M. SENTHIL KUMAR

ISSN 0543-5846
METABK 58(1-2) 109-112 (2019)
UDC – UDK 666.189.2-648.7:620.178.1:544.64:621.9:621.224.3=111

INVESTIGATION OF HARDNESS AND SURFACE ROUGHNESS IN END MILLING GLASS FIBRE REINFORCED POLYMER COMPOSITE

Received – Primljeno: 2018-07-02
Accepted – Prihvaćeno: 2018-10-10
Original Scientific Paper – Izvorni znanstveni rad

The increase use of glass fibre reinforced polymer (GFRP) composites in recent years has led to an increased demand for machining. Milling of glass fiber reinforced polymer (GFRP) composites becomes essential in order to enhance its surface quality. In this paper, optimization of machining parameters in milling of horizontal axis wind turbine (HAWT) blade wrapped with E-glass fiber reinforced plastics (GFRP) composites with multi-response criteria-based desirability function analysis (DFA). The machining parameters such as spindle speed (A), feed rate (B) and depth of cut (C) are optimized by considering multiple response characteristics namely surface roughness (Ra) and hardness (HB). The desirability at a high of 0,83 provides minimum surface roughness about 2,64 µm 0,7 and maximum hardness about 49,12 BH.

Key words: GFRP, hardness, scanning electron microscopy (SEM), machining, wind turbine

INTRODUCTION

To meet the energy crisis, the wind energy has led its emergence on wind turbine [1]. Using the composite materials, the HAWT blades are made strong and light in structure. Due to the high stiffness, strength and low weight the combination of Reinforced Plastics (GFRP) and Carbon-Fiber Reinforced Plastics (CFRP) are broadly used. The blade of the wind turbine drives the energy from wind and convert the kinetic energy into rotational energy with the rotor and transmits to the generator. The torque produced to drive the generator is influenced by the characteristics of the material and aerodynamic efficiency [2]. The optimal aerodynamic efficiency is obtained by designing the small scale HAWTs which also limit the rotor speed. Capturing the wind energy at low and moderate speed can be enhanced by optimizing the design of the blade [3]. In the industries, HAWT is widely used due to low rotational speed, low noise with greater life cycle maintenance and stability of the rotor [4]. Unoptimized machining forces lead to the failure of GFRP, while improving the quality of the surface during the machining process. So it is important to understand the mechanism behind the machining process and process parameters to obtain the preferred machined surface quality [5-7]. The hardness of material is affected in the workpiece due to the stress and induced strain [8]. Various attempts have been made by the researchers in analyzing and identifying the effects of process parameters by design of experiment, Response Surface Methodology (RSM) and Taguchi [9-10]. Optimization based on RSM with Desirability Function Approach (DFA) is adopted for multi response optimization to optimize process parameters [11].

The study of literature has reveals that several experimental optimization researches have been done on machining process to improve surface finish. But effect of milling parameters of GFRP composite has not been studied to improve the multi response such as hardness and surface roughness simultaneously.

M. Senthil Kumar, Department of Aeronautical Engineering, Kumaraguru College of Technology,Coimbatore, India.

EXPERIMENTAL METHODOLOGY

Material selection

The material selection and shape are important parameters as a daunting task in the design of a wind turbine blade. E glass fiber and epoxy resin with symmetric layup scheme of $[45/-45/0/90]_s$ was selected for this study along with a full depth foam core to help retain the shape of the blade and prevent the skin from local buckling. This is the typical layup used in industries to avoid bending- shearing coupling between plies [6]. The blade was wrapped with glass fiber reinforced plastics (GFRP) laminates of varied thicknesses from the root to tip. The properties of GFRP, with E glass fiber are shown in Table 1. Meshed model of HAWT blade is shown in Figure 1.

Experimental setup and design of experiments

MAKINO computer numerical vertical milling machining centre is used to conduct experiments. The brazed carbide tip tool is used for performing end milling slot-

Table 1 **GFRP material properties.**

Material Properties	Values
E_1 (along fiber)	54 000 MPa
E_2 (perpendicular to fiber)	18 000 MPa
Poisson's Ratio	0,25
Shear modulus of elasticity	9 000 MPa
Density	1 800 x10^{-9} kg/mm^3
Tensile Stress	1 035 MPa
Compressive Stress	1 035 MPa
Shear Stress	41 Pa

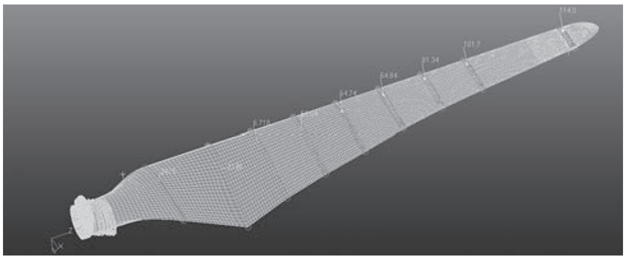

Figure 1 Meshed model

ting operation. The design matrix has been developed using Design expert (version.10) software. The design parameters selected to form a central composite face centered design matrix are six centre points, half fraction, one axial and factorial point. The each experiment has been performed thrice for set of 15 experiments in order to enhance the accuracy of an average value of responses such as surface roughness and hardness. The input of milling parameters selected for performing slotting path of operation are shown in Table 2 and Experimental design and Reponses are shown in Table 3.

Table 2 **Milling parameters**

Milling parameters	Units	levels		
		-1	0	1
A	Rpm	1 400	2 500	3 600
B	mm/min	50	125	200
C	mm	0,5	1	1,5

Table 3 **Experimental design and responses**

A / Rpm	B / mm/min	C / mm	Ra / µm	HB
3 600	125	1	3,5	43,7
2 500	125	1	4,6	48,6
1 400	125	1	4,8	51,5
2 500	125	1,5	7,8	51,1
2 500	50	1	5,1	47,1
3 600	200	0,5	2,2	42,1
2 500	125	0,5	2,9	47,9
2 500	125	1	4,9	48,1
1 400	200	1,5	7,9	50,2
2 500	125	1	5	49,9
3 600	50	1,5	6,1	43,1
2 500	200	1	4,5	46,9
2 500	125	1	4,3	50,9
1 400	50	0,5	6,3	47,5
2 500	125	1	3,8	47,8

The hardness values were measured using r Brinell hardness (HB) test with the application of 250 kg load for 10 to 15 seconds. The surface roughness values were measured using surf tester SJ210.

STATISTICAL ANALYSIS

The variance of analysis portrayed that F- statistical value for model is 19,40. This value proves that the developed model for surface roughness is significant. The F-value of lack of fit is 0,22 indicates that the Lack of Fit is not significant comparative to the pure error. The F-statistical values for spindle speed (4,22), feed rate (0,899) and depth of cut (60,01) shows the effects of milling parameter on each responses. The variance of analysis portrayed that F- value for model is 9,02. This value proves that the developed model for surface roughness is significant. The F-value of lack of fit is 0,01 indicates that the Lack of Fit is not significant comparative to the pure error. The F-statistical value of depth of cut has a greater influence on surface roughness comparing all other parameters. The F-statistical values for spindle speed (22,24), feed rate (0,014) and depth of cut (3,74) shows the effects of milling parameter on each responses. The F-statistical value of spindle speed has a greater influence on hardness comparing all other parameters. The value of R^2 97,2 indicates the coefficient of determination for surface roughness. This value designates that the developed model has less variation and fitted in regression line. The value of R^2 94,1 indicates the coefficient of determination for surface roughness. This value designates that the developed model has less variation and fitted in regression line. The Equation 1 and 2 were the developed regression models that can be used for the prediction of surface roughness and hardness.

$$\text{Surface roughness} = 13,33 - 0,0017A - 0,07B - 6,77C + 0,0000013A*B + 0,00049A*C + 0,022B*C - 0,000000019A^2 + 0,0000072B^2 + 3,83C^2 \quad (1)$$

$$\text{Hardness} = 39,93 + 0,0027A + 0,094B + 5,36C + 0,00000081A*B - 0,00095A*C - 0,020B*C - 0,00000012A^2 - 0,00038B^2 + 1,4C^2 \quad (2)$$

RESULTS AND DISCUSSION OF MULTI RESPONSE OPTIMIZATION

Multi response optimization was performed using desirability function. The desirability function varies from 0 to 1 to meet the need of the objective. The skilled value is nearer to one.

Figure 2 depicts the perturbation of coded units vs surface roughness. It is evident that the surface roughness becomes minimum (2 – 4 µm) when the optimum milling parameters preferred in the ranges of (3 400 – 3 600 rpm) for spindle speed, (110 – 130 mm/min) for feed rate and (0,5 – 0,8 mm) for depth of cut.

Figure 3 depicts the perturbation of coded units' versus hardness. It is evident that the hardness becomes

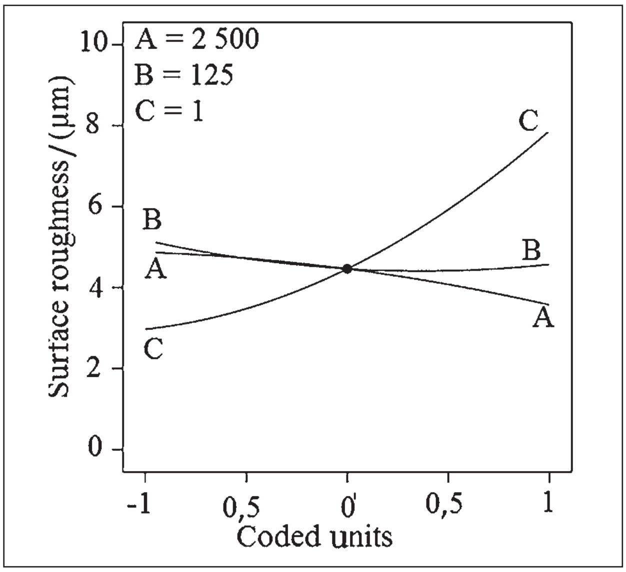

Figure 2 Perturbation analysis of Ra

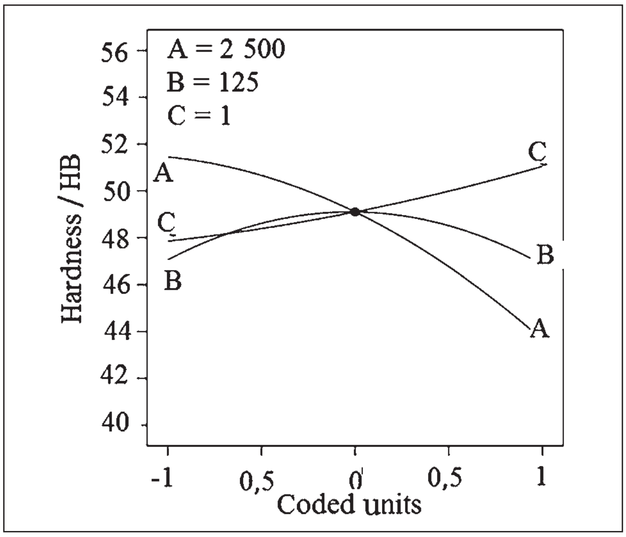

Figure 3 Perturbation analysis of hardness

maximum (47 to 51 HB) when the milling process parameters drops down between (1 400 – 1 800) rpm for spindle speed, (115 – 135 mm/min) for feed rate and (1,2 – 1,5 mm) for depth of cut**.** The Figure 4 overlay plot denotes that the maximum hardness of 49,1 HB and 2,64 μm as minimum surface roughness for the possible combination of process parameters of spindle speed 1 400,1 rpm, feed rate 164,60 mm/min and depth of cut 0,52 in the milling parameters carried out a highest desirability of 0,83. Higher the desirability value leads higher hardness and lower surface roughness.

The Figure 5 bar graph shows the single objective and combined desirability values for machining parameters and responses. The surface roughness achieves minimum at highest desirability of 0,92 and maximum hardness achieves at highest desirability of 0,74. The multi response optimized values achieves beneficial from combined solution of both the responses at highest desirability of 0,83.

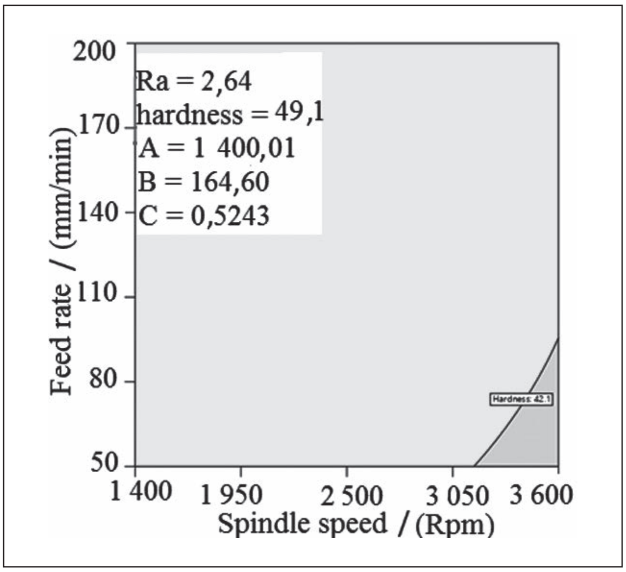

Figure 4 Overlay plot

SEM MICROGRAPH

The Figure 6 SEM micrograph of optimum combination of machining process parameters achieves less surface defects. The main forms of surface damage in machining of GFRP composites can be eliminated with the help of proper selection of cutting parameters during end milling process. It was ascribed from the Figure.6 , major feed mark occurred due to the high values of feed rate and re-deposited of tool or workpiece material was reduced.

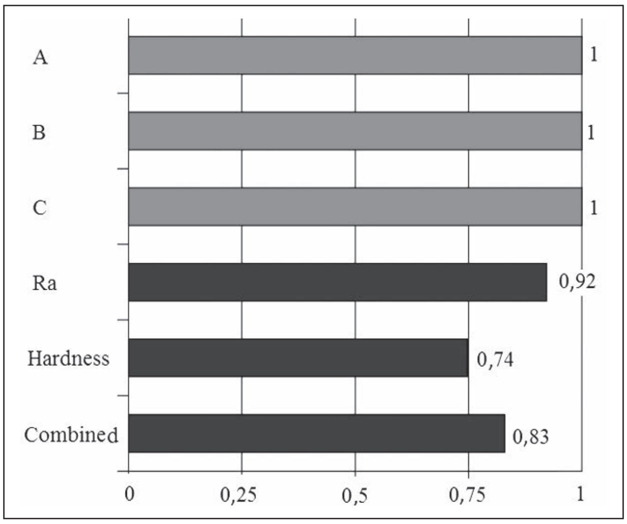

Figure 5 Bar graph of DFA

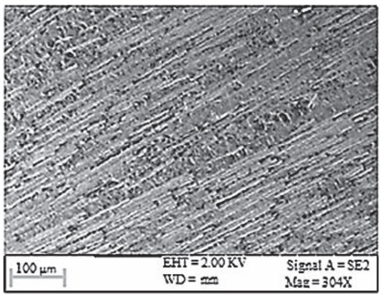

Figure 6 SEM micrograph of machined surface

CONCLUSION

Multi response optimization technique such as desirability function approach (DFA) was employed to find optimum machining parameters which provide beneficial responses.

- It has been observed that the depth of cut and spindle speed are high from F-statistical values and indicates that both the values have greater effect on responses compared to all other parameters.
- From the perturbation analysis of coded units versus surface roughness evidences portays that surface roughness becomes minimum (2 – 4 μm) when the optimum milling parameters preferred in the ranges of (3400 – 3 600 rpm) for spindle speed, (110 – 130 mm/min) for feed rate and (0,5 – 0,8 mm) for depth of cut.
- From the perturbation analysis of coded units versus hardness evidences portays that hardness becomes maximum (47 to 51 HB) when the milling process parameters drops down between (1 400 – 1 800) rpm for spindle speed, (115 – 135 mm/min) for feed rate and (1,2 – 1,5 mm) for depth of cut.
- The overlay plot denotes that the maximum hardness of 49,1 HB and 2,64 μm as minimum surface roughness for the possible combination of process parameters of spindle speed 1 400,1 rpm, feed rate 164,60 mm/min and depth of cut 0,52 in the milling parameters carried out a highest desirability of 0,83.

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Note: The responsible translator for English language is Dr. G. Mahesh, India.