Journal of Engineering Science and Technology
Vol. 12, No. 10 (2017) 2792 - 2804

THERMOPLASTIC MATRIX SELECTION FOR FIBRE METAL LAMINATE USING FUZZY VIKOR AND ENTROPY MEASURE FOR OBJECTIVE WEIGHTING

N. M. ISHAK, D. SIVAKUMAR*, M. R. MANSOR

Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
*Corresponding Author: sivakumard@utem.edu.my

Abstract

The purpose of this study is to define the suitable thermoplastic matrix for fibre metal laminate for automotive front hood utilisation. To achieve the accurate and reliable results, the decision making process involved subjective and objective weighting where the combination of Fuzzy VIKOR and entropy method have been applied. Fuzzy VIKOR is used for ranking purpose and entropy method is used to determine the objective weighting. The result shows that polypropylene is the best thermoplastic matrix for fibre metal laminate by satisfying two compromise solutions with validation using least VIKOR index value scored 0.00, compared to low density polyethylene, high density polyethylene and polystyrene. Through a combination of Fuzzy VIKOR and entropy, it is proved that this method gives a higher degree of confidence to the decision maker especially for fibre metal laminate thermoplastic matrix selection due to its systematic and scientific selection method involving MCDM.

Keywords: Fuzzy VIKOR, Entropy, Thermoplastic matrix, Fibre metal laminate, Automotive front hood.

1. Introduction

FML is a hybrid composite material consisting of interlacing layers of thin metals sheets bonded to fibre reinforced composite. FML combine metals' characteristics such as ductility, impact and damage tolerances with fibres' performance such as high specific strength, high specific stiffness and fatigue resistance [1] which often applied in the military applications, aerospace structures, automotive industries, etc. Dou *et al*. [2] conducted finite element analysis on two aluminium based FMLs

Nomenclatures

A	Alternative
C	Criteria
DM	Decision maker
d_{iv}	Degree of divergence
e	Entropy value
f_{ij}	Performance value of *i* according to j^{th} criteria
f_i^*	Best value of *i*
f_i^-	Worst value of *i*
k	Number of decision maker
m	Number of alternatives
n	Number of criteria
Pij	Projection value of *i* according to j^{th} criteria
Q	VIKOR index value
R_i	Regret value of *i*
R^*	Best regret value of *i*
R^-	Worst regret value of *i*
Si	Utility value of *i*
S^*	Best utility value of *i*
S^-	Worst utility value of *i*
T melt	Melting temperature, ˚C
U_{ij}	Decision matrix value of i according to j^{th} criteria
v	Index value
W_j^o	Objective weight according to j^{th} criteria
W_i^s	Subjective weight according to j^{th} criteria
X_{ij}	Aggregated fuzzy rating

Greek Symbols

$\mu_{\tilde{A}}(x)$	Membership function

Abbreviations

AHP	Analytic Hierarchy Process
ARALL	Aramid Fibre Reinforced Aluminium Laminate
CARE	Carbon Fibre Reinforced Aluminium Laminate
CFP	Carbon Fibre Prepreg
FAHP	Fuzzy Analytic Hierarchy Process
FML	Fibre Metal Laminate
GLARE	Glass Fibre Reinforced Aluminium Laminate
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
MCDM	Multiple Decision Criteria Making
PMC	Polymeric Matrix Composite
PP	Polypropylene
PS	Polystyrene
PROMETHEE	Preference Ranking Organisation Method for Enrichment of Evaluations
VIKOR	Vlsekriterijumska Optimizacija I Kompromisno Resenje

WA	Water Absorption
Linguistic terms	
EI	Extremely Important
F	Fair
G	Good
LI	Low Importance
MG	Medium Good
MP	Medium Poor
MI	Moderate Important
N	Neutral
NI	Not at all Important
P	Poor
SI	Slightly Important
VG	Very Good
VI	Very Important
VP	Very Poor

with fibre reinforced composites and the results showed that the high stiffness of the reinforcement constrains the flow of the matrix in the composite layer, which could attribute to the different behaviour of the FMLs compared to the monolithic aluminium alloy. The most commercially available metal for FML is aluminium and most common fibres used are aramid or glass [3] that produce high fatigue resistance FMLs' family such as; ARALL, GLARE and CARE.

FML, as shown in Fig. 1, provides excellent mechanical properties, such as high fatigue resistance, high strength, high fracture toughness, high impact resistance, etc. Homan [4] performed the fatigue test on GLARE 3-3/2-0.3 and the results showed that there is no effect on the fatigue initiation properties even after exposure to high temperature (70˚C) and humidity (85%) for 3000 hours before testing. Moreover, Khan *et al*. [5] found that the GLARE 3-3/2-0.3 has no significant effect on subsequent fatigue crack growth during the transition in delamination shape. Macheret and Bucci [6] conducted a study on a crack growth resistance curve approach to FML fracture toughness and the outcome shows that the tests on wide and centre slotted panels FML performed slow stable tearing before rapid fracture just like metals, while the 7475-T6 based ARALL-1 laminate has the lowest crack growth resistance. The use of GLARE has been expanded due to its impact properties relative to monolithic aluminium of the same areal density. Hoo Fat [7] proved impact resistance of GLARE for high velocity impact with epoxy-based GLARE increase 15% in the ballistic impact compared to the bare 2024 aluminium with equal areal density. Study by DharMalingam [8] on the effect of preheat temperature, blank holder force and feed rate on the formability of polypropylene based FML consist of 2:2 twill weave glass fibre/ polypropylene composite prepreg, showed that the FML systems have potential in forming characteristics compared to monolithic aluminium.

The most common matrix materials for composite are PMC. The mechanical properties of polymers are inadequate for many structural purposes. There are two types of matrices used for PMC which are thermoset and thermoplastics. Thermoplastics are preferable compared to thermosets due to the low production cycle, lower processing cost and high reparability [9]. Several synthetic thermoplastics were utilised including polypropylene, polyethylene, polystyrene and polyamides (nylon 6 and nylon 6, 6). Properties of typical thermoplastic are listed in Table 1. Polypropylene commonly used to produce fibre reinforced polymeric composites due to the better durability, moisture resistance and high strength properties [10]. Latiff *et al*. [11] found that the addition of recycled CFP into polypropylene would increase its wear resistance with a minimum coefficient of friction. Bachtiar *et al.* [12] studied tensile properties of hybrid sugar palm/kenaf fibre reinforced polypropylene composites and the results showed that the stiffness of the hybrid composites was higher compared to pure polypropylene.

Fig. 1. Fibre metal laminate.

In many MCDM methods, the criteria weights are obtained from the decision makers. The decisions do not clarify the relatives importance of the criteria without defining the word “importance” clearly [13]. This decision leads to confusion and misunderstanding in using MCDM models. According to Chen *et al*. [14], the evaluation of criteria entails diverse opinions and meanings. Therefore we cannot assume that each evaluation criterion is of equal importance. In weighting method, there are two categories, subjective weighting and objective weighting. The subjective weighting is determined based on decision maker based on expert’s evaluation [15]. While the objective weighting is determined by the mathematical solving such as entropy method and multiple objective programming [16] without any consideration from the decision maker preferences. Entropy method is a measure of uncertainty in information formulated regarding probability theory which the parameter describes how much different alternatives approach one another on a certain attribute [17]. Ishak *et al*. [18] used the entropy method to determine the importance weight of criteria for the thermoplastic matrix to prevent failure during FML fabrication. Fuzzy VIKOR is one of the MCDM methods to solve problems with imprecise and fuzzy data where in fuzzy MCDM, ratings and weighting always in fuzzy numbers [19]. Reliable results had been found, by combining VIKOR and entropy method, in supplier selection by Shemshadi [20]. MCDM also could be applied in material selection for automotive applications such as Mansor *et al*. [21], used AHP method to determine optimal natural fibres as a reinforcement material for hybrid polymer composites for automotive parking brake lever. While Ishak *et al*. [22] used Fuzzy VIKOR to identify the appropriate type of natural fibre for fibre reinforced composites to be applied on the FML for car front hood. Mayyas *et al*. [23] integrated QFD with AHP for material selection of body-in-white for the lightweight automotive application. Ilangkumaran *et al*. [24] used integrated FAHP with PROMETHEE to select the suitable material for automobile bumper.

To date, there is no work found using the combination of VIKOR and entropy method in engineering material selection. Since entropy method is a highly reliable and can be adjusted to information measurement to determine weighting criteria in decision making environment, utilisation of the entropy method in this study can increase the success probability of the product since through determination of the weighting main criteria; the decision results are more reliable and accurate. Therefore, the aim of this study is to explore the combination of both methods in selecting suitable thermoplastic matrix for FML using Fuzzy VIKOR based on entropy measure for objective weighting for automotive front hood utilisation. In this study, the automotive front hood involved is the outer panel (Fig. 2). Through Fuzzy VIKOR method, the thermoplastic matrix to be selected are designated as polypropylene (*A1*), low density polyethylene (*A2*), high density polyethylene (*A3*) and polystyrene (*A4*) while the objective weighting or the importance criteria that need to evaluate are Young's modulus (*C1*), melting temperature (*C2*), impact strength (*C3*) and water absorption (*C4*). It is crucial to determine the melting temperature of the thermoplastic for FML fabrication because the car front hood temperature could bear more than 160˚C. The impact strength of the car front hood is also an important criterion since it will absorb impact energy during a collision. While the water absorption is essential to define since in this study, the FML is interlacing layers of aluminium sheets bonded to natural fibre reinforced composite. Hence, to prevent failure during FML fabrication for car front hood utilisation, it is important to evaluate each criterion.

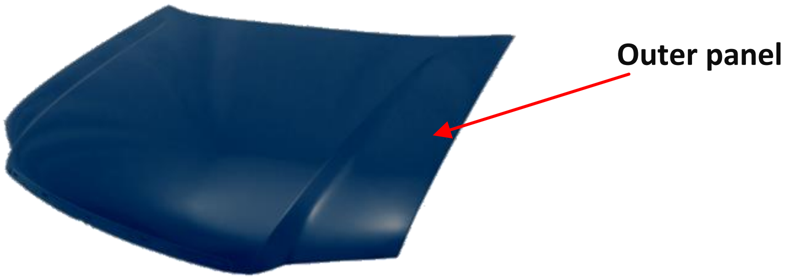

Fig. 2. Car front hood structures.

Table 1. Properties of typical thermoplastic polymers [25].

Matrix	Tensile strength (MPa)	Young modulus (GPa)	Impact strength (J/m)	Density (g/cm^3)	WA (%)	T melt (˚C)
PP	26-41.4	0.95-1.77	21.4-267	0.899-0.920	0.01-0.02	160-176
LDPE	40-78	0.055-0.38	>854	0.910-0.925	<0.015	105-116
HDPE	14.5-38	0.4-1.5	26.7-1068	0.94-0.96	0.01-0.2	120-140
PS	25-69	4-5	1.1	1.04-1.06	0.03-0.10	110-135
Nylon 6	43-79	2.9	42.7-160	1.12-1.14	1.3-1.8	215
Nylon 6,6	12.4-94	2.5-3.9	16-654	1.13-1.15	1.0-1.6	250-269

2. Methods

To determine the compromise solution from a set of alternatives, linguistic variables were used to calculate the importance of criteria and the ratings of alternatives with various respects to various criteria as shown in Table 2.

Table 2. Linguistic terms and corresponding fuzzy numbers for each criterion and alternatives.

Linguistic variable for criteria	Linguistic variable for alternatives	Fuzzy number
VP	**NI**	(0.0, 0.0, 0.1,0.2)
P	**LI**	(0.1, 0.2, 0.2, 0.3)
MP	**SI**	(0.2, 0.3, 0.4, 0.5)
F	**N**	(0.4, 0.5, 0.5, 0.6)
MG	**MI**	(0.5, 0.6, 0.7, 0.8)
G	**VI**	(0.7, 0.8, 0.8, 0.9)
VG	**EI**	(0.8, 0.9, 1.0, 1.0)

Step 1: The membership function is determined as Eq. (1).

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

Step 2: The aggregated fuzzy ratings X_{ij} of alternatives with respect to each criterion:

$$X_{ij}=\{X_{ij1};X_{ij2},X_{ij3},X_{ij4}\} \tag{2}$$

where $X_{ij1}=\min\{X_{ijk1}\}$, $X_{ij2}=\frac{1}{k}\sum X_{ijk2}$, $X_{ijk3}=\frac{1}{k}\sum X_{ijk3}$, $X_{ijk4}=\max\{X_{ijk4}\}$

Step 3: The aggregated fuzzy weight W_j of each criterion:

$$Wj_j^s=\{W_{j1}^s;W_{j2}^s,W_{j3}^s,W_{j4}^s\} \tag{3}$$

where $W_{j1}^s=\min\{W_{jk1}^s\}$, $W_{j2}^s=\frac{1}{k}\sum W_{jk2}^s$, $W_{j3}^s=\frac{1}{k}\sum W_{jk3}^s$, $W_{j4}^s=\max\{W_{jk4}^s\}$

Step 4: Defuzzify the fuzzy decision matrix and fuzzy weight of each criterion into crisp value:

$$Defuzz(X_{ij})=\frac{\int \mu(x).xdx}{\int \mu(x)dx}$$

$$= \frac{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}} \right).xdx + \int_{x_{ij2}}^{x_{ij3}} xdx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x_{ij4} - x}{x_{ij4} - x_{ij3}} \right).xdx}{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}} \right)dx + \int_{x_{ij2}}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}} \right)dx}$$

$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}(x_{ij4} - x_{ij3})^2 - \frac{1}{3}(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}} \tag{4}$$

Step 5: The objective weights determined using entropy method. The corresponding value needs to be normalize for each criterion C_i (i= 1, 2, …, n):

$$P_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}} \tag{5}$$

Step 6: After normalized the corresponding value, the entropy value, e_j is calculated as:

$$e_j = -k \sum_{j=1}^{n} P_{ij} \ln P_{ij} \tag{6}$$

k is constant, let $k = (\ln(m))^{-1}$ (6)

Step 7: The degree of divergence div_j of the basic information of each criterion:

$$div_j = 1 - e_j \tag{7}$$

Step 8: The objective weight W_j^o for each criterion:

$$W_j^o = \frac{d_j}{\sum_{k-=1}^{n} d_k} \tag{8}$$

Step 9: The overall performance:

$$F = \lfloor f_{ij} \rfloor_{m \times n}$$

$$f_{ij} = defuzz(u_{ij} \otimes w_j^s) \tag{9}$$

$$f_{ij} = \frac{-(u_{ij1}u_{ij2})(w_{j1}^s w_{j2}^s) + (u_{ij3}u_{ij4})(w_{j3}^s w_{j4}^s) + \frac{1}{3}(u_{ij4}w_{j4}^s - u_{ij3}w_{j3}^s)^2 - \frac{1}{3}(u_{ij2}w_{j2}^s - u_{ij1}w_{j1}^s)^2}{-u_{ij1}w_{j1}^s - u_{ij2}w_{j2}^s + u_{ij3}w_{j3}^s + u_{ij4}w_{j4}^s} \tag{10}$$

Step 10: The best f_j^* and the worst f_j^- value of all criterion ratings:

$$f_i^* = \max\{f_{ij}\} \tag{11}$$

$$f_i^- = \min\{f_{ij}\} \tag{12}$$

Step 11: The utility (S_i), regret (R_i) and VIKOR index (Q_i):

$$S_i = \sum_{j=1}^{n} \frac{w_j^s \left(f_i^* - f_{ij} \right)}{\left(f_i^* - f_i^- \right)} \tag{13}$$

$$R_i = \max_i \left(\frac{w_j^s \left(f_i^* - f_{ij} \right)}{\left(f_i^* - f_i^- \right)} \right) \tag{14}$$

$$Q_i = \left(\frac{v\left(s_i - s^*\right)}{s^- - s^*} \right) + \frac{(1-v)\left(R_i - R^*\right)}{R^- - R^*} \tag{15}$$

Step 12: 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*: $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq 1/(m-1)$, 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 $A^{(1)}$, $A^{(2)}$, $A^{(m)}$ if **Condition 1** is not satisfied. $A^{(M)}$ is calculated using the relation $Q\left(A^{(M)}\right) - Q\left(A^{(1)}\right) < 1/(m-1)$ for maximum M.

3. Results

Through linguistic terms, decision makers determine the importance of each criterion and then analyse and evaluate each alternative with respect to evaluation criteria. Results are shown in Tables 3 and 4.

The aggregated fuzzy numbers were calculated by using Eqs. (2) to (3) and the results are shown in Table 5.

The aggregated fuzzy values of thermoplastic matrix rates are then defuzzyfied using Eq. (4) which results are shown in Table 6.

Projection value of each criterion is calculated using Eq. (5) which results are shown in Table 7.

Based on w_j^o, the e_j and div_j relations are calculated using Eqs. (6), (7) and (8). Results are shown in Table 8.

The F matrix is determined according to Eq. (9) showed in Table 9, and arrays of the decision matrix using Eq. (10) displays in Table 10.

f_j^* and f_j^- are determined using Eqs. (11) and (12) which the results are shown in Table 11.

The utility (S_i), regret (R_i) and VIKOR index (Q_i) is calculated using Eqs. (13), (14) and (15) and results shown in Table 12.

The smallest alternatives value is determined to be the best solution. Arranging S_i, R_i and Q_i in increasing order to determine the rank and it is shown in Table 13.

Table 3. Importance weight of criteria assessed by decision makers (fuzzy values).

	C1	*C2*	*C3*	*C4*
DM1	(0.8,0.9,1.0,1.0)	(0.4,0.5,0.5,0.6)	(0.8,0.9,1.0,1.0)	(0.4,0.5,0.5,0.6)
DM2	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
DM3	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
DM4	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
DM5	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)

Table 4. Importance of material with respect to criteria assessed by decision makers (fuzzy values).

DM1	*C1*	*C2*	*C3*	*C4*
A1	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
A2	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.1,0.2,0.2,0.3)
A3	(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)
A4	(0.2,0.3,0.4,0.5)	(0.5,0.6,0.7,0.8)	(0.1,0.2,0.2,0.3)	(0.5,0.6,0.7,0.8)
DM2	*C1*	*C2*	*C3*	*C4*
A1	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.2,0.3,0.4,0.5)
A2	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.2,0.3,0.4,0.5)
A3	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.2,0.3,0.4,0.5)
A4	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)
DM3	*C1*	*C2*	*C3*	*C4*
A1	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.2,0.3,0.4,0.5)
A2	(0.1,0.2,0.2,0.3)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.1,0.2,0.2,0.3)
A3	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.2,0.3,0.4,0.5)
A4	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.0,0.0,0.1,0.2)	(0.4,0.5,0.5,0.6)
DM4	*C1*	*C2*	*C3*	*C4*
A1	(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)
A2	(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)
A3	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
A4	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
DM5	*C1*	*C2*	*C3*	*C4*
A1	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
A2	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
A3	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
A4	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)

Table 5. Aggregated fuzzy values of material ratings and criterion weights.

	C1	*C2*	*C3*	*C4*
W_j^s	(0.5,0.8,0.8,1.0)	(0.4,0.6,0.7,0.9)	(0.7,0.9,0.8,1.0)	(0.4,0.8,0.8,1.0)
A1	(0.4,0.7,0.7,0.9)	(0.5,0.7,0.8,0.9)	(0.5,0.7,0.8,0.9)	(0.2,0.5,0.6,1.0)
A2	(0.1,0.6,0.6,0.9)	(0.5,0.7,0.8,0.9)	(0.5,0.7,0.8,1.0)	(0.1,0.4,0.4,0.8)
A3	(0.4,0.6,0.6,0.9)	(0.5,0.7,0.8,0.9)	(0.5,0.8,0.8,1.0)	(0.2,0.5,0.6,0.9)
A4	(0.2,0.6,0.6,0.9)	(0.5,0.7,0.7,0.9)	(0.0,0.4,0.5,0.9)	(0.2,0.5,0.6,0.9)

Table 6. Defuzzyfied values of thermoplastic matrix.

	C1	*C2*	*C3*	*C4*
W_j^s	0.77	0.65	0.87	0.72
A1	0.66	0.72	0.72	0.60
A2	0.52	0.72	0.76	0.43
A3	0.64	0.72	0.77	0.54
A4	0.57	0.70	0.45	0.55

Table 7. Defuzzyfied values of the initial thermoplastic matrix.

	C1	*C2*	*C3*	*C4*
A1	0.28	0.25	0.27	0.28
A2	0.22	0.25	0.28	0.20
A3	0.27	0.25	0.29	0.26
A4	0.24	0.25	0.17	0.26

Table 8. Calculated entropy measure, divergence and objective weights of criteria.

	C1	*C2*	*C3*	*C4*
e_j	0.77	0.77	0.76	0.77
div_j	0.23	0.23	0.24	0.23
W_j^o	0.25	0.25	0.26	0.25

Table 9. $u_{ij} \otimes w_s^j$ **matrix F.**

f_{ij}	*C1*	*C2*	*C3*	*C4*
A1	(0.2,0.5,0.6,0.9)	(0.2,0.5,0.5,0.8)	(0.4,0.6,0.7,0.9)	(0.1,0.4,0.5,1.0)
A2	(0.1,0.4,0.5,0.9)	(0.2,0.5,0.5,0.8)	(0.4,0.6,0.7,1.0)	(0.0,0.3,0.3,0.8)
A3	(0.2,0.5,0.5,0.9)	(0.2,0.5,0.5,0.8)	(0.4,0. 7,0.8,1.0)	(0.0,0.4,0.4,0.9)
A4	(0.1,0.5,0.5,0.9)	(0.2,0.4,0.5,0.8)	(0.0,0.4,0.4,0.9)	(0.0,0.4,0.5,0.9)

Table 10. Decision matrix *F*.

	C1	*C2*	*C3*	*C4*
A1	0.48	0.37	0.90	0.46
A2	0.43	0.37	0.62	0.35
A3	0.46	0.37	0.63	0.41
A4	0.45	0.37	0.41	0.42

Table 11. f_j^* **and** f_j^- **for each criterion.**

	C1	*C2*	*C3*	*C4*
f_j^*	0.48	0.37	0.90	0.46
f_j^-	0.43	0.37	0.41	0.35

Table 12. The values of S_i, R_i and Q_i for each criterion.

	S_i	R_i	Q_i
A1	0.01	0.01	0.00
A2	0.64	0.26	0.90
A3	0.30	0.14	0.44
A4	0.77	0.27	1.00

Satisfied by the two conditions, Fig. 3 summarised the overall rank where *A1* (polypropylene) is selected as the suitable thermoplastic matrix for FML. Based on the analysis, polypropylene scored the lowest VIKOR index (Q_i) value with 0.00, followed by HDPE with 0.44 scores, LDPE with 0.90 scores and Polystyrene with 1.00 scores.

Table 13. Decision matrix *F*.

	1	2	3	4
By S_i	*A1*	*A3*	*A2*	*A4*
By R_i	*A1*	*A3*	*A2*	*A4*
By Q_i	*A1*	*A3*	*A2*	*A4*

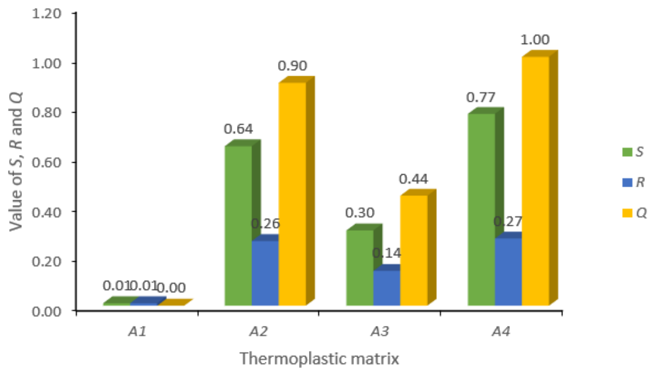

Fig. 3. Ranking of S_i, R_i and Q_i.

4. Conclusion

Using Fuzzy VIKOR based on entropy measure for objective weighting, the polypropylene is selected as the suitable thermoplastic matrix for FML compared to the other four potential thermoplastic matrix by satisfying two compromise solution with validation using least VIKOR index value. The combination of Fuzzy VIKOR and entropy proved that this method gives a higher degree of confidence to the decision maker which could be applied in a similar polymer composite material selection process involving MCDM method where it provides a systematic and scientific selection method.

However, there is a limitation in this method, where it could not solve the uncertainties presented in random data. Although there is limitation exist in this method, it is still appropriate since the combination of these two approaches can increase the success probability of the product since through determination of the weighting main criteria; the decision results are more reliable and accurate and can be implemented in the utilisation of car front hood using FML panel.

References

1. Ng, L.; Sivakumar, D.; Zakaria, K.; and Selamat, M. (2017). Fatigue performance of hybrid fibre metal laminate structure. *International Review of Mechanical Engineering (IREME)*, 11(1), 61-68.

2. Dou, X.; Malingam, S.; Nam, J.; and Kalyanasundaram, S. (2015). Finite element modelling of stamp forming process on thermoplastic based fiber metal laminates at elevated temperatures. *World Journal of Engineering and Technology*, 3(3), 253-258.
3. Ahmed, S.M.; and Kumar, C.A. (2014). Mechanical characterization and analysis of perforated fibre metal laminates. *International Journal of Engineering trends and Technology*, 13(1), 18-24.
4. Homan, J.J. (2006). Fatigue initiation in fibre metal laminates. *International Journal Fatigue*, 28(4), 366-374.
5. Khan, S.U.; Alderliesten , R.C.; and Benedictus, R. (2011). Delamination in fiber metal laminates (GLARE) during fatigue crack growth under variable amplitude loading. *International Journal Fatigue*, 33(9), 1292-1303.
6. Macheret, J.; and Bucci. R.J. (2013). A crack-growth resistance curve approach to fiber metal laminate fracture toughness evaluation. *Enginerring Fracture Mechanic*, 45(6), 729-739.
7. Hoo Fatt, M.S.; Lin, C.; Revilock, D.M.; and Hopkins, D.A. (2003). Ballistic impact of GLARE™ fiber metal laminates. *Composite Structure*, 61(1-2), 73-88.
8. DharMalingam, S.; Compston, P.; and Kalyanasundaram, S. (2009). Process variables optimisation of polypropylene based fibre metal laminates forming using finite element analysis. *Key Engineering Material*, 410-411, 263-269.
9. Shubhra, Q.T.; Alam A.; and Quaiyyum, M. (2011). Mechanical properties of polypropylene composites: A review. *Journal Thermoplasic Composite Material*, 26(3), 362-391.
10. Maddah, H.A. (2016). Polypropylene as a promising plastic: A Review. *American Journal Polymer Science*, 6(1), 1-11.
11. Latiff, A.A.; Mohamad, N.; Jeefferie, A.R.; Nasir, M.H.M.; Rahmah, S.S.; Mahamood, M.A.; Abdullah, M.I.H.C.; and Abdollah, M.F.B. (2015). Friction and wear characteristics of recycled aerocomposite carbon fibre reinforced polypropylene composites. *Proceedings of Malaysian International Tribology Conference*. Malacca, Malaysia, 211-212.
12. Bachtiar, D.; Siregar, J.P.; Sulaiman, A.S.; and Mat Rejab, M.R. (2014). Tensile properties of hybrid sugar palm/kenaf fibre reinforced polypropylene Composites. *Applied Mechanic Material*, 695, 155-158.
13. Choo, E.U.; Schoner, B.; and Wedley, W.C. (1999). Interpretation of criteria weights in multicriteria decision making. *Computers and Industrial Engineering*, 37(3), 527-541.
14. Chen, M.F.; Tzeng, G.H.; and Ding, C.G. (2003). Fuzzy MCDM approach to select service provider. *IEEE International Conference Fuzzy System*, 1(1), 572 - 577.
15. Nang Idayu, N.Z.; and Lazim, A. (2012). Evaluation of sustainable development indicators with fuzzy topsis based on subjective and objective weights. *IIUM Engineering Journal*, 13(1), 13-25.
16. Saad, R.; Ahmad, M.Z.; Abu, M.S.; and Jusoh, M.S. (2014). Hamming distance method with subjective and objective weights for personnel selection. *The Scientific World Journal*, 2014, 1-9.

17. Wang, T.C.; and Lee, H.D. (2009). Developing a fuzzy topsis approach based on subjective weights and objective weights. *Expert System Application*, 36(5), 8980-8985.
18. Ishak, N.M.; Sivakumar, D.; and Mansor, M.R. (2016). Thermoplastic matrix selection based on entropy method for importance weight of criteria. *Proceedings of Mechanical Engineering Research Day 2016*. Malacca, Malaysia, 106-107.
19. Chen, S.J.; and Hwang, C.L. (1992). *Fuzzy multiple attribute decision making methods and applications*. Berlin: Springer- Verlag.
20. Shemshadi, A.; Shirazi, H.; Toreihi, M.; and Tarokh, M.J. (2011). A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting. *Expert System Application*, 38(10), 12160-12167.
21. Mansor, M.R.; Sapuan, S.M.; Zainudin, E.S.; Nuraini, A.A.; and Hambali, A. (2013). Hybrid natural and glass fibers reinforced polymer composites material selection using analytical hierarchy process for automotive brake lever design. *Material Design*, 51, 484-492.
22. Ishak, N.M.; Malingam, S.D.; and Mansor, M.R. (2016). Selection of natural fibre reinforced composites using fuzzy VIKOR for car front hood. *International Journal of Material and Product Technology*, 53(3/4), 267-285.
23. Mayyas, A.; Shen, Q.; Mayyas, A.; Abdelhamid, M.; Shan, D.; Qattawi, A.; and Omar, M. (2011). Using quality function deployment and analytical hierarchy process for material selection of body in white. *Material Design*, 32(5), 2771-2782.
24. Ilangkumaran, M.; Avenash, A.; Balakrishnan, V.; Barath Kumar, S.; and Boopathi Raja, M. (2013). Material selection using hybrid MCDM approach for automobile bumper. *International Journal Industrial And System Engineering*, 14(1), 20-39.
25. Holbery, J.; and Houston,D. (2006). Natural fibre reinforced polymer composites in automotive applications. *Journal of Minerals, Metals and Material Society,* 58(11), 80–86.