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Experimental Study of the Surface Roughness and the Delamination in the Drilling of GFRP and AL/SiCp Composites with Different End Mills

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Abstract

In this research, the influence of the drilling process parameters; three cutters (end mill) of different diameters, three of cutting speeds and five of feed rates on the process responses, i.e. the surface roughness (Ra) and the delamination factor (df) of the drilled hole are studied. The two types of the used composites are GFRP and AL/SiCp. From the analysis of the results, the feed rate and the cutter diameter are had a large effect on surface roughness and delamination factor, while both of them are increased with the increase of cutter diameter and the used feed rates. The results of surface roughness and the delamination factor when drilling GFRP composite are bigger than that values of AL/SiCp composite at all used cutters, cutting speeds and all used feed rates. Also, from the results, using of cutting speed (2500 rpm), end mill 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 the resulted.

الملخص:

في هذا البحث تم دراسة تأثير ثلاث سرعات قطع وخمسة قيم تغذية وثلاث سكاكين (End Mill) ذات أقطار مختلفة على كلا من خشونة السطح ومعامل التنسيل الناتج في الثقب المشغل وذلك لنوعين من المؤتلفات أولهما البلومري(GFRP)والثاني المؤتلف المعدني (AL/ SiCp) وذلك على ما كبنة تفريز رأسية موديل (ZX7032). ومن تحليل النتائج اتضح أن كلا من معدل التغذية وقطر السكينة المستخدمة في الثقب لهما التأثير الأكبر على كلا من خشونة السطح (Ra) ومعامل التنسيل (df)بينما كلاهما يزداد مع زيادة سرعة الثقب ومعدل التغذية المستخدم .وأظهرت النتائج أن قيم خشونة السطح(Ra) ومعامل التنسيل (df) عند ثقب GFRP)) أعلي من القيم الناتجة أثناء إجراء الثقب في المؤتلف المعدني (AL/ SiCp) وذلك عند استخدام جميع عناصر الثقب المذكورة. وللحصول علي أقل قيم لكلا من خشونة السطح ومعامل التنسيل نوصي باستخدام سرعة قطع (٢٥٠٠ لفة/دقيقة) وأصغر سكينة (قطر٨مم) وأقل معدل تغذية (١٠مم/ دقيقة) لكلا المؤتلفين المستخدمين.

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

Introduction

AL/SiCp metal matrix composite 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. In addition, 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. The components made of AL/SiCp and GFRPs need certain machining operations, such as; milling, grinding, and drilling for fastening, where it is used. At drilling operation, different sorts of damage may occur such as, the 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. The bad surface finish of the drilled hole and faster tool wear led to the further study of composite machining.

In these cases, it becomes very important to study drilling in case of composite materials. Many works have been made in the direction of studying the effect of drilling parameters and conditions for minimizing the drilling induced damage around the hole and improved the quality of the drilled hole. The estimation of the circularity, cylindricity and surface roughness in drilling Al-Si3N4 metal matrix composites using the artificial neural network is presented by B.M. Umesh Gowdaa, et al. [1]. This 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 time of machining, circularity, cylindricity and surface roughness for each hole at different cutting conditions are conducted. The output parameters are estimated by the sophisticated method of signal analysis like the one Artificial Neural Network (ANN) is made also. The effect of network architecture is used to know the drilled hole status at different training sets viz. 30%, 50% and 70%. Several structure of a neural network with a 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 value of (R) for different output parameters is obtained at 70% of the training set. The relationship between the measured parameters is well represented by the new proposed model with 70% training set and with 6% Si3N4 reinforcement material. Erol Kilickap [2] is to investigate the influence of drilling parameters, such as feed rate, cutting speed, and the point angle of the used tool on the produced delamination when drilling GFRP composite. The delamination at the entrance and exit of the hole during the drilling GFRP composites are observed. To analyze the influence 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 models are developed to correlate and predict the used parameters and delamination factor in drilling. The analysis of the results indicated that the developed models are adequate at 95% confidence level within the limits of factors being considered. The used of the drill with 90°-point angle is preferred for reducing the delamination factor and the delamination factor is smaller at the entrance than at exit for three used drills. The developed models in this research can be used effectively to predict the delamination factor at the entrance and exit due to the results of RSM models and experimental results and, can be utilized to select the level of drilling parameters to save time and cost. Gong-Dong Wang and Melly S Kirwa [3], presented 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, the thrust forces have been monitored during drilling experiments where one spindle speed and four different feed rates are used. In addition, a finite element model has also used to study the delamination damage on the laminates and validate the experimental results. From the results, thrust forces increase with an increase of feed rates and show; drilling by step drill is the most appropriate method as it records low forces hence minimal delamination damage. Also from the results, the ratio of the pilot hole to the drilling tool diameter is inversely proportional to the thrust force. 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. In addition, 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. In addition, the use of step drill is the best option for minimal damage to composites. Anant B. Marathe and Anil M. Javali [4], studied the effect of different tool geometries, speeds and feeds during drilling on a composite plate, which have a different chemical composition for specific cutting energy, peel up at the entrance and push out delamination. The experimental work is established based on Taguchi techniques. Statistical methods such as signal-to-noise ratio, the analysis of variance and regression analysis are used to investigate the 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 higher efficiency of machining that is, for the combined effect of these two parameters as indicated by SCE, when used smallest point angle of 80°, the highest speed of 2355 rpm and feed rate of 353.25 mm/min. The basic contribution factor is feed rate (79.93%) followed by tool point angle (6.17%) and cutting speed (2.35%) as indicated by the response for S/N ratio and the ANOVA calculations.

However, 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 contributing factor is feed rate (92.95%) followed by cutting speed (2.36%) and tool point angle (0.82%) as indicated by the response for S/N ratio and the ANOVA calculations and the delamination is negligible at all observations. When the value of 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 and the shear force is directly proportional to glass fiber content of the composite, and more energy is consumed in shearing them. The associated error with specific cutting energy in both composites varying from 20.12% to 21.68%. The effect of different 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 work to study the effect of process parameters on quality characteristics of standard and special geometry design of a drill body. In the drilling experiments, the carbide drills (twist drill and ratio drill) are conducted using response surface methodology. From the results, it is observed that for a twist drill, the feed rate is more consequential followed by cutting speed in influencing the quality characteristics. In addition, for ratio drill, the feed rate is more paramount in influencing thrust force, torque and damage factor, whereas, spindle speed is more paramount in influencing surface roughness. The factor of damage 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 a 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 combination level of process parameter is (feed rate of 0.05 mm/rev and a 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 of results, 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. In addition, 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. The drilling of glass fiber reinforced polymer (GFRP) composites with three dissimilar tools, having different materials and geometries are investigated by Dhiraj Kumar, et al. [6]. The tool materials, geometries and the parameters of cutting are considered major factors, which is responsible for drilling-induced damage and the resulted damages are measured by two factors of delamination. This investigation indicated that qualities of drill holes significantly improved when solid carbide eight-facet drill is used. The 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. In addition, 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. 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 resulted values of surface roughness 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. Thus, solid carbide eight-facet drill is recommended for drilling of the 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 values of delamination factor, adjusted delamination factor and surface roughness of carbide tipped straight shank (K20) are more than the solid carbide eight-facet drills. Moreover, the Surface roughness values vary from 0.794 to 2.769 μm. 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 is presented by Tom sunnya, et al. [7]. To analyze the data obtained from the experiments and determine the optimal parameters in drilling of GFRP composite ANOVA is used and it is used to determine the best levels of the parameters in the drilling induced delamination. The results indicated that the delamination is increased with the increase of spindle speed (1000rpm-2500rpm) and decreases with feed rate (100mm/min to 400mm/min). The opposite trend is shown with very low feed rate i.e., 50mm/min and high spindle speed 300rpm. In addition, from the results, in both cases, delamination factor increases instead of decreasing. The ANOVA results reveal that the feed rate is the main cutting parameter, which has a 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. Also, 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 used tools show 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 show higher values of mean delamination factor at very low feed rate. An experimental investigation on the drilling of unidirectional carbon fiber reinforced plastic (UD-CFRP) composite using polycrystalline diamond (PCD) tipped eight-facet drill is presented by Eshetu D. Eneyew, Mamidala Ramulu [8]. The surface quality of the drilled hole is examined through surface roughness measurements and surface damage by scanning electron microscopy (SEM). The results of this research indicated that 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 used prediction model agrees with the measured value of the thrust force with an average error of 3%. 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 pullout fiber 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. Better hole surface is obtained with a combination of higher cutting speed and lower feed rate. From the results, 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. The research of Haijin Wang, et al. [9], presented experiments with different drilling depth, which used to investigate the developing process of delamination. To evaluate the delamination of different cross sections in the radial direction of the hole, the grinding method is adopted. Three-dimensional morphology of delamination at the exit of the hole are measured and the regularity of delamination with the change of drilling depth is analyzed, and the existence of "hidden delamination zone" is finally obtained. The results of experimental work 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, 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 the delamination area is compressed tightly. It is obvious that 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 paper 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. Different techniques are used to predict the delamination factor as a function of the different combination of machining parameters. The analysis of the results indicated that, 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 an increase of PA up to 118°. The comparison between the experimental and the predicted results indicated that, the root means square error at dF at entry and exit are; 1.4732% and 2.9277% respectively.

From the deep study of literature review, it is obvious that, a little number of investigations are made to compare the behavior of AL/SiCp and GFRP composites during drilling. In addition, the results are varying 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. Thus, 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 used parameters for the experiments are; spindle speed, feed rate, and the diameter of used cutters. In addition, the volume fraction ratio is the same in the two types of composites.

2. Experimental work

2.1. Materials, Used parameters and Tools

The first type of 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 type of 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 a matrix for the composite material] and the plates are fabricated by hand lay-up process followed by a cure process under constant pressure. The drilling process has been carried out on the plate (200 x40 x 20 mm) of the fabricated AL/SiCp and GFRP composites. Three 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 results of the experiments, each of them is used for making five holes only. The specifications of the used drilling machine are listed in Table (1) and the cutting parameters are listed in Table (2)

Table (1): Specifications of the drilling machine.

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

Table (2): 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 and 12				
Cutting speed, rpm	500, 1500 and 2500				
Volume fraction %	30				

2.2. Surface roughness measurement of the drilled holes

The machined holes are prepared for measurements and the measurements are made at the drilled holes of the two composites after the calibration of the instrument (SJ-201P surface test), 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.

The delamination factor (df) can be calculated as follows;

$$df = \text{D max/D}$$

Where:

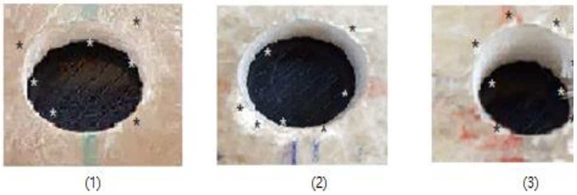
D max = the maximum diameter created due to delamination around the hole. And,

D = the hole or drill diameter.

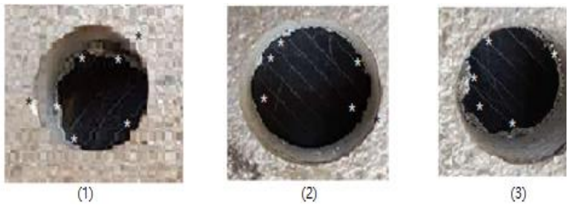
3. Results and discussion

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 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 %). 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.

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)



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

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)

The relation between, the feed rate (f) and the surface roughness (Ra) at; 30 $\%Vf$, 500 RPM and three cutters (end mill of different diameters) for GFRP and AL/SiCp composites is plotted in Fig. (2). from the 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 can be noticed that, the result values of (Ra) when drilling AL/SiCp composite are smaller than that when drilling GFRP composite. (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. 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 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 higher than that when drilling AL/SiCp composite. (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. Also (Ra) is increased from; 11 and 13 to 21 and 23 µm for the other two cutters of diameters (10 and 12 mm) respectively. 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 comparison 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 the second type of composite, AL/SiCp, 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 (Ra) at the used parameters, but with 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 the surface roughness (Ra) when drilling GFRP composite are bigger also than that when drilling AL/SiCp composite. The values of 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. The values of surface roughness (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 the second type of composite, AL/SiCp, (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. 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. However, 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 the second type of 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 results demonstrated a very strong association between the resultant surface roughness $(Ra)$with, feed rate and the cutter diameter when changing the composite from one to another. From 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 of drilling of GFRP composite, the surface roughness (Ra) is almost increasing 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. In addition, this behavior is clear in the results of AL/SiCp composite, this may be due to especially at high values of feed rates, to the increase in the content of particles that increase the friction between the teeth of cutter and the wall of the hole and leads to the bad surface of the drilled hole.

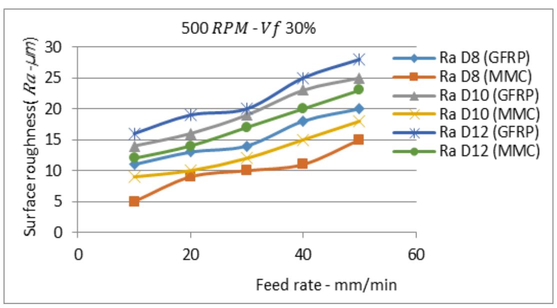


Figure (2): $(Ra\text{ -}f)$ Relation for GFRP and AL/SiCp composites at: 30 %,rpm 500 and three cutters (end mill of different diameters).

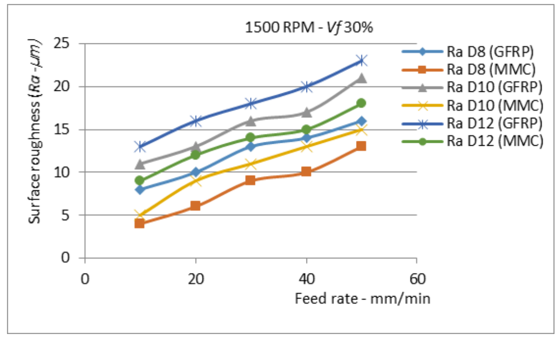


Figure (3): $(Ra\text{ -}f)$ Relation for GFRP and AL/SiCp composites at: 30 % , rpm 1500 and three cutters (end mill of different diameters).

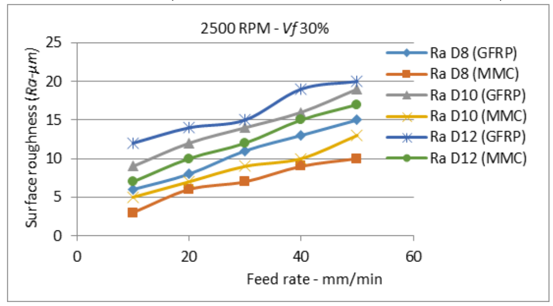


Figure (4): $(Ra\text{ -}f)$ Relation for GFRP and AL/SiCp composites at: 30 % ,rpm 2500 and three cutters (end mill of different diameters).

3.2. Effect of cutting speed (RPM) and the cutter diameter on the surface roughness(Ra)

From the results plotted 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 figures. In addition, 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. However, 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. When used 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 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 the used MMCs composite, the values of (Ra) are also changed. The average percentages of increase in surface roughness (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 %. In addition, 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 the values of (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. The average percentages of increase in (Ra) between the same two cutters When used feed rates (20, 30, 40 and 50 mm/min), are; 13.43, 10.35, 9.68 and 13.51% when drilling GFRP composite, but it becomes, 20.0, 10.0, 13.04 and 7.14% for AL/SiCp composite. For the other 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 RPM 2500 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. The previous 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. When used 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 used 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 cutters. In addition, 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 the surface roughness (Ra) between AL/Sicp and GFRP composites is; 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 the surface roughness (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. In addition, 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 surface roughness (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. In addition, 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. When used 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 the plotted average results shown in Figures (5 –a, b), 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. It is obvious that, both of feed rate and cutting speed play a vital role in the resultant values of (Ra) for AL/SiCp and GFRP composites. From the same figures, all the results of the surface roughness (Ra) when drilling AL/SiCp composite are small when compared with the results of GFRP composite. In addition, the deviation percentages are decreased with the increase in feed rate values. Also, these values are decreased with the increase of the cutting speed. It is clear 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. In addition, the cutting speed has a strong effect on the resultant values of surface roughness (Ra). (Ra) value is decreased with the increase in cutting speed from (500 to 1500 and to 2500 rpm) for the two types of composites. The average percentages of increase of (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 the cutter of big diameter gives a 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.

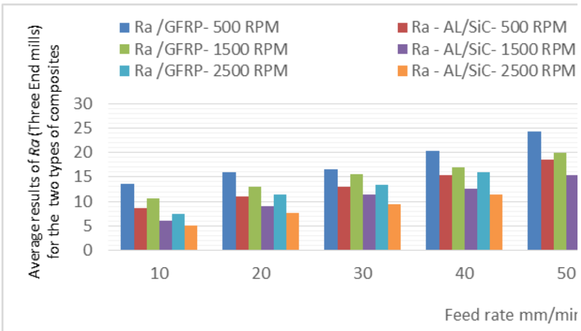


Figure (5-a): The average results of (Ra) for the two types of composites at, [Three cutters, three cutting speeds and the five feed rates].

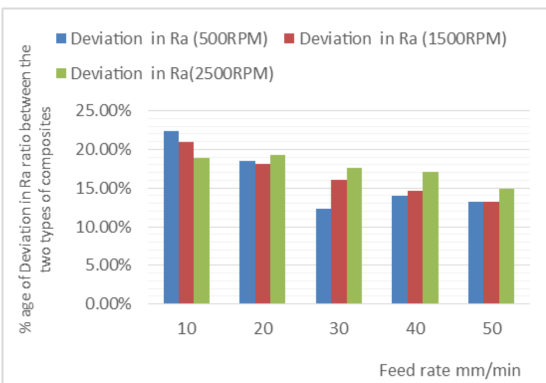


Figure (5-b): The % ages of deviation in (Ra) between AL/SiCp and GFRP composites at; [three cutting speeds and the five feed rates].

3.3. Effect of feed rate (f) and cutter diameters on the delamination factor (df)

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 the delamination factor (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, (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. When used 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 the 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 values of 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 for the other two cutters of diameters (10 and 12 mm) respectively. When drilling the second type of 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 plotted 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. At 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.

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 in Figure (8). 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 delamination factor (df) values when drilling GFRP composite are bigger than that when drilling AL/SiCp composite. The (df) values 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. It 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. At 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. At 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. However, 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 using 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. In addition, it can be asserted that, the feed rate is the main parameter that effects on the delamination factor (df)during drilling operations of AL/SiCp and GFRP composites. It is obvious that, the increase of cutter diameter leads to an 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.

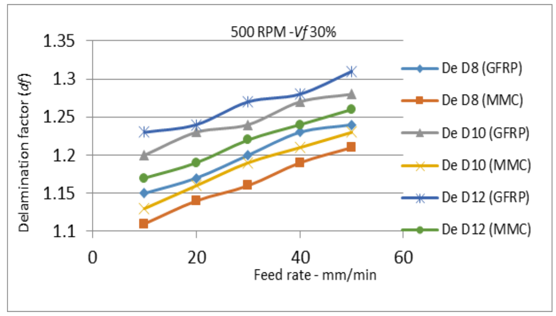


Figure (6): $(df\ -f)$ Relation for GFRP and AL/SiCp composites at: 30 % , rpm 500 and three cutters (end mill of different diameters).

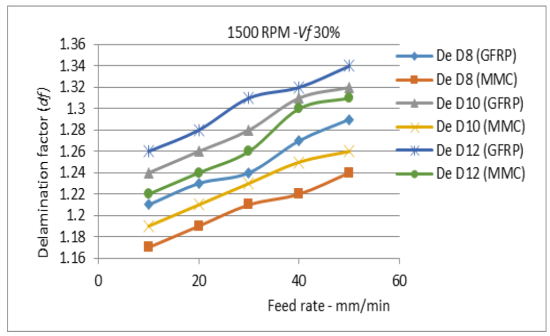


Figure (7), $(df\ -f)$ Relation for GFRP and AL/SiCp composites at: 30 % , rpm 1500 and three cutters (end mill of different diameters).

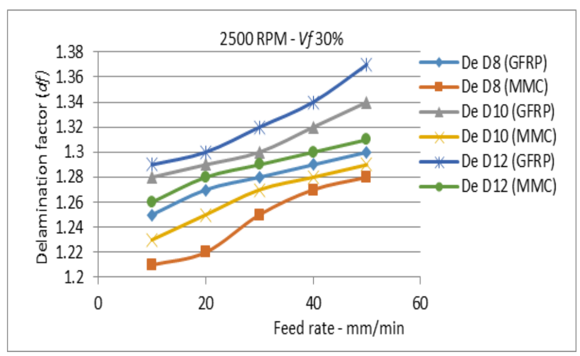


Figure (8) :$(df\ -f)$ Relation for GFRP and AL/SiCp composites at: 30 % ,rpm 2500 and three cutters (end mill of different diameters).

3.4. Effect of cutting speed and cutter diameter on the delamination factor (df)

From the plotted 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 is increased with the increase of the three cutting speeds. 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. At the drilling of 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 feed 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%. When using 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 used 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. For the other 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 becomes, 0.83, 0.82, 1.22 and 0.80% for AL/SiCp composite. When used the other 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. The results 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 other 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. When used 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. In addition, 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). Also, at cutting speed 500 rpm, 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).

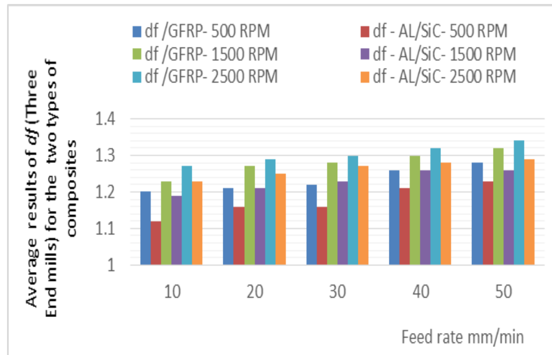


Figure (9-a): The mean results in (df) for GFRP and AL/SiCp composites at, [Three cutters (end mill of different diameters) and the three cutting speeds].

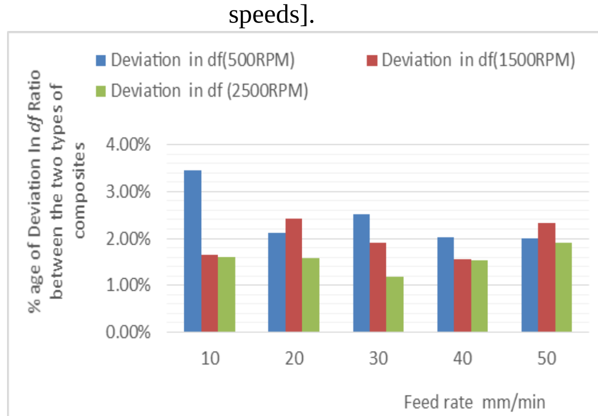


Figure (9-b): The deviation percentage of increase in (df) between AL/SiCp and GFRP at the three cutting speeds.

The average results of (df) for GFRP composite when used cutting speed 1500 rpm, 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). In addition, 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 results 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 clear that, the cutting speed has a strong effect on the resultant values of delamination factor (df). The delamination factor (df) 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 the delamination factor (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. In addition, 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 the delamination factor (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 deeply 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. In addition, 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 led to an obvious increase in the delamination factor with all feed rates and with all used cutters.

4. The conclusions

The used experimental methodology is applied in this research to study the effects 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 accurate analysis of the results, it can be concluded that:

1) both of the feed rate and the cutter diameter are had a large effect on surface roughness (Ra) and delamination factor (df), while both of (Ra) and (df) 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 delamination factor (df) values of 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 a strong 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 a clear 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 larger than that of AL/SiCp composite at all used cutters, cutting speeds and all used feed rates.

6) The average results of the surface roughness (Ra) between GFRP and AL/SiCp composites are; 16.084, 16.614 and 17.632 respectively for the three used 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 used 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 the surface roughness (Ra) and the delamination factor (df) 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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