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Research paper

Experimental Analysis of Surface Roughness While Drilling the Glass Fibre Reinforced Polymer Composite Materials using Response Surface Methodology

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Abstract

Drilling is the most widely used material removal process and contributes to be one of the most important processing techniques in almost all the assembly process. Composite material, in particular the glass fibre reinforced polymer composites, is an advanced family of materials, which keeps attracting the manufacturers since the marking of its existence. Drilling a glass fibre reinforced (GFR) polymer composites varies from drilling any conventional metal due to its anisotropic behavior. The article majorly focuses on optimizing the drilling process parameters viz., cutting parameters (cutting speed and feed), drill tool parameters (drill diameter) and material parameters (specimen thickness) to minimize the surface roughness. Response surface method is been used as the experimental analyzing tool to achieve the required machining quality. The results obtained clearly depicts that the chosen drill parameters significantly affects surface roughness value and optimizing the chosen parameters can enhance the machining quality

Keywords: Glass fibre reinforced polymer; composite materials; drilling, surface roughness; machining quality; response surface method

1. Introduction

The current world's material engineering sector, houses nearly fifty thousand variety of materials being used for the design and manufacturing of engineering appliances. These materials comprises of conventional materials viz., metals and alloys along with the advanced family of materials viz., composites, high performance steels, etc. The composite materials are those, formed by combining two physically different materials to deliver one single material at macroscopic level. Matrix materials (binders) and the reinforcing materials (actual functional constituent) are the basic components of any composite. Fibre reinforced polymers (FRPs), in particular the glass fibre reinforced polymers are one which finds its application in almost all the existing industrial sectors in the globe [1–3]. Drilling has proved to be the most widely used material removal machining operations and most suitable in almost all the assembly process. It is the most preferable operation used to clamp or join two composites together [4].

The drilling of composites differs from the drilling of conventional materials, as the machining quality is highly affected by the process parameters, causing damages viz. delamination, matrix cracking, increased surface roughness, etc., [5]. Surface roughness plays a significant role in the drilling operations of composites, especially when the past is subjected to fatigue and fastener loading conditions, which possibly can reduce by optimizing the drilling process parameters [6,7].

This article communicates the work focusing on the experimental analysis of surface roughness while drilling a glass fibre reinforced polymer wherein response surface method (RSM) is been employed to develop the empirical model based on the experimental analysis. Analysis of variance (ANOVA) is been used in the end to validate the model and determining the significant drilling process parameter.

RSM method in simple words is a statistical tool, utilized for engineering problem modelling and analysis. The experiment conducted utilizes RSM tool to establish the empirical relations between response (surface roughness) and drilling parameters [8].

2. Materials and Methods

GFRP is prepared using hand lay-up technique wherein the high-strength E-glass chopped fibre mat acts as the reinforcing fibre and the polyester resin is the biding matrix material. The laminate slabs in use for this experiment is of size 200 x 200 mm. The fibre-volume fraction of the prepared material is 63%. The top-most mat comprises of E-glass exhibiting the modulus of elasticity of 72,500 N/mm2 and the density of 2,590 kg/m3, whereas, the polyester resin has the elastic modulus of 3,250 N/mm2 and the density of 1,350 kg/m3.

High-speed steel (HSS) drill tool is been used in the work of four different diameter (3, 6, 10 and 12mm) and the experiment is conducted using the Denford TRIAC vertical machining center computer numerical center. Figure 1 represents the experimental setup been used for the work.

Fig.1: Experimental setup for conducting the drilling operation on GFRP

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The accomplishment of the surface roughness (Ra) measurement is achieved using the Taylor Hobson Surtronic 3+ instrument as depicted in Figure 2 wherein the final values are the average of four measurements been taken (parallel to hole axis) at four different portions of the GFRP.

Fig. 2: Surface measurement using Taylor Hobson Surtronic 3+ instrument

Table 1 represents the details of the chosen drilling parameters with their respective levels. To conduct the experiment, the full factorial method is used and analysis by using the central composite response surface method (CC-RSM). Figure 3 represents the pareto chart obtained from RMS, representing the significant factor.

Table 1:. Details of the drilling process parameters and respective levels

S. No	Parameters	Levels	
		-1	1
1	Feed (mm/min)	50	150
2	Speed (rpm)	600	1500
3	Material Thickness (mm)	3	12
4	Drill Diameter (mm)	3	12

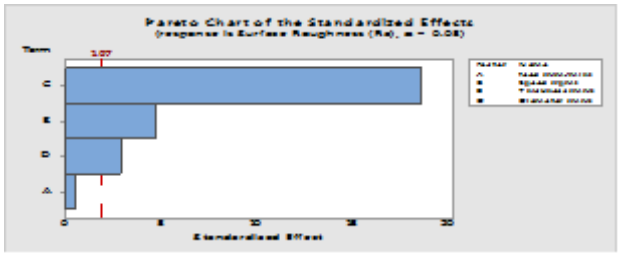

Fig. 3:. Significance chart for the parameters affecting the surface response

From the Pareto chart and the results from ANNOVA, it is evident that the material thickness affects most the surface roughness, followed speed and thickness. In simple words, it is been seen that the feed is statistically not a significant factor in the experiment. The effect of feed change on the surface roughness is determined to be the least. The equation 1 represents the coded linear regression response equation generated by the RMS analysis..

$$\mathbf{1.287} - \mathbf{0.00185}f + \mathbf{0.001526}s + \mathbf{0.5787}\,t - \mathbf{0.0911}\,d \quad \text{--- Equation 1}$$

$$\beta_0 + \beta_1 f - \beta_2 s + \beta_3 t + \beta_4 d \quad \text{---- Equation 2}$$

Wherein, f – Feed in mm/min, s – Speed in rpm, t – Thickness in mm and d – Drill diameter in mm. Table 2 given in this article represents the ANOVA results for the surface roughness (Ra).

Table 2:. Surface roughness - ANOVA results

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	1423.72	355.93	94.37	0.000
Linear	4	1423.72	355.93	94.37	0.000
feed (mm/min)	1	1.37	1.37	0.36	0.548
Speed (rpm)	1	83.83	83.83	22.23	0.000
Thickness (mm)	1	1306.12	1306.12	346.30	0.000
Diameter (mm)	1	32.40	32.40	8.59	0.004
Error	315	1188.08	3.77		
Total	319	2611.80			

Figure 4 represents the contour plots for (i) Surface roughness versus thickness and speed, (ii) surface roughness versus thickness and diameter and (iii) surface roughness versus speed and diameter. The most critical value of surface roughness obtained in the result is [F2S4T4D3] i.e. feedbeing 75 mm/min, speed at 600 rpm and thickness and diameter being 12 and 10mm respectively. Figure 5 represents the optimization curve at the highest surface roughness value. The dynamic optimization curve is been used to minimize the roughness by varying the speed while keeping all other factors constant. The prediction from the optimized response graph for changing the speed to 600 rpm from 1500 rpm, with rest all condition constant for the high Ra value, say that the surface roughness could be bought down to 8.143 i.e. a reduction of 39.16%. The experimental value of surface roughness attained for the said parametric value is 7.980, which is 2% better than the predicted theoretical value.

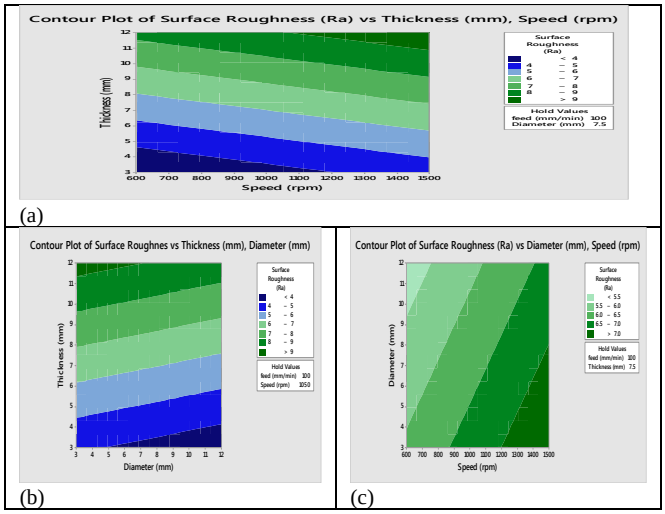

Fig.4: Contour plots of surface roughness versus most significant drilling parameters

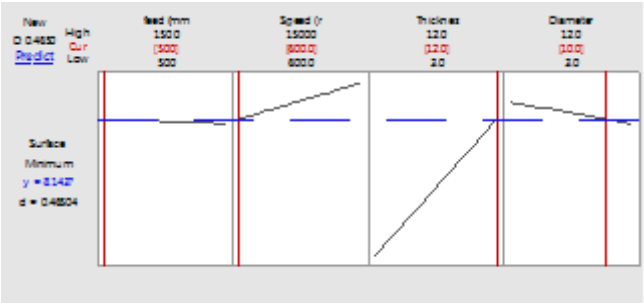

Fig.2: Optimized response plot for surface roughness

3. Conclusion

From the experimental analysis, it is been seen that the thickness of the material and drill size plays an important role with respect to the surface roughness. It is also been noted that the cutting speed remains to be the most affecting drilling parameter compared to the feed, which is the least significant parameter. From the optimization process, it is been observed that for a given material of specific thickness and while using a drill of specified diameter, the surface roughness can be minimized (machining quality can be improved) by changing the speed.

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