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A Predictive Model for Surface Roughness in Turning Glass Fiber Reinforced Plastics by Carbide Tool (K-20) Using Soft Computing

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Abstract

Glass fiber reinforced plastics are finding its increased applications in various engineering fields such as aerospace, automobile, electronics and other industries. This paper discusses the use of fuzzy logic for modeling turning parameters in turning of glass fiber reinforced plastics by carbide tool (K-20). Experiments were conducted based on the established Taguchi's Design of Experiments (DOE) L25 orthogonal array on an all geared lathe. The cutting parameters considered were cutting speed, feed, depth of cut, and work piece (fiber orientation). Fuzzy based model is developed for correlating the cutting parameters with surface roughness (Ra). The results indicated that the model can be effectively used for predicting the surface roughness (Ra) in turning of GFRP composites.

Keywords: GFRP composites; turning; Surface roughness (Ra); Fuzzy logic; Model

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1. Introduction

Composite materials are continuously replacing traditional materials due to their excellent properties. A single large part made of composites can replace many metal parts. Composite materials can be embedded with sensors, which can monitor fatigue and performance. They have high stiffness to density ratio thereby providing greater strength at lighter weights. The use of light-weight materials means an increase in the fuel efficiency of automobiles and airplanes. Also the endurance limit of some composites is higher than that of aluminum and steel. Most composites are made up of plastics or resins and hence provide a high level of resistance to corrosion, while aluminum and iron need special treatments like alloying to protect them from corrosion. Composites have a low co-efficient of thermal expansion, which can provide a greater dimensional stability when required. Despite recent developments in near-net shape processing, composite parts often require post-mould turning and drilling to meet dimensional tolerance, surface quality and other functional aspects [1] Experimental studies on traditional turning of FRP were first reported by A. Koplev et al and K.Sakuma et al [2-3]. Koing et al [4] investigated the turning of fiber reinforced plastics (FRP) using different processes like drilling, routing, milling, water jet cutting and laser cutting. Santhanakrishnan et al.[5] analyzed the surface roughness and morphology. It is known that during turning of FRP composites, the mechanism of cutting is associated with the combination of plastic deformation, shearing and rupturing of fibers along with turning matrix material. Eriksen [6] has enumerated guidelines for the turning of short fiber reinforced thermoplastics (SFRTP). The turning of FRP is different from that of metal working in many aspects because, the FRP behavior is not only inhomogeneous, but also dependent on fiber and matrix properties, fiber orientation, and type of weave. During the turning of fiber reinforced plastics fiber, which intermittently come into contact with tool produces poor surface finish. The studies carried out on FRP composites shows that minimizing the surface roughness is very difficult and is to be controlled. Taguchi's parameters design is used for conducting the experiments [7]. Taguchi's approach extensively uses statistical design of experiments [8]. By applying this approach this technique one can significantly reduce the number of experiments and time required for experimentation. In turning of GFRP composites, hard and abrasive glass fibers results in high tool wear.

Artificial intelligence tools are playing an important role in modeling and analysis. Fuzzy logic is relatively easier to develop and require less hardware and software resources. Fuzzy logic controller is the successful application of fuzzy set theory and was introduced by zadeh[9] in 1965 it is a mathematical theory of inexact reasoning that allows modeling of the reasoning process in human linguistic terms. This theory proved to be an effective means for dealing with objectives that are linguistically specified. Linguistic terms such as low, medium and high may be defined by fuzzy sets [10]. Fuzzy logic has been applied successfully for turning process such as cutting force evaluation by Suleyman et al [11], surface roughness prediction by Yue Jiao et al [12]. In the present study arithmetic average height (Ra) in

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turning of GFRP composites by carbide (K-20) tool is modeled and analyzed. The results indicate that fuzzy logic modeling technique can be successfully applied for the prediction of surface roughness parameters in turning GFRP composites.

2. Experimental Work

The work material used for the present investigation is glass fiber reinforced plastics (GFRP) pipes. The inner diameter of the pipe is 30mm; outer diameter is 60mm and length 500mm respectively shown in figure 1. The pipes used in the study are manufactured by filament winding process. The orientation of the fibers on the works piece has been set during the manufacture of pipes. The fiber used in the pipe is E-glass and resign used is epoxy. The specification of the material used in this work is given in Table 1.

Table 1: Specifications of fiber and resign.

Fiber: E-glass – R099 1200 P556	Resin: Epoxy
Manufacturer: Saint Gobain vetrotex India Ltd.	Manufacturer: CIBA GEIGY
R099- Multi filament Roving	Product: ARALDITE MY 740 IN
1200-Linear Density, Tex	110KG Q2
P556- Sizing reference for vetrotex	Hardener: HT 972

The experiments are planned using Taguchi's orthogonal array L25 [13] in the design of experiments (DoE), which helps in reducing the number of experiments. The experiments were conducted according to orthogonal array. The four cutting parameters selected for the present investigation is cutting speed (v)m/min, feed (f)mm/rev , depth of cut (d)mm and work piece (fiber orientation 'Φ') in degrees . Since the considered factors are multi-level variables and their outcome effects are not linearly related. The studies related to the GFRP composites indicated that the higher cutting conditions leads to high tool wear and poor surface finish [14].

The turning parameter used and their levels chosen are given in Table 2. All the GFRP pipes are turned in a BHARAT all-geared lathe of model NAGMATI-175 with a maximum speed of 1200 rpm and power of 2.25KW. The ISO specification of the tool holder used for the turning operation is a WIDAX tool holder PC LNR 2020 K12 and the tool insert used for the study is solid carbide (K-20)120408 sandvik make.

Figure 1: GFRP Composite Pipe Specimens.

Table 2: Cutting parameters, their notations and their limits.

Process parameters With units	Notation	Variable	Levels				
			-2	-1	0	1	2
Speed, m/min	v	x_1	40	60	95	145	225
Feed, mm/rev	f	x_2	0.048	0.096	0.143	0.191	0.238
Depth of cut, mm	d	x_3	0.25	0.5	0.75	1	1.25
Fiber orientation angle, deg	Φ	x_4	30	45	60	75	90

The average surface roughness (Ra), which is mostly used in industrial environments, is taken-up for this study. The machined surface was measured by using surface roughness tester (FORM TALY SURF) manufactured by Taylor Hobson, U.K. The mean response table for surface roughness (Ra) is presented in Table 3.

Table 3. Response table for surface roughness.

Level	Cutting speed (v),m/min	Feed (f), mm/rev	Depth of cut (d), mm	Fiber orientation angle (Φ) degrees
1	3.847	2.876	3.625	3.109
2	3.731	3.203	3.540	3.301
3	3.403	3.569	3.368	3.487
4	3.041	3.758	3.254	3.612
5	3.198	3.815	3.434	3.711
Delta	0.806	0.939	0.371	0.602
Rank	2	1	4	3

3. Fuzzy Model for evaluation of surface roughness

The studies on turning of GFRP composites shows 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 purposes. The structure of fuzzy logic system consists of three conceptual components:

- Fuzification : formation of member ship functions
- Selection of proper shape and definition of expert rules
- Selection of proper defuzzification method

The fuzzifier uses membership functions to fuzzify the input and output values. The inference engine is used for fuzzy reasoning on fuzzy rules to generate a fuzzy value.

Finally, the defuzzifier converts the fuzzy in to crisp output [15-16]. Cutting speed, feed, depth of cut, and work piece (fiber orientation) are chosen as input parameters. Surface roughness parameters Ra is chosen as output response in the system. In fuzzy system, membership function is used. Membership functions characterize the fuzziness in a fuzzy set whether the elements in the set are discrete or continuous in graphical form for eventual use in the mathematical formalism of fuzzy set theory [17] .The input and output variables are fuzzified and represented by means of membership functions (MF). The shapes of the membership function depend on the form of horizon approach function. In this study, triangle membership function is considered. Triangular membership function has gradually increasing and decreasing characteristics and only one definite value and is generally used. The relationship between the input and outputs in a fuzzy model is characterized linguistic statements called fuzzy rules. Linguistic variables low, low medium, Medium, High medium, and High for cutting speed, feed, depth of cut and work piece (fiber orientation) were taken to represent the input numerical values. The number of membership functions used for the output response is nine such as Lowest, Lower, Low, Low medium, medium, High medium, High, Higher, and Highest. More precise results can be obtained by using more number of membership functions and hence 9-membership functions were selected for the present work. The expressions used for cutting speed, feed, depth of cut, fiber orientation and cutting force (Fz) is given in Table 4. Membership functions and their ranges of input parameters are shown in Fig 2-5. Similarly the membership function used for the output response surface roughness is presented in Fig 6. The fuzzy rules were developed based on experimental results and expertise. 25 fuzzy rules were developed for 25 experimental results by taking the max-min compositional operation. The output response of the fuzzy process is available only in fuzzy values and is to be defuzzified. For defuzzyfying the values defuzzification is used. Dufuzzification is the conversion process and it converts fuzzy quantity into precise quantity. There are several methods of defuzzification is used. Centroid of area defuzzification method is a general method and it gives more reliable results than other methods and it calculate the centroid of the area under the membership function. The non fuzzy value gives the output value in numerical form. The relationship between the output value and the experimental values are plotted and are shown in Figs. 7. The figures indicate a very close correlation between the experimental values and fuzzy predicted values, which shows that fuzzy logic can be effectively utilized for prediction of surface roughness parameters in turning of GFRP composites.

Table 4: Fuzzy expressions of input and output parameters.

Inputs				output
Cutting speed (v)	Feed (f)	Depth of cut (mm)	Fiber orientation angle (Φ)	Surface roughness (Ra)
Low	Low	Low	Low	Lowest
Low medium	Low medium	Low medium	Low medium	Lower
Medium	Medium	Medium	Medium	Low
High medium	High medium	High medium	High medium	Low medium
High	High	High	High	Medium
				High medium
				High
				Higher
				Highest

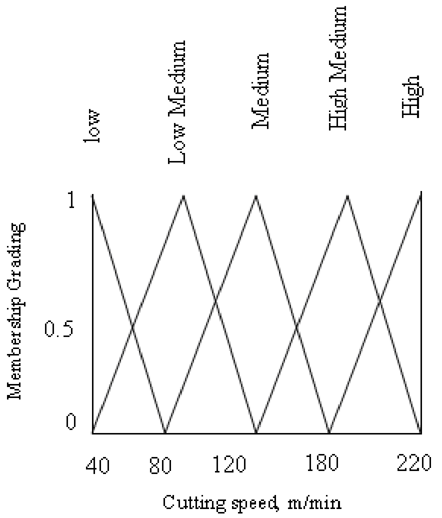

Figure 2: Membership function and their ranges for cutting speed.

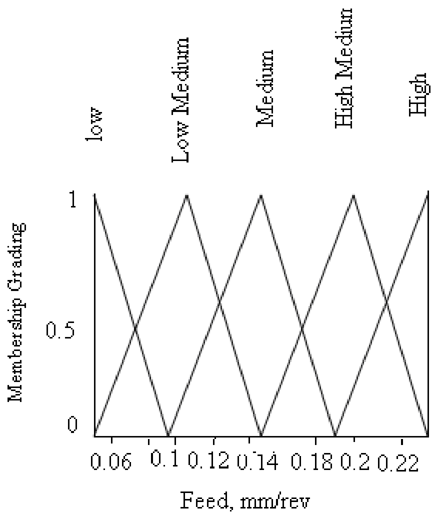

Figure 3: Membership function and their ranges for feed.

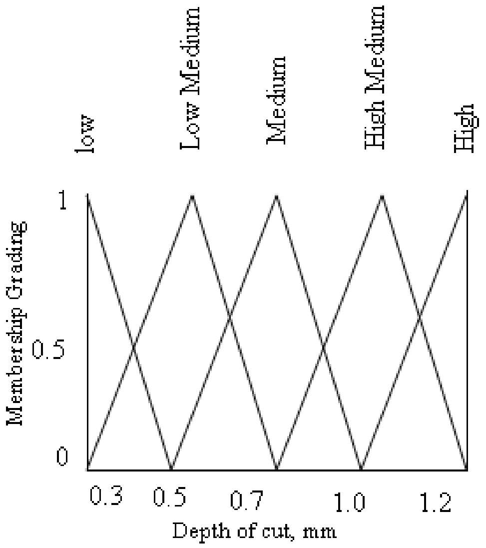

Figure 4: Membership function and their ranges for depth of cut.

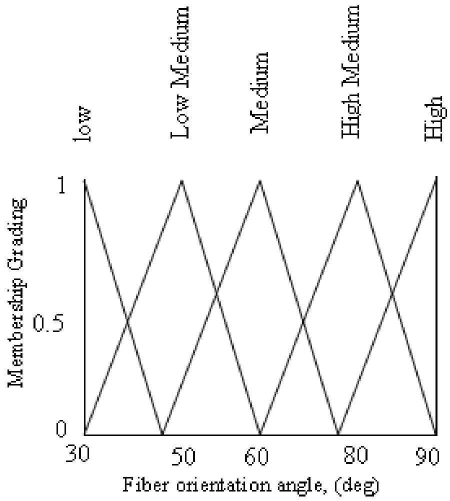

Figure 5: Membership function and their ranges for fiber orientation angle.

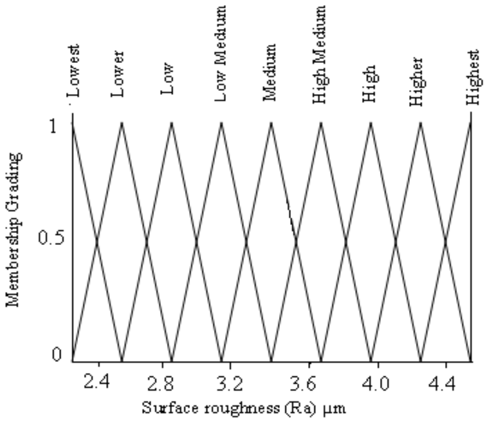

Figure 6: Membership function and their ranges for output response surface roughness.

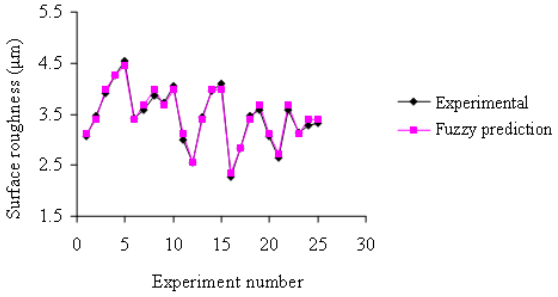

Figure 7: Comparison of experimental results and fuzzy output for Ra.

4. Results and Discussion

Surface roughness plays a predominant role in determining the turning accuracy. The study of surface roughness characteristics of GFRP composites dependent on many factors, it is more influenced by the cutting parameters like cutting speed, feed, depth of cut, etc., for a given machine tool and work piece set-up. The influence of different cutting parameters on turning of GFRP composites can be studied by using response graph and response table. Figure 8 shows the influence of cutting parameters on surfaces roughness. The observed surface roughness at high cutting speed is low as compared to low cutting speed. The experimental results indicated that the surface roughness parameter is low at low feed as compared to the high feed. The effect of depth of cut on turning of GFRP composite indicated that the surface roughness reduces with increase of depth of cut. The experimental results indicated that low surface roughness is observed for low fiber orientation angle as compared to high fiber orientation angle. The response table for surface roughness, table 3 shows the effect of different cutting parameters. From the response table, it can be asserted that feed is the main parameters which affect the surface roughness.

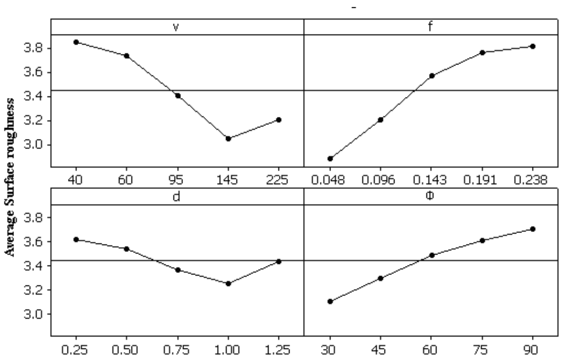

Figure 8: Effect plot for surface roughness.

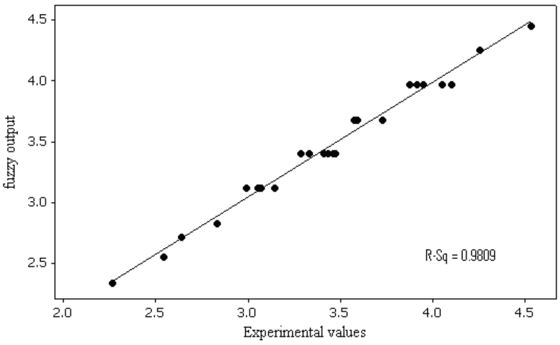

Figure 9: Correlation graph for Ra.

The modeling of machining parameters for surface roughness in turning of GFRP composites is carried out by fuzzy logic. Fig. 9 shows the correlation graph for experimental values and observed values. The adequacies of the developed models have been verified through R-Sq values, which are presented in the figures. The quantity R-Sq is called as coefficient of determination and is used to judge the adequacy of the models developed. In the present case the coefficient of determination is 0.9809 for Ra which shows high correlation that exists between the models and experimental results and hence fuzzy logic can be effectively used for the prediction of surface roughness in turning of GFRP composites. Fig 10 (a) - (e) shows the microstructure of machined GFRP composite specimen in which the distribution of fibers in the polymer matrix can be seen.

For confirmation of the fuzzy logic rule based modeling technique, verification tests were conducted at three different selected conditions. Fig 11 shows the test results for surface roughness (Ra), from the results it can be inferred that the variation between experimental results and model are within the limit and are very close to each other and hence fuzzy modeling technique can be effectively used for prediction of surface roughness parameters in turning of GFRP composites.

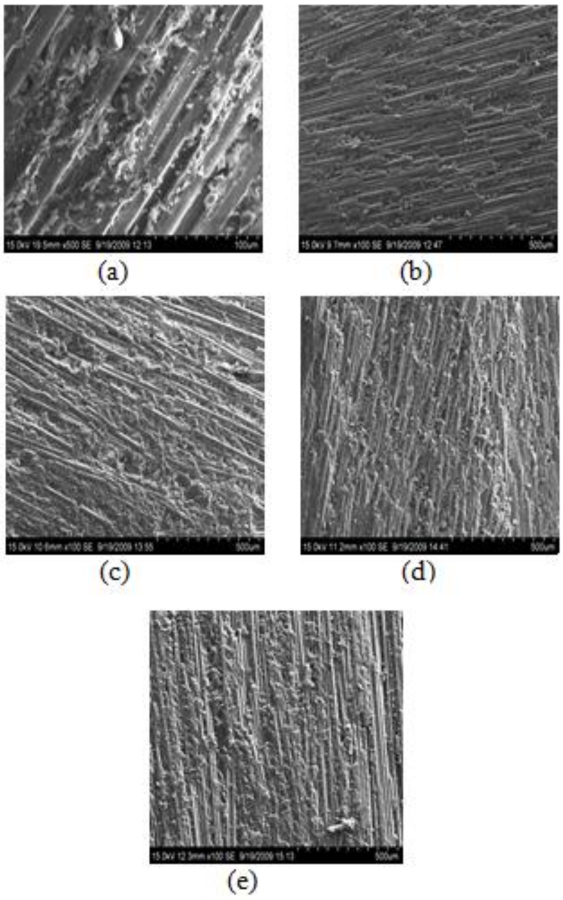

Figure 10: (a) – (e): Microstructure of machined GFRP composite.

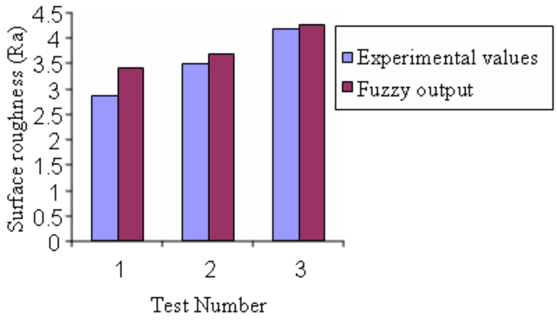

Figure 11: Verification Test Results for Surface roughness (Ra).

5. Conclusions

Experiments are conducted for modeling the surface roughness parameter Ra in turning of GFRP composites. Taguchi’s orthogonal array L25 design of experiments has been used for experimentation. Fuzzy rule based model has been developed for predicting the surface roughness in turning of GFRP composites. Based on the experimental and fuzzy modeling results, the following conclusions are drawn.

- Rule based fuzzy logic model for surface roughness is developed from the experimental data. The predicted fuzzy output values and measured values are fairly close to each other, which indicate that the fuzzy logic model can be effectively used to predict the surface roughness in turning of GFRP Composites.
- In machining of GFRP composites, increase in cutting speed and depth of cut reduces the surface roughness, where as the increase in feed and fiber orientation angle increases the surface roughness
- The feed is the dominant parameter which affects the surface roughness of GFRP composites, followed by cutting speed, fiber orientation angle. Depth of cut shows a minimal effect on surface roughness compared to other parameters.
- The confirmation experiment reveals that the developed model can be effectively used for predicting the surface roughness (Ra) in turning of GFRP composites.
- The accuracy of prediction by fuzzy model can be further improved by increasing the number of membership functions.
- Further improvement of model can be possible by introducing more number of variables and wider range of cutting conditions.
- The technique used is simple and can be used as an on-line monitoring tool, if proper equipments are used. This model can reduce the tedious model making, computational cost and time.

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