SURFACE ROUGHNESS PARAMETERS MODEL FOR MACHINING GFRP COMPOSITES BY CEMENTED CARBIDE TOOLS

Palanikumar K.[1], Mata F.[2], Paulo Davim J.[3]
[1]Department of Mechanical & Production Engineering, Sathyabama University, Chennai, India
[2]Polytechnic School of Almaden, University of Castilla-La Mancha, Plaza Manuel Meca, Almaden, Spain
[3]Department of Mechanical Engineering, University of Aveiro, Campus Santiago, Aveiro, Portugal
E-mail: [1]palanikumar_k@yahoo.com

Abstract

Glass Fiber Reinforced Plastics (GFRP) is finding increased applications in various fields of mechanical engineering, due to their good properties such as high strength, high stiffness and light weight. The application fields include automobile, biomechanics and aerospace industries. The good properties and potential applications necessitate machining of these composite materials. Though many investigators worked on machining of GFRP composites, the work on the effect of machining parameters on surface roughness parameters is minimum. In the present paper the influence of main cutting parameters and their interactions on surface roughness parameters (R_a, R_t, R_q, R_p and R_{3z}) in turning of glass fibre reinforced composite materials is investigated. The parameters considered for the investigation are: cutting speed and feed. Models were developed to correlate the machining parameters with surface roughness parameters. The adequacy of the models was checked by *R-Sq* values. The effect of parameters was evaluated by using main effect graphs and interaction graphs. The results indicates that the increase in feed mainly influence the surface roughness parameters in machining of GFRP composites.

Key words: Fibre-reinforced plastics, turning, surface roughness parameters, model.

I. INTRODUCTION

Glass fiber reinforced plastics are one of the important composite materials. With the increasing use of these materials outside the defense, space and aerospace industries, namely, civilian industries, machining of these materials is assuming a significant role (Bhatnagar etal, 1995). Their own properties, particularly the high strength, high stiffness and simultaneously low weight, allow substitution for metallic materials in many cases.

The use of GFRP´s requires the development of suitable processes and machining is assuming a significant role of manufacture. Various machining techniques are made to obtain the mechanical pieces, with rigorous dimensional characteristics and correct surface roughness. Turning is a commonly used machining operation in the industry. Mating surfaces for many tribological applications are processed currently by turning operations (Petropoulos and Pandazaras, 2003). Therefore, modelling of the turning database to associate cutting parameters with cutting performance is very important for the industry (Lee et al., 2000). The cutting of GFRP´s is made difficult due to delamination in composite materials and short tool life (Sang-Ook et al, 1997). It is therefore necessary to asses the influence of cutting parameters to ensure a satisfactory result from the machining (Eriksen, 1999).

Surface roughness is an important topic in manufacturing engineering for controlling produced components. It is a characteristic that could influence the performance of mechanical pieces and the production costs. In the field of engineering, the exact degree of roughness can be of considerable importance, affecting the functioning of a component (Abouelatta and Mádl, 2001). Surface roughness is a widely used index for product quality and in most cases; it is a technical requirement for mechanical products, especially in contact mechanics (Person, 1999; Bernardos and Vosniakos, 2003; Petropoulos and Pandazaraz, 2003), because the essential tribological aspects (friction, wear, state of lubrication) are highly dependent. For these reasons, research had been carried out with the objective of optimizing the cutting parameters to obtain a determined surface roughness (Eriksen, 1999; Abouelatta and Mádl, 2001). For achieving the desired surface roughness, it is necessary to understand the mechanisms of material removal and the kinetics of machining processes affecting the performance of cutting tools (Sreejith et al, 2000).

Different works carried out on turning of glass fiber reinforced plastics concluded that the surface roughness increased with the feed rate and decreased with the cutting speed (Davim and Mata, 2004 and 2005a), and confirmed surface roughness is an important machinability parameter for these materials, which is closely associated with quality, reliability and functional performance of components (Davim and Mata, 2005b and 2007).

When GFRP composites are machined, it is clearly seen that the fibers are cut across and along their lay direction, leaving deformed projecting and partially disclosed fibers on the machined surface (Santhanakrishnan et al, 1988). Eriksen (1999) has enumerated guidelines for the machining of short fiber-reinforced thermoplastics (SFRTP). Wang et al, (2003) carried out an experimental investigation on the orthogonal cutting of unidirectional fiber reinforced plastics and concluded that surface roughness, subsurface damage and cutting forces all change dramatically with fibre orientation. Spur and wunsch (1988) found that during turning of GFRP composites surface roughness increases with increase of feed rate but no dependence on the cutting velocity. In contrast to the above, Ramulu et al, (1994) achieved better surface roughness at high velocity, so the machining of FRP is an area still with full of open question.

Most of the studies on GFRP composite machining shows that minimizing the surface roughness was a serious task. In order to know surface quality and dimensional properties, it is necessary to employ theoretical models for prediction purpose. In the present study, models have been developed for surface roughness parameters (R_a, R_t, R_q, R_p and R_{3z}) in machining of GFRP composites. Even though R_a is the commonly-used surface roughness parameter, in this study R_a, R_t, R_q, R_p and R_{3z} are considered for analysis. Two different composite pipes manufactured through hand lay-up and filament winding are considered for experimentation. In machining of GFRP composites, depth of cut does not influence the surface roughness and hence cutting speed and feed are considered as cutting parameters. In machining of composites, vibration on machine tool, tool rake angle and tool nose radius also influence the surface roughness, which are not considered in this study. In this study the influence of cutting parameters and their interactions in machining of GFRP composites is analysed in detail.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

Experiments were conducted on lathe. GFRP tubes (polyester matrix reinforced with 65 % of glass fiber) were used for tests. Two different composite pipes manufactured through hand lay-up (HLU) and filament winding (FW) are considered for experimentation. The different orientation angle of fibres in both cases can be seen in Fig. 1.

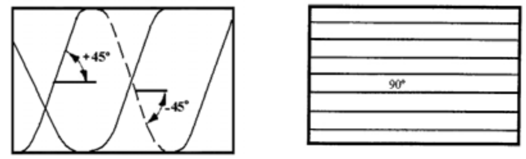


Fig. 1(a). Tubes produced by wet filament winding with a fiber orientation of 45 degrees and Fig. 1(b). by hand lay-up with a fiber orientation of 90 degrees.

The experiments were carried out in tubes of diameters 110 and 113 mm with wall thickness of 4 mm and 6 mm, respectively. A CNC lathe (MHP KINGSBURY) with 18.7 kW spindle power and maximum speed of 4500 rpm was used for the experiments. In order to hold the tube, a rigid system of fixation was designed, that eliminates the vibrations and allows obtaining good results. The fixation system consists of screwing the tube to a massive aluminium bar as shown in Fig. 2.

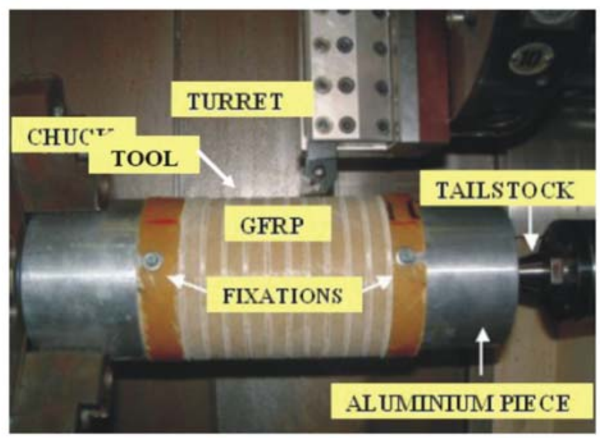


Fig. 2. Fixation system of GFRP.

The plan of test was developed without refrigeration and contemplates the nine combinations between three values of cutting speed (100, 200, 400) (m/min) and three values of feed (0.05, 0.1, 0.2) (mm/rev). A constant depth of cut of 0.5 mm was used.

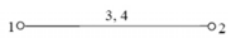
Table 1. Factors studied and assignment of the levels to the factors

Level	Cutting speed, V (m/min.)	Feed, f (mm/rev.)
1	100	0.05
2	200	0.10
3	400	0.20

Table 1 shows the factors studied and the assignment of the corresponding levels. Levels referred to the values taken by the factors. For experimentation L_9 (2^4) orthogonal array shown in

Table 2. Orthogonal array L_9 (2^4) and linear graph

Experiment No.	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



Linear graph (L_9 (2^4)

Table 2 was chosen, which had 9 rows corresponding to the number of tests. In L_9 orthogonal array, the first column was assigned to the cutting speed (V) and the second column to the feed (*f*) and the remaining were assigned to the interactions according to L_9 linear graph.

` In machining, the increase of positive rake angle increases the surface finish. As the rake angle is increased in the positive direction, the normal force between the chip and the tool is reduced and the formation of built-up edge also reduced (Sadasivam and Sarathy, 1999). The positive clearance angle reduces rubbing against the work. The positive cutting edge angle increases tool life, diminishes chip thickness for the same amount of feed and it dissipates heat quickly which leads to better surface finish (Choudhury et al, 1985). Because of the above facts, a cemented carbide (K15) tool (TPGN 16 03 04 H13A) with a tool geometry of rake angle 6º, clearance angle 11º, edge major tool cutting 91º and cutting edge inclination angle 0º are used. The tool holder used for the experimentation is of the type CTGPL 20 20 K16 (ISO). The geometry of the cutting tool is selected based on the recommendation of the cutting tool manufacturer. With positive rake angle and inclination angle, it is possible to obtain easy cutting.

The surface roughness is evaluated (according to ISO 4287/1) using Hommeltester T1000 profilometer. For each palpation 5 measurements are taken over turning surfaces parallel to the axis of the pipes. Considering the high number of palpations, a programmable technique is used, by previously selecting a roughness profile, the cut-off (0.8mm) and surface roughness parameters R_a, R_t, R_q, R_p and R_{3z}. Data acquisitions are made through profilometer, by interfacing RS-232 to PC using the software Hommeltester Turbo-Datawin®.

III. RESULTS AND DISCUSSION

Surface roughness plays an important role for any component. Achieving of best surface on the composite materials is difficult due to their anisotropic properties. During machining, the cutting parameters such as cutting speed and feed are the main parameters which affect the surface profile of the GFRP composite workpiece. Depth of cut plays only a minor role in machining of GFRP composites [Sang-Ook et al, 1997; Palanikumar et al, 2006). The effect of cutting parameters such as cutting speed and feed rate on different surface roughness parameters for machining of GFRP composites is analysed and the results are given below:

A. Models for surface roughness parameters

Most of the studies on GFRP composite machining show that minimizing the surface roughness is a serious task. In order to know the surface quality and dimensional properties, it is necessary to employ theoretical models for prediction purpose. For prediction, the response surface method (RSM) is used and is practical, economical and relatively easy of use (Sahin and Motorcu, 2004). For example, Sahin et al, (2008) investigated the use of RSM in developing a surface roughness model for machining mild steel. Modeling of cutting parameters such as cutting speed and feed with respect to surface roughness parameters for machining GFRP composites is carried out through response surface regression method. Response surface methods are used to examine the relationship between a response and a set of quantitative experimental variables or factors (Montgomery, 1991). In the present work response surface regression is used for making the models. The regression equation is an algebraic representation of the regression line and is used to describe the relationship between the response and predictor variables. The regression equation takes the form of (Minitab, 2003):

Response = constant + coefficient (predictor) + … + coefficient (predictor) (1)

$$\text{or } y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k \quad (2)$$

For the machining experiment, representing the surface roughness parameters R_a, R_q, R_p, R_t and R_{3z} of the GFRP composite "*R*", the response surface regression model can be expressed as

$$R = \beta_0 + \beta_1 (A) + \beta_2 (B) + \ldots + \epsilon \quad (3)$$

where A, B, … are variables representing different machining parameters and interaction between the parameters. The β's are regression coefficients and Є represent error associated with the model. In the present case, the model chosen includes the effects of two main factors (A, B) and interaction between these parameters (AB). The model selected is expressed as follows:

$$R = \beta_0 + \beta_1 (A) + \beta_2 (B) + \beta_3 (AB) \quad (4)$$

where β_0 = constant and

β_1, β_2 and β_3 are co-efficients of factors and their interaction. The models developed for hand lay-up made composites and filament winding composites are presented as follows:

For hand lay-up made (HLU) composite pipes

$R_a = 0.535 + 0.00178*V + 7.30*f - 0.01949*Vf;$ R-Sq = 66.70% (5)

$R_q = 0.93250 + 0.00116*V + 9.8500*f - 0.01409*Vf;$ R-Sq = 79.44% (6)

$R_p = 0.1575 + 0.0043*V + 43.9214*f - 0.0883*Vf;$ R-Sq = 80.32% (7)

$R_t = 1.3875 + 0.0086*V + 73.0357*f - 0.1113*Vf;$ R-Sq = 90.21% (8)

$R_{3z} = 10.4875 + 0.0026*V + 18.4643*f - 0.0264*Vf;$ R-Sq = 73.60% (9)

where V = cutting speed in m/min and f = feed in mm/rev.

For filament winding (FW) made composite pipes

$R_a = 2.2325 - 0.0016*V + 13.5214*f - 0.0034*vf;$ R-Sq = 93.89% (10)

$R_q = 2.4325 + 0.0005*V + 23.6357*f - 0.0413*Vf;$ R-Sq = 80.72% (11)

$R_p = 2.8250 + 0.0237*V + 78.6286*f - 0.1870*Vf;$ R-Sq = 61.78% (12)

$R_t = 11.213 + 0.020*V + 215.821*f - 0.358*Vf;$ R-Sq = 63.79% (13)

$R_{3z} = 12.8825 - 0.0105*V + 16.0786*f + 0.0581*Vf;$ R-Sq = 84.59% (14)

where V = cutting speed in m/min and f = feed in mm/rev.

The quantity *R-Sq* is used to judge the adequacy of regression models developed. *R-Sq* gives the amount of variation in the observed response values that is explained by the predictor. Normally, the *R-Sq* value is the variability in the data accounted for by the model in percentage (Montgomery, 1991). The *R-Sq* values are calculated and are above 60% for all the models developed, from which it is evident that good correlation exists between the experimental and predicted values.

B. Analysis of experimental results

The surface texture of GFRP composites mainly depends on flexibility, orientation of fibre in the matrix and toughness of the fibers. From the published results, it is known that the mechanism of cutting GFRP composites is due to the combination of plastic deformation, shearing and bending rupture (santhanakrishnan et al, 1990). Machining of composites differs in many respects from that of metals. The behaviour of composites is heterogeneous and depends upon the fiber and matrix properties, orientation of fibers, bond strength between fiber and matrix, and the type of weave (Tandon et al, 1990; Palanikumar, 2004). The effect of cutting parameters namely cutting speed and feed rate can be analysed through area graphs, main effect graphs and interaction graphs.

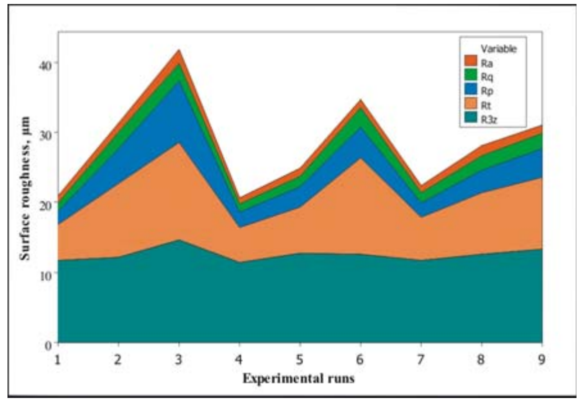


Fig. 3. Area graph for surface roughness parameters with respect to experiment number for hand lay-up process

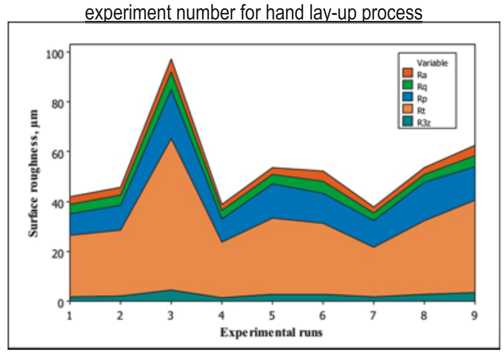


Fig. 4. Area graph for surface roughness parameters with respect to experiment number for filament winding process

Fig. 3 and 4 shows the area graph for surface roughness in machining GFRP composites by K15 tool. The area graphs are used to evaluate the trends in multiple variable series as well as each series contribution to the sum. The effect of cutting speed on surface roughness parameters R_a, R_q, R_p, R_t, and R_{3z} for hand lay-up made composite pipes is presented in Fig. 5

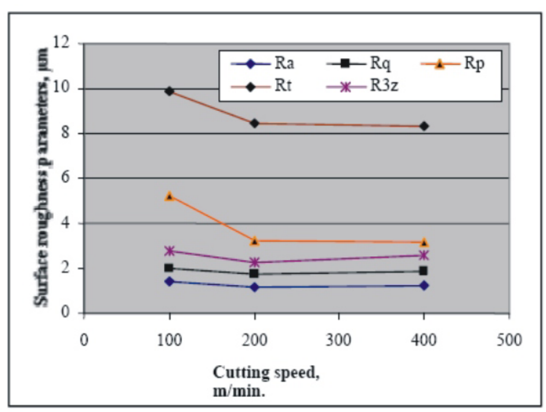


Fig. 5. Effect of cutting speed on surface roughness parameters for hand lay-up made GFRP composites.

From the figure it can be noticed that all the surface roughness parameters are showing the same tendency. The maximum surface roughness is observed at minimum cutting speed. The surface roughness parameters observed at 100 m/min. is more than the surface roughness parameters at 200 m/min. Further increase of cutting speed does not show considerable effect in surface roughness parameters and hence middle level cutting speeds are preferred for machining of hand lay-up made GFRP composites using K15 tool.

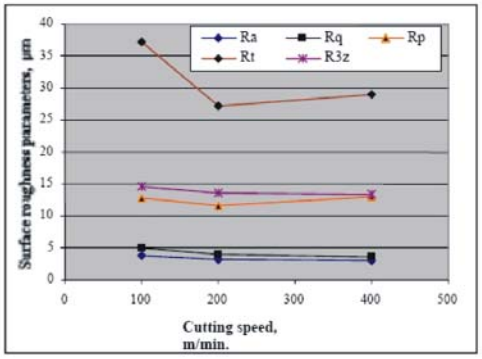


Fig. 6. Effect of cutting speed on surface roughness parameters for filament winding made GFRP composites.

Fig. 6 shows the effect of cutting speed on surface roughness parameters for machining of filament winding composites. Filament winding composites also show almost same tendency as that of hand lay-up made composites. But the variation in surface roughness parameters is comparatively high.

The effect of feed rate on surface roughness parameters R_a, R_q, R_p, R_t, and R_{3z} for hand lay-up made GFRP composite is presented in Fig. 7.

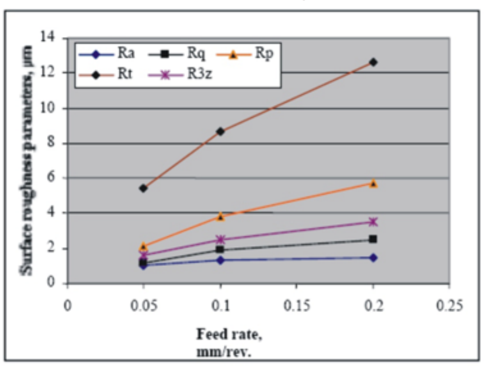


Fig. 7. Effect of feed rate on surface roughness parameters for hand lay-up made GFRP composites.

The figure indicates that the surface roughness parameter increases with increase in feed rate. The observed surface roughness parameters are less at 0.05 mm/rev. It increases steadily upto 0.1 mm/rev. Further increase of feed rate increase the surface roughness parameters at a higher rate. Filament-winding composite also shows almost the same tendency, as shown in Fig. 8.

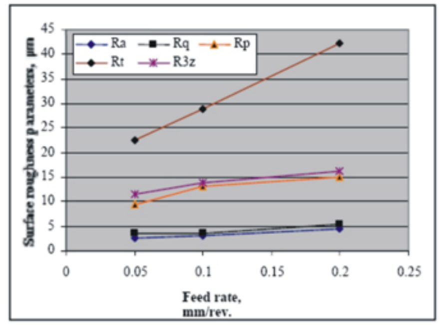
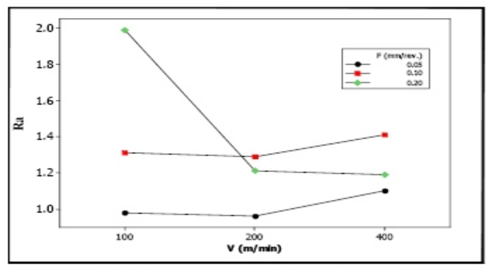
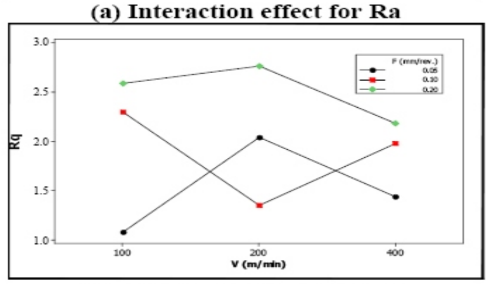


Fig. 8. Effect of feed rate on surface roughness parameters for filament winding made GFRP composites.

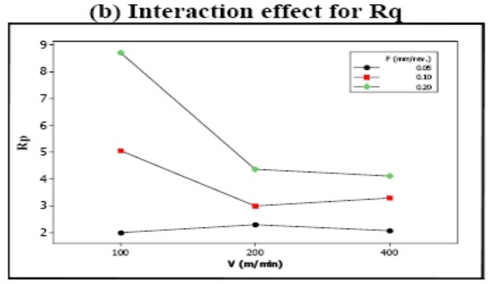
In machining of composites, interaction between the parameters also plays some role in deciding the surface roughness. The interaction between cutting speed and feed rate on surface roughness parameters R_a, R_q, R_p, R_t, and R_{3z} in machining of hand lay-up made GFRP composite is presented in Fig. 9.



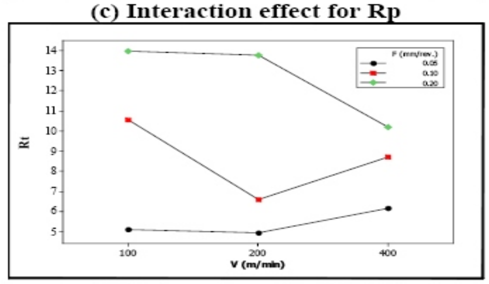
(a) Interaction effect for Ra



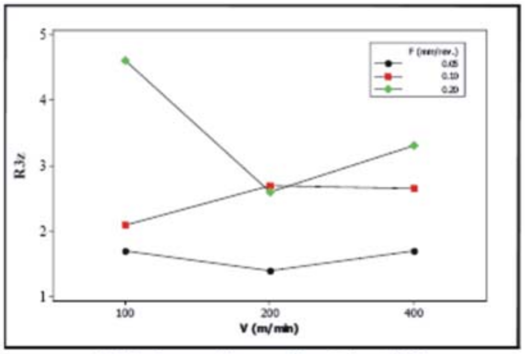
(b) Interaction effect for Rq



(c) Interaction effect for Rp



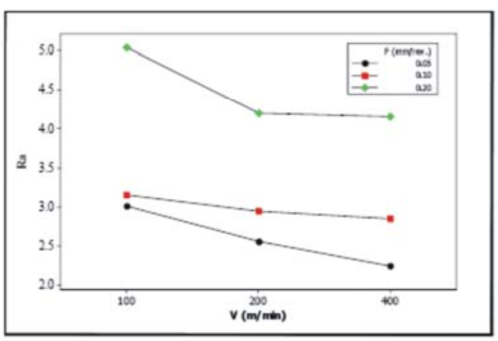
(d) Interaction effect for Rt



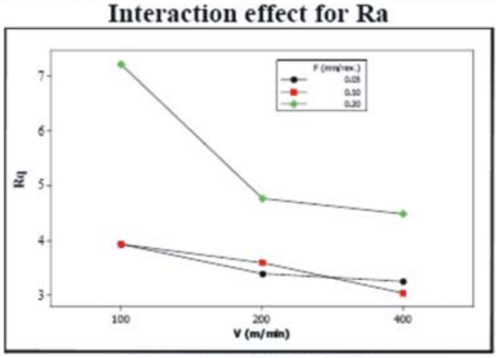
(e) Interaction effect for R3z

Fig. 9. Interaction effect of cutting speed and feed on different surface roughness parameters for hand lay-up made composites.

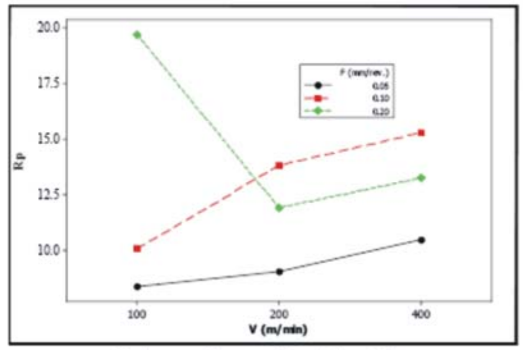
The figure shows that the best surface roughness could be arrived only at medium speed. In some instance, variation in tendency is observed between the surface roughness parameters. This variation may be due to insufficient distribution of fibres in the matrix materials and/or protruding fibres to the stylus point of the surface roughness meter. It can be avoided by taking more number of readings. The interaction between the parameters cutting speed and feed rate on surface roughness parameters R_a, R_q, R_p, R_t, and R_{3z} for machining of filament-winding composite pipe is shown in Fig. 10. The interaction effects for different parameters are almost same as that of the hand lay-up process.



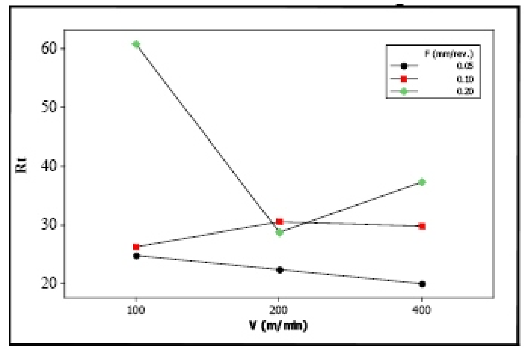
Interaction effect for Ra



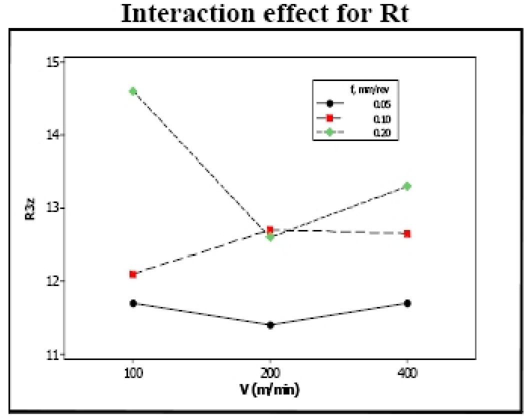
Interaction effect for Rq



Interaction effect for Rp



Interaction effect for Rt



Interaction effect for R3z

Fig. 10. Interaction effect of cutting speed and feed on different surface roughness parameters for filament-winding composites.

IV. CONCLUSION

Experiments are conducted for analysis of surface roughness parameters (R_a, R_t, R_q, R_p and R_{3z}) in machining glass fibre reinforced composite materials manufactured by filament winding and hand lay-up process using K15 tool. The conclusions drawn are as follows.

- Models are developed for predicting surface roughness parameters in machining GFRP composites manufactured through hand lay-up and filament winding processes. The cutting parameters used are cutting speed and feed rate.

- The adequacies of the developed models are checked by using *R-Sq* values and are satisfactory and hence the developed models can be used for the prediction of surface roughness parameters. The effectiveness of the models are only within the limits of factors studied.
- The experimental results are analyzed using graphs. The results indicate that the increase of cutting speed reduces the surface roughness and vice versa for both hand lay-up made composites and filament winding composites.
- The results also indicate that the surface roughness parameters increases with the increase of feed almost linearly.
- The comparison between the experimental results indicate that the hand lay-up made composite pipes produce better surface roughness than filament winding made pipes for machining FRP composites.
- The interactions between the parameters also have some effect on the surface roughness in machining of GFRP composites, since the lines are not parallel to each other.

NOMENCLATURE

β_0, β_1, β_2 ...	Coefficients
V	Cutting Speed, m/min.
f	Feed rate, mm/rev.
HLU	Hand Lay-Up
FW	Filament winding
R-Sq	Coefficient of determination
R_a	Arithmetic average height, µm
R_q	Root mean square roughness, µm
R_p	Maximum height of peaks, µm
R_t	Maximum height of the profile, µm
R_{3Z}	Mean of the third point height, µm

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Dr. K. Palanikumar is a Professor and Head of the Department of Mechanical and Production Engineering at Sathyabama University, Chennai.