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Cause-and-Effect Relationship Analysis of Cocoa Pod Husk Composites in Water Absorption Process Parametric Evaluation: A DEMATEL Approach

Isaac Temitope Abiola, Sunday Ayoola Oke *, Victor Chidiebere Maduekwe
Department of Mechanical Engineering, University of Lagos, Lagos, 100213, Nigeria

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Polymer composites are expanding in scope and applications to water-based structures such as the ship's hull in ship vessels due to their resistance to water and satisfactory mechanical properties. Unfortunately, few studies have tackled their water absorption properties. In this paper, a novel method, DEMATEL, is used to analyze the conflicting water absorption process parameters of cocoa pod husk composite using the cause and effect associations of the parameters. The parameters considered are particulate loading, initial weight, particulate weight, the weight of the matrix, and weight after 150 days and rate of water absorption. A comparison scale explains the extent of influence of a criterion on the other. The direct relationship matrix is normalized and the total relation matrix generated to produce a causal diagram. The most fascinating findings of the study are the differences between the sum of row and columns, which place particulate weights as the most appealing, 1.0798, while the rate of water absorption is the least appealing criterion. Besides, the sum of the row and column that yields the most attractive results is the particulate weight (5.4982) while the least attractive result is the rate of water absorption (3.5436). The novelty of this work lies in the application of DEMATEL structure to examine contextual associations between the essential pointers of water absorption process parameters, for cocoa pod husk composites in the water environment. To our knowledge, it is the first type of work in this area on the selected agro-filler-based composite.

***Corresponding Author**

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

1. INTRODUCTION

Nowadays, new composite products are continuously developed every day (Munoz and Garica-Manrique, 2015; Gupta et al., 2018; de Brito et al., 2019). This has increased interests in biodegradable composites that are cheap and environmentally-friendly (Dhandapani et al., 2020;Wardhono et al., 2020; Zhao et al., 2020). Also, there is consensus to exploit agro-fillers for composite usage to create wealth and reduce health cost (Maraveas, 2020). Furthermore, as the demand for waste fillers is expected to heighten in the next few years, the problem of environmental threat of wastes to citizens may be reduced (Dungani et al., 2016; Ajibade et al., 2020). Consequently, such agro-based composite applications play a substantial stake in the nation's economy (Bismarck et al., 2006, Todor et al., 2018).

This highlights the requirement for additional studies on the account that the composite literature has stressed the research on water absorption of the composite (Haruna et al., 2014; Muñoz and García-Manrique, 2015; Ehi et al., 2016; Ayanladun and Oke, 2020). In an attempt to understand the contributions of scholars on water absorption of polymer composites, the database of a prominent publisher was exploited on the 21st November 2020. On using the keyword, "water absorption, polymer composites," the Taylor and Francis database brought out 18,496 results, which were modified to reveal the "title" and the choice of "date range" from 2010 to 2020. On applying the filter, it showed result for 12,343 items from the publication date of 1/1/2010 to 31/12/2020. When ordered by preference with the newest publications displayed first, unfortunately, no single article appears to have been contributed on cocoa pod husk composite.

Commonly, water absorption of polymer composites has been a theme of attention to multiple investigators, including Ayanladun and Oke (2020), Ajibade et al (2019), de Brito et al. (2019), Muñoz and García-Manrique (2015), Gupta (2018) and Ehi et al. (2016). Ayanladun and Oke (2020) examined the sensitivity of water absorption parameters of cocoa pod husk composites. Ajibade et al (2019) established the optimal parametric settings of composites using the Taguchi methods while considering the parameters of time of immersion, initial weight, sample thickness, final weights and length. De Brito et al. (2019) conducted a numerical study on the moisture absorption of a polymer composite by deploying the Langmuir model. These studies emphasized the requirement for parametric analysis of water absorption parameters. A few have highlighted the important parameters of the water absorption process in composites as in the study by Ajibade et al. (2019). The concerns of Gupta (2018) was to associate the mechanical characteristics of sisal composite. Ehi et al. (2016) was concerned with the kinetic elements and its association with water absorption features of composites reinforced with cocoa pod.

For composite manufacturers to take advantage of the inter-relationship among the water absorption process parameters, they ought to account for the essential pointers. These pointers teach composite developers on the parameters that are crucial to turning around the performance of the composite starting from the design stage, to development and usage of the composite. There is a growing literature on the essential pointers of water absorption process parameters of agro filled composites. Consider the integrity of the composite over its lifecycle, involving introduction, growth, maturity and decline phases in the manufacturing of ship's hull in ship vessels; it would be difficult for composite developers to enhance the composite performance through simply recognizing the essential pointers, which covers diverse components.

Certainly, it is crucial to investigate the contextual process pointers that are meant to provide composite engineers, designers and developers a profound cause and effect insight of the crucial pointers and how they associate with one another (Bhanot et al., 2020). This would assist composite developers to prioritise the distribution of composite resource to the most essential crucial pointers that exhibit the largest influence on the crucial pointers. Besides, to grasp the complex features of the association among the essential pointers, the viewpoints of composite practitioners in the industry and researchers in the area ought to be acknowledged. Generally, the opinion of these two set needs to be reconciled as their working environments differ.

Furthermore, for long term experimentation, it is essential to choose comprehensive parameters, covering the matrix usages, the length of the experimental period regarding weight examinations, and the particulate loading. This will make the analysis robust, to complement the recommendation in the literature by Ajibade et al (2019). Consequently, the current study proceeds regarding this parametric concern by analysing the relationship among six parameters: particulate loading, particulate weight, the weight of the matrix, weight after 150 days, rate of water absorption and initial weight. The study aims to establish the causal relationships among the parameters of the water absorption process in cocoa pod husk composites using the DEMATEL method.

When any pair of criteria is involved as preferences of the composite developer, and the growth in a criterion over the data points corresponds with the growth or decay of the other criteria, then a linear regression curve fitting may be a straight forward predictive model to declare the relationship between the two criteria. However, as the number of criteria expands to three or more, while the behavior of a criterion is at conflict with the others, it becomes a multi-criteria problem. Conflicting criteria are characterized by the growth and decay of a criterion in concurrence with the growth and decay of others. Thus, this study draws attention to the need for multicriteria research, using DEMATEL method that establishes the cause and effect relationships for the cocoa pod husk composite parameters in the water absorption process. The present paper is one of the earliest investigations to analyse the causal associations among the essential pointers of how the water absorption process parameters relate regarding cocoa pod risk composite with data from a laboratory experiment. The principal contribution of this work is the unique application of DEMATEL method to the pointers of the water absorption process. To our knowledge, the work is a first type contribution in the area.

This article is organized as follows. The motivation was given with rationale declared in the introduction. A concise literature review was conducted to elaborate on the research gap and declare the literature observations in the literature review section. The methods aspect is the next section, and it contains the evaluation method. Next is the presentation of results and discussions. Lastly is the conclusion section.

2. LITERATURE REVIEW

2.1. General

The principal concerns in building water-resistant polymer composites are to consider the structural integrity of the composites at manufacturing and during the projected service life of the composites. Besides, the composite development group analyse the life-cycle and the impacts of the composites on the environment. These concerns are greatly influenced by the concentration and/or spread of composite resources during manufacturing. Unfortunately, the literature offers little guidance in this respect. But resource distribution by acknowledging the importance of each polymer composite parameter during water absorption process may be evaluated through the determination of the intensity of interactions among the composite's water absorption process parameters. These parameters are represented as the particulate loading, initial weight, particulate weight, weight of the matrix, weight gained after 150 days and rate of water absorption. To respond to this research gap, this section provides a survey of the literature, revealing the progress made on water absorption process of cocoa pod husk composite regarding the scientific study of cause and effect relationships of the parameters. The review of the literature for this work falls under two aspects. The first concerns water absorption studies on cocoa pod husk composites while the second entails previous research on DEMATEL method.

For studies involving water absorption process concerning cocoa pod composite, the following are relevant. Chun et al. (2013) adapted filler made of cocoa pod husk to polypropylene matrix and examined how it is impacted by methacrylic acid. An improvement of torque, tensile strength and modulus for the composites were reported. In two separate studies, Imoisili et al. (2013a) first considered the mechanical features of cocoa pod composite in association with filler proportion. In the second study, Imoisili et al. (2013b) analysed the physicochemical attributes of cocoa pod composite and associated it with filler composition using polyester resin as the matrix. El-Shekeil et al. (2014) associated fibre loading and tensile strength when considering cocoa pod composites. Chun and Husseinsyah (2016a) analysed the influence of filler constitution with chemical modification on cocoa pod husk loaded polypropylene composites. An enhancement in the interfacial linkage between the filler and the matrix was confirmed. Elri et al. (2016) instituted research to analyse the kinetics of water absorption characteristics with a focus on cocoa pod composites.

Chun et al. (2016b) coupled polypropylene and cocoa pod husk with waste oil fatty acid in biodiesel production. An enhancement in the elongation at break, tensile strength and tensile modulus of the composite was recorded. The work promoted waste oil fatty acid as a promising agent to enhance bonding in composites. Koay et al (2017) studied the torque rheological characteristics regarding polypropylene composites filled with cocoa pod husk materials. The palm oil-oriented coupling agent was tested in developing the composite. The outcome showed that the composite enclosing 40 phr filler loading and the coupling agent had superior processing torque and power-law indicator.

Chun et al. (2017) deployed rheological theory to evaluate the characteristics of plastic wood composites. By using a torque evaluation rheometer, the processing torque was established to grow with the motors speed, the appendage of maleate polypropylene and filler composition. Chun et al (2018) used cocoa pod husk to fill the polypropylene matrix for composites coupled with a green agent to compete with alternative coupling agents such as silane and maleic anhydride embedded polypropylene. The focus was to test the feasibility to use the coconut oil-based coupling agent. It was declared that the green coupling instrument competes favourably with alternatives. Olabisi et al. (2016), Puglia et al. (2016) and Sanyang et al. (2017) in independent studies analysed the cocoa pod composite by using it as brank pod (Olabisi et al., 2016). Other authors analysed their thermal, tensile and morphological attributes (Puglia et al., 2016) while the influence of filler loading was analysed on the tensile properties by other authors (Sanyang et al., 2017).

Of late, the DEMATEL method has been gaining increasing acceptance in all aspects of human endeavour that requires understanding the interaction intensity among parameters. Consequently, there is a plethora of modelling research on DEMATEL that analyse the cause-and-effect relationship of parameters in a system. The research uses single and multiple models to study situations. To start with, a review of studies with single models is provided. The interest of Tzeng et al. (2007) was on e-learning and the DEMATEL method was applied in this regard. The articles that combine the DEMATEL with other models and concepts are reviewed as follows. Yang et al. (2008) combined DEMATEL and ANP and showed some applications. Li and Tzeng (2009) showed the application of DEMATEL in a semi-conductor system. Lee et al. (2010) showed interest in fuzzy DEMATEL with an application to benefit assessment. Hu et al. (2011) combined DEMATEL and IPA to analyse performance in the communication industry. The concern demonstrated by Wu (2012) was towards adding fuzzification to DEMATEL and the framework was applied to knowledge management. Lu et al. (2013) applied DEMATEL in health care and demonstrated it with data from Taiwan.

Lee et al. (2013) used DEMATEL in library applications. Sumrit and Anuntavoranich (2013) studied the competence of Thailand's know-how-oriented organisations on technology innovation. Uygun et al. (2015) established an association between DEMATEL and Fuzzy ANP and showed interest in telecommunications. Apan and Nguyen (2015) also showed interest in consumer satisfaction by regarding manufacturing practices and applied DEMATEL for the purpose. Hu et al. (2015) appraised the performance of supplier quality by applying combined DEMATEL and ANP. Hsieh et al. (2016) showed the relevance of DEMATEL in the food and beverage industry. Wang et al. (2016) applied DEMATEL to barriers in implementing supply chain programs. Asad et al. (2016) showed interest in consumer satisfaction and applied DEMATEL in the banking system. The VIKOR method was combined with DEMATEL by Rajan et al. (2016) and the framework was applied to railway systems.

Besides, it was observed that fuzzy theory has significantly been applied to transform the application of DEMATEL in various aspects of human endeavour. Therefore, interest was shown here to review the aspect of fusion of fuzzy theory with DEMATEL, Table 1.

Table 1. Past articles on the fusion of fuzzy theory with DEMATEL

Aspect	Articles covering the characteristic	Characteristic of interest	Applied tools
Fuzzy DEMATEL studies	Agarwal and Bharti (2019)	Autonomous mobile robots	Fuzzy DEMATEL and TOPSIS
	Nematkhah et al. (2017)	Condition-based maintenance	Fuzzy DEMATEL and fuzzy ANP
	Liu et al. (2015)	Risk assessment using FMEA	Fuzzy weighted average and fuzzy DEMATEL
	Ardeshir and Mohajeri (2018)	Safety culture	Fuzzy DEMATEL and fuzzy ANP
	Pourjavad and Shahin (2020a)	Supply chain	Fuzzy DEMATEL, fuzzy AHP and TOPSIS
	Pourjavad and Shahin (2020b)	Supply chain	Fuzzy DEMATEL and fuzzy TOPSIS
	Mavi and Standing (2018)	Business intelligence	Fuzzy DEMATEL
	Tsao and Wu (2014)	Composite drilling	Fuzzy DEMATEL
	Keskin (2015)	Supply chain	Fuzzy DEMATEL and fuzzy C
	Ghadami et al. (2019)	Hospital	Fuzzy DEMATEL
	Shakeri et al. (2020)	Project management	Fuzzy DEMATEL, ISM and BWM

2.2 Literature gaps and key observations

The literature survey reveals the following gaps and observation:

1. The requirement to improve the structural integrity of composites used in a water-based environment is compelling. However, enhanced performance of composites in service life could be built into the composites during development stages. Knowledge of interaction intensity among parameters in water absorption process is therefore a requirement for progress in performance enhancement of cocoa pod husk composites.
2. The DEMATEL method is competent to analyse the cause-and-effect relationship of parameters in a process. It is a promising method for a deep understanding of the intensity of interaction measurements.
3. The DEMATEL method has been applied successfully in several areas, including supply chain, customer satisfaction, banking, manufacturing practices, healthcare, library, technology innovation, benefits scheme, railway systems.
   However, there is no report on its application to the water absorption process. Besides, the cocoa pod husk composites have not been reported in the literature. Furthermore, reports have been given concerning the application of DEMATEL method using data from Taiwan, China, India. However, an extremely low account was given on the use of DEMATEL model for studies from developing countries such as Nigeria.

3. RESEARCH METHOD

3.1 DEMATEL

The credit of birth of the multicriteria concept, DEMATEL, was taken by the Battelle Geneva institute as far back as in 1973 when DEMATEL was proposed to solve challenging problems (Fontela and Gabus, 1976) (Figure 1). The initial framework was subsequently improved in 1976 by the combined efforts of Fontela and Gabus (1976). The goal of these concept innovators was in search for the direct and indirect association of the elements/parameters considered, to assess the strength by impact among diverse elements. The environment of study is however complicated. The foundation of DEMATEL method hinges on the graph theory and serves the purpose of setting up a structural model between complicated parameters using causal associations (Wu and Lee, 2007; Bhanot et al., 2020).

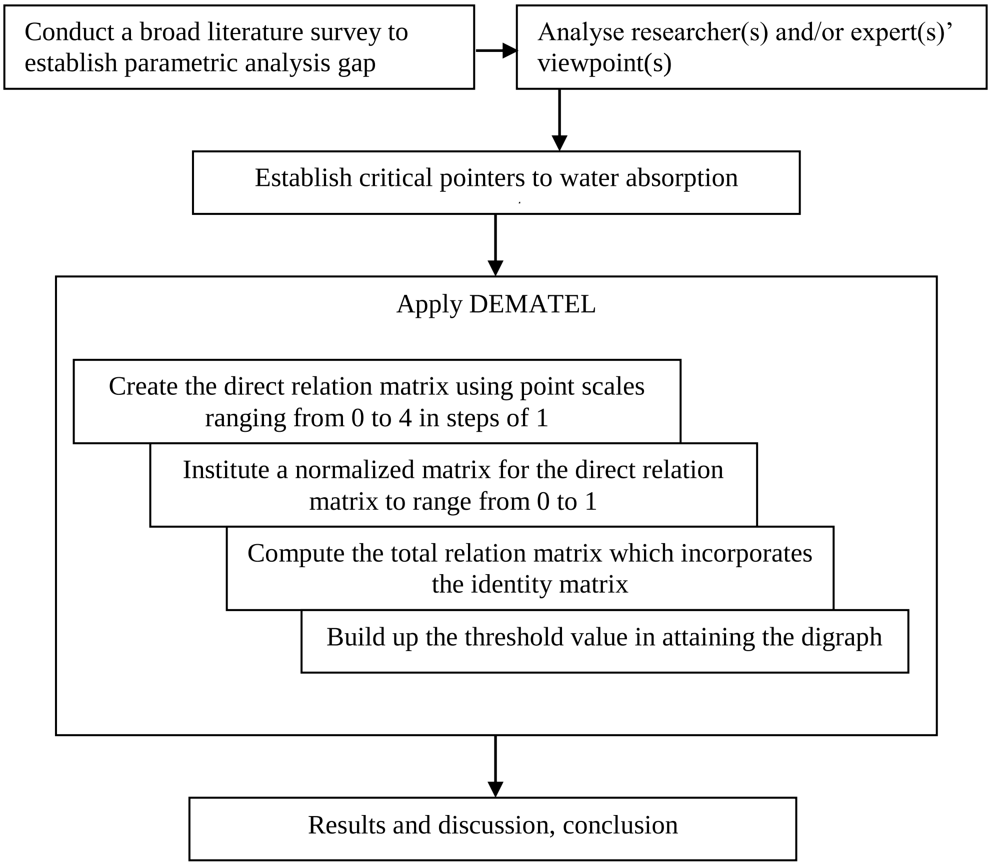

Fig. 1. A DEMATEL method to water absorption process performance analysis for cocoa pod husk composite

The DEMATEL approach has of the ability to evaluate the degree to which each pointer is associated to every other pointer; this offers a measure of the intensity between the diverse pointers (Chen, 2012; Bhanot et al., 2020). The composite development group (composite engineers and designers) can understand that several causes contribute to the outcome of an effect. Besides, the DEMATEL method pictorially reveals the association of the causes with the influence as well as to one another. Furthermore, DEMATEL assists the composite development group to establish aspects of the project that warrants enhancement. The following steps are taken in the execution of the DEMATEL approach (Tang, 2018; Bhanot et al., 2020):

Step 1: Evaluate the average matrix while the responses from the experts and researchers are compiled. The representative matrix is labelled as A. The questionnaire seeks for an answer from the respondents on the level at which each pointer in a particular row, say "*i*" influences the other pointer in a column labelled as "*j*" using a scale of measurement from 0 to 4 on a step of 1. Using the data, the average matrix is generated as (Shieh et al., 2010; Bhanot et al., 2020):

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

where p_{ij} is the level that the respondents evaluate indicator i to impact on indicator j. Also, Q is the respondents. Notwithstanding, the respondent used for this analysis is the researcher and only an item each for the respondent side is available and need not be averaged. Thus, this phase of evaluation in DEMATEL is omitted in the present work.

Step 2: Normalise the direct relation matrix

Here, $X = K \times A$ (2)

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

Step 3: Compute the total-relation matrix
This is achieved using the expression:

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

where I signifies the identity matrix

Step 4: Obtain the digraph using the dataset of ($D + R$, $D - R$).

3.2 Causes-and-effect relationship

A cause-and-effect link is a connection such that one occasion (cause) creates another occasion (effect). A cause may yield multiple effects and the illustration using the parameters of the water process may provide some insights. Consider an experiment using different values of particulate loading of cocoa pod husk in the epoxy matrix to form a thermoset composite. Suppose the loadings are expressed in percentage of the whole mixture of particulate cocoa pod husk and the epoxy matrix as 0%, 1% to 31% in steps of 2. Suppose a cause is taken as increasing the particulate loading from 9% to 21%. It is expected that such a cause will provide corresponding changes in the particulate weight, the weight of the matrix, weight gained by the composite under the water influence for 150 days and the rate of water absorption. These occasions of changes are referred to as the effects. A cause triggers four effects.

Literature provides conditions that should be met to establish a cause-effect association. The first condition, temporal precedence, stipulates that the cause needs to happen before the effect. As in the illustrative example, the changes in particulate loading from 9% to 21% must happen before the four consequences. The second condition is that soon after the cause happens, the effects must be triggered. Thus, if the cause fails to exist, then the effects also cease to happen. Furthermore, the magnitude of the cause establishes the magnitude of the effect. In the instance considered, a change in particulate loading from 9% to 21% is a difference of 12 points. Compare it to a change of 2 points whereby the particulate loading changes from 1% to 3%. In the latter case, the magnitude of change is smaller. It is not expected to produce the same effects as an earlier case.

4. RESULTS AND DISCUSSION

This study has a focus on the water absorption process, in testing the resistance of cocoa pod husk composite to water. The direction of research is to understand the interactions among the defined parameters, which dictates the structural integrity and the life-cycle behavior of the cocoa pod husk composite. The parameters of importance are the particulate loading, initial weight, particulate weight, weight of the matrix, weight gained after 150 days and the rate of water absorption. Particulate loading is the amount (by mass or value) of cocoa pod husk particles in a unit space of the matrix before composite fabrication. The DEMATEL approach is based on four steps. To commence the direct relation matrix is created. This involves the development of the average matrix that reflects the summarized results from the survey. Although only an expert is used, who is one of the present authors, judgement from this expert is represented at this stage. The matrix reveals the original influence that a parameter exercises on and obtains from other parameters. This stage depends on the standard scale between 0 and 4 used as the platform for assessment in the DEMATEL method. The expert, when assessing puts a value of 0 when the judgment is that there is no perceived influence of a particular parameter in the water absorption process on another parameter. If the judgment is that of a minimal influence, then the expert scores the association as 1. A higher value of 2 is given to the association when the influence is perceived as average (medium). However, a more impactful influence is assigned a value of 3 while the most impactful influence, "very high", may be given a value of 4. Considering two parameters, an elevated score reveals that the expert has a firm believe that substantial enhancement in a parameter is necessary to enhance the other parameter. The results of the evaluation are shown in Table 2.

Table 2. Direct-relationship matrix

Parameters	Particulate loading	Initial weight	Particulate weight	Weight of matrix	Water absorption after 150 days	Rate of water absorption	$\sum_{j=1}^{n} a_{ij}$
Particulate loading	0	1	2	3	3	2	11
Initial weight	3	0	2	3	2	2	12
Particulate weight	3	2	0	4	4	3	16
Weight of matrix	4	3	3	0	1	2	13
Water absorption after 150 days	1	2	2	1	0	1	7
Rate of water absorption	1	2	1	1	1	0	6

As noted from Table 2, particulate loading does not have any influence on itself and was assigned a value of 0. Likewise, each of the other parameters has no influence on itself and all are assigned a value of 0, displayed at the intersections of the matrix. Along the first row, the relationship of particulate loading with initial weight is 1. This means particulate loading impacts on initial weight at a low interaction plane. The same argument is true on the fourth row when the weight of the matrix is the reference point and weighed against water absorption after 150 days. When water absorption after 150 days is taken as a reference, its interaction with particulate weight, the weight of the matrix, and water absorption after 150 days was taken as 1, indicating a low interaction. By following the same logic, the values from 2 to 4 are assigned in the appropriate cells in the matrix.

The next phase in the procedure is to normalize the matrix using Equation (2). This means obtaining the product of K as well as A to finally obtain X. However, K depends on the reciprocal obtained from the greatest quantity achieved from all calculations to add up the various values in each row.

Consider the first row, which is for particulate loading; there are six entries in cells at its front. These values are 0, 1, 2, 3, 3 and 2 and their sum is 11. Likewise, computations may be made for the second to the sixth row. For the second row, the six entries in cells along the row are 3, 0, 2, 3, 2 and 2 to yield 12. The third, fourth, fifth and sixth rows then yield 16, 13, 7 and 6, respectively. On comparing the yields at each row, the row labelled as "particulate weight", which is the third row carries the highest value of 16. It follows that the normalisation matrix would emerge if Table 2 is re-considered by dividing all the entries into all rows by this highest value of 16. The exception in the division is the last column of the matrix. Consequently, Table 3 emerges.

Table 3. Normalised matrix

Parameters	Particulate loading	Initial weight	Particulate weight	Weight of matrix	Water absorption after 150 days	Rate of water absorption
Particulate loading	0	0.0625	0.125	0.188	0.188	0.125
Initial weight	0.188	0	0.125	0.188	0.125	0.125
Particulate weight	0.188	0.125	0	0.25	0.25	0.188
Weight of matrix	0.25	0.188	0.188	0	0.0625	0.125
Water absorption after 150 days	0.25	0.125	0.125	0.0625	0	0.0625
Rate of water absorption	0.0625	0.125	0.0625	0.0625	0.0625	0

Now, take Table 3 and consider its first row, particulate loading. The interaction between particulate loading and itself is assigned a null value. The same logic is followed to assign null values to the intersection of the parameters on the next rows and themselves. Hence, the diagonal matrix has elements of null value (Table 3). Referring to the first row of Table 3, the next cell after the null cell is the intersection of particulate loading with initial weight. The normalized value for this cell is obtained when 1 is multiplied with the reciprocal of 16, which is the highest sum of all entries along the row. The obtained value is 0.0625. For the next cell along the particulate parametric row, which is the interaction of particulate loading and particulate weight, by multiplying the value in the cell, i.e. 2 with the reciprocal of 16, we obtained 0.125. Similarly, for the next three cells, the values of 0.188, 0.188 and 0.125 are obtained. By following the procedure for all the cells in other rows, the entries in Table 3 may be completed.

The third step in the DEMATEL method's application makes use of values from Table 3. Equation (3) is used on the values to transform Table 3 to Table 4. Equation (3) contains two parts on the right-hand side, which is the product of the Matrix I and the transpose of the difference between the identity matrix I and matrix X. First, the later part is first computed as the identity matrix I, which has 1 along the diagonal of the 6 x 6 matrix and 0 elsewhere is subtracted from the matrix formed by Table 3. The results of (I – X) is given in a transpose form as $(I - X)^{-1}$ (Table 5). Furthermore, the value T, which is the product of the two parts, $X(I - X)^{-1}$ is given as Table 6.

Table 4. Total-relation matrix

Parameters	Particulate loading	Initial weight	Particulate weight	Weight of matrix	Water absorption after 150 days	Rate of water absorption	D
Particulate loading	1.0000117	0.00000895	-0.00000125	-0.00005845	-0.0000044	0.0000133	0.99997
Initial weight	0.0000202	1.0000034	-0.0000021	-0.0000672	-0.0000105	0.0000124	0.999956
Particulate weight	0.0000182	-0.0000025	0.9999961	-0.0000825	-0.0000124	0.0000148	0.999932
Weight of matrix	0.00002285	-0.0000085	-0.00000365	0.9999922	-0.0000095	0.00000685	1
Water absorption after 150 days	0.00001875	-0.00000625	-0.00000625	-0.000025	0.9999875	0.00000625	0.999975
Rate of water absorption	0.00000625	0	-0.00000625	-0.00001875	-0.00000625	1.00000625	0.999981
R	1.000098	0.999995	0.999977	0.99974	0.999944	1.00006	

Note: D – sum of each row; R – sum of each column

Table 5. Computation of $(I-X)^{-1}$

Parameters	Particulate loading	Initial weight	Particulate weight	Weight of matrix	Water absorption after 150 days	Rate of water absorption
Particulate loading	-7.1902	6.3723	0.6445	2.0401	-4.3832	4.2654
Initial weight	4.4212	-8.8357	1.6527	-1.6829	7.2234	-0.5556
Particulate weight	2.2120	3.5687	-4.4975	1.8548	-1.7424	2.3443
Weight of matrix	6.1056	-4.1780	0.2638	-8.287	11.9247	-2.7781
Water absorption after 150 days	-9.9697	11.9084	0.2837	7.7576	-20.2460	13.2797
Rate of water absorption	9.3891	-10.7773	2.8477	-0.2176	10.6459	-17.8608

Table 6. Computation of $X(I-X)^{-1}$

Parameters	Particulate loading	Initial weight	Particulate weight	Weight of matrix	Water absorption after 150 days	Rate of water absorption
Particulate loading	1.0000117	0.00000895	-0.00000125	-0.00005845	-0.0000044	0.0000133
Initial weight	0.0000202	1.0000034	-0.0000021	-0.0000672	-0.0000105	0.0000124
Particulate weight	0.0000182	-0.0000025	0.9999961	-0.0000825	-0.0000124	0.0000148
Weight of matrix	0.00002285	-0.0000085	-0.00000365	0.9999922	-0.0000095	0.00000685
Water absorption after 150 days	0.00001875	-0.00000625	-0.00000625	-0.000025	0.9999875	0.00000625
Rate of water absorption	0.00000625	0	-0.00000625	-0.00001875	-0.00000625	1.00000625

Concerning Table 7, the information about the degree of importance of the water absorption process parameters are revealed and are attached to their respective (D+R) scores. Particulate loading, which has a (D+R) score of 2.000068 exhibits the greatest degree of importance, and next to it is the rate of water absorption, initial weight, water absorption after 150 days, particulate weights, and weight of the matrix, respectively.

Table 7. Sum of influences provided and obtained on parameters

Parameters	D	R	(D – R)	(D + R)
Particulate loading	0.99997	1.000098	-0.00013	2.000068
Initial weight	0.999956	0.999995	-3.9E-05	1.999951
Particulate weight	0.999932	0.999977	-4.5E-05	1.999909
Weight of matrix	1	0.99974	0.00026	1.99974
Water absorption after 150 days	0.999975	0.999944	3.1E-05	1.999919
Rate of water absorption	0.999981	1.00006	-7.9E-05	2.000041

Furthermore, after analysing the values of their respective (D - R) scores, the particulate loading, initial weight, particulate weight and rate of water absorption are divided as the cause collection parameters. Through distinction, the weight of the matrix and water absorption after 150 days is the effect collation. The values of (D) as well as (R) for the separate parameters show the intensity of influence offered and obtained by the total system. In Susanty (2020) and Mangla et al. (2014), the authors concurred that the cause collection parameters are essential concerning their direct influence on the total system. Taking inspiration from Susanty et al. (2020), it is essential to address and focus on the cause collection parameters to increase the performance of the water absorption process.

Taking a close observation of the elements of the cause collection parameters, the particulate loading demonstrates the largest (D - R) score of -0.00013. The interpretation is that particulate loading exerts the utmost effect on the total system. Apart, its (D + R) score is comparatively high. The justification is that particulate loading may exert influence on other parameters; however, it also receives comparatively great influence in return. This circumstance shows that the policy regarding particulate loading with detail and clear steps on resource distribution to this parameter will substantially enhance composite development plans regarding cocoa pod husk composites. The second greatest parameter considering the (D - R) column is the water absorption after 150 days that has the (D - R) score of 3.1 E-05. With a close value to particulate loading, the (D + R) score of 1.999919 is relatively small. In defence of this, water absorption after 150days may have less influence in return. The initial weight having a (D - R) score of -3.9E-05 is in the third position in revealing its influence on the complete system to increase the water absorption process performance concerning the cocoa pod husk composite.

Regarding the effect collecting parameters (Fig. 2), the rate of water absorption obtains the lowest score of -7.9E-05 that implies that the parameter receives the greatest effect from all other parameters. Apart, it is a member parameter concerning the (D + R) score of 2.000041. This shows the importance of the rate of water absorption in a composite development arrangement as it aids in achieving improved prioritisation of resources. The other parameters that follow in order of priority are particulate weight, initial weight, water absorption after 150 days and particulate loading.

The research findings offer implications for different people. First, composite developers are required to gain insight into the complex inter-relationships among the water absorption parameters. This appears as necessary especially when water-based composite structures are manufactured in regulated environments. Ship's regulatory bodies impose strict sanctions on sub-standard composite manufacturers as this regulation refines standards in the composite industry.

Secondly, composite engineers and developers need to establish how changes in any of the water absorption parameters may impact on the structural integrity of the cocoa pod husk composite and its lifespan. With a strong control of the water absorption parameters, composite engineers and developers can negotiate new businesses to expand the scope of application of the composites. Thirdly, the research highlights the need for the water absorption mechanism that aids to the development of water-resistant composites.

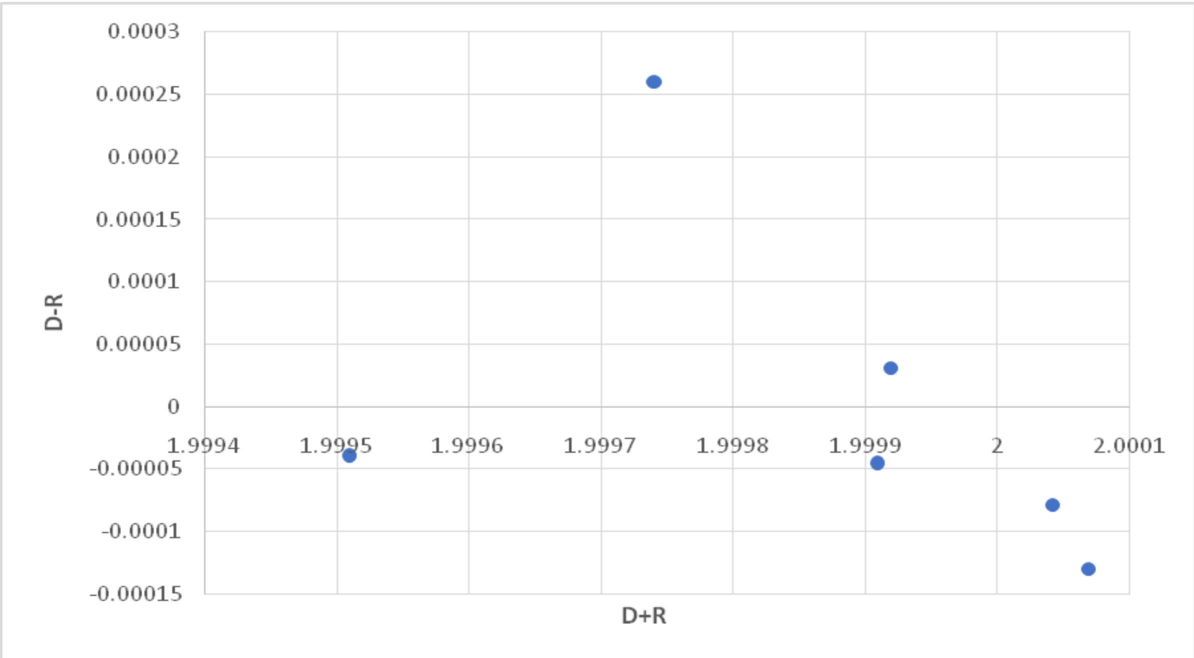

Fig. 2. Impact relationship for the criteria

5. CONCLUSIONS

This investigation has tackled the problem of distinguishing the complex inter-relationship among the key parameters of the water absorption process for cocoa pod husk composites. The DEMATEL approach was deployed to efficiently control the composite's failure by water attack containing salts. The prioritization of key influential parameters implored by DEMATEL may be employed as a setting-rooted reference for planning the composite development phase and as an instrument to select and assess probable composite grade with the expected water absorption properties. The findings revealed that the differences between the sum of row and columns place particulate weights as to most appealing, 1.0798, while the rate of water absorption is the least criterion. Besides, the sum of the row and column that yields the most attractive results is the particulate weight (5.4982) while the least attractive result is the rate of water absorption (3.5436). This article has deployed DEMATEL as a decision tool to reveal a plethora of key influential parameters obtained from a combination of literature search and practice experience into a prioritized structure at variance from the previous initiative method to plan for water absorption parametric influences in a composite development effort.

This research offers important implications in the management of water-based composites regarding cocoa pod husk composites. The research will assist composite development team to divide the parameters of the water absorption process into essential segregations. This will address plans aimed at enlarging and implementing appropriate steps for the build-up of robust resource distribution practices in the composite industry. This research has contributions to composite development practice. The most substantial part of this work is that it engages the DEMATEL method to initiate and implement a cause-and-effect association of the parameters for the water absorption parameters of cocoa pod husk composites.

An evident natural enlargement of the study would be to reproduce the study undertaken using other fillers (i.e. palm kernel shell, coconut shell) and different matrices (i.e. epoxy, vinyl ester). The key highlights of this work centered on articulate fillers in an untreated manner. However, the application of waste-based composites has witnessed a significant strengthening in the last few years but the composite literature still reflects an unclear composite development record. It would be especially valuable to establish:

- Similarities and differences in particle-based and fiber-based cocoa pod husk composites.
- Differences and similarities between treated (NaOH) samples of particulate-based cocoa pod husk composites and non-treated samples.
- The behavior of fused Taguchi scheme–DEMATEL Taguchi–Pareto DEMATEL, Taguchi–ABC DEMATEL for particulate–based cocoa pod husk composites.
- Characteristics of cocoa pod husk mixed with palm oil bunch particulates with starch binders.
- The issue in the immediately preceding point while considering treated and untreated samples and models involving the Taguchi-Scheme–DEMATEL, Taguchi–Pareto DEMATEL, Taguchi–ABC DEMATEL.

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