction drilling was about 1/2 to 2/3 of melting temperature of the work piece. In addition, they observed that the frictional heating at the interface between the tool and work piece enabled the softening, deformation and displacement of work material and created a bushing surrounding the hole without generating chip or waste material. This fact was very suitable for drilling AlSiC work material using conventional tool material with satisfactory tool life. Extended tool life in comparison with conventional twist drill was expected out of this friction
drilling process since the tool material is not cutting the abrasives present in the AlSiC work material but pushes them to make holes. Hence, the tool materials used in the present work are made up of HSS, TiN Coated HSS and Carbide avoiding the expensive PCD or CBN tools.

The published literatures on friction drilling of AlSiC work material are very few. From the literature review, it is understood that the large number of research papers are focusing on minimizing tool wear by altering either tool geometry or tool material. Very few investigations are available related to prediction of machine tool requirement incorporating drilling process parameters and to correlate the influence of proportion of SiC particles in the composite and thickness of the composite work material.

2.4 MOTIVATION FOR THE PRESENT RESEARCH WORK

AlSiC work material is used in less quantity by industries mainly due to the difficulty in machining and maximum tool wear caused by the presence of abrasive SiC particles in the composite. Hard and expensive PCD or CBN tools are recommended by many researchers to drill AlSiC work material but these tools are not popular among the small and medium scale industries owing to the high tooling cost. More over the use of cutting fluid and disposal of chips lead to environmental pollution. This leads to find alternate drilling method to make holes in AlSiC work material.

The aim of this experimental work was to evaluate the potential for producing holes without secondary operations by friction drilling process and further to evaluate the performance of conventional tool materials like HSS, Coated HSS and Carbide for producing holes in AlSiC composite.

Hence, the present investigation was carried out to fabricate AlSiC work material and to study the influence of spindle speed, feed rate, wt % of
SiC and work material thickness on the circularity error, surface roughness of the drilled holes as well as the torque and thrust force requirement for making holes in AlSiC work material. The friction drilling process was analysed for any improvement and finally optimised for increasing the efficiency and reducing the cost of the process implementation.

2.5 SCOPE AND OBJECTIVES

Of all the aluminum matrix composites (AMC), particle reinforced AMC constitutes largest quantity of composites produced and utilised on volume and weight basis. AlSiC composites have been successfully used as components in automotive, aerospace, opto-mechanical assemblies and thermal management.

These sectors require AlSiC composite components with better surface integrity and higher dimensional accuracy. These requirements pose higher machining demands in conversion processes. Advances in tooling materials and tool design facilitated the use of conventional machining technology for machining AlSiC composites but using expensive PCD tool material. So far, no comprehensive analysis has been carried out in friction drilling of AlSiC composites and no optimisation of process parameters. Hence, there is a need for carrying out friction drilling studies on AlSiC composites with economical tool materials and more machining parameters. Also it is necessary to develop predictive models and empirical equation for describing friction drilling process in order to predict thrust force, torque, hole circularity error and surface roughness to facilitate easy industrial applications of this process.

Study of influence of various process parameters like spindle speed and tool feed rate, work piece composition of SiC particles and work piece thickness on the friction drilled hole quality will be useful in selection of
process parameters. Also the interactive influence of various process parameter combination on the friction drilled hole quality will be very useful in controlling the desired outcome of the process. In order to improve the tool life, surface finish of the work piece, and to reduce the hole circularity error, torque and thrust force in friction drilling of AlSiC composites, optimisation of these process parameters is essential.

Based on the above facts, objectives of the present investigation are set

- To fabricate the AlSiC work material with various weight percentage of SiC particles
- To design and develop suitable furnace with stirring facility for fabricating the AlSiC work material
- To fabricate indigenously friction drills as they are not readily available
- To investigate the effectiveness of tool materials like HSS, Carbide, and TiN coated HSS tools in making holes by friction drilling in AlSiC composites, using the performance indicators such as reduced thrust force, torque, hole circularity error and surface roughness.
- To develop an empirical model of the process that would predict the influence and interactive effect of the machining parameters like spindle speed, feed rate, weight percentage of SiC and thickness of work piece.
- To carry out the power and energy analysis of the friction drilling process, to provide the basic information for the machine requirements, such as the selection of the spindle speed and design of the fixture for work holding.
• To optimise the machining parameters using Grey relational grading method for effective implementation of the friction drilling process.

2.6 SUMMARY

The literatures related to drilling of composites, various materials were collected, and the important findings were critically reviewed.

From the literature review, it is understood that no comprehensive study is available on the influence of spindle speed, feed rate, wt % of SiC and work material thickness on the circularity error, surface roughness of the drilled holes as well as the torque and thrust force requirement for making these holes in AlSiC work material. Hence, it is important to carry out the study with said objective. The experimental details of the present research work are dealt in Chapter 3.