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An Application of The PROMETHEE Method To Select The Best Response for Carbon Fibre Reinforced Plastic Drilling in Machining Operations

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ABSTRACT

The manufacture of carbon fibre reinforced plastic (CFRP) composites from carbon fibres fused with epoxy matrix, deploying the hand layup method has raised considerable attention. Within this research domain, drilling with various tools such as coated and uncoated drills is of great significance. Unfortunately, the use of intuition and experience to select the best parameter in the drilling operation has been known to be less efficient, causing the inadequate distribution of drilling resources to actualize the effectiveness of drilling parameters. Energy wastages are also associated with the present practice of intuition in drilling process. In this study, a novel approach of PROMETHEE I and II are presented to avoid ineffectiveness in drilling resource distribution and select the best drilling operations parameters. The proposed method utilizes experimental data from the literature to verify the method's performance. This study helps in reducing waste due to the inadequate distribution of drilling operations sources. PROMETHEE analyses the drilling parameters of the CFRP composites using preference functions that map the differences among alternatives during machining judgments. Out of the six responses examined, the best response is exit delamination with a weight of 0.059, surface roughness with a weight of 0.031emerged as the second position, torque weighing 0.003 took the 3rd position while the last position is entry delamination, weighing -0.102.

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Research Type: Research Paper

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1. INTRODUCTION

The carbon fibre reinforced plastic (CFRP) composites experience tremendous commercial adoption since they exhibit corrosion confrontation, low density, elevated temperature and elevated specific strength (Krishnamoorthy, 2011). Besides, with extensive commercial appeals of CFRP composites in reducing the overall weights of cars and aircraft and an uncompromising characteristic, the drilling operation of several assembly connection holes has been successful over the years (Shyha et al., 2009; Kulkarni and Ramachandran, 2018; Tran et al., 2020a; Tran et al. 2020b; Tamura and Matsumura, 2021; Lv et al. 2021; Pereszlai et al. 2021; Geier et al. 2021; Goutham et al. 2021). However, the predominant use of intuition and experience of the process operators and engineers to select the best parameter in the drilling operation has been known to be less efficient (Jayaprakash et al., 2020). This process control perspective causes the inadequate distribution of drilling resources and wastage of resources that could have been more prudently managed for the sustainability of the drilling operation. Consequently, to address this deficiency, this study presents a novel approach of PROMETHEE I and II to avoid the ineffectiveness in drilling resource distribution, conservation of materials and select the best drilling operations parameters. The proposed approach deploys the experimental data by Krishnamoorthy (2011) to verify the performance of the PROMETHEE method.

In the best knowledge of the present authors, few reports have evaluated the best responses for carbon-reinforced plastic drilling in machining operations because of the complicated phenomenon of tool wear during drilling (Palanikumar et al., 2016; Srinivasan et al., 2017; Jayaprakash et al., 2020). Furthermore, the complexity in managing the drill strings weight and borehole friction in the presence of an increasing force dimension and the need to concurrently maintain the material and surface integrity of the CFRP composites are challenges of concern to prospective investigators in the CFRP composite domain (Palanikumar et al., 2016; Srinivasan et al., 2017). Unfortunately, the drilling operations of several composites, including CFRP composites are still being managed by the process operators and engineers through intuition and experience (Srinivasan et al., 2017). But matched against the sustainability drive of drilling operations for several composite machining organizations the deployment of intuition and experience of operators and engineers are no longer sufficient to respond proactively to the needs of a sustainable drilling operation according to the following reasons: (1) Several hundreds of assembly connection holes for the entire industry are always scheduled for drilling (Goutham et al., 2021), leading to substantial resource deployment and management by process operators and engineers; (2) the complication to achieve effective drilling and timely job delivery poses serious challenge to process operators and engineers since they have to struggle to fully utilize the limited drilling resources to achieve the system's goals and needs; (3) the best that could be achieved using the subjective intuitive practice and experience of managers fall within a local optimal situation but the opportunities of global optimum solution attainment has been completely ignored (Neseli, 2014; Tran et al., 2020a). Consequently, it is urgent to select the best parameter for the CFRP composite drilling operation to ascertain optimum resource distribution and usage and enhance the economic efficiency of the machining organization (Palanikumar et al., 2016; Srinivasan et al., 2017).

Thus, as an attempt to address this gap, this investigation analyses the parameters of the drilling operation while using the CFRP composites and deploys the PROMETHEE method to properly select the best response from the key responses used to define the drilling operation. The principal novelty of this article is that it establishes an efficient multicriteria method using PROMETHEE for the selection of the best response for the CFRP composite drilling operation. Second, the CFRP composite is employed in a case study to ascertain the superiority and effectiveness of the advanced multicriteria approach.

Besides, the study utilizes the PROMETHEE method to take full advantage of its completeness while ranking, where the ranking offers motivation for enhanced drilling data collection and utilization for resource deployment to responses. It exposes the drilling operation's weakness, affirming the strong responses, which could promote benchmarking among machining organizations and reduce waste. Furthermore, the advantage of using a user-friendly outranking approach is exploited while affirming the successful application of PROMETHEE in the CFRP composite drilling planning problem.

2. LITERATURE REVIEW

The quality of drilled CFRP composites allows customers to choose the desired drilled product for further manufacturing processes in their plants. However, quality is judged as a performance measure that depends on the performance characteristics of the drilling process. Consequently, in the drilling of CFRP composites, performance characteristics play a strong role in assisting process engineers/operators deliver high quality drilled products to their customers. Performance characteristics are the product traits that are needed for the satisfactory accomplishment of the drilling tasks. For the CFRP composites considered in the present article, six performance characteristics of interest are entry delamination, exit delamination, thrust force, surface roughness, torque and eccentricity. These attributes drive the process to attain outstanding drilling performance and extended HSS drill bit life. They are standard requirements that assist the process engineer/operator evade HSS drill bit burning or damages to the drilling machine. Since the CFRP material is comparatively difficult-to-machine compared to other composites such as biodegradable composites, understanding how to avoid drilling damages enhances the CFRP composite outputs in the present challenging drilling environment.

From the foregoing, to understand the link of the problem with the literature, this section is organized into several subsections, i.e. articles (i) related to carbon fibre reinforced plastics machining operation, (ii) related to optimisation method of CFRP machining operation, (iii) related to PROMETHEE. The details of these aspects are as follows.

(i) Research associated with carbon fibre reinforced plastics machining operation

Carbon fibre reinforced plastics depend on the carbon fibre to offer outstanding explicit fatigue, modulus and tensile strength while the protection attribute and holding behaviour in the composite is provided by the polymer. The polymer also offers some toughness. However, machining is a very vital process for the CFRP composite manufacture where these composites are transformed to the expected surface finish level and specification through progressive elimination of the excess material from the raw materials. These are referred to as preformed blanks and the unwanted materials are removed as chips as the HSS drill bits moves over the surface of the CFRP composite. Within this sub-heading, several research contributions have been made with success. First, Blatnagar et al. (1995) explored orthogonal machining to analyse the various fibre directions of laminates made from CFRPs. It was possible to predict the cutting forces and enhance the cutting orientation on machinability needs. Next, Person et al. (1997) contributed to revealing the influence of hole machining defects on carbon/epoxy laminates' fatigue life and strength. They concluded that hole defects in machined products substantially decreased the static and the fatigue strength for the laminates. Further, Pejryd et al. (2014) focused on hole defects in the drilling of CFRP composites. They concluded that the deployed X-ray computed tomography helped determine the association between the surface integrity of holes and the geometrical characteristics of drills. In an article, Ozekan et al. (2019) elaborated on the milling characteristics of the CFRP material and compiled information on the geometry of various cutting tools and materials mechanisms of tool wear, failures of the CFRP material and possible solutions during the milling process with a focus on defect analysis. Cepero-Mejias et al. (2019) found that the finite element models created for gaining insight into the mechanism of chip formation for CFRP laminates predicted the cutting forces applied in the machining study. They were also judged to offer useful insight into the changes of the chip morphology in the machining process. In a report by Samsudeensalham and Krishnaraj (in press), experimental studies on CFRP/Ti-6Al-4V stacks were conducted. It was concluded that a reduction in the cutting force concurrently with the growth of chip breakability dominated the results at maximum speeds. Besides, an unexpected result was that a substantial reduction of delamination occurred. It was also noted that lowered burr formation using the grooved drill to existed weighed against the normal tool. While the studies reviewed so far in this subsection mainly focused on the traditional machining operation, an interesting contribution on the CFRP composites using the modified electrical discharge machining was noted in the literature. The study due to Wu et al. (2020) identified a shortcoming in the use of the traditional wire EDM process but succeeded in using preheating-wire electrical discharge machining to process CFRPs. They declared that the proposed approach effectively improved the performance of CFRPs.

(ii) Studies related to optimization methods on CFRP machining operation

The literature recognizes an optimization procedure as a sequence of organized steps implemented intuitively to compare diverse solutions until a satisfactory outcome is known as a near-optimal solution or an optimized solution is obtained (Singh et al., 2003; Jadoun et al., 2006; Kıvak et al., 2012; Padhee et al., 2012; Thiagarajan et al., 2012; Noseli, 2014; Bosco et al., 2015; Vinayagamoorthy, 2017; Anand et al., 2018; Kaviarasan et al., 2019; Manickam and Nadarajan, 2019; Bhat et al., 2019; Shunmugesh and Pratheesh, 2020; Juliyana and Prakash, 2020). Given the significant role of optimization in the drilling function, as well as their influence on current industrial practices, several studies have been reported on optimization related to the drilling process. Prominent studies follow. Sekine and Shin (1999) optimally designed the thick-walled multi-strata CFRP pipes by reducing the process-motivated residual stresses in structural stiffnesses. It was found that for cross-ply pipes, a particular degree of reduction of the residual stress is possible through the regulation of the ply's thicknesses. Dong et al. (2017) instituted an optimisation procedure of CFRP waste management by focusing on cost reduction and the influence of global warming potential for the network. It was reported that economic interest conflicts with environmental concerns. Gebhardt et al. (2018) established a technique to optimize the structure of embedded inserts in CFRPs. The pull-out loads were recognized in the problem formulation. It was reported that growth in the load-bearing capacity was observed through the optimisation method deployment. The result was validated. Gara and Tsoumarev (2018) applied the graphic and particle swarm optimisation approaches to establish the optimal cutting situations while slotting CRP laminates. It was concluded that using the graphical approach, speed relies on the accomplishment of the utmost total removal rate but optimum feed per tooth relies on the roughness performance, which is linked to the tool geometry. Sun et al. (2019) analyzed the bending collapse characteristics and the capacity of CFRP/aluminium hybrid structures to absorb energy in experimental tests. The authors reported that the absorption behaviour of the transverse energy for the Al-CFRP hybrid tubes surpasses the addition of respective net Al-tube as well as net CFRP tube. It was further declared that optimisation triggered the growth of the particular energy absorption in the order of 42.96% while the average force of crushing the tube also increased by 37.75%. Nonetheless, a decay of 5.02% of the mass of the optimum design was noticed.

From the foregoing, several optimization methods for the CFRP machining operations have been established. However, the gap in the literature is the absence of a focused studying on the PROMETHEE method's assessment when subjected to choosing the best performance characteristics during the drilling of CFRP composites. This gap provides motivations to authors to further investigate the usefulness of effort in applying the PROMETHEE method in machining operations.

(iii) Studies associated with the use of the PROMETHEE method

The PROMETHEE method is a member of the multicriteria family and represents a substantial approach to assessing options regarding criteria used in the present CFRP composite drilling decision making problem. However, there is some related PROMETHEE based literature that helps to promote the gap identified and bridged in the present study. These are as follows. Karande and Chakraborty (2012) solved four process selection problems in the machining research domain using a combined PROMETHEE and GAIA approach. It was concluded that the obtained result was satisfactory. Besides, compared to expected solutions, the results exactly matched. In another work, Wiriyapirom (2017) applied the PROMETHEE method with weights attached to it from the AHP method, to select the most adequate 5 axis machine tool. The article by Rahimdel et al. (2020) disclosed the most adequate drilling pattern for an Iran based case study while developing the PROMETHEE method. It was concluded that the drilling pattern having 5m space, the burden of 4m and the respective hole diameter and hole depth of 15cm and 10cm yielded the most appropriate option. Furthermore, in laser drilling, Kannan et al. (in press) deployed the PROMETHEE II method in the search for optimum process parameters in laser drilling of square holes. It was declared that PROMETHEE II showed a constant output. Furthermore, Goswami (2020) established the application of PROMETHEE I and II to choose the superior laptop model from the six main available options. The AHP approach was used as the weight inputs for the PROMETHEE methods. It was concluded that model 4 yields the superior laptop model by attaining the frontline position. However, the author reported that model 1 occupies the last position.

From the foregoing, it is clear that there is a lack of literature concerning the performance of the PROMETHEE method in the drilling of CFRP composites and particularly, no study appears to have considered the application of the PROMETHEE method to monitor the performance characteristics of the drilling process.

3. METHODS

3.1 The drilling operation

In this article, the authors presented an application of the PROMETHEE method for selecting the best parameters of the drilling operation on carbon fibre reinforced plastic. However, the details of the drilling operation for the present work are presented in this section. Vertical drilling, which is the primary way to prepare carbon fibre reinforced plastic composites is adopted in this article as demonstrated by Krishnamoorthy (2011). However, horizontal drilling, which technological sophistication has made possible is a more advanced drilling type but not adopted by Krishnamoorthy (2011) because of its high cost and unavailability for experimentations. Vertical drilling is drilling straight downwards through the CFRP material with the aid of the HSS tool bit. Drilling is repeated at a feed rate until the desired depth is attained. The drilling process is controlled by the operator who totally manoeuvres the machine or partially controls it manually and partly automatically to the stage that the operator desires. The drill bit cuts through a hole and it is recalled at instances where the chips obstruct its free flow into the hole and the material is fed again. The 6mm HSS drill bit worked on the CFRP board in this article. With airflow, some of the particles are blown out. However, with the concentration of particles at the hole, the speed is reduced. While drilling the entrance side needs to be identified, which is the face allowing the penetration of the drill bit into the CFRP material. The other face of the material through which the drill bit is forced to pass through is the exit side. By observing the roundness of the holes, it may be noted that certain imperfection exists and are known by different terms among the following delamination (entry and exit), eccentricity, and others. Such imperfections may be difficult to measure with visual observations but easily observable with microscopes and may be expressed in micrometre units.

As the drilling commences, particles of the CFRP materials are removed and fly in random directions, which is dictated by the speed drilling and the depth of cut of the CFRP material. However, during the drilling process, excessive heat is generated, which is reduced by air in dry drilling or absorbed by the lubricants in the lubricated drilling system. With the necessary cooling system, the HSS drill bit for drilling the CFRP material is preserved in lifespan and can be used for a longer period than when applied without lubrication. The excessive heat during drilling is attributed to the delamination occurring on the drilled CFRP material. It could also trigger a burr at the exit axis of the CFRP material. Notwithstanding, it should also be noted that in oil-cooled drilling, some of the lubricants are absorbed by the composite material and may seriously compromise the integrity of the drilled material. Nonetheless, lubrication assisted drilling is still preferred over dry drilling (Figure 1). Furthermore, the cooling system is advantageous as it cools the CFRP material and keeps it at ambient temperature at which the integrity of the CFRP material is preserved.

Figure 1 illustrates the machine operation in the drilling of CFRP composites. Here, there is a part that could be rotated anti-clockwise to ensure penetration of the drill on the CFRP composite laminate and a close-wise movement to release the moving HSS drill bit from the plunged position is also possible. This is often achieved in a reverse direction from the forward movement. The entrance side is the surface of the CFRP composite laminate from which the HSS drill bit is allowed to enter the material. The bit penetrates the material through a defined workpiece thickness to the other surface, referred to as the exit side of the workpiece. There are two types of drilling situations, namely dry drilling and wet drilling. Dry drilling is without lubrication while wet drilling allows lubrication that may be of the flooded type or the minimum quantity level lubrication system.

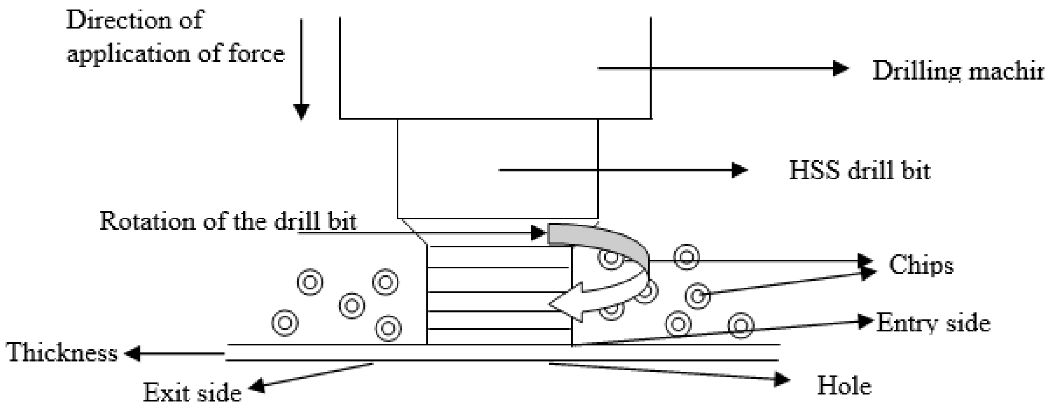

Figure 1. A typical CFRP material drilling process

3.2 Drilling terminologies

In the following, some problem-specific terminologies are explained to understand the drilling situation and the importance of the drilling problem. There are mainly six performance characteristics in drilling and the explanation commences with the term *entry delamination*. This term, which others refers to as the entrance side delamination describes accelerated stress crack damage at the transient entrance part of the carbon fibre reinforced plastic composite laminates. This triggers the in-plane failure of the drilled CFRP laminate. It motivates the transverse matrix cracks to units to create fracture surfaces, allowing the shedding of loads except that the laminates have little resistance against breaking. This description also fits the term *exit delamination* except that it happens on the opposite sides of the laminates. Further, the *surface roughness* performance characteristics evaluate the total spaced irregularities found on the CFRP laminate's surface. It is interpreted as a measure that establishes how the surface of the CFRP laminate will interact with its environment, possibly in contact with another surface. Next is the performance characteristic called *eccentricity*, which is an off-centre behaviour of a hole drilled of a diameter at the inner circle from another hole drilled outside it. If the holes are equispaced for the CFRP laminate, the correct definition of the drilled holes is concentric holes. However, due to imperfections in drilling, the outcome may be a fully eccentric pair of holes where the inner hole touches a part of the circumference of the outer hole. It could also be a case of partial eccentricity where the inner hole fails to touch any part of the circumference of the outer hole. Furthermore, the *thrust force* is the next performance characteristic of the drilling process for the CFRP laminate considered in the present study. The thrust force describes the mechanical force that propels the HSS drill bit through the hole from the entry side to the exit side of the CFRP laminates. The thrust force is instrumental to overcoming the drag of the HSS drill bit and the weight of the drill bit. As technology has advanced tremendously, the bi-axial sensor has been developed to evaluate the thrust force of the drill and the reaction torque generated from the drilling process. Next, the *torque* is a performance characteristic that describes a rotary force evolving from the drill string as well as the CFRP laminates.

3.3 General

The preference ranking organization method for enrichment of evaluations (PROMETHEE) was developed in 1982 by Professor Jean Pierre Brans. It is used in decision making to find the best alternative that suits the goal and understanding of a problem. It offers a thorough and rational framework for constructing a decision problem, finding and quantifying its conflicts and synergies, action clusters, and highlighting the primary alternatives and the systematic reasoning behind them. PROMETHEE has two options, options I and II. PROMETHEE I gives a partial ranking of the alternatives while PROMETHEE II gives a full ranking of the alternatives. Applications of PROMETHEE I and II can be found in various literatures in sectors such as healthcare, business, transportation, etc. PROMETHEE considers the weights of criteria with the preference functions in a more intricate approach when calculating the values of selected factors. Analytical hierarchical process (AHP) or Fuzzy analytical hierarchical process (FAHP) can be used to find the weights.

3.4 Steps to carrying out PROMETHEE I and II

The steps to carry out PROMETHEE I and II are as follows:

Step 1. Normalize the evaluation matrix (decision matrix): It is done by using Equations (1) and (2):

Beneficial criterion:

$$R_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]} \quad (1)$$

where $i = 1, 2, 3, 4, \ldots m$ and $j = 1, 2, 3, \ldots n$

Non-beneficial criterion:

$$R_{ij} = \frac{[\max(x_{ij}) - x_{ij}]}{[\max(x_{ij}) - \min(x_{ij})]} \quad (2)$$

where $i = 1, 2, 3, 4, \ldots m$ and $j = 1, 2, 3, \ldots n$

The beneficial criteria are the criteria that are wished to be maximized while the non-beneficial criteria are those that are wished to be minimized or reduced. In this work, the non-beneficial criteria are entry delamination, exit delamination, surface roughness and eccentricity, while beneficial criteria are thrust force and torque.

Step 2. Calculate the differences of i^{th} alternative concerning other alternatives

Step 3. Calculate the preference function, P(a,b)

While adopting the PROMETHEE method to intervene in establishing the best response among the CFRP composite responses of entry delamination, exit delamination, surface roughness, torque, thrust force and eccentricity, the preference function idea is implemented. This idea is based on establishing the differences among the responses. While comparing two responses it is expected that one term should be greater than the other, yielding a positive magnitude of the difference. Here the value is retained. However, when this difference is not positive as expected, a value of zero is returned as the outcome. The proponent of the PROMETHEE method distinguishes the two varieties of PROMETHEE I from the PROMETHEE II while applying the preference function. The evaluation using the PROMETHEE varieties introduces an averaging mechanism of the related terms as present in PROMETHEE I while it is absent in PROMETHEE II. In multicriteria analysis, the use of the preference idea is not limited to the PROMETHEE method but also used in the other methods where preference scores are coined as a term that distinguishes comparison between two terms.

The calculation is done by putting all values of the difference table that are less than or equal to zero to be zero, while the values that are greater than zero remains the same. i.e.

Table 1. Averaged experimental table and AHP weightage (Krishnamoorthy, 2011)

AHP weights obtained from Odusoro and Oke (2021) $\rightarrow$	**0.413**	**0.253**	**0.037**	**0.030**	**0.151**	**0.115**
Expt	Thrust force	Torque	Entry delamination	Exit delamination	Eccentrity	Surface roughness
1	0.601	0.611	0.656	0.635	0.599	0.515
2	0.374	0.653	0.442	0.417	0.473	0.364
3	0.497	0.588	0.581	0.593	0.578	0.470
4	0.558	0.808	0.645	0.652	0.647	0.555
5	0.575	0.716	0.657	0.658	0.622	0.514
6	0.247	0.816	0.405	0.382	0.420	0.289
Max(x_{ij}), min(x_{ij})	0.601, 0.247	0.816, 0.588	0.657, 0.405	0.658, 0.382	0.647, 0.420	0.555, 0.289

$P_j(a,b) = 0$ if $R_{aj} \leq R_{bj}$ where $D(E_a\text{-}E_b) \leq 0$ (3)

$P_j(a,b) = (R_{aj} - R_{bj})$ if $R_{aj} > R_{bj}$ where $D(E_a\text{-}E_b) > 0$ (4)

Step 4. Calculate the aggregated preference function
Aggregated preference function is calculated by multiplying the criteria weight from either AHP or FAHP with the preference table and summing the rows. The formula is given in Equation (5):

$$\pi(a,b) = \frac{\left|\sum_{j=1}^{n} w_j P_j(a,b)\right|}{\sum_{j=1}^{n} w_j} \quad (5)$$

Step 5. Determine the leaving and the entering outranking flows

For PROMETHEE II,
Leaving (positive) flow for a[th] alternative,

$$\varphi^+ = \frac{1}{m-1}\sum_{b=1}^{m} \pi(a,b) \qquad (a \neq b) \quad (6)$$

Entering (negative) flow for a[th] alternative,

$$\varphi^- = \frac{1}{m-1}\sum_{b=1}^{m} \pi(b,a) \qquad (a \neq b) \quad (7)$$

For PROMETHEE I,
Leaving (positive) flow for a[th] alternative,

$$\varphi^+ = \sum_{b=1}^{m} \pi(a,b) \qquad (a \neq b) \quad (8)$$

Entering (negative) flow for a[th] alternative,

$$\varphi^- = \sum_{b=1}^{m} \pi(b,a) \quad (a \neq b) \quad (9)$$

Step 6. Calculate the net outranking flow for each alternative
This is done by subtracting the leaving flow, from the entering flow. This is only done for PROMETHEE II as:

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \quad (10)$$

Step 7. Preference function for PROMETHEE I
It is carried out by comparing two alternatives. The following rules are applied.

4. RESULTS AND DISCUSSIONS

Literature data were obtained from the doctoral degree thesis of Krishnamoorthy (2011) that contains the performance of various drills and drilling responses but no effort was made in the work to prioritise the responses to discover the best one using any of the multicriteria methods. Although two previous studies due to Odudoro and Oke (2021a) on the application of the analytic hierarchy process and a second study on the use of fuzzy analytic hierarchy process by Odudoro and Oke (2021b) championed the prioritization of responses for the CFRP composites during the dulling operation, this work asserts a first time application of the PROMETHEE method to the problem. In the data from Krishnamoorthy (2011), the results of responses are displayed with multiple experimental trials. However, segmentation was done for groups of results equivalent to experimental trials and averages of the groups used in the computation. In the application of the PROMETHEE method in this result section, stepwise consideration of the procedure explained in section 3 of this article, on the PROMETHEE method is made here.

Furthermore, this section discusses the results obtained from the implementation of the PROMETHEE procedure. The computations are shown below stepwise.

Step 1. Normalize the Evaluation matrix (Decision matrix)
The results of the application of Equations (1) and (2) yield Table 1. It is interesting to note that Table 1, which displays the framework of the PROMETHEE method has two components of data for treatment. These are the adopted AHP weights and the computations commenced using the PROMETHEE method. Thus, to apply the PROMETHEE method users are required to first compute the weight of the performance characteristics using a different method such as the AHP method, or other weight-assigning methods. The PROMETHEE method then takes these weights as inputs and then uses them to multiply other defined items. However, given that previous research has been published on the same problem by Odusoro and Oke (2021), the data on the weight that the previous reports specified are then adopted in the present study.

Besides, the AHP weights used in this study follows literature approaches for the implementation of the PROMETHEE method; Wiriyapirom (2017) and Goswami (2020) adopted the AHP weighting scheme as inputs into the PROMETHEE method. This data is the first row displayed in Table 1. Furthermore, related to the case taken from Krishamoorthy (2011), the present authors took all the data from the case but not in the summarized form of six experiments. Initially, the data obtained on the responses were twenty-seven experimental trials. However, analyzing such experiments counts may be a little challenging as the volume of computations required may be time-consuming. Thus, as a strategy to ease computation, the experimental trials were divided into six experiments with each experiment being the average values of actual experiments originally reported in Krishnamoorthy (2011). To elaborate further, the experiments in Table 1 are averages of four to five experimental trials since an equal division of the experimental trials is not possible. Finally, a total of six experimental counts were used based on averages. Besides, by further analysis of Table 1, Table 2 is obtained.

Step 2. Calculate the differences of i^{th} alternative concerning other alternatives
This is done in Table 3.

Step 3. Calculate the preference function, P(a,b)
This is done by putting all values of the difference table that are less than or equal to zero to be zero, while the values that are greater than zero remains the same. This is the implementation of Equations (3) and (4) and presented

Table 2. Normalized decision matrix table

Expt	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness
1	1	0.1	0.004	0.083	0.211	0.15
2	0.359	0.285	0.853	0.873	0.767	0.718
3	0.706	0	0.302	0.236	0.305	0.319
4	0.879	0.965	0.048	0.022	0	0
5	0.927	0.561	0	0	0.11	0.154
6	0	1	1	1	1	1

Table 3. i^{th} difference table

Expt	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness
D(E1-E2)	0.641	-0.185	-0.849	-0.79	-0.556	-0.568
D(E1-E3)	0.294	0.100	-0.298	-0.153	-0.094	-0.169
D(E1-E4)	0.121	-0.865	-0.044	0.061	0.211	0.15
D(E1-E5)	0.073	-0.461	0.004	0.083	0.101	-0.004
D(E1-E6)	1.000	-0.900	-0.096	-0.917	-0.789	-0.85
D(E2-E1)	-0.641	0.185	0.849	0.79	0.556	0.568
D(E2-E3)	-0.347	0.285	0.551	0.637	0.462	0.399
D(E2-E4)	-0.52	-0.594	0.805	0.851	0.767	0.718
D(E2-E5)	-0.568	-0.276	0.853	0.873	0.657	0.564
D(E2-E6)	0.359	-0.715	-0.147	-0.127	-0.233	-0.282
D(E3-E1)	-0.294	-0.100	0.298	0.153	0.094	0.169
D(E3-E2)	0.347	-0.285	-0.551	-0.637	-0.462	-0.399
D(E3-E4)	-0.173	0.965	0.254	0.214	0.305	0.319
D(E3-E5)	-0.221	-0.561	0.302	0.236	0.195	0.165
D(E3-E6)	0.706	-1.000	-0.968	-0.764	-0.695	-0.681
D(E4-E1)	-0.121	0.865	0.044	-0.061	-0.211	-0.15
D(E4-E2)	0.52	0.68	-0.805	-0.851	-0.767	-0.718
D(E4-E3)	0.164	0.965	-0.254	-0.214	-0.305	-0.319
D(E4-E5)	-0.048	0.404	0.048	0.022	-0.110	-0.154
D(E4-E6)	0.879	-0.035	-0.952	-0.978	-1.000	-1.000
D(E5-E1)	-0.073	0.461	-0.004	-0.083	-0.101	0.004
D(E5-E2)	0.568	0.276	-0.853	-0.873	-0.657	-0.564
D(E5-E3)	0.221	0.561	-0.302	-0.236	-0.195	-0.165
D(E5-E4)	0.048	-0.404	-0.048	-0.022	0.110	0.154
D(E5-E6)	0.927	-0.439	-1.000	-1.000	-0.890	-0.846
D(E6-E1)	-1.000	0.9	0.996	0.917	0.789	0.850
D(E6-E2)	-0.359	0.715	0.147	0.127	0.233	0.282
D(E6-E3)	-0.706	1.000	0.698	0.764	0.695	0.681
D(E6-E4)	-0.879	0.035	0.952	0.978	1.000	1.000
D(E6-E5)	-0.927	0.439	1.000	1.000	0.89	0.846

in Table 4.

Step 4. Calculate the aggregated preference function
Aggregated preference function is calculated by multiplying the criteria weight from either AHP or FAHP with the preference table and summing the rows. The implementation of Equation (5) yields this, presented in Table 5.

A further step in the computation of aggregated preference function is demonstrated in Table 6.

Step 5. Determine the leaving and the entering outranking flows
It is found by taking the average of the leaving and entering flow. This is where the distinction between PROMETHEE I and PROMETHEE II comes in, as suggested by Equations (6), (7), (8) and (9) and the results are shown in Tables 7, 8 and 9.

Table 4. Preference function

Expt	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness
D(E1-E2)	0.641	0.000	0.000	0.000	0.000	0.000
D(E1-E3)	0.294	0.100	0.000	0.000	0.000	0.000
D(E1-E4)	0.121	0.000	0.000	0.061	0.211	0.150
D(E1-E5)	0.073	0.000	0.004	0.083	0.101	0.000
D(E1-E6)	1.000	0.000	0.000	0.000	0.000	0.000
D(E2-E1)	0.000	0.185	0.849	0.790	0.556	0.568
D(E2-E3)	0.000	0.285	0.551	0.637	0.462	0.399
D(E2-E4)	0.000	0.000	0.805	0.851	0.767	0.718
D(E2-E5)	0.000	0.000	0.853	0.873	0.657	0.564
D(E2-E6)	0.359	0.000	0.000	0.000	0.000	0.000
D(E3-E1)	0.000	0.000	0.298	0.153	0.094	0.169
D(E3-E2)	0.347	0.000	0.000	0.000	0.000	0.000
D(E3-E4)	0.000	0.965	0.254	0.214	0.305	0.319
D(E3-E5)	0.000	0.000	0.302	0.236	0.195	0.165
D(E3-E6)	0.706	0.000	0.000	0.000	0.000	0.000
D(E4-E1)	0.000	0.865	0.044	0.000	0.000	0.000
D(E4-E2)	0.520	0.680	0.000	0.000	0.000	0.000
D(E4-E3)	0.164	0.965	0.000	0.000	0.000	0.000
D(E4-E5)	0.000	0.404	0.048	0.022	0.000	0.000
D(E4-E6)	0.879	0.000	0.000	0.000	0.000	0.000
D(E5-E1)	0.000	0.461	0.000	0.000	0.000	0.004
D(E5-E2)	0.568	0.276	0.000	0.000	0.000	0.000
D(E5-E3)	0.221	0.561	0.000	0.000	0.000	0.000
D(E5-E4)	0.048	0.000	0.000	0.000	0.110	0.154
D(E5-E6)	0.927	0.000	0.000	0.000	0.000	0.000
D(E6-E1)	0.000	0.900	0.996	0.917	0.789	0.850
D(E6-E2)	0.000	0.715	0.147	0.127	0.233	0.282
D(E6-E3)	0.000	1.000	0.698	0.764	0.695	0.681
D(E6-E4)	0.000	0.035	0.952	0.978	1.000	1.000
D(E6-E5)	0.000	0.439	1.000	1.000	0.890	0.846

Table 5. Aggregated preference $\pi(a,b)$ table

Expt	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness	$\sum_{j=1}^{n} w_j P_j$
Weights	0.413	0.253	0.037	0.030	0.151	0.115	
0.253	0.413*0.641	0.253 * 0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.265
D(E1-E3)	0.413*0.294	0.253 *0.1	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.147
D(E1-E4)	0.413*0.121	0.253 *0	0.037 * 0	0.030 * 0.061	0.151 * 0.211	0.115 * 0.15	0.101
D(E1-E5)	0.413*0.073	0.253 *0	0.037 * 0.004	0.030 * 0.083	0.151 * 0.101	0.115 * 0	0.048
D(E1-E6)	0.413*1	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.413
D(E2-E1)	0.413*0	0.253 *0.185	0.037 * 0.849	0.030 * 0.79	0.151 * 0.556	0.115 * 0.568	0.251
D(E2-E3)	0.413*0	0.253 *0.285	0.037 * 0.551	0.030 * 0.637	0.151 * 0.462	0.115 * 0.399	0.227
D(E2-E4)	0.413*0	0.253 *0	0.037 * 0.805	0.030 * 0.851	0.151 * 0.767	0.115 * 0.718	0.254
D(E2-E5)	0.413*0	0.253 *0	0.037 * 0.853	0.030 * 0.873	0.151 * 0.657	0.115 * 0.564	0.222

Table 5 (cont'd). Aggregated preference $\pi(a,b)$ table

Expt	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness	$\sum_{j=1}^{n} w_j P_j$
Weights	0.413	0.253	0.037	0.030	0.151	0.115	
D(E2-E6)	0.413*0.359	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.148
D(E3-E1)	0.413*0	0.253 *0	0.037 * 0.298	0.030 * 0.153	0.151 * 0.094	0.115 * 0.169	0.049
D(E3-E2)	0.413*0.347	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.143
D(E3-E4)	0.413*0	0.253 *0.965	0.037 * 0.254	0.030 * 0.214	0.151 * 0.305	0.115 * 0.319	0.343
D(E3-E5)	0.413*0	0.253 *0	0.037 * 0.302	0.030 * 0.236	0.151 * 0.195	0.115 * 0.165	0.067
D(E3-E6)	0.413*0.706	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.292
D(E4-E1)	0.413*0	0.253 *0.865	0.037 * 0.044	0.030 * 0	0.151 * 0	0.115 * 0	0.220
D(E4-E2)	0.413*0.52	0.253 *0.68	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.387
D(E4-E3)	0.413*0.164	0.253 *0.965	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.312
D(E4-E5)	0.413*0	0.253 *0.404	0.037 * 0.048	0.030 * 0.022	0.151 * 0	0.115 * 0	0.105
D(E4-E6)	0.413*0.879	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.363
D(E5-E1)	0.413*0	0.253 *0.461	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0.004	0.117
D(E5-E2)	0.413*0.568	0.253 *0.276	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.304
D(E5-E3)	0.413*0.221	0.253 *0.561	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.233
D(E5-E4)	0.413*0.048	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0.11	0.115 * 0.154	0.054
D(E5-E6)	0.413*0.927	0.253 *0	0.037 * 0	0.030 * 0	0.151 * 0	0.115 * 0	0.383
D(E6-E1)	0.413*0	0.253 *0.9	0.037 * 0.996	0.030 * 0.917	0.151 * 0.789	0.115 * 0.85	0.509
D(E6-E2)	0.413*0	0.253 *0.715	0.037 * 0.147	0.030 * 0.127	0.151 * 0.233	0.115 * 0.282	0.258
D(E6-E3)	0.413*0	0.253 *1	0.037 * 0.698	0.030 * 0.764	0.151 * 0.695	0.115 * 0.681	0.485
D(E6-E4)	0.413*0	0.253 *0.035	0.037 * 0.952	0.030 * 0.978	0.151 * 1	0.115 * 1	0.339
D(E6-E5)	0.413*0	0.253 *0.439	0.037 * 1	0.030 * 1	0.151 * 0.89	0.115 * 0.846	0.410

Table 6. Aggregated preference function

Aggregate Preference Function	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness
Expt 1	-	0.265	0.147	0.101	0.048	0.413
Expt 2	0.251	-	0.227	0.254	0.222	0.148
Expt 3	0.049	0.143	-	0.343	0.067	0.292
Expt 4	0.220	0.387	0.312	-	0.105	0.363
Expt 5	0.117	0.304	0.233	0.054	-	0.383
Expt 6	0.509	0.258	0.485	0.339	0.410	-

Table 7. Leaving and entering flow calculation for PROMETHEE II

Aggregate Preference Function	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness	φ^+ * Leaving flow
Expt 1	-	0.265	0.147	0.101	0.048	0.413	0.227
Expt 2	0.251	-	0.227	0.254	0.222	0.148	0.220
Expt 3	0.049	0.143	-	0.343	0.067	0.292	0.179
Expt 4	0.220	0.387	0.312	-	0.105	0.363	0.277
Expt 5	0.117	0.304	0.233	0.054	-	0.383	0.218
Expt 6	0.509	0.258	0.485	0.339	0.410	-	0.4
φ^- Entering flow	0.229	0.217	0.281	0.218	0.257	0.319	

Step 6. Calculate the net outranking flow for each alternative
This is done by subtracting the leaving flow, from the entering flow. This is only done for PROMETHEE II. It is given in Equation (10) while the results are shown in Table 10.

Table 10 shows that Exit delamination is the most preferred attribute, and Entry delamination is the least desirable attribute.

Step 7. Preference function for PROMETHEE I
It is carried out by comparing two alternatives. Table 11 shows the outcome.

Table 8. Leaving and entering flow calculation for PROMETHEE I

Aggregate Preference Function	Thrust force	Torque	Entry delamination	Exit delamination	Eccentricity	Surface roughness	φ^{+} * Leaving flow
Expt 1	-	0.265	0.147	0.101	0.048	0.413	0.947
Expt 2	0.251	-	0.227	0.254	0.222	0.148	1.102
Expt 3	0.049	0.143	-	0.343	0.067	0.292	0.894
Expt 4	0.220	0.387	0.312	-	0.105	0.363	1.387
Expt 5	0.117	0.304	0.233	0.054	-	0.383	1.091
Expt 6	0.509	0.258	0.485	0.339	0.410	-	2.001
φ^{-} Entering flow	1.146	1.357	1.404	1.091	0.852	1.329	

Table 9. Leaving and entering flow for PROMETHEE II

Response	φ^{+} Leaving flow	φ^{-} Entering flow
Thrust force	0.227	0.229
Torque	0.220	0.217
Entry delamination	0.179	0.281
Exit delamination	0.277	0.218
Eccentricity	0.218	0.257
Surface roughness	0.4	0.319

Table 10. Net outranking flow

Response	φ^{+} Leaving flow	φ^{-} Entering flow	$\varphi(a)$	Rank
Thrust force	0.227	0.229	0.002	4
Torque	0.220	0.217	0.003	3
Entry delamination	0.179	0.281	-0.102	6
Exit delamination	0.277	0.218	0.059	1
Eccentricity	0.218	0.257	-0.039	5
Surface roughness	0.4	0.319	0.031	2

Table 11. Leaving and entering flow for PROMETHEE I

Response	φ^{+} Leaving flow	φ^{-} Entering flow
Thrust force	0.947	1.146
Torque	1.102	1.357
Entry delamination	0.894	1.404
Exit delamination	1.387	1.091
Eccentricity	1.091	0.852
Surface roughness	2.001	1.329

4.2 Comparison of PROMETHEE with other methods

First, some efforts on establishing the best response to the drilling operation's problem of carbon fibre reinforced plastic composite have been made in the past in the literature in two studies. The first study (Odusoro and Oke 2021a) establishes the priority of the responses using the analytic hierarchy process. The authors evaluated responses by weights as the delamination at entry as 0.037, delamination at the exit as 0.030, torque as 0.253, surface roughness as 0.115, eccentricity as 0.151 and thrust force as 0.413. But the method of analytic hierarchy process is deficient in outranking principles and excludes a very extensive preference selection mechanism that guarantees a thorough analysis of the responses in diverse possible scenarios. From the foregoing, the use of the PROMETHEE method is a novel route to analyzing the responses obtained in the drilling of CFRP composites. Furthermore, a second study by Odusoro and Oke (2021b) discusses the relative importance of the responses concerning the drilling operations while using the CFRP composites as the work material while the fuzzy analytic hierarchy process is the focus. The assessed responses are the delamination at entry as 0.034, delamination at the exit as 0.029, thrust force as 0.415, torque as 0.253, eccentricity as 0.151 and surface roughness as 0.107. It was argued that the determined response values are better than those earlier obtained using the analytic hierarchy process alone as it incorporates the uncertainty analysis and imprecision in the experimental data gathering and analysis. While the present authors agree with the proposal of the article as an improvement to the work on the analytic hierarchy process alone, the method of fuzzy analytic hierarchy process utilized is also deficient in outranking mechanisms. Besides, the thoroughness experienced in analyzing the different scenarios using the preference function concept, which places the PROMETHEE method ahead of several other methods is absent in the fuzzy analytic hierarchy process. Therefore, the introduction of the PROMETHEE method to establish the best responses among the six identified CFRP composite drilling responses considered is a novel approach in analysis within the CFRP composite domain.

Besides the claim of the novelty of the PROMETHEE method in the application perspective to the CFRP composite drilling process in this results section, it is interesting to compare the obtained results in the current work and past studies that attempted to use the analytic hierarchy process and fuzzy analytic hierarchy process. The comparison was made using the correlation coefficient. Correlation refers to the association between the results of responses of each of the analytic hierarchy processes on one part and those of the PROMETHEE method on the other part. The correlation of the results of ranks between the fuzzy analytic process and the PROMETHEE method was examined on the other part. Furthermore, the results of correlation analysis between the PROMETHEE methods' responses and the analytic hierarchy method's responses reveal a value of 0.1190. This shows a very weak relationship between the outcomes, indicating that the analytic hierarchy process does not match in performance compared to the PROMETHEE method, but the PROMETHEE method is still novel. Besides, the outcomes of correlation analysis between the PROMETHEE method and the fuzzy analytic hierarchy methods responses show a value of 0.1172. It is an indication that a weak relationship exists between the two methods' outcomes. This also shows a very weak relationship between the outcomes, indicating that the fuzzy analytic hierarchy process does not match in performance compared to the PROMETHEE method, but the PROMETHEE method is still novel.

To further enhance the quality of presentation of this article, an analysis of variance (ANOVA) procedure was implemented based on the extensive success report on its application in engineering practices. It was desired to know of any statistical differences that occur between the means of the results produced by the PROMETHEE methodical application on the responses and each of those produced by the analytic hierarchy process and the fuzzy analytic hierarchy process. On applying ANOVA to the groups of data produced between the PROMETHEE method and analytic hierarchy process, the alpha value of 0.05 was set. This implies that the present authors have the intention of accepting close to a 5% possibility of rejecting the null hypothesis while in truth the null hypothesis stands correct. But at the outset, the null hypothesis in the ANOVA framework in this study for both comparisons of the outcome of the PROMETHEE method and AHP method as well as the PROMETHEE method versus the FAHP method is that there exists no difference between the means of the two output types. Side-by-side, the alternative hypothesis is that the means are not all the same.

Now, the result between the outcomes of the PROMETHEE method and the AHP method is a p-value of 0.027743, which interprets as the difference between the two is not significant. Thus, the output by the AHP method is as useful as the PROMETHEE method, yet the PROMETHEE method is novel. As the results between the outcomes of the PROMETHEE method and the FAHP method are compared, a p-value of 0.43418 was obtained, which interprets as the difference between the means of the two methods is significant, hence the FAHP method may not be as useful as the PROMETHEE method. Although the result comes out this way, it is understandable as the FAHP method already tracks uncertainty, which is not tracked in the PROMETHEE method. But uncertainty and imprecision are drawbacks in model evaluation, which when ignored does not give the true situation of the problem and the interpretation of decisions may be wrong. Thus, the FAHP method may not be thrown out as inadequate. Yet, the PROMETHEE method is novel and useful, in the domain of drilling operations' practices.

4.3 Managerial implications, limitations and future research directions

The present literature on CFRP composites offers scant data-driven and practical support to process engineers and operators despite that the knowledge of prioritized order of responses to drilling operations is known to influence resource distribution practices during drilling. This research and practice gap is tackled by providing some implications arising from the present investigation as follow. However, these implications are suggestions to machining shops to embrace the PROMETHEE method as an adaptable framework and to all stakeholders of the machine shop. An implication from the present study's findings is that process engineers and operators should exercise careful attention to the resource distribution system and evaluate if the present scheme of distributing drilling resources provides the expected results regarding efficiency and waste-avoidance utilization of drilling operations resources. The direct consequence of the PROMETHEE result is that the process engineer/operator can concentrate on the most important factor while avoiding time and energy wastage. While intuition and experience are limited, the prioritized responses may assist in identifying the important responses to channel efforts, for value-adding activities to the resources being distributed. The findings in this study reveal that delamination at the exit is the best response whereas the worst response belongs to delamination at the entry.

Furthermore, the present article is possibly the third to apply the multicriteria decision-making method to the drilling operation's response selection for the carbon fibre reinforced plastic composites to the best of the authors' knowledge. As such, it is one of the earliest efforts to disclose the use of outranking methods within the CFRP composite drilling domain. However, it has its limitations. Though the findings of the research discuss prioritization of responses within the CFRP composite dulling domain, the data used for the study, obtained from the literature, was generated about eleven years ago. Future studies could correct this weakness by collecting experimental data on an up-to-date basis, thus reflecting the present status of the attributes of responses for the CFRP composites.

5. CONCLUSION

The present study examines the selection of the best response for the CFRP composite drilling operation using the PROMETHEE method. By unveiling an outranking procedure through preference function deployment and the use of net leaving and entering flows, this work developed a PROMETHEE structure to describe how to choose from alternatives. This research is a unique contribution in the application domain of the PROMETHEE method to the problem of response selection during the drilling process of the carbon fibre reinforced plastic composites.

Furthermore, the ultimate objective of carbon fibre reinforced plastic composite assessment and choice problem in the drilling domain is to choose an adequate drilling response that suits the drilling process needs and guides on resource deployment machining decisions. In the context of the pursued study, there are six experimental-based responses adopted from the literature with different magnitudes of importance. However, selecting the best response while understanding the conflicting criteria, which responses are subjected, is a complicated issue. But a simple yet efficient multicriteria method to guide process operators and engineers in actualizing an adequate drilling machining decision is sparse in the literature. In this paper, an adequate step used to establish the comparative importance of drilling responses in machining decision making and preference ranking of competing responses using the PROMETHEE method is showcased.

This work applies the PROMETHEE method to select the best drilling response while drilling the carbon fibre reinforced plastic. It was confirmed that the adopted approach is feasible. Since the best response is exit delamination, it is suggested that preference should be given to this response in resource distribution above other responses. Also, the distribution of resources should be observed by utilizing the relative weights of the responses as higher weights, of responses should cause the researcher to channel more resources to responses than those with lower weights of responses. The findings in this study reveal the effectiveness of the method. In the future, a combination of multicriteria methods with the PROMETHEE method may be attempted.

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