Optimization of Cutting Forces and Surface Roughness for Turning Process of Glass Fiber Fein forced Polymer (GFRP) using Taguchi Method

Amit Moray, Preeti Singh

Abstract - Machining Fiber Reinforced Polymers (FRPs) is different in many aspects from machining metals. FRPs are inhomogenous materials that consists of distinctly different phases. The reinforcement fibres are strong and brittle while the polymer matrix is ductile and weak. This paper deals with the study of machinability of Glass Fiber Reinforced Polymer (GFRP) composite tubes. The experiment were conducted on a DRO pioneer -175 lathe machine using three different cutting tool: Cemented Carbide, Cubic Boron Nitride(CBN), Poly-Crystalline Diamond(PCD). The experiments were conducted according to Taguchi's Design of Experiments L_9 orthogonal array. The cutting parameters considered were cutting speed, feed rate and depth of cut. The results were measured in terms of cutting forces and surface roughness.

Keywords- ANOVA, GFRP composite material, cutting force and surface roughness.

I. INTRODUCTION

Composite materials are being developed to replace conventional materials for competitive reasons, such as strength to weight ratios. A composite material can be defined as, "a material system composed of a mixture or combination of two or more macro-constituents that differ in form and chemical compositions and are inseparable from each other." Thus, the matrix or reinforcing fibres can be inorganic (ceramic or glass), organic (polymers) or metallic (aluminium or titanium).The successful development of Glass-Fibre-Reinforceed-Plastics (GFRP) dates back to the 1940s, which in turn paved a way for the development of new materials. Since then, a new vista has been opened in materials development. The first theoretical work was done by Everstine and Rogers in 1971. They developed a theory of plane deformation of incompressible composites reinforced by strong parallel fibres. Koplev et al. have investigated the process of machining of Carbon Fiber Reinforced Plastics (CFRP). They measured cutting force both parallel and perpendicular to the fibre orientation using quick stop experiments. They also studied the effect of rake angle machining of CFRPs . Wang et al. have studied, both analytically and experimentally, the orthogonal cutting mechanism of uni-directional graphite/epoxy composites with a diamond tool. In a study (1983) and Bhatnagar et al (1988) studied how the fiber orientation influence both the quality of machined surfaces and tool wear.

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Tekeyama and lijma (1988) studied the surface roughness while machining GFRP composites and concluded that higher cutting speed produces more damage to the machined surface this is because of high cutting temperature which results in local softening of the material. Further Ramulu et al (1994) carried out a study on machining of polymer composites and find out higher cutting speeds gives better surface finish. Davim amd Mata(2004) studied influence of cutting parameters on surface roughness in turning glass-fibre-reinforced plastics using statistical technique. Palanikumar (2008) made a mathematical model to predict tool wear on the machining of glass fibre reinforced plastics composites. Adamkhan et al.(2011) have carried out machining of GFRP composites using two alumina cutting tools. Syed Altaf Hussain et al. (2011) studied machinability of GFRP composites tubes of different fibre angle using three different cutting tools. Experiments were based according to Taguchi's design design of experiments considering cutting speed, feed rate, depth of cut and fibre orientation angle as cutting parameters.

From the literature it seems that limited work has been done in machinability of GFRP composites material. Thus, this present work aims at investigating the effects on cutting forces (F_c) and surface roughness(R_a) while turning GFRP tubes using different cutting tools.

II. MATERIALS AND METHOD

E-glass Bi-directional glass fiber is used as the reinforcement and vinyl ester is the matrix matrial used for making cylindrical workpiece of 30mm diameter and 160 mm length. The workpiece is made by the hand lay up technique.

III. EXPERIMENT DETAILS

The experiments are conducted according to Taguchi's Design of Experiments L_9 orthogonal array. Three cutting parameters has been selected cutting speed(rpm), feed rate(mm/rev), depth of cut(mm). The GFRP samples are turned on DRO pioneer-175 lathe machine using cutting tools inserts namely Cemented Carbide (CCMT 09T304-PF 4225), Poly-crystalline Diamond insert(CCMW 09T304FP CD10), Cubic Boron Nitride (CCMW 09T304 –PF 3215) these inserts are having the same geometry, as given

Specifications

Nose Radius = 0.4mm, Side Rake Angle = 0°, Front Clearance Angle = 7°,Side Clearance Angle = 80°

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TABLE I. CUTTING PARAMETERS, THEIR UNITS, SYMBOLS AND LEVELS

Control Parameters	Unit	Symbol	Levels		
			Level 1	Level 2	Level 3
Cutting Speed	rpm	A	128	224	508
Feed Rate	mm/rev	B	0.10	0.15	0.22
Depth of Cut	mm	C	0.25	0.5	0.75

In this present work DKM2010 turning dynamometer is used. DKM2010 is a 5-components Tool Dynamometer for use on every type of lathe machine be conventional or CNC. it measures forces on the cutting tool up to 2000n with a resolution of 0.1%. Surface roughness is determined from the vertical stylus displacement produced during the detractor traversing over the surface irregularities. The measurements results are displayed digitally/graphically on the touch panel.

Fabrication of Glass Vinylester Composite: The composites are made taking **50%vinylester (resin) + 50% bi-directional fibre (reinforcement).** Hand lay – up method is used to fabricate the composite. The mixture was applied to the glass fabric with the help of a hand brush. The excessive resin squeezed out to reduce the void content and any trapped air bubbles. The resin, premixed with 1.5wt% of hardener HY 956 and 1.5wt% of accelerator, applied on the surface of a sheet of fiber cloth or mat. Fibers are assured for complete impregnation in the resin using metallic rollers. A metallic roller was used to remove the excessive resin. The top of the mold was placed on the base plate and the bolts were tightened. The whole mold assembly was placed in a compression molding machine at a pressure of 60 Kgf/cm^2. The thickness of the glass vinlyester composite is (8±0.2) mm. Samples are then cured at room temperature for 24 hours. Samples were cleaned using acetone.

Fig.1. Developed GFRP Samples

IV. RESULTS AND DISCUSSIONS

Effect of cutting parameters on cutting force has studied using Cemented Carbide (CC), Cubic Boron Nitride(CBN), Polycrystalline Diamond(PCD) and their effect on the developed material is studied in terms of S/N ratio.Taguchi L_9 has been used for planning the experiment for the cutting parameter. The experimental data are analysed using the software MINITAB 15.The means response refers to the average value of the performance characteristics for each parameter at different levels for cutting forces.

TABLE II SHOWS THE EXPERIMENTAL RESULTS FOR CUTTING FORCE (F_C) AND SURFACE ROUGHNESS (R_A) FOR THREE DIFFERENT TOOL MATERIAL

C.S r.p.m A	F.R mm/ rev B	Do Cm m C	F_c for CC	R_a for CC	F_c for CBN	R_a for CBN	(F_c) for PCD	(R_a) For PCD
128	0.10	0.25	60	3.65	19	2.42	23	2.03
128	0.15	0.5	72	4.36	47	3.01	11	2.30
128	0.22	0.75	43	2.85	17	2.99	42	2.83
224	0.10	0.5	42	2.53	21	2.43	18	2.13
224	0.15	0.75	39	2.97	32	2.68	24	2.09
224	0.22	0.25	48	4.46	25	3.24	18	3.11
508	0.10	0.75	42	2.75	24	2.45	28	2.14
508	0.15	0.25	51	3.57	31	2.89	12	2.20
508	0.22	0.5	22	2.68	30	3.23	13	2.18

TABLE III. EFFECT OF CEMENTED CARBIDE INSERT, CBN, PCD INSERT ON CUTTING FORCE (F_C)

Cutting speed r.p.m A	Feed rate mm/rev B	Depth of cut mm C	S/N ratio db Tool 1	S/N Ratio db Tool 2	S/N Ratio db Tool 3
128	0.10	0.25	-35.56	-25.57	-27.23
128	0.15	0.5	-37.15	-33.44	-20.82
128	0.22	0.75	-32.67	-24.60	-32.46
224	0.10	0.5	-32.46	-26.44	-25.10
224	0.15	0.75	-31.83	-30.10	-27.60
224	0.22	0.25	-33.62	-27.96	-25.10
508	0.10	0.75	-32.46	-27.60	-28.94
508	0.15	0.25	-34.15	-29.87	-21.58
508	0.22	0.5	-26.85	-29.56	-22.27

Following are the graphs which shows the variation of cutting force with the cutting parameters for different tool materials.

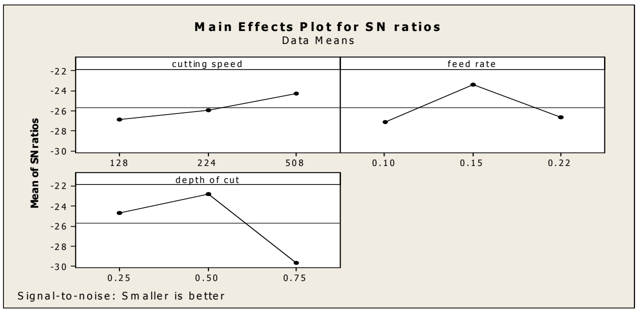

Fig.2.Main effects plot for S/N ratio for CC

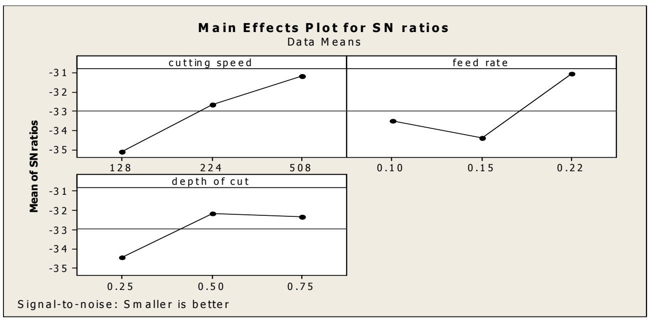

Fig.3. Main effects plot for S/N ratio for CBN

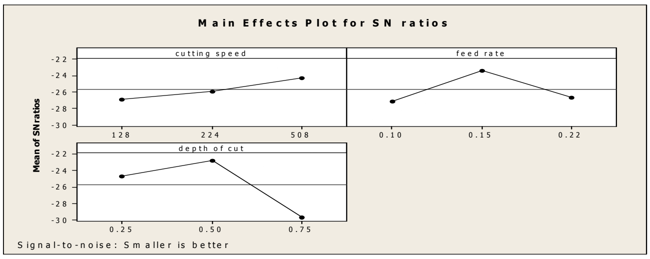

Fig.4. Main effects plot for S/N ratio for CBN

V. ANALYSIS OF THE EXPERIMENTAL RESULTS FOR CUTTING FORCE

The experimental data for cutting force with Cemented Carbide, Cubic Boron Nitride, Poly- Crystalline Diamond is given in Table 3. In order to understand the impact of the various control factors on the response of experimental data it is desirable to develop the analysis of the variance (ANOVA) to find the significant factors. The analysis was performed with a level of significance of 5% i.e. level of confidence 95%.

TABLE IV. ANOVA TABLE FOR CEMENTED CARBIDE INSERT

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
A	2	24.165	24.165	12.083	1.78	36.0
B	2	17.829	17.829	8.914	1.31	43.20
C	2	9.813	9.813	4.907	0.72	58.01
Residual error	2	1.832	1.832	0.92		2.80
Total	8	65.386				

S= 2.606, R-Sq = 95.8% , R-Sq(Adj) = 84.9%

TABLE V. ANOVA TABLE FOR CBN INSERT

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
A	2	2.675	2.675	1.338	7.97	80.0
B	2	35.27	35.27	17.63	88.64	23.8
C	2	9.670	9.670	4.835	203.0	53.3
Residual error	2	11.01	11.01	5.509		6.74
Total	8	58.64				

S=2.347 R-Sq= 96.2% R-Sq(Adj) = 86.8%

TABLE VI. TABLE FOR PCD INSERT

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
A	2	10.23	10.231	5.115	9.80	23.0
B	2	25.07	25.079	12.540	69.13	10.30
C	2	76.99	76.993	38.497	124.56	38.00
Residual error	2	3.052	3.052	1.526		2.64
Total	8	115.3				

S=1.235 R-Sq = 97.4% R-Sq(Adj) = 89.4%

Using Cemented Carbide insert it is observed from the ANOVA Table 7. that the effect of cutting parameters the depth of cut (P=58.01%), feed rate (P=43.20%), cutting speed (P=36%). Among these factors depth of cut is highly significant . CBN tool, depth of cut (P=53.3%), feed rate (P=23.8), cutting speed (P=80.05%). By PCD we get depth of cut (P=38.0%), feed rate (P=10.30%), cutting speed (P=23.01%).

TABLE VII. EFFECT OF DIFFERENT TOOL MATERIAL ON SURFACE ROUGHNESS (R_A)

Cutting Speed r.p.m A	Feed rate mm/rev B	Depth of cut mm C	S/N Ratio Tool 1	S/N Ratio Tool 2	S/N Ratio Tool 3
128	0.10	0.25	-11.25	-7.71	-9.05
128	0.15	0.5	-12.79	-9.57	-7.23
128	0.22	0.75	-9.09	-9.51	-9.10
224	0.10	0.5	-8.06	-7.71	-6.66
224	0.15	0.75	-9.55	-8.56	-6.40
224	0.22	0.25	-12.99	-10.21	-9.86
508	0.10	0.75	-8.79	-7.78	-6.61
508	0.15	0.25	-11.05	-9.21	-6.85
508	0.22	0.5	-8.56	-10.18	-6.87

Following are the graphs which shows the variation of surface roughness with the cutting parameters for different tool materials

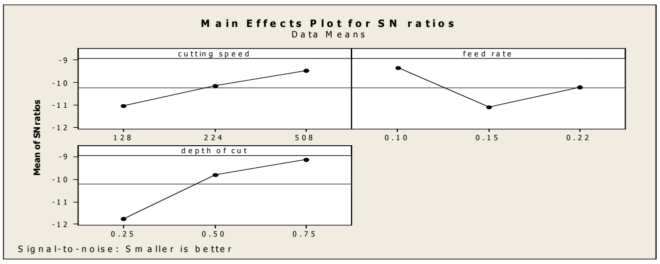

Fig. 5. Main effect plot for S/N of R_a ratio for CC

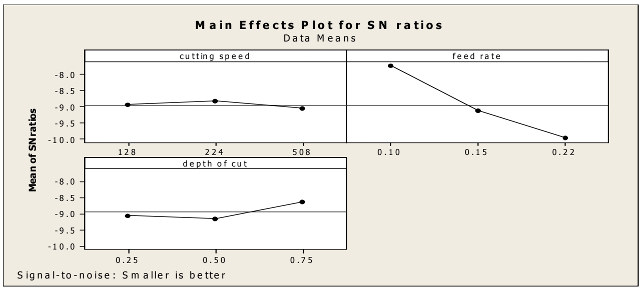

Fig.6. Main effect plot for S/N of R_a ratio for CBN

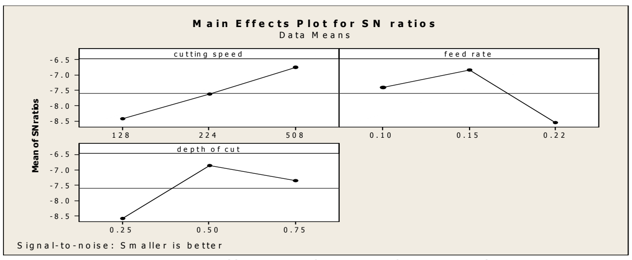

Fig.7. Main effect plot for S/N of R_a ratio forPCD

VI. ANALYSIS OF EXPERIMENTAL RESULTS OF SURFACE ROUGHNESS(R_A)

The experimental data for cutting force with Cemented Carbide, Cubic Boron Nitride, Poly- Crystalline Diamond is given in Table 3. In order to understand the impact of the various control factors on the response of experimental data it is desirable to develop the analysis of the variance (ANOVA) to find the significant factors. The analysis was performed with a level of significance of 5% i.e. level of confidence 95%.

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TABLE VIII. ANOVA TABLE FOR R_A FOR CEMENTED CARBIDE INSERT

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	3.744	3.744	1.687	0.48	40.54
B	2	4.513	4.513	2.256	0.58	67.4
C	2	11.327	11.327	5.663	1.47	55.64
Residual error	2	0.724	0.724	0.362		2.65
Total	8	27.307				

S=1.965, R-Sq = 96.8, R-Sq(Adj) = 84.6%

Table IX. ANOVA table for R_a for CBN insert

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
A	2	0.0891	0.0891	0.04095	0.30	77.1
B	2	7.7235	7.7235	3.8115	27.62	36.5
C	2	0.4815	0.4815	0.24802	1.75	36.4
Residual error	2	0.276	0.276	0.13800		3.26
Total	8	8.4631				

S=0.3715, R-Sq = 96.7%, R-Sq(Adj) = 87.0%

Table X. ANOVA table for R_a for PCD insert

Source	DF	Seq SS	Adj SS	Adj MS	F	P(%)
A	2	4.3021	4.3021	2.150	10.10	90.00
B	2	4.6268	4.6268	2.313	10.86	84.98
C	2	4.7246	4.7246	2.362	11.04	55.08
Residual error	2	0.4260	0.4260	0.213		3.02
Total	8	14.0795				

S= 0.4615, R-Sq= 97.0%, R-Sq(Adj)= 87.9%

With Using Cemented Carbide insert it is observed from the ANOVA Table 14 that the effect of cutting parameters the depth of cut (P=55.64%), feed rate (P=67.46%), cutting speed (P=40.54%). Among these factors feed rate is highly significant.The result obtained by CBN tool, depth of cut (P=36.4%), feed rate (P36.5%), cutting speed (P=77.1). By PCD insert we get depth of cut (P=55.08%), feed rate (P=84.98%), cutting speed (P=90.0%).

VII. CONFIRMATION EXPERIMENT

The confirmation of experiment is a final step in Taguchi analysis for verifying the conclusions from the previous round of experiments especially when the optimum set of parameters and levels are not included in the experimental layout. The optimum conditions are set for the significance parameters and selected numbers of experiment are run under specified conditions. The average of the confirmation experiments results is compared with the anticipated average based parameters levels tested. The confirmation experiment is conducted to validate the inference drawn during the analysis phase. The estimated S/N ratio for cutting force can be calculated with the help of following prediction.

$$\bar{\eta} = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_3 - \bar{T})\,(\bar{A}_2\bar{B}_3 - \bar{T}) - (\bar{A}_2 - \bar{T}) - (\bar{B}_3 - \bar{T}) + (\bar{C}_2 - \bar{T}) \qquad (1)$$

where $\bar{\eta}$ is the predictive average, $\bar{T}$ is overall average and $\bar{A}_2\bar{C}_2$ and $\bar{B}_2$ is the mean response the factors and interactions at desired levels. By combining all the terms equation reduces to

$$\bar{\eta} = \bar{A}_2\,\bar{B}_3 + \bar{C}_2 - \bar{T} \qquad (2)$$

A new combination of factor levels A_2B_3 and C_2 are used to predict the cutting force of the composite turning .

TABLE XI. .RESULTS OF THE CONFIRMATION EXPERIMENT FOR THE CUTTING FORCE TURNING WITH CEMENTED CARBIDE INSERT, CBN,PCD

Level	Optimal control parameters	
	Prediction $A_2B_3C_2$	Experimental $A_2B_3C_2$
S/N ratio for Cemented Carbide insert	-29.8924	-29.2333
S/N ratio for CBN insert	-28.4218	-28.5647
S/N ratio for PCD insert	-22.9259	-22.8967

TABLE XII. RESULTS OF THE CONFIRMATION EXPERIMENT FOR THE SURFACE ROUGHNESS TURNING WITH CEMENTED CARBIDE, CBN AND PCD INSERT

Level	Optimal control parameters	
	Prediction $A_2B_3C_2$	Experimental $A_2B_3C_2$
S/N ratio for Cemented Carbide insert	-9.7352	-10.123
S/N ratio for CBN	-9.2199	-8.4567
S/N ratio for PCD	-7.8284	-7.5454

In case turning with cemented carbide insert an error of 2.20%, with CBN insert 1.85% and with PCD insert an error of 1.27% . similarly in case of surface roughness when turning with cemented carbide insert an error of 2.98%, with CBN insert 1.77% and with PCD insert 1.68%. However if the number of observations of performance characteristics are increased further these errors can be reduced. This validates the statistical approach used for the prediction of the measure of perform based on the knowledge of the input data.

VIII. CONCLUSION

An optimized machining of the polymer composites for turning has been investigated as an objective of the study. The focus was on surface roughness of the polymer composites for turning operation. The major conclusions that can be drawn from the present research are:

- Machining of the E-glass vinylester composite for turning has been investigated as an objective of the study. The focus was on cutting force and surface roughness of the polymer composites for turning operation.
- With increase in feed rate and depth of cut, the cutting force and roughness in turning of the glass vinylester composite are increased. But for a combination of high feed rate and low depth of cut cutting force F_c is found to be minimum.
- From the investigation it has been found that the value of R_a increases with the feed rate and decreases with the cutting speed, i.e. to get better surface finish it is necessary a high cutting speed and a low feed rate.
- PCD insert gives the minimum cutting force and better surface roughness. The cemented carbide insert gives the maximum cutting force and roughness at all combination of the speed, feed and depth of cut.

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- The analysis of variance for experimental data obtauined shows that the errors associated to the ANOVA tables (maximum value 3.48% and minimum 0.626) for all factor which indicates that design of experiments using Taguchi for these experiments gives justifiable analysis statistically.
- The predictive equations developed are successfully used for the prediction of effects of factors on machinability and predicted results are consistent with experimental results.The error in the confirmation experiments show that the difference in experimental and predicted value are within the permitted range. Therefore, the mathematical modeling in this investigation using Taguchi Technique and predictive equations developed are successfully implemented. Also regression model used in the investigation and higher values of R^2 obtained shows the suitability of model used.

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