Effect of Vibration on Surface Roughness of Drilling on Glass Fiber Reinforced Plastic

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Abstract. In present scenario, Glass Fiber Reinforced Plastics (GFRP) has found to be highly influential in the field of manufacture of automotive and aerospace parts due to its high strength and lightweight characteristics. Processed GFRP components are assembled to the main structure by means of mainly rivets and fasteners. So, drilling in a GFRP material becomes inevitable in manufacturing for its wide applications. The purpose of this experiment is to conduct a study of the effect of vibration on surface roughness while drilling a GFRP plate using a 10mm HSS drill. The experiment has been implemented by varying the drill speed and feed accordingly in a 10mm thick GFRP plate and the respective vibration and surface roughness results were obtained. Furthermore, the results obtained have been processed in Minitab to provide a comprehensive understanding. ANOVA has been performed to establish a relation between the vibrations developed and surface roughness of the hole.

1. Introduction

GFRP are widely employed in automotive, aerospace and sporting equipment industries owing to its low weight, high strength and specific stiffness [1, 2]. A number of research papers have focused on the study of delamination, cutting force, thrust force and damage developed due to drilling in GFRP which have provided a broad understanding in machining GFRP. The surface roughness over a drilled hole in a GFRP is indispensable for assessing the hole quality as it affects the functionality of a component such as wear resistance, fatigue resistance and friction [3, 4]. Cutting speed, feed rate, thrust force, thickness of plate and drill point angle are some factors which have direct influence on surface roughness of the material [5, 6]. Among the various drilling parameters, feed and spindle speed are the major parameters affecting the surface roughness of the hole [7, 8]. Experiments determined that drilling methods and drill bits used also contribute significantly to the delamination of GFRP [9-11]. Analysis of Variance (ANOVA) has been utilized to study the effect of drilling parameters on surface roughness of the GFRP [12-14].

Suresh kumar M S [15] investigated surface roughness of drilled holes by varying the drill speed, feed, thickness of GFRP plate using Taguchi's L27 full factorial design. Further, ANOVA was performed to test the results and a mathematical model was designed based in Box-Behkn design method. The results indicated that low speed and low feed rate has less effect on surface roughness.

Isik Birhan [16] carried out experiments to investigate damage factor in drilling on hole entrance and exit using 8mm cemented carbide drill. The results revealed that the damage occurred at both hole...
entrance and exit were reduced when cutting speed is increased. On the other hand, increasing feed decreases hole quality at exit and affects inversely at hole entrance.

Ulas Hasan Basri [17] observed that the vibration developed in drilling process using HSS and carbide drill bit are directly proportional to the cutting speed and feed rate. It has been concluded that vibration effects should be minimized in order to maintain both precise dimensions and quality of the surface.

The vibration developed while drilling a GFRP cannot be eliminated but can be minimized to a considerable extent by selecting appropriate drilling parameters. When GFRP workpiece is subjected to external vibration, it has been found that the workpiece vibration affects thrust force and tool wear, which further influences the surface roughness of drilled holes [18, 19]. So, it is noticeable that excluding other factors, workpiece vibration also contributes towards surface roughness of a drilled hole. Experiments have been conducted by varying the speed and feed of the drill, and the respective vibrations occurred are noted. This study is aimed to find the direct effect of vibration on surface roughness developed while drilling a GFRP plate. Obtained results are interpreted via different forms of graph processed using Minitab and ANOVA has been performed to study the relationship between surface roughness and vibration occurred. Considering the quality of drilled holes, the results obtained from this study can be made use for dampening the workpiece vibration along a particular axis amplifying the surface quality of the drilled holes while maintaining other effective parameters.

2. Experimental work

2.1. Specimen preparation

The GFRP specimen used in this study is manufactured by hand lay-up technique. The glass fibers are reinforced with isophthalic resin with 30% of reinforcement and fiber length between 20mm to 30mm. The GFRP specimen size of 80mm × 120mm has been cut for conducting the experiment. Further, two 4mm holes were drilled alongside and tapped to fix the accelerometer rigidly with the help of screws.

![Figure 1. GFRP specimen plate.](image-url)
2.2. Methodology
The drilling experiments were carried out according to full factorial design consisting of 9 drilled holes on the GFRP plate. In this study, the drilling parameters, cutting speed and feed rate are used as control parameters and each parameter has three distinct levels as shown in Table 1. The workpiece has been drilled using a 10mm HSS drill bit in a vertical machining center(Siemens 802D) and the vibrations developed during drilling along x, y and z axes have been measured with the help of an accelerometer(Dytran 7543A). The vibrations were measured by placing the accelerometer as close as possible to the drilled holes to acquire precise measurements. Positioning the accelerometer at a different location does not directly affect the results but provides the results in terms of multiples and shows minimized values, so it is effective when placed close to the drilled hole. Finally, surface roughness tester(Mitutoyo SJ210) has been utilised to measure the surface roughness of each hole at the inner surface to ensure that the delamination at the rim does not affect the measurements. Three trials were taken for each hole and average of the three reading were considered for analysis.

Table 1. Control factors and three levels of variation.

| Factors     | Level 1 | Level 2 | Level 3 |
|-------------|---------|---------|---------|
| Speed (rpm) | 1000    | 2000    | 3000    |
| Feed (mm/min)| 40      | 80      | 120     |

3. Results and discussion
The results obtained from the experimentation are represented in Table 2. The results are fed into Minitab for statistical analysis and to establish regression models. With the help of these analyses and mathematical models, the effect of control parameters was studied and optimum values are found.
Table 2. Experimental results.

| Hole no. | Speed (rpm) | Feed (mm/min) | Vibration (mm) | Surface roughness (µm) |
|----------|-------------|---------------|----------------|------------------------|
|          |             |               | x-axis | y-axis | z-axis |               |                      |
| 1        | 1000        | 40            | -0.8069 | 1.561  | 9.42   | 6.648         |
| 2        | 1000        | 80            | -0.7571 | 1.627  | 10.21  | 7.635         |
| 3        | 1000        | 120           | -0.797  | 1.619  | 10.16  | 8.098         |
| 4        | 2000        | 40            | -0.792  | 1.627  | 10.50  | 7.961         |
| 5        | 2000        | 80            | -0.788  | 1.654  | 10.47  | 8.367         |
| 6        | 2000        | 120           | -0.807  | 1.770  | 10.69  | 5.496         |
| 7        | 3000        | 40            | -0.748  | 1.662  | 10.70  | 9.30          |
| 8        | 3000        | 80            | -0.826  | 1.639  | 15.17  | 7.981         |
| 9        | 3000        | 120           | -0.739  | 1.670  | 9.34   | 6.848         |

3.1. Analysis Of Variance (ANOVA)

ANOVA is widely used to determine significant relationship between two groups of variables. Table 3 represent the results of ANOVA conducted between the vibrations developed along the three axes and surface roughness of the drilled holes. When considering vibration as a factor, number of external interferences such as the bed of drilling machine, acoustic noise and temperature may have some effect on measuring vibration. The probability values exhibit the reliability of the derived results. The coefficients obtained are used to derive the regression equation which is used to derive predicted results for the required inputs.

Table 3. Analysis of Variance table.

(a)

|               | Coefficients | Standard Error | t Stat | P-value |
|---------------|--------------|----------------|--------|---------|
| Intercept     | 37.45652     | 15.64965       | 2.393441 | 0.062123 |
| x-axis        | 23.29576     | 14.44509       | 1.612711 | 0.167726 |
| y-axis        | -9.54506     | 6.519095       | -1.46417 | 0.203028 |
| z-axis        | 0.385479     | 0.248452       | 1.551523 | 0.181476 |

(b)

|                 | DOF | SS    | MS    | F      | Significance F |
|-----------------|-----|-------|-------|--------|----------------|
| Regression      | 3   | 4.751306 | 1.583769 | 1.537689 | 0.313926        |
| Residual        | 5   | 5.149834 | 1.029967 |         |                |
| Total           | 8   | 9.90114 |        |        |                |
Figure 4 represents the normal probability plots in which the points lie closer to the normal line. The versus fit has a symmetrical section between the upper and lower section of the versus line. The histogram figures follow a curve similar to the normal curve. The residuals in the versus order follows a non-uniform pattern and shows no trend. Thus, the residual plots show that there is a significant relation between the vibration developed along each axis and surface roughness.

3.2. Mathematical model

\[ R_a = 37.46 + 23.29(x\text{-axis}) - 9.54(y\text{-axis}) + 0.38(z\text{-axis}) \]  

Equation (1) is the derived regression equation for surface roughness. The equation also indicates that vibration along x-axis has more influence over \( R_a \). Since significance F value is comparatively lower than F value, it is clear that null hypothesis can be rejected.

The regression equation has been utilized to predict the surface roughness of the hole, provided that the vibrations along the three axes are given which in this case, are the measured results. Under a similar case, when the position of the accelerometer is adjusted, it provides results which are of multiples to that of the original results. The differences between the measured and predicted results
indicate the residuals. The residual of each hole and the variance percentage between the measured and predicted are shown in Table 4. The maximum and minimum variance percentages are 15% and 5% respectively, and the variance percentage changes averaged to 9.2%. Figure 5 represents the measured vs. predicted graph indicating that the predicted line follows a similar path to that of the measured line.

**Table 4. Residuals.**

| Measured | Predicted | Residuals | Variance percentage |
|----------|-----------|-----------|---------------------|
| 6.648    | 7.390542  | -0.74254  | 11%                 |
| 7.635    | 8.225226  | -0.59023  | 8%                  |
| 8.098    | 7.352811  | 0.745189  | -9%                 |
| 7.961    | 7.523992  | 0.437008  | -5%                 |
| 8.367    | 7.347894  | 1.019106  | -12%                |
| 5.496    | 5.882854  | -0.38685  | 7%                  |
| 9.3      | 8.292024  | 1.007976  | -11%                |
| 7.981    | 8.417581  | -0.43658  | 5%                  |
| 6.848    | 7.901075  | -1.05307  | 15%                 |

![Figure 5. Measured results vs. predicted results.](image)

**4. Conclusion**

The relationship between the surface roughness of drilled holes and vibration developed in GFRP composite has been studied. Mathematical models were generated in order to provide analytical results and are found to be reliable. Regression equation decisively indicates that the vibration along the x-axis influences surface roughness to a greater degree. So, it is evident that reduced vibration along x-axis while drilling can provide better surface roughness of the hole. Investigations in vibration dampening of work piece would further emphasize the reduction of surface roughness leading to an improved quality of drilled holes. In addition to that, GFRP being highly abrasive in nature, tool wear
also plays a crucial role in producing surface quality. Further research can be done taking tool wear into consideration to attain high surface quality of drilled holes.

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