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An Evaluation of Water Absorption Process Parameters for Composites by Deploying A Novel DEMATEL Method-PROMETHEE Method

Victor Chidiebere Maduekwe [1], Sunday Ayoola Oke [2*]

[1] Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria

[2] Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria

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Parametric ranking and selection in water absorption process of composite development are obligatory as they guide on resource distribution during the planning phase of composite development. However, the present literature model seems inaccurate as the PROMETHEE method fails to offer the likelihood of structuring the water absorption problem making it challenging to achieve a concise problem viewpoint and assess the results without difficulty. In this paper, the DEMATEL method is introduced to assign weights, revealing a cause and effect mechanism to overcome the aforementioned problem. The coupling point of the DEMATEL method-PROMETHEE method is at the weight determination of the DEMATEL method and the net outranking results are the final output of the model. Based on literature data, the DEMATEL method produced weights of 0.182, 0.114, 0.290, 0.242 and 0.244 for the parameters of final weight, initial weight, length, thickness and time, respectively. The PROMETHEE procedure yields the outranking results of -0.2166, -0.2742 and -0.0079 for the length, thickness and time, revealing time as the best parameter. The proposed method is user-friendly, complete in outranking, successful in real-world applications and capable to establish the cause and effect series constituent of the complicated water absorption system. The usefulness of this research is to help composite developers to achieve effective distribution of resource and decision regarding priority of parameters, leading to lean and effective manufacturing outcomes.

***Corresponding Author**

Sunday Ayoola Oke
E-mail: sa_oke@yahoo.com

1. INTRODUCTION

The present case study illuminates a literature gap regarding the development of a novel parametric prediction model for a composite, considering the parameters of the thickness of the composite, time, initial weight, final weight and length of the composite (Ajibade et al., 2019). Literature data were used to illustrate the working principle of the DEMATEL (DEcision MAking Trial and Evaluation Laboratory) method -PROMETHEE (The Preference Ranking Organization Method for Enrichment of Evaluations) method, which is an integration of the DEMATEL method (Susanty et al., 2020; Sen et al., 2021) and the PROMETHEE method (Gul et al., 2018; Aydemir et al., 2019; Makan and Fadili, 2020). The approach combines the synergic advantages of DEMATEL method, which establishes the relationship among factors and the PROMETHEE method capable of outranking factors (Behzadian et al., 2010; Sumrit and Anuntavoranich, 2013; Si et al., 2018; Sivakumar et al., 2018). In recent work, the AHP-PROMETHEE method was promoted as a promising tool to evaluate the process parameters of an epoxy composite in water absorption experiments from the literature (Maduekwe and Oke, 2020). But composite developers are often seeking to enhance method that will bring about more accuracy in judgment.

While the DEMATEL method has potentials for enhanced performance, there is no single literature support for the method in the water absorption process literature of epoxy composites (Imoisili and Jen, 2020; Kusmono et al., 2020; Oladele et al., 2020; Sari et al., 2020). The hull of a ship has recently been studied in Maduekwe and Oke (2020) but the call for more extensive tests of composite materials for the ship’s hull with high structural integrity should be answered. While motivated by the performance of the DEMATEL method in previous studies (Rajput and Singh, 2019; Amirreza et al., 2020; Du and Li, 2020; Pothal et al., 2020; Rostamnezhad et al., 2020; Sen et al., 2021), an effort was made in the present study to analyse the ranks of the five prominent parameters in the water absorption process by using an integrated method of DEMATEL method-PROMETHEE method.

This paper argues that the composite development process needs a re-organisation in the perspective of actualizing design options and material choices. For a successful implementation of the hull of a ship's project where the water absorption process is undergone by the developed epoxy composite by Ajibade et al. (2019), the introduction of the classical PROMETHEE method in the composite planning and design process for shipbuilding is a compelling requirement (Maduekwe and Oke, 2020). PROMETHEE method has been established as an effective tool in tackling multi-criteria and preferential engineering problems (Goumas and Lygeoru, 2000; Duvivier et al., 2013; Gul et al., 2018; Aydemir et al., 2019; Pradhan and Singh, 2019; Makan and Fadili, 2020; Patnaik et al., 2020).

PROMETHEE method, whose introduction to the scientific domain was due to Brans in 1982 and the joint work of Brans and Vincke in 1985 is an outranking method (Behzadian et al., 2010). Outranking is a binary association of an element on given choices such that the inputs of the decision-maker on preferences of one choice over the others provide enough arguments that the quality of evaluations may be relied upon for sound judgments.

The PROMETHEE method enjoys widespread usage in several research domains such as energy (Goumas and Lygeoru, 2000), waste treatment (Makan and Fadili, 2020) material selection (Gul et al., 2018; Patnaik et al., 2020), machinability studies (Pradhan and Singh, 2019), and business incubators (Schwartz and Gothwer, 2009). However coupled with the several areas of applications mentioned above, additional studies have been made, more extensive studies have been documented on material/composite parametric selection. Beyond the mentioned references, the work by Maduekwe and Oke (2020) is a recent addition to the literature in this domain. While it is convincing that the PROMETHEE method is successful in the material selection/composite development area, it is not convincing to find the PROMETHEE method united to other methods in studies. The Maduekwe and Oke's (2020) paper where the AHP was united to PROMETHEE appear as a first instance in the water absorption arena. Thus, to extend the frontier of knowledge concerning the integration of multi-criteria methods in the water absorption process of epoxy composites, this study contributes to the literature by an integration of the DEMATEL method and the PROMETHEE method as an effective and novel approach to the evaluation of process parameters in water absorption studies.

Notwithstanding, a unique innovation of this research is the introduction of the DEMATEL framework within the PROMETHEE method. Why do we need the DEMATEL method to support the PROMETHEE framework? The literature reveals the PROMETHEE method could improve in its inability to offer the likelihood to completely structure the problem. Thus, the DEMATEL method bridges this gap in the following ways (Si et al., 2018): First, it competently examines the joint influences from direct and indirect perspectives among the diverse water absorption process parameters and provides insights into the advanced cause and effect associations of the composite decision problem. Si et al. (2018) also declared that the powerful capability of DEMATEL method enables it to envisage the interrelationships of the water absorption parameters through a unique influential relationship map and permits the composite developer and researcher to appreciate the parameters of the water absorption process that have shared influences on one another. Si et al. (2018) were also quick to declare that DEMATEL method provides crucial assessment criteria and evaluates the weights of the water absorption process parameters.

The purpose of this study is to examine the effectiveness of a novel method for ranking and selection of the best water absorption process parameter using the combined DEMATEL method-PROMETHEE method in a decision to design for the hull of the ship with structural integrity. Multi-criteria models have entered the water absorption process evaluation environment speedily, leaving composite developers and designers unprepared for the challenge of resource conservation which multi-criteria tools could enhance. As engineering practice depends more on quantitative approaches to attain the lean solution to resource conservation, there is a viewpoint that multi-criteria analysis and holistic problem formulation should be the minimum acceptable standard of practice in the composite development area. However, the gap between multi-criteria usage, holistic problem formulation and the effectiveness of lean practices towards resource conservation is still excessively wide. This gap has been recognized by a recent study involving Maduekwe and Oke (2020) to exist and responded with a multi-criteria model to identify the best parameter in a water absorption process of composite testing.

The authors developed an integrated AHP-PROMETHEE method for effective communication between composite developers and researchers to attain the goal of lean practices whereby resource conservation and distribution effectiveness is the central focus. With the initiative by those authors, it is possible to develop a composite development plan or both short and long ranges from the predictions and available computations from the AHP-PROMETHEE method. This developed model implies a relationship between the best parametric selection and the degree of resource conservation and distribution, which is yet to be fully exploited. Consequently, more intensive examinations of other weight determining methods and their associations with the PROMETHEE method are compelling to achieve the goal of lean practices and associated objectives.

The development and testing of an integrated DEMATEL method-PROMETHEE method that addresses the best parametric selection in water absorption process analysis should be a top priority of composite developers and researchers. In the shipping sector, several parts of the ship such as accessories have received a widespread utilization of composite materials but in practice, the hull of the ship, which controls the high height of the ship and energy efficiency, has not been previously studied extensively in the literature. After the successful development of the hull of a ship with composites as a replacement to the present materials huge cost saving through energy conservation is promising. So the use of the DEMATEL-method-PROMETHEE method of best parametric selection and ranking in the context of the hull of a ship is needed for the successful development of an eco-friendly and economical hull of a ship.

2. LITERATURE REVIEW

2.1 General

Epoxy composites entertain moisture diffusion in three modes (Onyekwere et al., 2019; Imoisili and Jen, 2020). In the first mode, water molecules are diffused within the gaps that exist in the matrix, epoxy, and specifically within the chains (Onyekwere et al., 2019). In the second mode, moisture is moved through the gaps and causes harm between the agro-waste particles and the epoxy matrix at the interface (Onyekwere et al., 2019). In the third mode, water molecules are transmitted through the micro-cracks existing in the epoxy matrix, which must have been created during the process of fabricating the epoxy composites (Onyekwere et al., 2019). Given all these situations, the epoxy composites studied in the present article for the hull of the ship's application are subject to a high probability of water attack while in use in ships within the water environment (Oladele et al., 2020; Kusmono et al., 2020). While it is essential to understand the magnitude of water attack that the hull of a ship may be subjected to in practice, demonstrated in laboratory experiments, Ajibade et al. (2019), it is more compelling to understand which of the water absorption process parameters has the greatest impact on the process (Onyekwere et al., 2019; Oladele et al., 2020; Kusmono et al., 2020; Imoisili and Jen, 2020). But the literature survey will reveal if such a mission has been previously accomplished in the literature or not. Thus, in this section of the article, the literature is reviewed to understand previous studies and debates on the multi-criteria analysis of water absorption process parameters in epoxy composites regarding the development of the hull of a ship in water applications.

In this article, an exhaustive search of databases, including, Sciencedirect, Inderscience, Springer and Emeraldinsight was done together with a general search using the google searched engine. The emerald insight database were first search on the 7th March 2021, using the search words; “dematel, material selection, composites". A total of 93 articles emerged. As the articles were screened, there was no article directly related to the topic. Furthermore, the search words were modified to "PROMETHEE, material selection, composites" and 52 articles appeared. Surprisingly, no article was directly relevant to the area of study. In one case, the nearest article on a material selection with the use of multicriteria methods was in the construction industry domain. The best-worst method and fuzzy TOPSIS method were the tools used but PROMETHEE method and DEMATEL method was not mentioned in the analysis. In a second instance where DEMATEL method was mentioned, the scope of the applied fuzzy DEMATEL model was limited to manufacturing concerns; the composite development industry was not examined at all. The search words “dematel, material selection, composites” and “PROMETHEE, material selection, composites” were used on the science direct database. In the first instance, 109 results emerged and no article fell within the boundary of the specified word search. In the second instance, 235 results emerged but Gul et al. (2017) are an interesting article that is close to the specified knowledge search pursued. The article is on the fuzzy PROMETHEE approach with a focus on the choice of composite materials. However, the integration of the DEMATEL approach and the water absorption process background are still missing in this found article.

As the search words became "dematel, material selection composites, the Inderscience database returned no great matches occurred. This was none as the search words change to “PROMETHEE, material selection, composites. Furthermore, the search words “dematel, material selection, composites” and “PROMETHEE, material selection, composites” were used on the Springer database. The instances revealed, 1742 and 1759 items but not in the relevant area. However, the last phase in the search is the use of google search engine. The words “dematel, material selection, composites” was first used. Then, the words “PROMETHEE, material selection, composites were used. Interestingly, a key article in the area was sighted, notably. Maduekwe and Oke (2020) where the authors deployed the PROMETHEE method which was aided by the AHP method to water absorption process parametric evaluation. Fortunately, it falls within the domain of this research. However, the difference between the article and the current one is that the present research endeavour tackled the problem of relationship analysis in a cause-and-effect mode similar to the tools of system dynamics and integrated structural modelling. But the AHP-PROMETHEE method is limited in this aspect, which is concerned with the DEMATEL method-PROMETHEE method. Since the literature is limited in applications of the tools used in this paper, an effort is made to review some studies that may still be helpful to reveal the gap in the literature. First, studies on DEMATEL methods are reviewed.

2.2 The DEMATEL method and PROMETHEE method

DEMATEL is a method that is effective to establish complex and interlinked water absorption process parametric analysis (Si et al, 2018). It depends on an impact relations map popularly called the cause and effect diagram to accomplish the interpretation of the relationships among the parameters. The methodology of DEMATEL method has been adopted as single methods in various endeavors, including supply chain management (Mangla et al, 2014; Wu and Chang, 2015; Susanty et al., 2020), technological evaluations (Sumrit and Anuntavoranich, 2013), sustainability (Sivakumar et al., 2018), hospital service (Shieh et al., 2010), flood control (Sen et al., 2021), error proofing (Islam et al., 2019), real estate management (Golabeska, 2018) and complex structure analysis (Du and li, 2020).

Over years, it was recognized that imprecision and uncertainty are common in the activities being capture by the DEMATEL model and the fuzzy DEMATEL method was revealed as adequate to capture the situation. Consequently several scholars have applied the methodology to various aspects of human activities such as recycling (Gan and Luo, 2017), supply chain (Patil and Kant, 2013; Mavi and Shahabi., 2015; Mangla et al., 2016; Pothal et al., 2020), construction projects (Rostamnezhad et al., 2020), management in offices (Wu and Lee, 2007), and pharmaceutical industry (Shahin et al., 2019). In the broad area of application, DEMATEL method had been combined with Taguchi loss function (Amirreza et al., 2020), grey relational analysis (Bai and Sarkis, 2013), ANP method (Yang et al., 2008; Golcuk and Baykasoglu, 2016), PCA method and ISM method (Rajput and Singh, 2019), and factor analysis (Tzeng et al., 2007).

PROMETHEE method called the preference ranking organisation method for environment evaluation, was developed to rank a defined number of parameters such as the water absorption process in a situation of conflicting criteria and multiple options and the final results are usually net outranks (Behzadian et al., 2010). The method of PROMETHEE method has been used as a single model in diverse situations, including composite development (Aydemir et al., 2019), healthcare (Makan and Fadility 2020), electrical discharge machining (Pradhan and Sigh, 2019) and business incubation (Schwartz and Gothner, 2009). As time progressed, the uncertainty and imprecision in activities were identified and fuzzy PROMETHEE method were deployed (Gul et al., 2018; Goumas and Lygeoru, 2000). Furthermore, PROMETHEE method has been combined with another method (Patriak et al. 2020).

2.3 Differences between the current paper and previous studies

Regarding the work by Maduekwe and Oke (2020), the elaboration was based on a methodology sectioned into the following: AHP method, and PROMETHEE method. The AHP contains the Saaty’s theory, which relied on the Saaty's scale of comparative importance. The attribute design, pairwise relationship and establishment of the normalized pairwise comparison matrix are the principal elements of the AHP framework deployed by the authors. Furthermore, within the PROMETHEE method, the normalisation of the decision matrix based on the weights provided by the AHP is one of the elements. Others are the evaluation of the difference of the alternative in a comparable manner, computation of the preference function, the establishment of the departing and arriving outranking flows and the evaluation of the net outranking flow.

Notwithstanding, the current research has a methodology that consists of the DEMATEL approach and the PROMETHEE approach contains the creation of the direct relation matrix, normalisation of the direct relation matrix, the establishment of the total relation matrix and the creation of the causal diagram. Although the PROMETHEE approach in Maduekwe and Oke (2020) appears similar, the difference in the two approaches is the synergic influences caused by the integration of the DEMATEL approach and the PROMETHEE approach in imparting a causal association into the framework. As may be concluded from the literature search, users may benefit hugely from the integration using the new approach as a call for improvement on the literature method has been made.

2.4 The implications of the review and scope of the current research

The review of associated articles on the DEMATEL method, PROMETHEE method, composites and water absorption process reveals the following:

1. DEMATEL method as a multicriteria tool has been extensively applied in the engineering domain.
2. Very limited applications of the DEMATEL method as combined with other multicriteria methods have been observed in the composite industry.
3. A case of PROMETHEE method application regarding the hull of a ship replacement with composite and the selection of the best parameter has been identified. However, this literature is insufficient to provide detailed guidelines for the most accurate composite development planning; more extensive studies are needed in this area.
4. Consequently, the present authors prefer to study the integration of the DEMATEL method and PROMETHEE method focusing on the development of the hull of a ship in water absorption process parameter evaluation. The research is envisaged to be in-depth in perspective.

3. METHODS

The two key methods in the development of a DEMATEL method-PROMETHEE method are the DEMATEL method and the PROMETHEE method. In a previously substituted method that comprises of the analytical hierarchy process (AHP) method instead of DEMATEL method, championed by Maduekwe and Oke (2020), the motivation for the AHP method-PROMETHEE method is to assume that the criteria are independent. But in an effective system, interactions cannot be avoided. Hence, to improve the performance of the method, the DEMATEL method is substituted by assuming that there is an interaction that may be traceable to certain causes and there are corresponding effects on the system. In this section, the DEMATEL method is first presented and later, the PROMETHEE method is presented.

3.1 DEMATEL method

The structure of the DEMATEL method is based on five important pillars, notably the creation of a direct-relation matrix; normalization of the direct relation matrix, total relation matrix, producing the causal diagram and the conversion of the obtained values to weights. The DEMATEL method is heavily hinged on the working of the matrix, three of the five stages of the DEMATEL method engages the use of a matrix. Thus, it is important to understand what a matrix is and its working mechanism regarding the ranking and selection method of the DEMATEL method-PROMETHEE method. As widely known to be used in solving engineering problems, a matrix is a rectangular collection of numbers representing scores from the various parameters of time, thickness, initial weight, final weight and length of the composite. With an arrangement in rows and columns, the direct relation matrix, total relation matrix and the normalized matrix are used to represent the water absorption process parametric data and also to form mathematical equations such as the linear equations that are introduced at the conversion of certain observed values to weight in the DEMATEL method's computation. DEMATEL method uses a matrix to attain compactness; several linear equations may need to have been written if the choice of the matrix is not made.

To conduct a study on the DEMATEL method, the investigation may be approached using the following steps (Abiola and Oke, 2021):
The first stage of the DEMATEL method is the creation of a direct relation matrix. Direct relation describes the association between any pair of parameters such as (time, thickness), (time, length), (time, initial weight), etc. These relations are always positive as the association between the stated pairs of parameters move in the same direction. Usually, a comparison scale for the DEMATEL method is drawn on numerals that range from 0 to 4 as 0, 1, 2, 3 and 4 with each being defined by the extent of influence a parameter has on the other, Table 1.

Step 1: Generation of the direct-relation matrix

Table 1. The comparison scale of the DEMATEL method

Definition	Numeral
No influence	0
Low influence	1
Medium influence	2
High influence	3
Very high influence	4

The first case where 0 is assigned, no influence; is a state of total disconnection regarding influence. Thus, no parameter can affect the result of the other. For the second case where 1 is assigned, low influence, it is a state where the effect of a parameter on the other is less than average. For the third case where 2 is assigned, medium influence is a condition where the effect of a parameter on the other is of a middle position. For the fourth case where 3 is assigned, high influence, it is a state where the effect of a parameter on the other is great. For the fifth case where 4 is assigned, very high influence, it is a condition where the effect of a parameter on the other is excessive.

Step 1: The assessment of the experts' results from the survey is assessed by using the average matrix. The common label to this is A. Questions that may be graded on a 5-point scale starting from 0 through 1, 2, 3 and 4 are asked the respondents. A pointer "*i*", which mean that a factor influences another at no degree or to some extent is used. This is mapped to another "*j*" on a scale of evaluation from 0 to 4 in a step of 1. By analysing the data, it is possible to produce the average matrix (Shieh et al., 2010; Bhanot et al., 2020; Abiola and Oke, 2021):

$$A = [a_{ij}] \text{ and}$$
$$a_{ij} = \frac{1}{Q}\sum_{q=1}^{Q} p_{ij}^{q} \qquad (1)$$

where p_{ij} is regarded as the level at which the expert assesses the performance indicator *i* to influence the performance indicator *j*. Furthermore, *Q* represents the experts. However, the expert engaged in this work for assessment is the researcher and consequently one item each for the expert's side was used; so averaging is avoided. It then means that this stage of the research regarding DEMATEL method is not considered in the present study.

Step 2: Normalisation of the direct relation matrix

The starting expression is X = K × A (2)

where $K = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}$; $i, j = 1, 2, \ldots, n$

The next phase of the DEMATEL method is the normalisation of the direct relation matrix. This entails dividing every entry in the matrix by a magnitude to produce a new matrix. It is aimed at conforming to a standard of values ranging from 0 to 1 within the matrix.

Step 3: Calculation of the total-relation matrix
This may be attained by using Equation (3):

$$T = X(I - X)^{-1} \qquad (3)$$

where *I* means the identity matrix

The next stage in the DEMATEL method computation is to evaluate the total relation matrix. This is a new matrix that is produced through the multiplication of an identity matrix which shows the total impacts of a parameter on the parameter. These may be indirect, where the association between parameters move in the opposite direction or direct, where they move in the same directions. The total effect assists to account for all possible contributions for all parameters and gives an unbiased state of analysis.

Step 4: Pursue the causal diagram using digraph on the dataset of ($D + R$, $D – R$).

The next phase is to produce the causal diagram. It is a diagram that assists to visualise how the various parameters considered for the water absorption process are associated. The main elements of the causal diagram are nodes and edges. Edges are links that reveal the connection between two parameters while nodes are the parameters. A properly drawn causal diagram will reveal the behavior of the parameters of the water absorption process. The causal diagrams may assist the composite developer in enhancing the composite design for the most water-resistant option. By such diagrams, some questions previously unclear to the composite development engineer may be answered from the present collected data.

Step 5: Convert values into weights

The last phase of the DEMATEL method is to convert the obtained values to weights. In this instance, linear equations are developed and solved and the conclusions on the weights reached. The weights obtained during the application of the DEMATEL method are then presented with the original matrix from Ajibade et al. (2019). This is then normalised as previously done.

3.2 The PROMETHEE method

The phases of evaluation using the PROMETHEE method are as follows:

Step 1: Evaluative difference of i^{th} alternatives with respect to other alternatives

Evaluation of the difference of the i^{th} options regarding the other options.

The difference of each alternatives with respect to other alternatives in the same criteria/attributes are evaluated. This is done using the expression D [R_i - R_j]

where if i = 1, then j = 2, 3, 4, 5 and if i = 2, then j = 1, 3, 4, 5,

Steps 2 and 3: Calculation of the preference function

The second phase of work is to compute the preference function. The idea of the preference is the choice of a water absorption parameter rather than another. A preference function, represented by a symbol, exhibits a domain set, which comprises several criteria. This contains two aspects and steps 2 and 3 of the PROMETHEE method is said to be advised.

The evaluation of the preference function may be achieved by following this procedure:

(1) $P_j(a,b) = 0$. If, $R_{aj} \leq R_{bj} \rightarrow D\,(R_a - R_b) \leq 0$

That is, if the difference between two alternatives as calculated is less than or equal to zero: then that value automatically becomes zero.

(2) $P_j(a,b) = (R_{aj} - R_{bj})$, if $R_{aj} > R_{bj} \rightarrow D\,(R_a - R_b) > 0$.

That is if the difference between one alternative with respect to others are greater than zero; then it retains its value.

Step 4 and 5: Determination of leaving and entering outranking flows

The next phase is to evaluate the aggregate. It implies summing up, establishing the total strength and behavior of the parameters.

(1) Leaving (positive) flow for a^{th} alternative,

$$\phi^{+} = \frac{1}{C-1}\sum \pi(b,a);(a \neq b)$$

(2) Entering (negative) flow for a^{th} alternative,

$$\phi^{-} = \frac{1}{C-1}\sum \pi(b,a);(a \neq b)$$

where C, number of alternatives.

The development of a matrix has an order mapped to the number of alternatives Consequently, we limit the Aggregated Preference Function from R1 to R2

Step 6: Net outranking flow of each alternative

Here, a computation of the net outranking flow for each option is made:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a)\,\Phi(\text{a}) = \phi^{+}(a) - \phi^{-}(a) \quad (4)$$

The next phase is to establish the leaving and entering outranking flows. Often, like the simplex algorithm, the terms leaving and entering variables are adopted regarding the need to have a feasible solution. This also covers two phases. The next phase is the evaluation of the net outranking flow for each alternative.

4. THE CASE STUDY

In this case, the idea of ranking through multi-criteria analysis has been proposed as a solution to the problem of water absorption of composites. The idea proposed here is from Ajibade et al. (2019) that formulated different composites comprising of five principal reinforcements, ground to particulates, and mixed with the epoxy resin to form epoxy composites. The water absorption process is introduced because it is envisaged to use the composites to develop the hull of a ship. As a beam within the ship's body that provides support for the height of the ship, resisting the buoyant and dynamic forces as the ship operates on water, the hull of a ship is a key member of the ship and any composite material made for such a part of the ship should be extensively tested in water. This illuminates the engineer’s mind on the possible future problems to expect when the particular composites are used in practice.

The five powders used to reinforce the epoxy matrix by Ajibade et al. (2019) are the particles of the periwinkle shell, orange peels, palm kernel shell, eggshell and coconut shell. Experiments were conducted for the various mixtures of powders and epoxy resin for varying times. But it is not known if time is important and if its importance exceeds other parameters. As the experiments are conducted, the length of the composites is expected to change.

Could it reduce or lengthen? But is this parameter highly important? Thickness swelling is an important attribute of composites embedded in water. But is this swell of high significance to the composite to lead as an evaluation parameter? What about the initial and final weights. Are they huge enough to have the attention of composite developers as leading parameters in water absorption experiences? The technique of water absorption is quite useful as it dictates the integrity of the composites and possibly provides an insight into the lifecycle of the composites. This case study is concerned with only five parameters although more are available in the literature.

To deepen our understanding of the water absorption process, it is essential to understand the conditions under which Ajibade et al. (2019) produced the epoxy composite whose parameters are ranked and distinguished as the most impactful among others. A measured quantity of epoxy, often in a volume percentage of the whole solution due to the varying proportions of the particulates in epoxy was provided from the storing bottles with the epoxy resin purchased from Tony enterprises, Ojota. Following this is the addition of particulates by specified volumetric mixtures of combinations of each of the following: Orange peels, periwinkle shell, palm kernel shell, eggshell and coconut shell. These were added (mixed form) to the epoxy matrix and manually stirred to prevent agglomeration of particles by ensuring even distribution of the reinforcements in the epoxy matrix. Furthermore, the hardener was then added homogeneously and stirred manually with an improvised spoon stirrer. Following this, the mixtures of the reinforcements and matrix, which now forms a solution, were allowed to degas for roughly 10 minutes, which helps to remove the air particles that were created during the mixing process.

The lubricating oil of the Azola category was purchased from the petroleum filling stations and used on the surface of the mould to permit the removal of the fabricated composite from the mould once it is cured and ready for removal. Then the mixture containing the reinforcement and matrix was poured into the mould, which was kept cool at room temperature while the curing process was allowed between two and three days. If the mixture of the hardener is insufficient in the solution, an improperly cured mixture will be observed. Otherwise, the good quality output is expected devoid of holes and imperfections. Some little filing of the edges of the composite may be necessary to make the edges smooth.

5. RESULTS AND DISCUSSION

5.1 The DEMATEL approach-PROMETHEE approach

The starting point of analysis of results is Table 1. This contains the original data that is transformed in this work.

Table 1. Taguchi S/N ratios response table for water absorption of dual-filler composite (Ajibade et al. (2019)

Level	A	B	C	D	E
1	*-30.7422	-30.7418	-30.7096	-30.7455	*-30.2670
2	-30.7435	-30.7468	-30.7707	-30.7443	-30.6012
3	-30.7431	-30.7438	*-30.7071	-30.7419	-30.9083
4	-30.7431	-*30.7397	-30.7847	*-30.7403	-31.1955

*optimal level

By applying step 1, the generation of the direct-relation matrix, the following table is obtained, Table 2.

Table 2. The direct-relation matrix

Factors	A	B	C	D	E	$\sum_{j=1}^{n} a_{ij}$
A	0	1	1	2	1	6
B	1	0	1	1	1	4
C	3	1	0	2	3	9
D	3	1	2	0	4	10*
E	4	1	2	3	0	10*

Furthermore, normalisation of the direct relation matrix is done by using the formula X = $K \times A$, where $K = 1/(\max A \sum_{j=1}^{n} a_{ij}]$, $i,j = 1,2,\ldots,n$

A = matrix element

$\sum_{j=1}^{n} a_{ij}$ = maximum value in the summation column = 10

Hence, each value in the relation matrix is divided by 10.

Table 3. Normalization of the direct-relation matrix

Factors	A	B	C	D	E
A	0	0.1	0.1	0.2	0.1
B	0.1	0	0.1	0.1	0.1
C	0.3	0.1	0	0.2	0.3
D	0.3	0.1	0.2	0	0.4
E	0.4	0.1	0.2	0.3	0

Next is the development of the total relation matrix obtained from $T = X (I - X)^{-1}$

where I = identity matrix. This yields

Table 4. Total relation matrix

Factors	A	B	C	D	E
A	0.5472	0.3087	0.4144	0.5856	0.5432
B	0.5237	0.1731	0.3426	0.4231	0.4417
C	1.1521	0.4519	0.5282	0.8715	0.9674
D	1.2587	0.4918	0.7558	0.7871	1.1166
E	1.2793	0.4787	0.7312	0.9869	0.7899

Table 5a. Causal diagram information – phase 1

Factors	A	B	C	D	E	**X**
A	0.5472	0.3087	0.4144	0.5856	0.5432	**1.8519**
B	0.5237	0.1731	0.3426	0.4231	0.4417	**1.9042**
C	1.1521	0.4519	0.5282	0.8715	0.9674	**3.9711**
D	1.2587	0.4918	0.7558	0.7871	1.1166	**4.4100**
E	1.2793	0.4787	0.7312	0.9869	0.7899	**4.266**
Y	**4.2138**	**1.9042**	**2.7722**	**3.6542**	**3.8588**	

Table 5b. Causal diagram information – phase 2

Factors	X	Y	X-Y	X+Y	Rank
A	1.8519	4.2138	-2.3619	6.0657	4
B	1.9042	1.9042	0	3.8084	5
C	3.9711	2.7722	1.1989	6.7433	3
D	4.41	3.6542	0.7558	8.0642	2
E	4.266	3.8588	0.4072	8.1248	1

The total relation matrix provides information on how one criterion affects another. Furthermore, it is necessary to produce the causal diagram. But the following calculations are necessary.

(X + Y): This shows the degree of importance that the criteria have. Hence, it indicates the degree of relation between each of the criteria with other criteria. The criterion E has the highest value of (X + Y) indicating that it is the most important criterion and also has more relationship with other criteria. This followed by D, C and A.

(X - Y): This tells the kind of relation between criteria. If the value is positive, that criterion belongs to the cause group, which is otherwise called the dispatcher. Such criterion is said to influence other criteria. Also, when the value is negative, such a criterion belongs to the effect group called the receiver. Hence, the criterion is said to be influenced by other criteria. From the table, criteria B, C, D and E belong to the dispatchers, while criterion A belongs the receiver.

Ranking: The ranking is based on the value of (X + Y). The criterion with the highest value of (X + Y) is placed on rank one, followed by the next higher value.

Table 5c. Causal diagram information-phase 3

Factors	X - Y	X + Y
A	-2.3619	6.0657
B	0	3.8084
C	1.1989	6.7433
D	0.7558	8.0642
E	0.4072	8.1248

The information from this section is used to produce the causal diagram, Fig. 1.

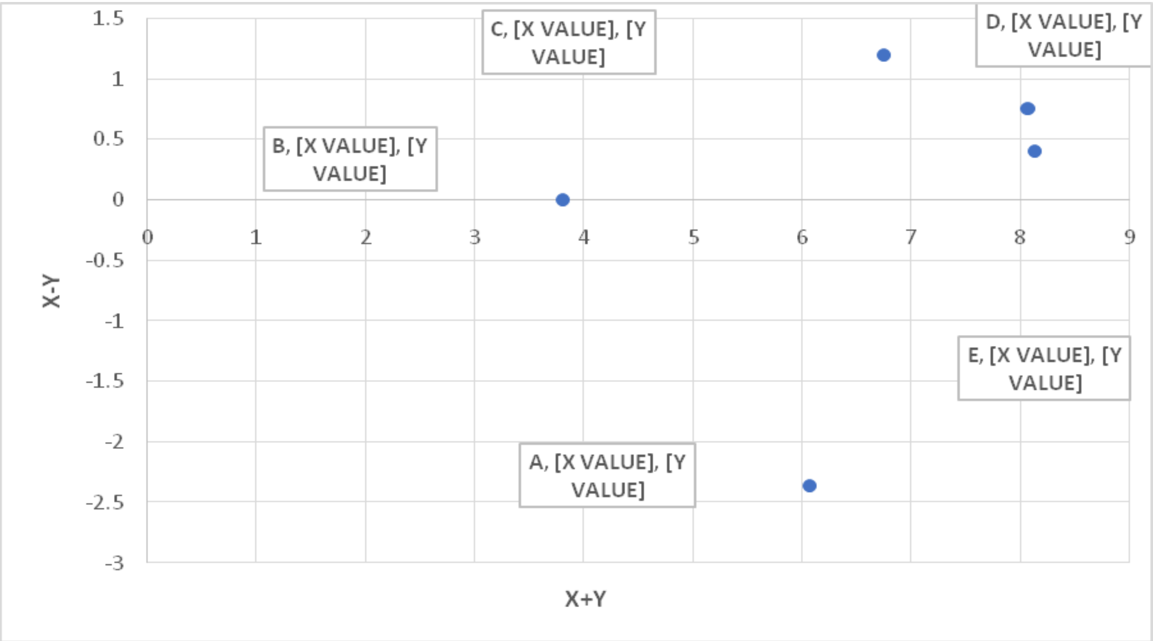

Fig. 1a. Point-by-point representation of the factors in relationship

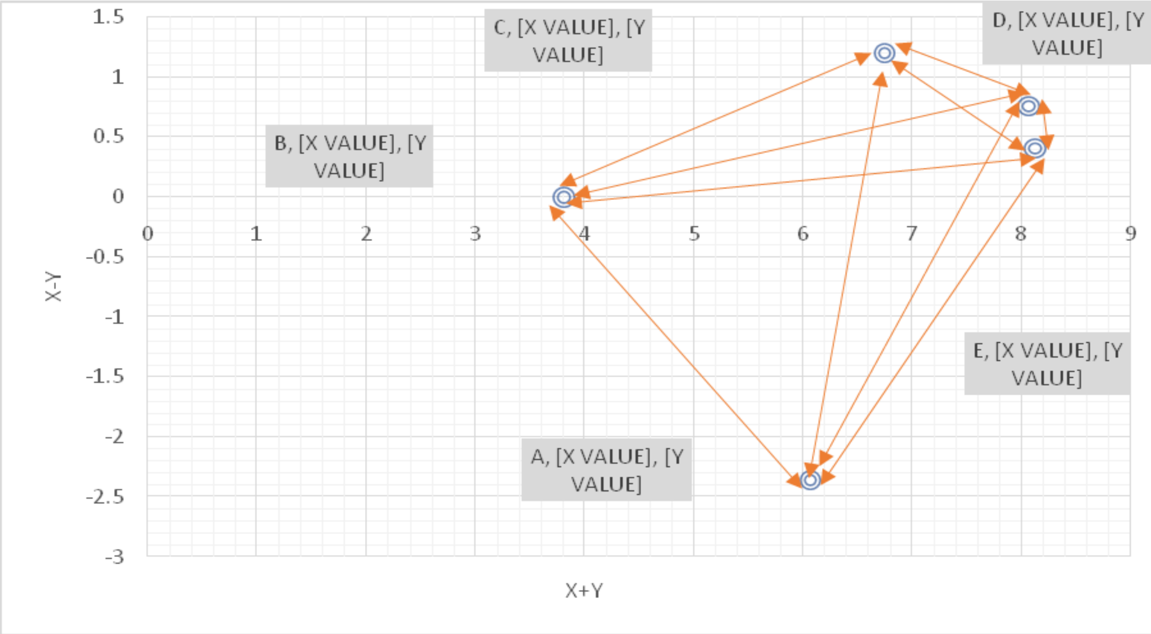

Fig. 1b. Causal diagram for the water absorption process parameters

The causal diagram shows the concept of direct and indirect effects of various criteria over each other.

Conversion of the values of (X + Y) to weights: To convert the values of (X + Y) to weights, a linear programming model is formed and solved with the following representations:

Condition:
Let W_A, W_B, W_C, W_D and W_E represent the respective weights of A, B, C, D and E.
But, $W_A + W_B + W_C + W_D + W_E \leq 1$
We multiply by a proportional factor x to the values of (X + Y), such that

$$A.x + B.x + C.x + D.x + E.x \leq 1$$

On substitution,

$$6.07x + 3.81x + 6.74x + 8.06x + 8.13x \leq 1$$
$$x \leq 0.03$$

Hence, $W_A = 0.182$, $W_B = 0.114$, $W_C = 0.202$, $W_D = 0.242$ and $W_E = 0.244$
While these weights are summed, they are roughly equal to 1 as follows:

Summation of the weights = 0.182 + 0.114 +0.2022 + 0.242 + 0.244 = 0.9842 ≈ 1.

But this information, which represents the weights of the parameters from the DEMATEL approach could be added to the original table from Ajibade et al. (2019) as follows:

Table 6. Criteria and their weighted values

weightage →	0.182	0.114	0.202	0.242	0.244
Level ↓	A	B	C	D	E
1	-30.7422	-30.7418	-30.7096	-30.7455	-30.2670
2	-30.7435	-30.7468	-30.7707	-30.7443	-30.6012
3	-30.7431	-30.7438	-30.7071	-30.7419	-30.9083
4	-30.7431	-30.7397	-30.7847	-30.7403	-31.1955

Next, we produce the normalization of the evaluated matrix (decision matrix) by using Equation (5) and this produces Table 7. It should be noted that Equation (5) is used for the non-beneficial criteria (factors):

$$R_{ij} = \frac{[Max(x_{ij}) - x_{ij}]}{[Max(x_{ij}) - Min(x_{ij})]} \qquad (5)$$

where i = 1, 2, 3, 4, 5 and j = 1, 2, 3, 4, 5

To analyse the parameters one by one, we start with the parameter A, which is initial weight. For the parameter, the maximum value is -30.7422 while the minimum value is -30.7435. It thus implies that the max value – min value is 0.0013 and R_{11} becomes 0. Similarly, R_{12}, R_{13} and R_{14}, become 1, 0.692 and 0.692, respectively. Next, the parameter B, which is final weight is evaluated with R_{21}, R_{22}, R_{23} and R_{24}, becoming 0.296, 1, 0.577 and 0, correspondingly. Now, concerning the parameter C, length, R_{31}, R_{32}, R_{33} and R_{34} are obtained as 0.003, 0.820, 0 and 1, correspondingly. Furthermore, considering parameter D, which is thickness, we obtain R_{41}, R_{42}, R_{43} and R_{44} as 1, 0.769, 0.308 and 0, correspondingly. Now, concerning the parameter E, which is time, the R_{51}, R_{52}, R_{53} and R_{54} obtained are 0, 0.360, 0.691 and 1, correspondingly. The summary of results is produced in Table 7.

Table 7. The normalized matrix

Attributes	A	B	C	D	E
1	0	0.296	0.003	1	0
2	1	1	0.820	0.769	0.360
3	0.692	0.577	0	0.308	0.691
4	0.692	0	1	0	1

Now, to apply the PROMETHEE's procedure, the first step in assessing the difference of i[th] options regarding other alternatives is taken, Table 8. This is however achieved by implementing the expression D [R_i - R_j] in which if i = 1, then j = 2, 3, 4, 5 and if i = 2, then j = 1, 3, 4, 5,

Table 8. Computations based on normalized matrix

Attributes	A	B	C	D	E
1	0	0.296	0.003	1	0
2	1	1	0.820	0.769	0.360
3	0.692	0.577	0	0.308	0.691
4	0.692	0	1	0	1
D (R_1-R_2)/5	-1	-0.708	-0.817	0.231	-0.36
D (R_1-R_3)/5	-0.692	-0.285	0.003	0.692	-0.691
D (R_1- R_4)/5	-0.692	0.292	-0.997	1	-1
D (R_2-R_1)/5	1	0.708	0.817	-0.231	0.36
D (R_2- R_3)/5	0.308	0.423	0.82	0.461	-0.331
D (R_2- R_3)/5	0.308	1.18	-0.18	0.769	-0.64
D (R_3- R_1)/5	0.692	0.285	-0.003	-0.692	0.691
D(R_3- R_2)/5	-0.308	-0.423	-0.82	-0.461	0.331
D(R_3- R_4)/5	0	0.577	-1	0.308	-0.309
D(R_4- R_1)/5	0.692	-0.292	0.997	-1	1
D(R_4- R_2)/5	-0.308	-1	0.18	-0.769	0.64
D(R_4- R_3)/5	0	-0.577	1	-0.308	0.309

Furthermore, steps 2 and 3 involving the computation of the preference function are implemented. The preference function may be evaluated from the following relationships:

1. pj(a,b) = 0. If, $R_{aj} \leq R_{bj} \rightarrow D(R_a - R_b) \leq 0$

That is, if the difference between two alternatives as calculated in Table 8 is less than or equal to zero: then that value automatically becomes zero.

2. pj(a,b) = (R_{aj} - R_{bj}), if $R_{aj} > R_{bj} \rightarrow D(R_a - R_b) > 0$.

That is if the difference between one alternative with respect to others is greater than zero then it retains its value. The results obtained are in Table 9.

Table 9. The preference function,P_j (a,b)

Attributes	A	B	C	D	E
$P(R_1\text{-}R_2)/5$	0	0	0	0.231	0
$P(R_1\text{- }R_3)/5$	0	0	0.003	0.692	0
$P(R_1\text{-}R4)/5$	0	0.292	0	1	0
$P(R_2\text{-}R_1)/5$	1	0.708	0.817	0	0.36
$P(R_2\text{- }R_3)/5$	0.308	0.423	0.82	0.461	0
$P(R_2\text{- }R_3)/5$	0.308	1	0	0.769	0
$P(R3\text{- }R_1)/5$	0.692	0.285	0	0	0.691
$P(R3\text{-}R_2)/5$	0	0	0	0	0.331
$P(R3\text{-}R_4)/5$	0	0.577	0	0.308	0
$P(R_4\text{- }R_1)/5$	0.692	0	0.997	0	1
$P(R_4\text{- }R_2)/5$	0	0	0.18	0	0.64
$P(R_4\text{- }R_3)/5$	0	0	1	0	0.309

Next, the aggregated preference function is computed using the relation on the weights of the criteria:

$\Pi(a,b) =[W_jP_j(a,b)]/\Sigma W_j$ (6)

where Π(a,b) is the aggregated preference function, W_j is the criteria weight, and $P_j(a,b)$ is the preference function

But $P_j(a,b) = P(R_{aj} - R_{bj})$ (7)

Thus, the summation of weight, ΣW_j = 0.182 + 0.114 + 0.2022 + 0.242 + 0.244 = 0.9842 ≈ 1. Then, Table 10 is produced

Table 10. Aggregated preference function

Attributes	A	B	C	D	E	$\prod(A,B)$
Weights	0.1	0.06	0.12	0.20	0.52	
$W_i{*}P(R_1\text{-}R_2)/5$	0	0	0	0.055902	0	0.055902
$W_j{*}P(R_1\text{-}R_3)/5$	0	0	0.000606	0.167464	0	0.16807
$W_j{*}P(R_1\text{-}R4)/5$	0	0.033288	0	0.242	0	0.275288
$W_j{*}P(R_2\text{- }R_1)/5$	0.182	0.080712	0.165034	0	0.08784	0.515586
$W_j{*}P(R_2\text{- }R_3)/5$	0.056056	0.048222	0.16564	0.111562	0	0.38148
$W_j{*}P(R_2\text{- }R_3)/5$	0.056056	0.114	0	0.186098	0	0.356154
$W_j{*}P(R_3\text{- }R_1)/5$	0.125944	0.03249	0	0	0.168604	0.327038
$W_j{*}P(R_3\text{- }R_2)/5$	0	0	0	0	0.1080764	0.080764
$W_j{*}P(R_3\text{-}R4)/5$	0	0.065778	0	0.07436	0	0.140314
$W_j{*}P(R_4\text{- }R_1)/5$	0.125944	0	0.201394	0	0.244	0.571338
$W_j{*}P(R_4\text{- }R_2)/5$	0	0	0.03636	0	0.15616	0.19252
$W_j{*}P(R_4\text{- }R_3)/5$	0	0	0.202	0.	0.075396	0.277396

Following this the leaving and entering outranking flows are determined

A. Leaving (positive) flow for a[th] alternative,

$$\phi^{+} = \frac{1}{C-1}\sum \pi(b,a);(a \neq b)$$

B. Entering (negative) flow for a[th] alternative;

$$\phi^{-} = \frac{1}{C-1}\sum \pi(b,a);(a \neq b)$$

where C, number of alternatives, is 4

By forming a matrix of order corresponding to the number of alternatives (Table 11)

Hence, restricting the Aggregated Preference Function from R_1 to R_2

Table 11. Outranking flow

Aggregate preference function	A	B	C	D	E	Φ^+ Leaving Flow
A	-	-				
B	-	-	0.055902	0.16807	0.275288	**0.49926**
C	-	-	0.515586	0.38148	0.356154	**1.25322***
D	-	-	0.327038	0.080764	0.140314	**0.548116***
E	-	-	0.571338	0.19252	0.277396	**1.041254***
Φ^-Entering Flow			**1.469864***	**0.822834***	**1.049152***	

Ranking the most important criteria*

Finally, the net outranking flow of each alternative is produced, Table 12. This is computed using

$$\phi(a) = \phi^+(a) - \phi^-(a) \; \Phi(a) = \phi^+(a) \; - \; \phi^-(a)$$

Table 12. Net outranking

Factor	$\phi^+(a)$	$\phi^-(a)$	$\phi(a)$	Rank
C	1.25322	1.469864	**-0.216644**	**2**
D	0.548116	0.822834	**-0.274718**	**3**
E	1.041254	1.049152	**-0.007898**	**1**

5.2 Comparison and validation of methods

In this article, Maduekwe and Oke (2020) that applied the AHP method-PROMETHEE method to the same problem considered here is compared with the results of the proposed method. Furthermore, the work contributed by Onyekwere et al. (2019) was used validate the proposed method. Concerning Maduekwe and Oke (2020), the principal areas of comparison are the outcome of the weight generation by the AHP method against the outcome of the DEMATEL method by weight in our proposed method. A further aspect is the result of the net outranking. For the AHP weights, Maduekwe and Oke (2020) assigned the first and second positions to time and length, respectively, while the third position was assigned to the thickness and the fourth position was shared by the initial and final weights of the composites. The outcome of the DEMATEL method for determining the weights to be injected into the PROMETHEE method shows that time, thickness, length, initial weight and final weight are the first to the fifth positions, respectively. The outcome of the two methods is the same concerning the first position, which is time. However, there is a divergence of results with other positions.

Furthermore, the final results of the AHP-PROMETHEE method are compared with the proposed method of DEMATEL method-PROMETHEE method and the conclusion is that the two methods limits the feasible parameters to three. While the AHP-PROMETHEE method made the time, thickness and length with the corresponding net outranking values of 0.1445, -0.1635 and -0.6932 as first, second and third positions, the DEMATEL method-PROMETHEE method obtained varied results by making the time, length and thickness of the corresponding net outranking as -0.0079, -0.2166 and -0.2747 to be first, second and third positions respectively. This means that for the two methods, time was ranked as the best parameter.

Based on validation of the model, the data by Onyekwere et al. (2019) was run through the proposed model of DEMATEL method-PROMETHEE method and an interesting set of results were obtained at the first stage of analysis by using the DEMATEL method alone, Table 13.

Table 13. Ranks produced by the DEMATEL method – Validation data (Onyekwere et al., 2019)

Parameters	X	Y	X - Y	X + Y	Rank	Weights
Acetic Acid Concentration (%)	20.8	19	1.8	39.8	3	0.174
Time soaked in Acetic Acid (minute)	23.2	19	4.2	42.2	2	0.184
Acetic Anhydride concentration (%)	20.8	19	1.8	39.8	3	0.174
Time soaked in Acetic Anhydride (minute)	23.2	19	4.2	42.2	2	0.184
Difference in % water absorption (24 Hours)	23	35	-1.2	58	1	0.253

From the results, the difference in % of water absorption was ranked the best with a corresponding weight of 0.253. Furthermore, by implementing the DEMATEL method-PROMETHEE method on the data, the net outranking results reduced the five parameters to only two feasible ones. Out of these two parameters, the difference in % of water absorption was given the first position with a net outranking value of 0.1406 while the second position was given to the parameter, time soaked in acetic anhydride with a net outranking value of -0.157. The interesting result is that these two parameters are as the DEMATEL method results showed. In summary, through the validation results of Onyekwere et al. (2019), it becomes evident that our method works and has potential applications within and outside the composite development area (Table 14).

Table 14. Net outranking produced by the DEMATEL method- PROMETHEE mehtod – Validation data (Onyekwere et al., 2019)

Parameters	$\phi^{+}(a)$	$\phi^{-}(a)$	$\phi(a)$	Rank
Time soaked in Acetic Anhydride (minute)	0.406	0.563	**-0.157**	**2**
Difference in % water absorption (24 hours)	0	1.406	***0.1406**	**1**

5.3 How effective is the study result of this novel method?

The sign of the effectiveness of this method was observed in the complete outranking performance whereby the method eliminated insignificant parameters of initial and final weights to deal with the other three parameters of length, thickness and time in the net outranking analysis. These findings are apparent in the ranks obtained whereby time with the net outranking value of -0.007898, length with a net outranking value of -0.274718 were ranked first, second and third, respectively. The authors then used the literature data of Onyekwere et al. (2019). Moreover, the results of Onyekwere et al. (2019) also reduced the initial five parameters to two main parameters of time soaked in acetic anhydride and difference in % water absorption. These have the corresponding ranking of 2nd and 1st, respectively.

5.4 Advantages of the proposed approach

The advantages of the article are stated as follows. At the introduction of the DEMATEL approach, Si et al. (2018) argued that it brings in its capability to establish the cause and effect series constituents of the complicated water absorption process. To achieve this, Si et al. (2018) explained that it assesses the independent association among the water absorption parameters and establishes the crucial one, deploying a visual structural model. A visual structure appends a visual part to the evaluation of water absorption parameters to help the composite design engineer perceive better how the parametric evaluation task will be accomplished. Thus, by deploying a visual model, the composite development engineer can visualise the large picture, such that the long-term results of the evaluation process are achieved, including the greater features.

The DEMATEL approach is competent for its visual structural application. However, by introducing the DEMATEL method-PROMETHEE approach, the complete outranking feature of PROMETHEE is brought into action. This means that PROMETHEE exhibits a total preference analytical ability to make the most crucial parameter to be preferred to others. Besides, the DEMATEL method-PROMETHEE approach is user friendly, providing ease to understand and use the method in guided steps. This has promoted its wide-ranging applications in real life.

5.5 Contributions of the paper

This work contributes to the water absorption process in composite study literature by:

1. Highlighting the evaluation parameter in a cause and effect relationship analysis followed by outranking decisions. This method is not previously clear to researchers on the water absorption process and thus will broaden our understanding of research concerning parameter assessment.
2. Installing the DEMATEL method–PROMETHEE method for the hull of a ship, which offers new thoughts in the shipping industry regarding composite development.
3. Establishing flaws in a previous study and then correcting it with a novel method of DEMATEL method.

6. CONCLUSIONS

In building the hull of a ship using epoxy composites, the establishment of the best parameters in the water absorption process is a crucial issue that has remained unresolved in the composite literature. At present, the PROMETHEE method used has the deficiency of inadequate treatment of the parameters and the introduction of a causal relationship principle coupled with the PROMETHEE method had been actualized to solve this problem.

The conclusion arising from the study is that the new method, the DEMATEL method-PROMETHEE method is effective to analyse the water absorption process parameters of composites immersed in water. This was confirmed by a feasible net outranking method that completely ranked the parameters and assigned the first to the third positions to time, length and thickness. This was validated by another data set, Onyekwere et al. (2019). It then follows that in a decision to design the hull of the ship with structural integrity time should be given the utmost attention while the thickness should attract the least attention of the composite designer.

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