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Fabrication and Drilling Characterization of Hemp & Grewia-Optiva Hybrid Composite and Comparison with ANN Model

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Abstract

In recent days the use of natural fibers has increased over synthetic fibers due to various advantages. The alkali treatment for these natural fibers further improves the adhesion between fiber and matrix and greatly enhances the mechanical properties of the composite. The present study involves the fabrication of a hybrid composite using the alkali-treated (5% NaOH concentration) natural fibers – Hemp &Grewia-optiva as reinforcement material and epoxy as a matrix material with a hand lay-up technique while maintaining the maximum fiber content at 12% of the composite. The drilling operation was performed on the fabricated hybrid composite to characterize the output parameters such as thrust force and torque while the input parameters are feed rate, cutting speed, and drill bit diameter. Further, the artificial neural network (ANN) approach was also adopted to predict and compare the thrust force and torque with experimental results. The results of experimental drilling parameters, predicted parameters with the ANN model, and a comparison of both are discussed in this paper. The results show a maximum error of 4% between the predicted and experimental values.

Keywords: *Feed, Thrust Force, Torque, Alkali Treatment, ANN*

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INTRODUCTION

In the last few years, there has been a growing paradigm shift towards sustainable and eco-friendly materials, driven by a collective global effort to address environmental concerns and promote sustainable practices. In this context, natural fiber composites have emerged as a promising alternative in various industrial applications, garnering increasing attention from researchers, engineers, and industries alike. Natural fiber composites are composed of a matrix reinforced with fibers derived from renewable resources, such as plant fibers (e.g., jute, flax, hemp) and animal fibers (e.g., wool, silk). These composites offer a compelling array of advantages, including but not limited to their lightweight nature, ease of sourcing, affordability, non-toxicity, and inherent eco-friendliness. The pursuit of eco-friendly materials has fueled research endeavors aimed at exploring the full potential of these composites across diverse fields. Natural fiber-reinforced polymer (FRP) composites are not only biodegradable and cost-effective but also environmentally friendly and impermeable to electromagnetic radiation [1]. Composites in combination with more than one high performing fibers, such as glass, carbon, Kevlar, and basalt the obtained materials are defined as hybrid composites [2]. In contrast to synthetic fibers, natural fibers are readily accessible locally, demand less chemical treatment, and involve lower costs for the Natural fiber-reinforced polymer (FRP) composites are not only biodegradable and cost-effective but also environmentally friendly and impermeable to electromagnetic radiation [3]. The present study is on the fabrication of hemp and Grewia-optiva (Bhimal) hybrid composite reinforced with epoxy resin (LY556) and hardener (HY951). Previous academics have published in-depth analyses on natural fiber as a reinforcement composite by using

Artificial Neural Network (ANN) for drilling operations. Athijayamani et al. [4] have reported that Artificial Neural Network (ANN) models can be used effectively for predicting the thrust force and torque in drilling of roselle/sisal hybrid composite.

Satish Pujari et al. [5] have revealed that the feed-forward ANN model could be a very good mathematical tool for predicting swelling behavior characteristics of banana and jute fiber Composites. Boopathi et al. [6] have reported the effects of various natural fibers on the mechanical and drilling characteristics of coir-fiber-based hybrid epoxy composites with reinforcement of various natural fibers (Coir, Jute, Flax, Cotton, Human hair, Sisal, Kenaf, and Calotropis). The examination of the drilling of a natural fiber reinforced polymer composite material manufactured using jute fiber, isophthalic polyester matrix, and a solid lubricant through hand layup technique with appropriate pressure has been reported by Pradeep et al. [7].While it was discovered that the forces produced by various drill tools varied, it was determined that the force produced by drilling with a tungsten carbide tool produced superior results. Jayabal et al. [8] have reported on the drilling of natural coir reinforced plastics revealing that the thrust force and torque are significantly affected by the feed rate. Their findings suggest that optimal machining conditions are achieved with a medium feed rate of 0.2 mm/rev, a high-speed of 1503 rpm, and a medium drill diameter of 8 mm. Vinayagamoorthy et al. [9] have investigated thrust force and torque during drilling on the developed bio-degradable sandwich composites and analyzed using the response surface methodology and non-linear regression. Using fuzzy logic for optimization, Vinayagamoorthy et al. [10] also looked into the drilling parameters on natural fiber reinforced composite. What he discovered was that the thrust force and torque were primarily influenced by the speed feed and point angle parameters.Mahadevappa et al. [11] have reported that at cutting speed, feed rate and hole diameter process parameters significantly influence thrust force, torque, and delamination at both the entry and exit points of the hole in sisal fabric herringbone reinforced epoxy composites. Specifically, these parameter values result in the minimum required effort. Erkan et al. [12] have reported ANN model can be used effectively to predict the damage factor in end milling of glass fiber reinforced plastic composites. Khashaba et al. [13] have documented the outcome of drilling parameters feed, speed, and drill pre-wear on the machinability parameters thrust force, and torque in drilling woven glass fiber-reinforced by using an Artificial neural network and multivariable regression model. The correlation coefficients for each of the training, validation, and test data sets for the developed ANNs approach to one, which gives a strong indication that the obtained ANNs can be used effectively to model and predict thrust force, torque, peel-up, and push-out delamination, surface roughness, and bearing strength. Issam Hanafi et al. [14] have reported that ANN modeling is efficient in the context of predicting machining criteria for composite materials. Balaji et al. [15] have investigated the creation of a model using an artificial neural network to forecast how cutting parameters will affect the thrust force, torque, and delamination factor of composites made of zea fiber and polyester.Wang et al. [16] have reported drilling of carbon fiber-reinforced polymer (CFRP) by using ANN-genetic algorithm (GA) for predicting the specific cutting force coefficients and their results showed that the proposed model can predict the instantaneous cutting forces in carbon fiber-reinforced polymer drilling. Model predictions agree well with experimental data and are beneficial for optimizing the machining processes of CFRP composite laminates. Mercy et al. [17] have investigated the impact of variables such as spindle speed (N), feed rate (f), and drill bit diameter (d) on the drilling process of biocomposite mats comprising pineapple fiber and epoxy resin and Genetic algorithm was used for optimizing thrust force. Belaadi et al. [18] have reported the effect of jute fiber length and drilling parameters of biocomposites by using RSM, ANN, and GA and it was found that ANN model is more accurate than the other model. Ranakoti et al. [19] have investigated the mechanical, and wear properties of hybrid Jute/Grewia-optiva fibers laminates and analysis of composite was done by ANOVA technique. Kumar and Mandal used Response surface method (RSM) based optimisation of advanced mechanochemical approach for bead minimisation in bamboo fiber extraction [20]. Goutham et al. [21] have discussed the effects of variables such as feed rate, drill bit diameter, and geometry on the drilling capabilities of natural fiber composites. Reduced thrust force and torque are achieved by minimizing delamination at the entrance and exit by decreased feed rates and low-to-moderate spindle speeds. Statistical methods such as analysis of variance (ANOVA) and gray relational analysis, which rely on the output variables, can be used to find the optimal input parameters. In their study, Rjesh et al.[22] examined Al-Hybrid Fibre Metal Laminates (HFMLs) reinforced with fibers derived from basalt, hemp, and bamboo. This included commercial-grade Al6061 alloy mesh (Al-DMEM) made by compressing sustainable fibers into a variety of stacking configurations. The results showed impressive mechanical and structural properties.

Hence, from the literature, it was found that limited work has been carried out on the drilling characterization of hemp &Grewia-optiva natural fiber hybrid composite. Therefore, the present study is focused on the characterization of on thrust force and torque of the fabricated hybrid Hemp/Grewia-optiva fiber composite and compares the experiment and predicted values of thrust force and torque by ANN

MATERIAL AND METHOD

Materials

The plant-based fiber, Grewia-optiva, was collected from the local village area of Chakrata Dehradun, Uttarakhand, India, and hemp fiber was collected from Uttarakhand bamboo and fiber developmentboard Dehradun. Epoxy resin LY 556 as a matrix material (density 1.2 g/cm^3) and hardener HY 951 (density 1.05 g/cm^3) were supplied by Northern Polymers (Pvt.) Ltd. New Delhi, India, whereas NaOH was acquired from Central Drug House (P) Ltd., India, for the alkaline treatment of natural fiber.

Development of Hybrid Composite

The collected hemp and Grewia-optiva fibers were chemically treated with a 5% wt./v sodium hydroxide (NaOH) (i.e., 100 gm of NaOH in 2 liters of distilled water) solution at 60°C to enhance the fibers' surface properties. This treatment involves immersing the fibers, where NaOH acts to break down hemicellulose, remove impurities, and increase wettability. The modified surface chemistry improves adhesion between the fibers and the polymer matrix, like epoxy resin, leading to enhanced mechanical properties in resulting composites. The chemically treated fibers were cleaned with purified water. The clean fibers were arranged bi-directionally to form a bi-directional mat of 200 mm x 200 mm as shown in Figure 1. Using the hand lay-up method, the Grewia-optiva/hemp fiber hybrid composite was fabricated with different layer arrangements and epoxy as a matrix material.

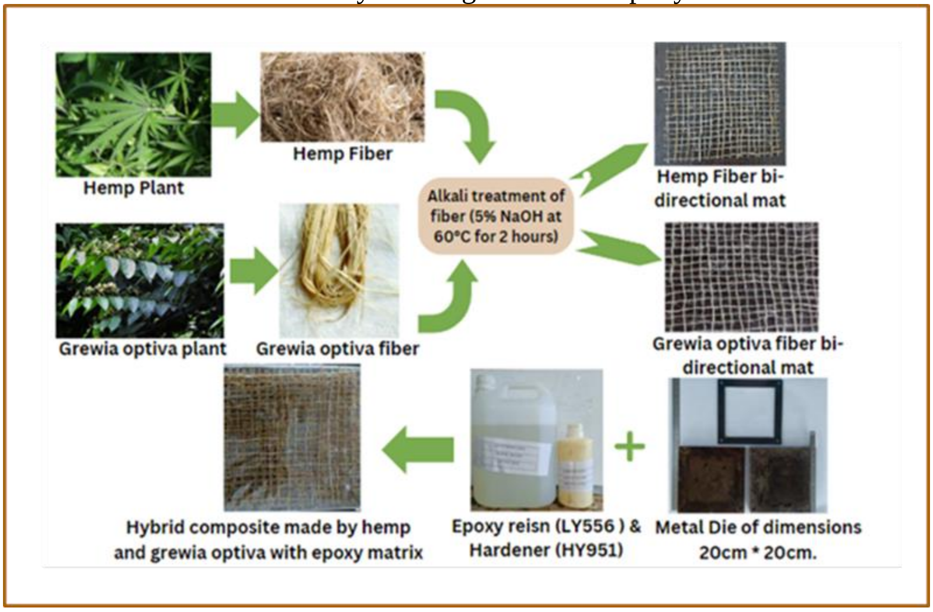

Fig.1: *Steps in Development of Hemp/Grewia-OptivaFiber Hybrid Composite*

Experimental setup of drilling

In the present work, drilling operations are conducted on natural fiber hybrid composites using a FLEXMIL CNC machining center with standard constant geometry high-speed steel (HSS) twist drills shown in Figure 2. A piezoelectric drill dynamometer (Kistler, Type: 9272) was used to note the thrust force and torque signals during the drilling processes, and torque and thrust force exerted on the drill bit are recorded from the DynoWare software. The FLEXMILL CNC machine was programmed to follow a particular path by considering the drilling bit diameter. The drill diameter, feed rate, and cutting speed of the drill were considered as input process parameters and varied during the drilling operation as tabulated in Table 1.

Table1: *Machining Parameters used for Drilling Composite*

S.No.	Drill Diameter(mm)	Feed Rate (mm/min)	Cutting Speed (rpm)
1	3	20	500
2	5	30	1000
3	7	40	1500

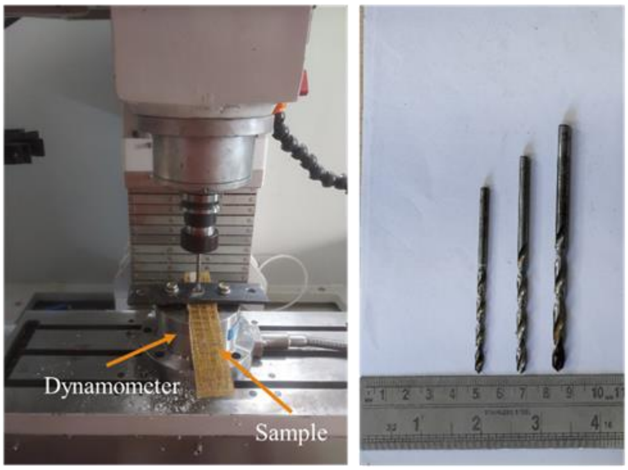

Fig.2: *DrillingExperimental Setup*

ANN MODELING

Neural networks, simplified models inspired by the biological neuron system, constitute a massively parallel distributed processing system comprising interconnected neural computing elements. These elements possess the capability to learn, acquire knowledge, and make it accessible for various applications. Leveraging extensive datasets, from which they construct knowledge bases, artificial neural networks (ANN) develop analytical models to address problems in estimation, prediction, decision-making, and diagnosis. The general ANN architecture model is shown in Figure 3.The choice of the ANN model in this study was determined by evaluating the degree of data fitting and predictive capabilities of the developed models. Based on the precision of the forecasts, feed-forward backpropagation networks were chosen to train flexural strength. The feed-forward back-propagation algorithm, recognized as one of the most established training algorithms for multilayer perceptrons, employs a gradient descent technique to minimize errors for specific training patterns. This involves adjusting the weights incrementally. The development of predictions using the ANN model was carried out using MATLAB R2019b. Supervised learning was chosen as the preferred method among supervised, unsupervised, and reinforcement learning to enhance the network's performance. The training process involved the utilization of the back-propagation algorithm within layered feed-forward Artificial Neural Networks (ANNs). In this configuration, artificial neurons are structured in layers and transmit signals in a forward direction. Subsequently, errors are retroactively propagated. The network's input layer receives inputs, while the output layer produces the network's output. Through the back-propagation algorithm, which employs supervised learning, the network computes the error, representing the disparity between actual and expected outcomes. The back-propagation algorithm's primary goal is to fix errors using the steepest-decent method possible.

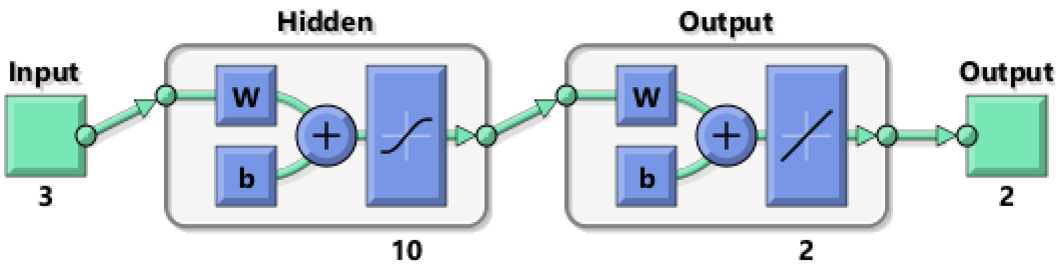

Fig.3:*General ANN architecture model*.

RESULTS AND DISCUSSION

Trust force and Torque

To capture the thrust force and torque produced during drilling operations, a drill dynamometer of the Kistler Type 9272 was employed. A piezoelectric sensor is strategically positioned to detect the axial forces exerted along the drilling axis. It was noted that the lower feed rates led to low thrust forces, while higher feed rates significantly increased the thrust force, possibly due to an augmented shear area of hybrid composite. The dimensions of the drill and cutting speed also played a major role, as an escalation in drill size resulted in higher thrust forces and torque, attributed to the increased shear area. Therefore, it can be concluded that the best machining can be performed at low cutting speed and feed rate which leads to lower thrust force and torque, and utilizing a smaller drill bit diameter can enhance stability during the machining process of hybrid hemp/Grewia-optiva composite as shown in figure 4.

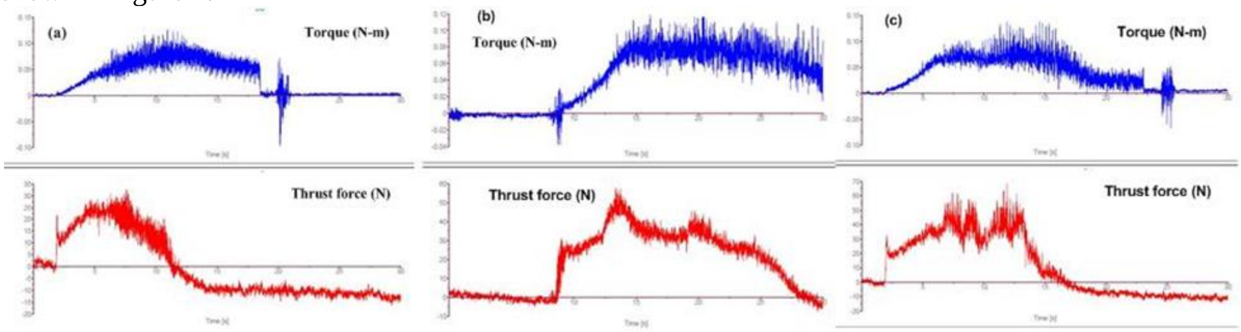

Fig.4:*Thrust force and torque signal drill diameter 3 mm at (a) Feed rate 20 mm/min, 500 rpm (b) feed rate 30mm/min. 1000 rpm (c) feed rate 40mm/min. 1500rpm*

ANN OUTPUT

The input parameters for training the neural networks consisted of spindle speed, feed, and drill bit diameter, while the output responses included torque and thrust force. The Feedforward Back-propagation algorithm was employed for training the artificial neural network (ANN) in MATLAB R2019b software with a total of 27 patterns. The training process was conducted without specifying any allowable error. The maximum number of training epochs was established at 1000, resulting in the training of the Artificial Neural Network (ANN) over 1000 iterations. The Regression (R) value serves as an indicator of the correlation between outputs and targets shown in Figure 5 (a). An ideal scenario is represented by an R-value of one, indicating a strong connection between targets and outputs, while R values approximately equal to 0.98 for training data, validation data, testing data, and the overall dataset, it can be concluded that there exists a close and substantial relationship between the targets and outputs in all instances. The breakpoint for thrust force and torque was deemed ideal by ANN at gradient 0.084133 and gradient gain (Mu) 1e-5, when the gradient was recorded at the 23rd iteration and the epoch with the lowest validation error yields the highest performance. The gradient and training gain's modest values suggest that there is little variation between the output and the target. Beyond this point, the validation bias exceeded the anticipated allowances, as shown in Figure 5 (b). The Mean Square Error (MSE) chosen for training is shown in Figure 5 (c) alongside the epoch, showing a decrease in MSE as the epoch grows, and stabilizes at epoch 17. As illustrated in Figure 5 (d), the ANN model generates the distributed error histogram with a 20-bin interval utilising test, validation, and learning errors. It is evident that the mistakes were positioned in close proximity to the line of zero. Despite this stabilization, training persisted for additional iterations until it eventually halted. The error reached a level below 4%, which is considered acceptable. The crucial step of validating the network was accomplished by generating a regression plot.

Comparison of Experimental & ANN Output

Figures 6 and 7 show the comparative graphs of the experimental values and ANN-predicted values for thrust force and torque, respectively. It can be observed that high prediction accuracy was indicated by the ANN predicted values, which closely match with the experimental values. Thus, it can be concluded that the predictive model is useful in determining thrust force and torque. The principal goal of this study was to aid users in scrutinizing, contrasting, and determining optimal drill diameter and suitable cutting parameters to achieve process optimization in the drilling of hybrid Hemp/Grewia-optiva fiber composites.

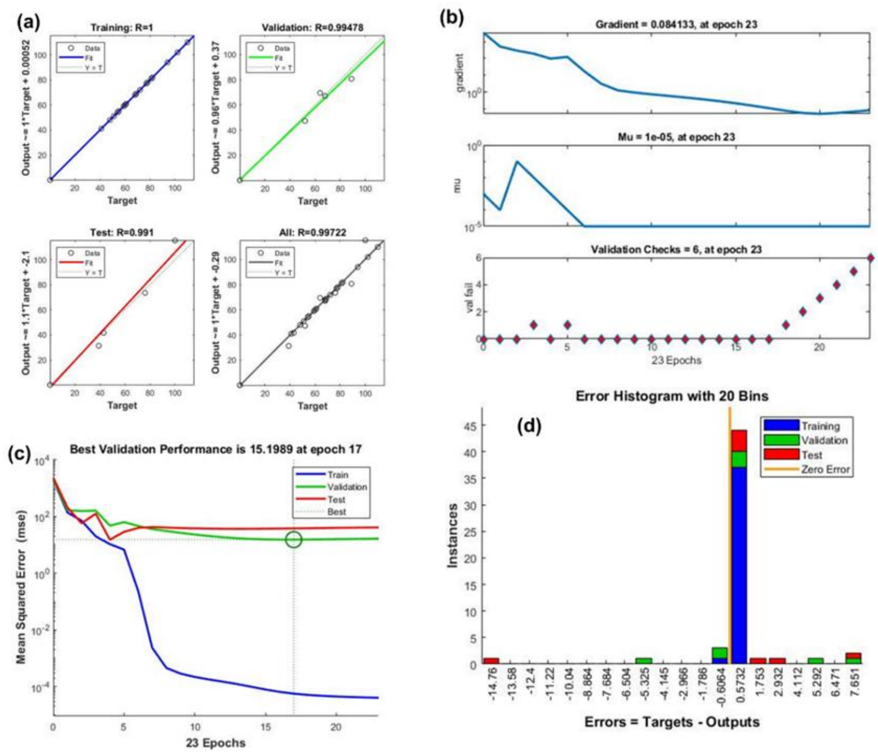

Fig.5:*ANN Plots for thrust force and torque (a) Regression plots (b) Training results (c)Validation results (d) Error results.*

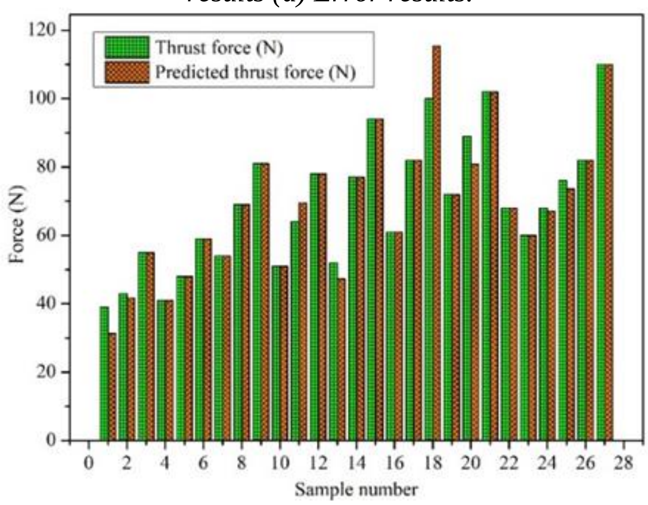

Fig.6:*Experimental thrust force vs. predicted thrust force using ANN model.*

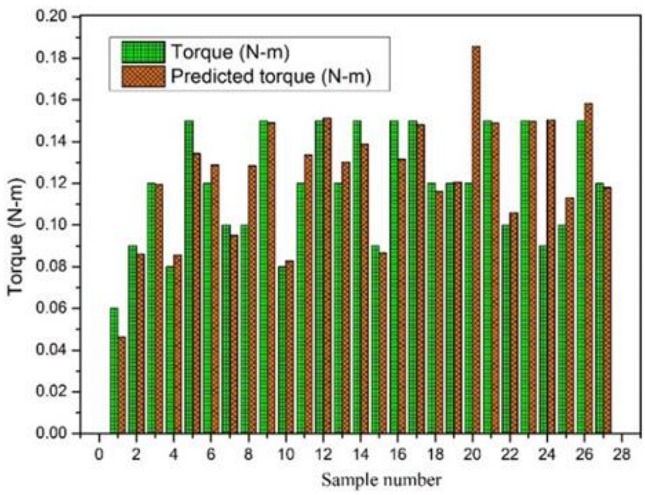

***Fig.7:** Experimental torque vs. predicted torque using ANN model.*

CONCLUSIONS

This study examined the effects of drill bit diameter, feed, and spindle speed on thrust force and torque during the drilling of hybrid hemp/Grewia-optiva composites. The study revealed that machining parameters significantly influenced the thrust force and torque factor during the drilling of hybrid hemp/Grewia-optiva composites. Utilizing an Artificial Neural Network (ANN) model improved the accuracy of predicting the machining behaviors of hybrid hemp/Grewia-optiva composites, with an average absolute percentage of error of less than 4%. In order to forecast thrust force and torque factors in hybrid hemp/Grewia-optiva composites under various drilling conditions, a methodical technique was created using the artificial neural network (ANN) method. The investigation of drilling characteristics aimed to explore the potential for manufacturing engineering products using hybrid hemp/Grewia-optiva composites.

This experimental investigation of Hemp &Grewia-Optiva woven hybrid composites has led to the following specific conclusions:

- Successful fabrication of Hemp &Grewia-Optiva woven hybrid composite by using hand lay-up technique.
- The observation indicated that both thrust force and torque exhibit an increase as the drill diameter, feed, and cutting speed increase. This escalation is attributed to the corresponding rise in the shear area of woven hybrid composite, therefore it can be concluded that the drill diameter and spindle speed exerted a significant influence on both thrust force and torque.
- The findings imply that the smallest drill diameter, a reduced feed rate, and a moderate spindle speed are the ideal settings for creating precise and accurate holes.

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