Effect Of Drilling Parameters In Drilling Of Glass Fiber Reinforced Vinylester/Carbon Black Nanocomposites

R.M. Kulkarni, H. N. Narasimha Murthy, G.B.Rudrakshi, Sushilendra

ABSTRACT: This paper focused on investigating the effects of drilling parameters like spindle speed (600rpm, 1860 rpm and 2700 rpm), Feed rate (0.1mm/rev, 0.2mm/rev and 0.3mm/rev), drill point angle (1180, 1100 and 900), drill material (HSS, Co-HSS and Tungsten Carbide) and carbon black (0, 4 and 8 wt %) on the responses: thrust force and delamination factor (entry and exit) in drilling of carbon black dispersed vinyl ester GFRP, by Design of Experiments approach. Drilling experiments were designed to control the drilling parameters based on L27Orthogonal Array. The experimental results were analyzed using MINITAB V16. Signal-to-Noise (S/N) ratio, ANOVA and Grey Relation Analysis (GRA) were employed to analyze the effect of drilling parameters on the quality of the drilled holes. Minimum value of thrust force was obtained for 4 wt% carbon black, 2700 rpm, 0.1 mm/rev, 1100 drill point angle and HSS drill. Delamination was minimum for 4 wt% carbon black, 2700rpm, 0.1mm/rev, 4mm diameter with Tungsten Carbide (WC) drill. SEM confirmed that delamination at the exit is greater than delamination at the entry.

Key words: DOE, S/N ratio, Grey relational analysis, SEM, GFRP

1.INTRODUCTION

Composite materials are widely used in the diverse applications such as aircraft, automobile, sporting goods, marine vessels, audio equipment etc. Because of its unique properties such as specific strength, fatigue strength, strength to weight ratio and corrosion resistance Machining of FRP is essential for all applications. The most common machining operation for GFRP parts is drilling. It is observed that delamination, fibre pullout, tool material, damage to the surface finish and slow speeds are some of the major problems associated with the drilling operation [1-5]. S.Arul et al. [3] studied the influence of tool material on dynamics of drilling GFRP composites. In their investigation, Tipped carbide drills performed better than HSS. drilling trials were carried out on GFRP using HSS drill bit, Ti-N coated HSS and tipped tungsten carbide drill. Erol Kilickap [4] utilized Taguchi method and design of experiments to determine the optimum parameters on delamination in drilling of GFRP composites. The ANOVA results revealed that the Feed rate and speed were the dominant cutting parameters having greater influence on delamination factor for all the drills. The electrically conductive, non-ageing matrix system for GFRP with an electrical resistivity less than 108 Ωcm is required.

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A conductive polymer matrix can be developed by dispersing electrically conductive filler like carbon black in the medium. [6]. In most of the investigations, design of experiments is adopted for designing the experimental layout and to analyze and optimize the results, procedures such as ANOVA, S/N ratio and grey analysis are used [7-9]. The objective of this paper is to investigate the drilling damage characteristics of CB dispersed vinylester GFRP and the effect of drill tool material, speed, feed rate, and drill point angle on the thrust force and delamination factor of the drilled holes. This paper incorporates the techniques of Taguchi in planning and executing experiments, orthogonal arrays to design the with respect to critical factors. The significance of the factors is then identified based on analysis of variance (ANOVA). SEM is adopted to characterize the drilled hole at entry and exit.

2. EXPERIMENTAL WORK

2.1. Material

The materials used for fabrication were E-Glass with 360 GSM, Ecmalon 9911 Bisphenol Epoxy based Vinylester resin and carbon nano powder Carbon black N220 grade

2.2. Preparation

Carbon black with (0%, 4% and 8%) is dispersed in vinylester as a filler material using ultrasonication and co-rotating twin screw extruder.The gel so prepared by this method was mixed with 2 wt% of promoter, 2 wt % of accelerator and 2 wt % of catalyst at room temperature to initiate the cross-linking process, which was used to prepare CB/vinylester/glass specimens using Hand lay-up technique. The specimen of 250x250x3mm size is prepared. The specimens were cured at room temperature for 24 hours.

2.3. Drilling Test

The drilling machine used for the experiment is sensitive drilling machine, With maximum and minimum feed rate is 0.3 mm/rev and 0.1 mm/rev and Spindle speed of 2700 rpm and 600 rpm. A Cylindrical Grinder was used for precisely grinding the drill tools. Drill tool angles of 900, 1000 and 1180 are prepared. Drilling is carried out according to DOE, drill tool dynamometer used to measure thrust force and toolmakers microscope is used to measure delamination factor.

2.4. Design of Experiments

DOE is based on orthogonal array experimental planning. Orthogonal array experimental planning is a technique used to evaluate multiple effects with least amount of experimental effort. It is an optimal experimental plan.

Table 1 Factors and their corresponding levels chosen for DOE

Factors	Level 1	Level 2	Level 3
CB wt %	0%	4%	8%
Spindle Speed	600rpm	1860rpm	2700rpm
Feed rate	0.1mm/rev	0.2mm/rev	0.3mm/rev
Drill point angle	1180	1100	900
Drill material	HSS	Co-HSS	WC

For this investigation, we had to find an orthogonal array which could accommodate five factors with three levels. This accommodation was possible in the feature “Taguchi Design” in MINITAB where in it was decided to select an L27 array. The factors and their levels were assigned as per the requirement of the selected L27 array in MINITAB

Table 2.Experimental layout obtained through MINITAB statistical software

Expt no.	CB % wt	Speed rpm	Feed rate mm/rev	Drill point degree	Drill material
1	0	600	0.1	118	HSS
2	0	600	0.1	118	Co-HSS
3	0	600	0.1	118	WC
4	0	1860	0.2	110	HSS
5	0	1860	0.2	110	Co-HSS
6	0	1860	0.2	110	WC
7	0	2700	0.3	90	HSS
8	0	2700	0.3	90	Co-HSS
9	0	2700	0.3	90	WC
10	4	600	0.2	90	HSS
11	4	600	0.2	90	Co-HSS
12	4	600	0.2	90	WC
13	4	1860	0.3	118	HSS
14	4	1860	0.3	118	Co-HSS
15	4	1860	0.3	118	WC
16	4	2700	0.1	110	HSS
17	4	2700	0.1	110	Co-HSS
18	4	2700	0.1	110	WC
19	8	600	0.3	110	HSS
20	8	600	0.3	110	Co-HSS
21	8	600	0.3	110	WC
22	8	1860	0.1	90	HSS
23	8	1860	0.1	90	Co-HSS
24	8	1860	0.1	90	WC
25	8	2700	0.2	118	HSS
26	8	2700	0.2	118	Co-HSS
27	8	2700	0.2	118	WC

3. RESULTS AND DISCUSSION

3.1. S/N ratio

In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value (standard deviation, SD) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of characteristic; lower is better (LB), higher is better (HB), and nominal is best (NB)

Lower the better: measured data and ideal value is expected to be as small as possible.

$$SN_s = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right)$$

Higher the better: The larger-the-better characteristic should be non-negative, and its most desirable value is infinity.

$$SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right)$$

Nominal the best: This case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable.

$$S = \sqrt{\sum_{i=1}^{n}\frac{(Y_i - \bar{Y})^2}{n-1}}$$

Average S/N ratio for each of the responses of the experiment was calculated based on the relation for smaller the better.

Table 3 S/N Ratio results for Thrust force, delamination factor (entry and exit)

Expt no.	Mean thrust force	S/N ratio	Mean delamination factor (entry)	S/N ratio	Mean delamination factor (exit)	S/N ratio
1.	49.05	-33.82	1.227	-1.78	1.468	-3.40
2.	42.51	-32.63	1.231	-1.81	1.361	-2.68
3.	45.78	-33.26	1.117	-0.96	1.358	-2.68
4.	32.7	-30.38	1.229	-1.80	1.560	-3.87
5.	32.7	-30.38	1.206	-1.63	1.355	-2.64
6.	32.7	-30.38	1.202	-1.61	1.326	-2.46
7.	22.89	-27.37	1.199	-1.58	1.453	-3.26
8.	26.16	-28.49	1.218	-1.72	1.532	-3.71
9.	29.43	-29.38	1.188	-1.50	1.370	-2.75
10.	55.59	-34.93	1.234	-1.83	1.390	-2.86
11.	35.97	-31.19	1.135	-1.11	1.345	-2.58
12.	49.05	-33.82	1.139	-1.14	1.286	-2.20
13.	45.78	-33.26	1.254	-1.97	1.365	-2.72
14.	39.24	-32.06	1.210	-1.66	1.280	-2.19
15.	32.7	-30.38	1.196	-1.55	1.418	-3.04
16.	16.35	-24.61	1.103	-0.85	1.312	-2.36
17.	19.62	-25.86	1.096	-0.80	1.148	-1.20
18.	22.89	-27.37	1.072	-0.61	1.185	-1.47
19.	35.97	-31.19	1.197	-1.57	1.803	-5.14
20.	32.7	-30.38	1.191	-1.52	1.788	-5.05
21.	32.7	-30.38	1.167	-1.34	1.399	-2.92
22.	22.89	-27.37	1.206	-1.64	1.433	-3.15

From Table 3 shows the best performance identified for thrust force is experiment 16 with 4% CB (Level 2), 2700rpm (Level 3), 0.1mm/rev Feed rate (Level 1), drill point angle 1100 (Level 2) and HSS drill (Level 1) as this combination gave the lowest value of S/N ratio with respect to thrust force. For delamination factor-Entry the lowest value of S/N ratio was recorded for experiment 18 which had 4% CB (Level 1), 2700rpm (Level3), 0.1mm/rev (Level 1), 1100 drill point angle (Level 2) and WC drill material (Level 3). For delamination factor-Exit presented that experiment 17 gave the best performance. The factors in the combination were 4% CB (Level 1), 2700rpm (Level 3), 0.1mm/rev (Level 1), 1100 drill point angle (Level 2) and Co-HSS drill (Level 2).

3.2 Main effect plots for different values of S/N ratios

The main effects plot for S/N ratio values for thrust force is shown in Fig 1. For 8% CB produced the lowest thrust force while 0% CB produced the highest. Spindle speed of 2700rpm produced the lowest thrust force while there was highest variation in the response value for speed 600rpm. Lower Feed rate of 0.1mm/rev gave the lowest thrust force and the value increased as the Feed rate increased. 1100 point angle gave the best thrust force values. Though there was not a remarkable variation in the thrust force owing to drill material, Co-HSS resulted in lower thrust force values compared to HSS and WC drills. Fig 2 presents S/N ratio values for delamination entry. 4% CB produced minimum delamination at the entry while 0% CB produced the maximum delamination. Delamination at the entry decreased with the increase in spindle speed. Feed rate of 0.1 mm/rev resulted in lesser delamination while high Feed rates produced larger delamination damage. 1100 point angle gave the best thrust force values and using tungsten carbide drill resulted in lower delamination. The main effects plot for delamination factor-Exit is presented in fig .3. 4% CB resulted in lower delamination damage at the exit and 8% CB produced the highest. Lower spindle speeds resulted in higher damages. A lower Feed rate of 0.1mm/rev gave the minimum delamination damage. There is no much significant change for point angle only by small margin 1180 point angle shows lower delamination. Tungsten Carbide drill material produced the lowest damage compared to HSS and Co-HSS material.

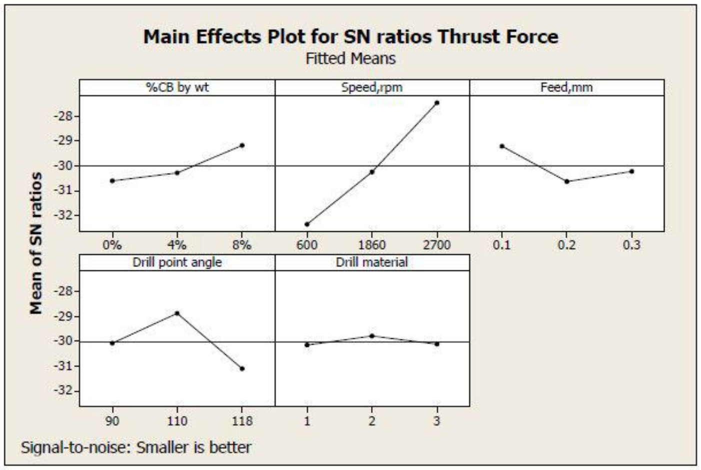

Fig 1 Main effects plot of for S/N ratio values of Thrust Force (TF)

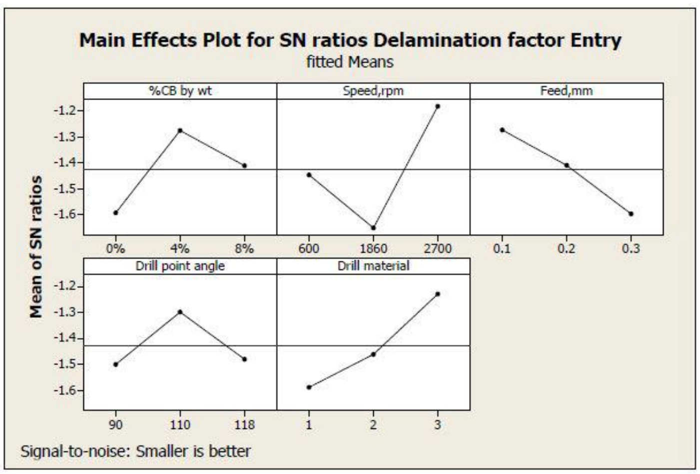

Fig 2 Main effects plot of for S/N ratio values of Delamination factor-Entry

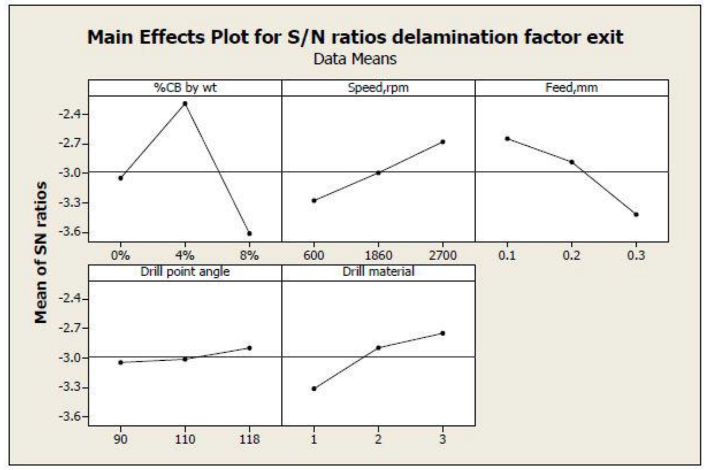

Fig 3 Main effects plot of for S/N ratio values of Delamination factor-Exit

3.3 ANOVA results for S/N Ratio

Analysis of Variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. ANOVA is mainly carried to analyze the statistical significance of different factors at different levels on the response variables. ANOVA is performed based on the DOE.

Table 4.Response table for ANOVA for S/N ratio Thrust Force (TF)

Source	DOF	Sum of Squares (SS)	Adj SS	Adj Mean Square	F (variance ratio)	P (Probability)	Rank
Carbon black%	2	216.23	216.23	108.12	4.7	0.025	3
Spindle speed rpm	2	1485.13	1485.13	742.56	32.26	0.001	1
Feed rate mm/rev	2	85.54	85.54	42.77	1.86	0.188	4
Drill Point angle, degree	2	316.03	316.03	158.02	6.86	0.007	2
Drill Material	2	38.02	38.02	19.01	0.83	0.456	5
Error	16	368.31	368.31	23.02			
Total	26	2509.27				**R-Sq = 85.30%**	

Table 5.Response table for ANOVA for S/N ratio Delamination factor-Entry

Source	DOF	Sum of Squares (SS)	Adj SS	Adj Mean Square	F (variance ratio)	P (Probability)	Rank
Carbon black%	2	0.008019	0.008019	0.004009	6.65	0.008	4
Spindle speed rpm	2	0.017759	0.017759	0.008879	14.73	0.001	1
Feed rate mm/rev	2	0.008283	0.008283	0.004142	6.87	0.007	3
Drill Point angle	2	0.003877	0.003877	0.001938	3.22	0.067	5
Drill material	2	0.010965	0.010965	0.005482	9.09	0.002	2
Error	16	0.009647	0.009647	0.000603			
Total	26	0.058549				**R-Sq = 83.5%**	

Table 6.Response table for ANOVA for S/N ratio Delamination factor-Exit

Source	DOF	Sum of Squares (SS)	Adj SS	Adj Mean Square	F (variance ratio)	P (Probability)	Rank
Carbon black%	2	0.21998	0.21998	0.10999	10.62	0.001	1
Spindle speed rpm	2	0.04744	0.04744	0.02372	2.29	0.134	3
Feed rate mm/rev	2	0.07614	0.07614	0.03807	3.67	0.049	2
Drill Point angle	2	0.00938	0.00938	0.00469	0.45	0.644	5
Drill material	2	0.03625	0.03625	0.01813	1.75	0.206	4
Error	16	0.16577	0.16577	0.01036			
Total	26	0.55495				**R-Sq = 70.1%**	

It is evident fromTable-4, that spindle speed was the most prominent factor affecting thrust force followed by CB% and Feed rate. From Table 5 spindle speed was yet again the most influential factor on the delamination factor –Entry. CB% and Feed rate followed speed in that respect. From Table-6, though there was not a much significant effect of any factor on delamination at exit, spindle speed showed more effect compared to all the other factors.

3.4 Grey Relational Analysis of the Experimental results

The Grey relational grades represent the level of correlation between the reference and the comparability sequences; the larger Grey relational grade means the comparability sequence exhibiting a stronger correlation with the reference sequence. Based on this study, one can select a combination of the levels that provide the largest average response. The multiple performance characteristics can be converted into the optimization of a single grey relation grade. The grey relational coefficients are calculated to express the relationship between the ideal (best) and actual experimental results. The grey relational coefficient ξi (k) can be expressed as

Δoi = the difference of the absolute value between Xo(K) and Xi(K),
ξ = distinguishing coefficient between zero and one. In this study ξ

$$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{min}}{\Delta_{oi}(K) + \xi\Delta_{max}}$$

value is taken as 0.5
Δmin = smallest value of Δoi
Δmax = largest value of Δoi
In this investigation Grey relation analysis was used to optimize parametric combination for conventional drilling process of CB/VE/GFRP. The multiple performance characteristics include thrust force and delamination (entry and exit).

Table 7 Rank assignments to experiments based on Grey relational grades

Expt. No.	CB wt%	Speed rpm	Feed rate mm/rev	Drill Point angle	Drill material	Grey relational grade	Rank
18	4	2700	0.1	110	WC	0.887	1
17	4	2700	0.1	110	CO-HSS	0.884	2
16	4	2700	0.1	110	HSS	0.813	3
27	8	2700	0.2	118	WC	0.656	4
3	0	600	0.1	118	WC	0.637	5
23	8	1860	0.1	90	Co-HSS	0.618	6
14	4	1860	0.3	118	Co-HSS	0.593	7

From Table 7 it can be concluded that the combination of 4% CB, 2700rpm speed, 0.1mm/rev Feed rate, 110 drill point angle and WC drill material has attained the highest value of grey relational grade and thus the top rank. This indicates that this factor combination of experiment 18 is closer to the optimal.

4. SEM of drilled holes with the best characteristics

The drilled holes of the top ranked were studied under a scanning electron microscope to observed the damage due to delamination.

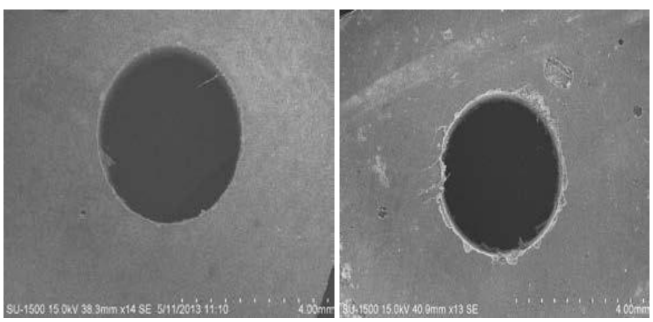

Fig-4. SEM of a 4 mm drilled hole on CB/VE/GFRP laminate with 4% CB, at 2700 rpm and 0.1mm/rev Feed rate with a Co-HSS drill bit (Entry and Exit)

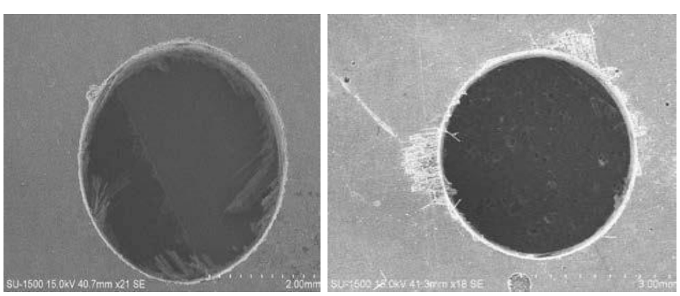

Fig-5. SEM of a 4mm drilled hole with HSS drillbit (Entry and Exit)

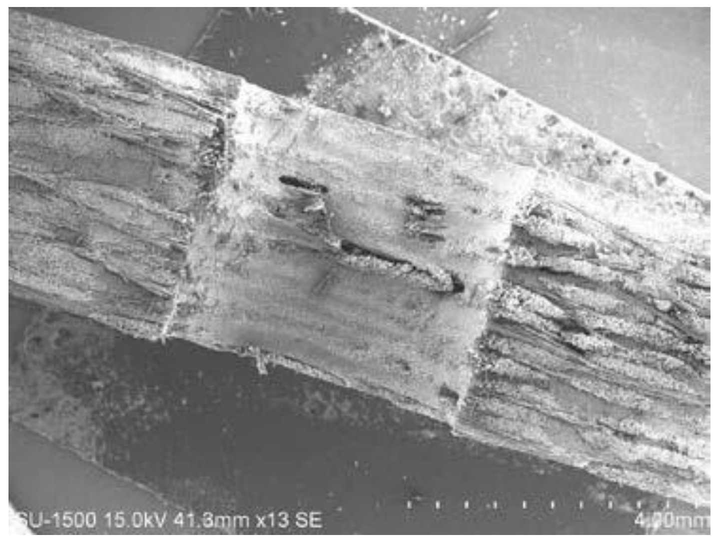

Fig 6 SEM of cross section CB/VE/GFRP

SEM observations showed that delamination occurred at the entrance and at the exit, the edge quality at the hole entrance is better than at the hole exit.

5. MECHANICALTESTS

5.1. Microhardness

Vickers hardness numbers measured for all the specimens. It can be stated that the hardness numbers increased as the carbon black concentration increased. Hence the presence of carbon black in GFRP contributes to the improvement in hardness of the material.

Table 8 Vickers hardness numbers (HV) of the specimens

CB content	Trial 1	Trial 2	Trail 3	Average	HV (Table)
0 wt%	121.5	119.5	119.5	120.16	32.10
4 wt%	114.5	109.5	112.5	112.16	36.88
8 wt%	113.5	115.5	117.5	115.5	34.77

5.2. Tensile Strength

The tensile strength of the specimen is measured UTM from INSTRON, MODEL 5569A without drilled hole and strengths of specimens with different drilled holes were given by the UTM output interface.

Table 9 Tensile stress of the specimens

Specimen	CB % wt	Tensile stress at Yield (MPa)
1	0%	242.2
2	4%	323
3	8%	223.56

6. Conclusions

Experimental studies of drilling of glass fibre reinforced plastic laminates dispersed with 0, 4 and 8 wt% carbon black employing a sensitive drilling machine were undertaken. Design of experiments provided an experimental plan of L27 orthogonal array by considering carbon black % weight, spindle speed, Feed rate, drill point angle and drill material as factors. The response parameters were set as thrust force, delamination entry and delamination exit. Based on the experimental results and analysis, the following conclusions were arrived.

- Thrust force increased as the speed decreased and as CB% increased. This was due to the improvement in hardness of the material because of CB wt% and also because lower speed creates more axial thrust.
- Both thrust force and delamination decreased with increase in spindle speed.
- Increase in Feed rate resulted in higher delamination at exit. Also, CB %caused little effect on delamination.
- There were three different drill material used for investigation i.e HSS, Co-HSS and Tungsten carbide in that later two gave better results for both delamination thrust force specially Tungsten carbide gave lower delamination as compared to with other two material.
- Decreasing the Feed rate reduces delamination at both entry and exit.
- Grey relational analysis helped to arrive at the best performance combination of parameters that could minimize undesirable response magnitudes (thrust force, delamination entry and exit, collectively), which was known to be 4 wt% carbon black, 2700 rpm, 0.1 mm/rev Feed rate, 1100 point angle and Tungsten carbide drill material.
- SEM confirmed previous research conclusions that delamination at the exit is greater than delamination at the entry.
- It can be concluded from the results that for obtaining minimum delamination damage for both entry and exit, high speed and low Feed rates and drill point angle 1100 and tungsten carbide drill material are optimum.
- Microhardness and tensile strength increases with increase in %wt of CB

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