The Effect of Coolant in Delamination of Basalt Fiber Reinforced Hybrid Composites During Drilling Operation

S. Rathinavel
PG Scholar
Department of Mechanical Engineering
RVS College of Engineering and Technology, Coimbatore – 641402

G. Vignesh Kumar
Assistant Professor
Department of Mechanical Engineering
RVS College of Engineering and Technology, Coimbatore – 641402

Abstract

Fiber reinforced composites are used in many engineering applications because of their low strength to weight ratio. Delamination is one of the major problems in manufacturing field for using composites as a raw material. In this work, the delamination of basalt fiber reinforced composites was studied with the effect of coolant in drilling operation. The three set of Basalt fiber reinforced composites is prepared by using hand layup techniques with Vetiver and vinyl ester at varying composition. Taguchi design of experiment was used to investigate the effects of drilling parameters such as spindle speed [2500, 2750, 3000 rpm], feed rate (0.2, 0.4, 0.6 mm/rev). A series of experiments based on L9 orthogonal arrays are conducted using CNC machine for both with the coolant and without the coolant and resulting delamination factor was determined. It was observed that speed is highly influencing parameters than feed rate for the delamination of the basalt fiber reinforced composites when the coolants were not employed. The delamination is very less even at the high speed and feed rate when the coolants were employed for all the three varying compositions made.
Keywords: Basalt Fiber Reinforced Hybrid Composites, Basalt Fibre, Fibre Volume Fraction, Vetiver Fibre

I. INTRODUCTION

Usage of fiber reinforced composites in automobiles, aerospace, sport goods play a major role. Basalt fibre is a material made from volcanic ingenious rock. Basalt fiber reinforced composites nowadays replaces the application of the glass fiber. Glass fibre reinforced composites has increased in various areas of science and technology due to its special property. The wide range of application in Aircraft industries.

On Aircraft's for Assembling two structures accomplish machining process. The mechanical drilling is used as generally for application mainly,

- To Create hole,
- To enlarge hole,

As drill is rotated and advanced into a work piece a material is removed in the form of chips that move along the fluted shank of the disk.

Fibre Reinforced hybrid Composite Consists of two or more fibres which are reinforced along with the resin system. So, the properties of the resulting composite material will combine something of the properties of resin on its own with that of fibre on their own.

Overall, the property of their composite depends mainly on

- Property of fibre
- Property of composite
- Fibre Volume fraction (ratio of fibre to resign)

The literature review shows that many researchers have worked towards attaining hole quality considering thrust force, torque, surface roughness, drill temperature and damage/delamination around the dry drilled hole in thin laminated composites.

However, literature on the drilling of non-laminated composite materials and literature on the drilling of thick composite materials under different cooling methods (dry, external and internal) is scarce. Non-laminated composites, because of their superior properties than laminated composites, find application in construction of bridges, prefabricated walkways and platforms, bus components, ballistic applications, etc.

In ballistic applications, mostly thick non-laminated composites with a higher percentage of fibre weight fractions are used to ensure higher order energy absorption. As composites are poor conductors of heat, the drill temperature affects tool wear and thereby hole quality

Hence the present study is aimed to investigate the influence the cooling methods (dry and External) on quality characteristics (drill temperature and damage factor) while drilling the parameters like (feed, spindle speed) are optimized within the selected range for minimizing the delamination characteristics. The paper also If drill temperature and drill induced damage like delamination can be minimized, and thereby the service life of the assembled components can be substantially increased.

II. EXPERIMENTAL DESCRIPTION

A. *Materials*

Basalt fibre (chopped), Unsaturated vinyl ester resin and Vetiver were used as main compositions. methyl ethyl ketone peroxide (MEKP) and co-napthenate were used as catalyst to speed up the chemical process.

B. *Fabrication of Composites*

Basalt fibre and Vetiver fibre reinforced hybrid composites were fabricated using the hand layup method and vinyl ester resin has been used for the matrix. . For a proper chemical reaction, cobalt naphthenate and methyl ethyl ketone peroxide were used as an accelerator and a catalyst, respectively. One volume per cent cobalt naphthenate (accelerator) was also added. A stirrer was used to homogenize the mixture. Then, the resin mixture was used to fabricate the basalt fibre reinforced with the hand layup technique using a roller. The samples were cured for approximately 24 hours at room temperature.

In this fabrication Basalt fibre, Vetiver fibre, Vinyl ester Resin was employed under three different compositions.

Table – 1
Compositions of three samples:

Sample	*Basalt fibre (%)*	*Vetiver fibre (%)*	*Vinyl ester Resin (%)*
I	*24*	*10*	*66*
II	*15*	*19*	*66*
III	*10*	*24*	*66*

Fig. 1: Fabricated composite sample I II III(from left to right)

C. *Drilling of Composites*

Computer Numeric Control drilling machine is used for drilling. The HSS (high speed steel) drill is fixed to the drill bit holder. The drill bit dimension is mentioned in the table (2)

Table – 2
Drill bit configuration

Material	*Hss*
Point Angle	*118^0*
Size	*6mm*
Helix Angle	*33^0*
Chisel Edge Angle	*129^0*

D. *Analysis of Delamination*

The typical drilled composite is presented in Fig. 1 and the measurement of data is shown in Fig. 2. The delamination of the drilled holes is measured by the optical microscope.

Fig. 2: Drilled Composite sample I II II (1st row without coolant 2nd row with coolant)

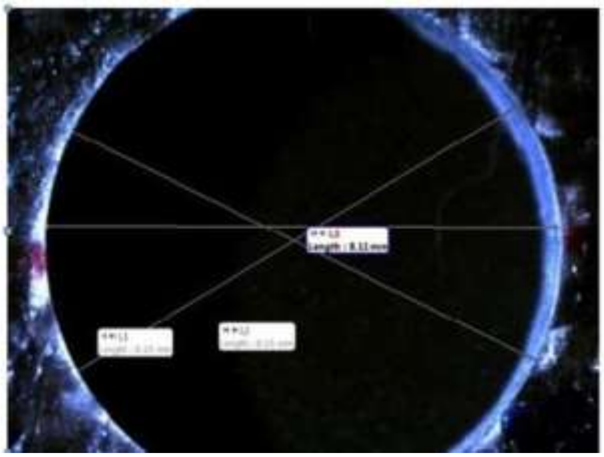


Fig. 3: Measurement of delamination:

E. Optimization of Drilling Parameter using Taguchi Method

The two major tools used in Taguchi's method are the orthogonal array (OA) and the signal to noise ratio (S/N ratio). OA is a matrix of numbers arranged in rows and columns. Each row represents the level of factors in each row and each column represents a specific level for a factor that can be changed for each row (Table ()). S/N ratio is indicative of quality and the purpose of the Taguchi experiment is to find the best level for each operating parameter so as to maximize S/N ratio.

Table – 3
Drilling optimization parameters:

S. No	*Speed, Rpm*	*Feed Rate, Mm/Rev*
1	*2500*	*0.2*
2	*2750*	*0.4*
3	*3000*	*0.6*

In the Taguchi method, the term signal represents the desirable value (mean) for the output characteristic and the term noise represents the undesirable value (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 the characteristic; lower the better, nominal is best and higher the better. The lower the better characteristic Eq. (1) is used for determination of delamination factor, and to achieve better hole quality.

$$S/N = -10 \log \sum_{i=1}^{m} 1/n[y_{ij}^2] \quad \text{………………………………(1)}$$

i=experiment number; y^{ij}=output response for i^{th} experiment for j^{th} response; n= number of replications.

The Analysis of Variance (ANOVA) technique is used to predict the relative significance of the process factors and estimate the experimental errors. It gives the percentage contribution for each factor and proves the better for the relative effect of the different factor on experimental responses.

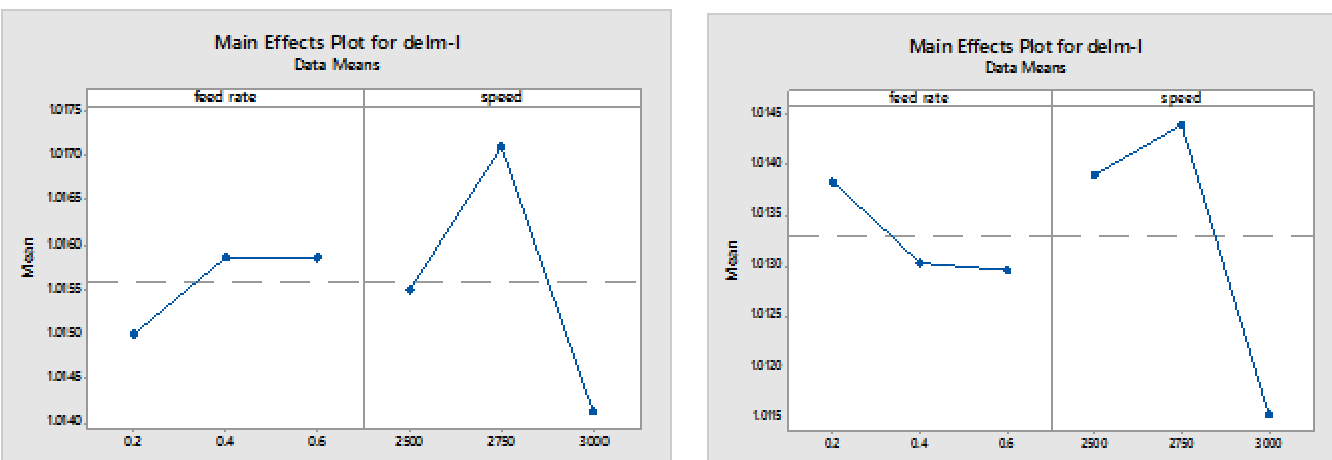
III. RESULT AND DISCUSSION

A series of drilling test was conducted to assess the influence of coolant in drilling parameters on delamination factor on drilling Basalt fibre. The S/N ratios for each experiment of L9 were also calculated by applying an equation(1).The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor.

A. Composite Sample I:

Table – 4
Shows the delamination factor and S/N ratio for Composite sample I (with and without coolant)

Composite 1	*Parameters*		*Without Coolant*			*With Coolant*		
Sl. No.	*Speed, rpm*	*Feed rate, mm/rev*	*Drill Temperature(^{0}c)*	*Delamination factor, mm*	*S/N ratio*	*Drill Temperature(^{0}c)*	*Delamination factor, mm*	*S/N ratio*
1	*2500*	*0.2*	*209.67*	*1.017*	*-0.14641*	*141.0*	*1.0145*	*-0.12504*
2	*2500*	*0.4*	*206.20*	*1.0143*	*-0.12332*	*128.1*	*1.0133*	*-0.11476*
3	*2500*	*0.6*	*217.17*	*1.0152*	*-0.13103*	*138.9*	*1.0139*	*-0.11990*
4	*2750*	*0.2*	*216.43*	*1.0168*	*-0.14471*	*141.0*	*1.0150*	*-0.12932*
5	*2750*	*0.4*	*218.8*	*1.0175*	*-0.15068*	*150.0*	*1.0143*	*-0.12332*
6	*2750*	*0.6*	*228.97*	*1.017*	*-0.14641*	*168.5*	*1.0139*	*-0.11990*
7	*3000*	*0.2*	*203.17*	*1.0112*	*-0.09674*	*167.1*	*1.0120*	*-0.10361*
8	*3000*	*0.4*	*238.19*	*1.0158*	*-0.13616*	*169.0*	*1.0115*	*-0.09933*
9	*3000*	*0.6*	*238.19*	*1.0154*	*-0.13274*	*125.9*	*1.0111*	*-0.09588*



(a) (b)

Fig. 4: Main effects plot for means (a) for without coolant (b) for with coolant

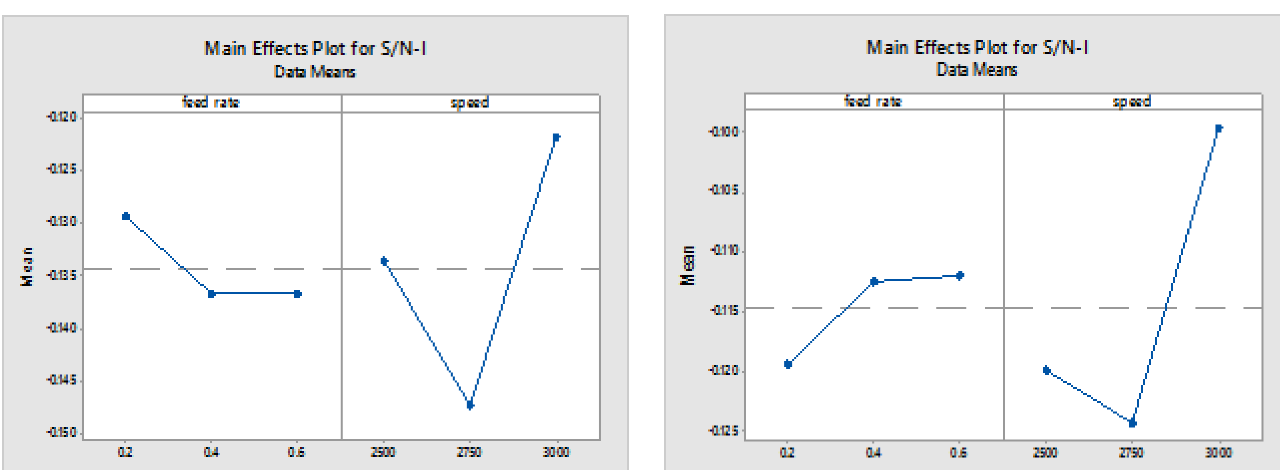


Fig. 5: Main effects plot for S/N ratios (a) without coolant (b) with coolant

1) *Response Table for Composite Sample I:*

Table – 5
Response table for composite sample I without and with coolant

	Without coolant		*With coolant*	
factors	*Speed*	*Feed*	*Speed*	*feed*
L 1	*-0.1335*	*-0.1236*	*-0.1199*	*-0.1193*
L 2	*-0.1472*	*-0.1364*	*-0.12418*	*-0.11246*
L 3	*-0.1219*	*-0.1359*	*-0.0995*	*-0.1118*
Delta(Max-Min)	*0.0253*	*0.0129*	*0.0246*	*0.0035*

2) *Scheme for ANOVA:*

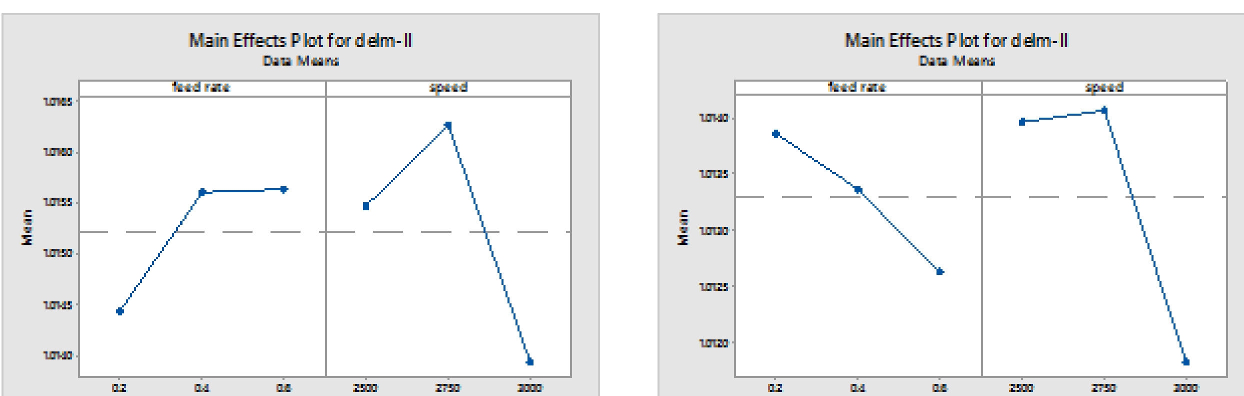
Table – 6
ANOVA table for composite sample I

		Without coolant				*With coolant*		
	DOF	*Sum of sq.*	*Mean sq*	*Contribution*	*Contribution, %*	*Sum of sq*	*Mean sq*	*Contribution %*
Speed	*2*	*0.00113*	*0.000565*	*0.48707*	*48.71*	*0.00098*	*0.000487*	*24.11*
Feed rate	*2*	*0.00031*	*0.000158*	*0.136309*	*13.63*	*0.00016*	*0.000096*	*20.34*
Error	*2*	*0.00043*	*0.000216*	*0.1865032*	*18.65*	*0.00032*	*0.000108*	*11.09*
Total	*6*	*0.00187*				*0.00146*		

B. *Composite Sample II:*

Table - 7
Shows the delamination factor and S/N ratio for Composite sample II (with and without coolant)

Composite 1I	*Parameters*		*Without Coolant*			*With Coolant*		
SLNO	*Speed, rpm*	*Feed rate, mm/rev*	*Drill temperature(^{0}c)*	*Delamination factor, mm*	*S/N ratio*	*Drill temperature(^{0}c)*	*Delamination factor, mm*	*S/N ratio*
1	*2500*	*0.2*	*218.67*	*1.0160*	*-0.13787*	*150.0*	*1.0147*	*-0.12675*
2	*2500*	*0.4*	*215.20*	*1.0150*	*-0.12932*	*145.4*	*1.0139*	*-0.11476*
3	*2500*	*0.6*	*217.17*	*1.0154*	*-0.13274*	*149.8*	*1.0133*	*-0.11990*
4	*2750*	*0.2*	*216.43*	*1.0163*	*-0.14043*	*146.1*	*1.0146*	*-0.12589*
5	*2750*	*0.4*	*218.8*	*1.0160*	*-0.13787*	*150.0*	*1.0140*	*-0.12075*
6	*2750*	*0.6*	*220.97*	*1.0165*	*-0.14214*	*161.2*	*1.0136*	*-0.11733*
7	*3000*	*0.2*	*201.17*	*1.0110*	*-0.09502*	*128.8*	*1.0123*	*-0.10618*
8	*3000*	*0.4*	*230.19*	*1.0158*	*-0.13616*	*155.2*	*1.0122*	*-0.10532*
9	*3000*	*0.6*	*231.19*	*1.0150*	*-0.12932*	*120.1*	*1.0110*	*-0.09500*



(a) (b)

Fig. 6: Main effects plot for means (a) for without coolant (b) for with coolant

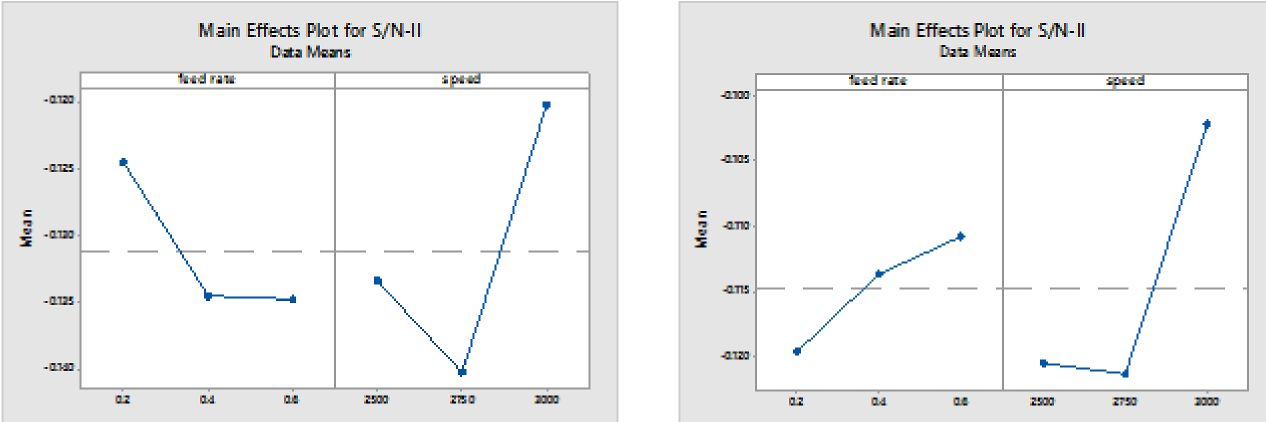


Fig. 7: Main effects plot for S/N ratios (a) without coolant (b) with coolant

3) *Response table for Composite sample II*

Table – 8
Response table for composite sample II without and with coolant

	Without coolant		With coolant	
factors	*Speed*	*Feed*	*Speed*	*feed*
L 1	*-0.1331*	*-0.1244*	*-0.1240*	*-0.1196*
L 2	*-0.1401*	*-0.1344*	*-0.1213*	*-0.1136*
L 3	*-0.1201*	*-0.1347*	*-0.102*	*-0.1107*
Delta(Max-Min)	*0.020*	*0.0103*	*0.0191*	*0.0088*

4) *Scheme for ANOVA*

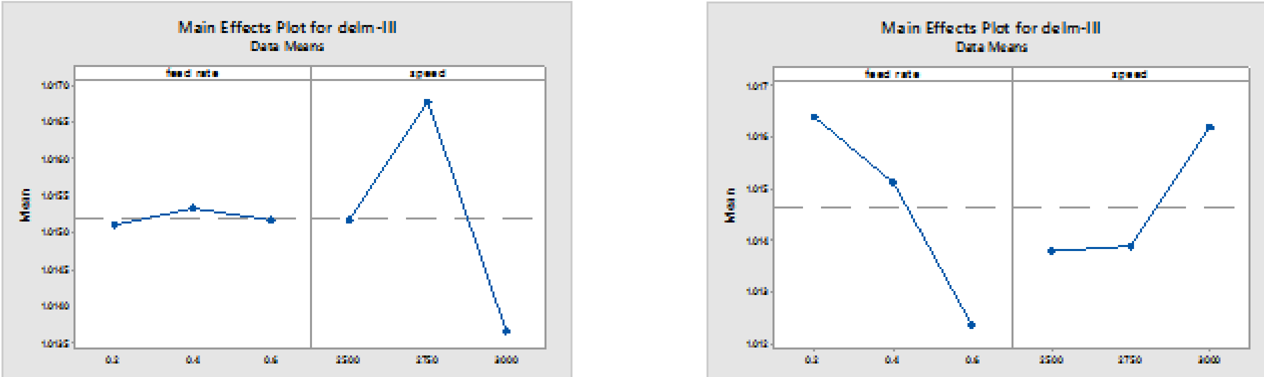
Table - 9
ANOVA table for composite sample II

		Without coolant				With coolant		
	DOF	*Sum of sq.*	*Mean sq*	*Contribution*	*Contribution, %*	*Sum of sq*	*Mean sq*	*Contribution %*
Speed	*2*	*0.00114*	*0.000584*	*0.477071*	*47.70*	*0.000987*	*0.000443*	*25.59*
Feed rate	*2*	*0.00021*	*0.000137*	*0.233301*	*23.33*	*0.00181*	*0.000098*	*19.17*
Error	*2*	*0.00033*	*0.000195*	*0.161513*	*16.15*	*0.000121*	*0.000096*	*10.87*
Total	*6*	*0.00168*				*0.00121*		

C. *Composite Sample III*

Table – 10
Shows the delamination factor and S/N ratio for Composite sample III (with and without coolant)

Composite 1II	*Parameters*		*Without Coolant*			*With Coolant*		
SL. NO.	*Speed, rpm*	*Feed rate, mm/rev*	*Drill temperature(^{0}c)*	*Delamination factor, mm*	*S/N ratio*	*Drill temperature(^{0}c)*	*Delamination factor, mm*	*S/N ratio*
1	*2500*	*0.2*	*207.67*	*1.0165*	*-0.14214*	*127.10*	*1.0148*	*-0.12766*
2	*2500*	*0.4*	*209.20*	*1.0140*	*-0.12075*	*141.0*	*1.0136*	*-0.11733*
3	*2500*	*0.6*	*217.17*	*1.0150*	*-0.12932*	*147.0*	*1.0130*	*-0.11218*
4	*2750*	*0.2*	*215.43*	*1.0168*	*-0.14471*	*145.1*	*1.0144*	*-0.12418*
5	*2750*	*0.4*	*217.8*	*1.0170*	*-0.14641*	*149.5*	*1.0138*	*-0.11904*
6	*2750*	*0.6*	*228.97*	*1.0165*	*-0.14214*	*168.1*	*1.0135*	*-0.11647*
7	*3000*	*0.2*	*203.17*	*1.0120*	*-0.10361*	*140.1*	*1.0200*	*-0.10360*
8	*3000*	*0.4*	*236.19*	*1.0150*	*-0.12932*	*164.7*	*1.0180*	*-0.12932*
9	*3000*	*0.6*	*237.19*	*1.0140*	*-0.12075*	*120.1*	*1.0106*	*-0.09158*



(a) (b)

Fig. 8: Main effects plot for means (a) for without coolant (b) for with coolant

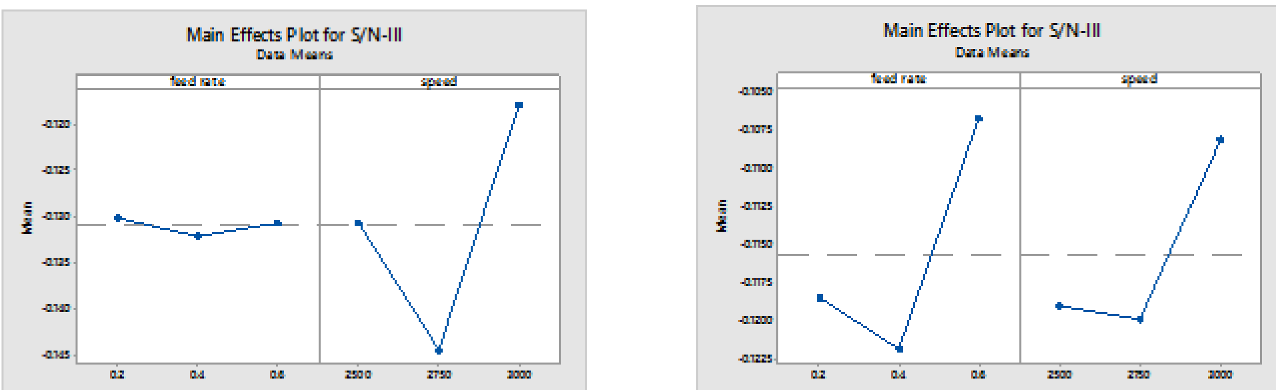


Fig. 9: Main effects plot for S/N ratios (a) without coolant (b) with coolant

1) Response table for Composite Sample III

Table - 11
Response table for composite sample III without and with coolant

	Without coolant		*With coolant*	
factors	*Speed*	*Feed*	*Speed*	*feed*
L 1	*-0.1307*	*-0.1301*	*-0.1190*	*-0.1184*
L 2	*-0.1444*	*-0.1321*	*-0.1198*	*-0.1220*
L 3	*-0.1179*	*-0.1307*	*-0.1081*	*-0.1067*
Delta(Max-Min)	*0.0265*	*0.020*	*0.0117*	*0.0154*

2) Scheme for ANOVA:

Table – 12
ANOVA scheme for composite sample III

		Without coolant				*With coolant*		
	DOF	*Sum of sq.*	*Mean sq*	*Contribution*	*Contribution, %*	*Sum of sq*	*Mean sq*	*Contribution %*
Speed	*2*	*0.00118*	*0.000531*	*0.497072*	*49.70*	*0.00091*	*0.000429*	*27.98*
Feed rate	*2*	*0.00034*	*0.000188*	*0.126309*	*12.63*	*0.00046*	*0.000109*	*17.09*
Error	*2*	*0.00042*	*0.000215*	*0.175503*	*17.55*	*0.00041*	*0.000109*	*12.64*
Total	*6*	*0.00189*				*0.00098*		

From the ANOVA Table (6),(9),(12) indicated that the drilling speed is the significantly influencing parameter for the drilling of basalt fiber composites. At lowest feed rate and highest speed the composite shows the lowest delamination for without coolant. When increasing the spindle speed which reduces the delamination and with increasing of feed rate, the delamination also increased. The contribution for the error value places significant parameters. The error value may be due to orientation of the fiber and depth of cut.

The withcoolant shows very less influence of both the spindle speed and the feed rate compare to the without coolant process so the error vales also less and the delamination of the composite samples are comparatively very low

IV. Conclusion

The hybrid composite with Vetiver fibre and basalt fiber is prepared successfully by hand layup technique and the following conclusion can be drawn:

1) The Taguchi method successfully verified the optimum drilling parameters on the delamination of the composite using ANOVA for both the with the coolant process and without coolant process
2) The results of ANOVA revealed that speed was most significant drilling parameter which has greater influence on the delamination factors. The optimum parameter were cutting speed (3000 rpm), feed rate (0.2 mm/rev) for without coolant process. For achieving minimal delamination factor in the Basalt fiber always higher cutting speed, and higher drill bit angle to be preferred.
3) The result of ANOVA for with coolant process has very close delamination factor for all the parameters but they doesn't have much influence with the spindle speed and the feed rate the optimum parameter were cutting speed (3000 rpm), feed rate (0.6 mm/rev)
4) The drill bit temperature is very minimum while the spindle speed of 3000rpm and feed rate of 0.6 while using coolant for the drilling operation for all the three composite samples(I,II,III)
5) So, while using coolants the drill bit temperature is reduced drastically and then the delamination factor also reduced when compared to without coolant process

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