Research Article

Multiple Decision Criterion for Material Selection by using Ranking System

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Abstract: Selecting a material for any application requires in depth knowledge on the part of specialist and selection of material is of vital importance in any industry, incorrect selection may lead to loss of equipment, machinery, money, and most importantly human lives. To circumvent this in decisiveness a relatively simple solution is presented basing on multi criteria decision making techniques. TOPSIS technique is utilized by considering multiple qualitative and quantitative criterions for a given set of materials and an alternative material is selected basing on the closeness between positive and negative ideal solution. Validation of the mathematical formulation was done by considering hybrid bio-composites of Glass fiber/ reinforced with thermoset polymers. The relationship between fiber length and the mechanical properties is studied, while TOPSIS algorithm is utilized in selecting the better material out of the given subset.

Key words: Bio-Composites, Material Selection, Multiple-Criteria Decision Making, Thermoset Resins.

1.Introduction

Increasing progress in the technological advancements leading to materials development with various properties, applications, merits, and demerits. Materials form basic building block of any component its functionality, the properties of the said material the one of the most important aspect in design and manufacturing The technical advancements have created a path for the newer materials which are proliferating in all demanding applications, laying accent on low cost, weight, and enhanced performance Some applications like automotive, aerospace, and marine requiring high strength, operating temperatures and low density are required in order to improve the any operating parameter . The material's choice for any given application requires deep knowledge, on the part of the design engineer. However, the bad design choices often lead to disastrous situations ensuing loss of life, property and drain on the economy. Ashby [2004] had reviewed the strategies that involved to deal selecting and subsequent screening the material for its process and progress. Edwards [2005] addresses the gap between knowledge and the quality of decision making. Thakkar [2008] discusses a hybrid material selection strategy by combining three methods: Cambridge material selector, adapted value engineering techniques and technique for order preference by similarity to ideal solution. Huang [2011] presents multicriteria decision making model and uncertainty analysis method for environmentally conscious material selection. Khorshidi [2005] employed TOPSIS and fuzzy TOPSIS method to rank the material for maximum tensile strength. Ghaseminejad [2011] used TOPSIS method for data enhancement analysis to solve facility layout problem with multiple objectives. Chakladar [2008] combines TOPSIS and AHP method to select the most appropriate nontraditional method for specific work, also developed expert systems to automate the decision-making process. Lin [2008] presents a framework that integrates AHP and TOPSIS method to assist the designer to identify the customer requirement, design characteristics to arrive at an ideal solution. Isiklar [2007] evaluated the mobile phone options with respect to the user preferences. Ashby [1993] implemented the material selection scheme by developing a software to display the material selection scheme, its properties, performance indices and the combination of material property which govern its performance. Ashby [2013] developed a framework for material selection in product design by rapid retrieving of the data about the material, process, and function to enhance the design process. Maniya [2010 implemented a tool to help the designer to select the material that will meet all the requirement of the decision makers. Shanian [2006] uses ELECTRE model in selecting a suitable material for a application of a loaded thermal conductor. Karanade [2013] uses two conceptual methods to solve material selection problem, a close match was obtained between the rankings. Zhou [2009] integrated ANN and GA to optimize the multi-objectives of material selection and the hypothesis was validated by a case study. Behzadian [2012] had reviewed 266 papers from 106 journals for nine different applications requiring multi-criterion decisions and formulated guideline for future academics for using these techniques. Yue [2011] presented a method to measure weights for decision making, a illustrated the hypothesis by a case study. The most popular technique available for the solution of multi criterion decision making problem is TOPSIS (Technique for order preference by similarity to ideal solution) method. This algorithm is efficient in dealing with properties and the number of alternatives material choices that need to be evaluated. An optimum design methodology was presented by combining the traditional TOPSIS method with the entropy method to rank the alternatives, Rajnish [2014]. A new weighting method based on the concept of combining eigen value with TOPSIS method and was found that this method was easy to implement in Excel and it was suitable for manufacturing industries, Tonghua [2016]. In another research, design of experiments was combined with evaluation based on distance from the average solution (EDAS) to solve material selection dilemmas in industries and the study revealed that this hybrid model is robust and could solve problems involving multi criteria decisions, Prasenjit, [2018]. Host of methods are available to solve multi criteria selection issue, these methods were combined, and the hybrid algorithm was implemented to select a material automobile wheels, Won- Chol Yong [2019]. In this method it is tactility assumed that the properties and the performance ratings are known, however in reality most of these conditions are not known, human judgements play a vital role in materials selection.

2. Mathematical Formulation

TOPSIS algorithm begins with determination and identifying the appropriate criteria, that is determining relevant attributes for a problem on hand and sorting the materials according to satisfying the designated attributes. The next step would be to formulate a decision matrix M with N number of distinct attributes in columns and having M as alternatives assigned as rows.

$$D_{ij} = \begin{bmatrix} X_{11} & \cdots & X_{1N} \\ \vdots & \ddots & \vdots \\ X_{1M} & \cdots & X_{MN} \end{bmatrix} \quad (1)$$

Then decision matrix must be normalized and rendering it dimensionless with the range from 0 to 1and the normalization can be obtained based on attributes criterion: beneficiary or non-beneficiary

$r_{ij}= X_{ij}/ X_j^{max}$larger the better for beneficial attributes (2)

and for non-beneficial attributes

$$r_{ij}= X_j^{min}/ X_{ij} \quad (3)$$

To obtain the normalized decision matrix it will required to obtain a projection of all alternatives Pij

$$P_{ij} = r_{ij}/ \sum_{i=1}^{m} r_{ij} \quad (4)$$

Theentropy for the j^{th} criterion can be obtained from

$$E_j = -k\sum_{j=1}^{m} P_{ij} \, lnP_{ij} \quad (5)$$

And k= 1/ln(M)

Now the normalized weight matrix must be determined from the decision matrix

$$[S_j] = E_j x \, r_{ij} \quad (6)$$

Next: To identify the best and worst solution based on weighted normalized rating

$$[A+] = [S_1^+, S_2^+, \ldots\ldots S_N^+] \quad \text{and} \quad [A-] = [S_1^-, S_2^- \ldots S_N^-] \quad (7)$$

$$\text{Where } [A+] = \begin{cases} max\, S_{ij} & if\ j\ is\ benificiary\ criterion \\ min\ S_{ij} & if\ j\ is\ non-benificiary\ criterion \end{cases}$$

$$\text{And } [A-] = \begin{cases} min\, S_{ij} & if\ j\ is\ benificiary\ criterion \\ max\, S_{ij} & if\ j\ is\ non-\ benificiary\ criterion \end{cases}$$

For j=1 to N

The distances Y are required for estimating the closeness index and are obtained from the normalized weight matrix, while the closeness index can be calculated from:

$$CI = \frac{Y^-}{Y^+ + Y^-} \quad (8)$$

Thus, the following the mathematical formulation, ranking the materials in the descending order of performance, indicating the most preferred solution.

To validate the formulation coir and chopped glass fiber, figure 1 material combinations were chosen, and they were assessed for its mechanical properties. Laminate was fabricated using hand lay-up technique and were post cured suitably. LY566, polymer resin while corresponding hardener HY951 was obtained from M/S Javanthee enterprise, Guindy. Chopped glass fiber was obtained from M/S S.T. Composites, Ambattur, Chennai.

The first step in any experimental work was to fabricate a laminate of size 300 mmx 300 mm having a thickness of 5 mm. The samples were machined according to standards, while the testing of the samples was conducted with standard equipment and at ambient conditions. The weight gain of the samples was estimated by immersing the samples for unto 264 hours. The samples were weighed for every 24 hours the percent weight gain was recorded.

a. Coconut Fiber Strands

b. Chopped Glass Fiber

Figure 1: Making of Bio-Composite.

To select the better material out of the given alternatives the laminates were fabricated according to the composition shown in table1. The variables were the fiber loading and the length of the fiber their influences on the mechanical properties were observed.

Table 1: Material Designation

Designation	Chemical Composition			
	Glass Fiber Content %	Coir Fiber Content %	Epoxy Content %	Fiber Length (mm)
D1	20	5	75	5
D2	20	5	75	10
D3	20	5	75	15
D4	20	5	75	20
D5	20	10	70	5
D6	20	10	70	10
D7	20	10	70	15
D8	20	10	70	20

3. Results

In this work the most appropriate material must be selected amongst the set of alternatives with the chemical compositions as indicated in table 1. The results of the mechanical characterization and water absorption data in table 2. It can be observed that, by increasing the fiber content and length led to the improvement of the mechanical properties but the water absorption percent increased while the density decreased. These results are utilized in computing the decision matrix and finally determining the better material system. Table 3 represents for selection of the properties. The decision matrix can be formulated basing on the attributes provided in Table 3 containing six attributes. Experimental results were used in formulating decision matrix, refer table 4. The normalized decision matrix has been prepared basing on the equations 6 and 7 in Fig. 1 and weighted normalized matrix presented in figure. 2. The ideal and the non-ideal solution matrix in figure 3 while the distances are presented in figure.4. The ranking of the designated composites is presented in table 5 basing on the closeness index.

Table 2: Results of Mechanical Properties and Water Absorption Content

Sl. No	Designation	Mechanical Characterization				Water Absorption PERCENT
		Tensile Strength	Flexural Strength	Hardness HV	Density	
1	D1	18.473	52.644	17.65	2.547	6.225
2	D2	19.439	62.410	21.90	2.528	6.676
3	D3	20.412	68.59	22.65	2.527	7.471
4	D4	18.178	64.162	23.00	2.524	7.785
5	D5	18.073	62.959	23.00	2.527	8.345
6	D6	19.834	66.645	19.85	2.770	8.504
7	D7	21.208	75.606	22.50	2.499	8.781
8	D8	15.793	69.135	23.55	2.485	9.455

Table 3: Selected Criterion of the Attributes

Sl. NO	Attributes	Selection Criteria
1	Tensile Strength	Beneficial (Better if high)
2	Flexural Strength	Beneficial (Better if high)
3	Hardness	Beneficial (better if high)
4	Density	Beneficial (Better if low)
5	Water Absorption	Not Beneficial (Better if low)

Table 4: Decision Matrix

Sl. NO	Designation	Mechanical Characterization				Water Absorption Percent
		Tensile Strength	Flexural Strength	Hardness HV	Density	
1	D1	18.473	52.644	17.65	2.547	6.225
2	D2	19.439	62.410	21.90	2.528	6.676
3	D3	20.412	68.59	22.65	2.527	7.471
4	D4	18.178	64.162	23.00	2.524	7.785
5	D5	18.073	62.959	23.00	2.527	8.345
6	D6	19.834	66.645	19.85	2.770	8.504
7	D7	21.208	75.606	22.50	2.499	8.781
8	D8	15.793	69.135	23.55	2.485	9.455

$$\begin{bmatrix} D1 & 0.439 & 0.365 & 0.385 & 0.461 & 0.346 \\ D2 & 0.460 & 0.432 & 0.464 & 0.456 & 0.372 \\ D3 & 0.482 & 0.473 & 0.484 & 0.455 & 0.421 \\ D4 & 0.432 & 0.43 & 0.506 & 0.454 & 0.440 \\ D5 & 0.430 & 0.436 & 0.308 & 0.455 & 0.475 \\ D6 & 0.469 & 0.460 & 0.429 & 0.453 & 0.484 \\ D7 & 0.500 & 0.519 & 0.476 & 0.447 & 0.501 \\ D8 & 0.401 & 0.476 & 0.522 & 0.443 & 0.543 \end{bmatrix}$$

Figure 2: Normalized Decision Matrix.

D1	0.077868	0.063199	0.06711	0.082380	0.059249
D2	0.082189	0.076472	0.082975	0.081201	0.064426
D3	0.086527	0.084662	0.086941	0,081140	0.74209
D4	0,076566	0.078794	0.091303	0.080959	0,078108
D5	0.076097	0,077201	0.051643	0.081171	0.085063
D6	0.083952	0.082085	0.075836	0.080717	0.0869906
D7	0.090077	0.09396	0.085354	0.079448	0.090316
D8	0.07376	0.085385	0.094476	0.078608	0.098607

Figure 3: Weighted Matrix.

best solution	0.090	0.0939	0.0944	0.0786	0.0592
least preffered solution	0.0703	0.06319	0.0516	0.0823	0.0986

Figure 4: Preferred Solution.

D1	0.0531	0.0529
D2	0.0331	0.05967
D3	0.0296	0.0506
D4	0.0379	0.0577
D5	0.0446	0.0303
D6	0.0459	0.0455
D7	0.0423	0.0404
D8	0.0548	0.0538

Figure 5: Distances Between Solutions.

Table 5: Ranking of the Composites Basing on Closeness Index

Designation	Closeness Index	Ranking
D1	0.59905	7 th
D2	0.78250	2nd
D3	0.82044	1st
D4	0.73021	3rd
D5	0.37131	8th
D6	0.59712	6th
D7	0.70914	4th
D8	0.61901	5th

4. Conclusions

Composite laminate was fabricated using wet lay-up technique requiring a minimum tooling and effort in different combinations by using natural fiber namely coir and chopped glass fiber with a thermoset resin. All the samples were characterized for various mechanical properties utilizing the standard equipment at ambient conditions to address the issue multi-criteria based selecting a material with given set of attributes in any subset of given material combinations. Here TOPSIS methodology was utilized in selecting the better alternative form a given set of material compositions. The weights of selected criteria have been determined by entropy method. To test this formulation the physical, mechanical properties hybrid bio-composite made from the combination of coir and short glass fiber, was utilized. It can be concluded that 5 % weight loading has the optimum properties and can be used in different applications such as in automotive as well as in civil construction. This method has tremendous scope in the areas which require multiple criteria of decision-making applications.

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