A REVIEW OF ULTRASONIC ASSISTED DRILLING OF COMPOSITE MATERIALS

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Abstract : ***Composites can be considered as a future materials due to their unique properties, and machining of this material plays a vital role in manufacturing and assembly of different mechanical components. There are plenty of machining operations are available to dealt with composite materials such as, drilling, milling, laser cutting and alike. The primary aim of this work is to shed the light on various ultrasonic assisted machining of composites. Moreover, the effect of input parameters i.e. speed, feed and their effect on machining is also examined. It gives some insights which are essential to considered while dealing with the machining of composites.***

IndexTerms - Ultrasonic Assisted Drilling(UAD), Milling, Composite Materials, Delamination, Thrust Force

I. INTRODUCTION

Composites can be made up of two phases namely, reinforcement and matrix phase. These together act as a single material and carries load. Reinforcement can be of various types like, natural fibers, synthetic fibers whiskers and so on. Similarly, matrix are primarily polymers which bind this fibers together while acting as a load transmitting medium. The properties of composite materials are greatly affected by type of fiber, orientation of fiber, surface finish, bonding etc. Composite materials can be formulated by using different techniques i.e. hand lay-up, resin transfer molding, spray layup, pultrusion and filament winding. These methods are often categorized into two types, open and close mold process.

Machining is a crucial element while assembling composites as it has profound effect on their strength and failure behavior. Numerous techniques can be employed to carry out machining, for instance, drilling, milling, laser cutting, and alike. Each of this process offers different mechanisms and material removal rate. At the same time, these processes have its own advantage and disadvantage which needs to be considered while machining. Machining involves input parameter like feed and depth of cut which has significant impact on the output of machining. Additionally, these input parameters may cause harm to the material while machining if not controlled carefully which lead to the failure of entire composite materials. Machining assisted with ultrasonic forces can prove to be boon to achieve the optimum parameters along with greater surface finish.

The broader application of composites can be found in the area of defense, space, pharmaceutical, wind energy and mechanical industries.

II. MACHININIG OF COMPOSITES

Composite materials cannot be joined together by using welding, hence for the purpose of assembly nut and bolt mechanism is an ideal. For the purpose of mechanical joining drilling is required in finished part which can be done with the help of CNC machine. But this kind of drilling has some problems associated with it in terms of higher thrust force and torque which affects the quality of hole. To alleviate this concern ultrasonic drilling is carried out on material which leads to improved hole quality with lower thrust force and torque. It also reduces the delamination factor which plays vital role in the failure of the material.

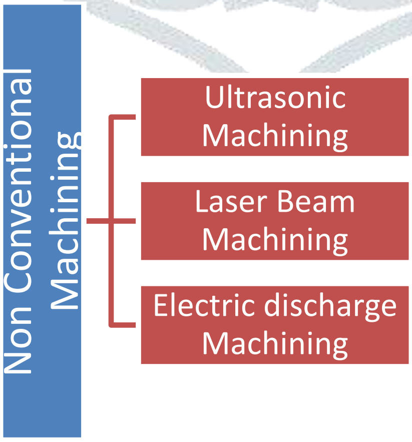

Fig. 1 non-conventional machining processes

Drilling of composites is a most easiest and basic technique among different machining operations. But it is greatly affected by several parameters like tool geometry, material of tool, feed, depth of cut, cutting speed and so on. A combination of optimum cutting variables are required for the successful execution of drilling, and can be obtained by performing range of iteration and mathematical calculations. Figure 2 represents some principal aspects which needs to be considered while drilling composite material.

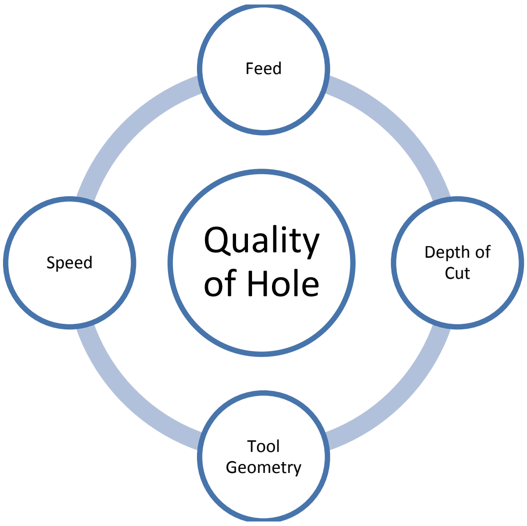

Fig. 2 parametres affectiting quality of drilling

III. EFFECT OF MACHINING PARAMETERS ON THRUST FORCE, TORQUE AND DELAMINATION

Plenty of authors have carried out drilling on composites with different input parameters and analyze each of them to get optimum results. Some of them are discussed below.

S.Arul et.al. carried out the work with aim to mitigate defects and increased tool life. They performed vibratory and conventional drilling on woven glass fabric composites to assess the various parameters. The authors observed that thrust is increased with feed rate while it is found to be lowest in comparison with conventional drilling[2]. Additionally, they also observed greater limiting numbers of holes to be drilled for defect tolerancing.

Saeidi Amini et.al. investigated a thrust force, dimensional tolerance and cylindricity on carbon fibre reinforced plastics using rotary ultrasonic drilling. The researchers conclude 30% decrease in thrust force compared to conventional drilling methods. They also find that roundness and cylindricity decrease by 80% and 72%[1]. The study also suggests that thrust force, roundness, and cylindricity occurs at higher rate than conventional drilling.

Kishore Debnath et.al. investigated the influence of process parameters mainly slurry concentration and abrasive size on material removal rate and average surface roughness. The researchers led to the findings that delamination is prevented while the hole quality greatly enhanced when produced through rotary mode ultrasonic drilling[5]. It has also been found that material removal rate can be increased with some modification in conventional drilling. The study led to the findings of hollow tool have an edge over solid tools when compared rotary mode ultrasonic drilling with conventional one. The developed process have capability to deliver damage free holes in glass epoxy composites.

Alejandro Sanda et. al. compared the ultrasonic assisted drilling and conventional drilling to observe the benefits of hybrid process and in terms of hole quality. The authors investigated the effect of process parameters on carbon fibre reinforced composites. After the completion of experiments, authors see 30% reduction in thrust force in comparison with traditional drilling methods. The delamination is found to be lower with less spindle speed[17,8]. Moreover, study also suggests that surface roughness of drilled hole is lower compared to conventional drilling. Reduction in thrust force is closely associated with lower feed rates and cutting velocities.

Richard Zemann et. al. investigated the possibility to lower fraying to minimize damage during drilling. They analyzed the frequency and amplitude to ascertain fraying behavior in drilling and milling operations. The findings suggest that fraying behavior can be improved with geometrical defined blades[20]. Fraying in milling can be reduced by vibration in the direction of feed and in a circular way. Additionally, drilling can also be improved by circular vibration with traditional cutting conditions.

Sadek et. al. studied the thermal and mechanical defects induced by drilling. They developed model to represent the effect of process parameters on hole quality attributes in low frequency – high amplitude regime. The authors concluded that intermittent cutting plays a vital role in thrust force reduction[16]. The study suggests thermal performance can be improved by forming vortices in the air gap between tool flank's face and machined surface. They also proposed that combination of high speed along with lower feed and high frequency would give better productivity.

Oliver Pecat et. al. investigated the tool wear on low frequency ultrasonic assisted drilling. The authors find that tool life can be enhanced by 300% while flank wear and cutting edges is found to be lower with LFVAD. The study also suggests thermal load has significant impact on tool wear owing to diffusion[12]. The researchers also recommend further investigation to understand the wear mechanism and interactions among various materials. They proposed LFVAD compare to traditional drilling to reduce tool wear.

Yasuhiro Kakinuma et. al. carried out drilling on carbon fibre reinforced thermoplastics to analyze material properties and feasibility of ultrafast drilling. The investigation suggests that delamination and burr volume can be minimized at higher feed rate and spindle speed, 3000mm/min, 20,000min^{-1} respectively[7]. Authors reach to a conclusion, UFFD enhances both hole quality and efficiency in drilling.

Weixing Xu et. al. developed elliptical vibration assisted technique to cut FRP and established 3D finite element model to understand material removal mechanisms. They found that cutting forces decrease significantly with the application of vibration during drilling, and suggest cutting directions play vital role in reducing cutting force. The key parameters in this study are the ratio of tool-feed-rate to higher vibration velocity and ratio of cutting distance to fibre diameter[19]. It is imperative to keep this parameters below their critical values to gain advantages.

Mohammad Baraheni, Saeid Amini investigated thrust force and delamination in glass fibre reinforced plastics. They designed and fabricated drill using ABAQUS. The study involves a range of parameters from influence of tool size and vibration to spindle speed and thrust force, and suggested delamination caused by higher thrust force. The authors see reduction of thrust force and delamination up to 70% and 23% respectively[3]. Decreased fibre volume led to the reduction of delamination up to 28%, and high cutting speed with lower feed rate decrease the delamination.

W.L. Cong et. al. compared rotary ultrasonic machining of carbon fibre reinforced plastic with twist drilling. Comparisons are made across six aspects from cutting force to material removal rate. The researchers find greater cutting force and torque in twist drilling in comparison with RUM[4]. Tool life found to be longer than twist drilling while it has higher material removal rate for similar conditions with same diameter. Delamination cannot be observed in the holes machined by RUM, and surface roughness seems to be greater in case of twist drilling.

Chunliang Kuo et. al. investigated vibration frequency and amplitude along with cutting parameters on CFRP/AL piles. For steady state drilling, empirical model was developed to study the interactions between vibration parameters and machine tool[8]. The vibration amplitude is the significant factor to reduce the thrust force, and found background noises could interact with drilling action as well as vibration frequency. The authors suggest low frequency vibration was mostly absorbed during cutting which could help in the reduction of thrust force.

Farrukh Makhdum et. al. investigated the effect of ultrasonic assisted drilling on CFRP. They also analyzed the nature of drilling force reduction using finite element analysis technique. The authors observed greater reduction in drilling forces with wider drills. However, the temperature is found to be higher compared to conventional drilling, but it is still lower than the thermal decomposition temperature of composites[10]. The holes drilled by using UAD have higher quality in terms of circularity and improved surface roughness while delamination is lower. A numerical model represents the closer result when compared to experimental data except thrust force (due to drill dynamics).

Zhe Li et. al. analyzed the chip removal in drilling of CFRP using core drill. The experimental results indicate higher cutting ability of core drill along with greater effects of chip removal. The researchers concluded reduction in thrust force, temperature, surface roughness and machine rod contraction[9]. Moreover, the accuracy of hole is higher than traditional drilling. The study suggests 5.0 and 7.5 of vibration amplitude to enhance the ability of cutting tool.

Farrukh Makhdum, Luke T Jennings et. al. performed experiments on CFRP using UAD and compared results with conventional drilling. The authors found lower delamination with vibration assisted drilling. The chip is found to be continuous when drilled with UAD, whereas conventional drilling produces powder dust. The study suggest 60% reduction in thrust force with lower delamination at entry and exit[11].

Vaibhav A. Phadnis et. al. carried out physical and numerical investigation in drilling of CFRP. They studied the effect of cutting speed on thrust force and developed 3D model to analyze the dynamic frictional characteristics of UAD. The researchers concluded 30% reduction in thrust force and validated FEM model with experimental results which proves to be accurate in predicting thrust force[13].

IV. CONCLUDING REMARKS

Ultrasonic assisted drilling of composite materials offers a distinct advantages over conventional drilling methods. This work represents a review of modern drilling process including various parameters thrust force, feed, torque, delamination, tool geometry and alike. It is obvious to have lower delamination and higher machining productivity with the assistance of ultrasonic drilling. Moreover, tool life and surface roughness improve significantly when compare with conventional drilling operations. Further research work is needed to understand the cutting mechanism and the effect of vibration on output.

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