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Surface Roughness and Delamination Analysis in Drilling of GFRP and AL/Sicp Composites with Different End Mill

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Abstract: ***In the present research the influence of the input process parameters; three of cutting speeds, five of feed rates and three cutters (end mill) of 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 are studied. From the deep analysis of the results, the feed rate and the cutter diameter are had a large effect on surface roughness (Ra)and delamination factor (df), while both are increased with the increase of cutter diameter and the used feed rates. The average values of results for surface roughness (Ra) and delamination factor (df) when drilling GFRP composite are bigger than that values of AL/SiCp composite at all used cutters, cutting speeds and all used feed rates. Used of 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 a better surface roughness of drilling hole.***

Keywords: Metal -matrix composites, GFRP, Defects, Surface Quality, Surface Delamination, Milling, Machining processes.

1. Introduction

Metal matrix composite such as AL/SiCp has widespread applications due to its excellent properties like high strength, fracture toughness and stiffness and due to the significant potential of improvement in the thrust-to-weight ratio, which is suitable for aerospace and automobile applications. Also, AL/SiCp base alloys are used due to its attractive properties such as, corrosion resistance, good thermal conductivity, good workability and especially excellent cast ability. In the other side and due to their low weight and high aspect ratio, glass fiber reinforced polymer (GFRPs) composite materials are extensively used in many applications such as; domestic sector, railway, aeronautics, sporting goods, energy field and automobiles. Parts and components made of AL/SiCp and GFRPs need certain machining operations, such as; milling, grinding, and drilling for fastening, where it is used. During drilling operation, different sorts of damage may occur such as, pullout of fibers, breakage of fiber, cracking of matrix and drilling-induced damage, i.e. delamination which it happens due to the separation of layers of the materials. Poor surface finish of the drilled hole and faster tool wear led to the further study of composite machining.

B.M. Umesh Gowdaa, et al. [1], presented a work, to estimate the circularity, cylindricity and surface roughness in drilling Al-Si3N4 metal matrix composites using artificial neural network. The aluminum silicon nitride composite forged plate with 6% and 10% Si3N4 reinforcement material is drilled using high-speed steel drill bit and the various cutting speeds and feed rates are used in these experiments. The measurement of machining time, circularity, cylindricity and surface roughness for each hole at different cutting conditions are conducted .The estimation of the output parameters by sophisticated method of signal analysis like the one Artificial Neural Network (ANN) is made also. The influence of network architecture is used to know the drilled hole status at different training sets viz. 30%, 50% and 70%. Several structure of neural network with different number of neurons in a single hidden layer are trained and tested to find the best structure with (R) value nearer to one. The optimum (R) value for different output parameters is obtained at 70% of training set. The relationship between the measured parameters is well represented by the proposed model with 70% training set and with 6% Si3N4 reinforcement material. The object of the work of, Erol Kilickap [2], is to investigate the influence of drilling parameters, such as cutting speed, feed rate and point angle of the used tool on the delamination produced when drilling GFRP composite. The damage at the entrance and exit of hole during the drilling GFRP composites are observed. In order to analyze the effects of drilling parameters on delamination, the experiments are planned as per Box–Behnken Design and the second order nonlinear delamination factor models are developed using RSM. The empirical models are developed to correlate and predict the used parameters and delamination factor in drilling. From the analysis of the results, the developed models are adequate at 95% confidence level within the limits of factors being considered. The delamination factor is bigger for higher cutting speed and feed rate. The drill with 90° point angle is preferred for reducing the delamination factor and the delamination factor is smaller at entrance than at exit for three used drills. The developed models in this research can be effectively used to predict the delamination factor at entrance and exit due to the results of RSM models and experimental results and Also, can be utilized to select the level of drilling parameters to save time and cost. In the research of Gong-Dong Wang and Melly S Kirwa [3], a comparative study of different drilling tools (a twist drill, a pilot hole/pre-drilled hole and a step drill) on the influence of the hole quality. To achieve this comparison, thrust forces have been monitored during drilling experiments where one spindle speed and four different feed rates are used. A finite element model has also used to study the delamination damage on the laminates and validate the experimental results. The results show that, thrust forces increase with increase of feed rates and show; drilling by step drill is the most appropriate method as it records low forces hence minimal delamination damage. From also the results, the

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ratio of the pilot hole to the drilling tool diameter is inversely proportional to the thrust force. The use of twist drill may not be the appropriate method to drill laminates as it records the highest thrust forces at low and high feed rates as compared to other methods. For the delamination, there has been a good consensus between the experimental and the FE simulation results. Finally, from this work, low to moderate feed rates and proper selection of tool geometry for optimum results as far as hole quality is concerned for composite laminates. Also, the use of step drill is the best option for minimal damage to composites. Anant B. Marathe and Anil M. Javali [4], investigated the effect of different tool geometries, speeds and feeds during drilling on a composite plate, which have different chemical composition for specific cutting energy, peel up at entrance and push out delamination. Experimental work is established based on the Taguchi techniques. Also, Statistical tools such as signal-to-noise ratio, the analysis of variance and regression analysis are used to investigate effect on specific cutting energy and delamination. For mechanical-grade composition(A), the minimum power is consumed using point angle of 80°, speed of 98 rpm and feed rate of 39.2 mm/min, that is at smallest point angle and both of lowest speed and feed. The better efficiency of machining that is, for the combined effect of these two parameters as indicated by SCE, when used smallest point angle of 80°, highest speed of 2355 rpm and feed rate of 353.25 mm/min. The main contribution factor is feed rate (79.93%) followed by tool point angle (6.17%) and cutting speed (2.35%) as indicated by response for S/N ratio and the ANOVA calculations. But the delamination factor is found to be zero for most of the point angle, speed and feed combination. For electrical grade composition (B), the results are similar to that of a mechanical grade composite. The main contribution factor is feed rate (92.95%) followed by cutting speed (2.36%) and tool point angle (0.82%) as indicated by response for S/N ratio and the ANOVA calculations and the delamination is negligible at all observations. When the E-glass fiber content is increased, more power is consumed at optimum processing condition of point angle 80°, cutting speed of 2355 rpm and feed rate of 353.25 mm/min. The shear force is directly proportional to glass fiber content of the composite, and more energy is consumed in shearing them. An error associated with specific cutting energy in both composites varying from 20.12% to 21.68%. The influence of all factors has been identified and it is believed that the results of this work can help engineers in composite fabrication field for determining the optimum machining process parameters. B. Ramesh, et al. [5], presented experimental investigation to study the effect of process parameters on quality characteristics of standard and special geometry design of a drill body. The drilling experiments using carbide drills (twist drill and ratio drill) are conducted using response surface methodology. From the results, it is observed that, for a twist drill, feed rate is more consequential followed by cutting speed in influencing the quality characteristics. Also, for ratio drill, feed rate is more paramount in influencing thrust force, torque and damage factor, whereas, spindle speed is more paramount in influencing surface roughness. The damage factor is lesser with ratio drill than a twist drill because of its special point geometry (relieved cone).The combination of the process parameter level, (feed rate of 0.052 mm/rev and spindle speed of 1059 rpm) having the highest desirability of 0.691 is the optimum for drilling the pultruded composites with a twist drill. The process parameter level combination (feed rate of 0.05 mm/rev and spindle speed of 750 rpm) having the highest desirability of 0.817, is the optimum for drilling the pultruded composites with ratio drill. From the analysis, thrust force, torque, surface roughness, ovality, and damage factor have been reduced by 36.79, 47.73, 12.55, 2.30, and 6.77% respectively in the optimal drilling of pultruded composites using a ratio drill as compared to that of the twist drill. This work indicated that, the developed response surface models could be effectively applied to anticipate the quality characteristics within the chosen range of parameter levels. Dhiraj Kumar, et al. [6], presented experimental investigation in the drilling of glass fiber reinforced polymer (GFRP) composites with three dissimilar tools, having different materials and geometries. Tool materials, geometries and the parameters of cutting are considered major factor, which is responsible for drilling-induced damage. The resulted damages are measured by two factors of delamination. This work indicated that, qualities of drill holes significantly improved when solid carbide eight-facet drill is used. Both of delamination and adjusted delamination factors are calculated for the damage analysis of GFRP composite materials and higher delamination factor, adjusted delamination factor, and surface roughness values are recorded for the helical flute HSS drill. Also, from these results, helical flute HSS drill is not recommended for asymmetric laminates of GFRP composites and its surface roughness values vary from 1.226 to 3.591 μm. In the other side, the delamination factor and adjusted delamination factor are lower for solid carbide eight-facet drill compared with the other two geometries at 1500 rpm and 0.02 mm/rev. The values of surface roughness resulted when used solid carbide eight-facet drill are lower than that of the other two used drills and surface roughness values vary from 0.384 to 2.227 μm. Therefore, solid carbide eight-facet drill is recommended for drilling of asymmetric laminate of GFRP composites. Due to the ability to dissipate heat rapidly, carbide tipped straight shank (K20) drill can be used for drilling asymmetric laminates of GFRP composites. The delamination factor, adjusted delamination factor and surface roughness values of carbide tipped straight shank (K20) are more than the solid carbide eight-facet drills. In addition, the Surface roughness values vary from 0.794 to 2.769 μm. Tom sunnya, et al. [7], presented a study on the effect of spindle speed and feed rate on delamination behavior of composite materials by conducting drilling experiments using Taguchi's L25, 5-level orthogonal array and Analysis of variance by using three different tools namely Twist drill ,End mill and Kevlar drill. ANOVA is used to analyze the data obtained from the experiments and determine the optimal parameters in drilling of GFRP composite and it is used to determine the best levels of the parameters in the drilling induced delamination. From these results, the delamination is increased with spindle speed (1000rpm-2500rpm) and decreases with feed rate (100mm/min to 400mm/min). But the opposite trend is shown with very low feed rate i.e., 50mm/min and high spindle speed 300rpm. The results also indicated that, in both the cases, delamination factor

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increases instead of decreasing. ANOVA results reveals that, feed rate is the main cutting parameter, which has greater influence on the delamination factor. Due to the S/N results, the optimal parameters for the minimum delamination are the spindle speed at level (2500 rpm) and the feed rate at level (100mm/min).From the analysis, the predicted values of delamination at optimized process parameters are in a good agreement with the test results. The delamination is decreased with the increase of the spindle speed and decreasing with the feed rate for all used tools, but the delamination is observed to be less in the case of Kevlar drill. All the tools shows higher values of mean delamination factor at higher spindle speeds. Similarly, feed rate, delamination is high, irrespective of the tool geometry and material, all the tools shows higher values of mean delamination factor at very low feed rate. Eshetu D. Eneyew, Mamidala Ramulu [8], presented an experimental investigation on the drilling of unidirectional carbon fiber reinforced plastic (UD-CFRP) composite using polycrystalline diamond (PCD) tipped eight-facet drill. The quality surface of the drilled hole is examined through surface roughness measurements and surface damage by scanning electron microscopy (SEM). Based on the results of this research, the thrust force is increased with the increase of feed rate and decreases slightly with the increase of cutting speed and the feed rate is more influenced on the thrust force than the cutting speed. The prediction model, which used agrees with the measured value of the thrust force with an average error of 3%. Also, the thrust force varies significantly over the rotational position of the drill and a lower value of the thrust force is observed around the rotational angles of 135° and 315°. The maximum average of (Ra, Rq, Rz and Rt) are associated with angles of 135° and 315° along the circumference of the hole. The fiber pullout is observed in two regions where the angle of interaction between the cutting direction and the fiber orientation is from, 135°to 175° and 315° to 355°. The maximum peak-to-valley height (Rt) is found to be a sensitive parameter to characterize the fiber pullout. Good hole surface is obtained with a combination of higher cutting speed and lower feed rate. The experimental results indicated that, the minimum thrust force, delamination factor, and lower values of surface roughness (Rt) are associated with a cutting speed of 4500–6000 rpm and feed rate of 64 μm/rev. Haijin Wang, et al. [9], presented an experiments with different drilling depth which used to investigate the developing process of delamination. In order to evaluate the delamination of different cross sections in radial direction of the hole, the grinding method is adopted. Three-dimensional morphology of delamination at the exit of hole are measured and the regularity of delamination with the change of drilling depth is analyzed, and also, the existence of "hidden delamination zone" is finally obtained. The critical thrust force of delamination is also studied, and it is proved correct. The experimental results indicated that, the delamination formation is obtained, and the three-dimensional morphology of delamination in different stages of drilling are concluded finally. The actual delamination area is made up of the observed delamination zone that can be detected and the hidden delamination zone that cannot be detected, so the delamination area detected by popular detection means is smaller than the actual delamination and the hidden delamination zone will be generated under the condition that the edge of delamination area is compressed tightly. Finally, the theoretical position of the critical delamination coincides with the experimental result, and the theoretical analysis of critical thrust force is proved right. Ashish. B. Chaudharia et al. [10], presented a work to evaluate the delamination factor by studying process parameters of drilling. Delamination factor is evaluated with an influence of process parameter during the drilling of composites such as, cutting speed, depth of cut and feed rate. To predict the delamination factor as a function of different combination of machining parameters Analysis of Variance (ANOVA) is used. From the analysis of the results, minimum delamination factor at entry is observed at 1060 during drilling of C-GFRP and the cutting speed has less effect on entry and exit of delamination factor (DF). In addition, the less delamination at exit is observed in 1300 and gradual increase of delamination at exit is recorded after1060 with increase of PA up to 118°. From the comparison between the experimental and the predicted results it is found that, the root means square error at DF at entry and exit are; 1.4732% and 2.9277% respectively. The used models are helpful in predicting delamination factor (DF) within the range of specified input with more than 95% accuracy and the data for each response is well fitted in the developed models. Kumar D., Singh K. [11], presented a research to investigate the effect of multi-walled carbon nanotube (MWCNT) loading on drilled hole surface roughness of MWCNT doped carbon/epoxy polymeric composite material. The root mean square roughness (Rq) is used to assess the effect of (MWCNT) on the resultant surface roughness. Rq is measured at the entrance and exit of the hole. Experiment is performed using (Box- Behnken Design) for develop an empirical model to predict the surface roughness value at the entrance and exit of the hole. The developed model is accurate within the level of confidence and the surface roughness of the hole at entrance and exit are improved due to loading of (MWCNT) in polymer matrix. Surface roughness is good at entrance more than at exit, due to the less damage at exit. When used 1.5 wt% of (MWCNT) doped carbon/epoxy polymeric composite material, minimum surface roughness has been observed and maximum surface roughness is recorded when used 0.5 wt% of MWCNT doped carbon/epoxy polymeric composite material. Also, drilling parameters has influences on surface roughness and (Rq) is increased with the increase in spindle speed and feed rate. The developed empirical model for (Rq) at (entrance and exit) is predicted the value accurately within level 95% level of confidence. M.P. Jenarthanan, A. Lakshman Prakash [12], developed a mathematical model for evaluate the delamination and the surface roughness during end milling by using response surface methodology (RSM). The mathematical model is developed to determine the effect of input parameters (cutting speed, depth of cut, helix angle and feed rate) on the output response (delamination and surface roughness) in machining of hybrid glass fiber reinforced plastic (GFRP; Abaca and Glass) composite using solid carbide end mill cutter. Design/methodology/approach – four-factor, three-level, Taguchi orthogonal array design in RSM are used, and to analyze the data, which collected graphically, the "Design Expert 8.0" is used. In addition to,

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Analysis of variance is used to validate the model and for determining the most significant parameter. From the analysis of the results, feed rate is the main parameter, which has greater influence on delamination (88.39 %), followed by cutting speed (53.42 %) for hybrid GFRP composite materials. Both delamination and surface roughness are increased with the increase of feed rate and when the cutting speed increases, the delamination factor is increased, whereas the surface roughness decreases. The increase in depth of cut leads to a decrease in delamination factor whereas the surface roughness increases with increase in depth of cut at first and then decreases with an increase in depth of cut and also, the delamination and surface roughness decrease with an increase in the helix angle. The developed model is used to calculate the surface roughness and delamination under different cutting conditions with the chosen range with 95 % confidence intervals. By using such model, one can obtain remarkable savings in time and cost and the used technique is convenient to predict the main effects and interaction effects of different influential combinations of machining parameters. I. Sultanaa, et al. [13], investigated orbital drilling of composites to observe hole surface integrity in terms of surface roughness, delamination, surface burning, and geometric accuracy. Experiments are conducted with a brazed single layer diamond tool of ball-end geometry to drill 220 holes and the cutting forces and temperatures are measured during drilling. The results of the experimental work showed that, the forces increased sharply during drilling of the first 44 holes followed by a gradual rise. The variation of part temperatures varied between 98 and 184°C. Surface roughness (Ra) is varied from 13-17 μm. Almost 99% of the holes are drilled without exit delamination, and 2.3% of the holes showed entrance delamination. The peripheral and thrust forces are found to increase with increasing number of drilled holes and no thermal damage is observed on hole surfaces. On the hole peripheries fuzzing and fiber pull-out are observed. S. T. Huang, et al. [14], used high-volume-fraction of SiCp/Al composites because this kind of composites have excellent thermo-physical properties. The influences of the cutting speed and feed rate on the drilling performance of SiCp/Al composites with 56% Sic particles are investigated experimentally. Surface quality of drilled-hole, drilling forces and tool wear are studied and determined. From the results, it is clear that, the feed rate is one of the main cutting parameters, which had large affect the drilling performance, but cutting speed had no significant effect on the thrust force. A finite element model has been developed using finite element platform (ABAQUS/Explicit) to simulate the drilling behavior of Al1100/10% SiC metal matrix composite is presented in the research of, Vikas K Doomra, et al. [15]. The effect of cutting speed and feed rate on the thrust force is studied experimentally. From the analysis of the results, the thrust force increases with an increase in cutting speed and feed rate. The low values of cutting speed and feed rate should be preferred while drilling Al1100/10% SiC MMCs. The model of a three-dimensional (FE) has been proposed for predicting the thrust force during drilling of MMCs and the predicted results of the model have been compared with experimental results. The magnitude of thrust force obtained from the proposed finite element model is in close agreement with the experimental values. The proposed model is quite efficient to predict the thrust force signals generated during drilling of Al1100/10% SiC MMCs. The present research of, Sarbjit Singh [16], investigated the effect of change in drill point geometry on the drilling quality characteristics of the drilled hole wall for Al-6063/10% Sic MMC using Taguchi design of experiments. The input process parameters levels are established by Taguchi's methodology for optimum values of the output responses. From the analysis of the results, single conical chips is produced in the case of primary cutting edge and single ring type of chips is produced in the secondary cutting edge respectively. No burr formation is observed either at entrance or at the exit side during drilling with the modified drill geometry. Due to these results, no additional machining operation is needed and overall cost of production is reduces. It is obvious that, the step diameter is the main factor, which influences the specific cutting pressure followed by feed rate and tool point angle. At the higher feed rate, a large lump of material has been sheared off from the cutting zone by the cutting edge and the energy is increased and transferred from drill point geometry to the work piece material being sheared and also causes an increase in the thrust force and torque values. The burnishing and honing effect produced by the SiC particulates have an important effect on the behavior of surface roughness with respect to process parameters. The variation in the cutting forces values increases the temperature at the cutting zone. The surface finish of the drilled hole wall is improved due to the burnishing effect produced by entrapped abrasive particles. In the study of Srinivasan, et al. [17], an attempt has been made to model the machinability evaluation through the response surface methodology for machining of homogenized 10% micron Al_2O_3 LM25 Al MMC. The combined effects of three parameters including; cutting speed, feed rate and depth of cut on the basis of three performance characteristics of tool wear, surface roughness (Ra) and cutting force are investigated. The machining parameters are optimized using desirability-based approach response surface methodology (RSM). The developed model is used for predicting surface roughness, tool life and cutting force. From the results, the optimizing of the parameters give lower values of both surface finish and cutting force and the surface roughness is better with increase of the cutting speed but the increasing of feed rate adversely affects the surface roughness. From the analysis, cutting speed has the most dominant effect on tool wear and the cutting force almost linearly varies with feed rate. At low cutting speed, the cutting force is higher, the interactions of cutting speed with feed rate, and depth of cut is dominantly and affects the cutting forces. R.Venkatesh A., et al. [18], presented a work to overcome the problem of poor machinability of Aluminum Silicon Carbide (A356-SiC) materials. The used composite, Aluminum A356 is the base matrix material reinforced with 20 % weight by volume of Silicon Carbide particles of mean diameter 55 μm to 80 μm. The major parameters, which investigated, are minimum power consumed by main spindle, less surface roughness and minimum tool wear. Due to the stability of the tool at high cutting speed and easy removal of material, the surface roughness is better at this stage. The (PCD) tool (grade 1300) performs well in metal removal rate, but wear in this case is more. The decrease in cutting force is shown when used low

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feed rate (0.108 mm/rev) but when using high feed rate of (0.368 mm/rev) with high depth of cut a good amount of metal removal is resulted. Surface finish is improved with the increase in cutting speed and as the feed rate increases, surface finish improves only up to certain level after that it starts deteriorate. The machinability aspects of B4Cp reinforced 6061Al alloy (reinforced with 37µm and 88µm particulates) is presented by Vijaykumar Hire math, et al. [19]. The composite is prepared using Scanning Electron Microscopy equipped with EDX analysis (Hitachi Su–1500 model) to identify morphology and distribution of B4C particles in the matrix of 6061Al. (PCD) tool is used to study the effect of particle size on the cutting forces and the surface roughness under varying machinability parameters; two of cutting speeds, feed rate and depth of cut. From the analysis, good uniform distribution of B4C particulates in 6061Al matrix is achieved due to the addition of K2TiF6 halide salt. The resulted surface roughness of the machined composite is influenced by cutting speed and also, surface roughness is high with 88µm particle reinforced composites and when the particle size increases, surface roughness is increased. V. M. Rabindranath, et al. [20], presented a work about the effect of cutting parameters on thrust force, surface roughness and burr height during drilling of the pure base alloy (Al-2219), mono composite (Al- 2219+8%B4C) and hybrid composite (Al-2219+8%B4C+3%Gr) MMCs. The drilling is conducted on CNC machine with three tools [TiN coated HSS tool, M42 (Cobalt grade) and carbide tools], at various spindle speeds and feed rates. From these results, the feed rate has more influence on thrust force and surface roughness and the less values of thrust force and discontinuous chips are produced during drilling of hybrid composites when compared with the others composites. It is may be due to the solid lubricant property of graphite which reduces the thrust force, burr height and surface roughness. Less surface roughness is obtained with Carbide tool at low feed rate and high spindle speeds compared to other two types of cutting tool materials. The surface finish is bad with the increase of feed rate and became better with the increase of cutting speed. When machining hybrid composites the graphite particles pull out from the drilled surface and produce poor surface finish. When compared the height of exit burr when drilling using different drill tools, it is less during drilling Graphitic composites.

Based on the previous literature review, it is clear that, a little number of investigations are made to compare between the behavior of AL/SiCp and GFRP composites during drilling. Also, the results are varies between most of the previous researches and need more investigations and studies to understand the defects of drilling in the two types of composites accurately. Therefore, the objective of the present research is to study and compare the influence of three cutters [HSS end mill (four fluted) and different diameters] and cutting process parameters on the surface roughness and delamination factor of AL/SiCp and GFRP composites. The process parameters considered for the experiments are; spindle speed, feed rate, and the diameter of used cutters. In addition to, the volume fraction ratio is the same in the two types of composites.

2. Experimental work

2.1. Materials, Tools and Used parameters

The first composite used is AL/SiCp MMC, (aluminum 1050 is the base matrix material reinforced with 30 % of Silicon Carbide particles of mean diameter 88 µm). This composite is produced by stir casting technique. The second composite is GFRP, [glass fiber is used as reinforcement in the form of bidirectional fabric (Standard E-Glass Fiber glass)-30 % and polyester with catalyst addition as matrix for the composite material] and the plates are fabricated by hand lay-up process followed by a cure process under constant pressure. The experiments have been carried out on the plate (200 x40 x 20 mm) of the fabricated AL/SiCp and GFRP composites. Three cutters -End Mill (φ8, 10 and 12 mm, high-speed steel –HSS-four fluted) with the same tool geometry are used for the drilling operations in the two types of composites. To prevent the effect of wear at the cutters on the experiments results, each of them is used for making five holes only. The cutting parameters are listed in Table (1) and the specifications of the used drilling machine are listed in Table (2).

Table (1): The levels used of identified factors.

Parameters	The used levels				
Feed rate, mm/min	10	20	30	40	50
End Mill diameters-φ-mm	8		10	12	
Cutting speed, rpm	500		1500	2500	
Volume fraction %	30				

Table (2): Specifications of the drilling machine.

Model	Drilling Capacity	Face Milling Capacity	End Milling Capacity	Voltages
ZX7032	31.5mm	80mm	22mm	380/50HZ/1500W
Speeds	300,...,500...,700,…,1000,…,1200,...,1500,..,1700 and….2500,…..etc. rpm.			

2.2. Surface roughness measurement of the machined holes

The measurements of surface roughness are performed using SJ- 201P surface test after the machined holes are prepared for measurements and the measurements are made at the two composites after the calibration of the instrument and with the cut-off length of (0.8mm) according to (ISO 4287-1997). The surface roughness 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 investigation. From [21 and22], it can be calculate the delamination factor (df) which is used to determine the extent of delamination as follows;

df = D max/D ……….. [22]

Where:

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

3. Results and discussion

The analysis of the experimental results has been carried out to study the influence of the following input process parameters; three of cutting speeds; 500, 1500 and 2500 rpm), five of feed rates; (10,20,30,40 and 50mm/min) and

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three of End Mill (HSS - φ 8, 10, and 12 mm-have the same tool geometry) on the process responses, i.e. the surface roughness (Ra) and the delamination (df) of the drilled hole (when using volume fraction ratio ,Vf - 30 %). From the study of the previous works, the proposed methodology of experiments is suitable for analysis the surface roughness and delamination at drilling of AL/SiCp and GFRP composites. In the assessment of the surface roughness (Ra) and delamination (df) all the estimated ratios with respect to the results when used feed rate 10 mm/min and cutter of diameter φ8mm.
In the first, and from the drilling results, some of the defects in the drilling hole of the two types of composites are shown in Fig. (1).

ϕ 8mm and rpm 500 - ϕ 10 mm and rpm 500 -ϕ 12mm and rpm 500

ϕ 8mm and rpm 500 - ϕ 10 mm and rpm 500-ϕ 12mm and rpm 500

Fig. (1) Defects at drilling holes of GFRP and AL/SiCp composites.

3.1. Effect of feed rate (f) and cutter diameter on surface roughness (Ra) at [Three cutting speed and Vf30 %]

The relation between, the feed rate (f) and the surface roughness (Ra) at; 30 %Vf, cutting speed 500 rpm and three cutters (end mill of different diameters) for GFRP and AL/SiCp composites is plotted in Fig. (2). from these results, the surface roughness (Ra) values for the two types of composites and different cutters are increased with the increase of feed rate (f). It must be noticed that, the result values of (Ra) when drilling AL/SiCp composite are smaller than that when drilling GFRP composite. The surface roughness (Ra) when drilling GFRP is increased from; 11 to 20 µm when feed rate is changed from (10 to 50 mm/min) with the cutter of diameter 8 mm. Also, (Ra) is increased from; 14 and 16 to 25 and 28 µm for the other two cutters of diameters (10 and 12 mm) respectively. In the other side, when drilling AL/SiCp composite, (Ra) is increased from; 5 to 15 µm when the feed rate is changed from (10 to 50 mm/min) with the cutter of diameter 8 mm and for the other two cutters, the values are changed from; 9 and 12 to 18 and 23 µm. The relation between the feed rate (f) and the surface roughness (Ra) at; 30 %Vf, cutting speed 1500 rpm and the used cutters for GFRP and AL/SiCp composites is plotted in Fig. (3). from the results plotted in this figure,(Ra) values for the two types of composites and with the used cutters are increased with the increase of feed rate (f). The results values of (Ra) when drilling GFRP composite are bigger than that when drilling AL/SiCp composite. The surface roughness (Ra) of GFRP composite is increased between; 8 to 16 µm when feed rate is changed from (10 to 50 mm/min) with the cutter of diameter 8 mm. (Ra) is increased also from; 11 and 13 to 21 and 23 µm for the other two cutters of diameters (10 and 12 mm) respectively. In the other side, when drilling AL/SiCp composite, (Ra) is increased between; 4 to 13 µm when feed rate is changed from (10 to 50 mm/min) with the cutter of diameter 8 mm and for the other two cutters, the values are changed to; 5 and 9 to 15 and 18 µm.
From the comparison between the results of surface roughness (Ra) when used the same drilling parameters using cutting speed 500 rpm as shown in Fig. (2) With the results plotted in Fig. (3) when using cutting speed 1500 rpm, these results indicated that, the percentage of increase in (Ra) values when drilling GFRP composite and between the two cutting speeds with feed rate 10 mm/min is ; 12.29% and are from;10.34 ,3.1 , 8.92 and to 9.77% for feed rates (20,30,40 and 50mm/min) respectively. When drilling AL/SiCp composite, the percentages of increase in (Ra) values between the two cutting speeds are; 18.2, 10.0, 6.85, 9.5 and 9.82 % for the used feed rates. The relation between the feed rate (f) and the surface roughness (Ra) at the used parameters, but with cutting speed 2500 rpm is plotted in Fig. (4). these results indicated that,(Ra) values for the two types of composites and the used cutters are increased with the increase of feed rate (f) from (10 to 50 mm/min). The values of (Ra) when drilling GFRP composite are bigger also than that when drilling AL/SiCp composite. The surface roughness (Ra) when drilling GFRP composite is increased between; 6 and15 µm when feed rate is changed from (10 to 50 mm/min) with the cutter of diameter 8 mm. (Ra) is increased also from; 9.0 and 12 to 19 and 20 µm for the other two cutters of diameters (10 and 12 mm) respectively. When drilling AL/SiCp composite, (Ra) is increased between; 3 and10 µm with the used feed rates and with the cutter of diameter 8 mm .For the other two cutters, the values are changed from; 5 and 7 to 13 and 17 µm. At the comparison between the results of surface roughness (Ra) shown in Fig. (2) With the results plotted in Fig. (4) when the cutting speed is changed to 2500 rpm, the results in the two figures indicated that, the percentages of increase in (Ra) values between the two cutting speeds (500 and 2500 rpm) when drilling GFRP composite are; 30.16, 17.1, 11.13, 11.92 and 14.95 % and when drilling AL/SiCp composite, the percentages of increase in (Ra) values between the two cutting speeds also are; 26.85, 17.84, 16.44, 15.0 and 16.69% for the used feed rates. But the comparison between the results when used the two cutting speeds (1500 and 2500 rpm) with the same used parameters as shown in Figs. (3 and 4), the values of increase in (Ra) are changed to; 18.56, 6.86, 8.1, 3.03 and 5.26% for GFRP composite. When drilling AL/SiCp composite at the same previous conditions the values of increase in (Ra) are became; 9.1, 7.98, 9.68, 5.58 and 6.98% for the used feed rates. The previous results demonstrated a very strong association between the resultant surface roughness (Ra) with, feed rate and the cutter diameter when change the composite from one to another. From this 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

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AL/SiCp and GFRP composites. Due to the results of drilling of GFRP composite, the surface roughness (Ra) is almost increases with the increase of feed rate but some places it fluctuates with different feed rates. It may be due to the imperfection and uneven distribution of chopped fiberglass, which had a bad effect on the teeth of cutter and producing poor quality of holes. Also, this behavior is clear in the results of AL/SiCp composite, this may be due to especially at big values of feed rates, to the increase in the content of particles, which increase the friction between the teeth of cutter and the wall of hole, and leads also to bad surface of drilled hole.

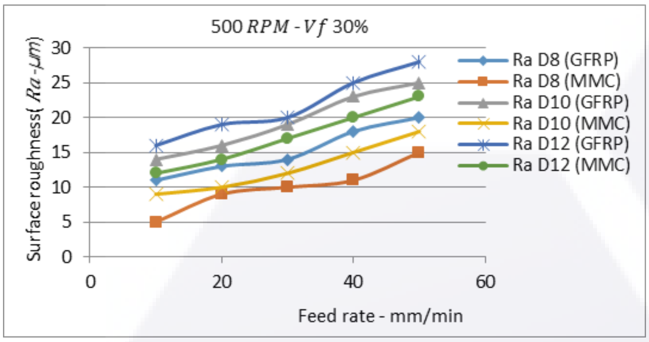

Figure (2): (Ra -f) Relation for GFRP and AL/SiCp composites at: 30 % Vf, rpm 500 and three cutters (End mill of different diameters).

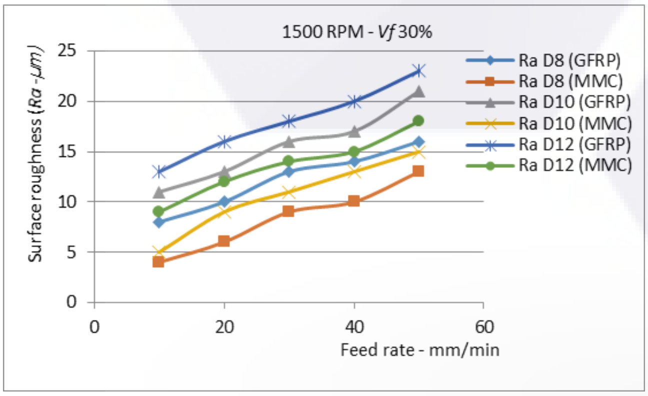

Figure (3): (Ra -f) Relation for GFRP and AL/SiCp composites at: 30 % Vf , rpm 1500 and three cutters (End mill of different diameters).

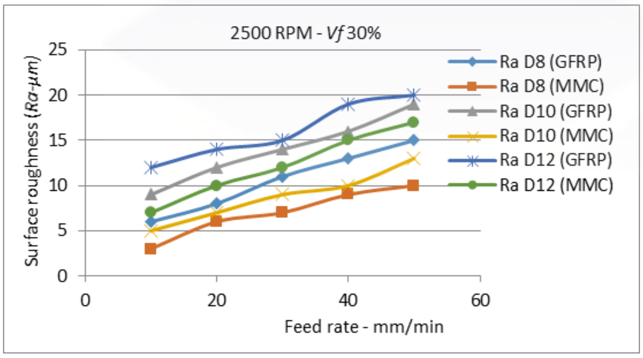

Figure (4): (Ra -f) Relation for GFRP and AL/SiCp composites at: 30 % Vf, rpm 2500 and three cutters (End mill of different diameters).

3.2. Effect of cutting speed and cutter diameter on surface roughness (Ra) at drilling GFRP and AL/SiCp composites

From the results shown in Figs. (2, 3 and 4), the surface roughness (Ra) values for the three cutting speeds and the end mill of (φ8mm) are increased with the increase of feed rate (f) and it is decreased with the increase of cutting speed as shown in these results. Also, from the results plotted in the previous figures and Figs. (5-a, b), it is obvious that, the results of surface roughness (Ra) have the same trend as shown with the previous results. But when used the other two cutters of (φ10 and φ12mm), the results are different as compared with the results when used the cutter of (φ8mm) and with the three cutting speeds. From the results shown before for drilling GFRP composite and from the comparison between the results when used the three cutters, the average percentage of increase in (Ra) is, 12 % between the cutters of (φ10 and φ8 mm) for feed rate 10 mm/min and the cutting speed 500 rpm. For the other feed rates (20, 30, 40, and 50 mm/min) with the same cutting speed, the average percentages of increase in (Ra) are; 13.35, 15.15, 12.20 and 11.11% between the same used cutters. For the two other cutters of (φ12 and φ8) and feed rates (10, 20, 30, 40, and 50 mm/min), the average percentages of increase in (Ra) are; 16.67, 18.75, 19.65, 14.17, and 16.67%. For AL/SiCp composite, the values of (Ra) are also changed. The average percentages of increase in (Ra) between the cutters (φ10 and φ8 mm), feed rate 10 mm/min and 500 rpm are; 18.57, 20.23, 19.09, 15.39, and 9.09 %. For the two cutters of (φ12 and φ8mm), the average percentages of increase in (Ra) are; 27.29, 29.24, 25.93, 29.03 and 21.06 % for the used feed rates respectively. When used cutting speed 1500 rpm, the average percentages of increase in (Ra) between the two cutters of (φ10 and φ8) and for feed rate 10 mm/min is; 15.79 % when drilling GFRP composite and 11.11% when drilling AL/SiCp composite. When used feed rates (20, 30, 40 and 50 mm/min), the average percentages of increase in (Ra) between the same two cutters are; 13.43, 10.35, 9.68 and 13.51% when drilling GFRP composite, but it is became, 20.0, 10.0, 13.04 and 7.14% for AL/SiCp composite. For the two cutters of (φ12 and φ8) and feed rates (10, 20, 30, 40, and 50 mm/min), the average percentages of increase in (Ra) when drilling GFRP composite are; 23.81, 23.07, 16.13, 17.55 and 17.99 % and for AL/SiCp composite, the average percentages of increase in (Ra) between the same two cutters are; 38.46, 33.33, 21.74, 20.0 and 16.13%. When using cutting speed 2500 rpm at drilling GFRP composite with the cutters of (φ10 and φ8 mm), the average percentages of increase in (Ra) are; 20.0, 20.0, 12.0, 10.35 and 11.77 % for the used feed rates respectively. These values are changed when drilling AL/SiCp composite to; 25.0, 7.69, 12.5, 5.26 and 13.04 % for the same two cutters and the same used feed rates. For the other two cutters of (φ12 and φ8 mm) and the used feed rates, the average percentages of increase in (Ra) when drilling GFRP composite are; 33.33, 27.27, 15.39, 18.75 and 14.29% and these values are changed to, 36.36, 25.0, 26.32, 25.0 and 25.93% when drilling AL/SiCp composite. When using cutting speed 500 rpm, the average results of (Ra) for GFRP composite are; 13.66, 16.0, 16.67, 20.33 and 24.33 μm for the used feed rates and the three used

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cutters. Also, at the same drilling conditions, the average results of (Ra) for AL/SiCp composite are; 8.67, 11, 13, 15.33 and 18.67 µm as shown in Fig. (5-a). The deviation percentages in (Ra) between AL/Sicp and GFRP composites are; 22.35% when used feed rate 10 mm/min. But the values are changed to; 18.52, 12.37, 14.02 and 13.16 % for the other used feed rates respectively as shown in Fig. (5-b). The average results of (Ra) for GFRP composite when used cutting speed 1500 rpm are; 10.67, 13.0, 15.67, 17.0 and 20.0 µm for the used feed rates and the three used cutters. Also, at the same conditions of drilling, the mean results of (Ra) for AL/SiCp composite are; 6.0, 9.0, 11.33, 12.67 and 15.33 µm. Also, the deviation percentage of increase in (Ra) when used cutting speed 1500 rpm between AL/Sicp and GFRP composites is; 21.01% when used feed rate 10 mm/min. But the values are changed to; 18.18, 16.07, 14.59 and 13.22 %(for feed rates (20, 30, 40 and 50 mm/min) respectively. The average results of (Ra) for GFRP composite when used cutting speed 2500 rpm are; 7.33, 11.33, 13.33, 16.0 and 18.0 µm for both the used feed rates and the three used cutters. Also, at the same drilling conditions, the average results of (Ra) for AL/SiCp are; 5.0, 7.67, 9.33, 11.33 and 13.33 µm. At cutting speed 2500 rpm, the deviation percentage of increase in (Ra) between AL/Sicp and GFRP composite is; 18.9% when used feed rate 10 mm/min. But the values are changed to; 19.26, 17.65, 17.1 and 14.90% for feed rates (20, 30, 40 and 50 mm/min) respectively. From Figures (5 –a, b), the plotted average results indicated that, the increase in the used feed rate leads to a clear increase in the values of surface roughness (Ra) with the two types of used composites. Also, the average values of surface roughness (Ra) are decreased with the increase in the cutting speed from 500 to 2500 rpm. Both of feed rate and cutting speed are play a vital role in the resultant values of (Ra) for AL/SiCp and GFRP composites. From the same figures, all the results of (Ra) when drilling AL/SiCp composite are small when compared with the results of GFRP composite. The deviation percentages are decreased with the increase of feed rate values. Also, it is decreased with the increase of the cutting speed. It is obvious that, all the values of surface roughness are affected by the diameter of cutter and the values of (Ra) are decreased with the increase of cutter diameter. Also, the cutting speed has a strong effect on the resultant values of surface roughness (Ra). The surface roughness (Ra) is decreased with the increase of cutting speed from (500 to 1500 and to 2500 rpm) for the two types of composites. The average percentages of increase of surface roughness (Ra) between GFRP and AL/SiCp composites are; (16.08, 16.61 and 17.63 %) for the three cutting speeds with all used feed rates and all used cutters.

From the previous results, it can be seen that, the cutter of big diameter gives better hole surface compared with the cutter of small diameter. This is may be due to the burnishing effect 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.

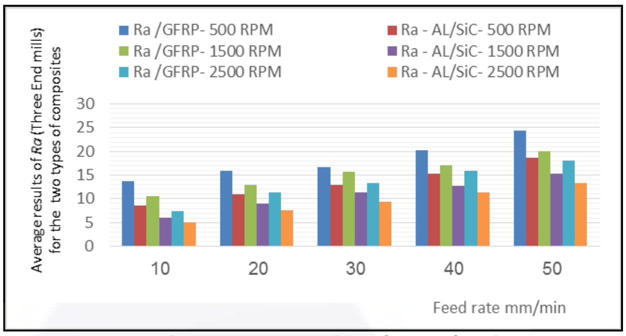

Figure (5-a): The average results of (Ra) for the two types of composites at, [Three cutters, three cutting speeds and the five feed rates].

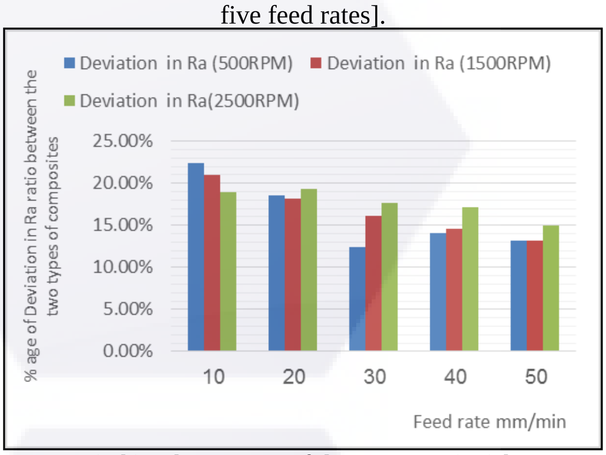

Figure (5-b): The % ages of deviation in (Ra) between AL/SiCp and GFRP composites at; [three cutting speeds and the five feed rates].

3.3. Effect of feed rate (f) and cutter diameters on delamination factor (df) at [Three rpm-Vf30 %]

The relation between the feed rate (f) and the delamination factor (df) for GFRP and AL/SiCp composites at; 30 %Vf, cutting speed 500rpm and the three used cutters is plotted in Fig. (6). from these results, the values of delamination factor (df) for the two types of composites and the used cutters are increased with the increase of feed rate (f). The values of (df) when drilling GFRP composite are bigger than that when drilling AL/SiCp composite. The delamination factor (df) when drilling GFRP is increased from; 1.15 to 1.24 when feed rate is changed from, (10 to 50 mm/min) and with end mill of diameter 8 mm. The delamination factor (df) is increased from; 1.2 and 1.23 to 1.28 and 1.31 for the other two cutters of diameters (10 and 12 mm) respectively. When drilling AL/SiCp composite, the delamination factor (df) is increased from; 1.11 to 1.21 with the used feed rates from (10 to 50 mm/min) and end mill of 8 mm diameter. For the other two cutters, the values are changed from; 1.13 and 1.17 to 1.23 and 1.26 respectively. The relation between the feed rate (f) and the delamination factor (df) at the used parameters but with cutting speed 1500 rpm is plotted in Fig. (7). From these results, the values of delamination factor (df) for AL/SiCp and GFRP composites and the used cutters are increased with the increase of feed rate (f). The values of (df) when drilling GFRP composite are bigger than that when drilling AL/SiCp composite. The delamination factor (df) when drilling GFRP composite is increased between; 1.21 to 1.29 when the feed rate is changed from (10 to 50 mm/min) and with end mill of diameter 8 mm. The delamination factor (df) is increased also, from; 1.24 and 1.26 to 1.32 and 1.34

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for the other two cutters of diameters (10 and 12 mm) respectively. When drilling AL/SiCp composite, the delamination factor (df) is increased from, 1.17 to 1.24 when feed rate is changed from (10 to 50 mm/min) with end mill of diameter 8 mm. For the other two cutters, the values are changed from; 1.19 and 1.22 to 1.26and 1.31. The comparison between the results of the delamination factor (df) when used the same drilling parameters shown in Fig. (6) With the results plotted in Fig. (7) when used cutting speed 1500 rpm, the results in the two figures indicated that, the percentage of increase in (df) values when drilling GFRP composite between the two cutting speeds (500 and 1500 rpm) with feed rate 10 mm/min is ; 1.25% and are; 2.08, 2.31, 1.60 and 1.54% for feed rates (20, 30, 40 and 50mm/min) respectively. When drilling AL/SiCp composite, the percentages of increase in (df) values between the two cutting speed are; 3.04, 2.17, 3.04, 2.8 and 1.25 % for the used feed rates.

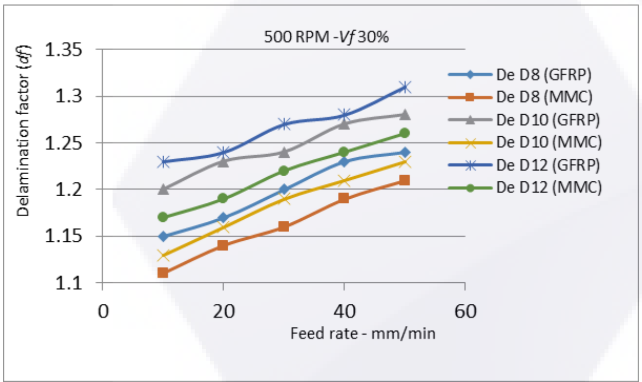

Figure (6): (df -f) Relation for GFRP and AL/SiCp composites at: 30 % Vf , rpm 500 and three cutters (end mill of different diameters).

In Figure (8), the relation between the feed rate (f) and the delamination factor (df) for the AL/SiCp and GFRP composites at; 30 %Vf, cutting speed 2500 rpm and the three used cutters is plotted. From this figure, (df) values for the two types of composites and the three used cutters are increased with the increase of feed rate (f). The values of delamination factor (df) when drilling GFRP composite are bigger than that when drilling AL/SiCp composite. The delamination factor (df) when drilling GFRP composite, is increased from; 1.25 to 1.30 when the feed rate is changed from (10 to 50 mm/min) and used end mill of diameter 8 mm. The delamination factor (df) is increased from, 1.28 and 1.29 to 1.34 and 1.37 for the other two cutters of diameters (10 and 12 mm) respectively. When drilling AL/SiCp composite, (df) is increased from; 1.21 to 1.28 when the feed rate is changed from (10 to 50 mm/min) and used end mill of diameter 8 mm. For the other two cutters, the values are changed to; 1.23 and 1.26 to 1.29 and 1.31respectively. The comparison between the values of delamination factor (df) when used the same drilling parameters shown in Fig. (6) with the values plotted in Figure (8) when used cutting speed of 2500 rpm, the results in the two figures indicated that, the percentages of increase in (df) when drilling GFRP composite between the two cutting speeds (500 and 2500 rpm) when used feed rate 10 mm/min are ; 2.83 , 3.2 ,3.17 ,2.33 and 2.28 % for the used feed rates. When drilling AL/SiCp composite, the percentages of increase in (df) values between the two cutting speeds are; 4.49, 3.72, 4.53, 2.81 and 2.38 % for the used feed rates. But the comparison between the values when used the cutting speeds (1500 and 2500 rpm) and from the results plotted in Figs (7 and 8), the values of increase are changed to; 1.6, 0.78, 0.78, 0.76and 0.75% for GFRP composite. When drilling AL/SiCp composite at the same previous conditions the values of increase in (df) are became; 1.65, 1.63, 1.54, 0.79 and 1.88% for the used feed rates. Also, it can be asserted that, the feed rate is the main parameter which effect on the delamination factor (df) during drilling operations of AL/SiCp and GFRP composites. The increase of cutter diameter leads to obvious increase in delamination factor (df). These results demonstrated an association between the values of delamination factor (df) with feed rate (f) and cutter diameter when using Vf 30% and with the three used cutting speeds.

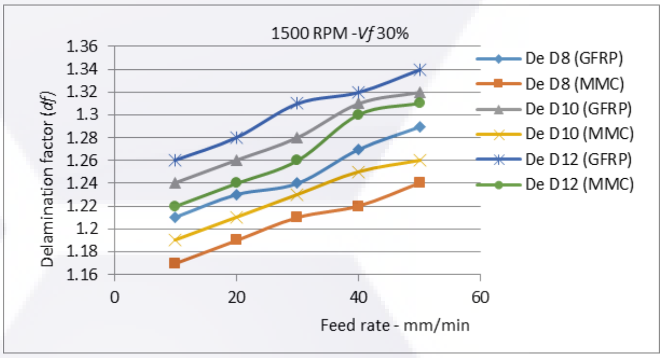

Figure (7), (df -f) Relation for GFRP and AL/SiCp composites at: 30 % Vf , rpm 1500 and three cutters (end mill of different diameters).

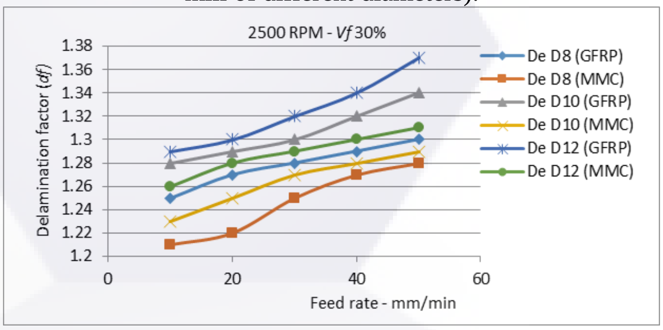

Figure (8) :(df -f) Relation for GFRP and AL/SiCp composites at: 30 % Vf ,rpm 2500 and three cutters (end mill of different diameters).

3.4. Effect of cutting speed and cutter diameter on the delimitation factor (df) at drilling GFRP and AL/SiCp composites

From the results shown in Figs. (6, 7 and 8), the values of the delamination factor (df) for the three cutting speeds and the cutter of φ8mm are increased with the increase of feed rate (f) and also is increased with the increase of the three cutting speeds. From these results, it is obvious that, the results of delamination factor (df) when used the other two cutters and with the same parameters have the same trend as shown with the previous results. For drilling GFRP composite and from the comparison between the three used cutters, the average percentage of increase in (df) is; 2.13 % between the two cutters (φ10 and φ8mm) when used feed rate 10 mm/min and cutting speed 500 rpm. For the other feed

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rates (20, 30, 40, and 50 mm/min) with the same cutting speed, the average percentages of increase in (df) are; 2.50, 1.64, 1.60 and 1.65%. For the two cutters (φ12 and φ8mm) and the used feed rates, the average percentages of increase in (df) are; 3.36, 4.97, 2.83, 1.99, and 2.75%. For AL/SiCp composite, the average percentages of increase in (df) are changed when used the two cutters of (φ10 and φ8 mm), feed rate 10 mm/min and 500 rpm to; 0.89 % and the values for the other used feed rates are; 0.87, 1.28, 0.8, and 0.82 %). For the two cutters (φ12 and φ8 mm) and the used feed rates with the same cutting speed, the average percentages of increase in (df) are; 2.63, 2.15, 2.52, 2.58 and 2.24 %. When used cutting speed 1500 rpm, the average percentage of increase in (df) between the two cutters (φ10 and φ8mm) and for feed rate 10 mm/min is; 1.22 % when drilling GFRP composite and 0.85 % when drilling AL/SiCp composite. When used feed rates, (20, 30, 40 and 50 mm/min), the average percentages of increase in (df) between the same two cutters are, 1.20, 1.59, 1.55 and 1.15 % when drilling GFRP composite, but it is became, 0.83, 0.82, 1.22 and 0.80% for AL/SiCp composite. For the two cutters (φ12 and φ8 mm) and the used feed rates, the average percentages of increase in (df) when drilling GFRP composite are; 2.06, 1.99, 2.75, 1.93 and 1.52% and for AL/SiCp composite with the same used parameters the values are; 2.92, 2.06, 2.02, 3.18 and 2.75 % respectively. When used cutting speed 2500 rpm in drilling GFRP composite with the two cutters of (φ10 and φ8 mm) , the average percentages of increase in (df) are; 1.19, 0.8, 0.8, 1.15 and 1.52 % for the used feed rates respectively. These values are changed when drilling AL/SiCp composite to; 0.82, 1.21, 0.8, 1.9 and 0.4% for the same two cutters and the same used feed rates. For the two cutters of (φ12 and φ8mm) and the used feed rates, the average percentages of increase in (df) when drilling GFRP composite are; 1.57, 1.17, 2.5, 1.9and 2.62 % and these values are changed to; 1.21, 1.19, 1.57, 1.17 and 1.16% when drilling AL/SiCp composite. At cutting speed 500 rpm, the average results of (df) for GFRP composite are; 1.2, 1.21, 1.22, 1.26 and 1.28 for feed rates from (10 to 50mm/min) and the three used cutters. Also, at the same conditions of drilling, the average results of (df) for AL/SiCp composite are; 1.12, 1.16, 1.16, 1.21and 1.23 as shown in Fig. (9-a). At cutting speed 500 rpm also, the deviation percentage of increase in (df) between AL/SiCp and GFRP is; 3.45% when used feed rate 10 mm/min. But the values are changed to; 2.11, 2.52, 2.02and 2.0% for feed rates (20, 30, 40 and 50 mm/min) respectively as shown in Fig. (9-b).

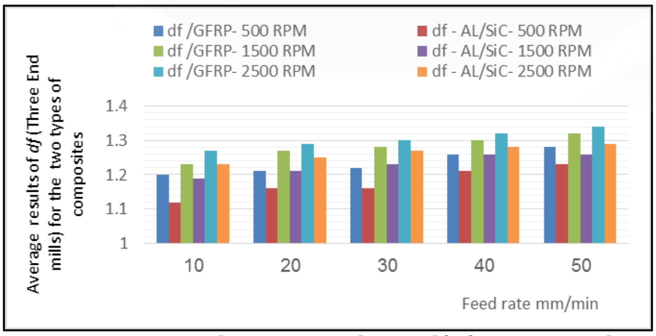

Figure (9 -a): The mean results in (df) for GFRP and AL/SiCp composites at, [Three cutters (end mill of different diameters) and the three cutting speeds].

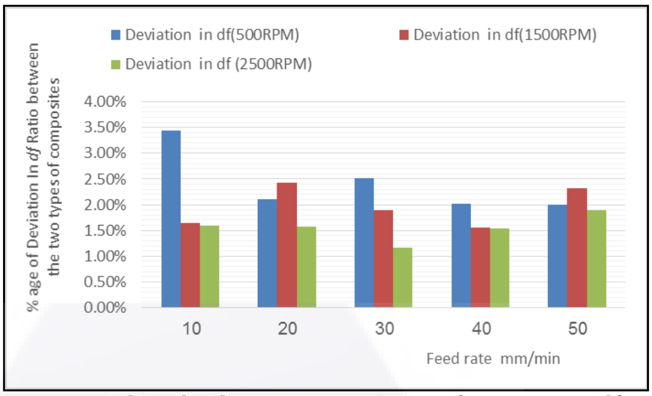

Figure (9-b): The deviation percentage of increase in (df) between AL/SiCp and GFRP at the three cutting speeds.

When used cutting speed 1500 rpm, the average results of (df) for GFRP composite are; 1.23, 1.27, 1.28, 1.30 and 1.32 for the used feed rates and the three used cutters as shown in Fig. (9-a). Also, at the same conditions of drilling, the average results of (df) for AL/SiCp composite are; 1.19, 1.21, 1.23, 1.26 and 1.26. At the same cutting speed 1500 rpm, the deviation percentages of increase in (df) between AL/SiCp and GFRP is; 1.65% when used feed rate 10 mm/min. But the values are changed to; 2.42, 1.90, 1.56 and 2.33% for the used feed rates as shown in Fig. (9-b). It is obvious that, the cutting speed has a strong effect on the resultant values of delamination factor (df). It is increased with the increase of cutting speed from (500 to 1500 and to 2500rpm) for the two types of composites. The mean deviation of the delamination factor (df) between GFRP and AL/SiCp composites are; 2.42, 1.97and 1.56 for the three cutting speeds with all used feed rates and all used cutters. The average results of (df) for GFRP composite at cutting speed 2500rpm are; 1.27, 1.29, 1.3, 1.32 and 1.34 for feed rates from (10 to 50mm/min) and the three used cutters. Also, at the same conditions of drilling, the average results of (df) for AL/SiCp are; 1.23, 1.25, 1.27, 1.28 and 1.29 as shown in Fig. (9-a). At the same cutting speed 2500rpm, the deviation percentage of increase in (df) between AL/SiCp and GFRP composites is; 1.60% when used feed rate 10 mm/min. But the values are changed to; 1.57, 1.17, 1.54 and 1.90% for the used feed rates respectively. The analysis of the results demonstrated a strong association between the resultant of delamination factor (df) with cutting speed, feed rate and the diameter of the cutter. Also, there is a positive correlation between the increase of feed rates and the increase in the delamination factor. The increase in the cutting speed and the cutter diameter are lead to obvious increase in the delamination factor with all feed rates and with all used cutters.

4. Conclusions

The experimental methodology is applied in this research to study the influence of the following input process parameters; three of cutting speeds (500, 1500 and 2500 rpm), five of feed rates (10,20,30,40 and 50 mm/min) and three cutters (end mill -HSS - φ 8, 10, and 12 mm-have the same tool geometry) on the process responses, i.e. the surface roughness (Ra) and the delamination factor (df) of the drilled hole (when using volume fraction ratio-Vf 30 %) for

the two types of composites GFRP and AL/SiCp. From the deeply analysis of the results, it can be concluded that:
1) The feed rate and cutter diameter are had a large effect on surface roughness (Ra) and delamination factor (df), while both of them are increased with the increase in the feed rate from (10 to 50 mm/min) and cutter diameter from (φ 8 to φ 12 mm).
2) The values of the delamination factor (df) are increased at the bigger cutting speed 2500 rpm and the feed rate 50 mm/min combined with the cutter diameter of φ 12 mm.
3) The increase of cutting speed leads to an obvious increase in the delamination factor (df) with all values of; the feed rates, and the three used cutters.
4) The increase of cutting speed leads to an obvious decrease in the surface roughness (Ra) with all values of; the feed rates, and the three used cutters.
5) The average results of surface roughness (Ra) for GFRP composite are bigger than that of AL/SiCp composite at all used cutters, cutting speeds and all used feed rates.
6) The average results of surface roughness (Ra) between GFRP and AL/SiCp composites are; 16.084, 16.614 and 17.632 respectively for the three cutting speeds with all used feed rates and all used cutters.
7) The average results of the delamination factor (df) between GFRP and AL/SiCp composites are; 2.42, 1.972 and 1.556 respectively for the three cutting speeds with all used feed rates and all used cutters.
8) Cutting speed (2500 rpm), cutter of diameter φ 8mm and low feed rate (10mm/min) are suitable for drilling GFRP and AL/SiCp to get a better surface roughness.
9) Both surface roughness and delamination are increased with the increase of feed rate, and when the cutting speed increases, the delamination factor is increased, whereas the surface roughness is decreased.

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