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Effects of Drilled Area Temperatures on Drilling of NFRP Composites: A Review

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Abstract:

The growth of high-performance semi-structural and structural applications made from natural resources is growing universal, due to renewable and ecological matters. Machining natural fibers reinforced polymer (NFRP) has become a challenger in the machining processes for incorporating them into the NFRP industrial production chains. The thermo-physical properties of fiber-reinforced plastics (FRPs) causes high temperatures at the tool tip when machined. The generated heat affects the process behavior as well as the machining surface quality. It causes accuracy errors when machining composites. This papers reviews the research published during drilling of natural fiber reinforced polymer composites with special reference to the effect of different cutting parameters.

Keywords: *NFRP, drilling, heat generation, composites*

I. INTRODUCTION

The growing demands and usage of Fiber Reinforced Polymer (FRP) composite have been perceptible as substitutes in the mechanical components, construction of buildings, sporting, equipment/appliances and automotive/aircraft parts. These composites have been replacing the conservative materials attributable to more enhancements obtainable by the advanced composite materials. The utilization of natural fibers as the main reinforcement material in the composite materials is ahead of time acceptance over the past years. The natural fibers are less expensive than synthetic fibers that able to replace synthetics in numerous applications where cost reserves outweigh high composite performance requirements [1]. The source of the fibers are such as jute, flax, ramie, kapok, cotton and other type of fibers. The natural fiber composites in overall, compromise plenty privileges over the traditional materials: light weight, high strength to weight ratio, parts consolidation, flexible design, corrosion resistance, dimensional stability, good thermal and others [2]. Most numbers of researches have been described on the machinability of natural fiber reinforced polymer (NFRP) and synthetics composites [3, 4, 5]. Sheikh-Ahmad [6] mentioned that the machining of composites is considered as one of the challenging process owing to its heterogeneity, anisotropy, low thermal conductivity and heat sensitivity of the specimens. Machining parameters which inappropriately and judiciously selected for machining composites could lead to damage of machine tools. Natural fiber composites are combination of either natural fibers with synthetic resin or natural fibers with bio-resin or in the form of thermoset and thermoplastic type of resin. The present work is the providing an inclusive review on mechanical drilling of NRFP composite laminates as well as in providing a useful understanding for the influence of cutting heat on machining quality during drilling of NFRP or other type of synthetic composites.

II. SELECTION OF DRILLING TOOLS AND MACHINING PARAMETERS

In drilling of composite materials, any defect emerging and formed are demanded for rework, or renders it as scrap which then contributes to great economic impact in the industry. Hence, machining of composites urges for a high performance and precision process in the whole machining process. Cutting speed, feed rate, drill and work piece material, drill point angle and coolant conditions are

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the drilling parameters that extremely have an effect on the performance measures [7].

In any machining operation, the point geometry of the cutting tool is one of the primary important factors variables in restricting the efficiency of the tool's performance. Chandramohan and Marimuthu [8] predicted that the feed rate, drill diameter and cutting speed, are recorded to play significant factors influencing the thrust force in drilling of fabricated banana, sisal and roselle fiber reinforced composites. They evaluated that the thrust force and torque increases with as the feed increases and decline as the cutting speed increases. Yaller et al. [9] investigated the outcome of different geometry of drill bit in drilling of jute fibre composite. They observed that parabolic drill demonstrated a better cutting behaviour with less induced damage in comparison to twist and Jo drill in drilling the woven jute composites. Such observation occurred owing to minimal drill contact between the composite sample that has subsequently lowering the torque and thrust force signals and thus producing a better quality drilled hole.

In another research study, Jayabal and Natarajan [9] carried out a investigation on the machinability and mechanical attributes of coir polyester composites, and observed that drill diameter (6 mm) and 600 rpm producing a minimal value of tool wear, thrust force and torque. The torque and thrust force out to be nominal in order to prevent damages formed and to obtain the precise roundness of the machined holes. Apart of that, the tool wear should be minimal as to prevent extra utilization of the drill bit and for the production of quality holes. Debnath et al. [10] concentrated on the drilling behaviour of sisal fiber-reinforced epoxy and polypropylene composites, and observed that the force decreases with spindle speed and increases as feed increases for all types of drill geometries (4-facet, parabolic and step). They also conclude that the generated thrust force and torque of parabolic drill, is quite low in comparison to the 4-facet and step drill geometry, in while the step drill geometry results in considerably greater value of thrust force and torque. The geometry of the drill bit immense a large impact in the drilling of fiber reinforced plastics. Durão et al. [11] reported on the thrust force results from standard twist drills with distinctive point angle. They found that the drill bit with the lower point angle provides lower thrust force that prompts to less severe delamination.

The number of flutes likewise influences the test results. Davim and Reis [12] utilized three differing kinds of drill bits (diameter of 5 mm, 118° point angle): (a) helical flute HSS drill, (b) four-flute K10 cemented carbide drill and (c) helical flute K10 carbide drill. He stated that the helical flute K10 drill delivered minimal damage to the composite laminate than the four-flute carbide (K10) drill bit. In drilling process, the drill geometry variables affect the drill performances. Thrust force, torque, tool life and character of the machined hole are affected by the drilling performances.

III. TOOL WEAR

The aim of the comprehension the composites machining method is specially to understand the machining conditions that are capable to deliver top quality merchandise with minimum tool wear and low price of machining productions. Jayabal and Natarajan [13] evaluated a set of optimum parameters in obtaining a minimum power consumed, minimum cutting forces, minimal tool wear and greatest metal removal rate. They found that the most suitable size of drill bit is 6 mm in diameter for the earning the aforementioned results during the investigation drilling of coir-polyester composites. Franke [14] expressed that the flank wear pressure of the tool increased with the increment of the cutting edge radius. The tool features a tendency to generate a high force so as to penetrate the work material and prompts to a rise of the thrust force. Besides, the increment of the cutting edge radius causes the materials to deform a lot of severely up to it can no longer being cut. Palanikumar and Davim [15] explored the influences of feed orientation angle, cutting speed, depth of cut and feed rate on tool flank wear during machining of glass fiber-reinforced composite material. They observed that the cutting speed encompasses a bigger impact on tool flank wear succeeded by feed rate.

In drilling of GFRP by Arul et al. [16], studied the influence of tool material on flank wear and thrust force that impacts the hole shrinkage in using of 6mm diameter of tipped cemented tungsten carbide drills, TiN coated HSS and high speed steel (HSS). The study claimed that the cemented tungsten carbide drill outperformed better than other drill materials. Abrão et al. [17] claimed that owing to the insufficient selection of tool geometry may consequences of greater temperature development

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owing to friction between the clearance faces (principal and secondary) as well as the work specimen, greater thrust force and torque values as well as the accelerated tool wear. These will eventually induces to surface damages in addition to poor hole quality. Rajesh and Marimuthu [18] conducted a study on-line drill wear state prediction through drilling of jute fiber-reinforced composites, perceived that through the drill wear state extrapolation, it permits the determination of the hole quality as well as tool replacement at appropriate time in the automated monitoring system. From the study, the proposed monitoring system able to offers a appropriate technique to predict he drill wear precisely through assistance of the cutting current signal. These literature outcomes showed that the utilization of type of drill materials exhibit a significant influence at the onset of delamination, hole dimensional accuracy, the quality targets of the tool wear, as well as the surface quality of the drilled hole. These literatures information will be a great reference for choosing optimal drill materials for acquiring the desired quality of the drilled holes.

IV. INDUCED DAMAGES ON DELAMINATION AND SURFACE QUALITY

Hole quality be subjected significantly to mechanical properties of the reinforcing fibres. The proper selection vary of cutting speed and feed rate is restricted not by the most effective tool life, nevertheless, may have many unfavorable results such as danger of thermal damage, the surface quality of the machined parts notably of fiber reinforced polymeric materials machining. The consequences of machining parameters are an imperative perspective to be considered in machining research study. Agreeing to Bhatnagar et al. [19], the feed rate and cutting speed are two operative parameters within the drilling process that required to be advanced as to make a good quality of the drilled hole.

Delamination of the manufactured composites part was one of the foremost causes for failure produced parts predominantly in the aeronautics industry and is frequently regards as the restrictive factor in the use of structural applications [20]. Delamination in composite materials often take place mostly attributable to the localized bending zone which is located at the point of drill bit penetration [21]. It extremely diminishes the strength against fatigue as well as the assembly tolerances which then lowering the lifelong performance of the parts. Delamination destruction was observed to be the most critical defect which was created through machining operation in the composites and it could extremely influences the performance of the finished part [22].

The feed rate and cutting speed caused the major influence to the delamination which were observed by Babu et al. [23] during drilling of hemp fiber reinforced composites. The delamination variation factor of cutting speed and feed rate were observed in drilling of natural fibre reinforced polylactic acid laminates by Bajpai et al. [24]. They stated that the delamination factor decreases as cutting speed increases, but increases feed rate increases, for all the drill geometries used (Jo, twist, parabolic). Babu et al. [23] presented an investigation in attempt to study the factors and combination of machining parameters that influence the tensile strength of the drilled unidirectional hemp fiber reinforced composites and delamination in using Taguchi analysis. They noted that the cutting speed and feed rate are perceived to make the main contribution to the tensile strength and delamination. They added that, to favors the minimal delamination, the usage of low feed and high cutting speed are suggested in on drilling of natural fiber reinforced composites.

Babu et al. [25] conducted an experimental study involving drilling of natural fibre reinforced plastic (glass fiber reinforced plastics, hemp, jute, and banana) using a cemented carbide drill (5 mm of diameter). From the study, they observed the hemp fibre reinforced plastic composite performs better (lowest delamination factor) than the other fiber reinforced composites which also means lowest damage in the composite laminate. They perceived that the cutting velocity factor contributes 47.72% and the feed rate factor contributes 50.93% for the statistical and physical significance for the delamination factor obtained.

The quality of the drilled hole depends on the machined surface finish on the basis of better surface discrepancies that appeared on the surface texture, are subjected upon the feed rate, cutting speed and mechanical properties of the machined specimen [26]. Franke [14] expressed that the cutting edge radius influences the feed force and affects the drilled hole quality. As according to Chandramohan and Marimuthu [27], the fact of using higher cutting speed values led to higher cutting temperature, that eventually inflicting the softening of the matrix and therefore the utilization of feed rates to be to a lower value of 0.3 mm/rev is related to the poor damaged of the composite surface (delamination). Caprino and Tagliaferri [28] observed that with high feed rate,

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drilling operation acts sort of a punching development and therefore the failure modes demonstrate the typical feature of impact damage with intra-laminar cracks in drilling of glass fiber reinforced plastic composite material.

The drilled hole quality as axial straightness, roundness of the crossed section hole and waviness/roughness of its wall surface may become the reason of developed high stresses on the rivet that later leads to a failure [29]. Santhanam and Chandrasekaran [30] identified that the consequences of fibre pull out from the matrix in the course of the cutting process by the drill tool resulted in extreme roughness on the side walls which in the end affected the hole quality.

These literature results showed that the utilization of type of drill materials exhibited a significant influence at the onset of delamination, the quality of the drilled hole. These literatures information will be referred in selecting ideal drill materials for acquiring the desired quality of the drilled holes.

V. CUTTING TEMEPRATURE MEASUREMENT IN DRILLING OF FRPS

In view of developed cutting temperatures in machining process, the heat source is occurred from the friction in the amidst of the chip and the cutting tool. The cutting temperature is considered as one of the main cause that impact the surface quality of composite materials. The developed cutting temperature influences the quality of the machined surface texture as well as the wear of the cutting tool. In any machining of polymeric composites, excessive heat generated during cutting process may cause matrix burning. Temperature assessment is one of the most challenging and complex task in composites machining as it is quite challenging to do temperature measurement very close to the cutting edge. Although the primary effect of temperature is due to tool wear, the temperature gradient along with maximum temperature also influences by metallurgical structural alterations in the machined surface, subsurface deformation, and residual stresses in the finished part [31]. As the spindle speed climbed from 1591 rpm to 3820 rpm, the temperature of the drill bit decreased. This is due to the higher cutting speed caused by higher temperatures leading to high deformation levels [32]. Machining quality at low temperatures was better than at high temperatures. Particularly, morphologies at high temperatures showed that the fibers were bent to fracture that resulted in worst subsurface damage [33]. In addition to that, they added that as the temperature was extremely low, that has dramatically increased the cutting force and prompted to lower tool life.

In a complex machining process such as in drilling, high stress and temperatures may develop in the cutting zone during the machining of the composites, thus affect the cutting tool performance and workpiece properties [34]. Cylindricity, hole diameter and perpendicularity, tool wear and surface roughness may affect due to high cutting temperature during the machining process. For instance, in drilling CFRP usually, high temperature (up to 231°C) occurred at the drill exit which will affect the mechanical properties of the specimen and hole qualities as mentioned by Fu et al [35].

According to Attia et al. [36], the FRPs are sensitive to the temperature rise during machining because the matrix material holding the fibres deteriorates and decomposes at relatively low temperature compared to metals. Resulting in matrix burnout which causing material debonding on the machined surface and/or within the heat affected zones. Maximum operating temperatures for CFRP composites are quite low as the polymer matrix thus susceptible to softening, chemical deterioration and degradation though at adequate temperatures. In the case of a standard epoxy-based CFRP material, it is approximately around 180 ° C above of the glass transition temperature that the degradation of the resin happens within the machined layer [37].

Wang [38] stated that it is a challenge to make holes on the composite material with high-quality. Drilling procedure incites a few matters, together with localized thermal shock, which caused by the presence of abrasive and extremely hard fibres as well as low thermal conductivity of composite, which limits the heat dissipation. Those problems able to be assessed by analyzing the procedure temperature, whose value be subjected to the cutting parameters which have been discussed by Sorrentio et al. [39]. There are few ways to measure the temperature during drilling process explained by Giasin and Ayvar-Soberanis [40] such as contact method by embedding thermocouples in the cutting tool or in the workpiece, or by a non-contact method such as infrared cameras and infrared pyrometers. Sheikh-Ahmad [6] has mentioned that the cutting temperature in drilling is greatly reliant on feed rate and cutting speed.

Similarly, Xu et al. [41] have discovered that the cutting speed caused a optimistic impact on the heat generated especially through the drilling of CFRP composited where temperature increase as the cutting speed is increased under the condition of 30 m/min for cutting speed and 0.03 mm/rev for feed rate which most likely to occurred on the flank tool surface. The position of the temperature measuring tools from the hole surface has influenced the temperature reading during the drilling process where, the nearer the tools to the hole surface the more the accurate the temperature reading. Evaluating the cutting temperature has become one of the important factors in order to increase the tool life. Furthermore, the helix angle also will affect the cutting temperature where Fuh et al. [42] have pointed out that the peak temperature gets smaller as the helix angle gets smaller. Likewise, Agapiou and Stephenson [43] has mentioned in their article that the helix angles has influence drill temperature where increasing the helix angle increase the effective rake and reduce temperatures. Additional to that, the effect is relatively weak for helix angle over 10 degrees. Bono and Ni [44] have studied that the temperature profile on cutting edges of a drill at the maximum temperature can occur near the chisel edge. From the above literatures from researchers, up to now, however there has been little work in the area of the study on cutting temperature during the drilling of natural fibre reinforced composite materials

CONCLUDING REMARKS

The work presented above are the summaries of recent advances of mechanical drilling of NFRP and synthetic composites particularly in drilling operations. The aim of the future research work is to evaluate and monitor the impact that the constituents (matrix and reinforcement) of the NFRP composite have on the heat dissipation in the drilling operation. NFRP composites required to be machined in a very circumscribed range of process parameters so as to avoid hot temperature damage on machined components. Thus

- to enhance the machining efficiency, reduced the machining cost, and improved the machined parts quality, it is essential the most appropriate machining conditions to be chosen
- further investigation on surface integrity on residual stress and different type of (thermoplastic resin) used, might gainful for definite study of the work material and cutting tool materials subsequent of the machining operations. With the comprehend of the mentioned studies, it is ideal to understand the surface completion attained and the perseverance of subsurface varieties that might occur as a consequence of drilling procedure on characteristics of natural fiber reinforced composite materials.

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