Effect of Tool Wear & Machinability Studies on Polymer Composites; a Review

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Abstract: The fibre-reinforced composite materials possess advantage for structural purpose in various industries. Delamination is considered the major concern in manufacturing the parts and assembly. Drilling is frequently applied in production cycle while the anisotropy and non-homogeneity of composite materials affect the chip deformation and machining behavior during drilling. Traditional and non-traditional Drilling processes are feasible for making fine holes for composite materials by carefully selected tool, method and operating conditions. In this work, the path towards the delamination-free drilling of composite material is reviewed. The major scenes are illustrated including the Aspects of the analytical approach, the practical use of special drill bits (tungsten carbide and hss), the objective of the present work is to optimize process parameters namely, cutting speed, feed, drill bit dia in drilling of glass fibre reinforced polymer (GFRP) composites. Using analysis of variance (ANOVA), the collected experimented data were analyzed.

Keywords: GFRP Composites, ANOVA, delamination, thrust force

1. INTRODUCTION

A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite materials possess superior properties. Which are not obtainable with a single constituent material[1]. Bone is a simple example of a natural composite material having the best properties of its constituents [3]. The most common synthetic composite material is glass fibre reinforced plastics

(GFPR) which is made out of plastics and glass fibre[1,2]. The individual components have altogether different properties to that of the composite material, GFPR. Plastics are light, durable, have excellent corrosion resistance and can be easily moulded to any complex shape. But they are not fit for load-bearing applications because of lack of sufficient strength, stiffness and dimensional stability. Glass fibre, on the other hand, possesses very high strength and is sufficiently stiff and durable. Like plastics, it also cannot be used for load bearing applications because of its brittleness and fibrous structure. But when both these are combined in the correct proportions and a particular glass fibre arrangement, we obtain GFRP which has the improved mechanical and other properties suitable for load bearing applications [1, 2-4].

Composite materials are playing an important role in a wide range of application fields and replacing many traditional engineering materials [1, 2]. Glass fibre reinforced composite materials are a class of materials used in various products including aerospace, automobile, sporting goods, marine bodies, plastic pipes, storage containers, etc. Composite materials have been in use since biblical times when chopped straw was added to brick to make building materials [1]. The modern composite materials age began with the introduction of particulate or fibrous reinforcement material into thermostet phenolic in the early 1900s. Glass fibre was commercially produced for the first time in the USA in 1937[3, 4]. Since then, there has been tremendous development in terms of new reinforcement materials, matrix Materials and production methods. Fibre reinforced plastics (GFRP), particular glass fibre reinforced Plastics are meeting the demanding techno-economic requirements of various industries as can be seen [1]

2. DRILLING OF COMPOSITE MATERIALS

The fibre-reinforced plastics, owing to their non-homogeneity, anisotropy and high abrasiveness of fibres, exhibit a considerable problems in drilling process such as delamination, fibre pull-out, hole shrinkage, spalling, fuzzing and thermal degradation [9].

The use of fibre-reinforced composite materials in automobile and aerospace industries has grown considerably in recent years because of their unique properties such as high specific stiffness and strength, high damping, good corrosive resistance and low thermal expansion. Hole making operations are essentially for these applications. For example, over 100,000 holes are made for a small single engine aircraft; in a large transport aircraft millions of holes are made, most for fasteners such as rivets, bolts and nuts [5]. Almost 50% of the total airframe production cost is in airframe assembly. The quality of the drilled holes can be critical to the life of the riveted joints for which the holes are used. Aspects of the hole such as waviness/roughness of its wall surface, axial
straightness and roundness of the hole cross-section can cause high stress on Revit, leading its failure [6-7]. Several hole production processes, including conventional drilling, ultrasonic drilling, laser-beam drilling, water-jet drilling, etc. Have been proposed for a variety of economic and quality reasons, but conventional drilling is still the most widely used technique in industry today [8].

In automotive and aircraft industries conventional drilling operations are extensively used for repairs and/or assembly operations. Drill wear is one of the serious problems associated with the drilling process of either traditional or composite materials, which leads to changes in the characteristics of the produced holes and failure of the cutting tool. Many experimental techniques have been conducted to correlate tool wear with process variables such as forces [11–12], surface finish [12-14], delamination [9,15], vibration [16], and acoustic emission [17,18]. Due to the difficulties concerning the reliability, calibration, and cost in the use of these experimental detection techniques, a considerable attention has been paid in the last years to develop and improve the machinability prediction models [9, 10]. Most of these models have been devoted to correlate the machining variables (feed, speed, drill diameter) with the machinability parameters (cutting forces, delamination, surface roughness), while some of them were reported to predict the effect of drill wear on the machinability of composite materials [9,15]. Delamination is often the limiting factor in the use of composite materials for structural applications. In the aircraft industry, 60% of all rejected parts during final assembly of an aircraft structure were due to delamination associated drilling [10].

The delamination analysis in drilling of composite materials is an important concern and has to be maintained at minimal. The analysis in drilling of GFRP composite material is carried out by many researchers. Experiments concludes HSM (High Speed Machining) is suitable for drilling GFRP composites ensuring low damage levels [19]. The various drill types such as saw drill, candle stick drill, core drill and step drill on thrust force and delamination in drilling GFRP composites [20]. They have analyzed the critical thrust force at the onset of delamination and compared with twist drill. The cutting performance of different coated twist drills are experimentally studied[21]. The experimental results indicated that the thrust force is the indicator of delamination. The drilling process is not significantly different for the various coated drills under the same drilling conditions. The delamination analysis using signal to noise ratio in drilling of GFRP composites also evaluated [22]. Results concluded that the use of high cutting speed and low feed favours the minimum delamination. Studies continued in the delamination analysis in drilling of chopped composites [23].

Experiments says that the delamination size decreases with decreasing the feed, whereas no clear effect of the cutting speed on the delamination size is observed. Drill studies on GFRP composites using linear elastic fracture mechanics, classical plate bending theory and the mechanics of composites [24]. Results show that the delamination is directly related to the thrust force during drilling, which in turn are a function of process parameters; feed, speed and the status of the cutting edge. From the above studies, it has been found that delamination in drilling is an important concern which has to be analyzed. Many authors, when reporting on the drilling of polymer matrix composites by conventional tools [24-26], have shown that the quality of the cut surfaces is strongly dependent on drilling parameters. An inappropriate choice of these parameters can lead to unacceptable material degradation, such as fibre pull-out, matrix cratering, thermal damage and widespread delamination [25], in recent years glass fibre reinforced plastics (GFRP) have attracted increasing attention for use in load-bearing components, particularly in the aerospace industry. This material has many excellent properties, such as high specific strength, high specific modulus of elasticity, lightweight, good corrosion resistance, etc. [27]. As the fields of application expand, the use of types of machining such as turning, drilling, milling, and cutting-off has increased in GFRP fabrication. However, the glass fibre constituent often renders the machining of GFRP difficult. Machining of composite materials requires a better understanding of cutting processes to achieve accuracy and efficiency [28].

Drilling of polymeric composites is a highly stochastic process due to anisotropy and inhomogeneity of composites. Technology for conventional drilling technique struggles to meet the need to enhance the quality of holes drilled in composites. Thus, searching for new drilling methods is imperative. Vibratory drilling is a branch of vibration assisted cutting, which is fundamentally different from conventional drilling. The conventional drilling process is a continuous cutting process, but the vibratory drilling process is a pulsed intermittent cutting process. The new vibratory drilling technique has attracted extensive interest in recent years [29]. Matrix composites, reinforced with different types of fibres have several potentially attractive properties [30]. They are also increasingly used for a number of mechanical components such as gears, cams, wheels, brakes, clutches, bearings, bushes, etc., most of which are subjected to tribological loading conditions. By reinforcing polymer with fibres, the mechanical and tribological Properties of the bulk composite can be improved considerably [31-32].

The hardness and compressive strength of a unidirectional E-glass fibre reinforced epoxy composite [30] were increased by adding the mica particles and so the tribological properties were improved. Investigation of the friction and wear behaviour of polyamide-66 reinforced by randomly oriented glass fibres [31-32]. Showed that the increase in the glass fibre content tends to raise the bulk composite hardness accompanied with limited increase in the friction coefficient. Meanwhile, the increase in the applied loads reduces the friction coefficient. The effect of fibre orientation on friction coefficient and wear rate of different composites was studied by several researchers. [30]
3. TOOL WEAR

A tool cannot cut for an unlimited period of time. It has its definite life. If a cutting tool is to have a long life it is essential that the face of the tool be as smooth as possible. Tool life is the time a tool will operate satisfactorily until it is dulled. A blunt tool causes chatter in machining, poor surface finish, increase in cutting forces and power consumption, overheating of the tool. The loss of sharpness of the cutting edge with usage is called tool wear.

There are five types of tool wear:
(a) Adhesion wear: In this the tool material gets welded to the work piece. This type of tool wear takes place under high cutting forces, high temperature and with less hard tool material.
(b) Abrasion wear: This wear is caused by the frictional force due to the moving of the chips over the face of the tool.
(c) Diffusion wear: It is a solid state diffusion phenomenon which leads to tool wear. This depends on the temperature and the contact area between the work and the tool. The rate of diffusion increases exponentially with increase in temperature.
(d) Chemical and electrolytic wear: Chemical wear is caused due to chemical reaction between the tool and the work piece in the presence of a cutting fluid. Electrolytic wear is the result of possible galvanic corrosion between the tool and the work piece.
(e) Oxidation wear: During cutting action the high temperatures generated at the tool work interface cause the oxidation of the tool. This results in the decrease in the strength of the tip of the tool resulting in failure.

4. LITERATURE REVIEW

A few papers were discussed about developing and validating procedures for predicting the Machinability studies on E –glass fibre reinforced in epoxy composites.

El-Sonbaty, U.A.Khashaba, T.Machaly (2003) The main objective of is to investigate the influence of some parameters on the thrust force, torque and surface roughness in drilling processes of fibre-reinforced composite materials. These parameters include cutting speed, feed, and drill size and fibre volume fraction. The results indicate that the start point of torque cycle is delayed by few seconds (depending on the value of feed) than the thrust force. From the experimental work the following conclusions they made, during the full engagement of the drill the thrust force was gradually drop and goes to zero when both the chisel edge and the cutting lips have exit of the laminate. In contrast the torque was increased up to the end of the cycle and sudden jump to a value about 10 times the peak value as the drill emerges out of the laminate. The cutting speed and feed have insignificant effect on surface roughness of epoxy resin. On the other hand for (GFRP) the surface roughness was improved by increasing cutting speed and fibre volume fraction. [10]

El-Sonbaty, U.A. Khashaba, T.Machaly (2010) Effect of drill wear the work is the continuation of the author’s work on machinability analysis in drilling woven glass fibre reinforced epoxy (GFRP) composites. They reported that the effect of drill pre-wear on the machinability parameters in drilling (GFRP) composites, at different cutting conditions. Machinability parameters were characterized by thrust force, torque, peel-up and push-out delamination, and surface roughness of drilled holes. They finally came in to conclusion that, the behavior of thrust force during drilling process was greatly affected by the drill pre-wear. This effect becomes extreme at high cutting speed and feed, which in turn increases delamination’s and surface roughness. The increasing of thrust force as a result of increasing drill pre-wear leads to destroying the matrix and micro-cracking at the ply interfaces, which deteriorates the surface finish. In addition, drilling at high speeds and drill pre-wear result in high surface roughness due to the generated temperature that, assisted by a low coefficient of thermal conduction and a low transition temperature of (GFRP) composites. [11]

T.V.Rajamurugan, K. Shanmugam, K. Palanikumar (2012) highlighted that Glass fibre reinforced plastic (GFRP) composite materials are finding increased application in aeronautical, automobile and structural applications. Drilling is a complex process, owing to their tendency to delaminate is used to join composite structures. An attempt has been made to develop empirical relationships between the drilling parameters such as fibre orientation angle; tool federate, rotational speed and tool diameter with respect to delamination in drilling of GFRP composites. The empirical relationship has been developed by using response surface methodology. The developed model can be effectively used to predict the delamination in drilling of GFRP composites within the factors and their limits are studied. The result indicated that the increase in feed rate and drill diameter increases the delamination size whereas there is no clear effect is observed for fibre orientation angle. The spindle speed shows only little effect on delamination in drilling of GFRP composites. The increase of drill diameter increases the delamination factor in drilling composites materials due to the increase of thrust force. Instead of using bigger holes similar smaller holes may be used[35]. G.capri v. tagliaferri (1994) reported to clarify the interaction mechanisms between the drilling tool and material. Drilling tests were carried out on glass-polyester composites using standard HSS tools; drilling was interrupted at present depths to study damage development during drilling. The specimens, polished by a metallographic technique, were examined by optical microscopy to identify any damage. The results obtained are useful in describing the damage history and to help design drill
geometries specifically conceived for composite machining. The main conclusions from the previous considerations are as follows. The type of damage induced in a composite material during drilling is strongly dependent on the feed rate. When the feed rate is high, the failure modes show the features typical of impact damage, with step-like delaminations, intralaminar cracks and high density microfailure zones. If the feed rate sufficiently low values are adopted, the failures consist of delamination's mainly originating near the intersection between the conical surface generated by the main cutting edges and the cylindrical surface of the hole. At low feed rates most of the delamination’s are induced near the tool exit edge and are generated when the chisel edge and the inner portion of the lips have already left the work material. The delamination located near the back face of the sample is characterized by a larger average length, showing a higher tendency to grow. A correlation exists between the global damage, revealed by microscopic examination, and the macroscopic damage evaluated by simple visual inspection; a macroscopic parameter is, therefore, representative of the real damage state in the material [27].

N.S. Mohan, S.M. Kulkarni b, A (2006) studied the Machining processes are generally used to cut; drill or contour composite laminates for building products. In fact, drilling is one of the most commonly used manufacturing processes to install fasteners for assembly of laminate composites. The material anisotropy resulting from fibre reinforcement heavily influences the machinability during machining. Therefore, the precise machining needs to perform to ensure dimensional stability and to obtain a better productivity of the component. The drilling parameters and specimen parameters evaluated were speed, feed rate, and drill size and specimen thickness. The experimental results indicated that the specimen thickness, feed rate and cutting speed are reckoned to be the most significant factors contributing to the delamination. A signal-to-noise ratio is employed to analyses the influence of various parameters on peel up and push down delamination factor in drilling of glass fibre reinforced plastic (GFRP) composite laminates. From the analysis of results in drilling of GFRP composite plates using conceptual S/N ratio approach, ANOVA and response surfaces, the following can be concluded within the range of the experiments. (1). as seen in this study, the Taguchi method provides a systematic and efficient methodology for the design optimization of the process parameters resulting in the minimum. (2). the feed rate, cutting speed and material thickness are seen to make the largest contribution to the delamination effect. Generally, the use of high cutting speed and low feed favour the minimum delamination on both entry and exit of the drilling leads to better surface finish and tool life. (4). Conceptual S/N ratio and ANOVA approaches for data analysis draw similar conclusion [42].

NavixZarrkarimi, Hossein Heidary, Giangiacomo Minak, Mehdi Ahmadi(2012) They report that Composite materials have been widely used in various industries due to their superior mechanical properties. Drilling is a very common machining operation to install fasteners for assembly of laminates. Delamination, however, is a serious concern in the drilling of fibre reinforced composite materials, because it reduces their compressive residual strength. They studied the effects of drilling parameters on the thrust force, adjusted delamination factor and compressive residual strength of unit-directional glass/epoxy resin. The design of the experiment was based on the Taguchi method. The results highlight the importance of the feed rate for maximizing the compressive residual strength of drilled laminates [38].

S. Arul, L.Vijayaraghavana, S.K. Malhotrab, R. Krishnamurthya(2005) Investigate the anisotropy of fibre-reinforced plastics (FRP) affects the chip formation and thrust force during drilling. Delamination is recognized as one of the major causes of damage during drilling of fibre reinforced plastics, which not only reduces the structural integrity, but also has the potential for long-term performance deterioration. It is difficult to produce good quality holes with high efficiency by conventional drilling method. This research concerning drilling of polymeric composites aims to establish a technology that would ensure minimum defects and longer tool life. Specifically, the authors conceived a new drilling method that imparts a low-frequency, high amplitude vibration to the work piece in the feed direction during drilling. Using high-speed steel (HSS) drill, a series of vibratory drilling and conventional drilling experiments were conducted on glass fibre-reinforced plastics composites to assess thrust force, flank wear and delamination factor[14].

FaramarzAshenaiGhasemi, AbbasHyvadi, GholamhassanPayganeh(2011) report that Drilling composite materials is considered a critical and sensitive operation because these materials are delaminated under the stresses caused by drilling operation. In this paper, the effects of feed rate, drill rotation speed and drill point angle on delamination factor in polymer-based composite laminate reinforced by E-glass fibres are studied. To this end, each of the mentioned parameters was defined at three levels using full factorial technique of design of experiments. During conducting the experiments, the drilling force was measured using a dynamometer. The amount of delamination factor was computed by scanning the exit hole of the drilled area. Using analysis of variance (ANOVA), the collected experimented data were analyzed. The results indicated that the delamination factor increased at low and high values of the parameters within the considered experimental range of the parameters. At the end, the optimum values of parameters were determined in order to minimize delamination [29].

R.VijayalakshmiRao.(2011) carried out the experimental investigation of the effect of drilling parameters such as cutting force, torque, speed, feed rate on the quality of drilled holes of polyurethane foam-E-glass-vinyl ester sandwich composite structure. The quality of the drilled hole is critical to the life of the fasteners in sandwich structures. The sandwich structures are subjected to
drilling, using HSS drill bits with different diameters of 3, 4, 5 and 8 mm at various cutting speeds of 550, 920, 1470 and 2300 rpm and the feed rates of 0.011, 0.022, 0.032 and 0.045 mm/rev using pillar sensitive drilling machine with the aid of drill tool dynamometer. The experiment revealed that the thrust force is influenced by the diameter and the torque by the feed rate. Four different grades of sandwich composites were selected for study and it is observed that at constant speed, the quality of the drilled hole increases with the increase in speed and tends to be poor as the diameter of the hole increases. It is observed that the rupture in the drill profile is found to be increasing with the reduction in speed at lower feed rates in all the sandwich composites. It is observed that the thrust force is influenced by the feed rate and the torque is influenced by feed rate and diameter of the drilled hole in all the types of composites. In drilling of woven roving sandwich composites, the cutting force acting in the peripheral direction cause delamination in the outer layer resulting in poor quality drilled hole. The thrust force is highest for woven roving sandwich composites, hence causes delamination. The drilling process is also affected by the fibre type, stack up sequence and the tool geometry. The friction between the tool and the drilling conditions results change in rate of heat dissipation. It is concluded that the delamination increases with the increase of feed rate in FRP sandwich composites and better quality of drilled holes can be achieved at lower feed rates[37].

B. Ramesh 1, A.Elayaperumal 2, D.AjayBalaji 3, N.Rakesh (July 2013) Nonlaminated composites having superior mechanical properties than laminated composites are widely used in ballistic applications. Since literature on the machinability of nonlaminated composites is scarce, an investigation was carried out to study the hole quality in drilling thick nonlaminated Glass Fiber Reinforced Plastic (GFRP) composite rods using coated tungsten carbide twist drill. The GFRP composite rods were made by pultrusion method with high fiber weight fraction. The ovality (hole diameter inaccuracy) of the drilled holes was measured using Coordinate Measuring Machine (CMM). Taguchi’s orthogonal array and analysis of variance (ANOVA) were employed to study the influence of process parameters such as feed and spindle speed on ovality of the drilled holes. The optimum level of process parameters towards minimum ovality was obtained to achieve defect controlled drilling of pultruded GFRP composite rods. Correlation for ovality with process parameters was established using statistical software MINITAB 16. The influence of speed on ovality was insignificant. The influence of feed was significant on ovality of the drilled holes. [40]

Vinod Kumar Vankantia, Venkateswarlu Gantab (June 2013) They noticed that objective of the present work is to optimize process parameters namely, cutting speed, feed, point angle and chisel edge width in drilling of glass fiber reinforced polymer (GFRP)composites. In this work, experiments were carried out as per the Taguchi experimental design and an L9 orthogonal array was used to study the influence of various combinations of process parameters on hole quality. Analysis of variance (ANOVA) test was conducted to determine the significance of each process parameter on drilling. The results indicate that feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width and point angle; cutting speed is the most significant factor affecting the torque, speed and the circularity of the hole followed by feed, chisel edge width and point angle. This work is useful in selecting optimum values of various process parameters that would not only minimize the thrust force and torque but also reduce the delimitation and improve the quality of the drilled hole [41].

5. CONCLUSION

Successful review work has been carried out in developing and validating procedures for predicting the machinability and tool wear studies on E-glass/epoxy composites with the aid of few research papers which highlights the same aspects to fulfill the need of sorting the issues under consideration.

The cutting speed and feed have insignificant effect on surface roughness of epoxy resin. On the other hand for GFRP, the surface roughness was improved by increasing cutting speed and fibre volume fraction. The increasing of thrust force as a result of increasing drill pre-wear leads to destroying the matrix and micro-cracking at the ply interfaces, which deteriorates the surface finish.

The increase of drill diameter increases the delamination factor in drilling composites materials due to the increase of thrust force. The use of high cutting speed and low feed favour the minimum delamination on both entry and exit of the drilling leads to better surface finish and tool life and delamination factor increased at low and high values of the parameters within the considered experimental range of the parameters. At the end, the optimum values of parameters were determined in order to minimize delamination. It is also observed that the rupture in the drill profile is found to be increasing with the reduction in speed at lower feed rates in all the sandwich composites. Study related to Taguchi’s orthogonal array and analysis of variance (ANOVA) says the influence of process parameters such as feed and spindle speed on ovality of the drilled holes. The optimum level of process parameters towards minimum ovality was obtained to achieve defect controlled drilling of pultruded GFRP composite rods.

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