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Investigation on the Turning Parameters for Surface Roughness using Taguchi Analysis

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Abstract

One of the important interests in the machining is attaining better surface roughness as well as dimensional accuracy. Polymer materials are continuously displacing the conventional materials. Their machining behavior is different in many aspects from machining of conventional metallic materials. Polymer based composite materials have superior properties for mechanical strength and stiffness, such as high strength-to-weight ratio and high stiffness-to-weight ratio. Fiber reinforced polymer composite materials are the one which are produced closer to the required shape, further machining is often necessary to achieve expected surface characteristics. This experimental study targets the machining of carbon fiber reinforced polymer material made into the form of tube. It examines various process parameters such as cutting speed, feed and depth of cut and their importance in deciding the surface roughness. Surface roughness was measured after machining is carried out under specified machining conditions. This experimental study focuses on the prediction of machining parameters that yield better surface characteristics in order to avoid machining of hard materials such as fiber reinforced composite materials so that enormous money spent in machining could be saved to some extent. For prediction this experimental study makes use of response surface methodology. The Taguchi method is used to solve many engineering problems. This work uses the Taguchi's orthogonal array method to find out the number of experiments to be carried out for turning operations. Also the analysis of variance is used to investigate the cutting parameters. In addition to the optimal cutting parameters for turning operations, the main cutting parameter that affect the cutting performance in turning operations could be found out.

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Nomenclature

R_a	Surface roughness (µm)
V	cutting speed (m/min)
f	feed (mm/rev)
d	depth of cut (mm)
T	tool nose radius (mm)

1. Introduction

Achieving desired quality on a machined surface itself is a general problem faced by engineers and scientists in manufacturing sector. In specific, achieving it within the prescribed limitations on machine tool, cost involved in machining and time spent in machining is seldom achieved [1]. Further it will be difficult to achieve some quality characteristics such as surface roughness. Because, there are many factors those govern the surface roughness of any machined component. The factors may include but not restricted to work piece material, cutting tool material, cutting tool nomenclature, machining parameters such as cutting speed, feed and depth of cut, condition of machine, coolant, environmental condition, precision of machine tool, etc., but machining parameters are the easiest factors that may be adjusted so as to attain a closer expected performance.

The above mentioned discussion is valid only for conventional materials like metals which are homogeneous and isotropic. Homogeneous means same density in all directions and isotropic means same properties in all directions. Machining and attaining required surface roughness on unconventional materials such as fiber reinforced materials which includes polymer matrix composites, ceramic matrix composites and metal matrix composites, etc., is difficult [2, 3]. The reason for this difficulty is their nature in which they are made. A composite material may 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'[4]. Matrix is of ductile in nature and fiber is of brittle in nature. Matrix is to transport the load and the fiber is to carry the load which acts on the material Matrix and fiber may be with any composition by which it could be made. Depending upon the composition their properties, performance varies. This leads to an uncertainty on their performance.

The components manufactured by carbon fiber reinforced polymer (CFRP) composites require machining to attain desired surface characteristics [5]. Surface quality is always accompanied with the surface roughness which can be determined by measuring arithmetic average of surface roughness. Surface roughness is defined as the surface irregularities found on the surface of machined material after a machining operation is carried out. The surface roughness is represented by the symbol, Ra. The surface roughness is considered so important because it decides the reliability of machined component in high strength applications, it severely affect the strength and chemical resistance of the materials [6].

Significant influence of surface roughness is realized on solid bodies particularly at their contact regions due to contact stresses, wear, and friction and lubrication conditions [7]. Surface roughness is found to be a key design feature in many applications, which includes fasteners, aesthetics parts, precision fits and parts which are subjected to fatigue loads [8]. One of the reasons for the composite materials contain more surface roughness on its machined surface is due to its inhomogeneity. That is varying properties at different points. Composite materials are more flexible in structural design due to their higher specific strength stiffness and fatigue limit [9].

Many researchers have worked on CFRP machining and study on the effect of their machining parameters. First theoretical work was taken up on fiber reinforced polymer FRP by Everstine and Rogers [10] on plane deformation, which was intended to find out the distribution of stress and displacement when machining. The surface quality of machined FRP material is determined by the fiber, matrix material in which the fiber is reinforced and the strength of bonding between them. Birhan Isik [11] carried out experimentation to investigate the surface roughness of unidirectional fiber reinforced plastic composites with the cermets cutting tool and expresses his concluding remark that the influence of depth of cut have only a least significant influence on surface roughness, but the cutting speed and feed rate.

When Palanikumar [12] conducted experiments and carried out analysis on the effect of cutting parameters to examine the surface roughness by using Taguchi method it was noticed that the feed rate played a key role. Palanikumar et al. [13] attempted to do turning operation with two types of FRP tubes, of which one is made by hand lay up process and the other by filament winding process, with the help of PCD tool, comes out with the findings that the surface roughness goes up when feed rate is increased, but it falls down with the cutting speed. Authors also have attempted to conduct experiment on carbon fiber reinforced polymer composites using various machining conditions with the help of different cutting tool materials [14,15]

This experimental study focuses on the determination of process parameters and their combination for better surface roughness in machining carbon fiber reinforced polyester (CFRP) composites. This study uses Taguchi's methodology which includes orthogonal array for carrying out experimentation and signal to noise ratio to identify the trend of process parameters and the highly influential parameter.

2. Method of experimentation

The objective of this experimental study was to determine the influence of cutting parameters on carbon fiber reinforced polyester resin when carrying out turning operation. Carbon fiber in the form of roving is reinforced by dipping into the polyester resin and filament wound with the orientation angle of 45° alternatively to produce a cylindrical tube. An unsaturated polyester resin was used by adding suitable hardener and accelerator. The CFRP composite material specimen used for conducting turning experiments is shown in the Figure 1

Figure 1. CFRP composite material used for experimentation

The cutting tool used was cubic boron nitride (CBN), which is shown in Figure 2. These tools are generally used for machining harder materials specifically for the finish hard turning, alloy steels, high speed tool steels, die steels, bearing steels, case-hardened steels, etc., [16, 17].

In the phase of designing machining parameters three important parameters namely cutting speed, feed and depth of cut were chosen though there are many that are affecting surface roughness. The cutting conditions used for machining composite material and their levels were provided in the Table 1.

Table 1. Machining conditions and their levels

Levels	Cutting speed (*m/min*)	Feed (mm/rev)	Depth of cut (mm)
1	100	0.05	0.50
2	200	0.10	0.75
3	300	0.15	1.00

The composite material was turned on a lathe (Make NAGMATI, India) with the spindle power of 2.25 kW having a rotational speed range between 54 rpm to 1200 rpm. Machining was carried out under dry environmental conditions. Work piece material was held in between head stock and tail stock for want of stability of work piece to avoid excess vibration caused due to the length of the work piece. Machining was done for the duration of 1.5 min with three replications.

The surface roughness measured was the commonly used and most popularly known parameter is the average surface roughness Ra. Taylor Hobson roughness tester developed by Time Group Inc., equipped with a clear display of all measurement parameters and profile graphs on LCD monitor and Stylus Tip Radius of 2 μm was used for this study. The roughness tester was set to a cut-off length of range 0.8mm.

Figure 2. Cutting tool and tool holder used for experimentation

The Taguchi method was used to determine the best combination of process parameters in machining CFRP material. It uses orthogonal array to plan the experiment with a lowest number of experiments to be carried out [18,19]. This leads to the economical experimentation and analyze the impact of process parameters [19, 20].

3. Methodology

The various machining parameters and its levels in the form of coded form used for machining CFRP material and the orthogonal array used by Taguchi [22] was used to conduct the experimental have been given. Statistical design of experimentation technique as well as least square fitting method for model generation has been made use in response surface methodology [23, 24].

The surface roughness may be calculated from the known relation [23] as:

$$Ra = (0.0321 \text{ X } f^2) / R \qquad (1)$$

where Ra, the surface roughness in μm; f, the feed in mm/rev; and R, the tool nose radius.

But the functional relationship between the surface roughness and independent variables cutting speed, feed and depth of cut may be described in a following way:

$$Ra = CF^pD^qV^rT^s \qquad (2)$$

where Ra, the surface roughness in μm; C, the constant; F, the feed in mm/rev; D, the depth of cut; V, the cutting speed; T, the tool nose radius and p,q,r,s are constants, which are to be derived.

Surface roughness relationship may be written in the linear form as follows:

$$\eta = \beta_0+\beta_{1x1}+\beta_{2x2}+\beta_{3x3} \qquad (3)$$

But in simple terms, the above equation can also be written in the following manner:

$$\hat{y}= b_0 +b_{1\ x1}+b_{2\ x2}+b_{3\ x3} \qquad (4)$$

where $\hat{y}$ is the value of surface roughness by prediction with the transformation in logarithmic form, b_0,b_1,b_2 and b_3 are coefficients of parameters β_0,β_1,β_2,β_3 respectively.

Using this first order model the three parameters are estimated. In the case of any statistical deficiency with the first order model then the second order model may be developed as given below:

$$\hat{Y} = b_0 + b_{1x1} + b_{2x2} + b_{3x3} + b_{12\ x1\ x2} + b_{13\ x1x3} + b_{23\ x2\ x3} + b_{11\ x1}^{2} + b_{22\ x2}^{2} + b_{33x3}^{2} \quad (5)$$

If the true response is nonlinear and unknown then the need of second order regression model arises.

4. Results and Discussion

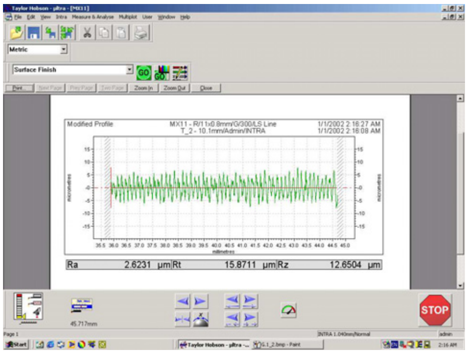
The empirical equation for surface roughness may be written as follows:

Surface roughness = 2.7572 - (0.0034 X Cutting speed) - (14.1333 X Feed) + (0.2400 X Depth of cut) + (91.3333 X Feed X Feed) - (0.1333 X Depth of cut X Depth of cut) - (0.0148 X Cutting speed X Feed) - (0.0078 X Cutting speed X Depth of cut) + (14.6667 X Feed X Depth) (6)

After completing the machining operation the response parameter that is, surface roughness was measured. Statistical analysis was performed on the results obtained for attaining main effects. The main effect of a factor may be described as the average change in the response generated by a change in the level of a factor studied. The response values resulting from the experimental work carried out by orthogonal array are analyzed using Taguchi's technique. This step determines the effect of various process parameters to achieve desired surface roughness. Taguchi's technique offers three category of signal to noise ratio. They are larger-the-better, medium-the-better, small-the-better. Larger is suitable for determining the profit, production rate, etc., medium the better is applicable to current. Smaller the better is appropriate for tool wear, surface roughness, tire wear, unit cost, etc., This experimental study uses smaller-the-better, because surface roughness is the one to be minimized.

Results obtained from the analysis of Taguchi have been provided here. Figure 3 shows the surface roughness profile obtained during measurement of surface roughness using Taylor Hobson surface roughness measurement instrument.

It shows the general trend of various process parameters cutting speed, feed and depth of cut on the response variable surface roughness. It is observed that the order of process parameters that influences the surface roughness is feed followed by cutting speed and depth of cut.



Ra 2.6231 µm Rt 15.8711 µm Rz 12.6504 µm

Figure 3. Surface roughness profile obtained during measurement

This observation is supported by the response table obtained from the analysis which is shown in Table 2. The correlation coefficient R-square for the experimental result obtained was 88.1 which shows a good correlation the experimental values possess. Main effects plot obtained from the analysis for individual machining parameters on the response surface roughness is shown in Figure 4. Figure 5 is the interaction plot, which shows the effect of the factor feed for different values of depth of cut 0.5 mm, 0.75 mm and 1 mm on surface roughness.

General observation from the plot is surface roughness increases when the feed is increased. This was witnessed irrespective of the value of depth of cut. An interaction was found out between two extreme values of depth of cut. This observation coincides with the findings of Paulo Davim [21,22] when he conducted experiments to determine the machinability study of PEEK composites. From this analysis, it could be suggested that for a better surface roughness the combination of machining parameters would be low value of feed and high value of depth of cut.

Table 2. Response table for means

Levels	Cutting speed (*m/min*)	Feed (mm/rev)	Depth of cut (mm)
1	3.222	2.308	2.849
2	2.839	2.688	2.846
3	2.459	3.524	2.826
Delta	0.763	1.217	0.023
Rank	2	1	3

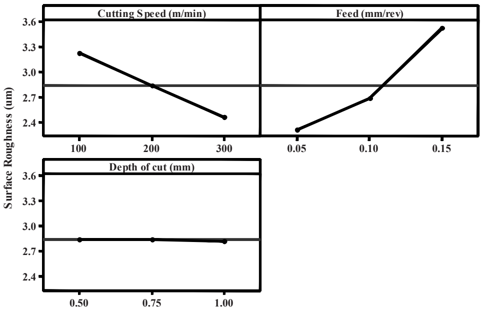


Figure 4. Response graph obtained for surface roughness

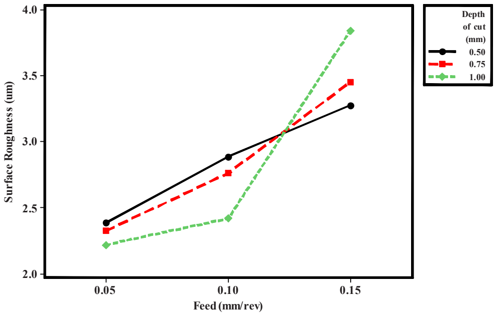


Figure 5. Interaction plot of feed and depth of cut on surface roughness.

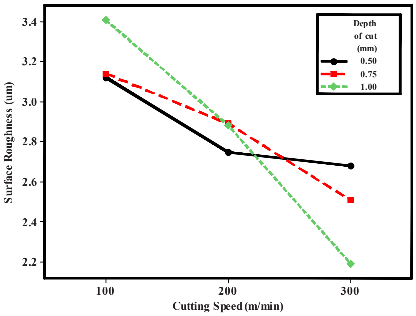


Figure 6. Interaction plot of cutting speed and depth of cut on surface roughness.

Interaction plot for the effect of process parameters cutting speed and various values of depth of cut 0.5 mm, 0.75 mm and 1 mm on surface roughness is shown in Figure 6. It is interpreted from the plots that increase in cutting speed results in decrease of surface roughness linearly for lower range of cutting speed and slightly non linear for the higher range of cutting speed with respect to all values of depth of cut. Further an interaction effect was found out between the lower value as well as higher value of surface roughness. It is suggested to choose the combination of parameters with higher cutting speed and higher value of depth of cut. Though the parameter depth of cut does not have any significant role on the part of the surface roughness [23-25], its trend was observed that the surface roughness was increasing on the increasing value of depth of cut.

Figure 7 presents the data for the interaction effect of process parameter cutting speed for various values of feed on surface roughness. There is interaction effect on these values of parameters for this case. Referring to the interaction plot it was noticed that surface roughness becomes high with the lower value of cutting speed particularly with the higher depth of cut. This is due to the high pressure exerted by the cutting tool to deform the composite material in shear mode along with the protrusion of fibers on the machined surface of CFRP composite material.

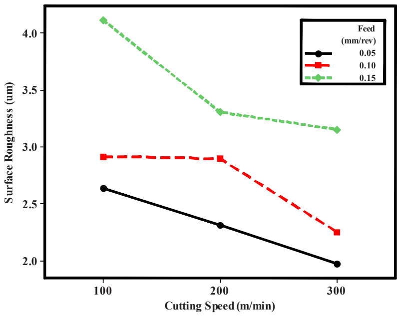


Figure 7. Interaction plot of cutting speed and feed on surface roughness.

Further Fig. 8 demonstrates the interaction plot matrix of various process parameters on surface roughness. This graph shows the interaction effects for three different cutting speed, feed and depth of cut together for better visualization.

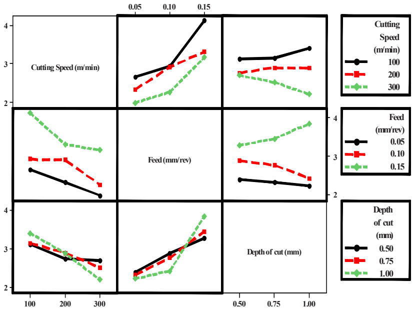


Figure 8. Interaction plot matrix for various process parameters on surface roughness

Figs. 9 and 10 show the SEM pictures of machined CFRP composite material at different machining conditions. Fig. 9 is the SEM picture of composite material at higher feed of 0.15 mm/rev in combination with constant cutting speed and depth of cut of 200 m/min and 0.75 mm respectively. It is observed from the figure that the fibers are cut in a huge amount and protruded on the surface of the machined material leading to the higher surface roughness. But Fig. 10 shows the SEM picture of composite material at a lower feed value of 0.05 mm/rev and illustrates only a few fibers are broken attributing a better surface roughness when compared to the former condition.

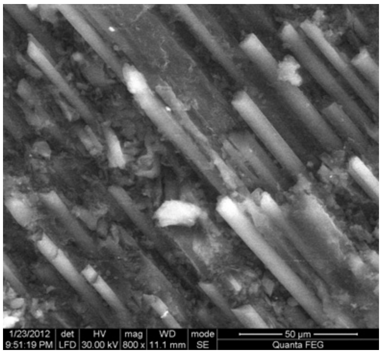


Figure 9. SEM image of CFRP material at feed = 0.15 mm/rev

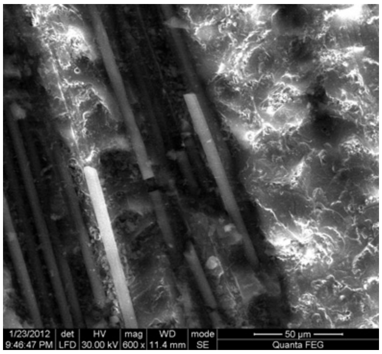


Figure 10. SEM image of CFRP material at feed = 0.05 mm/rev

Further the comparison of surface roughness between the experimental value as well as RSM value is shown in Fig 11. The correlation coefficient R-square is used to justify the predicted response. The value of R-square for the predicted result obtained was 88.1 which show a good correlation the experimental values possess.

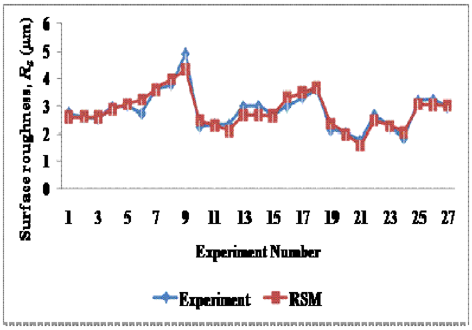


Figure 11. Comparison of surface roughness between experiment and RSM

5. Conclusion

Carbon fiber reinforced polyester material was used for carry out experimentation for determining the combination of process parameters that helps to achieve a better surface roughness. Based on the experimentation and analysis carried out the following concluding observation is recorded. The predicted surface roughness from response surface methodology was compared with the one obtained from experimentation. There found a good correlation between them in terms of R-square value, which is 88.1 %. Based on the correlation found out from the above analysis it is suggested that response surface methodology can well be utilized for predicting the surface roughness of carbon fiber reinforced polymer composites.

During machining the chip produced was powdery in form due to the brittleness of material. Among the various parameters feed is the factor play a primary role in deciding the surface roughness followed by cutting speed. But depth of cut does not make any significance for this particular case. Surface roughness was found to be increasing when feed is increased. Further on the other hand it was found that the surface roughness was decreasing when cutting speed was increased. This trend was identified evidently from SEM pictures that were acquired from the machined CFRP composite material at different feed conditions keeping cutting speed and depth of cut constant.

The combination of process parameters that offer better result is lower value of feed accompanied by the higher value of cutting speed.

References

[1] Benardos, P. G., Vosniakos, G. C., 2003. Predicting surface roughness in machining: a review, International Journal of Machine Tools & Manufacture 43 pp. 833–844.

[2] Abrate, S., Walton, D. A., 1992. Machining of composite materials. Part I: Traditional methods, Composites Manufacturing Vol 3 No 2.

[3] Rusinek, R., 2010. Cutting process of composite materials: An experimental study, International Journal of Non-linear Mechanics 45 pp. 458-462.

[4] Mohan, N. S., Ramachandra, A., Kulkarni, S. M., 2005. Influence of process parameters on cutting force and torque during drilling of glass–fiber polyester reinforced composites, Composite Structures 71, pp. 407–413.

[5] Hu, N. S., Zhang, L. C., 2004. Some observations in grinding unidirectional carbon fiber-reinforced plastics, Journal of Materials Processing Technology 152, pp. 333–338.

[6] Ramulu, M., Wern C. W., Garbini, J. L., 1993. Effect of fibre direction on surface roughness measurements of machined graphite /epoxy composite, Composites Manufacturing Vol 4 No 1.

[7] Bjo¨rklund, S., 2001. The influence of surface roughness in elliptical contacts, Tribology International 34, pp. 841–845.

[8] Palanikumar, K., Karunamoorthy, L., Karthikeyan, R., 2006. Assessment of factors influencing surface roughness on the machining of glass fiber-reinforced polymer composites, Materials and Design 27, pp. 862-871.

[9] Tsao, C. C., Hocheng*, H., 2008*. Evaluation of thrust force and surface roughness in drilling composite material using Taguchi analysis and neural network, Journal of Materials Processing Technology 203, pp. 342–348.

[10] Everstine, G. C., Rogers, T. G., 1971. A Theory of Machining of Fiber-Reinforced Materials, J. Composite Materials Vol. 5, pp. 94.

[11] Isik, B., Experimental investigation of surface roughness in orthogonal turning of unidirectional glass-fiber reinforced plastic composites, Int J Adv Manuf Technol DOI: 10.1007/s00170-007-0946-7.

[12] Palanikumar, K., Mata, F., Davim, J. P., 2008. Analysis of surface rougness parameters in turning of FRP tubes by PCD tool, Journal of Materials Processing Technology 204, pp. 469-474.

[13] Palanikumar, K., 2008. Application of Taguchi and response surface methodologies for surface roughness in machining glass fiber reinforced plastics by PCD tooling, Int J Adv Manuf Technol 36, pp. 19-27.

[14] Rajasekaran, T., Palanikumar, K., Vinayagam, B. K., 2011. Application of fuzzy logic for modeling surface roughness in turning CFRP composites using CBN tool, Prod. Eng. Des. Devel. 5, pp. 191-199.

[15] Rajasekaran, T., Palanikumar, K., Vinayagam, B. K., 2011. Experimental investigation and analysis in turning of CFRP composites, Journal of Composite Materials 46(7), pp. 809-821.

[16] Huang, Y., 2005. Effect of Cutting Conditions on Tool Performance in CBN Hard Turning, Journal of Manufacturing Processes Vol. 7 / No.1, pp. 10-16.

[17] Luo, S. Y., Liao, Y. S., Tsai , Y. Y., 1999. Wear characteristics in turning high hardness alloy steel by ceramic and CBN tools, Journal of Materials Processing Technology 88, pp. 114–121.

[18] Tzeng, C. J., Lin, Y. H., Yang, Y. K., Jeng, M. C., 2009. Optimization of turning operations with multiple performance characteristics using the Taguchi method and Grey relational analysis, Journal of Materials Processing Technology 209, pp. 2753–2759.

[19] Nourani, M., Milani, A. S., Yannacopoulos, S., 2011. Taguchi optimization of Process Parameters in Friction Stir Welding of 6061 Aluminum Alloy: A Review and Case study, Engineering 3, pp. 144-155.

[20] Chang, C. W., Kuo, C. P., 2007. Evaluation of surface roughness in laser-assisted machining of aluminum oxide ceramics with Taguchi method, International Journal of Machine Tools & Manufacture 47, pp. 141–147.

[21] Gaitonde, V. N., Karnik, S. R., Achyutha, B. T., Siddeswarappa, B., 2008. Taguchi optimization in drilling of AISI 316L stainless steel to minimize burr size using multi-performance objective based on membership function, Journal of Materials Processing Technology 202, pp. 374–379.

[22] Rajasekaran, T., Palanikumar, K., Vinayagam, B. K., Turning CFRP composites with ceramic tool for surface roughness analysis, Proceedia Engineering 38 (2012) 2922-2929.

[23] Davim , J. P., Reis, P., Lapa, V., Antonio, C. C., 2003. Machinability study on polyetheretherketone (PEEK) unreinforced and reinforced (GF30) for applications in structural components, Composite Structures 62, pp. 67–73.

[24] Rajasekaran, T., Palanikumar, K., Vinayagam, B. K., 2011. Analysis of Machining Parameters for Better Surface Characteristics in Turning CFRP Composites Using Coated Cutting Tool, Proceedings of the International Conference on Materials for future, (22-23 February 2011), Government engineering college Trichur, Thrissur, India.

[25] Rajasekaran, T., Palanikumar, K., Vinayagam, B. K., 2011. The role of precision cutting parameters into the effect of surface roughness in turning CFRP composites, Proceedings of the International Conference on Cutting, Welding and Surfacing (22-23 January 2011), Indian Welding Society, Coimbatore, India.