e-ISSN: 2685-4090 http://ojs.uajy.ac.id/index.php/IJIEEM

A Fuzzy Analytic Hierarchical Method to Reduce Imprecision and Uncertainty in Drilling Operation's Factor Selection Process for Unidirectional Carbon Fibre Reinforced Plastic Composite Plates

Salome Ifeoluwa Odusoro [1] and Sunday Ayoola Oke [2*]
[1,2] Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria
Email: sa_oke@yahoo.com

*Corresponding author

ABSTRACT

Parametric selection in machining processes is recently understood as a route to reducing waste generation in drilling activities and achieving a robust resource distribution in drilling activities. However, the selection methods dominant in the literature lack competence in reducing uncertainties and imprecision associated with the drilling process. The purpose of this research is to reduce the uncertainty and imprecision in previously analyzed data that used the analytic hierarchy process (AHP) method. This paper adjusts the uncertainty and imprecision by introducing a geometric mean-based fuzzy analytic hierarchy process. The selection method influences the drilling expert's preferences by imposing the fuzzy theory in a triangular member function that converts the crisp numerical values into fuzzy members and adequately suppresses the imprecision and uncertainty in the elements. The thrust force was positioned first in ranking with a FAHP method's weight of 0.415, which matched the literature value of 0.413 for the AHP method. It was found that the use of the FAHP method has corrected the imprecision and uncertainty introduced by the AHP method. It was found that the thrust force and torque were overestimated by or 0.48% and 3.95%, respectively and was accordingly corrected. Besides, no errors were found with the measurement of eccentricity response. Furthermore, the entry delamination, exit delamination and surface roughness were underestimated by -8.11%, -3.33% and -6.96%, respectively, and therefore corrected by the FAHP method. The usefulness of this effort is to enhance cost-effective decisions and the effectiveness in the distribution of scarce drilling resources.

DOI: https://doi.org/10.24002/ijieem.v3i1.4447

Keywords: Fuzzy analytic hierarchy process, geometric mean, multi-criteria decision making, drilling, machining

Research Type: Research Paper

Reference to this paper should be made as follows: Odusoro, S. I. and Oke, S. A. (2021). A Fuzzy Analytic Hierarchical Method to Reduce Imprecision and Uncertainty in Drilling Operation's Factor Selection Process for Unidirectional Carbon Fibre Reinforced Plastic Composite Plates. *International Journal of Industrial Engineering and Engineering Management,* 3, (1), 17-26.

1. INTRODUCTION

In the material removal area, it is conventional to recommend the best candidate parameter in a drilling operation through crisp numerical evaluation (Amini et al., 2017; Kulkarni and Ramachandran, 2018; Balaji et al., 2018; Agwa and Megahed, 2019; Odusoro and Oke, 2021). The common multi-criteria decision making (MCPM) technique of the analytic hierarchy process is used (Ayağ, 2007; Odusoro and Oke, 2021). Here, the preferences of the drilling operator or process engineer are considered through a comparative matrix that weights one criterion against the other is introduced (Ayağ, 2007; Odusoro and Oke, 2021). In this setup, the inaccuracies introduced by the operator in measurements, equipment-related errors and several other imprecision and uncertainty are unfortunately omitted in the MCDM results (Ayağ, 2007). This implies that decisions made on the MCDM results are sub-optimal and error-prone, leading to wrong decisions sometimes (Ayağ, 2007).

Unfortunately, the prevailing AHP model used to monitor the selection process of the drilling parameters for the carbon fibre reinforced plastic composites fails to reduce the imprecision and uncertainties in the AHP results (Odusoro and Oke, 2021). But it helps pursue cost-effective decisions and decision that optimizes the process variables within the limited frontier of drilling activity specifications. Pursuing such tracking and lowering of uncertainties and imprecision in dulling operations reflects the capacity and limitations of the real system (Krishnamoorthy et al., 2012). By reducing the imprecision and uncertainty through a mechanism, it is possible to offer a superior and practical picture of the drilling process, its parameters and interactions while drilling carbon fibre reinforced plastic composite (Krishnamoorthy et al., 2012; Shokrani et al., 2019; Soepangkat et al., 2020; Tran et al., 2020). Today, the need to accurately understand the practical picture of the drilling operation is reinforced by the dwindling fortunes of the business operation, the increasing turnover of staff, the higher processing cost of operations and the unstable government policies concerning manufacturing in developing countries (Krishnamoorthy et al., 2012). Thus, there is an expectation of incredible and impressive accuracies from initiating a factor selection process in selection model estimations.

While there is hardly any existing model to solve the problem described above, developing a novel framework to solve the problem is welcome. Consequently, this article presents a fuzzy analytic hierarchy process by geometric mean evaluation process to reduce the uncertainty and imprecision in the drilling of carbon fibre reinforced plastic composites. The fuzzy theory is introduced to the AHP to reduce the imprecision and uncertainty obtained in the MCDM results. The fuzzy analytical hierarchy process method appears more efficient than the analytic hierarchy process (Ayağ, 2007). It could evaluate the inaccuracies in tracking the imprecision and uncertainties in the AHP method in the context of the evaluating criteria (Ayağ, 2007). More objectivity could indicate the viewpoint of the system regarding the drilling process of the carbon fibre reinforced plastic composites (Krishnamoorthy et al., 2012).

The originality of this work consists, precisely, of analyzing and reducing the elements of imprecision and uncertainty while drilling the carbon fibre reinforced plastic composite, which involves the interactions of the drilling parameters (spindle speed, feed rate and point angle) and the responses (delamination at exit and entry), eccentricity, surface roughness, thrust force and torque (Abdul Nasir et al., 2015; Gunay et al., 2016; Meral et al., 2019; Singh et al., 2020). The drilling process was precisely conceptualized regarding the responses, the comparative matrix created. The triangular membership function is deployed to produce fuzzy triangular numbers in a fuzzification process. The weighted value of the fuzzy vector is developed, and the fuzzy weights are finally converted to crisp numeric values. The fuzzy analytic hierarchy process described and analyzed for the drilling process regarding the carbon fibre reinforced plastic composite plays an important role to understand how to reduce the imprecision and uncertainty that the analytic hierarchy process is incapable of achieving for the drilling process. Much remains unknown about the solved problem, such as the influence of introducing the multiple regression analysis to establish the relationship between drilling parameters and responses, among others. However, new information about the imprecision and uncertainty reduction potential of the FAHP method is presented to assist researchers in drilling operations. It conserves scarce drilling resources through waste reduction and establishes a justifiable resource distribution programme to the parameters of drilling the carbon fibre reinforced plastic composite. This contributes to a better understanding of the drilling operations and suggests a new way to monitor and conserve drilling resources, attracting stakeholders' attention lately.

The purpose of this research is to reduce the uncertainty and imprecision in previously analyzed data that used the analytic hierarchy process (AHP) method. This paper adjusts the uncertainty and imprecision by introducing a geometric mean-based fuzzy analytic hierarchy process. This article focuses on selecting responses to a drilling operation involving the CFRP composites that were drilled using a carbide tool drill bit. The fuzzy analytic hierarchy process is applied to reduce the imprecision and uncertainty that the analytic hierarchy process cannot control. Among the uncertainty and imprecision reduction tools such as fuzzy axiomatic design, fuzzy TOPSIS and fuzzy VIKOR, the fuzzy AHP is common and popular for its simplicity and accuracy in results. The literature shows that limited investigations have been reported on reducing imprecision and uncertainty in the multi-criteria decision-making results regarding the use of carbon fibre reinforced plastic composites. Thus there is a necessity and urgency to obtain tools and results that could reduce the uncertainty and imprecision in the values of the responses obtained during the drilling of carbon fibre reinforced plastic composites and enhance the drilling performance of the composite (Wang and Jia, 2020).

2. LITERATURE REVIEW

In the following discussions, a brief review of the literature is provided. Kaminski and Pawlak (2015) established different methods for the probabilistic homogenization of the carbon fibre reinforced plastic (CFRP) composites by incorporating Gaussian uncertainty. The outcome indicates that the fundamental tendencies noted in the framework reveal the uncertainty level and the sensitivity of the model features. Shirvanimoghaddam et al. (2017) presented a review on carbon fibre reinforced metal matrix composites. It was found that structure bonding and composition are three issues of remarkable impact on the properties of the composite. Furthermore, the interests of researchers were noted on the utilization of the composites and the optimization of their properties. Besides, a literature review was reported on the influence of carbon fibre on the physical, mechanical and structural characteristics of metal matrix composites and the different fabrication approaches.

Wu et al. (2017) tackled the design problem regarding the ply direction for a carbon fibre reinforced plastic door of a vehicle by executing a discrete material optimization approach. The method was developed by combining the ABACUS software and the MATLAB programme. The objective function of the model formulated uses the weighted mean compliance of the CFRP vehicle door since there are numerous loading situations. The constraints were picked as the principal natural frequency, manufacturability, and confined displacements. Then, the authors evaluated the sensitivity of the objectives and constraints using strain vectors. The study concludes that the method's performance efficiently exceeds the empirical design and other optimization approaches.

Lurie et al. (2018) treated the carbon nanotubes "fuzzy" stratum using the GradEla scheme, which permits an additional gradient coefficient or internal length compared with other composite constitutive and geometric attributes. The aim is to establish the optimal total mechanical properties and functionality thresholds. Chen et al. (2021) introduced a novel combined homogenization method to simulate the homogenized and local response that defines the nano-composites qualified as fuzzy fibre nanocomposites. These composites are subjected to inelastic deformations. It was concluded that the novel method promotes accurate and efficient research regarding the inelastic deformation scheme.

Furthermore, the selection process of parameters in composites is still at the forefront of composite discussions in the composite industry and in composite research. Composite researchers have been discussing the issue of selection of both organic-based and synthetic composites for several years (Bhat et al., 2019). It became a reality that efficient distribution and management of composite development resources may only be attained with knowledge of parametric selection, and substantial efforts were then invested in the research. However, the implication of this effort can be both positive and negative for the development of the composite literature. The positive results stem from the industry's proper and beneficial composite selection programmes.

Nonetheless, criticism of the composite parametric selection literature is vast. Several concerns as to why excessive focus on the selection parameters of composites is detrimental to the literature have been raised. An argument is that it completely omits the imprecision and uncertainty aspects of carbon fibre reinforced plastic composites during the drilling process.

Kaminski and Pawlak (2015) recognized this problem of uncertainty and imprecision in carbon fibre reinforced composites. In response, they proposed a different approach. They weighed them against one another to establish the probabilistic attributes of carbon fibre reinforced plastic (CFRP) composites within the framework of Gaussian uncertainty. While the work adds knowledge to the CFRP composites, there is no clue on the specific application of the method to the drilling operation. Besides, the recent results from the analytic hierarchy process concerning the drilling of CFRP composites seem to have lost the ability to detect imprecision and uncertainty when used for the drilling operation of carbon fibre reinforced plastic composites. These results limit decision making as sometimes wrong decisions may be made with the AHP method's outcomes. Therefore, it is thought that developing a fuzzy analytic hierarchy process method may be a channel to reduce imprecision and uncertainty.

In the drilling engineering domain, the carbon fibre reinforced plastic composite is one of the most innovative materials developed for various applications, including automotive usage (Abhishek et al., 2016; Baraheni and Amini, 2019). Though extremely central to the development of various industries in the recent past, it is difficult to drill as a finishing task in many component developments. As such, attention has been substantially directed to drilling defects that wipe away the efforts of all other machining operations since such defects render the components as reworks and reject with additional re-manufacturing costs to produce acceptable products to the customers. Thus, delamination (entry and exit), eccentricity, thrust force, torque, and surface roughness have been identified as the most important responses to control for the attainment of drilling excellence. Consequently, researchers have substantially studied only one or, at best, a combination of these responses at a time. Responses are analyzed to establish how they are impacted by the drilling parameters, including the point angle, speed, and feed rate for the carbon fibre reinforced plastic composite studied. Previous researchers have observed crashing criteria to settle on an appropriate response selection within the range of responses. This challenge prohibits further testing and a wide combination of responses because research on carbon fibre reinforced plastic composites is still in infancy regarding multi-criteria analysis involving conflicting issues.

So, most researchers settled to study the impact of only one response on the drilling parameters and vice-versa. Besides, no known tool to overcome this challenge is evident to the researchers in the carbon fibre reinforced plastic composites in the domain of drilling. However, at variance with the conventional practice in the literature, this article has studied six responses at once. Their effects are known; this represents the largest possible combination of responses to date ever evaluated in a single study, to the author's best knowledge. This appears as a new milestone in carbon fibre reinforced plastic composite drilling research. Furthermore, it is more to capture and reduce uncertainty and imprecision in the multi-criteria decision-making results of the analytic hierarchy process while combining multiple responses to select the best among the alternatives for the carbon fibre reinforced plastic composites. Thus, there is a wide research opportunity to expand the horizon of an investigation into another newness by considering extensions such as the augmentation of predictive models to the fuzzy analytic hierarchy process presented in this article.

The significance of this article is to offer a baseline drilling operations information to process engineers and drilling operations and researchers on the necessity of composite’s drilling response(s) to be adopted to curtail waste, ensure fair distribution of scarce drilling resources to essential response mechanisms and finally take superior drilling operations decision and enhance operational performance. The principal advantage of the FAHP method in its application to the drilling process for carbon fibre reinforced plastic composite is that it is a route to order and rank responses of the drilling problem by extracting priorities from drilling experts’ preferences and choices. The FAHP offers an established and valuable approach to tackle and control imprecision and uncertainty that the AHP permits in a complicated

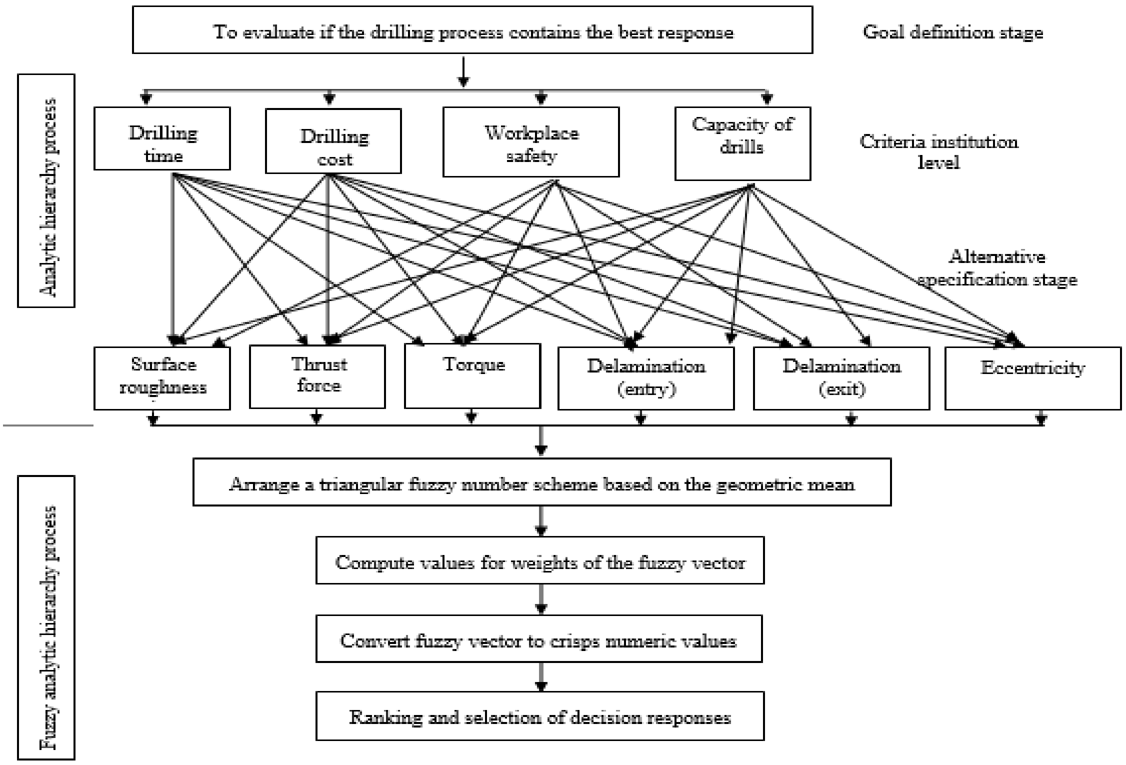

Figure 1. FAHP hierarchical multi-criteria structure (incorporating the AHP method) for the CFPR problem (Odusoro and Oke, 2021)

environment of multiple tasks and decision making options. The FAHP could then establish weights of responses by analyzing the crisp numerical data through a set of tasks, fuzzification and defuzzification, to finally advance drilling decision-making.

The unique and important element of the FAHP method that promotes its wide-scale usage is its preference opinions of the drilling experts, process engineers or researchers that it takes as input. Besides, the innovative mechanism at which the crisp numerical values of the AHP method are transformed into fuzzy numbers declares a robust triangular membership function. This function interprets relational language into linguistic dimensions and presents the FAHP method as a new and helpful methodology. This methodology selects responses at the best threshold for drilling operations decision-making.

3. RESEARCH METHODOLOGY

The procedures in obtaining outcomes from the fuzzy analytic hierarchy process (FAHP) for the geometric method used in this work is adopted from Putra et al. (2018). However, the AHP method structure serving as the basis for developing the FAHP method was borrowed from Odusoro and Oke (2021) and explained in Figure 1. The objectives of the drilling process while using the CFPR composites as the work material are many. For instance, an objective may be to reduce the rapid tool wear (HSS drill bits) used in the drilling process. A second objective may be to limit the damage generation as it affects the processed material (i.e. reduction of damage to the CPRP composites). A third objective may evaluate the best response from the available options. Unfortunately, the AHP method used as the framework for solving the drilling problem cannot retain more than one objective. Thus, only the principal objective out of these three is retained. The objective is chosen based on the availability of data to pursue it from the literature reference used to validate the method proposed in this work. The objective used for the AHP method is then stated in Figure 1.

The AHP method is the foundation of the FAHP method in that the structure form of decision making followed by the AHP method is followed by the FAHP method. This follows a decision tree that reveals the AHP hierarchy structure in the form of objectives, criteria and alternative selection in the drilling process decision making concerning the carbon fibre reinforced plastic composites. A decision tree is a structural diagram consisting of branches, with each branch further broken into sub-braches. It is through that the AHP hierarchy structure was a borrowed idea from the decision tree theory with a modification being that instead of the conventional two branches of the decision tree, the AHP hierarchy structure branches into at least two sub-trees. The number of sub-trees depends on the complexity of the problem. A largely complex problem such as the drilling process concerning the CFRP composites, the number of criteria is four, namely workplace safety, drilling time, drills' capacity, and the drilling cost (Figure 1, see also Odusoro and Oke, 2021).

This complicated problem also has six branches emerging from each criterion against two in the conventional decision tree diagram, Figure 1. In Figure 1, two sections are noticed; the analytic hierarchy process. The AHP method output in terms of the weights of the responses is translated from the crisps numeric form to fuzzy numbers. The components of each fuzzy number are a lower, middle and upper elementary. Often the order of the numbers increases from low to the middle to the upper element, which has the highest value of the three elements of the fuzzy number. The results of the fuzzy numbers are finally translated to fuzzy vectors, which are then changed to crisp numerical values. They are then ranked, and a selection of the best response is made (Figure 1).

Furthermore, this paper argues that the dulling operations regarding the carbon-fibre reinforced plastic composite are subjected to imprecision and uncertainty. It is further argued that the analytic hierarchy process that may be deployed to establish each response weight or parameter cannot track the imprecision introduced by many the process engineer judgements, the machining operator actions, the materials used in the experiment, and the measurement equipment used by Krishnamoorthy (2011) whose data is used for the analysis. The argument is that imprecision and uncertainty should be regulated. This paper advocates for the geometric mean-based fuzzy analytic hierarchy as an ideal candidate to regulate the imprecision and uncertainty that the classical analytic hierarchy process cannot capture through its generation of crisp numerical values.

The geometric-based FAHP has succeeded in an application-oriented multi-criteria decision-making (MCDM) problem-solving endeavour with merit in the engineering field. It has been used for different kinds of systems, including energy systems. Their MCDM results have been consistent with diverse case studies compared for the accuracy of the geometric mean based FAHP and in real application results analysis. Consequently, it is known that four major stages are involved in analyzing a problem using the FAHP. They are problem definition and the establishment of the anticipated solution, the establishment of a comparison matrix based on the analytic hierarchy process, defining the fuzzy numbers and the computation of fuzzy members. To further explain the stages, the following discussions are relevant:

Step 1: State the problem and establish the desired solution

As a first step, the fundamental approach in applying operations research principles to solve a drilling operation's problem is to formulate the problem and define it in all contexts: Boundaries, constraints, variables, alternatives, criteria, and so on. The problem is explained in the research gap that states that there is a difference between the results of the AHP MCDM method and the anticipated as it fails to capture uncertainty introduced through various sources, including the equipment used in the drilling activities by Krishnamoorthy (2011) and the judgments in measurements by the process engineer and drilling operator. Furthermore, alternatives are considered the various options possible for each chosen criterion. The criteria are the elements that show the system's performance as the different options are considered.

Step 2: Creation of a comparison matrix

The FAHP method is an advancement of the AHP method but still builds on the framework of the AHP method. The working principle of the comparison matrix is to determine the priority of one criterion over the other, aided by the scale of comparative importance based on a nine-point scale from 1 to 9 and sub-sections showing the intermediate importance of criteria with values shown as 2, 4, 6 and 8. There are also inverse values shown as 113, 115, 1/7 and 1/9, which reconsider the relationship between two criteria in a reverse manner. The term comparative matrix emerges as it contains results of a criterion weighed against another to create a matrix. This depends on the scale of comparative importance established by scanty. When an expert judges that one criterion is stronger or weaker than the other, the expert's preference is expressed. This is referred to as the decision maker's preference for criteria during the drilling operation.

Step 3: Set up the fuzzy numbers

Once the comparison matrix is created from the drilling expert's preferences, the form in which these numbers are is called crisp numerical mode. However, in fuzzy terms, the argument is that we cannot have such crisp values as the correct numbers may be either below or higher than the crisp number. Thus, by convention, fuzzy numbers contain three separate numbers. The fuzzy numbers are created by transforming the elements of the comparison matrix into a three-component number referred to as a fuzzy number. The conversion process is called fuzzification, transforming crisp numeric values into fuzzy numbers. However, fuzzy numbers may be transformed into crisp numeric values by a process referred to as defuzzification. The three-component number, a characteristic of a type of fuzzification, is referred to as fuzzy triangular numbers because it represents the triangle's vertices. This is one of the commonest methods in the literature, and the elements described by the three-component numbers are called membership functions. Researchers have used piecewise linear, Gaussian, and trapezoidal types in the triangular membership function. The triangular fuzzy values were used in this article. It comprises three values in each comparison cell, notably the upper side, middle, and lower part of a fuzzy diagram. However, the inverse values are $(u, m, l)^{-1}$.

Step 4: Calculate the weight of the fuzzy number

There are three main facets to evaluating the weight of the fuzzy rector for the dulling operation's parametric evaluation process: determination of geometric mean, fuzzy weight and the final weight.

Finding the geometric mean: A geometric mean is defined by considering two vectors where lower, middle and upper values represent each vector. But the adopted approach in this article is by Buckley (1985) as reported in Putra et al. (2018) and Okponyia and Oke (2020) and:

$$\tilde{\tilde{A}}_1 \times \tilde{\tilde{A}}_2 = (l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \qquad (1)$$

Table 1. Fuzzy table

	Thrust force (N)	**Torque (Nm)**	**Entry delamination**	**Exit delamination**	**Eccentricity (mm)**	**Surface roughness (μ m)**
Thrust Force (N)	1,1,1	2, 3, 4	7, 8, 9	6, 7, 8	4, 5, 6	3, 4, 5
Torque (Nm)	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	1,1,1	9, 9, 9	7, 8, 9	2, 3, 4	2, 3, 4
Entry delamination	$\frac{1}{9},\frac{1}{8},\frac{1}{7}$	$\frac{1}{9},\frac{1}{9},\frac{1}{9}$	1, 1, 1	1 2, 3	$\frac{1}{7},\frac{1}{6},\frac{1}{5}$	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$
Exit delamination	$\frac{1}{8},\frac{1}{7},\frac{1}{6}$	$\frac{1}{9},\frac{1}{8},\frac{1}{7}$	$\frac{1}{3},\frac{1}{2},\frac{1}{1}$	1,1,1	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$	$\frac{1}{7},\frac{1}{6},\frac{1}{5}$
Eccentricity (mm)	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	5, 6, 7	5, 6, 7	1, 1, 1	2, 3, 4
Surface Roughness (μ m)	$\frac{1}{5},\frac{1}{4},\frac{1}{3}$	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	4, 5, 6	5, 6, 7	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	1,1, 1

Here, each row's lower, middle and upper values are multiplied by themselves, raised to the power of the number of criteria.

Finding the fuzzy weight: By following Buckley's definition, the fuzzy weights are computed using the formula (Okponyia and Oke, 2020):

$$\tilde{\tilde{w}}_i = \tilde{\tilde{r}}_i \times (\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \tilde{\tilde{r}}_3)^{-1} \tag{2}$$

Note that $(\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \tilde{\tilde{r}}_3)^{-1}$ the values are added at the different locations of the fuzzy diagram, namely the upper, middle and lower positions, by using the geometric mean principle.

Finding the final weight: This is accomplished by finding the average of the fuzzy weight, referred to as defuzzification (Okponyia and Oke, 2020):

$$w_i = \frac{l + m + u}{3} \tag{3}$$

4. RESULTS AND DISCUSSIONS

FAHP-based multi-criteria drilling method entails a blend of theories and approaches to integrate drilling data and decision makers' evaluations to create information necessary in drilling decision making. However, from the complicated nature of the drilling decision-making process, the complicated conflicting criteria, the AHP method's results may not perfectly reveal the actual results because of uncertainty and imprecision. Accordingly, this research pursues the employment of the geometric-mean based fuzzy analytic hierarchy process to reduce the imprecision and uncertainty in the measurement of the data initially measured by the AHP method. The data from the AHP method (Odusoro and Oke, 2021), which analyzed the data of Krishnamoorthy (2011), was used to validate the FAHP method. To this end, the concern for choosing the best response (alternative) for drilling carbon fibre reinforced plastic composite regarding six responses was actualized. These responses are the entry delamination, exit delamination, surface roughness, eccentricity, thrust force and torque.

4.1 FAHP method computations (geometric mean method)

An analysis was carried out based on the experimental data in Krishnamoorthy (2011). Applying the fuzzy analytic hierarchy by the geometric mean method is analyzed hereafter. According to Putri et al. (2018), the procedures stated in the method section of this article is followed by the following results:

Step 1: State the problem and establish the desired solution

The problem is the same as Odusoro and Oke (2021) stated.

Step 2: Create a comparison mix

The comparison mix is the same as Odusoro and Oke (2021) stated.

Step 3: Check for consistency: to check for consistency, the same AHP process of checking for consistency as stated in Odudoro and Oke (2021) is followed. Since the same data is being considered, the same result is obtained. This means the consistency is 0.1, which is acceptable with the general standard.

Step 4: Set up a triangular fuzzy number: the triangular fuzzy number can be created by converting the pair-wise comparison matrix of the AHP section. It is also known as fuzzification. It is given in Table 1.

The inverse values are expressed as $(u,m,l)^{-1}$. However, u, m, l stand for upper, medium and lower values of the fuzzy diagram.

Step 5: Calculate the weighted value of the fuzzy vector
Finding the geometric mean: A geometric mean is defined

by considering two vectors where lower, middle upper values represent each vector. But the adopted approach in this article is by Buckley (1985) as reported in Putra et al. (2018) and Okponyia and Oke (2020). This is given in Table 2.

Finding the fuzzy weight. The fuzzy weight is obtained by using the formula;

$$\tilde{\tilde{w}}_i = \tilde{\tilde{r}}_i \times (\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \tilde{\tilde{r}}_3)^{-1} \qquad (4)$$

where $(\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \tilde{\tilde{r}}_3)^{-1}$ is the addition of the values at the different locations of the fuzzy diagram, namely the and upper, middle and lower positions, by using the geometric mean principle. Therefore,

$$(\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \tilde{\tilde{r}}_3)^{-1} = \left(\frac{1}{3.17+1.99+0.26+0.22+1.13+0.79}\right), \left(\frac{1}{3.87+2.45+0.31+0.26+1.39+0.97}\right), \left(\frac{1}{4.53+2.94+0.37+0.33+1.7+1.23}\right) = \left(\frac{1}{7.56}, \frac{1}{9.25}, \frac{1}{11.1}\right) \qquad (5)$$

The next step is the development of Table 3.

Finding the weight. The weight is found by finding the average of the fuzzy weight. It is also known as defuzzification. In a tabular form, the weight of the data is in Table 4.

The problem associated with imprecision and accuracy of the AHP method may be solved by evaluating the differences in the weights obtained with the FAHP and AHP methods. In Table 4, higher values of the FAHP method's weights reveal the extent of the imprecision by quantifying the difference as the improvement or reduction that the FAHP method can achieve. For example, the thrust force and torque in the FAHP method exceeded the AHP method's results by 0.48% and 3.95%, respectively. It means that at the measurement stage, the composite development engineer introduced 0.48% errors into the original value 0.413 weight of the thrust force used for decisions. However, measurement is less accurate initially for the torque outcome when the AHP method was used. The worst imprecision and uncertainty of 3.95% was introduced for this response. In fact, for the whole responses investigated, the downplaying of the torque values was the worst. An interesting result was obtained with the eccentricity response, indicating zero change in results. This implies that the composite engineer exactly presented the measures without imprecision and uncertainty. However, the previous results are the FAHP method's outputs for the entry delamination, exit delamination and surface roughness, which yielded -8.11%, -3.33% and -6.96%, respectively. This means that these responses ought to have been rated lower than the results displayed by the AHP method. Thus, the correction or reduction values for the responses are 0.48%, 3.95%, -8.11%, -3.33%, 0 and -6.96%, for the thrust force, torque, entry delamination, exit delamination, eccentricity and surface roughness, respectively.

In this article, the fuzzy analytic hierarchy process (FAHP) method was applied to correct the imprecision and uncertainty in the measurement data based on the work by Krishnamoorthy (2011). However, compared with the experimental data, the following observations of the FAHP results are made. First, instead of reporting the thrust force's initial and optimal drilling parameters as 310.47N and 84.23N, respectively, the correct measurements are 308.97N and 83.82N, respectively (0.48% reduction). This implies that excess thrust force measurements had earlier been given due to impression and uncertainty. Besides, excessive measurements were also recorded in the torque recording. The initial and optimal drilling parameters were reduced by the FAHP method to 3.77Nm and 0.89Nm, respectively, with a 3.95% reduction of the original values obtained.

Furthermore, the eccentricity measurements were perfectly done for the initial and optimal drilling parameters. Also, the entry delamination, exit delamination and surface roughness were understated both at the initial drilling and optimal drilling parametric results. For the entry delamination, the initial and optimal drilling parameters were increased by the FAHP method to 1.64 and 1.45, respectively, by 8.12% of the original

Table 2. Geometric mean table

	Thrust force (N)	**Torque (Nm)**	**Entry delamination**	**Exit delamination**	**Eccentricity (mm)**	**Surface roughness (μ m)**	**Geometric mean ($\tilde{\tilde{r}}_i$)**
Thrust Force (N)	1,1,1	2, 3, 4	7, 8, 9	6, 7, 8	4, 5, 6	3, 4, 5	3.17, 3.87, 4.53
Torque (Nm)	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	1,1,1	9, 9, 9	7, 8, 9	2, 3, 4	2, 3, 4	1.99, 2.45, 2.94
Entry delamination	$\frac{1}{9},\frac{1}{8},\frac{1}{7}$	$\frac{1}{9},\frac{1}{9},\frac{1}{9}$	1, 1, 1	1 2, 3	$\frac{1}{7},\frac{1}{6},\frac{1}{5}$	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$	0.26, 0.31, 0.37
Exit delamination	$\frac{1}{8},\frac{1}{7},\frac{1}{6}$	$\frac{1}{9},\frac{1}{8},\frac{1}{7}$	$\frac{1}{3},\frac{1}{2},\frac{1}{1}$	1,1,1	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$	$\frac{1}{7},\frac{1}{6},\frac{1}{5}$	0.22, 0.26, 0.33
Eccentricity (mm)	$\frac{1}{6},\frac{1}{5},\frac{1}{4}$	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	5, 6, 7	5, 6, 7	1, 1, 1	2, 3, 4	1.13, 1.39, 1.7
Surface Roughness (μ m)	$\frac{1}{5},\frac{1}{4},\frac{1}{3}$	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	4, 5, 6	5, 6, 7	$\frac{1}{4},\frac{1}{3},\frac{1}{2}$	1,1, 1	0.79, 0.97, 1.23

Table 3. Fuzzy weight table

Description	Fuzzy weight	Summarised fuzzy weights
Thrust Force (N)	$(3.17, 3.87, 4.53)\otimes\frac{1}{7.56},\frac{1}{9.25},\frac{1}{11.1}$	0.419, 0.418, 0.408
Torque (Nm)	$(1.99, 2.45, 2.94)\otimes\frac{1}{7.56},\frac{1}{9.25},\frac{1}{11.1}$	0.26,0.265, 0.265
Entry delamination	$(0.26, 0.31, 0.37)\otimes\frac{1}{7.56},\frac{1}{9.25},\frac{1}{11.1}$	0.034, 0.034, 0.033
Exit delamination	$(0.22, 0.26, 0.33)\otimes\frac{1}{7.56},\frac{1}{9.25},\frac{1}{11.1}$	0.029, 0.028, 0.030
Eccentricity (mm)	$(1.13, 1.39, 1.7)\otimes\frac{1}{7.56},\frac{1}{9.25},\frac{1}{11.1}$	0.15, 0.15, 0.153
Surface Roughness (μ m)	$(0.79, 0.97, 1.23)\otimes\frac{1}{7.56},\frac{1}{9.25},\frac{1}{11.1}$	0.105, 0.105, 0.111

Table 4. Weights obtained using the FAHP method

Criterion	Fuzzy weight	FAHP weight	AHP weight (Odusoro and Oke, 2021)	% deviation
Thrust Force (N)	0.419, 0.418, 0.408	0.415	0.413	0.48
Torque (Nm)	0.26,0.265, 0.265	0.263	0.253	3.95
Entry delamination	0.034, 0.034, 0.033	0.034	0.037	-8.11
Exit delamination	0.029, 0.028, 0.030	0.029	0.030	-3.33
Eccentricity (mm)	0.15, 0.15, 0.153	0.151	0.151	0
Surface Roughness (μ m)	0.105, 0.105, 0.111	0.107	0.115	-6.96

values. This means that the analyst did not correctly measure the original values of 1.5211 and 1.3398. Again, the exit delamination had the initial and optimal drilling parameters increased by the FAHP method to 2.14 and 1.38, with a percentage increase of 3.33%. Furthermore, the surface roughness had the initial and optimal drilling parameters increased by the FAHP method to 3.67mm and 1.32mm, respectively, by 6.96% of the original values.

Thus, from the above discussions, it was observed that for 16.67%, 33.33% and 50.00% cases there, were precise estimations, overestimation and underestimation of the response values from both experiments and the initial drilling parametric measurements, which the FAHP method helped to correct. But since roughly 83.33% of cases need adjustments, it may be mentioned that imprecision and uncertainty in the data were significant.

4.2 Comparison of the FAHP method with the literature results

In this article, the FAHP with the geometric mean based approach is used. However, the MCDM results could be compared with the AHP method, which omits the mechanism of controlling the uncertainty and imprecision in its operations. Consequently, the highest criteria weight is allocated to the thrust force based on the FAHP-geometric mean method's results at 0.415. Although the AHP chooses the same criterion (response) of thrust force at 0.413 (the first response and the best in ranking), the value given by the FAHP method appears more than that of AHP. Also, the difference is the amount of imprecision and uncertainty that the robust model of the FAHP approach was able to adjust in model. It enhances the value by 0.002 after removing the imprecision and uncertainty, which the AHP cannot remove. For the AHP method (literature), the positions occupied by the weight outcomes for the other responses are torque (Nm) as second with a weight of 0.253, eccentricity (mm) as third with a weight of 0.151, surface roughness (mm) as the fourth-ranked with a weight of 0.115, entry delamination as the fifth-ranked with a weight of 0.037 and the last-ranked (sixth) as the exit delamination with a weight of 0.030. Besides, from this article, the FAHP method claims the second, third, fourth, fifth and sixth positions as torque (Nm) with a weight of 0.263, eccentricity (mm) with a weight of 0.151, surface roughness (mm) with a weight of 0.107, entry delamination with a weight of 0.034 and exit delamination with a weight of 0.029.

The ranking given by the FAHP method is consistent with the literature ranking given by the AHP method. While the results appear to be the same, this claim is best supported or refuted using statistics. Consequently, the spearman's rank correlation is useful to examine the strength of a link between the two MCDM results of the FAHP and AHP approaches, each consisting of six data points deployed to make claims. The result of the spearman's rank correlation was 1. There appears to be a perfect correlation between the results of the FAHP method and the AHP method when carried out in drilling the carbon fibre reinforced plastic composites. An additional statistical test using the Mann-Whitney U test was made since a small sample of 6 data points each on the outcome of the FAHP method and the AHP method is considered. The researchers do not know if the two samples are normally distributed or not. The Mann-Whitney U test calculators were used with a significance level of 0.05 and a two-tailed hypothesis. The value of U obtained is 17.5, indicating that the results do not reach significance. This yields a critical value of U at $p < 0.05$ as 5.

Consequently, the result is not significant at $p<0.05$. the z score is 0, while the p-value is 1. The result is not significant at $p<0.05$.

5. CONCLUSION

The present study on establishing a selection method to reduce uncertainty and imprecision in the analytic hierarchy method, using the fuzzy analytic hierarchy method with the geometric mean based background, was undertaken on the carbon fibre reinforced plastic composites. In the present study, six responses were defined for uncertainty and imprecision control in the AHP method. The fuzzy theory was amalgamated with the analytic hierarchy process to produce triangular membership functions used to define the fuzzy table in a fuzzification process. Defuzzification was carried out to obtain crisp numerical values used for decision making in drilling operations. The obtained results ranked thrust force as the best response. This was confirmed using spearman's rank correlation which compared the results of the FAHP method with the AHP method to suggest a perfect correlation in relationship between the two sets of data. However, the relationship between the results of the FAHP method and the literature (AHP method) was found as not significant by using the U test.

Thus, it is concluded that the thrust force is the most important response in the drilling operation of the carbon fibre reinforced plastic composites and could be used for further planning regarding waste control and resource distribution for the drilling activities. Furthermore, the present study reveals that reducing uncertainty and imprecision in methods such as the AHP that contains imprecision and uncertainty is an important step to attaining more reliable results. In this article, the imprecision and uncertainty introduced by the AHP method have been corrected by using the FAHP method. It was found that the thrust force and torque were overestimated by or 0.48% and 3.95%, respectively and was accordingly corrected. Besides, no errors were found with the measurement of eccentricity response. Furthermore, the entry delamination, exit delamination and surface roughness were underestimated by -8.11%, -3.33% and -6.96%, respectively, and therefore corrected by the FAHP method.

However, it is perceived that some other aspects of the study warrant investigation and are suggested as possible future research. Could a study attempt to optimize and concurrently minimize imprecision and uncertainty in the MCDM results? In the drilling of fibre-reinforced plastic composites, the Taguchi method could be used together with the FAHP. The coupling point would be the factor-level mechanism of the Taguchi method. The results of weights obtained through the FAHP may be introduced into an exponential smoothening forecasting method whose output will predict the values to be substituted to the various levels for each parameter to be analyzed in the drilling operation.

REFERENCES

Abdul Nasir, A.A., Azmi, A.I., & Khalil, A.N.M. (2015). Measurement and optimization of residual tensile strength and delamination damage of drilled flax fibre reinforced composites. *Measurement*, *75*, 298-307.

Abhishek, K., Datta, S., & Mahapatra, S.S. (2016). Multi-objective optimization in drilling of CFRP (polyester) composites: Application of a fuzzy embedded harmony search (HS) algorithm. *Measurement*, *77*, 222-239.

Agwa, M.A., & Megahed, A.A. (2019). New nonlinear regression modeling and multi-objective optimization of cutting parameters in drilling GFRE composites to minimize delamination. *Polymer Testing*, *75*, 192-204.

Amini, S., Alinaghian, I., Lotfi, M., Teimouri, R., & Alinaghian, M. (2017). Modified drilling process of AISI 1045 steel: A hybrid optimization. *Engineering Science and Technology an International Journal*, *20*(6), 1653-1661.

Ayağ, Z. (2007). A hybrid approach to machine-tool selection through AHP and simulation. *International Journal of Production Research*, *45*(9), 2029-2050.

Balaji, M., Rao, K.V., Rao, N.M., & Murthy, B.S.N. (2018). Optimization of drilling parameters for drilling of TI-6Al-4V based on surface roughness, flank wear and drill vibration. *Measurement*, *114*, 332-339.

Baraheni, M., & Amini, S. (2019). Comprehensive optimization of process parameters in rotary ultrasonic drilling of CFRP aimed at minimizing delamination. *International Journal of Lightweight Materials and Manufacture*, *2*(4), 379-387.

Bhat, R., Mohan, N., Rohit, S.S., Agarwal, A., Kamal, A.R., & Subudhi, A. (2019). Multi-response optimization of the thrust force, torque and surface roughness in drilling of glass fiber reinforced polyester composite using GRA-RSM. *Materials Today: Proceedings*, *19*(2), 333-338.

Chen, Q., Chatzigeorgiou, G., & Meraghni, F. (2021). Hybrid hierarchical homogenization theory for unidirectional CNTS-coated fuzzy fiber composites undergoing inelastic deformations. *Composites Science and Technology*, *215*, Article 109012.

Gunay, M., Yasar, N., & Korkmaz, M.E. (2016, May). *Optimization of drilling parameters for thrust force in drilling of AA7075 alloy* [Paper presentation]. International Conference on Engineering and National Sciences, Sarajevo.

Krishnamoorthy, A. (2011). *Some studies on modelling* *and optimization in drilling carbon fibre reinforced plastic composites* [Doctoral dissertation, Faculty of Mechanical Engineering, Anna University].

Krishnamoorthy, A., Boopathy, S.R., Palanikumar ,K., & Davim, J.P. (2012). Application of grey fuzzy logic for the optimization of drilling parameters for CFRP composites with multiple performance characteristics. *Measurement*, *45*(5), 1286-1296.

Kaminski, M., & Pawlak, A. (2015). Various approaches in probabilistic homogenization of the CFRP composites. *Composite Structures*, *133*, 425-437.

Kulkarni, S., & Ramachandran, M. (2018). Multicriteria selection of optimal CFRP composites drilling process parameters. *REST Journal on Emerging Trends in Modelling and Manufacturing*, *4*(4), 102-106.

Lurie, S.A., Volkov-Bogorodskiy, D.B., Menshykov O., Solyaev, Y.O., & Aifantis, E.C. (2018). Modelling the effective mechanical properties of “fuzzy fiber” composites across scales length. *Composites Part B: Engineering*, *142*, 24-35.

Meral, G., Sarıkaya, M., Mia, M., Dilipak, H., Şeker, U., & Gupta, M.K. (2019). Multi-objective optimization of surface roughness, thrust force, and torque produced by novel drill geometries using Taguchi-based GRA. *The International Journal of Advanced Manufacturing Technology*, *101*, 1595–1610.

Odusoro, S.I., & Oke, S.A. (2021). Factor selection in drilling unidirectional carbon fibre reinforced plastic composite plates with the HSS drill bit using analytic hierarchy process. *International Journal of Industrial Engineering and Engineering Management*, *3*(1), 1-16.

Okponyia, K.O., & Oke, S.A. (2020). Exploring aluminium alloy metal matrix composites in EDM using coupled factor-level-present worth analysis and fuzzy analytic hierarchy process. *International Journal of Industrial Engineering and Engineering Management, 2*(1), 25-44.

Putra, M.S.D., Andryana, S., Fauziah, & Gunaryat,i A. (2018). Fuzzy analytical hierarchy process method to determine the quality of gemstones. *Advances in Fuzzy Systems*, *2018*, Article ID 9094380.

Singh, P.K., Kumar, K., & Saini, P. (2020). Optimization of surface roughness and hole diameter accuracy in drilling of EN-31 alloy steel – A TGRA based analysis. *Materials Today: Proceedings*, *26*(2), 2961-2971.

Shirvanimoghaddam, K., Hamim, S.U., Akbari, M.K., Fakhrhoseini, S.M., Khayyam, H., Pakseresht, A.H., Ghasali, E., Zabeth, M, Shadza, K., Munir, Jiag, S., Davim, J.P., & Naebe, M. (2017). Carbon fiber reinforced metal matrix composites: Fabrication processes and properties. *Composites part A: Applied Science and Manufacturing*, *92*, 70-96.

Shokrani, A., Leafe, H., & Newman, S.T. (2019). Cryogenic drilling of carbon fibre reinforced plastic with tool consideration. *Procedia CIRP*, *85*, 55-60.

Soepangkat, B.O.P., Norcahyo, R., Effendi, M.K., & Pramujati, B. (2020). Multi-response optimization of carbon fiber reinforced polymer (CFRP) drilling using back propagation neural network-particle swarm optimization (BPNN-PSO). *Engineering Science and Technology, an International Journal*, *23*(3), 700-713.

Tran, Q.P, Diem, M.T., & Huang, S.C. (2020, October 23-25). *Optimization of CFRP drilling process with multi-criteria using TGRA* [Paper presentation]. 2020 IEEE Eurasia Conference on IoT, Communication and Engineering, Taiwan.

Wang, Q., & Jia, X. (2020). Multi-objective optimization of CFRP drilling parameters with a hybrid method integrating the ANN, NSGA-II and fuzzy C-means. *Composite Structures*, *235*, Article 111803.

Wu, C., Gao, Y., Fang, J., Lund, E., & Li, Q. (2017). Discrete topology optimization of ply orientation for a carbon fiber reinforced plastic (CFRP) laminate vehicle door. *Materials and Design*, *128*, 9-19.