Application of ANOVA Method in Optimizing the Parameters of Drilling Process of Sandwich Composite Material

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Abstract— In this paper, analysis of variance (ANOVA) are applied to study performance characteristics of drilling parameters(feed rate, speed and rake angle).A L27 orthogonal array is used for predict the result. Full factorial design was successful in drilling of the Glass fiber-EPE foam sandwich composite plate. In the experiment the independent variables are feed rate, speed and rake angle and the dependent variables (output variables) are cutting force (thrust force) Fz in Z direction for sandwich composite material having different skin and core ratios made from glass fiber as skin, EPE foam as core and epoxy resin as adhesive. The drill speed is the main effective parameter followed by feed rate and rake angle for drilling.

Key words: ANOVA, glass fiber - EPE foam sandwich composite, drilling, feed rate, speed, rake angle, cutting force

I. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. A formal definition of composite materials give by ASM Handbook is "macroscopic combination of two or more distinct materials, having a recognizable interface between them". [7].

Owing to the growing use of composite materials, specifically the fiber reinforced plastics (FRP) outside the defence industry and the aerospace industry, the unit cost replaces the performance at any cost as the main concern for production. So, the production technologies, especially the machining of composites, are assuming a more and more significant role as they condition the economic viability of the product. Machining composite materials is a rather complex task owing to its heterogeneity, heat sensitivity, and to the fact that reinforcements are extremely abrasive. Conventional machining methods should be adapted in such a way that they diminish thermal and mechanical damage.

Drilling is a frequently practiced machining process in industry owing to the need for component assembly in mechanical pieces and structures. The drilling of laminate composite materials is significantly affected by the tendency of these materials to delaminate and the fibers to bond from the matrix under the action of machining forces (thrust force and torque)[6].

j.Pualo Davim et al in 2003 presented drilling of metal matrix composite based on taguchi techniques the influence of cutting parameters(cutting velocity and feed rate)and cutting time. By the result concluded that Cutting time is the factor which has great influence on the tool wear(50%) followed by feed rate(24%).[1]

C.C. Tsao et al. in 2004 investigated delamination associated with various drill bits in drilling of composite material by Taguchi analysis. The results summarized are he feed rate and drill diameter are seen to make the largest contribution to the overall performance. & The candle stick drill and saw drill cause a smaller delamination factor than twist drill.[2]

N.S. Mohan et al .in 2006 Experimentally investigated delamination analysis in drilling process of glass fiber reinforced plastic (GFRP) composite materials. . The feed rate, cutting speed and material thickness are seen to make the largest contribution to the delamination effect and the use of high cutting speed and low feed favor the minimum delamination on both entry and exit of the drilling leads to better surface finish and tool life.[3]

R.A. Kishore et al. in 2008 investigated analysis of the residual tensile strength after drilling in glass fiber reinforced epoxy compositesby Taguchi analysis. . It can be concluded that the drilling-induced damage at higher cutting speeds severely affects the residual tensile strength of drilled laminates.[4]

K. Palanikumar in 2011 presented an effective approach for the optimization of drilling parameters with multiple performance characteristics based on the Taguchi's method with grey relational analysis. The order of the importance for the controllable factors based on the grey relational grade is feed rate followed by spindle speed.**[5]**

II. EXPERIMENTAL PROCEDURE

A. *Materials for Experiment:*

The sandwich composite material used in that investigation was glass fiber as skin material, EPE foam as core material and epoxy resin as adhesive.

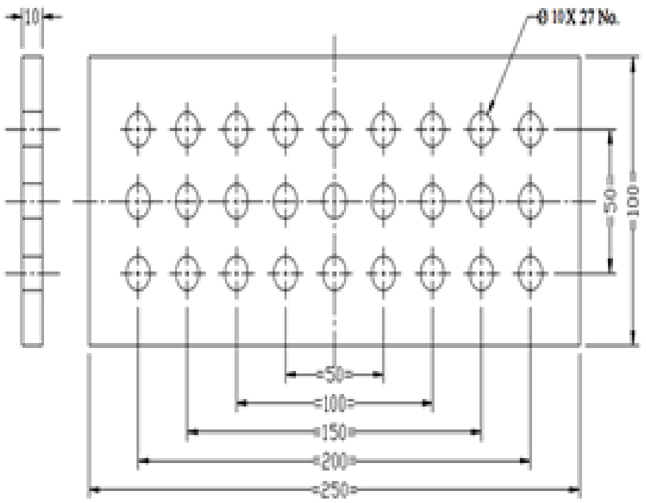

Fig. 1: Size of the sandwich plate

Total five types of materials were manufactured by compressing the different number of layers for skin and core. The materials having different skin and core ratio was manufactured by the following material numbers.

Material	Glass fiber no. of layer	EPE foam no. of layers	Core to skin ratio Vc/Vs
Specimen 1	8	10(3 mm thickness)	1.61
Specimen 2	9	8(3 mm thickness)	2.64
Specimen 3	10	7(3 mm thickness)	3.39
Specimen 4	11	6(3 mm thickness)	4.30
Specimen 5	12	4(3 mm thickness)	6.05

Table 1: No. of layers and core to skin ratio used in specimen

B. Plan of Experiments:

For the plan of experiment, ANOVA method with three factors at three level were used. The level of the rake angle, spindle speed and feed rate considered. Orthogonal array of L_{27} (3^3) was chosen. This orthogonal array was chosen since it has capability to check the interactions among the factors. The factors considered in the present study are cutting speed, feed rate, drill diameter and the responses to be studied are thrust force. In the plan of experiments with 27 tests.

C. Experimental Procedure:

Drilling tests were conducted on vertical milling machine. The machining samples were prepared in the form of 250mm×100mm×10mm blocks for each material. The Twist drill (HSS) of diameter 10mm type were used. The strain gauge based dynamometer was used to record the thrust force F_z.

Fig. 2: Drilling and measuring the force for sandwich composite

In the experiment, parameter selected having three factor and at the level. The treatment combination in 3^3.

FACTORS/ LEVELS	Min.	Avg.	Max.
(A) Rake angle (in degree)	30^0	35^0	40^0
(B) Feed rate (in mm/rev.)	0.01	0.04	0.08
(C) Drill speed (in rpm)	73	164	275

Table 2: factors and their levels

The ranges of the selected process factors are decided by the conducting experiments using one variable at-a-time approach. In total 27 runs of experiments the level of each factor is repeated 9 times.

In the experiment, parameter selected having three factor and at the level. The treatment combination in 3^3 L $_{27}$ orthogonal array designs is shown in the table.

Exp no.	A (Rake Angle) In degree	B (Feed Rate) In mm/rev.	C (Drill Speed) In rpm	Force in N
1	1	1	1	F1
2	1	1	2	F2
3	1	1	3	F3
4	1	2	1	F4
5	1	2	2	F5
6	1	2	3	F6
7	1	3	1	F7
8	1	3	2	F8
9	1	3	3	F9
10	2	1	1	F10
11	2	1	2	F11
12	2	1	3	F12
13	2	2	1	F13
14	2	2	2	F14
15	2	2	3	F15
16	2	3	1	F16
17	2	3	2	F17
18	2	3	3	F18
19	3	1	1	F19
20	3	1	2	F20
21	3	1	3	F21
22	3	2	1	F22
23	3	2	2	F23
24	3	2	3	F24
25	3	3	1	F25
26	3	3	2	F26
27	3	3	3	F27

Table 3: The 27 runs of the experiment

Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. The S/N ratio for each level of process parameters is computed based on the S/N analysis.

There are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the-nominal-the-better. The S/N ratio characteristics are given by Eqns.

1) Lower is better:

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n} y_i^2]$$

2) Nominal is better:

$$\frac{S}{N} = -10\log[V_e]$$

3) Higher is better:

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}]$$

Where yi = ith value of response
n = no. of test conducted
v = variance only

III. RESULT AND DISCUSSIONS

1) For Vc/Vs =1.61:

Factor	SS	DF	MS	F	%P
A(feed rate)	7451.0	2	3725	1	12.59
B(speed)	13808	2	6904	1.85	23.34
C(drill diameter)	37894	2	18947	5.08	64.06
Total	59153.	6	29576.		

Table 4: ANOVA table for force in Z direction

2) For Vc/Vs =2.64:

Factor	SS	DF	MS	F	%P
A(feed rate)	3628.5	2	1814	1	8.350
B(speed)	8273.4	2	4136	2.28	19.03
C(drill diameter)	31553	2	15776	8.69	72.61
total	43455	6	29576		

Table 5: ANOVA table for force in Z direction

3) For Vc/Vs =3.39:

Factor	SS	DF	MS	F	%P
A(feed rate)	3232.2	2	1616	1	7.87
B(speed)	7094.7	2	3547	2.19	17.29
C(drill diameter)	30693	2	15346	9.49	74.82
Total	41020	6	29576		

Table 6: ANOVA table for force in Z direction

4) For Vc/Vs =4.30;

Factor	SS	DF	MS	F	%P
A(feed rate)	3098	2	1549	1	8.12
B(speed)	7767	2	3883	2.50	20.36
C(drill diameter)	27286	2	13643	8.80	71.51
Total	38151	6	19075		

Table 7: ANOVA table for force in Z direction

5) For Vc/Vs =6.05:

Factor	SS	DF	MS	F	%P
A(feed rate)	3047	2	1523	1	7.23
B(speed)	11534	2	5767	3.7	27.3
C(drill diameter)	27553	2	13776	9.0	65.3
Total	42135	6	210676		

Table 8: ANOVA table for force in Z direction

A. Contributions of Factors over Vc/Vs IN Z Direction (Thrust Force):

Figure 3 shows contribution of factors feed rate (A), speed (B) and drill diameter (C) over core to skin ratio (Vc/Vs) for force in Z direction. Factor A (Rake angle) shows the lower contribution than other two factors. As figures clearly shows, for Vc/Vs 1.61, 2.64, 3.39, 4.30 and 6.05 the factor C (drill speed) is having maximum contribution. Then followed by B (Feed rate) and A (Rake angle)

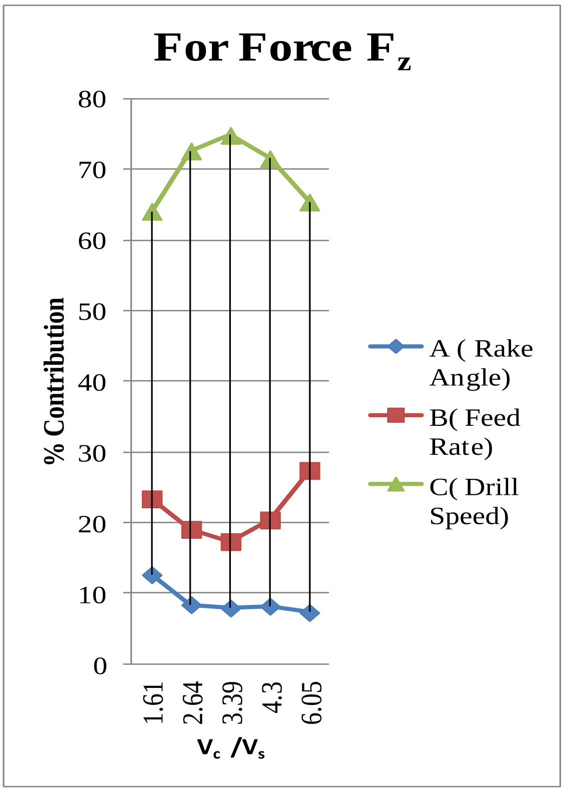

Fig. 3: Graph for contribution of factors on Vc/Vs in Z direction

B. Effect Plot of S/N Ratio for Thrust Force for Materials:

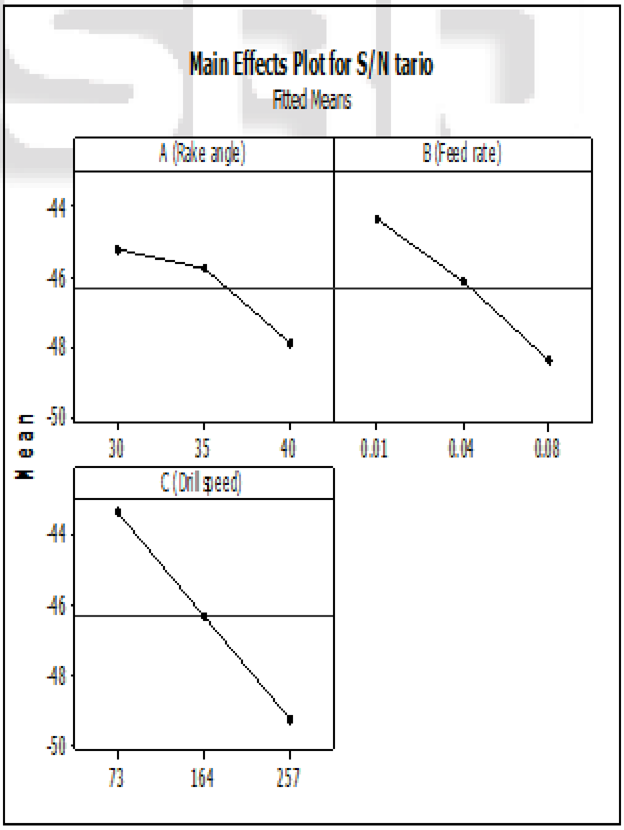

Fig. 4: Effect plot of S/N ratio for thrust force for material VC/VS = 1.61

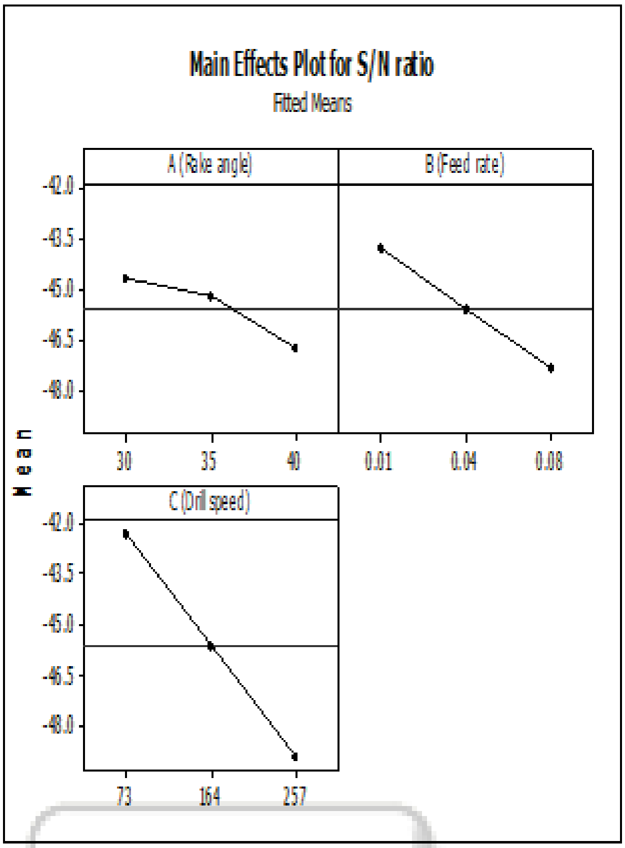

Fig. 5: Effect plot of S/N ratio for thrust force for material VC/VS = 2.64

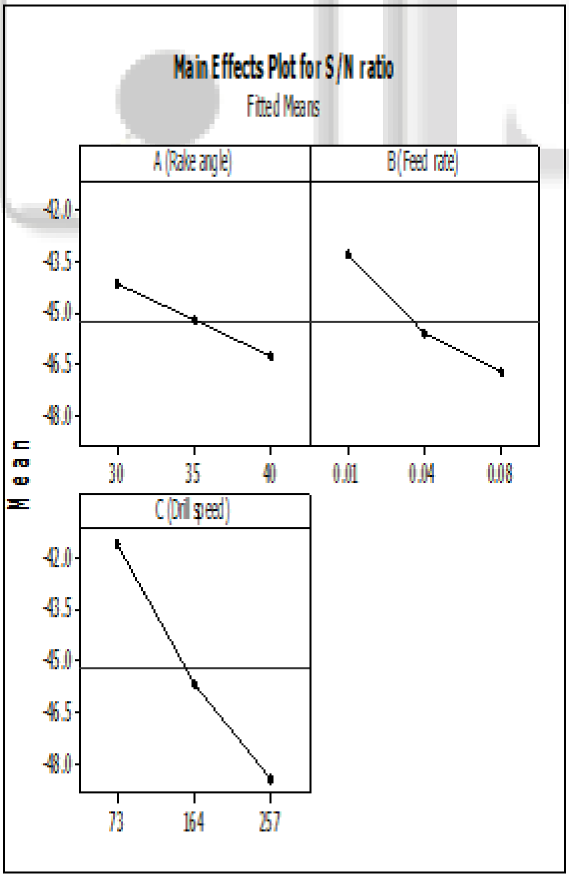

Fig. 6: Effect plot of S/N ratio for thrust force for material VC/VS = 3.39

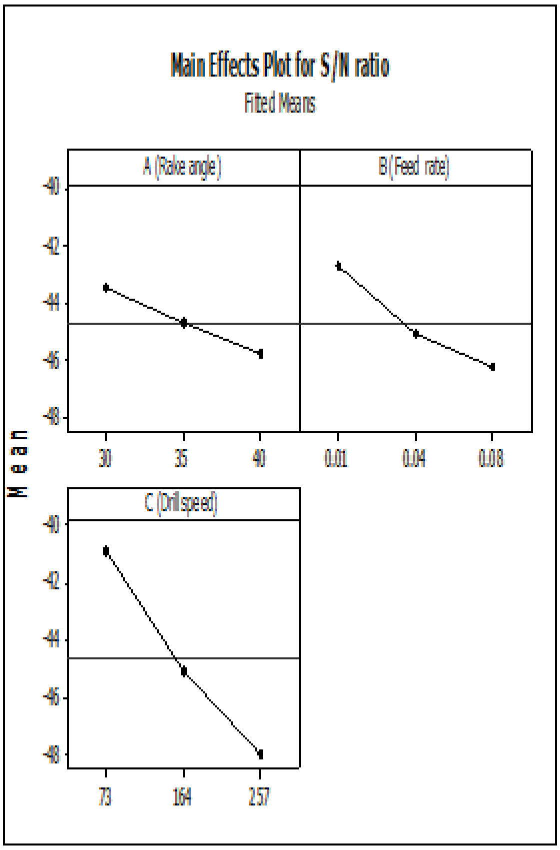

Fig. 7: Effect plot of S/N ratio for thrust force for material VC/VS = 4.30

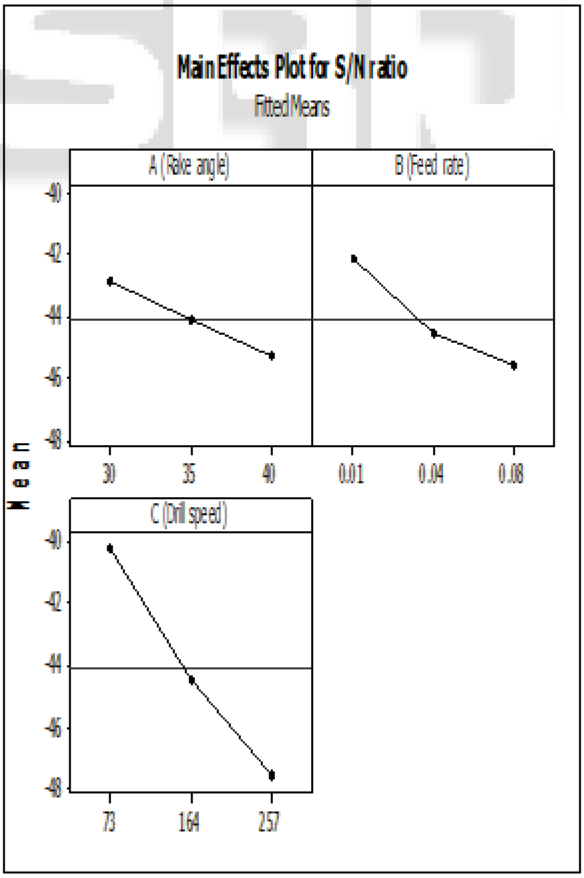

Fig. 8: Effect plot of S/N ratio for thrust force for material VC/VS = 6.05

IV. Conclusion

1) Figure 3 shows that the contribution of factors feed rate(A),speed(B), and drill diameter(C) on forces F_x, F_y, F_z for all core to skin ratios. Drill diameter is having very high contribution followed by drill speed and feed rate.
2) Figure 3 show that for force F_z factor feed rate having lower contribution and increase by speed and drill diameter.
3) Figure 5-8 shows that feed rate affect less for force F_z. As per the factor speed is concern F_z contribution goes on increasing as the core to skin ratio increases. Drill speed has maximum contribution effect on forces F_z.

VC/VS	Factors	A(Rake angle)	B (Feed rate)	C (Drill speed)
1.61	Min.	300	0.01	73
	Avg.	350	0.04	164
	Max.	400	0.08	275
2.64	Min.	300	0.01	73
	Avg.	350	0.04	164
	Max.	400	0.08	275
3.39	Min.	300	0.01	73
	Avg.	350	0.04	164
	Max.	400	0.08	275
4.30	Min.	300	0.01	73
	Avg.	350	0.04	164
	Max.	400	0.08	275
6.05	Min.	300	0.01	73
	Avg.	350	0.04	164
	Max.	400	0.08	275

Table 9: % contribution results for V_c/V_s ratios

Based on Taguchi method yielding the lowest S/N ratio is the optimum parameter for minimizing the force in X and Y direction are A (Rake angle) would be 300 ,B (Feed rate) would be 0.01 mm/rev. and C (Drill speed) would be 73 rpm.

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