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Statistical modelling and assessment of surface roughness in drilling of hybrid fiber composite

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Abstract In this article, the effects of conventional drilling parameters on the surface roughness of holes in hybrid fibre composites were investigated and quantified. A sample of a hybrid fibre composite with E-glass, hemp, and flax fibre reinforcements was fabricated by the hand lay-up method and subjected to drilling tests under different operating conditions by varying the drilling process parameters (drill diameter, spindle speed, and feed rate). The average surface roughness (Ra in µm) of the drilled hole was measured for each set of conditions. The results were subjected to statistical analysis (ANOVA) to determine the effects of process parameters on the measured variable. The calculations show that a combination of drill diameter and spindle speed, as well as drill diameter and feed rate, are the most important determinants of variation in bore surface roughness. A simple regression equation with linear terms was then established to model the observed interactions between the input and output variables. The equation was able to accurately model the behaviour of surface roughness, showing that this methodology can be extrapolated for use with different machining processes and/or materials. The 3-factor analysis ANOVA, performed with a confidence level of 95% and a statistical significance of a p-value less than 0.05, showed that the drill diameter ranked first and made the largest contribution (82.394% contribution), followed by the feed rate (16.719% contribution) and the spindle speed (0.6199% contribution). Regression modelling using linear regression yielded an R^2 value of 0.8015 and using the power-law equation yielded an R^2 value of 0.8796.

Keywords: surface roughness, hybrid fibre composite, drilling, ANOVA, regression

1. Introduction

Over the past few years technology has made the transition from finding the most suitable material for particular needs to fabricating the most appropriate material for a specific application. The processes of fabricating new materials have resulted in the creation of numerous composite materials that have targeted applications in specific domains. A composite material is a non-homogeneous specific mixture/arrangement of two or more materials In recent years, technology has made the transition from finding the most suitable material for specific needs to producing the most suitable material for a specific application. The processes used to produce new materials have led to the development of numerous composite materials that are targeted for use in specific areas. A composite material is an inhomogeneous specific mixture/arrangement of two or more materials that have different mechanical properties. Composites are developed to solve one or more engineering problems that require special materials with properties not normally found in naturally occurring materials. A typical composite material consists of 2 categories of materials - matrix/binder and reinforcing material. The matrix material is primarily used to shield the reinforcements and maintain their anisotropic properties; it also ensures that the applied load is distributed over the majority of the reinforcements to prevent load concentration. The reinforcing material is used to improve the material properties of the composite, provide directional properties, and support the applied loads. Composite materials are generally easy and economical to fabricate to meet a wide range of engineering requirements in areas with critical applications, such as aerospace (Puttegowda et al 2018), military applications (Navneeth et al 2020), electrical and electronic devices (Chung D D L 2003) , chemical engineering (Derbyshev et al 2015), fuel cells (Bashyam and Zelenay 2006), and many others (Mukbaniani et al 2019). In recent years, extensive research has been conducted to minimise the environmental impact and improve the sustainability of the composites manufacturing process. As a result, composites with interesting properties have been developed using unconventional materials such as banana fibres, jute (Easwara Prasad et al 2019), coconut fibres (Sarki et al 2011), hemp fibres, etc. along with advanced/synthetic materials such as e-glass, carbon nanotubes, Kevlar, silk, and many others. These composites are called hybrid fibre composites (Sathishkumar et al 2014). Hybrid fibre composites strike a balance between various factors such as required mechanical properties, cost effectiveness, sustainability, ease of disposal, and

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environmental impact. In their work (Jawaid and Abdul Khalil 2011), they have provided an overview of the main manufacturing methods and the mechanical, physical, electrical and thermal properties of cellulose reinforced hybrid fibre composites. According to (Panthapulakkal and Sain 2007), hybridization of hemp fibre composites with glass fibres improves the thermal stability of the material by increasing the decomposition temperature of the composite. In the experimental study conducted by (Muralidhar 2013), the tensile and compressive properties of plain weave epoxy composites reinforced with flax fabric were investigated and it was found that fibre volume fraction is an influential parameter for mechanical properties. Other researchers such as (Nagarajan et al 2017; Samsingh et al 2021) have analysed the effects of drilling process variables on thrust force as well as drilling torque acting on the workpiece during drilling of hybrid fibre composites and found that feed rate and spindle speed have a significant effect on these two parameters. Santhanam and Chandrasekaran (2014) studied the effects of feed rate and spindle speed on hole quality in drilling banana-glass fibre hybrid composites and found that the effects of fibre volume and spindle speed are not significant, while the effect of feed rate is significant. Researchers such as (Palanikumar et al 2012) and (Rajmohan and Palanikumar 2012) have obtained similar results in drilling of glass fibre reinforced composites and hybrid metal matrix composites, respectively. Surface roughness as a function of spindle speed, feed rate and tip angle has been studied for sisal reinforcement and red mud filler (Shanmugam et al 2021). Modelling of ANN was used (Rajmohan and Palanikumar 2011) to predict the surface roughness of hybrid composites during drilling. The surface roughness of carbon-glass hybrid composites was analysed (Tan et al 2016), and it was found that the surface quality is affected by the feed rate and tool geometry.

The objective of this research was to investigate the variations of hole surface roughness in relation to different drilling process variables in a hemp-flax-fibreglass hybrid composite. The composite sample used for the experiments was prepared by hand lay-up method. The process parameters to be investigated were selected for the experimental design at different stages, and drilling tests were performed on the composite. The results were subjected to statistical analysis to determine the relative magnitude of the effect of each parameter on surface roughness. The data were then used for regression analysis to build predictive models using the process parameters as inputs to estimate surface roughness.

2. Experimentation

2.1 Fabrication of HFC Sample

The resin and fibre materials used to prepare the composite sample were epoxy resin (Araldehyde LY556), hardener (Araldite) – HY951, fibre layers glass fibres of 0.2 mm (2 pieces), flax fibres of 0.35 mm (3 pieces) hemp fibres of 0.6 mm (2 pieces), gelcoat – liquid epoxy resin and release agent. The mechanical and physical properties of the fibres and matrix materials used are listed in Table 1.

For preparation, the mould to be used was cleaned and a layer of the release agent was applied to the surfaces to prevent the resin from curing and sticking to the mould walls. Layers of fibre reinforcement mats and resin coating were then applied alternately on top of each other, with the order of reinforcement stacking shown in Figure 1. The fibres were arranged in an orientation of 0◦ – 90◦ to each other. After applying each layer, a plastic sheet was temporarily placed over the top layer and pressure was applied to the fibre mats with a hand roller to ensure penetration of the resin for bonding the fibre laminates, squeeze out excess resin, achieve a uniform thickness of the composite sample, and remove any air bubbles trapped between the plies or in the resin. (The weight of the resin to be used was determined assuming a volume fraction of 50% reinforcement and 50% matrix material, the volume of resin required for this purpose was determined, and the mass was calculated based on the density of the resin. A small excess of resin was added to account for wastage). After this layering, the specimen was allowed to cure for 24 hours at room temperature. The final specimen thickness was measured and was 12 mm.

The composite sample was immersed in water until the absorption was saturated (m2). The sample was cut according to the fibre volume fraction and dried in an oven for 24 hours. It was heated to 50oC before cooling to room temperature. The process was repeated until the mass of the sample (m1) remained constant. The sample, which had been in the water bath for 24 hours, was removed and weighed once it was dried with a dry cloth. This procedure was repeated periodically at different time points. The weight gain was closely monitored during the procedure. The different weight fractions of the fibres were verified in this way (Muñoz and García-Manrique 2015).

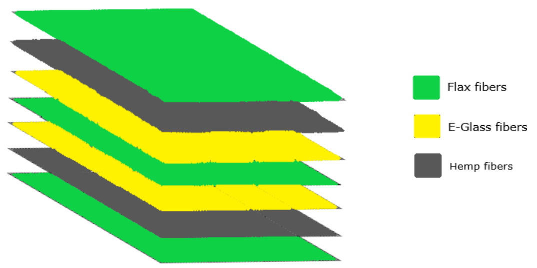

Figure 1 Stacking order of reinforcement fibres.

Table 1 Mechanical and physical properties of the fibre and matrix material.

Fibre	Density g/cm³	Tensile Strength MPa	Young`s Modulus GPa
E Glass	2.54	1750	72
Hemp	1.47	690	70
Flax	1.5	750	27.6
Epoxy	1.15	-	-
Hardener	0.946	-	-

2.2. Selection of process parameters and drilling trials

The work of (Samsingh et al 2021) and (Vimal Samsingh et al 2021) and the capabilities of the available drilling centre were considered when deciding on the process parameters to be considered for the experiments and the level of values to be assigned to each of them. Table 2 shows the parameters selected for the study and the values chosen for them.

Table 2 Process Parameters used in the study and levels.

	Parameter		
Levels	Feed rate (mm/min)	Spindle speed	Drill bit diameter (mm)
1	100	500	4
2	300	1000	6
3	500	1500	8

Since three parameters, each with three observation levels, were selected for the experiments, the experimental design was performed using Taguchi's orthogonal L9 array. The L9 array is shown in Table 3. Based on the above discussion, 9 experimental arrays with different combinations of process parameters were proposed for the drilling tests, as shown in Table 4. No lubrication was used in any of the drilling tests. This decision was made considering the results of the experimental analysis of lubrication levels in composite drilling (Fernández-Pérez et al 2019), according to which the lubrication level had little or no effect on the quality of the wellbore surface. It was also hypothesised that the absence of lubrication would lead to increased heat generation, which would soften the matrix material and facilitate drilling into the composite.

Table 3 Taguchi's L9 orthogonal array used.

Experiment	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

High-speed steel (HSS) drills with diameters and tip angles of 90◦ and 180◦ given in Table 4 were used for drilling. A vertical machining centre with a maximum spindle speed of 5000 rpm was used to perform the tests. The 9 drilling tests were performed on the previously fabricated HFC specimen. The experimental drilling setup is shown in Figure 2. Then, the average surface roughness Ra of each hole was measured with an electronic tool microscope over a gauge length of 4 mm. The instrument is shown in Figure 3. Figure 4 shows an example of the result of one of the measurements.

Figure 2 Experimental set-up with vertical machining centre and drill bit

Table 4 Process parameter values in experimental trials.

Trial No.	Feed Rate (mm/min)	Drill Diameter (mm)	Spindle Speed (rpm)
1	100	4	500
2	100	6	1500
3	100	8	1000
4	300	4	1000
5	300	6	500
6	300	8	1500
7	500	4	1500
8	500	6	1000
9	500	8	500

Figure 3 Toolmaker's microscope used for roughness measurement.

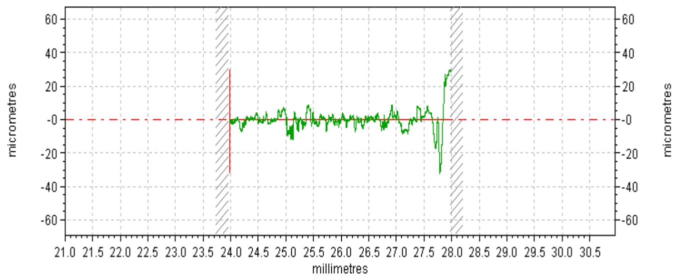

Figure 4 Microscope output of surface profile for one of the holes drilled.

3. Result and observations

The values determined in the individual tests for the surface roughness of the holes are listed in Table 5. Figure 5 shows the specimen image with the holes drilled with different drill diameters.

Table 5 Measurements of surface roughness in each trial.

Trial No.	Feed Rate (mm/min)	Drill Diameter (mm)	Spindle Speed (rpm)	Ra (µm)
1	100	4	500	5.8481
2	100	6	1500	3.6487
3	100	8	1000	3.326
4	300	4	1000	6.5648
5	300	6	500	3.6487
6	300	8	1500	3.7823
7	500	4	1500	7.5178
8	500	6	1000	4.7206
9	500	8	500	4.65

Figure 5 The sample specimen with the drilled holes.

Figures 6, 7, and 8 show the variations in mean bore surface roughness with each drilling process parameter, and the heat maps shown in Figures 9, 10, and 11 represent the simultaneous effects of two process variables on the variations in bore surface roughness. All charts have been created in Python.

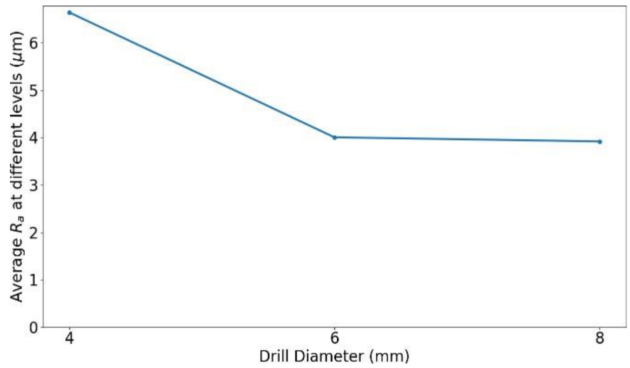

Figure 6 Variations in the surface roughness of the drilled hole against the Drill bit diameter.

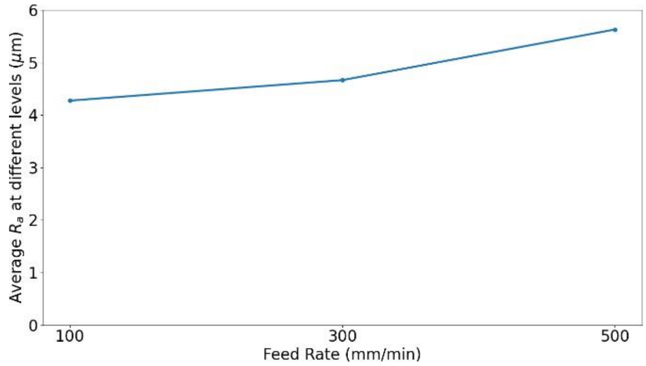

Figure 7 Variations in the surface roughness of the drilled hole against the Feed rate.

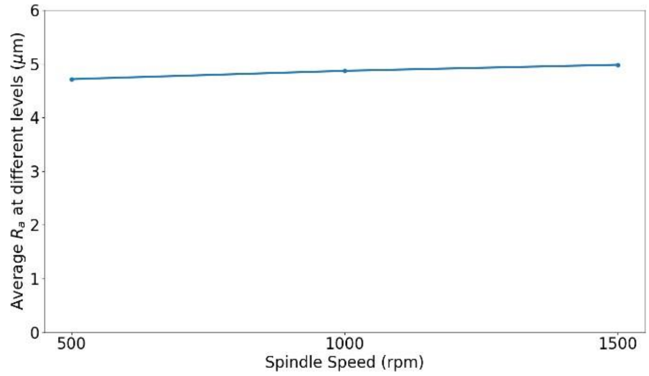

Figure 8 Variations in the surface roughness of the drilled hole against Spindle Speed.

The plots show that there was a clear upward trend with an increase in feed rate and a decrease in downhole surface roughness with the increase in drill diameter, while there was very little variation with spindle speed, indicating that it had little to no effect on surface roughness (Kumar et al 2016; Rajmohan and Palanikumar 2012). Another study of the effect of drill bit diameter on downhole surface roughness showed a sharp decrease when the diameter was increased from 4 to 6 mm, but only a marginal decrease in response when the drill bit diameter was increased further. These observations are in good agreement with those of (Parida et al 2015) and (Santhanam and Chandrasekaran 2014).

The increase in surface roughness with an increase in feed rate can be explained by the fact that at a higher feed rate, reinforcement fibres are likely to be pulled out of the matrix material, causing the sheared fibre ends to protrude from the borehole surface and contribute to roughness. In addition, the energy applied during drilling increases with higher feed rate and spindle speed, which can lead to local softening and globalisation of the matrix material, which hardens into non-uniform lumps and deposits on the bore surface.

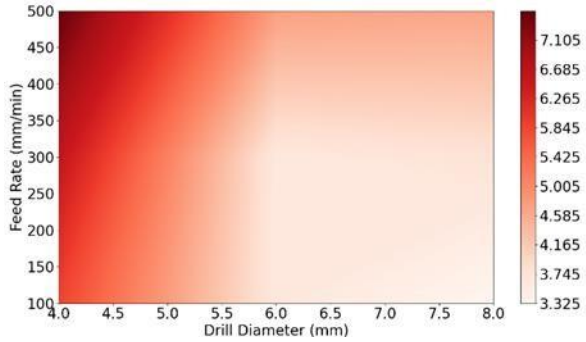

Figure 9 Variations in surface roughness with drill bit diameter and feed rate.

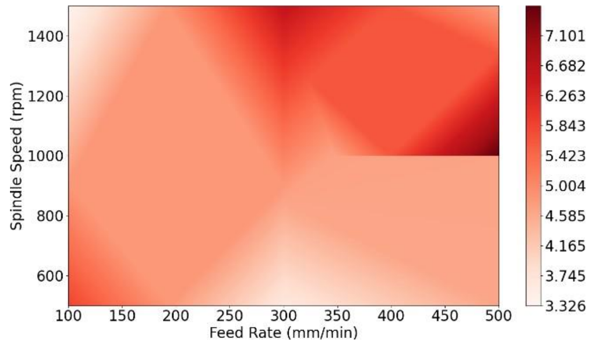

Figure 10 Variations in surface roughness with feed rate and spindle speed.

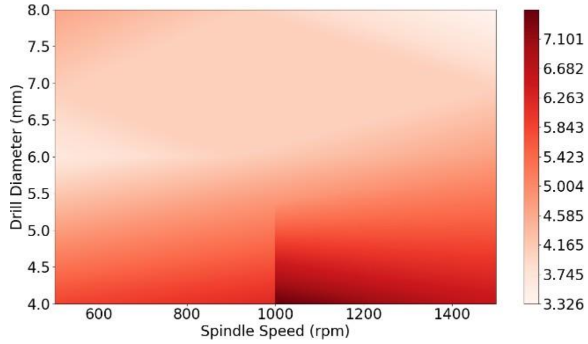

Figure 11 Variations in surface roughness with spindle speed and drill bit diameter.

4. Statistical analysis and modelling

4.1 Analysis of Variance

Analysis of variance (ANOVA) is a set of statistical procedures used for different purposes depending on the experimental methodology and the nature of the results being tested. A 3-factor ANOVA (the test used in this paper) is a mathematical test performed to determine the relationships between a given set of dependent and independent variables and to analyse the statistical significance of the contribution of the independent variables to the changes in the dependent variables. It can be used to rank the relative importance of the control variables based on their calculated contributions to the observed changes in the dependent variable.

Using a 95% confidence level for the analysis and an indication of statistical significance when the p-value is less than 0.05, a 3-factor ANOVA was performed under the experimental conditions with the collected data. The results of the analysis are shown in Table 6.

Table 6 ANOVA Results for Surface Roughness of Drilled Holes of HFC.

Source	DoF	Adj SS	Adj MS	F-Value	p-Value	% Contribution	Rank
Drill Diameter	2	14.3852	7.1926	308.02	0.003	82.394	1
Spindle Speed	2	0.1081	0.0541	2.31	0.302	0.6199	3
Feed Rate	2	2.9191	1.4596	62.51	0.016	16.719	2
Error	2	0.0467	0.0234	-	-	-	-
Total	8	17.4591	-	-	-	-	-

From Table 5, it is seen that the drill bit diameter was the process parameter with the most weightage, having a p-value of 0.003 (results are significant with a 99.7% level of confidence) and a percentage contribution of 82.4% to the variations in hole surface roughness. This was followed by the feed rate, which had a percentage contribution of 16.72% and statistical significance with a p-value of 0.016 (98.4% level of confidence). The calculations for spindle speed yielded a p-value of 0.302, indicating statistical significance with a confidence level of 69.8%, which was below the level required by the test, and was thus deemed to be statistically insignificant (it also showed a percentage contribution of only 0.62%). As each experimental trial had a unique set of process parameter values to be used, there were no repeated trials/conditions to be analysed, and so the effects and significance of interacting factors could not be calculated in the ANOVA.

4.2. Regression modelling

Following the above analysis, a Python script was written to generate a regression equation using the process parameters as independent variables to predict the dependent variable (surface roughness). The general linear regression equation (1) is in the following format:

$$(x_1, x_2, \dots x_n) = k_0 + k_1 x_1 + k_2 x_2 + \cdots k_n x_n \qquad (1)$$

where y is the dependent variable to be predicted, x1, x2, ...xn are the independent control variables, k1, k2, ...kn are the coefficients to the input variables and k0 is the y-intercept.

The regression modelling was performed using the numpy, pandas and sci-kit-learn modules, which are popular and well-documented Python packages widely used for data science applications. The linear regression modelling gave the following equation (2) to predict surface roughness:

$$R_a = 7.6588 + 2.67 \times 10^{-4} S + 3.388 \times 10^{-3} F - 0.681 D \qquad (2)$$

where S, F and D s represent the spindle speed (rpm), feed rate (mm/min) and drill bit diameter (mm) respectively. The linear regression model demonstrated a reasonably good fit to the experimentally determined values of roughness with an R^2 score of 0.8015.

In an attempt to create a model with a better fit to the data, a power-law formulation was proposed, wherein the inputs and output would be related in the form of equation (3).

$$R_a = c \times D^l \times S^m \times F^n \qquad (3)$$

To use the existing data to create such a model, the above equation was converted into a sum of logarithms as shown in equation (4).

$$\ln R_a = \ln c + l \ln D + m \ln S + n \ln F \qquad (4)$$

The available data were converted to logarithmic form and linear regression was performed using that data for the modelling, to obtain the values of ln c, l, m and n. This regression analysis yielded the power-law model equation (5) as follows:

$$R_a = 7.1895 \times D^{-0.79946} \times S^{0.01405} \times F^{0.15874} \qquad (5)$$

The power-law formulation achieved an R^2 score of 0.8796 and demonstrated a better fit to the experimental data than the linear model. The side-by-side comparison of the models' fit to the experimental data is shown in Figure 12.

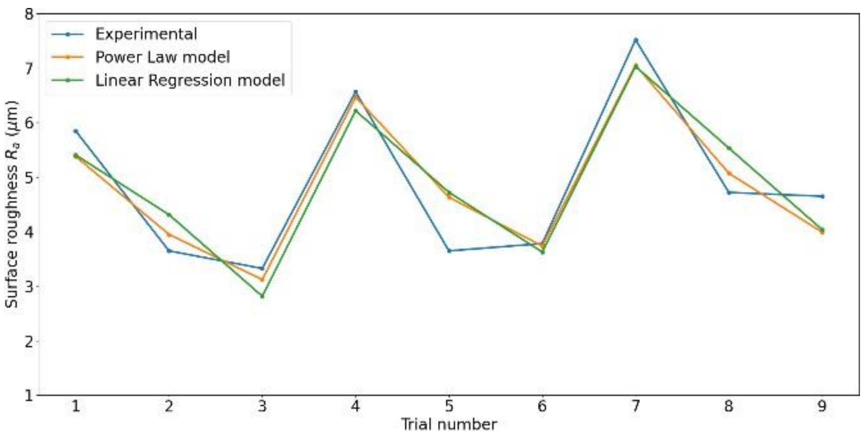

Figure 12 Comparison of experimental values and models

Table 7 Comparison of regression models.

Model	R^2	Mean% error	Absolute mean% error
Linear regression	0.8015	1.4435	12.9684
Power-law equation	0.8796	0.6154	8.8701

From the results in Table 7, it can be seen that the drill diameter has the greatest influence on the surface roughness of the drilled hole with a share of 82.394%, followed by the feed rate with a share of 16.719% and the spindle speed with a share of only 0.6199%. A similar trend is observed in the work of (Latha et al 2010).

5. Conclusions

The effects of drilling process factors such as spindle speed, feed rate, and drill diameter on hole surface roughness in hybrid fibre composites were studied experimentally. Based on the Taguchi experimental design using the L9 orthogonal array, a composite sample (with resin and hardener matrix and reinforcements of flax fibres, hemp fibres, and E-glass fibres) was prepared by manually layering the resin and fibres and used to conduct 9 drilling tests with different combinations of the above process parameters. The borehole surface roughness measured in each sample was recorded, and the contributions of each process variable to the variations in borehole surface roughness were determined using a statistical analysis of variance at the 95% confidence level. The analysis revealed that drill diameter was the parameter with the strongest influence, followed by feed rate, while spindle speed had a statistically insignificant influence. In addition, a cursory analysis of the data revealed a large decrease in bore surface roughness with an increase in drill diameter, a noticeable increase in feed rate, and an almost negligible but very subtle upward trend with an increase in spindle speed, consistent with the results of the statistical analysis.

Two predictive regression models were constructed based on the experimental results. The linear regression model provided a reasonable fit to the data with an R^2 value of 0.8015, while the power law regression model better predicted the values with an R^2 value of 0.8796. The results from ANOVA show that spindle speed has a negligible effect on surface roughness. In summary, the variation of surface roughness can be summarised as follows:

- Surface roughness decreases with increasing drill diameter.
- Surface roughness increases with an increase in feed rate.
- Surface roughness increases with an increase in spindle speed.

Future work in this area can include other process parameters such as temperature at the drill site, use of coolant, etc., in the experiments. Composite samples with different thicknesses and different stacking order and/or different reinforcing materials can be used for similar studies. Parameters can also be analysed at multiple levels of variation, and repeated tests can be performed to estimate the effects of interactions between process parameters on the ANOVA website. The use of machine learning techniques such as neural networks and fuzzy logic can be considered for predictive modelling of the output parameters, bringing one step closer to creating autonomous systems for predictive process control.

Ethical considerations

Not applicable.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

Bashyam R, Zelenay P (2006) A class of non-precious metal composite catalysts for fuel cells. Nature 443:63–66. DOI: 10.1038/nature05118

Chung DDL (2003) 4 Composite materials for electrical applications.

Derbyshev AS, Efimov AN, Sur'ev AN, Ladygin FA, Zholud' AS, Beresneva IA, Efremkina AI (2015) Prospects for Using Special Composites in Chemical Engineering. Chemical and Petroleum Engineering 50:745–748. DOI: 10.1007/s10556-015-9972-8

Easwara Prasad GL, Megha BE, Keerthi Gowda BS (2019) Study of mechanical characteristics of banana and jute fibre reinforced polyester composites. In Conference Proceedings of the Society for Experimental Mechanics Series (pp. 23–29). Springer New York LLC. DOI: 10.1007/978-3-319-95510-0_3

Fernández Pérez J, Cantero JL, Díaz-álvarez J, Miguélez MH (2019) Hybrid composite-metal stack drilling with different minimum quantity lubrication levels. Materials, 12(3). DOI: 10.3390/ma12030448

Jawaid M, Abdul Khalil HPS (2011) Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers 86:1–18. DOI: 10.1016/j.carbpol.2011.04.043

Kumar D, Singh KK, Zitoune R (2016) Experimental investigation of delamination and surface roughness in the drilling of GFRP composite material with different drills. Advanced Manufacturing: Polymer and Composites Science 2:47–56. DOI: 10.1080/20550340.2016.1187434

Mukbaniani OV, Balköse D, Susanto H, Haghi AK (2019) Composite materials for industry, electronics, and the environment: research and applications. CRC Press.

Muñoz E, García-Manrique JA (2015) Water absorption behaviour and its effect on the mechanical properties of flax fibre reinforced bioepoxy composites. International Journal of Polymer Science 2015. DOI: 10.1155/2015/390275

Muralidhar BA (2013) Tensile and compressive properties of flax-plain weave preform reinforced epoxy composites. Journal of Reinforced Plastics and Composites 32:207–213. DOI: 10.1177/0731684412469136

Nagarajan V, Kumar V, Samsingh V (2017) Artificial intelligence modelling and analysis of pivotal parameters in drilling hybrid fibre composite (HFC). FME Transactions 45:641–646. DOI: 10.5937/fmet1704641N

Navneeth V, Pranaav Sankar S, Saran Prasanth RR, Vimal Samsingh R (2020) Investigation on the mechanical and stealth behaviour of CNT-based polymer composites. Materials Today: Proceedings 39:1682–1687. DOI: 10.1016/j.matpr.2020.06.152

Latha B, Senthilkumar VS (2010) Modeling and analysis of surface roughness parameters in drilling GFRP composites using fuzzy logic. Materials and manufacturing processes 25:817-827. DOI: 10.1080/10426910903447261

Palanikumar K, Latha B, Senthilkumar VS, Davim JP (2012) Analysis on drilling of glass fibre-reinforced polymer (GFRP) composites using grey relational analysis. Materials and Manufacturing Processes 27:297-305. DOI: 10.1080/10426914.2011.577865

Panthapulakkal S, Sain M (2007) Injection-moulded short hemp fibre/glass fibre-reinforced polypropylene hybrid composites -mechanical, water absorption and thermal properties. Journal of Applied Polymer Science 103:2432–2441. DOI: 10.1002/app.25486

Parida AK, Routara BC, Bhuyan RK (2015) Surface roughness model and parametric optimization in the machining of GFRP composite: Taguchi and Response surface methodology approach. Materials Today: Proceedings 2:3065-3074. DOI: 10.1016/j.matpr.2015.07.247

Puttegowda M,Rangappa SM,Jawaid M,Shivanna P, Basavegowda Y, Saba N (2018) The potential of natural/synthetic hybrid composites for aerospace applications. In Sustainable Composites for Aerospace Applications 315-351. Elsevier. DOI: 10.1016/B978-0-08-102131-6.00021-9

Rajmohan T, Palanikumar K (2011) Ann model to predict surface roughness in drilling hybrid composites. Advances in Production Engineering and Management 6:281–290.

Rajmohan T, Palanikumar K (2012) Optimization of machining parameters for surface roughness and burr height in drilling hybrid composites. Materials and Manufacturing Processes 27:320–328. DOI: 10.1080/10426914.2011.585491

Samsingh V, Ramachandran A, Selvam A, Subramanian K (2021) Python implementation of fuzzy logic for artificial intelligence modelling and analysis of important parameters in drilling of hybrid fibre composite (HFC). IOP Conference Series: Materials Science and Engineering 1012:012037. DOI: 10.1088/1757-899x/1012/1/012037

Santhanam V, Chandrasekaran M (2014) A study on drilling behavior of banana-glass fiber reinforced epoxy composite. Indian Journal of Applied Research 4.

Sarki J, Hassan SB, Aigbodion VS, Oghenevweta JE (2011) The potential of using coconut shell particle fillers in eco-composite materials. Journal of Alloys and Compounds 509:2381–2385. DOI: 10.1016/j.jallcom.2010.11.025

Sathishkumar TP, Naveen J, Satheeshkumar S (2014) Hybrid fibre reinforced polymer composites - A review. In Journal of Reinforced Plastics and Composites 33:454–471. DOI: 10.1177/0731684413516393

Shanmugam V, Marimuthu U, Rajendran S, Veerasimman A, Basha AM, Majid MSBA, Neisiany RE, Försth M, Sas G, Razavi SMJ, and Das O (2021) Experimental investigation of thrust force, delamination and surface roughness in drilling hybrid structural composites. Materials 14. DOI: 10.3390/ma14164468

Tan CL, Azmi AI, Muhammad N (2016) Delamination and Surface Roughness Analyses in Drilling Hybrid Carbon/Glass Composite. Materials and Manufacturing Processes 31:1366–1376. DOI: 10.1080/10426914.2015.1103864