CHAPTER 2

LITERATURE REVIEW

2.1 THRUST FORCE AND TORQUE IN COMPOSITE DRILLING

Karri [37] on realizing the difficulty in achieving the accurate values of thrust force and torque in drilling operations using conventional mechanics of metal cutting approach, attempted an alternative approach of applying ANN. Through this method he obtained results which had values within 2% deviation. He considered the eight critical inputs.

Tsao et al., [38] conducted the drilling process on a 5mm thick carbon fiber reinforced polymer. They used three varieties of drills such as candle stick drill, twist drill and saw drill. The input parameters selected are feed rate, spindle speed and drill diameter and the measured output parameters are thrust force and delamination. They proposed a mathematical model to explain the effect of drill tip and eccentricity over the delamination. They noticed that the thrust can be reduced by minimizing the chisel edge effect. In order to estimate the delamination damage, authors calculated the delamination factor as the ratio of maximum damaged diameter to nominal drill diameter. The ultrasonic scanning was used to obtain the images for delamination estimation. The results of the experiment reveal that feed rate and drill diameter are the parameters that affect the delamination significantly. They also observed that the damage caused by twist drill is more than the damage caused by the candle stick drill. This may be due to the differences in the cutting edges of the drills.

Kashaba et al., [39] carried out the experiments on Glass Fiber Reinforced Plastic (GFRP) composites to estimate the thrust force and torque developed during machining of composite materials which are made of different matrix materials
(epoxy and polyester resin) and reinforcing shapes (chopped, cross winding, continuous winding and woven). The authors concluded that during machining of woven composite with various matrix materials and the matrix material had a negligible effect on thrust force and torque. They also noticed the higher torque when drilling the polyester composite. Due to the higher temperature produced by increase in heat generation, there is a decrement in the thrust force and torque as cutting speed increases.

El-Sonbaty et al., [40] conducted the drilling experiment with twist drills of diameter 8, 9, 10, 11, 12 and 13 mm in order to investigate the effect of drill size over thrust and torque in the drilling of glass fiber reinforced plastic. The constant speed of 875 rpm was used. The feed rates of 0.1, 0.23 and 0.5 mm/rev were considered. They identified that, the thrust and torque increases with increase in drill diameter because of the increment in the shear area. They also noticed elevation in thrust force and torque as the spindle speed and feed rate increases.

Bhatnagar et al., [41] from their experiment conducted on the composite laminate of glass fiber reinforced plastic, identified that the eight facet and Jo-drills produce the lower thrust force and torque. Hence, they suggested the use of these drills in the drilling of composite materials. The experimental results reveal that the drill with special geometry such as core drills, multifaceted drills, candle stick drills, parabolic drills etc., with modification of drill geometry such as chisel length, rake, clearance, point and helix angle are preferred when the drilling operation carried out with the tungsten carbide tools. Standard twist drill and special geometry drills perform equally in case of HSS drills.

Xinwang et al., [42] investigated the thrust force and torque in the case of vibration drilling over glass fiber reinforced plastics and carbon fiber reinforced
plastics composite materials using HSS drills and carbide drills. For both drills they observed the similar nature curves for the thrust force. During their experiments, they noticed the increment in the thrust force with the increment in the depth of the hole. They also observed the increment in the thrust force as the feed rate increases. This is because there is an increment in the material removal rate as the feed rate increases.

Dong –Woo et al., [43] conducted the experiments over step-faced micro drilling. They tried to achieve the minimum thrust force through Design Of Experiment (DOE) method. They optimized three cutting parameters such as feed rate, step-feed and cutting speed to obtain minimum thrust force and the optimization was done on the basis of DOE method. By using DOE they design the experiments and used $L_{27}(3^3)$ orthogonal array for the conduction of the experiments. They used ANOVA to analyze the results. They made the following conclusions based on their experimental results:

- ANOVA can be effectively used to predict the influence of feed rate, step feed and spindle speed over the thrust force in step-feed micro drilling process. Further, they also concluded that, in step-feed micro drilling feed rate is the most influential factor on the thrust force.

- Depending on the objectives of the experimentation, other parameters such as drill life, roughness, circularity of holes etc. could also be optimized by using the ANOVA method.

Velayudam et al., [44] carried out the experiment on a high volume fraction composite material in order to evaluate the effect of process parameters on thrust force and torque. The considered volume fraction was 65%. They also predicted the influence of number of holes drilled on the variation of the drill size. They identified that as the feed rate increases, there is increase in the thrust force and torque.
Palanikumara et al., [45] did the assessment of some factors which influences tool wear in the machining of glass fiber reinforced plastics using coated cemented carbide tools. Based on the results obtained authors made the following comments:

- Tool flank wear was greatly influenced by cutting speed, followed by feed rate.
- In the drilling process of GFRP composite materials, the interactions also play some role in deciding the tool wear. The interaction between cutting speed and depth of cut has more influence on tool wear in the drilling of GFRP composites.
- Using response table, effect graph, normal probability plot, interaction graphs and ANOVA technique, process parameters are optimized to obtain minimum flank wear.
- The validity of the optimization procedure followed in the present work is limited to the range of factors considered for the experimentation.

2.2 DELAMINATION IN COMPOSITE DRILLING

Piquet et al., [46] conducted the drilling experiments on the thin carbon/epoxy composite laminate in order to evaluate the quality of the drilled hole. They attribute the lower level of delamination to the smaller contact length between the special geometry drill and the hole. In their study they had used two tools of different geometry. The first one was the twist drill of 4.8mm diameter, twist angle of 25°, rake and clearance angles of 6°. The second one was the drill with special geometry of 4.8mm diameter, three cutting edges, twist and rake angles of 0°, and clearance angle of 6°. Both the drills used had major cutting edge angle of 59°. Further, they observed the superior performance by special geometry drill which confirms that the quality of the hole was significantly affected by the principal cutting edge.
Aoyama et al., [47] carried out the drilling experiments on a printed circuit board which is made of glass fiber reinforced plastic. The thickness of the plate was 1.6mm and the diameter of the drill bit used was 1mm. The cutting speed used was 15.7m/min and the feed rate was 0.063mm/rev. The aim of the work was to study the damage occurred during drilling of small size holes. They observed the larger damage when the angle between the cutting edge ad fiber directions was 45°. Further, researchers also noticed an almost linear relationship between the surface roughness and damage width.

Lachaud et al., [48] conducted the drilling experiments over the polymeric composites in order to estimate the delamination. They divided the delamination into four categories such as delamination during entry of the drill, defects due to drill geometry, damage due to temperature, and damage during the exit of the drill. They observed that, the delamination during entry of the drill is not always present. The damage related to tool geometry is always related to the angle between the cutting edge and the fiber orientation. Friction between the drill and wall of the hole is the principal reason for the temperature related damages. Delamination during exit is probably because of the fact that during this stage all fibers are not cut and thus develops the normal stress which opens the matrix/fiber interface. The authors also predicted that the drills which are used for the metal cutting are not suitable for machining of polymeric composites.

Devim et al., [49] predicted that during drilling process the delamination occurs during the entry and exit of the drill are affected by many process parameters. During the entry of the drill into the laminate the delamination was most affected by feed rate but, at the drill exit, the cutting speed is the parameter which affects the delamination more. They conducted the experiments with Tungsten carbide drills of
same diameter which had the two types of geometries. The test specimen used was the carbon fiber reinforced plastics (CFRP) composite laminate. They observed that for brad and spur drill, the cutting speed and feed rate influence the delamination negligibly and straight shank drill, the delamination factor was elevated as the cutting speed and feed rate were increased.

Tsao et al., [50] conducted the drilling experiments in order to estimate the delamination factor in the drilling of carbon fiber reinforced plastics (CFRP) composite material. They conducted the drilling experiments at various machining conditions and the delamination was measured using an ultrasonic C-Scan. The experimental results reveal that the feed rate and the drill diameters are the parameters which contribute more for the overall performance. They established the correlation between the feed rate, spindle speed and drill diameter with delamination induced in the (CFRP) composite laminate. They obtained the correlation by multi-regression and also made the comparison with the experimental results.

Davim et al., [51] tested the performance of two distinct tool material and three geometries such as helical flute drill of HSS and helical flute drill of K10. The diameter of the tool was 5mm and the point angle was 118°. The drilling experiment was conducted on a 4mm thick carbon fiber reinforced plastic. The independent input parameters selected were feed rates of 0.04, 0.08 and 0.15mm/rev. and the cutting speeds were 16, 24 and 32m/min. The response parameter was the delamination. The delamination was measured with the help of a Toolmaker’s microscope. The results of the experiments indicate that the delamination increases with increase in feed rate and cutting speed. They also observed that, the cemented tungsten carbide drill shows better performance than the HSS steel material under the same machining conditions. The performance of the twist drill was better than the performance of the
four flute drill. The wear of the carbide drill was very less when compared to the wear of the HSS drill throughout the work.

Capello et al., [52] conducted the experiments to study the effect of work piece damping over delamination in the drilling of thin composite material. He studied the influence of feed rate on the delamination factor in the drilling process of glass fiber reinforced plastic. He noticed that there was no delamination under low feed machining condition. The actual back rake angle becomes negative in the high feed machining condition. Thus, at this state the material pushing instead of hearing which increases the delamination.

Tsao [53] The effects of drilling parameters such as diameter ratio, feed rate and spindle speed on the thrust force and delamination in the drilling of carbon fiber reinforced plastic (CFRP) laminates using step core drill were experimentally investigated by this researcher. This research work reveals that, the drill diameter ratio and feed rate are the parameters which are have the most significant influence on the overall performance. Step-core drill generates the highest thrust during drilling process. Based on the results obtained the author made the following conclusions:

- The thrust generated by step-core saw drill is more when compared with other drills. The diameter ratio of step-core drill has influence on the thrust force in the drilling of composite material.
- Diameter ratio and the feed rate are the major cutting parameters affecting the thrust force. There is an increase in the thrust force with decrease in the diameter ratio and increase in feed rate.

Nilanjan Das Chakladaret et al., [54] did the experimental and finite element study on drilling of woven glass fiber reinforced plastics. Different speed-feed combinations were considered to study the delamination at various machining
conditions. They applied the finite element as numerical tool to estimate the drilling responses. A planned combination of speed-feed was considered for simulation and validation experiments. The results reveal that for the same number the wear of the carbide drill bit was much lesser than wear of the HSS drill in comparison.

Compos Rubio et al., [55] conducted the experiments in order to investigate effect of various drill geometries of cemented carbide drills in drilling of glass fiber reinforced laminates with high speed. The conclusions made by the authors are as follows:

- Within the range considered for the test, the delamination decreases as the spindle speed increases. This is due to fact that cutting temperature elevated with spindle speed promotes the softening of the matrix material and induces less delamination.
- To estimate the delamination factor, if the damaged area is measured by digital image processing method, it allows more realistic assessment of drilling induced damage.

2.3 SURFACE ROUGHNESS IN COMPOSITE DRILLING

Paulo Davin et al., [56] conducted the turning experiment. The objective of the study is to establish the correlation between the cutting speed, feed and depth of cut with surface roughness. They used the multiple regression analysis approach to obtain the relationship. They studied about the influence of cutting conditions over the surface roughness. The plan of experiments for this study was made by using Taguchi technique. In the present study the surface roughness of the work piece was measured using two different profilometers.

Hassan Oktem et al., [57] carried out the milling operation on the mould surface of 7075-T6 aluminum material. They selected feed, cutting speed, axial-
radial depth of cut and machining tolerances as the process parameters. They conducted the series of experiments to measure the roughness. The experiments were conducted on the basis of full factorial design. The optimal levels of process parameters to achieve low surface roughness and the effect of process parameters over surface roughness were obtained by using Taguchi orthogonal arrays, signal to noise ratio and analysis of variance (ANOVA).

Palanikumar [58] performed the machining experiments on the glass fiber reinforced plastics using polycrystalline diamond (PCD) tool. He utilized the Taguchi’s experimental design techniques to design the experiments. Cutting speed, feed and depth of cut were the considered independent design parameters. The Taguchi and response surface methodologies were used to predict the effect of considered independent parameters over the surface roughness and also to evaluate the optimum cutting condition to achieve the minimum surface roughness.

Krishnaraj et al., [59] have tested the drill geometry over thrust force and hole quality in drilling of glass/epoxy laminates. He tested the performance of twist, zircov and multifaceted (MFD) drills. He made the comparison between the results obtained by each type drills. The results show that compared to other two drills, the thrust force produced by zircov drill was less, thus resulted the better surface finish. The results also reveal that the delamination generated by MFD was less when compared with other two geometries. They used ANOVA to predict the effect of drill geometry, spindle speed and feed rate on the thrust force, delamination and surface roughness.

Tsao et al., [60] predicted and evaluated the thrust force and surface roughness when candle stick drill was used in drilling of composite material. To conduct the experiments and analyze the results they applied Taguchi and neural
network methods. They also simulated the process parameters using Radial Basis Function Network (RBFN). The correlation between the input and response parameters was obtained by multi-variable regression analysis method and RBFN method. The results obtained by these two methods are compared with the experimental results. The RBFN results indicated the better accuracy than regression analysis.

Jinsoo Kim et al., [61] developed a drilling Burr control chart, based on the experimental data, is a tool for prediction and control of drilling burrs. Burr classification was carried out based on the geometric characteristics, burr formation mechanisms and sizes of the burrs. New parameters consisting of cutting condition variables and drill diameter were developed, and used to show unique distributions of the burr types. Burr types and the resultant burr size showed great dependence on the new parameters regardless of the drill diameters.

Sanjay et al., [62] proposed a back propagation neural network model in order to predict the surface roughness in drilling process. The inputs used for the artificial neural network (ANN) model are drill diameter, feed, speed and machine time. They found the good agreement between the experimental results and the predicted results.

2.4 APPLICATION OF DOE, RSM AND ANN IN COMPOSITE DRILLING

Benardos et al., [63] performed the face milling operation by using CNC machine. The data collected during the experimentation were used for the training and checking of the neural networks performance. The experiments were designed on the basis of Taguchi method. The independent factors considered for the present experiment were depth of cut, feed rate per tooth, the cutting speed, the engagement & wear of the cutting tool, the use of the cutting fluid and the three components of the cutting force. The response parameter was the surface roughness. They have
developed the neural network model for the prediction of surface roughness and for this they used feed forward artificial neural networks (ANN) trained with Levenberg-Marquardt algorithm. They also identified the most influencing parameter using DOE principles.

Choudhury et al., [64] carried out the turning experiment which is designed on the basis of Design Of Experiment (DOE) technique. The input variables considered for the investigation are cutting speed, feed and depth of cut. The response parameters are the flank wear, surface finish and cutting zone temperature. They predicted the all responses through DOE method and also neural network (NN) program. The closeness between the experimental values and the values obtained by both techniques was predicted by comparison method. In order to measure the flank wear directly through the measurement of surface roughness and cutting zone temperature, the relationship between the surface roughness and the flank wear and also between the temperature and flank wear were predicted.

Jae-Seob-Kwak [65] measured the geometric error in the surface grinding operation by applying Taguchi and Response Surface Methodology (RSM). The author identified that the thermal effect and the stiffness of the grinding system effect the geometric error significantly in the surface grinding process. He noticed that selection of the grinding parameters was very important to minimize the geometric error. He evaluated the effect of grinding parameters on the geometric error and predicted the optimum grinding conditions to minimize the geometric error. He also developed a second order response model for the geometric error. He conducted the confirmation test at optimum machining conditions and observed the accuracy of the response surface model developed.
Petropoulos et al., [66] used Response Surface Methodology (RSM) to predict the effect of process parameters in the drilling of glass fiber reinforced plastics. They investigated the effect of feed rate, cutting speed and also two different drill types such as helical and Brad & spur drill on the thrust force, torque, delamination and surface roughness in the drilling of polymeric composite materials. They also developed the predictive empirical models for these responses through RSM and analysis of variance (ANOVA). The models which were in the quadratic polynomial form had exhibited the excellent correlation between the input and output parameters.

Edoardo Capello et al., [67] investigate the effect of the drilling on the residual mechanical behavior of glass fiber reinforced plastic (GFRP) laminates when the hole is subjected to bearing load. The damage is described at the macro level (delaminated area) and at the micro level (cracks, fiber-matrix debonding, etc). The design of experiments and Analysis of Variance techniques are used in order to determine the statistical influence on the drilling parameters on the delamination area. Moreover, the effects of drilling with or without a support beneath the specimens are analyzed and discussed. Results indicate that the degree of peel-up delamination depends on the feed rate and on the helix angle of the twist drill. Push down delamination is mainly affected by the feed rate, by the presence of support beneath the specimen and by the twist drill temperature.

Singh et al., [68] developed a neural network model in order to predict the flank wear. Speed, feed, thrust force, torque and drill diameter were considered as input parameters and the flank wear was considered as the measured parameter. Out of 49 data obtained, 34 were used for testing. The results of neural network show the good agreement with the experimental results.
2.5 THE RESEARCH GAP

The contemporary research has focused on the combined effect of variables related to tool geometry and machining conditions such as drill point angle, drill diameter, speed and feed rate variables on the responses such as thrust force, torque, surface roughness of the drilled hole and delamination. However there is a research gap in the study of the influence of material properties such as material thickness, volume fraction, fiber orientation etc. on the responses like thrust force, torque, surface roughness of the drilled hole and delamination using solid carbide drills. This research aims to fill this research gap by considering the material thickness as one of the variable along with the above said machining and tool geometry variables in order to estimate the individual and combined effect over the above listed response parameters and contribute to the body of the knowledge in working on GFRP composite material with solid carbide drills. Further, there is no evidence of using newer tool such as System Dynamics (SD) to simulate the influence of drill point angle, drill diameter, material thickness, spindle speed and feed rate on thrust, torque, surface roughness and delamination through the deterministic model technique in the drilling process of GFRP composites. Artificial Neural Networks (ANN) has been used by earlier researchers along with the Response Surface Methodology (RSM). So in this research, ANN, RSM and SD models have been used to develop the simulation and comparison was made. This comparison will enable the relative performance of the stochastic and deterministic models.