Effect of Process Parameters on Machinability of GFRP Composite Laminates By End milling

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Abstract: Machining of GFRP laminate materials are difficult task due to their anisotropic and non homogeneity in nature which consist of distinctly different phases. Machining of composite materials is rarely avoided in view of losing the strength of components due to fiber breakage and other damages. In specific situations where metal inserts are inevitable in case of joining or affixing with some other mating part, the need for high quality machining arises with minimal damage to the laminated structure. In this connection precision machining is needed the present research work deals with milling. The machining has become an important issue which needs to be investigated in detail and experimentations performed with various machining process parameters are carefully analyzed with the mill tool dynamometer, talysurf and travelling microscope so the analysis and results work were correlated by graphs. For finding the best optimal parametric combinations are very important aspect in order to minimize damages of machined parts and increasing the productivity. For this reason, different levels of factors like cutting speed, feed, and depth of cut, fiber orientation angle, fiber volume fraction, tool rake angle and tool clearance angle are chosen carefully to obtain optimum output values. This investigation is based on Taguchi's L_{27} orthogonal array was established and Analysis of variance (ANOVA) has been utilized explore the effect of input factors on surface roughness (R_a), cutting force (F) and delamination factor (F_d) are studied and performance evaluated by different tool nomenclature solid mill cutters. The correlation was obtained by multiple variable linear regressions using Minitab15 software.

Key words- ANOVA, L_{27} orthogonal array, GFRP laminates, solid end milling cutters, Desirability function analysis.

I.INTRODUCTION

FRP composites are characterized by their greatness when compared with metals, better in corrosion resistance, fatigue resistance, less weight to strength ratio, high fracture toughness. Hence GFRP composites frequently used in many applications such as sporting goods, racing car bodies and aero space components (wings, tails and fuselages). Commonly composite products are manufactured by near-net shapes, secondary processes involving machining to get the good dimensional accuracy and geometrical shapes by turning, drilling and milling operations in a specified manner. There is a lot of difference between the machining of conventional metals and their alloys and that of composite materials. However, each composite differs in its machining behavior since its physical and mechanical properties depend largely on the type of fiber, the fiber content, the fiber orientation and variability in the matrix material. Considerable amount of literature is readily available on the machinability of (Glass Fiber Reinforced Polymer) GFRP composites; with very limited work on machining parameters optimization for GFRP composites. Therefore, machining process optimization for all types FRP composites is seemed to be an emerging area of research. Milling is a correct machining operation to produce good dimensional accuracy and less damage s. jahanmir[1]. Secondly, the fiber orientation, poor surface roughness like fiber breaking , matrix damages , inter laminar delamination failures generally seen if machining is done by improper machining conditions Bhatnagar N[2]. The mechanistic modeling approach for predicting cutting forces in the milling process of carbon fiber reinforced composites. Specific energy functions were determined by regression analysis of experimental data and a machining model was developed, it was found that capable of predicting cutting forces in milling of both unidirectional and multidirectional laminates. Model predictions were concluded to be in good agreement with experimental results [3].

Further more studies in the cutting parameters (cutting speed and feed rate and depth of cut) under specific cutting force, thrust force, delamination and surface roughness in Glass Fiber Reinforced Polymers (GFRP's). A plan of experiments, based on the techniques of Taguchi was established considering drilling with prefixed cutting parameters in a hand layup GFRP material. The analysis of variance (ANOVA) was performed to investigate the cutting characteristics of GFRP's using Cemented Carbide (K10) drills with appropriate geometries[4]. To obtain the delamination free FRP composites, many researchers put more attention on conventional machining operations like drilling by number of literatures [5 to 8]. Surface finish is an important characteristic that would be effect on mechanical behavior and dimensional accuracy of machining process, in this connection researcher developed an optimum parameters to achieve the desirable surface roughness [9,10]. Apart from practicle research work the theoretical analysis work on FRP was proposed that reinforcement and direction of the fibers are studied to improvement of investigations for next generation [11]. Koplevet et al. Kaneeda Puw et al. and Hocheng et al. investigated the principal cutting mechanisms correlate strongly to workpiece fiber arrangement and tool nomenclature, ANOVA has pointed out that the surface roughness decrease by increasing the feed and speed using K-10 carbide end mill tool and found charecteristics of fiber length in chips [12,13,14]. Palanikumar et al. got experimentally measurement of surface finish in FRP is less affected compare to that in metals, because of FRP arrangement may cause to errors it will also cause the fiber stacks on the stylus, and finally developed a procedure to evaluate and optimize the selected factors to achieve minimum surface damage by integrating Taguchi method and analysis of variance (ANOVA) technique [15]. As the tool progresses into the workpiece, the fibers are subjected to compressive loading along the axial direction. This compressive loading then leads to fiber-matrix interfacial failure in the form of interfacial cracks ahead of the cutting tool similar to the positive rake angle case and studied in various fiber orientations [16]. The delamination of GFPR machined surfaces may rejection of products, and damages may caused by tool wear. Hintze et al. conducted experiments, and concluded that fiber orientation angle and tool wear together influenced on the surface damages of CFRP laminates [17]. Palanikumar et al. got experimentally measurement of surface finish in FRP is less affected compare to that in metals, because of FRP arrangement may cause to errors it will also cause the fiber stacks on the stylus, and finally developed a procedure to evaluate and optimize the selected factors to achieve minimum surface damage by integrating Taguchi method and analysis of variance (ANOVA) technique [18 to 19]. As the tool progresses into the work piece, the fibers are subjected to compressive loading along the axial direction. In recent literature surveys, it is observed that experimental studies are importantly supported with different modeling's, analysis and optimization techniques to minimize the number of complications, time consumption and expensive experiments [20-21].

In the above summary stated more studies which are carried out correlation of input parameters(fiber characterization, tool nomenclature, speed ,feed rate and depth of cut) with out put responses such as (surface roughness, cutting force and delamination factor), in various machining aspects under various environment conditions, but these investigations are approached only up to specific limitations of applications. For this connection extend this present investigation, which is based on Taguchi design method and model was based on experimental obtained data was developed to predicted surface roughness , cutting force and delamination factor by different tool nomenclature solid mill cutters on uni directional GFRP composite laminate plates. This paper presents a new approach to optimize the machining process parameters on GFRP composite laminates using desirability function analysis (DFA). Here the seven input factors selected are (Speeds are 960rpm, 1153 rpm and 1950 rpm, and feeds are 1 mm/sec, 2 mm/sec and 3 mm/sec, depth of cuts 1mm, 2mm and 3mm, fiber orientation angles 0^0,$45^0$and 90^0, fiber volume fraction 40%, 50% and 60%, tool rake angles 25^0,$30^0$and 35^0 and tool clearance angles 12^0,$14^0$and 16^0) respectively to conduct number of experiments as per the DOE, Taguchi L_{27} orthogonal array design was used as to conduct the experiments at various levels to obtain the optimal solutions. And also confirmation test was made by desirability function analysis (DFA).

II. Experimental set up:

2.1 Schematic of machining:

The work piece material selected for investigation is uni-directional(UD) (0^0,45^0, 90^0) glass fiber reinforced polyester polymer composites fabricated by hand layup compression moulding technique of 40%fiber, 50% and 60%of polyester resin with defect (voids) free. GFRP laminates are shaped by size of 100mmx100mmx10±0.5 mm by diamond dressed abrasive wheel cutter. In this study, the experiments were carried out on a conventional universal milling machine incorporated by high speed spindle motor 10KW to perform slots on work pieces with different carbide end mill cutters of 10 mm diameter. Here the machining component forces are (F_X-feed force, Fy-cutting force and F_z-Thrust force, Here resultant machining force 'F' is obtained by $F = \sqrt{F_x^2+ F_y^2+ F_z^2}$) were obtained by mill tool dynamometer with range of force measurement in coordinate direction is 0 to 50 Kgf . The surface roughness was measured along the cut slot from Mitutoyo profiler the cut-off value and transfer length were set as 0.5mm/sec 5mm while take the centreline average (R_a), of three different places readings are taken to obtain the precision data. The fiber orientations (Degrees), cutting speed (rpm) and feed rate (mm/sec) are controlled input parameters in this investigation. Each experiment was conducted three times and finds the delamination (W_{max}) around the each slot at three places by using travelling microscope with magnification of 200X. The average value is taken as the delamination value.

2.2. Taguchi experimental design and selection of parameters:

Extensive and expensive experimentations would typically be required to evaluate the machinability of a material. Hence, experimental approach of machinability assessments can be well achieved through statistically designed tests or series, commonly known as design of experiment (DOE). DOE methodology involves full factorial as well as partial or fractional approaches. In this study, Taguchi DOE method was used to design the experimental matrix. Taguchi method systematically plans the experiments according to a specially designed orthogonal array (OA) which can significantly reduce the number of experiments [22]. In Taguchi's OA, each combination of factors has a balance, in which within a column of the array, each factor has equal number of levels. The unique characteristics of GFRP composites affect their machinability differently to those of the traditional homogenous materials. Physical properties of fiber reinforcements and the matrix material, fiber orientation, types, matrix material and volume fraction greatly influence the machinability of GFRP composites apart from processing parameters which includes cutting speed, feed rate and depth of cut, tool materials and geometries. Such a large number of influencing factors inevitably add to the complexity of experimental investigations. Hence, in this part of work, only machining or processing parameters were considered for the parametric analysis of their significant influence. Here seven important machining parameters namely cutting speed ,feed rate , depth of cut , fiber orientation angle , fiber volume fraction, tool rake angle and tool clearance angle; that effect the surface roughness, machining force and delamination factor. The range of machining conditions was selected owing to the importance of industrial applications, within the limit of the machine tool as well as over the range of conditions employed.

In the traditional full factorial experimentation, 27 trials would be needed to complete the entire experimental work of three factors at three levels. However, based on the selected parameters and their levels, current parametric study could be well performed using the L_{27} Taguchi OA in which nine experimental runs would be required to complete the array. In the Taguchi analysis, the average value of experimental response and its corresponding signal to noise ratio (S/N) of each run can be calculated to analyze the effects of the machining parameters. However, in this paper, S/N ratio was chosen for the Taguchi analysis because S/N ratio can represents both the average (mean) and variation (standard deviation) of the experimental results. Hence, depending on the qualitative characteristics of the experimental response, the S/N ratio can take up either 'the lower the better' or 'the higher the better' category respectively. A robust quality of a characteristic always corresponds to higher value of S/N regardless of the category.

			Levels		
Process Parameters	**Units**	**Notations**	**1**	**2**	**3**
Cutting speed	RPM	N	960	1153	1950
Federate	mm/sec	f	1	2	3
Depth of cut	mm	d	1	2	3
Fiber orientation	Degrees	ϴ	0	45	90
Fiber volume fraction	Percentage	Φ_i	40	50	60
Tool rake angle	Degrees	Φ_R	25	30	35
Tool clearance angle	Degrees	Φ_C	12	14	16

Table1. Process control parameters and their levels

Speed (N)	**Feed(f)**	**Depth of cut(d)**	**Fiber orientation angle (Ɵ)**	**Fiber volume fraction (Φ_i)**	**Tool rake angle(Φ_R)in**	**Tool clearance angle(Φ_C)**	**Surface roughness (R_a)**	**Resultant Force (F)**	**Delamination factor (F_d)**	**Composite desirability (d_G)**
960	1	1	0	40	25	12	1.83600	17.6640	1.23540	0.864
960	1	1	0	50	30	14	2.30125	18.6020	1.16400	0.964
960	1	1	0	60	35	16	1.89500	20.2500	1.21300	0.684
960	2	2	45	40	25	12	1.85400	17.5820	1.19100	0.782
960	2	2	45	50	30	14	1.92800	18.5840	1.16300	0.568
960	2	2	45	60	35	16	1.89500	18.7550	1.14000	0.798
960	3	3	90	40	25	12	2.21300	19.9587	1.23580	0.886
960	3	3	90	50	30	14	2.26600	20.2890	1.24520	0.842
960	3	3	90	60	35	16	2.21350	22.0241	1.20100	0.594
1153	1	2	90	40	30	16	1.84960	17.6913	1.13460	0.547
1153	1	2	90	50	35	12	2.12850	20.3498	1.19860	0.648
1153	1	2	90	60	25	14	2.12060	22.3580	1.20640	0.532
1153	2	3	0	40	30	16	1.96310	17.6240	1.14590	0.024
1153	2	3	0	50	35	12	2.25800	18.9680	1.19560	0.235
1153	2	3	0	60	25	14	1.85740	16.8957	1.16180	0.459
1153	3	1	45	40	30	16	2.02560	19.0465	1.19820	0.589
1153	3	1	45	50	35	12	1.99650	21.1360	1.20450	0.622
1153	3	1	45	60	25	14	1.93210	20.2540	1.23470	0.548
1960	1	3	45	40	35	14	1.77440	19.8954	1.18520	0.349
1960	1	3	45	50	25	16	1.95340	21.2590	1.23080	0.466
1960	1	3	45	60	30	12	2.10240	19.9640	1.23810	0.762
1960	2	1	90	40	35	14	2.09650	20.2256	1.18870	0.486
1960	2	1	90	50	25	16	2.25760	21.9856	1.32540	0.437
1960	2	1	90	60	30	12	2.21340	19.9650	1.20390	0.365
1960	3	2	0	40	35	14	1.86140	18.8562	1.19260	0.216
1960	3	2	0	50	25	16	1.84820	20.2354	1.22660	0.248
1960	3	2	0	60	30	12	1.81640	18.3496	1.10246	0.296

Table2. Experimental test conditions and observed data with composite desirability

2.3. Measurement of machining force, Surface roughness and Delamination factor:

Forces acted on the cutting tool which can be measured by a mill tool dynamometer with data acquisition system and processed on a personal laptop. The surface finish was measured with Talysurf as shown in figure 1(b), for knowing the surface quality. The computation of the delamination was done by the measurement of the Maximum width of damage (Wmax) a affected by the material, the damage normally allocated by delamination factor (Fd) was resolved. This factor is defined as the quotient between the maximum width of damage (Wmax), and the width of cut (W). The value of delamination factor (Fd) can be achieved by the following equation: Fd= (Wmax/ W). Wmax is the maximum width of the damage in mm and 'W' is the width of cut in mm. All the above measurements are repeated three times to check for the consistency.

Fig 1. (a) Machining of GFRP laminate plate is properly fixed in machining center by special designed fixture (b). Measurement of surface roughness by Mitutoyo Talysurf (c). Measurement of delamination damage using Travelling Microscope

III. RESULTS AND DISCUSSION

3.1 Influence of the cutting parameters on the surface roughness based on S/N Ratio:

Table 2 shows the results of the surface roughness (Ra), machining force (F) and delamination factor (Fd) as a function of the input cutting process parameters for various GFRP composites. Table 3-5 accomplish the results of Taguchi analysis (S/N ratio) for surface roughness, machining force (F) and delamination factor (Fd) using the approach of smaller is better.

From the table 3 shows that the fiber orientation angle, fiber volume fraction is most influenced parameter fallowed by depth of cut, tool rake angle, cutting speed, tool clearance angle and feed rate for surface roughness of GFRP composite laminates. From the table 4 it is observed that the fiber orientation angle is most exceptional parameter followed by fiber volume fraction , tool rake angle, feed rate , tool clearance angle, cutting speed and feed rate for machining force of GFRP composite laminates. From the table 5, tool rake angle , depth of cut ,fiber orientation angle , Cutting speed and tool clearance angles are most significant parameters for delamination factor of GFRP composite laminates. This work presented that effect of surface roughness and machining force are almost same. From the above observation, the fiber orientation is most outstanding contribution to overall performance.

Levels	Factors						
	N	**f**	**d**	**Θ**	**Φi**	**Φ_R**	**Φ_C**
1	-6.177	-5.972	-6.259	-5.811	-5.742	-5.932	-6.191
2	-6.067	-6.148	-5.663	-5.747	-6.435	-6.213	-6.054
3	-5.952	-6.075	-6.274	-6.638	-6.019	-6.051	-5.915
Delta	0.225	0.176	0.612	0.891	0.693	0.281	0.240
Rank	6	7	3	1	2	4	5

Table3. Signal to noise ratio for the surface roughness of GFRP composites

Levels	Factors						
	N	**f**	**d**	**Θ**	**Φi**	**Φ_R**	**Φ_C**
1	-25.69	-25.90	-25.96	-25.38	-25.44	-25.89	-25.71
2	-25.71	-25.53	-25.64	-25.83	-26.07	-25.52	-25.80
3	-26.04	-26.02	-25.84	-26.23	-25.93	-26.03	-25.94
Delta	0.35	0.49	0.32	0.85	0.64	0.51	0.23
Rank	5	4	6	1	2	3	7

Table4.Signal to noise ratios for the machining force of GFRP composites

Levels	Factors						
	N	**f**	**d**	**Θ**	**Φi**	**Φ_R**	**Φ_C**
1	-1.571	-1.585	-1.712	-1.447	-1.506	-1.776	-1.583
2	-1.484	-1.507	-1.380	-1.569	-1.700	-1.411	-1.534
3	-1.650	-1.612	-1.612	-1.688	-1.498	-1.517	-1.5878
Delta	0.166	0.332	0.104	0.242	0.202	0.365	0.053
Rank	5	6	2	3	4	1	7

Table5.Signal to noise ratio for the delamination factor of GFRP composites

3.2. Effect of process parameters on surface roughness, resultant machining force and delamination factor and composite desirability based on response table:

The influence of various machining process parameters on milling of GFRP composite laminates will be studied by using responses from the graphs 2 to 4. And their main effects are shown in tables 6 to 9. Firstly, from the figure2, it shows that surface roughness increases with increasing the fiber orientation angle, fiber volume fraction and depth of cut where as cutting speed, feed rate and tool nomenclature decreases. Based on the main effect plot and response table for surface roughness, the optimum level of each parameter set is **Ө Φi1 d3 Φ_R4 Φ_C5 N 6 f7.** From the figure 3, it is evaluated that resultant machining force increases with increasing the fiber orientation angle, cutting speed and depth of cut feed rate where as fiber volume fraction is decreases. Based on the main effect plot and response table for machining force, the optimum level of each parameter set at **Ө1 Φi2 Φ_R3 f4 N5 d6 Φ_C 7.** From the figure 4, it is observed that the delamination factor increases with increasing the fiber orientation angle, the fiber volume fraction, cutting speed feed rate and tool angles where as depth of cut is decreases. Based on the main effect plot and response table for delamination factor, the optimum level of each parameter set at **Ө1 Φi2 Φ_R3 f4 N5 d6 Φ_C7 for** delamination factor (Fd).

Levels	**Factors**						
	N	**f**	**d**	**Ө**	**Φi**	**Φ_R**	**Φ_C**
1	2.045	1.996	2.062	1.960	1.942	1.986	2.046
2	2.015	2.036	1.922	1.940	2.104	2.052	2.015
3	1.992	2.019	2.067	2.151	2.005	2.013	1.989
Optimum levels	**N 6**	**f 7**	**d3**	**Ө1**	**Φi2**	**Φ_R4**	**Φ_C5**

Table 6. S/N ratios of Responses for means of the surface roughness of GFRP composites

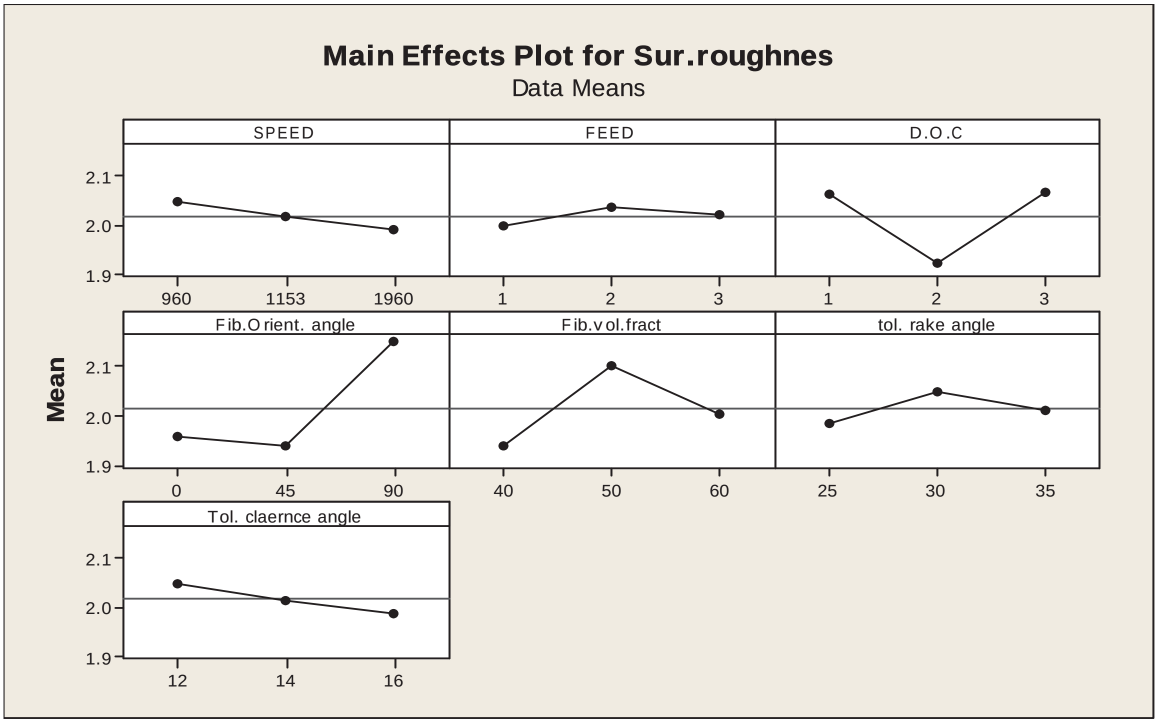

Fig 2. Illustration of factors effects on surface roughness

Levels	**Factors**						
	N	**f**	**d**	**Ө**	**Φi**	**Φ_R**	**Φ_C**
1	19.30	19.78	19.90	18.60	18.73	19.80	19.33
2	19.37	18.95	19.20	19.61	20.16	18.90	19.55
3	20.08	20.02	19.65	20.54	19.87	20.05	19.87
Optimum levels	**N 5**	**f 4**	**d6**	**Ө1**	**Φi2**	**Φ_R3**	**Φ_C 7**

Table 7. S/N ratios of Responses for means of the Resultant machining force of GFRP composites

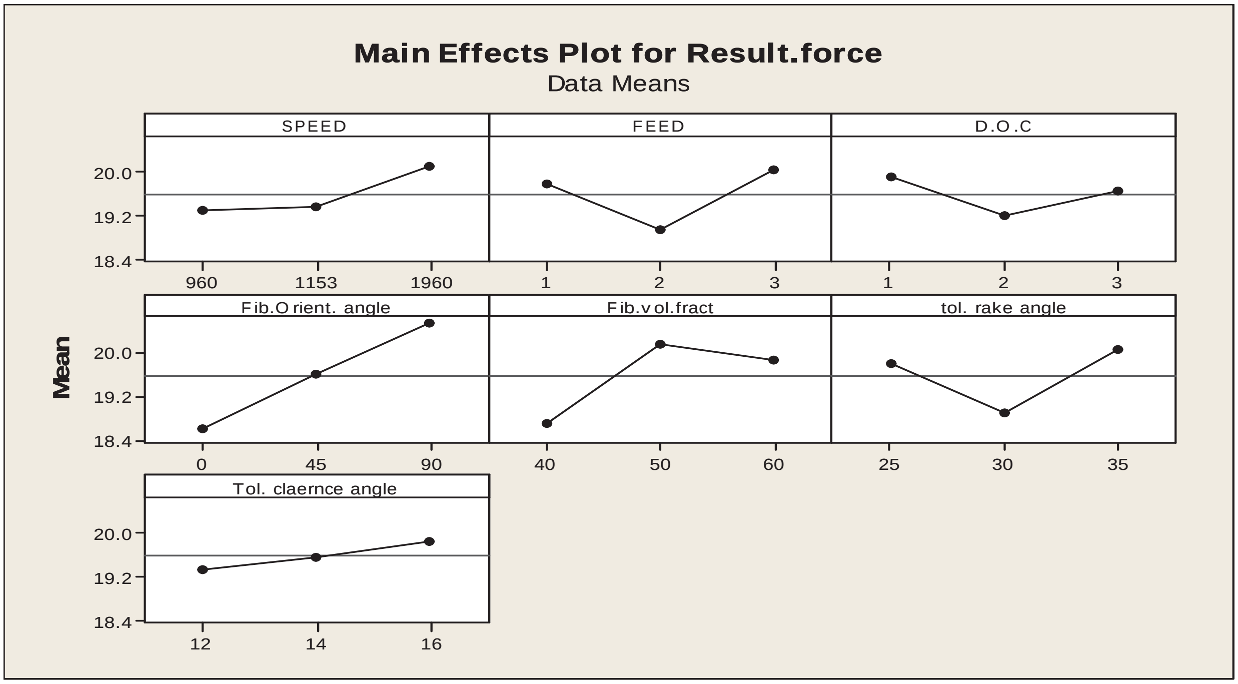

Fig 3. Illustration of factors effects on machining force

Levels	**Factors**						
	N	**f**	**d**	**Ө**	**Φi**	**Φ_R**	**Φ_C**
1	1.199	1.201	1.219	1.182	1.190	1.228	1.201
2	1.187	1.191	1.173	1.198	1.217	1.177	1.194
3	1.210	1.205	1.204	1.216	1.189	1.191	1.202
Optimum levels	N 5	f 6	d2	Ө3	Φi4	**Φ_R1**	Φ_C 7

Table 8. Signal to noise ratio for the delamination factor of GFRP composites

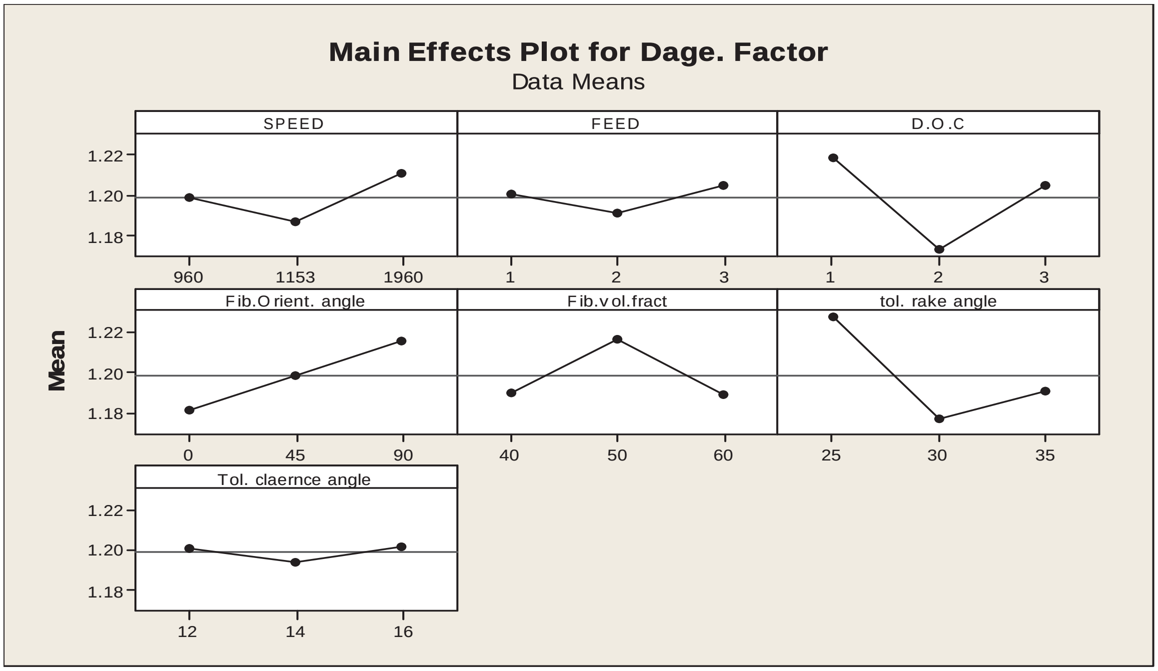

Fig 4. Illustration of factors effects on delamination factor

Levels	Factors						
	N	f	d	ϴ	Φi	Φ_R	Φ_C
1 2 3	1.206 1.198 1.276	1.214 1.195 1.258	1.235 1.184 1.253	1.186 1.201 1.278	1.201 1.286 1.203	1.294 1.186 1.204	1.268 1.210 1.254
Optimum levels	N 5	f 6	d2	ϴ3	Φi4	**Φ_R1**	Φ_C 7

Table9. Factors effects for composite desirability (dG) for GFRP composites

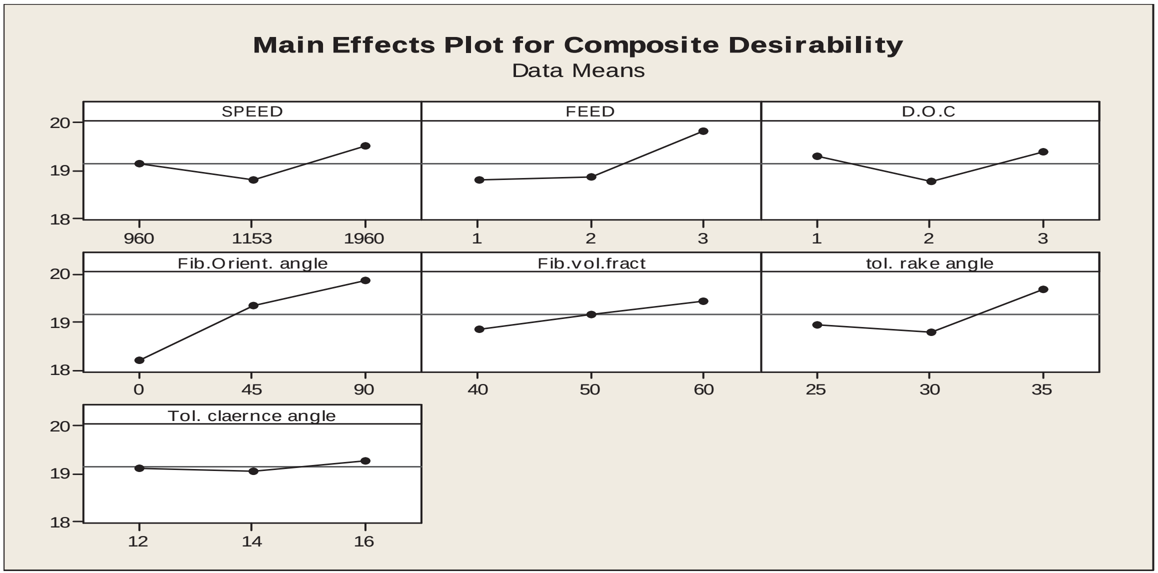

Fig5. Effect of process parameters on composite desirability (dG) for GFRP composites

3.3. Analysis of variance for GFRP composites (ANOVA):

ANOVA is carried out from design of experiments and shown from tables 10 to 12. From the table 10, it is examined that input factor fiber orientation angle has statistical and physical significance (P=39.24%), on the surface roughness of GFRP composite laminates. The error was found for ANOVA of surface roughness (R_a) is 4.49% . From the table 11, it is found that input factor fiber orientation angle has statistical and physical significance (P=36.36%), on the Resultant machining force of GFRP composite laminates. The error was found for ANOVA of resultant machining force (F) is 7.39 %. From the table 12, it is observed that input factor fiber tool rake angle has statistical and physical significance (P=38.35%), on the delamination factor of GFRP composite laminates. The error was found for ANOVA of delamination factor (F_d) is 6.93 %. From the ANOVA tables the input factors fiber orientation angle, fiber volume fraction and tool rake angle has more percentage contribution on surface roughness, resultant machining force and delamination factor followed by depth of cut , cutting speed, feed rate and tool clearance angle for milling of GFRP composite laminate plates

Factors	**Sum of square**	**Degree of freedom**	**Mean square**	**F- Test**	**Percentage contribution**	**Rank**
N	0.01277	2	0.00638	0.21	1.35%	6
f	0.00226	2	0.00115	0.19	0.86%	7
d	0.1598	2	0.0246	1.82	13.26%	3
Ө	1.230	2	0.635	7.45	39.24%	1
Φi	0.86314	2	0.42157	5.12	29.54%	2
Φ_R	0.1126	2	0.0624	1.35	9.28%	4
Φ_C	0.01368	2	0.00671	0.89	1.98%	5
Error	0.02138	24	0.01069		4.49%	
Total	2.41563	38			100%	

Table10. ANOVA for surface roughness

Factors	**Sum of square**	**Degree of freedom**	**Mean square**	**F- Test**	**Percentage contribution**	**Rank**
N	0.11362	2	0.05581	0.71	2.17%	5
f	0.19548	2	0.09774	0.86	3.68%	4
d	0.05145	2	0.02572	0.34	1.48%	6
Ө	18.2601	2	9.1301	8.25	36.36%	1
Φi	12.3514	2	6.1757	6.27	29.29%	2
Φ_R	2.3681	2	1.18405	1.24	18.68%	3
Φ_C	0.02148	2	0.01074	0.35	0.95%	7
Error	0.1925	24	0.09625		7.39%	
Total	33.30253	38			100%	

Table11. ANOVA for machining force

Factors	**Sum of square**	**Degree of freedom**	**Mean square**	**F -Test**	**Percentage contribution**	**Rank**
N	0.08964	2	0.04820	1.95	5.25%	5
f	0.0845	2	0.04225	1.13	2.98%	6
d	0.86314	2	0.42157	5.21	28.64%	2
Ө	0.1238	2	0.0619	4.26	9.56%	3
Φi	0.1124	2	0.0562	3.21	6.65%	4
Φ_R	1.365	2	0.81795	6.95	38.35%	1
Φ_C	0.0568	2	0.0284	0.86	1.64%	7
Error	0.01756	24	0.00878		6.93%	
Total	2.7196	38			100%	

Table12. ANOVA for delamination factor

3.4. ANOVA for composite desirability (d_G):

Based on the ANOVA, the importance of control process parameters with respective to surface roughness, resultant machining force and delamination factor was investigated to determine more precisely the optimum combinations of machining process parameters. The analysis based on 95% confidence level from table13, it is observed that fiber orientation angle (percentage contribution, P = 45.24% has statistical and physical significance on composite desirability fallowed by fiber volume fraction(25.52%) , depth of cut(12.26%), tool rake angle(4.28%), tool clearance angle(2.98%), speed (2.35%) and feed rate(1.86%) for UD-GFRP composite laminates.

Factors	**Sum of square**	**Degree of freedom**	**Mean square**	**F- Test**	**Percentage contribution**	**Rank**
N	0.01425	2	0.00712	0.52	2.35%	6
f	0.00315	2	0.00157	0.24	1.86%	7
d	0.1764	2	0.0882	2.03	12.26%	3
Θ	1.5634	2	0.7817	8.94	45.24%	1
Φi	0.9534	2	0.4767	5.74	25.52%	2
Φ_R	0.1226	2	0.0613	1.85	4.28%	4
Φ_C	0.0154	2	0.0077	1.02	2.98%	5
Error	0.0229	24	0.01145		6.51%	
Total	2.4984	38	1.1256		100%	

Table13. ANOVA for composite desirability (d_G)

3.5. Regression analysis:

The correlation between input parameters (cutting speed ,feed rate , depth of cut , fiber orientation angle , fiber volume fraction, tool rake angle and tool clearance angle) and variable responses (surface roughness, resultant machining force and delamination factor), for UD GFRP Composite laminates are examined by regression analysis with 27 runs of sample size. From the following regression equation shows the values of surface roughness, machining force and delamination factor as,

$(R_a)= 0.235+0.00248\ \Theta +2.154 -0.00234f\ (R^2=83.15\%)$ ------------------------------ (1)

$(F)= 12.24+0.00245\ \Theta +0.00485N-0.156f\ (R^2=79.63\%)$ --------------------------------- (2)

$(F_d)= 0.235+0.000489\ \Theta+0.00045N-0.325f\ (R^2=81.46\%)$ ------------------ (3)

Where, N is cutting speed in Newtons , f is feed rate in millimeters per seconds , d is depth of cut in millimeters, Θ is fiber orientation angle in degrees, Φi is fiber volume fraction in percentage, Φ_R is tool rake angle and Φ_C is tool clearance angle. These above equations are used to illustrate the machining induced responses like surface roughness in micrometers, resultant machining force in newtons and delamination factor in millimeters with varying the machining quality process parameters.

3.6. Confirmation test:

The conclusions are also made by confirmation test for optimum levels selected, the final step to predict and confirm the enhancement of the representing characteristics using the best optimal process parameters. A validation experiments were conducted to obtain for best solutions. The values for surface roughness, resultant machining force and delamination factor from validation of experiments on mailing of UD-GFRP laminates are 1.02µm, 17.25 N and 1.034 respectively. The percentage improvement of output responses with use of DOE are calculated from validated results and got optimum values as:

The percentage improvement in surface roughness = [(1.81-1.80/1.81] X 100 = 5.52%

The percentage improvement in surface roughness = [(18.86-17.75/18.86] X 100 = 5.88%

The percentage improvement in surface roughness = [(1.176-1.106/1.176] X 100 = 5.95%

IV. CONCLUSION

From the experimental runs represented that the following results are concluded by milling of uni-directional GFRP composite laminate plates with solid carbide mill cutters carried out by Taguchi's L_{27} orthogonal array. The experimentally collected data were exposed to desirability function analysis for optimization of machining process parameters. From this investigation, the fallowing conclusions are given for machinability responses.

1. Fiber orientation angle is most significant factor in milling of UDGFRP composite laminates. When the mill cutter fed perpendicular to fiber orientation (90^0) squeeze dominated fiber failure will occur in milling. Therefore more irregularities of machined slot will appear on surface of laminate, more over due to high friction which is created between tool and work piece the fiber peel up and thermal damage of matrix material will takes place. From the results which shows better surface finish and delamination factor was arrived when mill cutter edges fed along the direction of fiber orientation (0^0 and 45^0) this is due to rubbing action of the tool flank face on fiber plies.
2. Fiber volume fraction is also plays most vital role in milling of UDGFRP composite laminates. Milling of 60% of fiber percentage content laminates produces hazardous on surface roughness and damage factor. Better surface finish was achieved for composite with 40% fiber volume content. From the investigation it shows that when increases the fiber percentage has increased the surface roughness of the laminates. And also delamination factor (pull out of fiber, matrix crack, local plastic deformation) will attributed due to fact that increasing in percentage of volume fraction of fiber content, this is because of tool and fiber interaction causes excessive material flow behind tool sharp edge. Hence increased interaction of high modulus fiber with tool results in thermal softening of work material and wear of tool.
3. Fiber orientation angle (P = 45.24%) is the statistical and physical significant parameter followed by fiber volume fraction (P = 25.52%), depth of cut (P = 12.26%), tool rake angle , tool clearance angle , cutting speed and feed rate on GFRP laminates.
4. Desirability function in Taguchi method for optimization of multiple responses problems is very important tool for predicting the surface roughness, resultant machining force and delamination factor for milling of UD-GFRP composite laminates.
5. Even change of tool nomenclatures the effect of mechanical characterization of work piece is most outstanding factor on machinability of GFRP laminates and it is proved by this investigation.
6. The implementation of DFA in DOE improves the surface roughness (5.52%), resultant machining force (5.88%) and delamination factor (5.95%) for milling of GFRP composite laminates.

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