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Analyzing The Surface Roughness for GFRPs Drilled Hole When Using Different Tools and Different Methodology (A Review)

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ABSTRACT
The glass fiber reinforced composites are widely used in engineering applications such as aircraft, automotive, and manufacture of spaceships and sea vehicles' industries due to their significant advantages compared to the other materials. This type of composite provides high specific strength/stiffness, superior corrosion resistance, lightweight construction, low thermal conductivity, high fatigue strength, ability to char, and resistance to chemical and microbiological attacks. Many researchers in the previous years have attempted to study the machining of glass fiber reinforced composite materials to identifying the effect of various process parameters on the quality of machining structures. Drilling is an important process for making and assembling components made from Glass Fiber Reinforced Plastic (GFRP). Various processes like conventional drilling, vibration-assisted drilling, and ultrasonic-assisted drilling have been attempted to maintain the integrity of the material and obtain the necessary accuracy in the drilling of GFRP. In this research, an attempt has been conducted to review many of the previous researches on the drilling of GFRP. The process parameters such as the spindle speed, the feed rate, the depth of cut, the volume fraction ratios, the tool material, and the tool geometry and their influence on the multi responses as, the hole surface roughness, the delamination in the hole, the thrust force and the torque, all of this are studied and analyzed. Also, the different optimization techniques and methods for optimizing the mentioned parameters are studied and analyzed.

Keywords: *Composite Materials, GFRP, Delamination, Surface Quality, ANN, ANOVA, Machining processes.*

1. Introduction

The use of glass fiber reinforced composites (GFRP) is widespread in several areas of various industries. This prominence, apart from the lightness of composites, can be attributed to their high mechanical resistance, good corrosion resistance, and strength density ratios that are favorable over their metal counterparts. Nevertheless, GFRP often requires secondary operations such as turning, milling, or drilling. The demand for mechanical fastening in glass reinforced plastic (GRFP) composite materials is increasing due to their potential in great assemblies. Small components are combined into large assemblies drilling holes in composite materials and drilling defects of holes in this composite offering several challenges during part assembly and services. Due to the composite materials are not homogeneous, the machining process may give rise to bad outcomes like the tearing of fibers or damages to the matrix. The accurate holes are widely used in composite materials using a suitable drill tool method and operating conditions processes in various industries as aircraft and aerospace…. etc. Also, the drilled holes' precision importance increases due to market challenges and design requirements as the tight tolerances. The influence of the process parameters and tool geometry on the surface roughness and the delamination of the hole is the key aspect studied in the latter years. It is clear that from the previous researches, the defects caused by the drilling are the delamination, the fiber pull-out, the interlaminar cracking, or the thermal damages. This research effort to review the previous works on the effect of drilling parameters on the surface roughness and the delamination damage of (GFRP). Various processes like conventional drilling and CNC-assisted drilling are studied to obtain the necessary accuracy of the hole in the drilling of (GFRP). From the previous researches, in conventional and CNC machining, the feed rate, the tool material, and the cutting speed are the most influential factors on the surface roughness and the delamination. [1]. Therefore, in the present work, these parameters are accurately discussed and analyzed.

2. Influence of The Drilling Parameters on The Quality of The Hole:

The machinability of glass fiber reinforced polymer composite (GFRP) materials is related to the anisotropy/heterogeneity of their structure, together with the high abrasiveness caused by the fiber reinforcements. Drilling is a common machining process for components made of this type of composites. The hole quality is affected negatively by matrix cratering, thermal damage, spalling, surface delamination, and material degradation (e.g., fiber pullout). The design of drilling processes through the choice of suitable tools, process parameters, and cutting conditions appears to be a key task for reducing the hole delamination. Therefore, in the following the study and analysis of the previous researches in this field.

Ahmed M. Easa, Abeer S. Eisa [2], presented research on the influence of the input process parameters [three cutting speeds, five feed rates, and three cutters (end mill - different diameters)] on the process responses, i.e. the surface roughness (Ra) and the delamination factor (df) of the drilled hole for the two types of composites GFRP and AL/SiCp. The surface roughness (Ra) of the hole is measured at entry, middle, and exit of the drilled hole (three times), and the average value of the surface roughness is considered for the analysis. From this research and the comparison, the values of (Ra) are increased with the increase of the used feed rates and with the increase of the cutter diameter with the same cutting speed at drilling AL/SiCp and GFRP composites. Due to the results, the surface roughness (Ra) is almost increasing with the increase of the feed rate but in some places, it fluctuates with different feed rates. It may be due to the imperfection and irregular distribution of chopped fiberglass, which had a bad effect on the teeth of the cutter and producing reduced quality of the holes. Also, this behavior is clear in the results of the AL/SiCp composite; this may be due to especially at high values of the feed rates, to the increase in the content of particles that increase the friction between the teeth of the cutter and the wall of the hole and leads to the bad surface of the drilled hole. Furthermore, from the results, the cutter of big diameter gives a better hole surface compared with the cutter of the small diameter. This is maybe due to the burnishing influence produced by the rubbing action of the big cutter on the wall of the drilled hole and there is evidence of burnished surfaces at various locations within each drilled hole. Additionally, the delamination factor (df) is calculated as follows;

df = D max/D Where:

D max = the maximum diameter created due to delamination around the hole. And, D = the hole or drill diameter.

From the drilling results, it can see some of the defects (Pullout and delamination) in the drilling hole of the two types of composites in Fig 1.

ϕ 8mm, ϕ 10 mm, and ϕ 12mm (rpm 500- GFRP).

12mm (rpm 500- AL/SiCp). ϕ 10 mm and ϕ 8mm, ϕ

Figure 1- Defects (Pullout and Delamination) in the Drilling Hole of The Two Types of Composites

These results proved an association between the values of the delamination factor (df) with the feed rate (f) and the cutter diameter when using Vf 30% and with the three used cutting speeds. The analysis of the results demonstrated a strong association between the resultant delamination factor (df) with the cutting speed, the feed rate, and the diameter of the cutter. Besides, there is a positive correlation between the increase of the feed rates and the increase in the delamination factor. The increase of the cutting speed and the cutter diameter is led to an obvious increase in the delamination factor with all feed rates and with all used cutters. The feed rate and the cutter diameter are had a large effect on surface roughness (Ra)and the delamination factor (df), while both are increased with the increase of the cutter diameter and the used feed rates. The average values of the outcomes for the surface roughness (Ra) and the delamination factor (df) when drilling GFRP composite are bigger than the values of AL/SiCp composite at all used cutters, cutting speeds, and all used feed rates. When using cutting speed (2500 rpm), the cutter of the small diameter (ϕ 8mm) and low feed rate (10mm/min) are suitable for drilling GFRP and AL/SiCp to get an enhanced surface roughness of drilling hole. Kilickap [3] studied the influence of the cutting parameters, such as the cutting speed, the feed rate, and the tool point angle on the delamination produced when drilling a (GFRP) composite. The caused damage associated with drilling (GFRP) composites is detected, at both the entrance and the exit during the drilling. The optimum cutting parameters are obtained for minimizing the delamination at the drilling of (GFRP) composites. Taguchi technique and ANOVA are used for minimizing the delamination influenced by the drilling parameters and the drill point angle are studied. The analysis of the results revealed that the feed rate and the cutting speed are the most influential factors on the delamination, respectively. Ahmed M. Easa, et al. [4], presented research on the effect of, [two types of tools, two cutting parameters, and fiber volume fraction ratios] on the surface roughness and the delamination factor for drilling GFRP. The used composite material in this research is made of a polymer matrix reinforced with chopped fiberglass. The GFRP specimens are fabricated using the hand lay-up technique. Standard twist drills made of (HSS) with (10 mm diameter) and standard end mill of HSS (four fluted) with the same diameter of the twist drill are used for the drilling operations. The Machine used in these experiments is an Extron M218. , LH, CNC Machine, to perform the experiments. The experimental results showed that the higher cutting speed (1500 rpm), low volume fraction ratio (5%) and low feed rate (25mm/min) is suitable for drilling GFRP to get a good surface roughness when using the two types of tools. The Twist drill tool is further suitable than the end mill at the high cutting speed and low feed rate. The lowest delamination factor is shown at a feed rate of 25mm/min and a volume fraction of 5%. Similarly, a good surface of the drilled hole wall can be obtained with a low volume fraction (5%), low feed rate (25 mm/min), higher cutting speed (1500 rpm), and twist drill. The increase of volume fraction ratio leads to an increase in surface roughness at all values of the cutting speeds and the feed rates and for the two types of tools. On the other hand, Abrao, et al. [5], checked the influence of the tool geometry and the cutting parameters on the delamination during the drilling of GFRP. It is shown that the strong effect of the drill geometry in competition with the thrust force, generally assumed to the most influencing factor. Palanikumar, et al. [6] presented an experimental investigation to developed surface roughness and tool wear in the machining of glass fiber reinforced composites. The used material of the tool is sintered carbide (SNMG 12 04 08-5(ISO Designation) [P20] TG-Widadur coated carbides) with a different tool geometry and used a standard tool holder. The results indicated that the cutting speed, the feed rate, and the tool radius to some extent influence the roughness of the machined composite surface. This is made by the inhomogeneous microstructure of glass fiber reinforced composites, which results in surface details from deformations and fractures at the micro-level; (fiber ends sticking out, peaks of the deformed matrix material, and holes from deboning between fibers and matrix). Furthermore, K. Palanikumar [7] conducted experiments on GFRP composites using Brad & Spur drill and optimized drilling parameters by using two input variables with four levels and concluded that low feed rate and high spindle speeds are beneficial to reduce delamination. Ahmed M. Easa, Mamdouh I. Elamy,[8] study the influence of the following parameters; the cutting speed, the feed rate, the tool diameter, and volume fraction ratio on the drilling hole quality of GFRP in this experimental research. Moreover, the effect of using the different diameters of HSS tools, and five different cutting speeds, feed rates, and volume fraction ratios on the hole quality are analyzed. From the analysis of the results, the ratio of volume fraction and the feed rate are a more important influence on the hole quality than cutting speed and drill diameter. Furthermore, the cutting speed and the drill diameter are significant parameters on the thrust force. The obvious increase in the delamination is due to the increase of the tool diameter, volume fraction ratio, feed rate, and cutting speed respectively. Tsao, Shyha, et al. [9-12], presents studies on the effects of the cutting speed, the feed rate, and the tool point angle on the delamination at the drilling of GFRP. From the results of these studies, a decrease in the delamination tendency when cutting speed increases and advise the use of low feed rates combined with adequate tool point angle. Also, it is suggested that, tool cooling for the chip removal, when the use the machine for difficult-tocut materials. It decreases drill bit breakage, improves positional accuracy of the hole, and increases cycle times. Piquet R. et al. [13], used a great number of cutting edges (From three to six) to increase the contact length between the tool and the part (a point angle of 118° and a small rake angle) and the chisel edge should be as reduced as possible. The extent of delamination is determined with the help of an ultrasonic C-scan. From this study, the thrust force varies with the drill geometry and with the feed rate. It means that it can be used to higher feed rates if suitable drill geometry is selected. A.M. Abroa, et al. [14] studied and reported the effect of the tool geometry and the material on the thrust force and the delamination during the drilling of the GFRP composite. This study indicated that the effect of cutting speed on the thrust force is negligible and abrasion led to an elevation of thrust force. Palanikumar, et al. [15] investigated the influence of the twist drills of different point angles such as (85°, 115°and 130°) in drilling glass/epoxy composite material. The results, when used the different drill point angles, indicated that the (85°) point angle gives better results than (115° and 130°) and therefore, they have concluded that the drill with (85°) point angle produces less delamination than the drills with (115° and 130°) point angles. Ruslan Melentiev, et al. [16] presented a review on the influence of the process parameters and the tool geometry on the hole quality and the delamination on the drilling of GFRP. From the results, the cutting speed has an efficient influence on delamination, which depends on the specific range of variables considered and on the tool geometry used. Also, the feed rate is found to have the biggest effect on the delamination and therefore a low value of feed rate is recommended. Also, the drilling performance may be influenced by the type of workpiece material and tool material or coating. From the analysis of the results of this work, by using a standard twist drill, a low value of feed rate together with a high value of the cutting speed can reduce the risk of delamination. Vijayan Krishna raj, et al. [17] presented a study on the effects of drill points on glass fiber reinforced plastic composite while drilling at high spindle speed. In this work, the drilling experiments are conducted with three standard tools [point twist drill, Zhirov-point drill, and multi-facet drill], using a wide range of both the spindle speed and the feed rate to analyze the thrust force, the delamination, and the surface roughness. From the deep analysis of this work, the surface roughness when used a multi-facet drill is better than other tools and the delamination is less compared to the other used tools. The surface roughness is enhanced when used a multi-facet drill at a lower feed rate when compared to the standard twist drill. The thrust force at the start of the drilling increases sharply when used the standard twist drill and at the high-speed drilling, Zhirov point tool could use to drill holes with lower thrust force and the life of the Zhirov point is longer. Dhiraj Kumar, et al. [18] conducted an experimental study of the delamination and the surface roughness in the drilling of GFRP composite material with three dissimilar tools, having different materials and geometries [(i.e. helical flute (HSS) drill, carbide tipped straight shank (K20) drill, and solid carbide eight-facet drill]. The factors of the delamination and adjusted delamination are measured for the damage analysis of GFRP and the values of adjusted delamination and surface roughness are recorded for the helical flute HSS drill. Both factors of the delamination and adjusted delamination are lower for solid carbide (eight-facet) drill as compared with the other two geometries at 1500 rpm and 0.02 mm/rev. The values of surface roughness for the same tool are lower than that of the other two used drills. A solid carbide (eight-facet) drill is advised for the drilling of the asymmetric laminate of GFRP composites. Also, carbide tipped straight shank (K20) drill can be used for drilling asymmetric laminates of GFRP composites, but the delamination factor when used, adjusted delamination factor, and surface roughness values are more than the solid carbide eight-facet drills. Ahmed M. Easa, et al. [19], presented an analysis of surface integrity in the drilling of GFRP composite when using two types of cutting tools and different volume fraction ratios. Drilling experiments are conducted to study the influence of two types of tools, two cutting parameters, and the fiber volume fraction ratios on surface roughness and delamination factor. The experimental results showed that the higher cutting speed (1500 rpm), the low volume fraction ratio (5%), and the low feed rate (25mm/min) is suitable for machining GFRP to get a good surface roughness for the two types of the tools. Besides, the twist drill is more suitable than the end mill at high cutting speed and low feed rate, and the lowest values of delamination factor are showed at feed rate 25mm/min and the volume fraction 5%. Moreover, the good surface roughness of the drilled hole wall can be obtained with a low volume fraction (5%), low feed rate (25 mm/min), higher cutting speed (1500 rpm), and twist drill. Also, the increase of volume fraction ratio leads to an increase in surface roughness of the drilled hole at all values of cutting speeds and feed rates and for the two types of tools. Palanikumar [20] conducted experiments on GFRP composites using Brad, Spur drill, and optimized drilling parameters by using two input variables with four levels. From the analysis of this work, the low feed rate and the high spindle speed are useful to reduce delamination. Tsao, et al. [21], investigated the effects of drilling parameters on the delamination by various step-core drills. From the analysis of the results, drilling-induced delamination of various step core drills is inversely related to the diameter ratio, the spindle speed, and directly related to the feed rate. Ramesh, et al. [22] investigated to study the hole quality in drilling thick nonlaminated Glass Fiber Reinforced Plastic (GFRP) composite rods using coated tungsten carbide twist drill. The extrusion method is used to make the GFRP composite rods with a high fiber weight fraction. Taguchi's technique and analysis of variance (ANOVA) are employed to study the influence of process parameters such as; the feed and the spindle speed on the surface roughness of the drilling hole. The optimum level of process parameters to get the minimum surface roughness of the drilled hole walls is obtained. to controlled drilling of the used GFRP composite rods. Based on the used methodology, the feed and the drilling speed have no significance on the surface roughness of the drilled hole wall. This is similar to drilling nonlaminated composite rods using ratio drill but varies from drilling GFRP laminates where feed has a high degree of influence on surface roughness of the drilled hole wall. This due to the fiber orientation that is parallel and perpendicular to the axis of drill in nonlaminated composite rods and laminated composites respectively. The optimal drilling parameter levels to achieve lower surface roughness of the drilled hole wall and producing high-quality holes in pultruded GFRP composite rods is identified as 0.15 mm/rev feed and 750 rpm speed within the examined range. The used combination of optimal process parameter level gives surface roughness of the drilled hole wall in the order of 2.57 μm which is higher than that of using ratio drill. This may be due to the difference in geometry of the used drill. The mathematical developed model for the surface roughness of the drilled hole considers to not fitting, as the drilling parameters are not significant. Ahmed M. Easa, Abeer S. Eisa [23], studied the influence of five HSS twist drills (different point angles), five feed rates, three sets of fiber orientation angles, and three cutting speeds on the delamination and surface roughness of GFRP drilled hole. The results revealed a strong association between the results of the delamination factor (df) with the feed rate and also with tool point angle when using all sets of fiber orientation angles (0/0/0/0),(0/45/45/0)and (0/90/90/0) with the three cutting speeds. When used the higher cutting speed (3000 rpm), the fiber orientation angles (0/0/0/0), and the low feed rate (25mm/min) with the tool of point angle (60°), there are suitable for drilling GFRP to get a good surface roughness of drilled hole. Erol Kilickap, [24] investigated the effect of drilling parameters [the cutting speed, the feed rate, and the tool point angle] on the delamination produced when drilling GFRP composite. The damage formed with drilling GFRP composites is observed, at both the entrance and exit during the drilling. The conducted experiments are based on (Box– Behnken design). Also, the experiential models are developed to correlate and predict the drilling parameters and the delamination factor in the drilling of GFRP. These developed models for the delamination factor at entrance and exit are proposed that agree well with the experimental results. The models can be used also to select the level of drilling parameters. Therefore, time and cost are noticeably reduced. D. Abdul Budan, et al. [25] studied the influence of fiber volume ratio during the drilling of GFRP laminates. The studied parameters are; the tool wear, the hole quality, the chip characteristics, the delamination factor with the variation of the fiber volume reinforcement. From the analysis of the results, it is obvious that drilling of (70% fiber percentage content) composites produced bad surface roughness. Nevertheless, a better surface finish is obtained for the composite with 30% fiber volume content and it is evident that the increase in fiber percentage is increased tool wear. Lachaud, et al. [26], cleared that, using a twist drill causes numerous types of defects in the laminates, which can be divided into four main types. The fibers characters of the material and the drill geometry had a large influence on hole entry defect, though it does not appear on every occasion. It leads also to the tearing of the first ply of the first layer in contact with the drill. Due to the angular position of the cutting edges and just before cut, the fibers are subjected to an alternating action of bending or compression stresses. The damage from a heat source is due to the friction between the fibers and the two minor cutting edges of the drill and can cause damage to the matrix at the hole edge. Owing to the damage in the matrix, thus increasing the likelihood of torn fibers due to the mechanical action of the minor cutting edges and the removal of fibers leads to the roughness defect on the sidewall of the hole. Faramarz Ashenai Ghasemi [27], investigated the influence of the feed rate, the drill rotation speed, and the drill point angle on the delamination factor in polymer-based composite laminate reinforced by E-glass fibers. Three levels of the used parameters are defined using the full factorial technique of design of experiments. The drilling force is measured using a dynamometer and the amount of the delamination factor is computed by scanning the exit hole of the drilled area. The experimented data are analyzed using analysis of variance (ANOVA). The results indicated that the delamination factor increased at low and high values of the parameters within the considered experimental range of the parameters. Luís Miguel P., et al. [28], presented a comparative study on the different drill point geometries and the feed rate for drilling of composite laminates. The experimental study is planned and the results are evaluated. Also, the measurements during drilling are; the thrust force, the hole wall roughness measurement, and the delamination is assessed after drilling is accomplished. The laminates are drilled using five different tool geometries, three feed rates, and one cutting speed. The used comparison results for the drill tools are the maximum axial thrust force, the hole surface roughness, and the delamination. From the deep analysis of the results, a low feed rate may be appropriate for laminate drilling, as it decreases the axial thrust force and consequently, the risk of delamination onset, as is established by the previous analytical models. The special step drill is the preferred tool for the higher feed rates and the twist drill with a 120° point angle could be a decent option. From the analysis, the tool geometry had a large influence on the results for both thrust force and the delamination around the hole. The results also indicated that a 120° twist drill should use for minimal delamination and the special step drill could present a good alternative. Mohd Azuwan Maoinser, et al. [29], presented a work to study the influence of the cutting parameters used for drilling the holes in two types of composites, [Glass fiber reinforced polymeric (GFRP) and hybrid fiber reinforced polymeric (HFRP)] composites. Both of the composites plates of (3 mm) thickness are fabricated using a hand lay-up technique for assessing the effects of parameters on the quality of drilled holes. The holes are drilled using a (5 mm) solid carbide twist drill at different spindle speeds and feed rates. The holes are evaluated concerning damage factor (Fd) and the surface roughness (Ra) of the drilled holes. From the results, the [HFRP] composite experienced a lower damage factor (Fd) as compared to the [GFRP] composite at a lower feed rate or the spindle speed. (SEM) examination revealed that the occurrence of the delamination, the fiber pull-out, and the matrix cracking are accelerated in the drilled holes at both high spindle speed and feed rate. Rajesh Kumar Verma, et al. [30], presented a study on the machining of unidirectional glass fiber reinforced polymers (UD-GFRP) composites. In this work, three parameters including the tool wear or the tool life, the cutting forces or the power consumption, and better surface finish are investigated. It clear that good machinability means, less tool wear, low cutting forces, and low surface roughness. The factors such as the cutting parameters, the vibration, the tool wear, and the fiber orientations should take care of during machining to obtain a satisfactory environment for the best quality as well as productivity. From the results of this work, the conventional tools are not recommended for the machining of composites. The cutting tools such as [cemented carbides, tungsten carbides, PCD, PCBN] are widely used by the manufacturer. This work can be recommended for continuous quality improvement of a process/product in any manufacturing/production environment. The article of, Khashaba, et al. [31], tends to study the effect of cutting parameters (the feed rate and the cutting speed), and the laminate thickness on the thrust force, the torque, and the delamination in drilling woven E-glass fiber reinforced epoxy (GFRE) composites. Four of the feed rates (0.025, 0.05, 0.1, and 0.2 mm/r) and three of the cutting speeds (400, 800, and 1600 RPM) are exploited to drill square specimens of [36.6×36.6 mm], by using a CNC machine model [Deckel Maho DMG DMC 1035 V, ecoline]. The composite laminates with thicknesses of [2.6 mm, 5.3 mm, and 7.7 mm] are constructed respectively from [8, 16, and 24] glass fiber layers with a fiber volume fraction of about (40%). The specimen is scanned after drilling, using a highresolution flatbed color scanner, and the image is analyzed using CorelDraw software to assess the delamination factor. Multi-variable regression analysis is performed to present the main coefficients and contribution of each variable on the thrust force and the delamination. From the results, the drilling parameters and the laminate thickness have a significant influence on the thrust force, the torque, and the delamination factor. Marilena ColtStoica, et al. [32] presented a paper to study the defects in composite material caused by the drilling process. The holes are drilled and for each, it is measured the drilling force and monitoring the surface quality and the hole edge status, and some nondestructive methods of the defect evaluation are presented. It is preferred to optimize the process in terms of surface quality accomplished because the cutting speed is still limited by the processing tool to wear materials. Although other damage modes such as the matrix cracks may occur first, the delamination results in larger stiffness drops and a reduction in load-bearing capabilities. The delamination may occur from interlaminar stresses arising from geometric or material discontinuities from design features, such as an edge, a hole, a dropped ply. Besides, local variations in the volume fraction will always occur but large departures from specifications may cause by inappropriate process conditions and excess resin is important to avoid in pressurized or structural components such as pressure vessels. The work of, K.Siva Prasad, G. Chaitanya [33], studied the influence of machining process parameters on surface roughness and circularity of the drilled hole in GFRP composite and also selecting the optimal process parameters to improve the hole quality. The considered variables for experiments are the drilling speed (400,800 and 1200rpm), the feed rate (0.02, 0.04 and0.06 mm/rev), the material thickness (4, 6, and 8mm) together with the fiber orientation (0o, 45o, and 90o). The resulted responses are surface roughness and circularity of the hole. ANOVA (Analysis of Variance) test is conducted to analyze the significant effect of process parameters on surface roughness and circularity. The study of S. Ragunath, et al. [34], is essentially covered the drilling delamination factor on fiber-reinforced polymer composites. It has studied the influence of the process parameters, the material parameters, types of fabrication, and the optimization techniques at the drilling of the used composite. From the results of this study, the delamination factor on the exit is more than the entry panel of the drill bit because the compression action takes place between the fiber at the entry-level and bush out of fibers happened at the exit level of the drill bit and it is due to of direction of cutting tool to work. The feed rate is one of the major factors as compared to the other process parameters. The delamination effect can be reduced on FRP composites by the correct selection of parameters and their level. To minimize the thermal deviation effect on drilling, the small size hole is preferred as compared to the large size of the hole, owing to reducing contact between tool and work. Suitable optimization techniques are followed to predict the experimental value of output response by an empirical model. In the research of, Ahmed M. Easa, et al. [35], drilling experiments are conducted to study the influence of three sets of[the fiber orientation angles [0/45/45/0], [0/90/90/0] and [0/0/0/0], HSS twist drills(φ10, 12 and 14mm-point angle 90°), the feed rates (25, 50 and 75mm/min) and three of cutting speeds (1000, 2000 and 3000 rpm)] on surface roughness of drilled hole. The orientation of the fibers on the workpiece has been set during the manufacture of specimens. The plates are fabricated by hand lay-up process followed by a cure process under constant pressure. The mechanical properties of the used composite are calculated analytically using the mixture rules. The three sets of the orientation of the fibers are shown in the following figure 2.

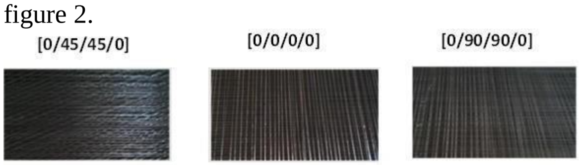

Figure 2- Three Sets of The Orientation of Fibers.

The Machine used in these experiments is an Extron M218.LH, CNC Machine, to perform the experiments. Programs written specifically for drilling of composites control the feed rate and spindle speed. Three cutting speeds and three feed rates can be used to obtain different surface roughness. The experimental setup is shown in the Figure 3 below.

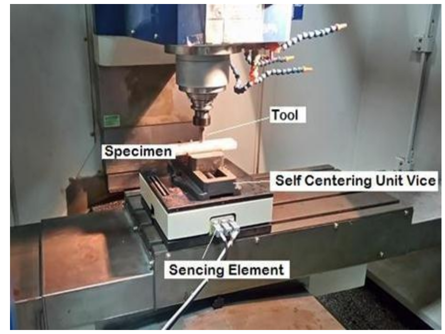

Figure 3- Experimental Setup.

The machined parts are prepared for measurements. The measurements of the surface roughness (Ra) are performed using the SJ-201P surface test. The measurements are made after the calibration of the instrument and with the cut-off length of (0.8mm) according to (ISO 4287- 1997). The surface roughness is measured at the entry, middle, and exit of the drilled hole, and the average value of surface roughness is considered for the investigation. The results showed that the higher cutting speed (3000 rpm), low fiber orientation (0/0/0/0), and the low feed rate (25mm/min) are suitable for drilling GFRP to get an enhanced surface roughness. The value of the surface roughness (Ra) increases with the increase of the feed rate, decreases with the increase of the cutting speed, and with the low fiber orientation angle. To get a better surface finish with any of the mentioned tools, it is necessary to use a high cutting speed, a low feed rate, and a low fiber orientation angle. Gheorghe Bejinaru Mihoc, et al. [36] presented a review on the drilling process of composite materials. In this work, the analysis of the drilling process from the used technological system, the machine tool, the tool, the device, and the material processing is presented. Furthermore, this work is made to understand the mechanism generating the phenomenon of delamination. To get the chosen quality at the composite material drilling, the drill geometry and the material have the main role and the resistance of the abrasive wear must take into consideration when choosing the drill tool material. The main problem of the defects met after the fabrication consists of the delamination of the hole.

3. Optimization of The Drilling Parameters

Composites are difficult to drill due to splintering and delamination of fiber, and these components are largely made net shape to achieving contour shape accuracy. Drilling composite materials are significantly affected by the tendency of these materials to delamination under the action of drilling forces. During the drilling of GFRP, the quality of hole is the most significant parameter to assess drilling performance because it influences the performance of the assembled performance. For optimization of machining parameters, many approaches such as numerical, statistical, and experimental methods are used. The objective of the research work is to optimize the process parameters on drilling performance on GFRP composites as introduced in the following part.

Gaitonde, et al. [37], developed a model based on response surface methodology for study the effects of the cutting speed, the feed rate, and the tool point angle on the delamination. The results of this work show that a decrease in the delamination when the cutting speed increases and advise the use of the low feed rates combined with adequate tool point angle. The objective of the work of Gallih Bagus W., et al. [38], is to optimize the drilling parameters such as the feed rate and the cutting speed, the tool geometries (Drill point geometry and drill point angle) on the thrust force, the hole roundness and the hole surface roughness in drilling GFRP stacks. In this research, the experiments are conducted using the Taguchi technique of experiments and an L18 orthogonal array is used to study the influence of various combinations of the drilling parameters and the tool geometries on the quality of the hole. From the results, the percentage influence of the feed rate, the drill point geometry, the drill point angle, and the spindle speed for reducing the total variance of multiple-performance characteristics are 42.78%, 42.26%, 6.97%, and 2.25% respectively. For minimizing the thrust force, the hole roundness and the hole surface roughness in the drilling composite material (GFRP), the drill point geometry, the drill point angle, the feed rate, and the spindle speed are set at level [2 (HSS Cobalt), level 1 (90°), level 2 (100 mm/min) and level 2 (2500 rpm)] respectively. From the experimental results, it obvious that the machining performance in the drilling process of GFRP composite can improve successfully through this method and the Taguchi-GRA method can simplify the optimization of the drilling parameters and the tool geometries with multiple-performance. I. Cavusoglua, et al.[39], presented an analysis of the surface roughness of the holes, which are drilled due to the different parameters by using L 18 matrix prepared with Taguchi's design of experiment on modified GFRP part, having 30% fiberglass, are investigated. In these experiments, the influence of changing the spindle speed, the feed rate, and the different drill diameters on the inner surface of the hole, are evaluated. From the analysis of the results of this work, the influence of the coating of the drilling bit being [HSS or TiN] is insufficient, and increasing the feed rate decreases the surface roughness measured. Moreover, decreasing the spindle speed increases the surface roughness of the hole. Irshad Ullah, et al. [40], presented a study to optimize the drilling parameters of the composite material. The studied responses are the surface roughness and minimizing the tool wear. In this research, machining parameters are optimized for three different types of composites, GFRP (Glass Fiber Reinforced Polymer), CFRP (Carbon Fiber Reinforced Polymer), and KFRP (Kevlar Fiber Reinforced Polymer). Also, in these experiments, PVD (Physical Vapor Deposition) coated carbide inserts are used with the same geometry. From the analysis of the results, in the drilling of the used samples, at a lower spindle speed of the three values, (1500 RPM), a better surface finish is accomplished in drilling CFRP composite. When the spindle speed is 2000 RPM (between the lower and higher value of the spindle speed), in this case, the surface roughness decreases, and a better surface is achieved. In drilling (KFRP) samples, at 2500 RPM, less surface roughness is attained. Moreover, the tool wear on the (PVD) coated cemented carbide is least while drilling of all three types of composite, but, depletion of the (PVD) coating increases with the increase in the cutting speed, which may lead to the built-up edges or sticking of composite material on the drill inserts. Shubham. S. Dabhade [41] presented an experimental work to find out the delamination factor of GFRP composite laminates using Taguchi‟s DOE L9 orthogonal array. The objectives of this research are to optimize the process parameters in the drilling of GFRP composite using Taguchi DOE and to find the significance of each process parameter using ANOVA. From the experimental results and Taguchi‟s analysis, both, the drill diameter and the drill material have a nearly predominant influence on the surface roughness of the drilled holes on GFRP composite. The minimum surface roughness value was observed as (0.458 μm) in this experiment and the drill material of carbide with bigger diameter drills gives the good drilled hole quality in the GFRP composite. The work of, Sachin Ghalmea, et al. [42], studied the factors affecting the delamination in glass fiber reinforced plastic (GFRP) composite during the drilling process. The selected two drilling parameters are the drilling speed and the feed rate that influence the delamination during the process. The used techniques for experimental design are Response Surface Methodology (RSM) and Analysis of Variance (ANOVA). The delamination is evaluated at the entry, middle, and exit positions of the hole. In addition, an effort is made to optimize the drilling speed and the feed rate for minimization of the delamination at these three positions using grey relational analysis (GRA). The results of this work can help in selecting the optimum level of the drilling speed and the feed rate to minimize the delamination at the entry, middle, and exit position of the hole improving the quality of the drilled hole. The prediction of the surface roughness in the drilling of the composite materials is carried out using fuzzy logic in the work of, B.Latha, V. S. Senthilkumar [43]. A fuzzy rule-based model is developed to predict the surface roughness in the drilling of glass fiber–reinforced plastic (GFRP) composites. The analysis of experimental results is carried out using a Pareto analysis of variance (Pareto-ANOVA) and ANOVA and presented in detail. For the damage analysis of the GFRP composite, both the delamination and adjusted delamination factors are calculated. The higher delamination factor, the adjusted delamination factor, and the surface roughness values are recorded for the helical flute HSS drill and therefore, this drill is not recommended for asymmetric laminates of GFRP composites. The delamination factor and the adjusted delamination factor are lower for the solid carbide eight-facet drill compared to the other two geometries at 1500 rpm and 0.02 mm/rev. The surface roughness values of the solid carbide eight-facet drill are lower than that of the other two drills used and the surface roughness values vary from 0.384 to 2.227 μm. From this, the solid carbide eight-facet drill is recommended for the drilling of the asymmetric laminate of GFRP composites. The carbide-tipped straight shank (K20) drill can be used for drilling asymmetric laminates of GFRP composites due to its ability to dissipate heat rapidly, but its delamination factor, adjusted delamination factor, and surface roughness values are more than the solid carbide eight-facet drills. The present work of, lK.Siva Prasad, G. Chaitanya [44], is focusing on the effect of the cutting parameters and the material parameters on the delamination of the drilled hole. The optimum cutting condition for minimizing the delamination is determined to increase the hole quality. The used parameters for the drilling operation are the drilling speed, the feed rate, the fiber orientation, and the material thickness. Using Taguchi's S/N ratio analysis to optimize the process parameters for the delamination in drilling of GFRP composites and ANOVA (Analysis of Variance) test is conducted to analyze the significant effect of the used parameters on the delamination. From the experimental results, it is obvious that Peelup delamination is highly influenced by the material thickness and followed by the feed rate and the fiber orientation. Also, the feed rate has a significant influence on the Push-down delamination next to the material thickness. Besides, a regression-based model is established to predict the delamination and good agreement between the experimental and predicted results is obtained with an order of 98%. The article of, Ritesh Bhat, et al. [45] is used as a central composite design to provide the framework for the experimental runs on glass fiber reinforced isophthalic polyester composite slabs. Grey relation analysis is used to optimize the drilling parameters such as; the drilling speed, the feed rate, and the material thickness. The three response outcomes are; the thrust force, the torque, and the drilled hole surface roughness, and ANOVA is used to find the ratio of influence of the drilling parameters. From the experimental results, the feed rate is the most influential factor in the drilling of glass fiber reinforced isophthalic polyester composites contributing 44.16% to the variation in the overall performance index, represented by the grey relation grade (GRG) for the given experimental range of control parameters. The edge defects in drilling which include incomplete fiber cutting are analyzed by, Vijayaraghavan, et al. [46]. In this work, a model that estimates edge defects during the drilling of FRP is discussed. The prediction results by the used model are compared to the experimental results and the possible techniques to characterize the defects in FRP drilling. The used model does not precisely predict the defects around a hole, it is offered as a "first step" in quantifying defects generated in FRP drilling. Although experiential methods may be currently better suited to predict defects, analytical models that take into account material properties are useful in the design of the material. A simple approach that predicts the optimum setting of the process parameters of the drilling operation on Polymer Based Glass Fiber (PBGF) composite is studied by, Dr. Murthy BRNand Dr. Rajendra Beedu [47]. In this study, three levels of the used parameters are used. These parameters are the drill angle, the drill diameter, the material thickness, the drilling speed, and the feed rate. The output responses are the thrust force, the torque, the surface roughness, and the delamination. Taguchi's L27 an array is used to set the process parameters and Gray relational analysis (GRA) is used also to find the optimum value of drilling process parameters. Conduction of ANOVA on GRA revealed the significance of each factor on the process output. The results revealed that the setting of parameters ensures optimum output and the grey relational analysis is established to be the most effective and simple approach for optimal setting of process parameters especially in case of multiple responses that too with contradicting objectives. ANOVA applied on GRG reconfirms the fact that the results of GRG are reliable. Multi-spindle drilling using a polydrill head is an industrial hole-making approach that allows drilling several holes simultaneously is studied in the work of, Muhammad Aamir, et al. [48]. In this work, the optimization of the drilling parameters and two drilling processes [One-time drilling and multihole drilling] using Taguchi technique. The analysis of variance and the regression analysis are implemented to indicate the importance of the drilling parameters and their impact on the measured responses; [The surface roughness and the hole size]. Taguchi optimization indicated that the optimal drilling parameters are found at a low of both the cutting speed and feed rate using a poly-drill head. Also, a fuzzy logic approach is employed to predict the surface roughness and the hole size. It is found that the fuzzy measured values are in good agreement with the experimental values; thus, the developed models can be effectively used to predict the surface roughness and the hole size in multi-hole drilling. Furthermore, confirmation tests are performed to validate that the Taguchi optimized levels and fuzzy developed models actively represent the surface roughness and the hole size. Vankanti and Ganta [49], used Taguchi experimental design and an L9 orthogonal array to study the influence of various combinations of the process parameters on the hole quality. The analysis of this work indicated that the feed rate is the most significant factor that affects the thrust force followed by the drilling speed, the chisel edge width, and the point angle. Moreover, the cutting speed is the most important factor affecting the torque, and the circularity of the hole followed by the feed rate, the chisel edge width, and the point angle. The optimization of the process parameters such as the feed rate, the cutting speed, the tool point angle, and the chisel edge width in the drilling of glass fiber reinforced polymer (GFRP) composites using the Taguchi method is presented in the work of, Vinod Kumar Vankanti, Venkates warlu Ganta [50]. An L9 orthogonal array is used to study the effect of various process parameters on the resultant hole quality. The importance of each parameter on the drilling is determined by (ANOVA) test. From the results, it is obvious that the feed rate is the most significant factor influencing the thrust force followed by the drilling speed, the chisel edge width, and the point angle respectively. Also, the optimum process parameters of the used range in the drilling of GFRP composites are; the drilling speed of 500 rpm, the feed rate at 0.04 mm/rev, the point angle at 90◦, and the chisel edge width of 0.8 mm for the thrust force. But for the torque; the drilling speed at 500 rpm, the feed rate of 0.06 mm/rev, the point angle at 95◦, and the chisel edge width of 1.6 mm are found to be optimum values. In addition to the previous researches, İlknur Çavuşoğlu, et al. [51] presented work on the optimization of the drilling parameters of glass fiber reinforced plastics via the Taguchi method. In this work, the analysis and evaluation of the delamination factor are investigated for the GFRP using high precision metrology techniques. The optimum values with the minimum of the delamination are determined by using Taguchi DoE. Thus, with these values in all sectors use of free of damage and delayed damage will be achieved. The Optimization of the drilling process parameters on surface roughness and material removal rate by using the Taguchi method is presented by S.V. Alagar Samy, et al. [52]. This method is used to investigate the effects of drilling parameters such as the cutting speed, the feed rate, and the depth of cut on the resultant surface roughness and the material removal rate in drilling and to find the optimal cutting parameters. A series of experiments based on the L16 orthogonal array is conducted using CNC vertical machine. To determine the most significant factors affecting the surface roughness and material removal rate, the analyses of variances are employed. When used Analysis of Variances (ANOVA- S/N ratio), it is showed that the depth of cut is majorly contributing of about 56.96% in obtaining optimal MRR(metal removal rate) followed by the feed rate of 20.11% and the depth of cut of 3.56%. But for surface roughness, ANOVA indicated that the cutting speed has a large effect in obtaining optimal surface roughness (about 28.65%) followed by the feed rate of (10.20%) and the depth of cut of (8.12 %). Ahmet Can, Ali Ünüvar, [53] presented work on the optimization of process parameters in drilling of SMC composites using the Taguchi method to discuss the machinability in the drilling of SMC (Sheet Mold Compound) A-Class composite materials. The work objects to study; the thrust forces, the surface roughness, and push-out - peel-up delamination behavior in the drilling process. Also, ANOVA is used to evaluate the effect of the different parameters on machinability outputs of the drilling process. The optimum parameters show a reduction in the thrust force by 9,8 %, the surface roughness by 33,3 %, push-out delamination by 2,5 %, and peelup delamination by 1,38 %. Kabakli, et al, [54] presented work for evaluating the effects of; the feed rate, the peripheral speed, the hole diameter, and the hole depth on the surface roughness, perpendicularity, and Cylindericity of the drilled hole. The performance characteristics and various signal-noise ratios are calculated with the Taguchi method. To identify the optimum drilling conditions for U-drills, ANOVA is performed and the influence of the controlled factors at different levels are analyzed. From the results, the hole diameter and the feed rate have a large effect on the resultant surface roughness of the drilled hole. The hole diameter plays a vital role in the quality of the surface roughness. The perpendicularity also is influenced by the hole diameter and the feed rate with the percentage contributions of 9.70 % and 11.31 %. Also, the most important variable affecting the perpendicularity is the hole depth with a percentage contribution of 75.18 %. This analysis of the results confirmed that, with the optimum parameter combination selected with the Taguchi design, the desired performance characteristics could be achieved in actual drilling conditions. Murthy B.R.N., et al. [55] presented work to optimize the effect of the process parameters such as the spindle speed, the feed rate, the drill diameter, the tool point angle, and the material thickness on the generated thrust force and the torque during drilling of Glass Fiber Reinforced Polymer (GFRP) composite material using a solid carbide drill bit. Full Factorial Design of Experiments (DOE) has been adopted and the results indicated that the spindle speed is the highest contributing parameter for the variation in the thrust force, but the drill diameter is the main contributing factor for variation in the torque. It is important to notice that, the results are based on the preselected range values of, [the spindle speed, the feed rate, the material thickness, the drill diameter, and the drill point angle], and therefore, the conclusions drawn cannot be completely generalized. From the analysis of the results, the thrust force is significantly influenced by the spindle speed, and they are inversely proportional. Due to the use of a bigger drill diameter, the thrust force increased and the cutting torque is significantly influenced by the drill diameter. It is evident from the results that, the thrust force and cutting torque are increased with the increase in feed rate and the material thickness. V. N. Gaitonde, S. R. Karnik [56] presented a work to minimize burr size at the exit of holes in the drilling at the manufacturing stage. A multi-response optimization method has been employed to determine the best combination values of; the cutting speed, the feed rate, the tool point angle and the lip clearance angle for specified drill diameters to simultaneously minimize the burr height and the burr thickness during the drilling. The experiments are planned as per the L9 orthogonal array and a multiresponse signal to noise ratio (S/N) is applied. To determine the optimal levels and to detect the level of important parameters, Analysis of Means (ANOM) and Analysis of Variance (ANOVA) are performed. The best combination values of process parameters for simultaneously minimizing the burr height and the burr thickness at the exit of the holes in the drilling are determined using Taguchi's quality loss function approach and the relative significance of the process parameters is determined by ANOVA. The optimal values of the cutting speed and the lip clearance angle are at the low level, i.e. (8 m/min and 8° respectively), for all identified drill diameters. ANOVA shows that the tool point angle has a significant effect in reducing the burr size for (4 and 10 mm) drill diameters. On the other side, the lip clearance angle has the main contribution in controlling the burr size for (16, 22, and 28 mm) drill diameters. The optimization of the drilling parameters using the Taguchi technique to obtain minimum surface roughness and maximum tool life is presented in the paper of Kadam Shirish, M. G. Rathi [57]. The experiments of the drilling are conducted using the L9 orthogonal array on a CNC vertical machine using uncoated (M32 HSS) twist drills under dry cutting conditions. The cutting speed, the feed rate, and the depth of the hole are selected as control factors, and the Signal to Noise (S/N) ratio is employed to optimize these factors. From the analysis of the results, less surface roughness in the dry drilling is shown when used high cutting speed, low feed rate, and low depth of cut. The use of Multiple Response Optimizations in the drilling using Taguchi and Grey Relational analysis is presented by B. Shivapragash, K.Chandrasekaran [58]. The main object of this work is to minimize the damage events occurring during the drilling process for [Al-TiBr2] composite when used radial drilling machining at dry conditions. From the analysis of the results, the optimum cutting parameters for minimizing the surface roughness are the spindle speed (low-level - 1000 rpm), the feed rate (maximum level -1.5 mm/min), and the depth of cut (middle level - 6 mm).

4. Conclusions

From the deeply study and analysis of the previous researches, the following conclusions can draw concerning the drilling of GFRP:

1- In conventional machining, when used a drill tool, the feed rate, the cutting speed, the point angle of the used tool, and volume fraction ratios are the most influential factor on the surface roughness and the delamination of the drilled hole.

2- Also, when used the (end mill - different diameters) at drilling, the results demonstrated a strong association between the results of the surface roughness and the delamination factor with the cutting speed, the feed rate, the diameter of the cutter, and volume fraction ratios

3- The experimental results at nontraditional machining showed that the high cutting speed, the low volume fraction ratio, and the low feed rate are suitable for the drilling GFRP to get a good surface roughness and low values of the delamination factor.

4- The surface roughness of the drilled hole is highly influenced by the fiber orientation angle, the cutting speed, the feed rate, and the tool diameter respectively when used conventional and nontraditional machining. 5- The use of different tool diameters with the same angle (90°) indicated that the diameter of the drilling tool is playing a vital role in the quality of the drilled hole.

6- The thrust force increased with increasing the cutting speed and the feed rate and changing the feed rate had an approximate linear effect on the thrust forces. Besides, the minimum thrust force falls in the smaller drill diameter region. A feed rate strategy can avoid delamination caused by the thrust in drilling. 7- The selection of the highest speed on the lowest volume fraction ratio with the biggest drill diameter and lowest feed rate results in the best combination to get the better quality of drilling hole. All these parameters have a major contribution to the quality of the hole, the cutting speed is inversely proportional to the thrust force and torque.

8- The Taguchi-GRA method can simplify the optimization of the drilling parameters and the tool geometries with multiple-performance. When used the methodology (RSM) and Analysis of Variance (ANOVA) optimize the drilling parameters, it minimizes the surface roughness and the delamination of the drilled hole.

9- The setting of parameters ensures optimum output using Taguchi"s techniques and the grey relational analysis is established to be the most effective and simple approach for optimal setting of process parameters especially in case of multiple responses that too with contradicting objectives. ANOVA applied on GRG reconfirms the fact that the results of GRG are reliable.

10-This work has provided a literature review on the drilling of polymer matrix composite machining over the last ten years with a specific focus on the process of drilling methods and the different optimization methods used to improve the hole quality. 11- This field needs more investigations and analysis to understand the behavior of various defects especially the surface roughness, Cylindericity, and the delamination of the drilled hole with different cutting parameters and different conditions of drilling accurately because there are a varies between many of the results.

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