WEIGHTING THE MATERIAL REQUIREMENTS OF NFRC BY USING FUZZY AHP WITH EXTENT ANALYSIS

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ABSTRACT: Natural fiber reinforced composite (NFRC) are developed well recently as it is an environmentally friendly material. The increase in attention for NFRC in additive manufacturing is parallel with the awareness to replace synthetic fiber in formulation of composites. The purpose of this study is to define the suitable NFRC filament for fused deposition modelling (FDM). In this paper, Fuzzy Analytic Hierarchy Process, (Fuzzy AHP) method with extent analysis was applied in the weighting of material requirements of NFRC filament for FDM. The selection of material requirements was conducted based on physical properties, chemical properties and mechanical properties of selected natural fiber. From literature review, nine material requirements were identified as the alternatives to achieve the objectives. Fuzzy AHP is used to establish fuzzy comparison matrices for each alternatives and extent analysis is used to satisfy the goal. The result showed that Young's modulus is the important material requirements for NFRC filament used in FDM. The selection of material requirements is important to ensure higher degree of confidence for utilization of NFRC filament for FDM.

KEYWORDS: *Fuzzy Analytic Hierarchy Process; Material Requirement; Material Selection; Natural Fibre Reinforced Composite; Additive Manufacturing*

1.0 INTRODUCTION

The growing concern and awareness towards environmentally friendly materials in community nowadays have caused an increasing number in research and innovation of natural fiber composites. Use of natural fiber as reinforcement has received many attentions due to the advantages of natural fiber over synthetic fiber. Generally, natural fiber is derived from animal, plant or mineral sources according to their origin. Natural fiber can be produced in structure of filament, thread, woven or matted and it is new generation of reinforcement for polymer -based materials [1]. The characteristics of natural fiber such as high strength, low cost and biodegradable are one of the reasons it becomes an alternative to synthetic fiber [2]. Recently, NFRC are emerging rapidly and have potential to substitute metal or ceramic based materials in automotive industry, sporting goods, aerospace and marine [1]. The automotive industry is one of the largest consumers of natural fibers due to its lightweight and good sound absorption properties [3]. Mansor et al. [4] designed an automotive parking brake level component by using kenaf fiber polymer composites. Besides, Ishak et al. [5] studied on the identification of suitable NFRC for car front hood and results suggested that kenaf is the most suitable material for automotive application. Dunne et al. [3] studied density and tensile strength of sisal-kenaf composites with an ABS matrix. The results showed that kenaf fiber with ABS matrix have low density and high tensile strength to be used as alternatives to synthetic based materials in automotive application.

Different types and quantitative properties of natural fiber are presented in Table 1 and Table 2. Table 1 shows the physical properties and chemical properties of natural fiber used in NFRC fabrication whereas Table 2 shows the mechanical properties of natural fiber for NFRC fabrication. The judgement made involving the material requirements were based on the material information from the literature review [6-7].

Table 1: Physical properties and chemical properties of natural fiber used in NFRC fabrication

Natural fiber	Density (g/cm3)	Diameter of fiber (μm)	Cellulose (wt.%)	Lignin (wt.%)
Abaca	1.50	10-30	56-63	7-9
Bamboo	1.10	240-330	26-43	1-31

Banana	1.35	50-250	83	5
Coir	1.15-1.46	10-460	32-43.8	40-45
Flax	1.50	40-600	64.1-71.9	2-2.2
Hemp	1.48	25-500	68-74.7	3.7-10
Jute	1.46	40-350	62-72.5	12-13
Kenaf	1.45	70-250	45-57	21.5
Ramie	1.50	50	68.6-91	0.4-0.7
Sisal	1.45	8-200	60-78	8-14

Table 2: Mechanical properties of natural fiber used in NFRC fabrication

Natural fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Abaca	400	12	3-10
Bamboo	500	35.91	1.4
Banana	600	17.85	3.36
Coir	175	4-6	15-51.4
Flax	800-1500	27.6-80	1.2-3.2
Hemp	550-900	70	1-3.5
Jute	393-800	10-30	1.5-1.8
Kenaf	930	53	1.6
Ramie	220-938	44-128	2-3.8
Sisal	530-640	9.4-22	2-7

In recent years, additive manufacturing (AM) technology has rapidly growth and introduced fabrication of conceptual and functional prototypes which can shorten the production development process [8]. AM is known with the ability to produce complex shape and geometry of products and it is widely used in industry such as automotive, aeronautic and bioengineering [9]. Plus, AM can minimize the usage of material which leads to reducing of waste materials and lower the cost of manufacturing [10]. Guo and Leu [11] stated that process of AM can be divided into four broad categories which are liquid, filament, powder and solid sheet. FDM is one of AM methods to melt or soften materials to produce layers other than selective laser melting (SLM) and selective laser sintering (SLS) [12]. FDM is widely used in AM technology for producing variety of products in numerous fields for its reliability and cost effectiveness [9]. Šafka et al. [13] stated that a filament should have a constant diameter to obtain a smooth production of 3D prototypes and by using FDM, there is a reduction of cost for material processes and a wider range of materials can be process.

Material selection is vital process at the early stage of product design development because it helps to narrow the range of materials as the design nears completion [14]. As range of materials have been narrowed, it will ease the decision maker to choose the suitable materials. It is necessary to select a suitable material type for engineering applications to satisfy the design requirements for market needs. Implementing a specific material type in a certain industry is restricted by several criteria and constraints [15] to ensure the stability of selected material in certain application. Rao and Patel [16] stated that it is important to consider the criteria or attributes when selecting materials where attribute can influence the selection of a material for any application. It is because each specific application requires different characterization of material capabilities such as inherent material, physical and chemical composition [17]. Al-Oqla and Sapuan [17], stated that criteria of selecting natural fiber properties can be divided into three levels and it is the key driver to utilize any NFRC product in a specific application. Table 3 shows the criteria of natural fiber according to level.

Table 3: Criteria of natural fiber materials on fiber level

Level 1 Category	Level 2 Characteristics	Level 3 Criteria
Natural fiber properties	Physical	Density and diameter of fiber
	Chemical	Chemical composition (cellulose, lignin)
	Mechanical	Tensile strength, Young's modulus, elongation to break, specific tensile strength, specific Young's modulus

There is a tool in multi-criteria decision making (MCDM) method that capable to derive the ranking of requirements and set the preferences numerically [18]. The tools are including technique for order preference by similarity to ideal solution (TOPSIS), the analytic hierarchy process (AHP), Fuzzy AHP technique, Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method, graph theory, simple additive weighted (SAW) method and weighted product method (WPM) [15]. AHP is used to solve the decision-making problems when occurred in uncertain situation or condition. The AHP systems is divided by levels and this level is arrange into an ascending hierarchy order. Even though AHP decision-making has low accuracy and subjectivity, AHP has the lower risk of making wrong choice in making decision [19]. Laarhoven and Pedrycz [20] used fuzzy set theory and fuzzy mathematics to improve AHP method and developed Fuzzy AHP.

Dağdeviren, and Yüksel [21] stated that there are many Fuzzy AHP methods proposed by various authors since fuzzy set theory allows the decision makers to incorporate with unquantifiable information. Laarhoven and Pedrycz [20] has developed a fuzzy to weight the significant criteria in a decision problem via pairwise comparison and each ratio is express in a matrix. Furthermore, Laarhoven and Pedrycz [20] have introduced threefold method which are using a fuzzy number with triangular membership functions. Next, the decision problems can be handling even though there is no or multiple decision and lastly using the principle of hierarchy composition to weight the criteria. Chang [22] has introduced method to prioritize decision variables compared with the conventional AHP which known as extent analysis. The extent analysis is referred as a consideration of the extent to satisfy the goal [18]. Mastura et al. [18] and Kwong and Bai [23] used Fuzzy AHP to prioritize the customer requirements in product design. Furthermore, Fuzzy AHP also used by Huang and Shen [19] to analyze the failure of service failure. Noor et al. [24] reviewed on the use Fuzzy AHP in solving problems with uncertainty judgement. In this study, Fuzzy AHP with extent analysis approach will be used to determine the material requirements of NFRC filament for FDM. Fuzzy AHP with extent analysis framework will help the decision maker which consists of the authors to decide which material requirements are most strongly vital over the other requirements.

2.0 METHODOLOGY

2.1 Fuzzy AHP

The methodology of Fuzzy AHP with extent analysis approach in weighting the material requirements of NFRC filament for FDM is proposed. Figure 1 shows the flow chart of material selection.

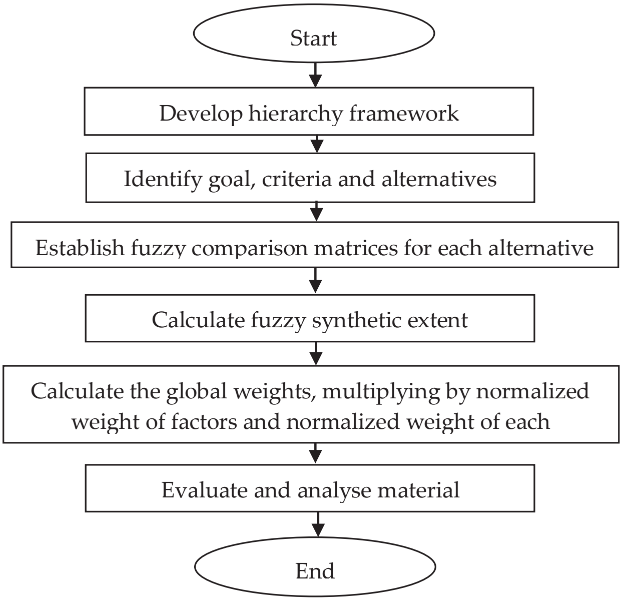

Figure 1: A flow chart of material selection

2.2 Stages in Fuzzy AHP

In this study, a three level of hierarchy framework was structured for weighting the material requirements. A hierarchy framework was developed to shows a systematic overview between goal and set of the criteria. Level 1 is set as the goal of decision making which is set as weighting the material requirements. Then, level 2 is the criteria that influenced the main goal. Finally, level 3 which is at the bottom level is the alternatives which able to fulfill the criteria and achieves the goal. There are three main criteria which are physical properties, chemical properties and mechanical properties. Then, there are nine alternatives which are density, diameter of fiber, cellulose, lignin, tensile strength, Young's modulus, specific tensile strength, specific Young's modulus and elongation at break. Figure 2 shows the structure of overall hierarchy framework.

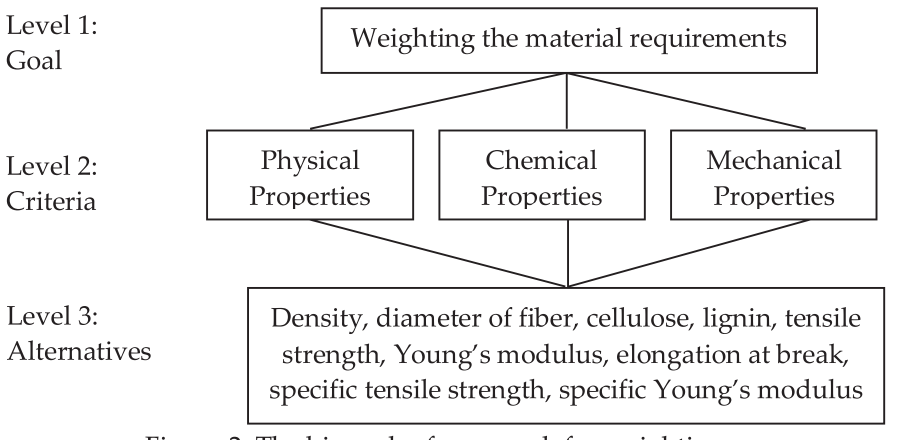

Figure 2: The hierarchy framework for weighting the material requirements

Performing a judgement by using pairwise comparison is the second stage after structure of hierarchy framework is completed. The pair-wise comparison is a measurement methodology which used to establish priorities among element within each level. The decision maker evaluates the criteria in a pairwise comparison with respect to the goal and the alternatives with respect to the criteria. The judgement in pairwise comparison made by decision maker are expressed verbally as equal, moderate, strong, very strong and extreme. The judgement is expressed in the scale of 1 to 9. Table 4 shows the relative pairwise scale used in pairwise decision-making process. The technique of triangular fuzzy number is used for Fuzzy AHP to represent the pairwise comparison.

Table 4: Crisp number and triangular fuzzy numbers used in weighting [12]

Intensity of Preference		
Crisp number	Triangular fuzzy number	Verbal definition
1	1, 1, 2	Equally preferred
2	1, 2, 3	Equally to moderately preferred
3	2, 3, 4	Moderately preferred
4	3, 4, 5	Moderately to strongly preferred
5	4, 5, 6	Strongly preferred
6	5, 6, 7	Moderately to very strongly preferred
7	6, 7, 8	Very strongly preferred
8	7, 8, 9	Moderately to extremely strongly
9	8, 9, 9	Extremely strongly preferred

Then, a triangular fuzzy comparison matrix is formed and expressed by Equation (1) such as

$$\widetilde{A} = (\tilde{a}_{ii})$$

$$= \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ \vdots & (1,1,1) & \cdots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & \cdots (1,1,1) \end{bmatrix} \quad (1)$$

where ãij=(lij,mij,uij) and ãij-1 =(1/uij,1/mij,1/lij) for i,j=1,…,n and i≠ j. The priority vector for Equation (1) was calculated using an extent analysis method from equations suggested by Chang [22].

Step 1: Each row of fuzzy comparison matrix A˜ is summed up by fuzzy arithmetic operations such as

$$RS_i = \sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right), i = 1, \ldots, n \quad (2)$$

Step 2: Wang et al. [25] suggested a normalization formula for a set of triangular fuzzy weights as in Equation (3) where

$$\widetilde{S}_1 = \frac{RS_i}{\sum_{j=1}^{n} RS_j}$$
$$= \left(\frac{\sum_{j=1}^{n} l_{mn}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} l_{kj}} \right),$$
$$i = 1, \cdots, n \quad (3)$$

Step 3: Roy et al. [26] used total integral value to deal with zero-weight problem found in Chang's method as shown in Equation (4) such as

$$J_T^{\alpha}(SE_j) = \frac{1}{2}\alpha(b_j + c_j) + \frac{1}{2}(1-\alpha)(a_j + b_j) = \frac{1}{2}\left[\alpha c_j + b_j + (1-\alpha)a_j\right] \quad (4)$$

Step 4: The normalized priority vector W = (w1, w2,…, wn) T, non-fuzzy number is calculated by Equation (5) as

$$w_j = \frac{J_T^{\alpha}(SE_j)}{\sum_{j=1}^{n} J_T^{\alpha}(SE_j)} \quad (5)$$

3.0 RESULTS AND DISCUSSION

Based on the hierarchy framework of the weighting material requirements, there are nine alternatives with respect to three criteria. Thus, there are three comparison matrix which are respect to physical, chemical and mechanical properties. Comparison matrices with respect to physical properties is shown as in Table 6.

From this comparison matrices, weights of the alternatives are calculated using Equations (2)-(5). The global weights are calculated and shown in Table 5, the most important material requirement is Young's modulus which is 0.1473 Wg whereas diameter is the least important for material requirement.

As mentioned by [21], Fuzzy AHP was used to measure the unquantifiable information. The triangular fuzzy comparison with extent analysis were used to weighting the material requirements. In addition, based on articles [18, 19, 24], they mentioned that Fuzzy AHP with extent analysis is much simpler in determining the weight vectors and the consistency in determining human judgements with imprecise and vague information. As a result, the importance weight for material requirements can be determined precisely since Fuzzy AHP with extent analysis able to capture the vagueness of human judgement.

Table 5: Global weight from Fuzzy AHP

Material requirements	Global weight (Wg)
Density	0.0841
Diameter	0.0689
Tensile strength	0.1454
Young's modulus	0.1473
Specific tensile strength	0.1095
Specific Young's modulus	0.1095
Elongation at break	0.1108
Cellulose	0.1122
Lignin	0.1122

Table 6: Comparison matrices with respect to physical properties

	Density	Diameter	Tensile strength	Young's modulus	Specific tensile strength	Specific Young's modulus	Elongation at break	Cellulose	Lignin
Density	1,1,1	0.17, 0.2,0.25	4,5,6	4,5,6	2,3,4	2,3,4	2,3,4	6,7,8	6,7,8
Diameter	4,5,6	1,1,1	4,5,6	4,5,6	2,3,4	2,3,4	2,3,4	4,5,6	4,5,6
Tensile strength	0.17, 0.2,0.25	0.17, 0.2,0.25	1,1, 1	0.25, 0.33, 0.5	0.17, 0.2, 0.25	0.17, 0.2, 0.25	0.25, 0.33, 0.5	0.25, 0.33, 0.5	0.25, 0.33, 0.5
Young's modulus	0.17, 0.2,0.25	0.17, 0.2,0.25	2,3,4	1,1,1	0.17, 0.2, 0.25	0.17, 0.2, 0.25	0.25, 0.33, 0.5	0.25, 0.33, 0.5	0.25, 0.33, 0.5
Specific tensile strength	0.25, 0.33, 0.5	0.25, 0.3, 0.5	4,5,6	4,5,6	1,1,1	1,1,1	2,3,4	2,3,4	2,3,4
Specific Young's modulus	0.25, 0.33, 0.5	0.25, 0.3, 0.5	4,5,6	4,5,6	1,1,1	1,1,1	2,3,4	2,3,4	2,3,4
Elongation at break	0.25, 0.33, 0.5	0.25, 0.3, 0.5	2,3,4	2,3,4	0.25, 0.33, 0.5	0.25, 0.33, 0.5	1,1,1	2,3,4	2,3,4
Cellulose	0.13, 0.14, 0.17	0.17, 0.2,0.25	2,3,4	2,3,4	0.25, 0.33, 0.5	0.25, 0.33, 0.5	0.25, 0.33, 0.5	1,1,1	1,1,1
Lignin	0.13, 0.14, 0.17	0.17, 0.2,0.25	2,3,4	2,3,4	0.25, 0.33, 0.5	0.25, 0.33, 0.5	0.25, 0.33, 0.5	1,1,1	1,1,1

4.0 CONCLUSION

The proposed material selection framework which is Fuzzy AHP technique was used in this study to identify the most important material requirement for NFRC filament based on nine alternatives. As the result, Young's modulus is selected as the important material requirements of NFRC with 0.1473 Wg. This indicates that Young's modulus is the most important material requirement in choosing

NFRC filament for FDM. The combination of Fuzzy AHP and extent analysis proved that this method gives a higher degree of confidence to the decision maker which could be applied in a similar NFRC material. Other than that, Fuzzy AHP able to capture the vagueness of human judgement by converted the decision maker linguistic assessment into a set of triangular fuzzy numbers.

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