Thermoplastic materials selection using VIKOR method for automotive part

M.A. Shaharuzaman[1,2,3,4], S.M. Sapuan[1,3,*], M.R. Mansor[2,4] and M.Y.M. Zuhri[1]

[1)] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2)] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3)] Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[4)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: sapuan@upm.edu.my

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ABSTRACT – The enforcement on emissions that need to comply by automotive manufacturers has open the market to study the alternative materials such as natural fiber composites (NFCs) that can replace metal based part. The objective of this paper is to find the best thermoplastic material to be the matrix of biocomposites for the automotive part. This paper presents the strategy on using multiple criteria decision making (MCDM) namely VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) in determining the thermoplastic materials as the matrix in biocomposites. Four criteria, six subcriteria and seven alternatives involve in this analysis. The result from VIKOR method shows that polypropylene (PP) with the least VIKOR values, Q is the best matrix to be the NFCs compared to others. This study shows that VIKOR method can solve the multi criteria problems with systematic strategies in finding the ideal solution for the multi criteria problems.

1. INTRODUCTION

In last decades, researchers and engineers are moving towards to produce environmentally friendly product mostly natural fiber composites (NFC) to overcome the metal based product. The current interest in automotive industry is to replace the metal based part to natural fiber reinforced polymers (NFRP). This is because of the lightweight of the composites compared to the current metal based product. Reducing the weight of vehicles can improve fuel efficiency and reduce emissions [1] while the automotive industry need to follow the Regulation (EC) No 443/2009 in limits of 95g CO_2/km by 2020 [2].

In product development, Pugh lists six (6) step where it starts from market investigation, product design specification, conceptual design, detail design, manufacture and selling the product [3]. For natural fiber composites design and development, Sapuan implemented the total design by Pugh in realizing the product development process [4]. Instead, Sapuan introduce preconcept generation in designing a composites product and shared the strategies in concept generation for composites product [5]. Mansor et. al share their strategies in material selection and conceptual design for natural fiber composites that can be develop in concurrent engineering design to reduce cost and time while increase the quality of the product developed [6-7].

In this paper, one of the preconcept generation idea is to develop the automotive part for thermoplastic materials using multiple criteria decision making (MCDM) which is VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The objective is to find the closeness to ideal solution of matrix material for a biocomposite parts depending on the product design specification selected with their sub-categories. By using VIKOR method, it presents very practical and systematic tool in completing the criteria needed, and simultaneously meet the objective to solve the MCDM problems.

2. RESEARCH METHODOLOGY

The product design specifications are shown in Figure 2.1 where it will be the criteria and subcriteria for the design specification with seven (7) alternatives of matrix with their properties as in table 2.1 which is polypropylene (PP), low density polyethylene (LDPE), high density polyethylene (HDPE), polystyrene (PS), polyamide 6 (PA6), polyamide 6,6 (PA66) and thermoplastic polyurethane (TPU) will be analyze using the VIKOR method.

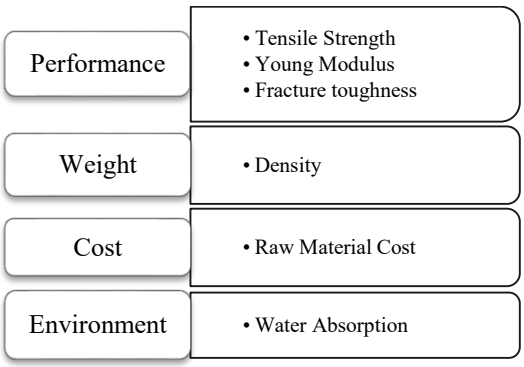

Figure 2.1 Product Design Specification

Table 2.1 Material properties for thermoplastic matrix [8].

*	TS	YM	FT	D	C	WA
PP	36.2-49.0	1.60-1.78	2.30-2.42	0.900-0.909	2.14-2.36	0.00975 -0.0103
LDPE	13.3-26.4	0.172-0.283	1.21-3.39	0.917-0.932	1.78-1.98	0.005-0.010
HDPE	22.1-31.0	1.07-1.09	1.52-1.82	0.952-0.965	1.76-1.98	0.005-0.010
PS	35.9-51.7	2.28-3.28	0.70-1.10	1.04-1.05	2.14-2.35	0.01-0.03
PA6	64.7-79.1	1.58-1.97	3.43-3.80	1.14-1.16	4.54-4.99	0.80-1.30
PA66	58.5-71.5	1.33-1.65	3.32-3.66	1.13-1.15	4.23-4.65	0.62-1.00
TPU	41.3-47.9	1.31-2.07	1.59-1.68	1.13-1.15	5.55-6.11	0.20-0.22

*TS: tensile strength (MPa), YM: Young modulus (GPa), FT: fracture toughness (MPa.m$^{1/2}$), D: density (g/cm^3), C: Cost (USD/kg), WA: water absorption

2.1 VIKOR [9]

The term of VIKOR is derived from Serbian, VIseKriterijumska Optimizacija I Kompromisno Resenje, which means Multicriteria Optimization and Compromise Solution. The method further developed by Opricovic and Tzeng, starting from the L_p-metric [10][11], as per Equation (1.1).

$$L_{pi} = \left\{ \sum_{j=1}^{n} \left[w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right]^p \right\}^{1/p}, \quad 1 \le p \le +\infty; i = 1, 2, \dots I \tag{1.1}$$

The VIKOR method compare and analyze the ranking of multiple criteria based on the measurement of closeness to ideal solution, where it can provide a maximum group utility for the majority and a minimum of an individual regret for the opponent [12]. The flowchart of the VIKOR method shows in figure 2.2 and the equation involve in the calculation are from Equation (1.2) until equation (1.6).

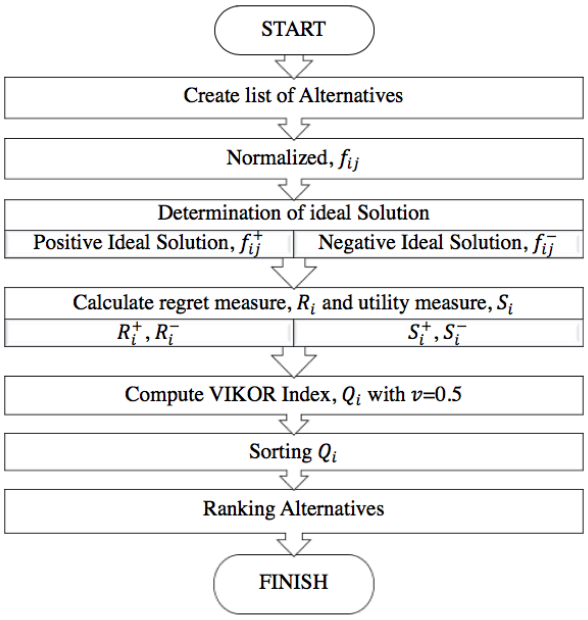

Figure 2.2 Product Design Specification

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{1.2}$$

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}, \; i = 1, 2, \dots, m; j = 1, 2, \dots, n \tag{1.3}$$

$$S_i = \sum_{j=1}^{n} w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \tag{1.4}$$

$$R_i = max \; w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \tag{1.5}$$

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*} \right] \tag{1.6}$$

The weight of criteria w_j in equation 4 and 5 will used the previous study from author [13] and recalculate depends on the criteria used in this study. The weightage of performance is 0.4284, weight is 0.2064, cost is 0.2315 and environment is 0.1337. In equation 6, v represents the weight of strategy or majority criteria was set at 0.5 value. Finally, after the analysis was done, the VIKOR value, Q_i will be sort in descending order where the least value will represent the best choice of thermoplastic matrix material to be the matrix for biocomposites of automotive part.

3. RESULTS AND DISCUSSION

The results of normalize values for the analysis are shown in table 3.1. The calculation of the normalize value used equation 1 and then the positive and negative ideal solutions need to determine as in the table.

Table 3.1 Normalized values, positive ideal solution and negative ideal solution of the matrix.

Criteria		TS	YM	FT	D	C	WA
Weights		0.1428	0.1428	0.1428	0.2064	0.2315	0.1337
Alternatives	PP	0.3345	0.3776	0.3295	0.328	0.2327	0.0075
	LDPE	0.1559	0.0508	0.3211	0.3352	0.1945	0.0056
	HDPE	0.2085	0.2413	0.2332	0.3476	0.1914	0.0056
	PS	0.344	0.6212	0.1257	0.3789	0.2322	0.0149
	PA6	0.5646	0.3966	0.5047	0.417	0.4929	0.7819
	PA66	0.5104	0.3329	0.4873	0.4134	0.4593	0.6032
	TPU	0.3502	0.3776	0.4754	0.4134	0.603	0.1564
f_j^*		0.5646	0.6212	0.5047	0.3280	0.1914	0.0056
f_j^-		0.1559	0.0508	0.1257	0.4170	0.6030	0.7819

Table 3.2 shows the results of regret measure, R and utility measure S from the calculation using equation 4 and equation 5. The results for the objective of this study is VIKOR value Q using equation 6. The VIKOR value, Q need to be sort in descending order where the least value will rank in first and the highest value in the last. From table 3.2 with the ranking number, it shows that polypropylene (PP) gives the least Q value which is the ideal solution of the outcome in this MCDM problem. High density polyethylene (HDPE) rank in the second place while low density polyethylene (LDPE) in number four with the Q value of 0.3291 and 0.3980 respectively.

Polystyrene (PS) in number three with 0.3834 Q value. Polyamide 6 (PA6) and polyamide 6,6 (PA66) in fifth and sixth place with 0.8180 and 0.8677 Q value respectively. thermoplastic polyurethane (TPU) is the worst matrix material if it needs to be composites with natural fiber for automotive parts compared to the other six materials.

Table 3.2 Results of R, S, Q and their ranking

Alternatives	S_i		R_i		Q_i	Rank
PP	0.2309		0.0804		0.0000	1
LDPE	0.3732		0.1428		0.3980	4
HDPE	0.3673		0.1244		0.3291	2
PS	0.3624		0.1428		0.3834	3
PA6	0.5659		0.2064		0.8677	6
PA66	0.5494		0.1981		0.8180	5
TPU	0.6025		0.2315		1.0000	7
	S_{max}	0.2309	R_{max}	0.0804		
	S_{min}	0.6025	R_{min}	0.2315		

4. CONCLUSION

This study revealed that VIKOR method can solve the multi criteria problems using their systematic strategies in finding the ideal solution for the multi criteria problems. In this project, polypropylene (PP) have been discovered as the best matrix material that close to the ideal solution by VIKOR method where it results in least Q value compared to others. Finally, polypropylene (PP) is suggested to be composites with the natural fiber materials depending on the four categories and six sub-categories of product design specification that have been chosen in the earlier stage of this product development study for automotive part.

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