APPLICATION OF FUZZY VIKOR IN AUTOMOTIVE BRAKE PAD MATERIAL

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ABSTRACT

Multi Criteria Decision Making methods is one of the most common methods used to determine the most appropriate material. In the decision making process, there are dissimilarities to elicit, specify and analyse the information on alternatives, criteria and relative significance of the criteria. Fuzzy set has been utilised in Multi Criteria Decision Making methods to optimise the method and created an extended approach to deal with uncertainty and increase the accuracy of decision making. As for many years' asbestos was viewed as having an optimal performance as a brake pad. However, this material has been banned by the Environmental Protection Agency. Due to the increasing awareness on environmental impact and subsequently the need towards sustainability, selection of the appropriate material for a brake pad that complies with the environment and regulations is vital and natural fibre reinforced composite has potential to replace the asbestos in the automotive brake pad application. Therefore, the objective of this study is to apply the Fuzzy VIKOR to select the best natural fibre reinforced composite for the automotive brake pad to replace the asbestos. Four alternatives of natural fibre reinforced composite with five criteria have been evaluated by three decision maker. The results of the Fuzzy VIKOR shows that the date palm fibre is selected as the best material for the automotive brake pad.

***KEYWORDS**: Material selection; Fuzzy VIKOR; MCDM; Brake pad*

1.0 INTRODUCTION

Material selection is one of the crucial processes in engineering design to fulfil the requirement in product design. Multi Criteria Decision Making (MCDM) methods is one of the material selection process that has many different methods such as the elimination and et choice translating reality (ELECTRE) method, Vlse kriterijumska optimizacija kompromisno rejense (VIKOR) method, technique for order preference by similarity to ideal solution (TOPSIS) method, analytical hierarchy process (AHP) and preference

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ranking organisation method for enrichment of evaluations (PROMETHEE) and many more. However, there are dissimilarities to elicit, specify and analyse the information on alternatives, criteria and relative significance of the criteria (Belton and Stewart, 2002). Therefore, Fuzzy set has been utilised in MCDM methods to optimise the MCDM methods and created an extended approach to deal with uncertainty and increase the accuracy of decision making (Asemi et al., 2014), especially in the material selection process.

There are several studies examining material selection that extend the MCDM method with fuzzy sets. Ishak et al., (2017) studied the selection of thermoplastic matrix for fibre metal laminate using Fuzzy VIKOR and entropy. Anojkumar et al., (2014) studied the pipe material selection in sugar industry using the Fuzzy AHP. Rathod and Kanzaria, (2011) studied the material selection of solar domestic hot water system using Fuzzy TOSIS. Yang et al., (2017) studied the material selection for automotive products design using Fuzzy TOPSIS. Xue et al., (2016) studied the material selection for the automotive instrument panel using Fuzzy MABAC. Ishak et al., (2016) studied the material selection of natural fibre reinforced composites using Fuzzy VIKOR for car front hood.

Brake is a device that stops motion. For many years asbestos was viewed as having an optimal performance as a brake pad. However, this material has been banned by the Environmental Protection Agency (EPA) as this material is very poisonousness and could affect human health and the environment (Ramazzini, 2010). Due to the increasing awareness on environmental impact and subsequently the need towards sustainability, selection of the appropriate material for a brake pad that complies with the environment and regulations is vital. Nowadays, natural fibre reinforced composite have gained interest among researchers due to its potential in reducing weight, cost-effective, environmentally friendly, a renewable source, biodegradable and recyclable (Tong et al., 2017). Natural fibre reinforced composite has high possibility to substitute the asbestos. Therefore, the objective of this study is to apply the Fuzzy VIKOR to select the best natural fibre reinforced composite for the automotive brake pad to replace the asbestos.

2.0 METHODOLOGY

2.1 Fuzzy VIKOR

VIKOR is the Serbian abbreviation which stands for “Vlsekriterijumska Optimizacija I Kompromisno Resenje” which means Multi Criteria Optimization and Compromise Solution method. Integration of VIKOR; one of the MCDM methods with Fuzzy set produced Fuzzy VIKOR method. To utilise the Fuzzy set, linguistic variables constitute evaluation were used to calculate the importance of criteria and the ratings of alternatives with various respects to various criteria. Table 1 shows the linguistic terms and their corresponding fuzzy numbers. Linguistic terms will be used by the decision maker to evaluate the respective alternatives and criteria. Trapezoidal fuzzy numbers were implemented since this function can perform calculation easily

Table 1: Linguistic terms and corresponding fuzzy numbers for each criterion and alternatives

Linguistic variable for criteria	**Linguistic variable for alternatives**	**Fuzzy number**
Unimportant (UI)	Very poor (VP)	(0.0, 0.0, 0.1, 0.2)
Low importance (LI)	Poor (P)	(0.1, 0.2, 0.2, 0.3)
Slightly important (SI)	Medium poor (MP)	(0.2, 0.3, 0.4, 0.5)
Moderate importance (MI)	Fair (F)	(0.4, 0.5, 0.5, 0.6)
Important (I)	Medium good (MG)	(0.5, 0.6, 0.7, 0.8)
Very important (VI)	Good (G)	(0.7, 0.8, 0.8, 0.9)
Extremely important (EI)	Very good (VG)	(0.8, 0.9, 1.0, 1.0)

The membership function is determined

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-n_1}{n_2-n_1}, & x \in [n_1, n_2] \\ 1, & x \in [n_2, n_3] \\ \left(\dfrac{n_4-x}{n_3-n_4}\right) & x \in [n_3, n_4] \\ 0 & x \in \textit{Otherwise} \end{cases} \tag{1}$$

The aggregated fuzzy weight w_j of each criterion

$$Wj_j^s = \{W_{j1}^s; W_{j2}^s, W_{j3}^s, W_{j4}^s\} \tag{2}$$

Where,

$W_{j1}^s = \min\{W_{jk1}^s\}$

$W_{j2}^s = \frac{1}{k}\sum W_{jk2}^s$

$W_{j3}^s = \frac{1}{k}\sum W_{jk3}^s$

$W_{j4}^s = \max\{W_{jk4}^s\}$

$k = \textit{decision makers}$

The aggregated fuzzy ratings x_{ij} of alternatives with respect to each criterion

$$X_{ij} = \{X_{ij1}; X_{ij2}, X_{ij3}, X_{ij4}\} \tag{3}$$

where,

$X_{ij1} = \min\{X_{ijk1}\},$

$$X_{ij2} = \frac{1}{k}\sum X_{ijk2}$$
$$X_{ijk3} = \frac{1}{k}\sum X_{ijk3}$$
$$X_{ijk4} = \max\{X_{ijk4}\}$$
$$k = decision\ makers$$

Defuzzify the fuzzy decision matrix and fuzzy weight of each criterion into crisp value

$$Defuzz(X_{ij}) = \frac{\int \mu(x).xdx}{\int \mu(x)dx}$$
$$= \frac{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right).xdx + \int_{x_{ij2}}^{x_{ij3}} xdx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x_{ij4} - x}{x_{ij4} - x_{ij3}}\right).xdx}{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right)dx + \int_{x_{ij2}}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right)dx}$$
$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}(x_{ij4} - x_{ij3})^2 - \frac{1}{3}(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}} \quad (4)$$

The best f_j^* and the worst f_j^- value of all criterion ratings

$$f_i^* = \max\{f_{ij}\} \quad (5)$$
$$f_i^- = \min\{f_{ij}\} \quad (6)$$

The utility (S_i), regret (R_i) and VIKOR index (Q_i)

$$S_i = \sum_{j=1}^{n} \frac{w_j^s\left(f_i^* - f_{ij}\right)}{\left(f_i^* - f_i^-\right)} \quad (7)$$
$$R_i = \max_i\left(\frac{w_j^s\left(f_i^* - f_{ij}\right)}{\left(f_i^* - f_i^-\right)}\right) \quad (8)$$
$$Q_i = \left(\frac{v(s_i - s^*)}{s^- - s^*}\right) + \frac{(1-v)(R_i - R^*)}{R^- - R^*} \quad (9)$$

Compromise solution if and only satisfy two conditions **1** and **2** are satisfied. The set of compromise solutions are composed of:

Condition 1: *Acceptable advantage*: $Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m-1)$, where $A^{(2)}$ is the second position in the alternatives ranked by Q.
Condition 2: *Acceptable stability in decision making*: Alternative $A^{(1)}$ must also be the best ranked by *S* or/and *R*. When one of the conditions is not satisfied, a set of compromise solution is selected. The set of compromise solutions are composed of:

(1) Alternatives $A^{(1)}$ and $A^{(2)}$ if only **Condition 2** is not satisfied (or)
(2) Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(m)}$ if **Condition 1** is not satisfied. $A^{(M)}$ is calculated using the relation $Q(A^{(M)}) - Q(A^{(1)}) < 1/(m-1)$ for maximum M.

3.0 CASE STUDY

Four (4) alternatives of natural fibre reinforced composite have been designated for the automotive brake pad to replace the asbestos which are palm kernel fibre (M1), date palm fibre (M2), sisal fibre (M3) and bamboo fibre (M4). Five (5) criteria; coefficient of friction (C1), thermal conductivity (C2), hardness (C3), tensile strength (C4) and wear (C5) will be evaluated by three (3) decision makers (DM). Table 2 shows the mechanical properties of the candidate materials.

Table 2: Mechanical properties of the candidate materials

	Coefficient of friction (μ)	**Thermal Conductivity ($W.m^{-1}.K^{-1}$)**	**Hardness (h)**	**Tensile Strength (MPa)**	**Wear (%)**
Palm Kernel Fibre	0.33	0.70	30	28.7	4.0
Date Palm Fibre	0.32	0.74	54.2	37.2	2.0
Sisal Fibre	0.43	0.25	52	36.6	1.4
Bamboo Fibre	0.31	0.20	22.3	26.4	3.0

Through linguistic terms, decision makers determine the importance of each criterion and then analyse and evaluate each alternative with respect to evaluation criteria. Table 3 and Table 4 shows the linguistic variables and the fuzzy value assessed by the decision makers.

Table 3: Importance weight of criteria assessed by decision makers (linguistic variable)

	C1	C2	C3	C4	C5
DM 1	VI	E	I	I	VI
DM 2	VI	VI	VI	I	E
DM 3	VI	E	I	I	E

Table 4: Importance weight of criteria assessed by decision makers (fuzzy value)

	C1	C2	C3	C4	C5
DM 1	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
DM 2	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)
DM 3	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)

Based on Equation 2, Table 5 shows the aggregated fuzzy value of natural fibre criterion weights assessments.

Table 5: The aggregated fuzzy value of natural fibre criterion weights assessments

	C1	C2	C3	C4	C5
W	VI	E	I	I	VI

Table 6 and 7 shows the evaluation of the decision makers on the importance of material with respect to criteria of the automotive brake pad.

Table 6: Importance of material with respect to criteria (linguistic variable)

		C1	C2	C3	C4	C5
DM 1	**M1**	MG	MG	F	MP	MP
	M2	MG	MG	G	F	MG
	M3	G	F	G	F	G
	M4	MG	F	MP	MP	F
DM 2	**M1**	F	G	P	F	F
	M2	F	G	F	F	G
	M3	MG	P	F	F	G
	M4	F	P	P	F	F
DM 3	**M1**	G	G	G	MG	MG
	M2	G	G	G	MG	MG
	M3	G	MG	G	MG	G
	M4	G	MG	G	MG	MG

Table 7: Importance of material with respect to criteria (fuzzy value)

		C1	C2	C3	C4	C5
DM 1	M1	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.2, 0.3, 0.4, 0.5)	(0.2, 0.3, 0.4, 0.5)
	M2	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	M3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
	M4	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.2, 0.3, 0.4, 0.5)	(0.2, 0.3, 0.4, 0.5)	(0.4, 0.5, 0.5, 0.6)
DM 2	M1	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.1, 0.2, 0.2, 0.3)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)
	M2	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
	M3	(0.5, 0.6, 0.7, 0.8)	(0.1, 0.2, 0.2, 0.3)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
	M4	(0.4, 0.5, 0.5, 0.6)	(0.1, 0.2, 0.2, 0.3)	(0.1, 0.2, 0.2, 0.3)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)
DM 3	M1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	M2	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	M3	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	M4	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)

The aggregated fuzzy value for the importance of material with respect to criteria assessments was calculated using Equation 3.

Table 8: The aggregated fuzzy value of the importance of material with respect to criteria assessments

	C1	C2	C3	C4	C5
M1	(0.4, 0.63, 0.67, 0.9)	(0.5, 0.73, 0.77, 0.9)	(0.1, 0.50, 0.50, 0.9)	(0.2, 0.47, 0.53, 0.8)	(0.2, 0.47, 0.53, 0.8)
M2	(0.4, 0.63, 0.67, 0.9)	(0.4, 0.73, 0.77, 0.9)	(0.4, 0.70, 0.70, 0.9)	(0.4, 0.53, 0.57, 0.8)	(0.5, 0.67, 0.73, 0.9)
M3	(0.4, 0.63, 0.73, 0.9)	(0.1, 0.43, 0.47, 0.8)	(0.4, 0.70, 0.70, 0.9)	(0.4, 0.53, 0.57, 0.8)	(0.7, 0.80, 0.80, 0.9)
M4	(0.4, 0.63, 0.67, 0.9)	(0.1, 0.43, 0.47, 0.8)	(0.1, 0.43, 0.47, 0.9)	(0.2, 0.43, 0.53, 0.8)	(0.4, 0.53, 0.57, 0.8)

The aggregated fuzzy value for the weight and importance of material with respect to criteria assessments were then defuzzified to derive their crisp value using Equation 4 shown in Table 9. Table 9: Crisp value for weight and importance of material ratings

	C1	C2	C3	C4	C5
W	0.08	0.87	0.70	0.65	0.87
M1	0.65	0.72	0.50	0.50	0.50
M2	0.65	0.69	0.67	0.58	0.70
M3	0.72	0.45	0.67	0.58	0.80
M4	0.65	0.45	0.48	0.50	0.58

Then, the best value f_j^* and worst value f_j^- of crisp material values are identified and they are shown in Table 10.

	C_1	C_2	C_3	C_4	C_5
f^*	0.72	0.72	0.67	0.58	0.80
f^-	0.65	0.45	0.48	0.50	0.50

Utility index (S_i) and regret index (R_i) were then defined using Equation 7 and Equation 8. The comprehensive utility value or the VIKOR value (Qi) was calculated using Equation 9. Table 10 shows the utility, regret measure and VIKOR index value. The value of v is taken as 0.5 to avoid bias (Mandal et al., 2015).

Table 10: Utility, regret measure and VIKOR index value

	(S_i)	(R_i)	(Qi)
M1	2.95	0.87	0.87
M2	0.87	0.80	0.06
M3	1.20	0.87	0.50
M4	3.65	0.87	1.00

Rank the preferences in an ascending order to determine the best alternatives as per the VIKOR method; the smallest alternative value was determined to be the best solution. Table 11 shows the ranking of the material.

Table 11: ranking of the natural fibre reinforced composite

	1	2	3	4
(S_i)	M2	M3	M1	M4
(R_i)	M2	M1, M3 & M4	-	-
(Qi)	M2	M3	M1	M4

Both conditions are satisfied in this context; therefore, the material with least VIKOR index which is M2 which is date palm fibre is selected as the best material for the automotive brake pad.

4.0 CONCLUSION

Based on the result of the Fuzzy VIKOR analyses, the ascending rank suggested that M2 has the best criteria among the other four candidate materials. M2 (date palm fibre) has been selected as the best natural fibre by satisfying both Conditions 1 and Condition 2 with validation using least VIKOR index, where the M2 has the lowest VIKOR index (Qi) value which is 0.06. M3 (sisal fibre) was in the second ranking with 0.50 scores, followed by M1 (kernel palm) with 0.87 scores and M4 (bamboo fibre) is the last choice of natural fibre in the automotive brake pad to replace the asbestos with the 1.00 scores.

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