CHAPTER - 2

LITERATURE SURVEY

2.1 Introduction

End milling process is one of the most conventional and commonly used machining methods for material removal. Like face milling, end milling can easily machine a workpiece surface into a flat surface. It can also use appropriate fixtures to machine complicated workpieces such as aircraft engines. Since end milling process is the final stage in manufacturing a product, it is important to control the performance of this process [14, 2]. In connection with this study a complete literature survey was made and presented in this chapter.

The literature included information on end milling of LM25 Al/SiCp metal matrix composites using uncoated and coated solid carbide end mill cutters. Tool flank wear and surface roughness were observed during machining. This information served as a guideline in the course of this study.

Kumar Reddy et al. [115] studied quality of components produced during end milling of Al/SiC particulate metal matrix composites (PMMCs). The results showed that the presence of the reinforcement enhances the machinability in terms of both surface roughness and lower tendency to clog the cutting tool, when compared to a non-reinforced Al alloy. These results would serve to understand that the end milling machining process can provide better inputs to ensure better machining of Al/SiC PMMC and are expected to lead technological and economical gains with the use of Al/SiC PMMC in various industrial applications by replacing Al alloys.

Tamer Ozben et al. [88] investigated the mechanical properties and the effects of machining parameters on tool wear and surface roughness of silicon carbide particulate (SiCp) reinforced aluminum MMC for different volume fraction. It was observed that the
increase in reinforcement addition produced better mechanical properties such as impact toughness and hardness. The machinability properties of the selected material were studied and higher SiCp reinforcement produced a higher tool wear. The surface roughness was generally affected by feed rate and cutting speed. Sahin [102] studied the effect of different particle sizes of SiC and machinability properties of these Al-MMC materials. It was noticed that the hardness and density of Al-MMC increased by addition of SiC-p.

Suresh Kumar Reddy. N and P. Venkateswara Rao [112] discuss the advantages of dry machining over wet machining by selecting proper cutting tools and tool geometry. The optimization, carried out in their work, gives an opportunity for the user to select the best tool geometry and cutting condition so as to get the required surface quality. Their work emphasizes that proper selection of parameters eliminates the use of cutting fluids during machining and hence makes machining more environmental friendly.

Alauddin et al. [6] established a mathematical model that predicts the surface roughness of 190 BHN steel after end milling. The prediction model was expressed via cutting speed, feed rate and depth of cut. The researchers also used response surface methodology (RSM) to explore the effect of such cutting parameters as cutting speed, feed rate and depth of cut on surface roughness.

Alauddin et al. [3] also established a mathematical model for predicting the tool life in the end milling process of 190 BHN steel under dry cutting conditions. The model included the following variables: cutting speed, feed rate and axial depth of cut. It also verified the suitability of the prediction model via ANOVA.

Fuh and Hwang [43] used RSM to construct a model that can predict the milling force in end milling operations. They considered the speed of spindle rotation, feed per tooth and axial and radial depth of cut as the three major factors that affect the milling force. Comparison between the experimental data and the values predicted by this prediction model showed the model accuracy to be as high as 95%.
Lin [72] studied the issue of inverse heat conduction in end milling process. He used the inverse finite element method to estimate the transient tool face temperature and heat dissipation to workpiece during the end milling processes. The findings indicate that the results of the end milling of both steel and aluminum alloy derived by the numerical prediction method is a close match to the experimental result.

2.2 Uncoated and coated end mill cutters

Carbide end mill cutters are widely used in metal cutting industry for the cutting of various hard materials such as, alloy steels, die steels, high speed steels, bearing steels, white cast iron and graphite cast iron. The past few decades have witnessed great advancements in the development of these cutting tools. Coating is also used on cutting tools to provide improved lubrication at the tool/chip and tool/workpiece interfaces and to reduce friction, and consequently reduce the temperatures at the cutting edge. During machining, coated carbide tools ensure higher wear resistance, lower heat generation and lower cutting forces, thus enabling them to perform better at higher cutting conditions than their uncoated counterparts [41]. The use of coated tools are becoming increasingly demanding among the other tool materials. More than 40% of all cutting tools are coated in modern industry today.

Che Haron et al [18] say that found that the straight-cemented carbide tools were suitable used in turning Ti-6Al-4V. The hard coating layer(s) on the surface of cutting tools can reduce the tool wear progression on the flank face. The thin layer(s) from TiN and TiCN material reduced the friction between the cutting edge and work piece materials, so it will produce a smooth surface of titanium alloys and less surface damages.

Nalbant et al. [85] used Taguchi method to find optimum cutting parameters for surface roughness in turning of AISI 1030 carbon steel bars using TiN coated tools. Three cutting parameters namely, insert radius, feed rate, and depth of cut are optimized with considerations of surface roughness. In turning, use of greater insert radius, low feed
rate and low depth of cut are recommended to obtain better surface roughness for the specific test range.

Ghani et al. [45] applied Taguchi method to find optimum cutting parameters for surface roughness and cutting force in end milling when machining hardened steel AISI H13 with TiN coated P10 carbide insert tool under semi-finishing and finishing conditions of high speed cutting. The milling parameters evaluated are cutting speed, feed rate, and depth of cut. In end milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtain better surface roughness and low cutting force.

Liew et. al.[71] found that while machining AISI 420SS coated tools exhibit higher wear resistance than uncoated one, highest flank wear was found at the flank face near the DOC zone. Abrasive wear take place at low cutting speeds as the work material is hard enough to plough into the tool.

Endrino et. al.[37] have reported his study on cutting SS with the use of Al based coating, having higher oxidation resistance due to formation of aluminum oxide surface layers. The nano-crystalline AlTiN coating outperformed the fine-grained AlTiN coating within the post running-in (stable) wear stage that almost doubled the tool life. As for the AlCrN-based coatings, the AlCrNbN coating with (200) texture performs significantly better than the AlCrN coating.

Shao et. al.[109] have reported the work on end milling of 3% Co–12% Cr heat resistance stainless steel. They have found that small rake angles give longer tool life and large rake gives steady machined surface integrity. Coating effectively decreases the formation of adhesive layer on tool and no BUE observed on inserts.

Abou-El-Hussein et al.[1] has done the experiments using AISI304 stainless steel. They had observed that increase in cutting speed caused a dramatic reduction in tool life and feed variation at high cutting speeds had small effect on tool life.
Alauddin et al. [4] studied the wear progression of carbide end mill inserts when dry machining hot forged and annealed Inconel 718 alloy (260 BHN hardness). Inconel 718 alloy was machined using full and half immersion milling techniques during up and down milling. Maximum and localized flank wear were found to be the main wear criterion. Test runs were repeated five times under identical cutting conditions and the corresponding arithmetic mean used to plot the tool wear progression. There were variations observed in the flank wear progression curves over time even if the same cutting conditions were used.

Bergman et al. [12] investigated the machinability of Al-MMC by cutting tools. For this purpose they used HSS and coated–uncoated hard metal cutting tools (WC). It has been emphasized that coated WC tools are more durable than HSS and uncoated tools, and the reinforcement element in MMC is an important parameter for wear of cutting tool.

Ibrahim Ciftci et al. [54] studied the influence of different particle size of SiC and cutting speed on tool wear and surface roughness during machining of Al/SiC MMC using cubic boron nitride (CBN) cutting tool. The results showed that tool wear was mainly observed on flank side with a strong influence by abrasive reinforcement.

Tool wear is a change of shape of tool from its original shape resulting from the gradual loss of tool material. Thus tool wear becomes an important parameter in the metal cutting process.

Li and Seah [70] investigated the machinability of MMC that contains different amounts of SiC, especially in terms of the size and ratio of particle reinforcement. According to the results, when the percentage of reinforcement element in MMC exceeds a critical point, the wear in settings will increase. Ciftci et al [54] studied the effect of SiC particle size on the turning force and tool wear, and revealed that for high particle size (above 45 microns) CBN tools aren’t applied and PCD tool should be employed. Ozben et al [117] studied the machinability of Al/SiC-p in turning operation which was
produced by casting method by adding 5, 10 and 15 wt% of SiC-p. Results demonstrate that feed rate is not as effective as cutting speed on tool wear.

Kilickap et al [65] studied tool wear and surface roughness in Al-5% SiC turning operations with uncoated and TiN-coated carbide tool. The results reveal that the flank wear in coated tool is less than that in uncoated tool. Gallab and Sklad [32] evaluated the machinability of aluminum reinforced with 20% silicon carbide. In dry turning operations, the effect of machining parameters on tool wear and surface quality was surveyed. They came to the conclusion that high cutting speed and depth of cut improve surface roughness.

Manna and Bhattacharayya [76] studied the machinability of cast Al/SiC-p with 15% of SiC particles. The fabrication method which they used for making the MMC samples was casting and the amount of reinforcing phase in their MMC was 15%. They found that the wear rate increases at lower cutting speed because of the built up edge. Li and Seah [70] studied the effect of size and volume content of SiC particles in machinability of MMC. According to their results, when the amount of reinforcement is more than some critical percentage, the tool wear is more severe. Ciftci et al. [54] examined tool wear in machining SiC-p reinforced Al-MMC and reported that coated carbide cutting tool produced a longer tool life, but uncoated type provided a better surface quality.

Surface roughness is one of the important factors for evaluating workpiece quality during the machining process because the quality of surface roughness affects the functional characteristics of the workpiece such as compatibility, fatigue resistance and surface friction. The factors that affect the surface roughness during the end milling process include tool geometry, feed rate, depth of cut and cutting speed.

Alauddin et al. [5] where a surface roughness model is developed for end milling of 190 BHN steel and Inconel 718. It was found that first- and second-order models constructed along with contour plots, easily enable the selection of the proper
combination of cutting speed and feed to increase the metal removal rate without sacrificing surface quality.

Palanikumar. K [89] discusses the use of Taguchi and response surface methodologies for minimizing the surface roughness in machining glass fiber reinforced (GFRP) plastics with a polycrystalline diamond (PCD) tool. The experiments were conducted using Taguchi’s experimental design technique. He concluded that for achieving good surface finish on the GFRP work piece, high cutting speed, high depth of cut and lower feeds are preferred.

El-Gallab and Reddy [33-36] have emphasized on the surface roughness in their study on the machinability of the 20% of SiC-p reinforced Al-MMC. By performing dry turning tests with different cutting parameters, they have investigated the effect of processing parameters on surface roughness. They have found that large chip depths and high cutting speeds reduce the surface roughness.

Abou-El-Hussein et al. [1] has done the experiments using AISI304 stainless steel. They had observed that increase in cutting speed caused a dramatic reduction in tool life and feed variation at high cutting speeds had small affect on tool life. After all the discussion done by various researchers it was found that no one has handled SS above 150 m/min, using end milling cutter. Also there is no sufficient data available about the effect of feed, as well as surface finish of the machined surface.

2.3 Modeling and Optimization

Fuh and Wang [42] studied a predicted milling force model for end milling operation. They found that the proposed predicted milling force had a good correlation with experimental values and is suitable for practical engineering application, since the milling force analyzed in the model has already encompassed the structural characteristics of the milling machine and the real conditions of the tool and workpiece.

Suresh et al. [113] adopted a two stage approach towards optimizing for surface roughness. Experimental results were used to build two mathematical models for surface
roughness by a regression method according to RSM. The second-order mathematical model obtained was then taken as an objective function and optimized with a GA to obtain the machining conditions for a desired surface finish.

Choudhury and el-Baradie [22] found that response surface methodology combined with the factorial design of experiments were useful techniques for tool life testing. Relatively, a small number of designed experiments are required to generate much useful information that is used to develop the predicting equation for tool life.

Mansour and Abdalla [77] developed a surface roughness model for end milling of a semi-free cutting carbon casehardened steel. They investigated a first-order equation covering the speed range 30 – 35 m/min and a second order generation equation covering the speed range 24 – 38 m/min. They suggest that an increase in either the feed or the axial depth of cut increases the surface roughness, while an increase in the cutting speed decreases the surface roughness.

S. Sharif et al [105] used factorial design coupled with response surface methodology in developing the surface roughness model in relation to the primary machining variables such as cutting speed, feed, and radial rake angle. Ghani [45] used Taguchi optimization methodology to optimize cutting parameters while end milling AISI H13 steel with TiN coated P10 carbide insert under dry cutting condition. The milling parameters to be optimization were cutting speed, feed rate and depth of cut. The results of the study showed that low resultant forces and a good surface finish can be obtained when using a high speed, a low feed and a low depth of cut.

Palanisamy et al [93] says that sudden failure of cutting tools lead to loss of productivity, rejection of Parts and consequential economic losses. Chiang et al [19] have performed experiment using standard response surface methodology (RSM) design called a central composite design (CCD). The factors considered are the quantity, diameter, and area fraction of spheroidal graphite particle. The performance of rapidly resolidified layer in terms of the layer thickness and ridge density are response variables investigated. The quadratic model was developed for the rapidly solidified layer thickness and ridge density
for the ferritic SG cast iron in the EDM process. The results of analysis of variance (ANOVA) indicate that the proposed mathematical model obtained can adequately describe the performance within the limits of the factors being studied.

2.4 Parameter optimization

Traditionally, the selection of the most favorable process parameters was based on experience or handbook values, which produced inconsistent machining performance. However, the optimization of parameters now relies on process analysis to identify the effect of operating variables on achieving the desired machining characteristics.

Ramakrishnan et al used Taguchi approach to analyze EDM of Inconel 718. Experiments were performed under different cutting conditions of pulse on time, delay time, wire feed speed, and ignition current. The responses were optimized concurrently using multi response signal-to-noise (S/N) ratio [99].

Dhara et al [30] used RSM optimization technique to optimize the process parameters such as lamp current, pulse frequency, pulse width and air pressure. The objectives were depth of groove and recast layer. In the first step optimization of individual responses has been carried out subjected to different conditions. Second step optimization of both responses has been carried out subjected to different conditions at a time. In this technique composite desirability is close to 1, it can be concluded that all parameters are with their working range.

Karthikeyan et al developed a polynomial model for the various EDM characteristics such as metal removal rate, tool wear rate and surface roughness in terms of the process parameters such as volume fraction of SiC, current and pulse time. The models were used to optimize the EDM characteristics using non-linear goal programming [63].

2.5 Multi objective optimization (NSGA-II)

Genetic algorithms, first specified by John Holland in the early 1970’s [51], are becoming an important tool for combinational optimization, function optimization, and
machine learning. GAs is a kind of (i) stochastic search, (ii) multi-point search, (iii) direct search, and (iv) parallel search. These characteristic features of GAs contribute robustness of the algorithms. Genetic algorithms have been mainly applied to single objective optimization problems. In order to handle multi objective optimization problems, the objective functions should be combined into a scalar fitness function. The characteristic features of GAs utilized in Schaffer’s work [103] are extended to multi objective optimization problems by Murata & Ishibuchi [83] and Dev et al [29]. They have described the ability of GAs to address multi objective optimization problems.

Jain et al optimized the three most important ECM process parameters namely tool feed rate, electrolyte flow velocity, and applied voltage with an objective to minimize geometrical inaccuracy subjected to temperature, choking, and passivity constraints using real-coded genetic algorithms. The formulated optimization model was found to be too complex to solve using traditional optimization techniques without any approximation. Therefore, it was solved using real-coded genetic algorithms which did not require any approximation or linearization of the objective function and constraints. The obtained optimization results were verified graphically and from the theoretical aspects. Comparison of the obtained results with that of the past studies has shown improvement in terms of geometrical accuracy [55].

In a single objective optimization, there exists only one solution. But in case of multiple objectives, there may not exist one solution, which is the best with respect to all objectives. In end milling process, it is difficult to find a single optimal combination of process parameters for the performance parameters, as the process parameters influence them differently. Hence, there is a need for a multi objective optimization method to arrive at the solutions to this problem. Classical methods for solving multi objective problem suffer from drawback. These methods transform the multi objective problem into single objective by assigning some weights based on their relative importance. Also these classical methods fail when the function becomes discontinuous. Since GA is a good tool for solving multi objective optimization and its works with a population of points, it seems natural to use multi objective GA in end milling process to determine the optimal solution point from best performance to capture a number of solutions.
simultaneously. Multi-objective genetic algorithm (MOGA), Vector evaluated genetic algorithm (VEGA), Non dominated sorting genetic algorithm (NSGA-II) are examples of GA based multi objective solution methods. In the present work, non dominated Sorting Genetic Algorithm-II (NSGA-II) has been used to obtain the optimal combination of process parameters [100].

Shajan Kuriakose, Shanmugam studied the application of a multiple regression model to represent relationship between input and output variables and a multi objective optimization method based on a non dominated sorting genetic algorithm (NSGA) is used to optimize wire EDM process and a non dominated solution set is obtained. The sorting procedure employs a fitness assignment scheme which prepares non dominated solution and uses a sharing strategy which preserves diversity among the solutions; also none of the solutions in the pareto optimal set is better than any other solution in the set. The process engineer can select optimal combination of parameters from the pareto optimal solution set, depending on the requirement [68].

Palanikumar et al investigated the optimization of machining characteristics of glass fiber reinforced plastic (GFRP) composites using NSGA-II algorithm. The parameters chosen were cutting speed, feed and depth of cut. The responses were metal removal rate, tool flank wear and average surface roughness. It can be asserted that most of the Pareto optimal points are concentrated on high cutting speed, low feed and at a high depth of cut; hence these can be treated as optimal points for achieving better multiple performances. The choice of one solution over the others depends on the process engineer’s requirements. If what is required is a higher metal removal rate, or a better surface finish, or a minimal tool flank wear, a suitable combination of variables can be selected accordingly. This method will help to increase production rates considerably by reducing machining time [91].

Kanagarajan et al have studied the EDM of WC/Co composites. The objective was to study the EDM process parameters such as pulse current, pulse on time, electrode rotation and flushing pressure on metal removal rate and surface roughness. EDM process parameters were optimized by using non dominated sorting genetic algorithm
Mandal et al have developed a mathematical model using artificial neural network (ANN) with back propagation algorithm and also use a multi-objective optimization method, non-dominated sorting genetic algorithm-II to optimize the process parameters of wire electro chemical machining of C40 Steel. Various ANN architecture have been studied, and 3-10-10-2 is found to be the best architecture, with learning rate and momentum coefficient as 0.6, having mean prediction error is as low as 3.06% and NSGA-II results indicates, values obtained from the optimization technique are in close agreement with the experimental values for more or less the same parameter settings. [75].

### 2.6 Problem Formulation

End milling is a method to conventional machining methods. End milling has tremendous potential on account of the versatility of its applications and it is expected that it will be successfully and commercially utilized in modern industries. End milling is able to machine a material irrespective of hardness and is able to produce complex shapes. A quality surface is produced without residual stress or surface damage to the microstructure. Good surface integrity is frequently required for metal matrix components. The machining of metal matrix composites with good surface integrity is becoming a key technology in engineering applications.

The large number of previous articles shows that the modeling of the end milling process can be regarded as a problem of correlating the input parameters of the process with its output parameters. This can be dealt with by means of response surface methodology (RSM), which is an empirical modeling approach for determining the relationship between various process parameters and responses with the various desired criteria and searching the significance of these process parameters on the coupled responses. It is a sequential experimentation strategy for building and optimizing the
empirical model. Sensitivity analysis has been investigated to represent the effectiveness of the processing parameters on these empirical equations and showed that the change of process parameters affects the tool flank wear and surface roughness.

In end milling process, it is difficult to find a single optimal combination of process parameters for the performance parameters, as the process parameters influence them differently. Hence, there is a need for a multi objective optimization method to arrive at the solutions to this problem. In the present work, non dominated Sorting Genetic Algorithm-II (NSGA-II) has been used to obtain the optimal combination of process parameters.

In this research tool flank wear and surface roughness of different end mill cutters (uncoated and coated solid carbide end mill) in the machining of the various mass fraction of SiCp particle-reinforced LM25 aluminum alloy composites which were produced by a stir casting method (Al/5%SiCp, Al/10%SiCp, Al/15% SiCp, Al/20%SiCp and Al/25% SiCp) are investigated. The average size of the silicon carbide is 25µm. It is having very good mechanical properties compared to other engineering materials.

2.7 Objectives of this Research

The following are the objectives of the present Research.

1. LM25 Al alloy with 5, 10, 15, 20 and 25 mass percentages of silicon carbide particulate (SiC_p) composites, manufacture through stir casting method.
2. End milling has been carried out using uncoated solid carbide, titanium nitride coated carbide and cubic boron nitride end mill cutters.
4. Identification of most influential input parameters on End milling characteristics through response surface methodology (RSM).
5. Optimization of End milling characteristics using RSM and non-dominated sorting genetic algorithm (NSGA-II).
Figure 2.1 Plan of work

Manufacturing MMC -LM25 Al-5, 10, 15, 20, 25 % SiCₚ

End milling with uncoated solid carbide, TiN coated carbide, CBN coated carbide tool

Identify the input and output parameters

Process parameters
- Spindle Speed
- Feed rate

Responses
- Tool flank wear
- Surface roughness

Developing the design matrix using RSM

Conducting the experiment as per design matrix and recording the response

Statistical analysis of data and development of mathematical models

Optimization of process parameters using RSM and NSGA -II

Validation of developed model