# Factor Selection in Drilling Unidirectional Carbon Fiber Reinforced Plastic Composite Plates with The HSS Drill Bit Using Analytic Hierarchy Process

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**ABSTRACT**

The present state of competition within the plastic composite industry calls for efficiency to be competitive. However, in the drilling of carbon-fiber-reinforced plastic (CFRP) composites, the process engineer still lacks knowledge of the priority of parameters as parameters are chosen at random, and resources are deployed without justification on their importance and strength. Consequently, production crises and productivity losses persist. In this article, the analytic hierarchy process (AHP) method is deployed to evaluate the weights of criteria in a CFRP composite drilling operation. The establishment of the decision, alternatives, and criteria is accomplished, and pairwise comparisons are conducted to allow the computation of the importance weight of each criterion. The weight is then established. The proposed approach was illustrated with experimental data from the literature with a plastic drilling case. Six criteria were chosen as crucial in determining the drilling parameters of CFRP composites. The results reveal the following: thrust force (0.413), torque (0.253), eccentricity (0.151), surface roughness (0.115), delamination at entry (0.037) and delamination at exit (0.030). In a validation exercise to ascertain the consistency of the analysis, a consistent analysis was obtained. The novelty of the article is using the AHP approach on the drilling of CFRP composites. Practically, these results impact operator training, indicating that attention should be focused on thrust force control. The industrial applications of CFRP composites include the basic structures of automobiles, ships, and airplanes.

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## 1. INTRODUCTION

At present, the plastic composite industry survives based on sustainable practices, the maintenance of a broad product range, insistence on quality outputs, timely product delivery to customers, and competitive pricing of plastic composite products (Teuber et al., 2016; Youssef et al., 2019). Furthermore, parametric selection has attained worldwide acceptance as a phenomenon that guides the justifiable allocation of a resource based on an important process (Shayan et al., 2013; Kulkarni and Ramachandran, 2018; Afolayan et al., 2020; Raghunathan et al., 2021). Besides, parametric selection has recorded heightened success at drawing the interest of manufacturers in various operations (Shayan et al., 2013; Kulkarni and Ramachandran, 2018). However, in the drilling of fiber-reinforced plastic composites, the process engineer still lacks knowledge of prioritizing and selecting parameters within the drilling domain (Shayan et al., 2013; Kulkarni and Ramachandran, 2018). To enhance the efficacy of the drilling operation, process engineers need to rank and select drilling parameters. The choice of parameters during the drilling of plastic composites needs to be enhanced. The most important parameters to devote substantial resources in decision-making and cost-cutting in wasteful expenditures are identified and implemented. This could be achieved by choosing a suitable multi-criteria tool for determining the weights of criteria. But analyzing the weights of the drilling parameters is a complicated issue since all the limiting conditions should be considered, including quality of information obtainable from the drilling process, degree of conflict of each parameter, and the state of association of the parameters.

Furthermore, there are convincing reports of the application of multi-criteria tools in the selection of composites (Kulkarni and Ramachandran, 2018; Tran et al., 2020a,b; Priti et al., 2021). However, still, selection of parameters is not followed by many machining processes due to lack of knowledge of process engineers and system coordinators who install selection programs during machining operations. Consequently, studies on selection practices for parameters in the drilling operations need to be aggressively promoted to benefit from this program. There exist several parameter selection tools available to implement successful selection programs. These include the best-worst method (Singh and Rathi, 2020; Raghunathan et al., 2021), criteria importance through inter-criteria correlation (CRITIC) approach, analytic hierarchy process (AHP) (Saaty, 2008), fuzzy analytic hierarchy process (FAHP) (Afolayan et al., 2020) and entropy (Kumar et al., 2021; Sidhu et al., 2021).

Interestingly, these methods are effective while implemented alone or jointly (Afolayan et al., 2020; Tran et al., 2020b; Priti et al., 2021). This article differs from others such that the parametric selection is derived from an experiment in the literature, and no simulation practices are involved, making the context of the problem and solution real and practical. Parametric selection using the analytic hierarchy process method has not been examined throughout the drilling literature on plastic fiber composites. But such an evaluation tool as an analytic hierarchy process tackles the real need of machining operations in drilling for the identification of the most important parameters considering the dynamic manufacturing that drilling operations operate. Although several studies offer systematic approaches to install the parametric selection process in composite manufacturing, none has attempted to employ the analytic hierarchy process approach to drilling plastic composites. Moreover, detailed and reliable steps on a parametric selection are sparsely found in the composite literature. Consequently, this article attempts to fill this gap by analyzing the drilling parameters for selection in plastic composite based on the analytic hierarchy process method.

Besides, carbon fiber reinforced plastics are extremely hard to machine in practice and cause substantial wear of the high-speed steel drill bit used in manufacturing. This rapid tool wear is accompanied by substantial material waste that erodes the profits of the machining industry. In attempts to solve this problem, most discussions have centered on fiber orientation and the drilling condition to control the tool wear. But this control is less effective since the selection of parameters (response) during the drilling process has been ignored. Thus, there is a strong need to tackle this research gap and introduce principles and techniques that will prevent the high-speed steel (HSS) drill bit wear and stop the erosion of profit for the machining operations. Fortunately, the use of multi-criteria tools has been confirmed as effective in tackling similar problems in the manufacturing domain. To the authors' knowledge, the literature has extensively discussed techniques such as the analytic hierarchy process, fuzzy analytic hierarchy process, CRITIC, entropy, among others. However, the analytic hierarchy process appears to have a distinguished record of success, and it is proposed as the solution approach in the present article. While the use of coated tools is claimed to be effective in reducing the tool wear to some extent, the cost in the purchase of coated tools and non-availability of the coated tool maybe two impediments that promote the use of the analytic hierarchy process as a multi-criteria tool to select factors (or responses) to tackle the tool wear problem in drilling operations effectively. Thus, the analytic hierarchy process method is deployed in this work.

Furthermore, in the machining shop, especially in the drilling process, prioritization of parameters or responses is a common challenge that affects drilled products' efficiency and surface integrity in several material process activities. In this article, the prioritization of responses is implemented by assessing the responses in the drilling process and ranking them according to their importance. To attain prioritization, the essential tasks to implement are urgent attention to enhance the efficiency of the drilling process and the surface integrity of the drilled products. Often, the operator is believed to accomplish the drilling process satisfactorily by being engaged in drilling activities. However, some of the tasks or responses are utterly unnecessary to the drilling outcomes. The specification of the surface integrity for the drilled composites and the operator should not be focusing on these responses. Unfortunately, excluding a thoughtful plan of attack in the drilling activities, the important responses may not be given attention until a crisis arises, which may stop the whole drilling process. This crisis should be prevented as a matter of urgency. However, by prioritizing, the following benefits are due to the production process first, understanding that the drilling process is time-consuming. Prioritization offers the opportunity to focus on the important drilling responses first, reducing stress to the operator and process engineer and enhancing productivity.

Second, by prioritizing responses, the operator and process engineer have the opportunity of checking and correcting errors in the drilling process, saving time and enhancing productive tasks. Finally, as the drilling responses are prioritized and positive changes to efficiency and surface integrity of the product are achieved, the operator and process engineer becomes more motivated to accomplish more in the drilling process. In this article, the purpose is to implement the analytic hierarchy process (AHP) method in the drilling of carbon fiber reinforced plastic composites. Literature data on experiments due to Krishnamoorthy (2011) was applied to verify the AHP method based on experiments conducted using the ARIX VMC 100 CNC vertical machining center and the unidirectional carbon fiber reinforced plastic plates with high-speed steel drill bits.

From the preceding discussion and on the platform of novelty, the novel element of this article is using the AHP method on the drilling of carbon-fiber-reinforced plastic composites. Consequently, the present article is probably the first to advance a discussion and apply the analytic hierarchy process in the drilling of carbon fiber reinforced plastic composites. It builds on the experimental data in the literature to analyze drilling responses' selection in a pioneering approach. Besides, the process engineer is led to making a reliable judgment on the appropriate response in the circumstance where the carbon fiber reinforced plastic composite is machined, which exposes the HSS drill bit to substantial wear and generates extensive waste from the drilling activities.

## 2. LITERATURE REVIEW

### 2.1. General

Drilling describes a generic name whereby holes are created either through the conventional route that uses a drill bit (Shyha et al., 2009; Srinivasan et al. 2017, Kaviarasan et al., 2019; Manickam and Parthipan, 2020) or non-conventional route by frequent pulsing application of laser energy on the work material (Hirogaki et al., 2001; Padlee et al., 2011). Although the main focus of this review is on the conventional drilling process given its wide application, a brief highlight on laser drilling is essential as the technology of laser drilling has evolutionally used the drilling process. However, the proposed method of AHP is still useful to enhance the laser drilling process further. Thus, three striking articles are reviewed here. These are the contributions by Hirogaki et al. (2001), Jadoun et al. (2006), and Padlee et al. (2011).

Besides, drawing from these articles, it has been shown that laser drilling is feasible to process non-metallic materials (Hirogaki et al., 2001) and metallic materials (Padhee et al., 2011). It was proved that aramid and glass epoxy composites are a candidate for printed wiring boards by Hirogaki et al. (2001), while Padhee et al. (2011) demonstrated that the use of aluminum matrix/silicon carbide particulates (Al/Si/Cp) metal matrix composites as a material for laser drilling. Hirogaki et al. (2001), the studied parameters/responses include spot diameter, build-up layer thickness, laser irradiation, and fabrication time. The study concludes that the proposed method is effective in plating reliability. However, in the case of Padhee et al. (2011), to optimize the aluminum metal matrix used, the multiple characteristics of the system are considered, including taper, spatter, and the heat-affected zone. The author adopted the response surface method of optimization and the grey relational method. They used the L20 orthogonal array as the design of experiments. The authors only used a few optimization techniques in the paper but did not consider selection techniques such as the analytic hierarchy process.

Furthermore, Jadoun et al. (2006) considered ultrasound-assisted laser drilling using input parameters such as workpiece material, tool material grit size of the abrasive, power rating, and slurry concentration on output parameters such as cutting ratio, which is the ratio of material removal to tool wear rate. The work material analyzed is ceramic, an inorganic non-metallic solid containing either non-metal or metal compounds. An experimental design of the L27 orthogonal array was used to experiment. Taguchi's method of optimization was adopted in which, through the analysis of variance method, the significant factors were identified, and conclusions were drawn. Notwithstanding, the work omits essential selection techniques such as the analytic hierarchy process method.

Furthermore, with the background on laser drilling, most of the remaining literature review in this article is devoted to the conventional drilling process characterized by the use of drill bits. However, the approach is first to examine the study that utilized rice husk, a natural material in the drilling process (Jayaprakash et al., 2019), then Delrina polymer (Kaviarasan et al. 2019), and then articles that centered on carbon fiber reinforced plastic composites in drilling (Lv et al., 2021; Gotham et al., 2021; Geiger et al. 2021; Tamura and Matsumura, 2021). Interestingly, the rice husk composite (Jayapracash et al., 2019) for drilling purposes has opened up a research avenue with great potentials given the benefits of rice husk. These include its high silica composition that is useful to strength structures in light structural applications. Moreso, it is biodegradable and environmentally friendly. Rice husk, which is a coating on rice grains, is built up from hard materials such as silica. Therefore, it is recommended for further drilling studies where it could be combined with other materials such as an aluminum metal matrix.

In Jayaprakash et al. (2019), the focus on using natural materials as reinforcing agents in composite production was because of the negative effects of synthetic polymers (such as pollution, high cost, etc.) and the advantages of using rice husks such as low density, biodegradability, and low cost. Although rice husk has many benefits, its drilling may be extremely difficult because of the abrasive nature of the composite. Consequently, the selection of the most suitable parameter for the drilling operation needs to be made. The machining process in this work is drilling, and the HSS drill bits and carbide drill bits were used in the experimental work and the parameters considered were speed and feed rate, while the responses considered were thrust force and torque. Notwithstanding, the authors did not include selection techniques such as the analytic hierarchy process, but the work is limited to the application of the Taguchi method.

Furthermore, the use of derin polymer was addressed in Kaviarasan et al. (2019). This polymer is also called the acetal photopolymer, which is very useful in the production of aircraft interiors, wire insulation, wired couplings, etc. the authors argued that drilling might affect the near-net shape of the final workpiece and then the need to optimize drilling parameters for derrin polymers under dry conditions is compelling. They used an L27 orthogonal array as the design of the experiment, focusing on three factors, Spindle speed, feed rate, and tool point angle. They focused on two responses; surface roughness of the HSS tool and the carbide tool of the machine in consideration. The authors applied an artificial newel network and the response surface method to optimize the parameters. The artificial newel network was used to predict the best response by combining the most optimized factors. Then, the response surface method was used to establish a relationship between the control variables and the responses using the Minitab software. There the analysis of variance was also used in work. However, the analysis excluded the use of selection techniques such as the analytic hierarchy process method.

Now, having discussed the drilling initiated on the use of rice husk-based composites and the delrin polymer, it turns to review the drilling activities that utilized the carbon fiber reinforced composites (Lv et al. 2021, Goutham et al., 2021, Tamura and Matsumura, 2021). Carbon fiber reinforced plastic composite evolved from the amalgamation of plastic resin and carbon fiber to form a high strength-to-weight ratio composite. But the process engineer still lacks knowledge of parametric selection during drilling. Unknowingly, huge manufacturing time and cost are expended in the drilling process. The process engineer finds it extremely difficult to tailor the properties of the composite to achieve particular requirements. Thus, this section presents a literature review to reveal the knowledge gap and how the present paper is different from previous contributions in the literature. In the carbon fiber reinforced plastic composite domain, there is a consensus by authors that a careful drilling process could help the engineer to achieve tailored material properties. However, the exclusion of parametric selection issues remains a weakness in this combination. The omission militates against the achievement of the optimal strength-to-weight ratios of composites and the optimal utilization of composite manufacturing resources.

Shyha et al. (2009) presented the results of a drilling experiment on carbon fiber reinforced plastic composite while optimizing the drilling process parameters. The considered parameters include the endpoint and helix geometry for the drill. They analyzed responses are the thrust force, delamination factors (exit and entry), and tool life. The article concludes that the delamination factors and entry and exit were close to 1.3 with a 0.2mm/rev feed rate. Furthermore, the index of the tool life criterion was less than 100mm.

In a study by Lv et al. (2021), the influences of high-level vibration on hole integrity during drilling were analyzed in rotary ultrasonic drilling involving carbon fiber reinforced plastic composites. The principal factors considered are chipping accumulation rate, thermal load, frictional effects, chipping adhesions, abrasive trajectories, and overlapping probabilities. It was concluded that the growth of CFRP plate thickness stimulated chipping pile-up at the clearance. Furthermore, Goutham et al. (2021) examined the influence of process parameters on two responses (tool wear and delamination) on drilling carbon fiber reinforced epoxy composites. The important responses/parameters discussed are the fiber volume fraction, elastic modulus and tensile strength, cutting conditions, tool wear, delamination, and tool's point angle. It was concluded that delamination and tool wear was substantial at the helix angle and pointed angle of 30° and 118° of the tool, respectively.

Besides, Geier et al. (2021) examined and weighed the emergence of burr during the drilling of carbon fiber reinforced polymer composites considering both curved and flat plates with complicated geometric studies. The principal parameters considered are the burr attributes, feed rates, cutting speeds, and curved plate's radius. It was concluded that the impact of the curved plate's radius on the emergency of burr was substantial. Besides, Tamura and Matsumura (2021) introduced the variable feed rate method to monitor the delamination of work materials using carbon fiber reinforced plastic composites while drilling holes at elevated machining rates. The interesting parameters are uncut chip thickness, cutting force, friction angles, rake angles, and feed rates. The thrust is an important response considered in the article. It was asserted that negative thrust was effective in monitoring delamination at elevated feed rate during drilling.

Furthermore, damage concerning delamination was substantially reduced by evaluating the tool wear. Pereszlai et al. (2021) optimized and compared the performance of the glass and carbon fiber-reinforced polymer (GFRP and CFRP) composites while milling on an end mill. The examined parameters/responses are the pitch, tilting angle, cutting force, and burr. The conclusion of the study is that minimization of the burr and cutting forces were achieved by optimizing the pitch and tilting angle.

Several other methods emphasize methods, including the following: Rajmohan et al. (2013) applied the central composite design version of the response surface methodology to optimize parameters while establishing the most significant influence on burr height, thrust force, and surface roughness. The regression analysis method was employed. It was concluded that the least thrust force value of 84N, burr height of 0.16mm, and surface roughness of 1.67 mm were obtained in the experiment. In the drilling research domain, the contribution of Neseli (2014) is important. The authors considered the drilling process and stated that the quality of finished components is heavily dependent on the process, workpiece, and tool-related parameters employed while machining. Some of these factors are cutting speed, helix angle, and feed rate. From the research, these factors significantly affect the performance measures or responses like the thrust force and torque. With a design of an experiment of an L27 orthogonal array, the author established cutting speed, feed rate, and helix angle as factors and thrust force and torque as responses. The author used the Taguchi optimization method (signal-to-noise ratio analysis) to achieve an optimal condition of factors for low thrust force and minimum torque. The author also deployed the analysis of variance to check the significance of the parameters on the responses. Although extensive, the work did not consider using selection techniques such as the analytic hierarchy process method.

To further expand knowledge in the drilling field, Vinayagamorthy (2017) considered how input factors like spindle speed, feed rate, point angle, and tool diameter could affect output factors such as thrust force, surface roughness, and delamination entry when drilling newly made sandwich composites. The method of optimization used was Box-Behnken. Conclusions were drawn based on the method of optimization. However, selection techniques such as the analytic hierarchy process method were not considered for the robust conclusion.

In Rajmohan et al. (2012), it was argued that the finished process of composites tends to be affected by machining parameters such as feed rate, retract rate, point angle, speed, chip load, velocity, and in-feed rate. Furthermore, they asserted that for the efficient and economical machining of the aluminum metal matrix, the optimization of the machine parameters must be done to obtain the desired dimensions and surface finish as well as reduced cost and increase in quality of the drilled surface. The parameters they focused on were speed, feed rate, and point angle. The authors used the Taguchi technique as a method of performing optimization on the aluminum composites. However, they did not discuss the use of related selection techniques such as the analytic hierarchy process method.

Besides, Bosco et al. (2015) analyzed the parameters extensively; drilling diameters, spindle speed (rpm) and feed (mm/rev) as factors, and thrust force on armor steel, thrust force on GFRP-top (N), and thrust force on GFRP-bottom (N) as the responses. The design of the experiment was carried out using an L27 model, and optimization was carried out using the analysis of variance technique and the response surface regression analysis. The authors did pervasive work but did not consider related selection techniques such as the analytic hierarchy process method. Still, Anand et al. (2018) highlighted the need to use hybrid composites, their importance, and their constraint, which is the difficult machining of the materials. To minimize this constraint, optimization of important input parameters like spindle speed, feed rate, and drill diameter was considered with the delamination factor, thrust force, and torque considered as important responses. The Taguchi's L25 orthogonal array design of the experiment was used, and a grey relational optimization analysis was conducted. From the results, the authors showed that machining characteristics can be improved at optimum machining conditions and that the drill diameter has more effect on the output characteristics than others. However, the work omitted important selection techniques such as the analytic hierarchy process method.

Additionally, Manickam and Parthipan (2020) employed the Taguchi optimization method to obtain the best parameter combination that produces the best responses on the metal composite (stainless steel). The factors considered are cutting speed, feed rate, and drill parameter. The responses considered are thrust force, torque, surface finish, and metal removal rate. The L9 orthogonal array was used for the design of the experiment, while the grey relational analysis was also used to optimize the parameters. Nonetheless, the authors did not consider any selection technique such as the analytic hierarchy process method.

Another perspective in the literature discussions on drilling is an emphasis on parameters. For example, Singh et al. (2013) considered how input parameters like cutting speed, feed rate, step diameter, and point angle can be optimized to minimize the output response considered: thrust force, torque, and surface roughness to enhance the quality of the response. The authors used to L9 orthogonal array as the design of experiments. They used grey relational analysis as the optimization technique. The aim of the analysis and experiment was achieved. Nonetheless, selection techniques were not used, including the analytic hierarchy process method. Furthermore, Srinivasan et al. (2017) considered how input parameters like spindle speed, feed rate, and drill diameter for different experimental values affect output (responses) like delamination factor. The authors used the response surface method to optimize the input factors to conclude. The results obtained led to the conclusion that feed has the most influence on the delamination factor. Hence optimization was achieved, but selection techniques such as the analytic hierarchy process method were not adopted.

Although significant discussions were made on composite manufacturing, the literature review understood that no detailed study on carbon-fiber-reinforced plastic composites with the analytic hierarchy process has been carried out. Moreover, there are no helpful discussions on the appropriate response to select on this composite response selection issue. Consequently, the analytic hierarchy process has been uniquely implemented to select the appropriate response in this study. This was based on the outcome of the literature review, which revealed the importance of the analytic hierarchy process, the usefulness of the carbon fiber reinforced plastic composite in its expanding use in the industry, and the significance of the chosen response as foremost and most sought after the response for the composite drilling process.

### 2.2. Summary of the literature

A detailed literature review associated with the selection techniques in the drilling of carbon fiber reinforced plastic composite was conducted. At the same time, important findings with pointers for future studies were analyzed critically. It was understood that researchers in the drilling domain attempted to understand mainly the optimization details of the carbon fiber reinforced plastic composites. However, the association of these optimization parameters or response were not made with selection parameters or response researcher tend to be independent in their treatment with various optimization models proposed but ignoring the influence of the selection process in the composite drilling operation. Thus, there is a pointer to the fact that comprehensive research on the selection is an important and pressing concern that should be treated with urgency, particularly using the analytic hierarchy process multi-criteria selection technique.

### 2.3. The research problem

Machine shops nowadays strongly strive to drive parts with speed, smoothness of drilling activities, and economically. However, in the past twenty years, superior manufacturing sustainable programs have stimulated substantial performance improvement. The drive for continuous improvement is sometimes sustained, penetrating the machine shop and particularly drilling activities. In drilling operations, however, as management is aware of wasteful use of in front resources in the drilling of difficult to drill carbon fiber reinforced plastic composites, the process engineers are asked to re-plan and produce drilled components less wastefully either on normal operations with their experienced machining operators or at emergencies when permanent workers are supplemented with the casual workers due to shortages of skilled labors. Furthermore, process engineers are asked to re-strategies and re-plan to avoid random deployment of resources and priorities resource distribution during the drilling operation.

To attain the needed drilling objectives, the process engineer must establish certain parameters or responses in drilling that influence the effective utilization of drilling resources in selection metrology. The process engineer should prompt established parameters or responses that will support the item to attain effectively reduced waste generation in the use of the drilling resources. Consequently, diverse parameters and responses have been acknowledged in the drilling literature by diverse researchers. However, no work exists to select these parameters or responses in the drilling of carbon fiber reinforced plastic composites.

Furthermore, machine shops have been striving to enhance their performance on the judicious use of input resources in the drilling activities through quality management and lean initiatives. However, these efforts must be complemented with other techniques to enhance performance. Hence, drilling machine shops must enhance their parameters or response selection techniques to attain the expected performance thresholds. The traditional approach of a random selection of parameters or responses for drilling purposes or intuition by the experience of the drilling operation needs to stop it should be replaced with an innovative method based on modern scientific advancement. But multi-criteria decision-making methods have become widely used as intervention methods in this performance improvement endeavor. Out of the many multi-criteria decision-making tools, the analytic hierarchy process appears to be a widely used and effective tool to aid engineering decision making drilling experts input might be the driving force of the AHP in drilling operation while the researcher aggregates their opinions on Saaty's scale of preferences of the drilling experts are to understand which of the parameters or responses is favored awarding to the preferences of the drilling experts (Saaty, 2008). Therefore, the researcher produces a consensus of ideas from the input of the drilling experts; the philosophy of the AHP method should incorporate gathering data from expert's opinions and consensus of the idea. In this article, an analytic hierarchy process method is developed based on an expert's evaluation with the belief that the best alternative could evolve from the expert's opinion. Finally, experimental data from the literature regarding the drilling of carbon fiber reinforced plastic composite is used to demonstrate the AHP in selecting the best alternative for the responses of composites in the drilling operation.

## 3. METHODS

### 3.1. Justification for analytic hierarchy process

Often in the assembly of carbon fiber reinforced plastic composite structures, the drilling activity falls to the final tasks, sometimes suppressing the robust outcomes of other machining activities (i.e., cutting and milling) by poorly drilled parts which the customer may finally reject. Consequently, great care must be taken to avoid defects since rejected products are expensive to rework. In drilling operations, an aspect is to focus on the major drilling defects, including delamination, eccentricity, chipping and spalling damage procedures, thrust force, torque, and surface roughness. The issue is selecting the best response that requires low energy supply to the system and low operating and investment costs while maintaining acceptable levels of thermal comfort and environmental conditions. But the choice of response is even more complicated for the carbon fiber reinforced plastic composite drilling activity as the reinforcement is extremely difficult-to-drill, and the drilling problem involves multiple conflicting criteria that should be considered simultaneously. Thus, to help the process engineer achieve the stated goal of drilling and pursue more consistent decisions by adopting significant, influential aspects of drilling into account, particularly the needs of composite structure users, multi-criteria decision making may be the best match of tools for drilling real-life applications. It is thought that using multi-criteria methods in the drilling activity, a systematic and quantitative method to aid decision making in the selection of appropriate response will be made. However, of the several multi-criteria tools, the use of the analytic hierarchy process method, which is a robust tool in the composite research field, suggests adoption in this article.

### 3.2. Weights

Weights are co-efficient obtained from the computations in deploying multi-criteria techniques to control the strength of factors (parameters) in decision making. The study of weights is a critical aspect of the multi-criteria decision-making model. It helps identify the most important factors based on a set of criteria for analysis, usually strongly influenced by the experts' decisions or ratings. In selecting parameters for drilling fiber-reinforced polymer, the study of weights has significant importance on the choice of each response, namely thrust force, entry point delamination, exist point delamination, eccentricity, and roughness how they contribute to the finished product. In this article, the analytic hierarchy process method has been chosen as the selection technique to analyze the experimental data obtained in Krishnamoorthy (2011).

### 3.3. Selection

Selection by multi-criteria techniques is better than the use of intuition for selection; it chooses the appropriate parameter in drilling with which preliminary efforts could be directed towards minimizing resource depletion and waste during the drilling process. Selection is the procedure in establishing the parameters (responses) for use in the resource depletion control and waste minimization drive. An extensive literature review ends the selection process to establish the appropriate selection technique, which is the analytic hierarchy process in the present work. The selection of the appropriate parameter (response) in drilling is the choice of an asset to the drilling process as it will assist it in attaining the objective of drilling, which is a careful choice of the carbon fiber reinforcement, the matrix, and the drilling process that combines these elements, in which the process engineer

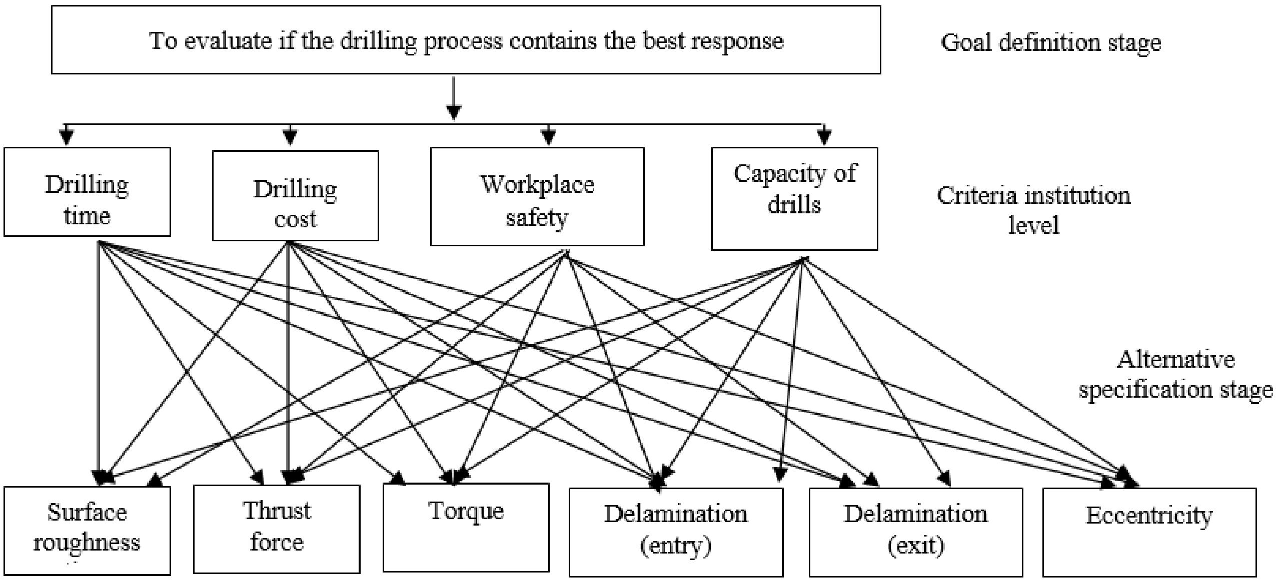


Figure 1. AHP hierarchical multi-criteria structure for the CFPR problem

produces composite properties that attain specific requirements. Nonetheless, no report has been published on achieving this objective using the analytic hierarchy process (AHP). But the AHP is a structured method that combines the principles of psychology and mathematics to organize and examine the complicated decisions in the drilling process. Thus, this investigation is targeted at studying the selection and weight determination of the foremost parameters (responses) in the drilling of carbon-reinforced plastic composites using the analytic hierarchy process method. The key point of the AHP analysis in the composite is the prioritization and selection in which the AHP permits the process engineer to confine the strategic goal of the drilling process, vis-à-vis combining the reinforcement, matrix, and the drilling process to obtain tailor-made properties, as a set of weighted criteria, which can be deployed to score the drilling operation. The AHP method is used to derive the ratio scales from paired comparison. It is competent in tackling the selection process in drilling the composite in a complicated array of activities.

### 3.4. Drilling parameters and responses

Drilling the carbon fiber reinforced plastic composite is a cutting process aided by the HSS drill bit that assists in cutting holes of circular cross-sections in the plastic composites. The HSS drill bit is tool steel which is hard and of higher resistance to heat than the high-carbon steel. With the full meaning of HSS being high-speed steel, this drill bit has recorded success to drill plastic composites while drilling at higher cutting speeds than carbon-steel bits. In this article, the drilling parameters considered are the spindle speed, feed rate, and point angle. These three factors are very important in the drilling of composites. The spindle speed contributes and also determines the type of chip formed. The responses studies in this article are the thrust force, torque, entry delamination, exit delamination, eccentricity, and surface roughness. The response characteristics in drilling plastic composite are strongly dictated by the optimal input parameters, which may be established using an appropriate optimization method. However, it is extremely difficult to establish these optimal input parameters since an adequate specification of the limiting constraints, and parametric attributes need to be specified. Besides, it is often determined in substantial experimental operations, trial and error environments, time and cost expenditure, which make the procedure extremely cumbersome.

### 3.5. Analytic Hierarchy Process (AHP)

The analytic hierarchy process is one of the widely used methods of finding weights (Saaty, 2008). It is a multi-criteria decision-making tool developed by Thomas L. Saaty in the 1970s used to obtain ratio scales from a paired comparison of criteria (Saaty, 2008). The AHP method obtains its solution by tackling the parametric selection problem from three angles. The ultimate goal, all possible solutions called alternatives and criteria to judge the alternatives from (Saaty, 2008), Figure 1.

A complete AHP procedure is dedicated to choosing the best alternatives using a hierarchical multi-criterion structure. The AHP hierarchy is a system in the drilling process where the units are ranked conforming to comparative standing. The foremost step in establishing the AHP procedure in the drilling process of carbon fiber reinforced plastic (CFRP) composite using the high-speed steel drills is to create a hierarchical structure such that three hierarchy levels are defined. For levels 1, 2, and 3, the corresponding definitions are the goal establishment, criteria specification, and the statement of the alternatives to consider. Figure 1 shows the AHP representation in a hierarchical multi-criteria structure. The goal is to evaluate the process and establish the best response from multiple alternatives (at exit and entry), surface finish, thrust force, and torque. The second level is defined as the criteria for judging the system. For the level, the concern

Table 1. The scale of comparative importance

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Identical importance | Two responses contribute similarly to the drilling objective. |
| 3 | Modest importance | Composite and drilling experts use experience and judgment to esteem a drilling response over another marginally. |
| 5 | Robust importance | Composite and drilling experts adopt experience and judgment to esteem a drilling response over another strongly. |
| 7 | Extremely robust importance | A drilling response is strongly esteemed over another while its superiority is established in drilling practice. |
| 9 | Ultimate importance | The importance of response in drilling over another is asserted on the ultimate extent. |

of the process engineer is how much drilling time is used while the defects emerge. Since the relation importance of one defect is desired, less time may produce insignificant defects of a kind. So that defect may not be important to the system according to drilling conditions in the particular workshop studied. Also, consideration is given to the drilling cost.

The drilling time is associated with the estimated time necessary in drilling CFRP composite for the HSS tool bit to enter a defined thickness of the composite. The drilling time is the machining time computed from the drilling depth, the number of holes drilled, the spindle's feed rate, and the feed on the workpiece per revolution. However, the drilling cost is the total drilling cost per footage of the work material drilled. The evaluation of the total drilling cost is based on the fixed cost added to the variable cost. While the fixed cost is obtained as the annual overhead cost in proportion to the annual meter budget, the variable cost is the sum of the cost of labor, fuel, work supervision by the superior, part repairs cost, repair maintenance cost, and the repair labor cost. In summary, the drilling cost sums up all related incurred costs on drilling, deepening of holes, re-entering of drilling holes, testing, and completing the drilling process. These segmentations would be appreciated when drilling parts in heavy equipment automobile and aerospace industries where some parts could be some meters in width.

Besides, the drilling capacity refers to the maximum diameters of the HSS drill bit that could be employed on the CFRP composites. This drilling capacity should not be misinterpreted as the depth of the hole, which the HSS drill bit could drill on the CFRP composites. From the literature, the power (a capacity surrogate) of an HSS drill bit may be measured in volts, where higher voltage means a more powerful HSS drill to use in the drilling process. Furthermore, for industrial drilling within the automobile and aerospace industries where the HSS drill is significantly used, battery sizes that range between 12V and 20V is often recommended. The fourth criterion in evaluating the drilling process for the CFRP composite is the drilling workplace safety. This means the limitation of elements with the potential to harm the drilling operator and other stakeholders in the workshop, cause accidents before, during, and after operations, and other negative results in the workshop. Thus, it is argued that the working environment in the workshop is an important element in the assessment of the best response for the drilling process of the CFRP composites; it covers the well-being of the operator and stakeholders, their health and safety considerations.

Furthermore, each response has its value of criteria associated with it. For example, surface roughness a response has a value of drilling time, drilling cost, workplace safety, and capacity of the drills related with it, which may be proportioned where all proportions sum up to 1. However, since published data from Krishnamurthy (2011) is utilized and these details were ignored in the experiments and data collection, it is challenging to include details of this aspect and, hence, be eliminated from the computation. This is a limitation of the present study.

In the AHP process, the input of the process engineer in the composite development process is taken as the bedrock of the computations that evolve afterward. In collaboration with experts in the drilling and composite manufacture, the process engineer gives the order of importance options based on preference. The basic framework of the AHP technique is the comparative importance scale, which has six grades of importance according to Saaty’s definition (Saaty, 2008). In the context of composite drilling with the defined responses, the scales are defined as follows, Table 1 (Saaty, 2008).

### 3.6. Steps to solving analytical hierarchy process (AHP) (Saaty, 2008)

*Step 1: Define Alternatives*

Alternatives are the different options available under each chosen criteria. It may be viewed as the drilling time, drilling cost, workplace safety, and capacity of drills. However, since the data was not obtained for them, this article uses the criteria as the same as alternatives.

*Step 2: Define the problem and criteria*

In this work, the aim of carrying out weight analysis is to find the percentage contribution of each response of the drilled workpiece. Thus, the criteria used for this drilling

Table 2. Random index table (Saaty, 2008)

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0.000 | 0.000 | 0.580 | 0.900 | 1.120 | 1.240 | 1.320 | 1.410 | 1.450 | 1.490 |

Table 3. Averaged experimental table containing alternatives and criteria using HSS drill

| Average | Thrust force | Torque | Entry delamination | Exit delamination | Eccentricity | Surface roughness |
|---|---|---|---|---|---|---|
| Exp. 1 to 5 | 0.601 | 0.611 | 0.656 | 0.635 | 0.599 | 0.515 |
| Exp. 6 to 10 | 0.374 | 0.653 | 0.442 | 0.417 | 0.473 | 0.364 |
| Exp.11 to 15 | 0.497 | 0.588 | 0.581 | 0.593 | 0.578 | 0.470 |
| Exp. 16 to 20 | 0.558 | 0.808 | 0.645 | 0.652 | 0.647 | 0.555 |
| Exp. 21 to 25 | 0.575 | 0.716 | 0.657 | 0.658 | 0.622 | 0.514 |
| Exp. 26 to 27 | 0.247 | 0.816 | 0.405 | 0.382 | 0.420 | 0.289 |

problem are the six responses: thrust force, torque, delamination entry, delamination exit, eccentricity, and surface roughness.

*Step 3: Establish priority among criteria using pair-wise comparison*
In this step, a pair-wise comparison table is created while each criterion is compared with another to form a cell value. The table of comparative importance is used to create the comparison for each cell.

*Step 4: Calculate normalized matrix table*
To create the normalized matrix table, each cell of the non-normalized table is divided by its corresponding column total.

*Step 5: Calculate the criteria weight*
The criteria weight is the average total of each row element.

*Step 6: Check for consistency*
The process of checking for consistency in the process of validating the criteria weight calculated. It is done through the following process:

1) Multiply the non-normalized cell values by their corresponding criteria weight.
2) Calculate the weighted sum value (ws)
The weighted sum value is calculated by adding all the cell values in the row.
3) Calculate the ratio of weighted sum value to the criteria weight.
4) Calculate $\lambda_{max}$. This is calculated by taking the average of all the calculated ratios.
5) Consistency index, consistency index is calculated with the formula:

$$\text{Consistency index (CI)} = \frac{\lambda_{\max} - n}{n-1} \qquad (1)$$

where, $n$ is the number of criteria.
6) The final step is to calculate the consistency ratio. The consistency ratio is given by

$$\text{Consistency ratio (CR)} = \frac{CI}{RI} \qquad (2)$$

The random index is a unique table created by Thomas L. Saaty to help calculate consistency ratio, Table 2 (Saaty, 2008). Table 2 has different values for different criteria values.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Analytical hierarchy process (AHP)

The structure of the scale of comparative importance used in this work has been defined in the section of methods. However, the implementation of the method is done in this section.
*Step 1: Define alternatives*
In this work, the alternatives are the values of the responses to the parameters, namely the thrust force, torque, entry delamination, exit delamination, eccentricity, and surface roughness. These responses are from the experiments conducted by Krishnamoorthy (2011). Of interest is Table 5.1 on the data preprocessing representing the entire responses obtained using the HSS drills in Krishnamoorthy (2011). These values are 27 in total for each response. However, the values will be compressed and averaged to form a 6 x 6 matrix for simplification purposes. To explain how these values are obtained, consider only the first column, thrust force, having experimental trials 1 to 27. The following entries are averaged to have six sets of averages: Experimental trials 1 to 5, 6 to 10, 11 to 15, 16 to 20, and 21 to 25. Consider the first set of averages where experimental trails 1 to 5 are first summed up. Here, the values of 0.9317, 06421, 0.4955, 0.6817, and 0.2527 are added as 3.0037, and an average of 0.60070 was obtained, approximated as 0.601. This is written at the intersection of the thrust force and "Experimental trials 1 to 5". Next, the researcher considers experimental trials 6 to 10, summed up and averaged as 1.8687 and 0.3734, respectively, and approximated as 0.374. By following this procedure, Table 3 is computed to contain leveraged experimental values, alternatives, and criteria using the HSS drill.

*Step 2: Define the problem and criteria*
The aim of carrying out weight analysis in this work is to find the percentage contribution of each parameter on the drilled workpiece. This analysis can help to figure out best the parameters to minimize and maximize. The criteria for this problem are the six output parameters: thrust force, torque, delamination entry, delamination exit, eccentricity, and surface roughness.

*Step 3: Establish priority among criteria using pair-wise comparison*

Table 4. Pair-wise comparison table

| | Thrust force | Torque | Entry delamination | Exit delamination | Eccentricity | Surface roughness |
|---|---|---|---|---|---|---|
| Thrust force | 1.000 | 3.000 | 8.000 | 7.000 | 5.000 | 4.000 |
| Torque | 0.333 | 1.000 | 9.000 | 8.000 | 3.000 | 3.000 |
| Entry delamination | 0.125 | 0.111 | 1.000 | 2.000 | 0.167 | 0.200 |
| Exit delamination | 0.143 | 0.125 | 0.500 | 1.000 | 0.200 | 0.167 |
| Eccentricity | 0.200 | 0.333 | 6.000 | 5.000 | 1.000 | 3.000 |
| Surface roughness | 0.250 | 0.333 | 5.000 | 6.000 | 0.333 | 1.000 |
| Column total | 2.051 | 4.903 | 29.500 | 29.000 | 9.700 | 11.367 |

A pair-wise comparison table is to be created, comparing each criterion to each other to form a cell value. Table of relative importance is used to create the comparison for each cell Table 4. Furthermore, Table 4 contains elements of a pairwise matrix, which displays the comparative importance of the responses related to the goal of the drilling process. Usually, an expert is expected to form the judgments on how to obtain values in the table. However, to achieve this goal, the researcher's judgment was used as the expert's opinion. In this case, the first author was asked to evaluate while the second author vetted the results of the judgments. The first author is a university undergraduate in mechanical engineering with relevant workshop practice experience for one year for the authors' background. This candidate was evaluated with appropriate training from the senior author on the key issues and how to judge adequately. However, the second author with a doctorate in industrial engineering has substantial experience both during the training and about twenty years of engineering experience both in teaching relevant workshop practice courses for many years and the undergraduate level and in the processing of materials (including metals and non-metals) on the late machine both for turning and drilling purposes. Thus the experiences and knowledge of the two authors were invested in ensuring accuracy in judgment for the values assigned to the alternatives during evaluations.

Furthermore, consider the thrust force along the row, intersection with itself, torque, entry delamination, exit delamination, eccentricity, and surface roughness. Along this row, as the thrust force is compared with itself regarding the importance, the criteria value is 1 as it is as important as itself. However, when the thrust force is compared with torque, the drilling process literature places substantial efforts on the thrust force more than torque due to its importance. Thus, a value of thrice as important as torque is assigned, which is indicated as 3 in the intersection cell of the thrust force and torque in the first row of Table 4. However, this evaluation is interpreted as the reciprocal of 3 if consideration of the importance of torque to thrust force in the second row and the first column is made. Here, a value of 1/3 is assigned to the relationship. The same procedure is used to fill the table. However, along each column in Table 4, the assigned values by the experts to each response are summed up. For instance, for the second column where the criteria values of 1,0.333,0.125, 0.143, 0.2, 0.250 are assigned to the intersection between the thrust force and itself, torque, entry delamination, exit delamination, eccentricity, and surface roughness, the sum is 2.051, and it is written as the last value in the column. Similarly, other values for the next columns are obtained from 4.903 to 11.367. Table 5 is obtained by considering the value in each cell along the column by the sum of the value along the second column; a value of 1 was obtained as the intersection between the thrust force and itself. This value is then divided by 2.051, the sum along the column as 1 divided by 2.051.

After obtaining the non-normalized matrix table, the next step is to calculate the normalized matrix table by dividing each cell by its corresponding column total, Table 5.

The next step is to calculate the criteria weight, which is the average total of each row element, Table 6. Notice that in Table 6, the computations of the division have been done. For example, for the interaction of the thrust force against itself obtained as 1/2.052, the direct value is 0.488, shown in Table 6.

Table 6 is the normalized pair-wise matrix table with criteria weight. The criterion weight, which is the last column in the six-by-six matrix, carries the average value. For the first now, thrust force, torque, entry delamination, exit delamination, eccentricity, and surface roughness, the entire values added yield 2.479, and the average when divided by 6 yields 0.413 as the weight for the thrust force. By following this procedure, the sum of values for the second column (torque) is 1.521, and the average is 0.253. Then the other criteria weights for entry delamination, exit delamination, eccentricity, and surface roughness are obtained as 0.037, 0.030, 0.151, and 0.115, respectively.

*Step 4: Check for Consistency*

Table 7 allows the user to check for consistency while validating the criteria weights computed. The non-normalized pair-wise values are selected for this assignment. The process commences by multiplying the non-normalized cell values by the corresponding criterion weight. Consider the first row containing the thrust force. The cell in its front is the thrust force also. Here, the non-normalized pair-wise value is 1, while the criterion weight is 0.413. The multiplication of 1 and 0.413 gives 0.413.

Table 5. Normalized pair-wise comparison table

| | **Thrust force** | **Torque** | **Entry delamination** | **Exit delamination** | **Eccentricity** | **Surface roughness** |
|---|---|---|---|---|---|---|
| Thrust force | 1.000/2.051 | 3.000/4.903 | 8.000/29.500 | 7.000/29.000 | 5.000/9.700 | 4.000/11.367 |
| Torque | 0.333/2.051 | 1.000/4.903 | 9.000/29.500 | 8.000/29.000 | 3.000/9.700 | 3.000/11.367 |
| Entry delamination | 0.125/2.051 | 0.111/4.903 | 1.000/29.500 | 2.000/29.000 | 0.167/9.700 | 0.200/11.367 |
| Exit delamination | 0.143/2.051 | 0.125/4.903 | 0.500/29.500 | 1.000/29.000 | 0.200/9.700 | 0.167/11.367 |
| Eccentricity | 0.200/2.051 | 0.333/4.903 | 6.000/29.500 | 5.000/29.000 | 1.000/9.700 | 3.000/11.367 |
| Surface roughness | 0.250/2.051 | 0.333/4.903 | 5.000/29.500 | 6.000/29.000 | 0.333/9.7 | 1.000/11.367 |
| Column total | 2.051 | 4.903 | 29.500 | 29.000 | 9.700 | 11.367 |

Table 6. Normalized pair-wise matrix table with criteria weight

| | **Thrust force** | **Torque** | **Entry delamination** | **Exit delamination** | **Eccentricity** | **Surface roughness** | **Criteria weight (CW)** |
|---|---|---|---|---|---|---|---|
| Thrust force | 0.488 | 0.612 | 0.271 | 0.241 | 0.515 | 0.352 | 0.413 |
| Torque | 0.163 | 0.204 | 0.305 | 0.276 | 0.309 | 0.264 | 0.253 |
| Entry delamination | 0.061 | 0.023 | 0.034 | 0.069 | 0.017 | 0.018 | 0.037 |
| Exit delamination | 0.070 | 0.025 | 0.017 | 0.034 | 0.021 | 0.015 | 0.030 |
| Eccentricity | 0.098 | 0.068 | 0.203 | 0.172 | 0.103 | 0.264 | 0.151 |
| Surface roughness | 0.122 | 0.068 | 0.169 | 0.207 | 0.034 | 0.088 | 0.115 |

Next, along the same row of thrust force, the next item is the torque with a non-normalized pair-wise value of 3 and a criterion weight of 0.253 to yield 0.759. By following this procedure along the first row, each of the next cells representing the entry delamination, exit delamination, eccentricity, and surface roughness may be computed as 0.296, 0.210, 0.755, and 0.460, respectively. The same procedure is followed for other rows, and Table 7 is filled except the last column for the weighted sum value. Furthermore, Table 7 is obtained as the weighted sum value by adding all the cell values in the row. As an example, for the row representing the thrust force, the cells containing the thrust force, torque, entry delamination, exit delamination, eccentricity, and surface roughness contain 0.413, 0.759, 0.296, 0.210, 0.755, 0.460, respectively, whose sum yields 2.893 as the weighted sum. Calculations are done using this procedure for the entire rows 1 of torque, entry delamination, exit delamination, eccentricity, and surface roughness as 1.762, 0.225, 0.188, 1.035, and 0.718, respectively. While calculating, the user is reminded of the criterion weight on the last row. A summary of the weighted sum values (Table 7) together with the extracts of criterion weight is used as the foundation of Table 8 to calculate the ratio. The ratio is the division of each weighted sum value and criterion weight, obtained as 7.001 for the thrust force, and the rest ranges from 6.255 to 6.951.

The next step is to calculate $\lambda_{max}$. This is calculated by taking the average of the entire calculated ratios as 6.560 (Table 8). Then, the consistency index is calculated from Equation (1) as:

$$\text{Consistency index (CI)} = \frac{\lambda_{\max} - n}{n-1} = 0.112$$

where, $n$ is the number of criteria.

However, for a criterion value of 6, the random index value is 1.240 (Table 2). When substituted in Equation (2) yields 0.090, a value that satisfies the condition that the consistency ratio must be less or equal to 0.100. Therefore, it can be concluded that the AHP analysis done in this work is consistent.

Table 9 shows the distribution of each criterion's importance on the drilled structure. To compare the results of the AHP method obtained with the literature, the outcome of Krishnamoorthy (2011) regarding the optimal grey relational grade has been referred to. The author identified experimental trial 19 in Table 5.2. For this experimental trial, the grey grade of 1, 0.7803, 1, 1, 1, and 1 were attached to the thrust force, torque, entry delamination, exit delamination, eccentricity, and surface roughness, respectively. On the same scale, the values of 0.413, 0.253, 0.037, 0.030, 0.151, and 0.115 were converted to a scale such that the highest criterion weight has a value of 1 and the rest are distributed according to their magnitude to yield the following respective values from the thrust force to the surface roughness: 1, 0.6126, 0.0896, 0.0726, 0.3657 and 0.2785. The thrust force obtained the highest priority score (1) from these results, while the exit delamination attained the lowest rank having a score of 0.0726 from the proposed AHP method. However, the grey relational grade approach also ranked the thrust force as having the highest priority score (1), while torque was ranked as the lowest grade response.

Table 7. Non-normalized pair-wise valued multiplied by criteria weight and weighted sum value table

| | Thrust force | Torque | Entry delamination | Exit delamination | Eccentricity | Surface roughness | Weighted sum (w.s) |
|---|---|---|---|---|---|---|---|
| Thrust force | 0.413* | 0.759 | 0.296 | 0.210 | 0.755 | 0.460 | 2.893 |
| Torque | 0.138 | 0.253 | 0.333 | 0.240 | 0.455 | 0.345 | 1.762 |
| Entry delamination | 0.052 | 0.028 | 0.037 | 0.060 | 0.025 | 0.023 | 0.225 |
| Exit delamination | 0.059 | 0.032 | 0.019 | 0.030 | 0.030 | 0.019 | 0.188 |
| Eccentricity | 0.083 | 0.084 | 0.222 | 0.150 | 0.151 | 0.345 | 1.035 |
| Surface roughness | 0.103 | 0.084 | 0.185 | 0.180 | 0.050 | 0.115 | 0.718 |
| Criteria weight | 0.413 | 0.253 | 0.037 | 0.030 | 0.151 | 0.115 | |

* Example: 1 x 0.413 = 0.413 shows how to obtain the value of the thrust force and thrust force interaction

Table 8. The ration of the weighted sum to criteria weight

| Criterion | Weight sum value | Criteria weight | Ratio |
|---|---|---|---|
| Thrust force | 2.893 | 0.413 | 7.001 |
| Torque | 1.762 | 0.253 | 6.951 |
| Delamination at entry | 0.225 | 0.037 | 6.099 |
| Delamination at exit | 0.188 | 0.030 | 6.219 |
| Eccentricity | 1.035 | 0.151 | 6.836 |
| Surface roughness | 0.718 | 0.115 | 6.255 |

Table 9. Weight of each criterion

| Criterion | Weight |
|---|---|
| Thrust force | 0.413 |
| Torque | 0.253 |
| Delamination at entry | 0.037 |
| Delamination at exit | 0.030 |
| Eccentricity | 0.151 |
| Surface roughness | 0.115 |

Thus, the experimental results on the grey relational analysis confirmed the results of the current approach of AHP.

### 4.2. Practical and industrial use of the results related to its managerial impact

Having obtained the various weights of the responses, what next with the weights? It is important to note that whatever are the weights of the responses are found to be. These will still be used in the drilling process, however, with a different perspective. Besides, in the drilling engineering domain, experimental and simulation research results are considered valuable if they enhance drilling outcomes as they are put into practice at the machine shop. Consequently, it is required to know how to implement the findings of this article in engineering practice to enhance the efficiency and cost of the drilling process for carbon fiber reinforced plastic composites.

The evidence from the analysis result supports the thrust force as the most important response (weight of 0.413), while the delamination at existing was recommended as the least important response (weight of 0.030) during the drilling of carbon fiber-reinforced composites. This drilling response results provide the information essential to organize training for the operators. Previously, efforts were directed equally at training the operators on the different kinds of drilling defects and how to prevent them on the drilled composites. However, the choice of the thrust force is the most important guide on a focus on the thrust force minimization training for the operators and how to limit and control this defect. Investments in training kits, both on-the-job or off-the-job, are encouraged mainly on the thrust force, while the least training should be done on the delamination at exit defect type.

Besides, while investing in materials and inputs to the drilling process, regulated measures are budgeted, and increased attention to the resources that greatly influence the thrust force is given. Resources to manage to include carbon fibers, imbricates, manufacturing hours (labour), electricity usage, and space. These resources affect the parameters during the drilling process, such as the speed, feed rates, and depth of cut. Thus, experimental and numerical analyses from the laboratory experiments permit the control and observations of variations in the drilling process with time. An important implication of this study is to interpret the drilling analysis results from the perspective of the anticipated thrust force response for the carbon fiber reinforced composites to be drilled given a particular environmental and management situation. This information may be extremely attractive to many process engineers who access published results in engineering periodicals for assistance and leads through safe and environmentally conscious interventions on surface integrity and preservation of drilled composites for carbon fiber reinforced plastic composites.

Besides, the industrial applications of the result of this work are diverse and important, covering aspects such as aircraft landing gear, fuel injector bodies, fluid assembly ends, and fuel injector bodies. Although light workpiece is commonly used while drilling CFRP composites, significant activities on drilling the CFRP exist for medium to large heavy impedes as in the example given in the proceeding sentence. Thus, for illustration of the industrial application of the study, the aircraft landing gear is considered. Using a deep hole drilling machine, holes of roughly 200mm diameter and above 1 meter could be drilled with strict tolerance. The landing gear has struts containing asymmetrical features, swinging features, and features to control an off-center weight while counter-rotating a workpiece, as the drilling process is active. Thus in this perspective, the AHP method could be introduced to guide in the choice of the best response for ease of planning and resource distribution.

## 5. CONCLUSION

In this paper, a selection technique based on the analytic hierarchy process has been proposed and tested for the drilling process of carbon fiber reinforced plastic composites using experimental literature data. The values of six different responses have been analyzed to ascertain the best properties of the composite with the chosen reinforcement matrix and the drilling process. The results in the application of the AHP method reveal the weights of responses as follows: Thrust force (0.413), torque (0.253), eccentricity (0.15), surface roughness (0.115), delamination at exit (0.030), and delamination at entry (0.037). Based on this result, the preferred parameter is the thrust force, while the delamination at the exit is the least preferred parameter.

The method discussed in this article opens up important opportunities to extend the drilling research. Based on the responses experimented with by Krishnamoorthy (2011), six items were considered. However, a more intensive literature review since the novel study may have revealed more responses. Thus, additional responses should be tested in experiments to engage fruitful discussion on the most important response. Specifically, future investigations on drilling environments could consider using drilling coolants; dry drilling, wet drilling (room temperature water), and wet drilling (hot temperature water) may be applied as coolants and the possible rating of the selected responses analyzed and compared with the present outcome of this study. Other selection techniques, such as entropy, fuzzy AHP, VIKOR, may also be applied to analyze the outcomes in comparison with the present study.

This study will serve as a valuable reference for future applications of the AHP method in the drilling of composites, particularly when considered in the practical context of composite manufacturing components made of carbon fiber reinforcements. Furthermore, examining a broad range of carbon fiber-based reinforcements such as various composition percentages will show the usefulness of this selection method in applications, especially when different drills are used. By bringing the idea of the analytic hierarchy process into focus, learning may be transferred to classroom learning. Furthermore, by practicing projects based on AHP, the researcher stands to be strengthened in experience and knowledge regarding decision making.

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