SURFACE ROUGHNESS INVESTIGATION OF A REINFORCED POLYMER COMPOSITE

George PETROPOULOS*, John KECHAGIAS, Vassilis IAKOVAKIS**, Stergios MAROPOULOS*****
* University of Thessaly, Volos, Greece
**Technological Educational Institute of Larissa, Greece
*** Technological Educational Institute of West Macedonia, Greece

Abstract. The influence of cutting speed and feed rate during turning on the surface roughness of a glass fiber polymer composite (Ertalon 66 GF-30) was experimentally investigated. Test specimens in the form of bars and a P20 cemented carbide cutting tool were used while the cutting depth was kept constant during the experiment. Parameter design using an orthogonal matrix experiment was conducted and the experimental results were analysed using an ANOM and an ANOVA analysis approach. Based on the statistical analysis of the experimental results it was found that the arithmetic mean roughness depends mainly on the feed rate parameter.

Keywords: turning, robust design, parameter design, arithmetic mean roughness

1. Introduction

Fiber reinforced polymer composites constitute an important class of materials in advanced structural applications owing to their light weight, high stiffness and mechanical strength, and are nowadays in competition with metals. They are widely used for manufacture in diverse industrial fields: defence, automobile, space, aerospace and electronics industries [1].

The machinability of an engineering material denotes its adaptability to machining processes in view of factors such as cutting forces, tool wear and surface roughness. Surface roughness plays an important role in product quality and is a parameter of great importance in the evaluation of machining accuracy [2-8]. The surface roughness of parts produced by turning is affected by various factors such as material hardness, tool geometry and cutting parameters [9]. Thus, parameter design for a new material is useful in order to have best performance and consequently decrease the quality loss of a process.

The present study examines the influence of cutting speed and feed rate on the average surface roughness (R_a, μm) of the glass fiber polymer composite (Ertalon 66 GF-30) during turning.

A robust design is adopted in order to decrease the experimental effort. Robust design uses an orthogonal matrix experiment for the parameter design of a process and exploits the orthogonality of the matrix in order to predict the performance of a quality characteristic according to parameter levels.

Additionally, by applying an analysis of means (ANOM) and analysis of variances (ANOVA) on the experimental results, the best combination of parameter levels is obtained and the effect of each process parameter on the average surface roughness is revealed [10, 11, 12].

Finally, interactions between the process parameters are examined and a regression model is adopted for surface roughness predictions.

2. Experimental set up

The composite used for cutting is specified as ERTALON 66- GF30 (PA 66-GF 30) (black).

The test specimens were in the form of bars 150mm in diameter and 500mm in length. They were carefully clamped on the headstock and a tailstock was used, considering the reduced elasticity modulus of the polymer matrix. The cutting tool material was a P20 cemented carbide of the throwing insert type and of square form. The clearance angle was α= 5°, the tip radius 0.8 mm and the rake angle $\gamma = +6^o$.

The average surface roughness (R_a, μm) was measured using the Surtronic 3^+ stylus profilometer.

A two parameter experiment was designed each having three levels (Table 1). The standard $L_9(3^4)$ orthogonal matrix experiment (Table 2, [10]) was used. Columns 1 and 2 are assigned to cutting speed (V) and feed rate (f), while columns 3 and 4 were left vacant. These columns were used to calculate the error of the process.

Table 1. Parameter Design

Parameters	Level 1	Level 2	Level 3
Cutting speed (V) m/min	100	200	400
Feed rate (f) mm/rev	0.05	0.16	0.32

Table 2. Orthogonal Array $L_9(3^4)$

	Column			
No of Exp	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3. Experimental results

Based on robust design [10], the standard orthogonal array $L_9(3^4)$ has been selected in order to perform the matrix experiment (Table 3).

Table 3. Matrix experiment

Exp. No	Process Parameter				R_a (μm)
	V	f	Vacant	Vacant	
1	100	0.05	1	1	1.301
2	100	0.16	2	2	3.257
3	100	0.32	3	3	9.223
4	200	0.05	2	3	1.973
5	200	0.16	3	1	3.490
6	200	0.32	1	2	6.523
7	400	0.05	3	2	2.113
8	400	0.16	1	3	3.833
9	400	0.32	2	1	9.673
Mean (m)					4.598

Three levels for each factor were selected (Table 1). Following the $L_9(3^4)$ orthogonal array nine experiments were performed with each experiment producing a test part which was tested for average surface roughness (R_a, μm).

For each process parameter V and f an average R_a for every value (level) was calculated (Table 4).

Table 4. Mean parameter values

Mean parameter values	Level 1	Level 2	Level 3
m_{Vi}	4.594	3.995	5.206
M_{fj}	1.796	3.527	8.473

Based on the average values, an analysis of means (ANOM) diagram (Figure 1) is constructed indicating the impact of each factor level on the average surface roughness of the parts produced.

Thus, based on the ANOM, one can derive the optimum combination of process variables, with respect to R_a, as a constraint of quality. The optimum level for a factor is the level that gives the minimum value of R_a in the experimental region.

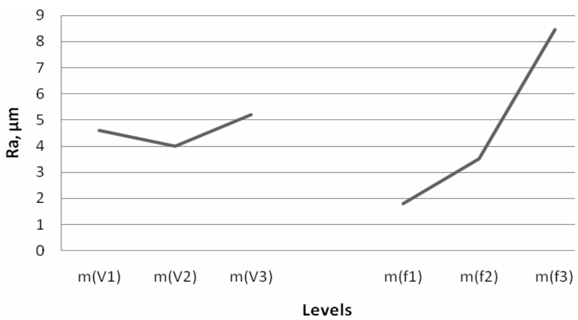

Figure 1. ANOM diagram

According to the ANOM diagram the feed rate plays the most important role on the average surface roughness and gives the best performance when it takes the level 1 value (0.05mm/rev).

Robust design performs an analysis of variables (ANOVA) of the experimental results in order to evaluate the relative importance of the process parameters and error variances. The ANOVA analysis results can be seen in Table 5.

Figure 2 shows the influence of each factor on the average surface roughness of the turning process. According to the ANOVA analysis the feed rate influences the surface roughness by 91.9 percent and the cutting speed by 2.8 percent.

The variance of the effect of each factor level for this case is:

$$\frac{1}{3}\sigma_e = \frac{1}{3}(1.037466) = 0.345822 \qquad (1)$$

thus, the width of the two standard deviation confidence intervals, which is approximately 95 percent the confidence interval for each estimated effect, is:

$$e(\mu m) = \pm 2\sqrt{1.037466} = \pm 1.176 \qquad (2)$$

Table 5: ANOVA analysis

Proc. par.	Deg. of Fr. (DoF)	Sum of Sq. (SoS)	Mean Sq. (MS)	F	Perc. %
V	2=(3-1)	2.19 (i)	1.09 (ii)	1.06 (vi)	2.8 (vii)
f	2=(3-1)	72.04	36.02	34.7	91.9
Total	8=(9-1)	78.39 (iii)			
Error	4= (8-2-2)	4.14 (iv)	1.03 (v)		

(i) $SoS_V = 3(m_{V1} - m)^2 + 3(m_{V2} - m)^2 + 3(m_{V3} - m)^2$

(ii) $MS_V = \dfrac{SoS_V}{DoF_V}$

(iii) $SoS_{Total} = \sum_{i=1}^{9}(Ra_i - m)^2$

(iv) $SoS_{Error} = SoS_{Total} - SoS_V - SoS_S$

(v) $MS_{Error} = \dfrac{SoS_{Error}}{DoF_{Error}}$

(vi) $F_V = \dfrac{MS_V}{MS_{Error}}$

(vii) $Percentage_V = \dfrac{SoS_V}{SoS_{Total}}\%$

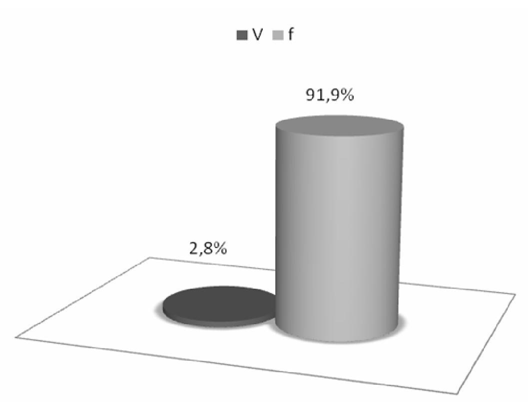

Figure 2. Factors percentage influence

According to robust design [10], the interaction between two or more parameters can be classified as:

(i) no interaction,

(ii) synergistic interaction, and

(iii) antisynergistic interaction.

Figure 3 shows the interaction type between the feed rate (f) and the cutting speed (V). The almost parallel lines without a change in the direction of improvement suggests that when the feed rate is changed from 0.05 to 0.16 or 0.32 mm/rev the corresponding change in R_a is almost the same regardless of the level of the cutting speed (V). Thus, it can be concluded that there is a slight 'synergistic interaction' between the two parameters.

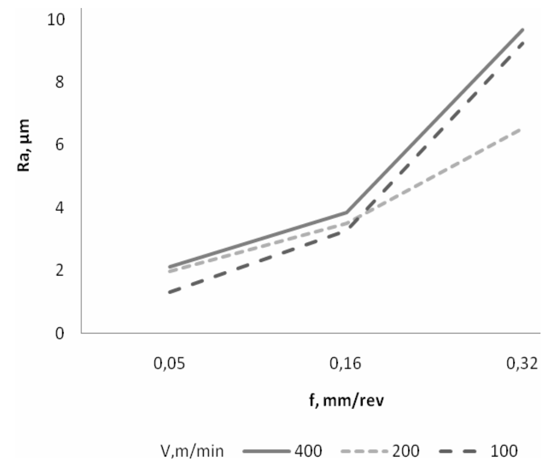

Figure 3. Interaction chart

A regression model with the cross product Vf is needed in this case in order to describe the variation of R_a in terms of process parameters.

Table 6. Mean parameter values (with product Vf)

Mean parameter values	Level 1	Level 2	Level 3
m_{Vi}	4.594	3.995	5.206
M_{fj}	1.796	3.527	8.473
M_{Vfk}	3.885	4.967	4.942
m_{el}	4.821	3.964	5.009

Assuming that the process parameters are continuous and controllable in the experimental region, the response can be expressed as follows:

$$Ra = b_1 + b_2V + b_3f + b_4Vf \pm e \qquad (3)$$

where, R_a is the response of surface quality, b_i, coefficients, which should be determined, and e is the error which is expected to be less than ±1.176μm while the cross product Vf was introduced to the regression model. In general, equation (3) can be written in a matrix form:

$$Y = bX + E \qquad (4)$$

where, Y is defined to be a matrix of measured values and X to be a matrix of process parameters and their products. The matrices b and E consist of coefficients and errors, respectively. The solution of equation (4) can be obtained by a matrix approach.

$$b = (X^T X)^{-1} X^T Y \quad (5)$$

where, X^T is the transpose of matrix X and $(X^TX)^{-1}$ is the inverse of the matrix (X^TX).

From the observed data listed in Table 3 and equation (5), eq. 3 can be written as:

$$Ra = -0.2713 + 0.0018069V + 24.11f + 0.004577Vf \pm 1.114 \quad (6)$$

The error e is calculated by inserting the cross product terms fV and e in the vacant columns 3 and 4, respectively (Table 3), and then performing an ANOM and ANOVA analysis (Table 6 and Table 7).

Table 7: ANOVA analysis (with product SV)

Proc. par.	DoF	SoS	MS	F	%
V	2	2.19	1.099	1.1	2.8
f	2	72.04	36.02	38.6	91.9
Vf	2	2.28	1.14	1.2	2.9
e	2	1.86	0.93		
Total	8	78.39			
Error	2	1.86	0.93		

Six experiments were undertaken to evaluate Eq. 6. The results are presented in Table 8.

Table 8:Evaluation experiments

Exp.	Parameters			Ra, μm		Error
No	V	f	Vf	Predicted	Actual	%
1	100	0.1	10	2.366	2.237	5.8
2	100	0.2	20	4.822	5.237	-7.9
3	200	0.1	20	2.592	2.447	6.0
4	200	0.2	40	5.095	5.390	-5.5
5	400	0.1	40	3.045	2.193	38,9
6	400	0.2	80	5.639	5.387	4,7

The evaluation experiments show that the regression model gives a good approximation of the average surface roughness.

4. Conclusions

An investigation of the influence of the feed rate and the cutting speed on the average surface roughness of Ertalon 66 GF-30 composite during turning was carried out.

The experimental results show that the most important parameter concerning the average surface roughness on turning of Ertalon 66 GF-30 composite was the feed rate (91.9 percent). In specific, when the feed rate was gradually increased the surface became rougher. The cutting speed was found to exert a weak effect on the average surface roughness (2.8 percent). The error of the process according to the robust design was ±1.114μm. The best result was obtained when the feed rate was set at 0.05mm/rev and the cutting speed at 200m/min, levels 1 and 2 respectively.

Finally, the regression model, which was extracted from the experiments conducted, provided good approximations when evaluated by six independent experiments.

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