MATERIAL SELECTION FOR AUTOMOTIVE FENDER DESIGN USING INTEGRATED AHP-TOPSIS

A., Hambali[1], C.M., Goh[2], F.M.T., Amira[3], J., Rosidah[4]

[*1, 2, 3, 4]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,
76100 Durian Tunggal, Melaka, Malaysia.

Email: [*1]hambali@utem.edu.my; [2]rumi1018@hotmail.com;
[3]amirafarhana1127@yahoo.com; [4]rosidah@utem.edu.my

ABSTRACT: This paper presented the integration of (Analytic Hierarchy Process) AHP and (Technique of Order Preference by Similarity to Ideal Solution) TOPSIS in material selection process of an automotive fender design. The selection of material for automotive fender focused on lighter materials due to new trend in producing light weight vehicles in automotive industry. The main objective was to determine the best material for automotive fender using the integrated AHP-TOPSIS approach by identifying important criteria in material selection of the automotive fender. The important criteria considered were Performance, Cost, Weight and Manufacturing criteria. Three different types of material categories were considered namely High Strength Steel, Aluminium Alloy and Thermoplastic in the selection process. AHP method was used to determine the weight of the selection criteria, followed by TOPSIS method to perform the ranking of alternatives. The results showed that PPE/PA/989 resin was the best material for the automotive fender based on the criteria chosen. The integrated AHP-TOPSIS approach is proven effective in assisting engineers in evaluating and determining the best material for the automotive fender which involve many criteria and alternatives in the material selection process.

KEYWORDS: *Material Selection, Automotive Fender, Lightweight, AHP, TOPSIS.*

1.0 INTRODUCTION

In recent years, new materials are used to replace traditional materials to achieve weight reduction and performance improvement in engineering application especially in automotive industry [1]. Currently, materials such as advanced steels, magnesium alloys, aluminium alloys and titanium alloys, plastics and composites are used in automotive industry to produce lightweight vehicles. New trends of lightweight vehicles not only can enhance fuel efficiency but can also lower the emissions for the driving performance improvement [2]. Reducing the weight of vehicle can cause a significant reduction of vehicle power requirement, hence, increasing the fuel economy. Studies have shown that every 10% of vehicle weight reduction can cause 5 to 8% greater fuel efficiency [3]. Weight reduction of automotive components becomes a new trend because it can meet the customer expectation in terms of fuel economy, emission reduction, vehicles safety and performance. Redesigning existing components with lightweight materials is one method to reduce weight in vehicle body construction. Weight saving in automotive components such as power-train, chassis and suspension, body panels and body structure might be achieved by using lightweight materials to replace high density materials like steels [4].

An Analytic Hierarchy Process (AHP) which was developed by Saaty in the 1970s has proven its efficiency in decision making process and has been widely used in manufacturing and production systems, business planning, economic planning, conflict resolution, logistics and capital budgeting [5-6]. The AHP hierarchy model enables a decision maker to break a complex problem into smaller sub-problems. Objectives, criteria and sub-criteria are structured from the highest to lowest level of the model which can help decision makers to understand the problem in-depth. Pair-wise comparison between sub-criteria or alternatives at the same level with respect to the objectives or criterion at the higher level can reduce the inconsistencies that are made possible by the decision makers. The AHP also helps the decision makers to evaluate the relative importance of the multiple criteria. The relative weightage of each criterion tells the decision makers which criterion is the most important and selects the highest weighted criteria as the best alternatives [7].

Furthermore, Hwang and Yoon proposed TOPSIS method for solving MCDM problem with several alternatives [8]. This method states that an alternative which has the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS) is the most appropriate alternative. The alternative has the maximum similarity with PIS and minimum similarity with NIS. PIS maximizes the benefit criteria and minimizes cost criteria, whereas NIS minimizes the benefit criteria and maximizes the cost criteria. The TOPSIS method is very useful in material selection decision making process because it is a quick and easy decision where its ranking output gives a better understanding of similarities and differences among alternatives [9]. TOPSIS has been applied in many multi criteria decision making processes in different applications such as engineering, design and manufacturing system [10]. The integrated AHP and TOPSIS was employed owing to its capability in providing a structure and hierarchy method for synthesizing selection problems and to rank the alternative or decision options based on their overall performance [12].

An integrated AHP-TOPSIS is one of the multiple-criteria decision making problem (MCDM) methods that can be implemented in solving the material selection problem. Various case studies are conducted to assist decision makers in determining the best decision in various engineering perspectives [7], [11-13]. Thus, this paper presented an approach of evaluating and determining the best material for the automotive fender design using an integrated AHP-TOPSIS.

2.0 METHODOLOGY

The materials considered for the automotive fender design were High Strength Steels (Docol600DP and Docol1000DP), Aluminium alloys (AA2036T4 and AA6010T4) and Thermoplastic polymers (PPE/PA/989Resin, PPO/PA66, NY66/40CF, PPS/40CF, AR/PC, PC/PBT resin). The material properties that were required for the material selection were Density (D), Ultimate Tensile Strength (UTS), Yield Strength (YS), Elongation at Break (EB), Young's Modulus (YM), Izod Impact, Notched (IP), Electrical Resistivity (ER), Linear Coefficient of Thermal Expansion (CTE), Specific Heat capacity (SHC) and Material Cost (MC). The material properties of the candidate materials are shown in Table 1. Table 2 summarizes the decision criteria used in the AHP-TOPSIS analysis for the material selection of the automotive fender design. There were two stages of conducting the integrated approach as discussed below:

2.1 Stage 1: Weighting of Criteria using AHP Method

Step 1: A hierarchy framework was developed which consisted of four levels. Goal, criteria, sub-criteria and alternatives were structured from the highest to lowest level of the model. A four level hierarchy decision process is shown in Figure 1.

Table 1: Material properties of candidate materials [14]

Material Properties	Candidate Materials									
	D600 DP	D1000 DP	AA 2036 T4	AA 6010 T4	PPE/ PA/ 989	PPO/ PA66	NY66/ 40CF	PPS/ 40CF	AR/ PC	PC/ PBT
Physical Properties										
D (g/cc)	7.9	7.9	2.7	2.7	0.9	1.3	1.5	1.5	1.2	1.3
Mechanical Properties										
UTS (MPa)	650.0	1100.0	338.0	290.0	55.0	53.0	267.0	175.0	49.8	54.0
YS (MPa)	400.0	850.0	193.0	170.0	60.0	54.0	120.0	143.0	56.3	58.0
EB (%)	16.0	7.0	24.0	24.0	40.0	2.2	6.7	0.8	26.7	120.0
E (GPa)	207.0	207.0	71.0	69.0	2.3	4.5	24.6	32.8	2.2	3.8
IP (J/cm)	57.5	57.5	8.5	8.5	2.4	0.4	1.6	0.5	9.4	2.5
Electrical Properties										
ER (μohm-cm)	20.0	23.0	4.12	4.4	5E+1	3E+2	1E+14	1E+1	2E+1	3E+2
Thermal Properties										
CTE (μm/m-°C)	10.8	11.7	23.4	24.8	85.0	64.8	14.8	17.3	93.6	46.0
SHC (J/kg.°C)	460.0	486.0	882.0	890.0	1700.0	1630.0	1520.0	1330.0	1580.0	1420.0
MC ($/kg)	0.8	0.8	11.8	12.7	5.2	4.7	6.05	20.4	3.8	2.7

Table 2**:** Decision criteria used in AHP-TOPSIS for the material selection of automotive fender

Goal: To select the best material for automotive fender		
Main Criteria	Corresponding material properties as sub-criteria	Aim
(i) Performance	Ultimate tensile strength, Yield strength, Young modulus and Izod impact	Maximum value to provide the required structural strength of the final material.
	Elongation at break	Maximum value to allow improved performance in term of deformation under physical loadings for the final material.
	Coefficient of thermal expansion	Minimum value to allow improved performance in term of deformation under thermal loadings for the final material.
(ii) Cost	Material cost	Minimum value to achieve lowest product cost specifically in term of material cost.
(iii) Weight	Density	Minimum value to attain lightweight property for the final material.
(iv) Manufacturing	Electrical resistivity	Minimum value to conduct electricity uring online painting.
	Specific heat capacity	Maximum value to withstand the high temperatures of online painting.

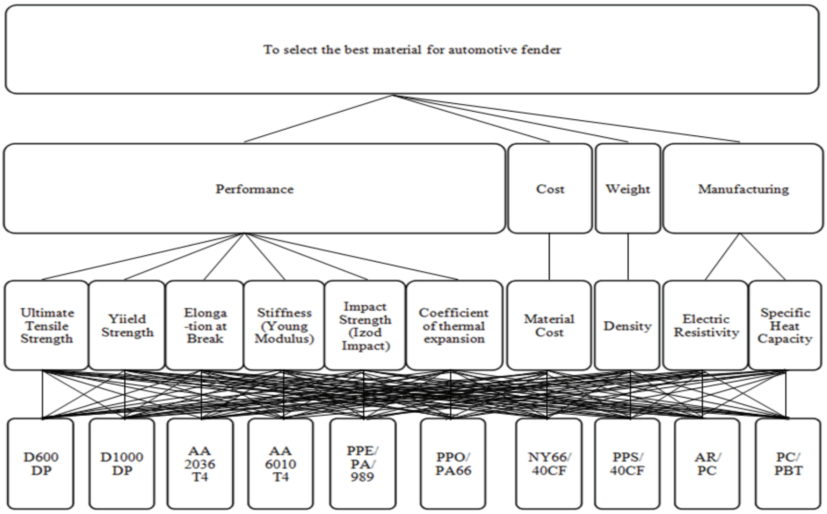

Figure 1: A hierarchy framework for the material selection

Step 2: The pair-wise comparison of main criteria with respect to the goal was constructed in Table 4 based on the Saaty rating scale (Table 3). For judgements in the first row, if Performance was equally important to itself, rate 1 was assigned. If Performance was much more important over Cost, rate 5 was assigned. If Weight was somewhat more important than Performance, rate 1/3 was assigned. Reciprocals value was automatically assigned to inverse comparison.

Table 3: Saaty rating scale for pair-wise comparison [5]

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

Table 4: Pair-wise of main criteria

Main Criteria	P	C	W	M
P	1	5	1/3	3
C	1/5	1	1/7	1/2
W	3	7	1	5
M	1/3	2	1/5	1
Σ	4.5333	15.0000	1.6762	9.5000

Step 3: The pair-wise comparison was synthesized by calculating priority vector. The Priority Vector (PV) or Eigenvectors (w) was calculated using.

$$w = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{a} a_{ij}}, \qquad i, j = 1,2, \dots , n \tag{1}$$

Where w is the priority vector (or eigenvector), n is the number of criteria, and a_{ij} is the importance scale, i.e. 1, 3, 5…n.

The Priority Vector in the first row was calculated as 1+1/5+3+1/3 = 4.5333; 1/4.533 3 = 0.2206; 0.2206+0.3333+0.1989+0.3158 = 1.0686; divide the sum of row by the number of elements (n=4) hence, 1.0686/4=0.2671. The calculation is summarized in Table 5.

Table 5: Synthesized pair-wise comparison and priority vector

Main Criteria	P	C	W	M	Total Row	PV
P	0.2206	0.3333	0.1989	0.3158	1.0686	0.2671
C	0.0441	0.0667	0.0852	0.0526	0.2486	0.0622
W	0.6618	0.4667	0.5966	0.5263	2.2513	0.5628
M	0.0735	0.1333	0.1193	0.1053	0.4314	0.1079
Σ						1.0000

Next, the overall consistency ratio, CR for the overall judgements was calculated based on the principle of Eigenvalues, Consistency Index, CI and Relative Index, RI.

Step 4: The Eigenvalue (ƛmax) could be calculated using Equation (2). The right matrix of judgements was multiplied by the priority vector (PV) to obtain a new vector (NV). The calculation to get a new vector is summarized in Table 6.

$$\text{Eigenvalue, } \lambda_{\max} = \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} \times w_j}{w_i} \qquad i, j = 1,2, \dots , n \tag{2}$$

Table 6: Calculated the Eigenvalue (ƛmax)

PV	P	PV	C	PV	W	PV	M	New Vector	NV/PV
0.2671	1	0.0622	5	0.5628	1/3	0.1079	3	1.0891	4.0770
	1/5		1		1/7		1/2	0.2500	4.0188
	3		7		1		5	2.3390	4.1560
	1/3		2		1/5		1	0.4339	4.0213
Total (Σ)									16.2731
ƛmax									4.0683

The calculation of the first row in the matrix was
0.2671(1) + 0.0622(5) + 0.5628(1/3) + 0.1079(3) =1.0891.

Then, dividing all the elements of the new vector by their respective priority vector element, hence

1.0891/0.2671 = 4.0070; 0.2500/0.0622 = 4.0188; 2.3390/0.5628 = 4.1560; 0.4339/0.1079 = 4.0213.

Next, calculate the average of these values to obtain
ƛmax = (4.0770+4.0188+4.1560+4.0213)/4 = 4.0683.

Step 5: The Consistency Index (CI) could be calculated using

$$CI = (\lambda max - n)/ (n - 1). \quad (3)$$

Where n is the matrix size, CI = (4.0683-4)/ (4-1) = 0.0228.

Step 6: The Consistency Ratio (CR) could be calculated using

$$CR = CI/RI. \quad (4)$$

The value of random index (RI) was selected by referring to the matrix size shown in Table 7. For the matrix size n = 4, RI = 0.9, the consistency ratio was calculated as CR = CI/RI = 0.0228/0.9 = 0.0253. As the CR value obtained was less than 0.1, the judgements were acceptable. If CR value obtained was more than 0.1, the judgements were inconsistent. Then, the pair-wise judgements should be reviewed and improved. The summary of the results as shown in Table 8.

Table 7: Random Index [5]

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10	11	12
Random Index (I)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Table 8: Consistency test for main criteria

Goal	Priority Vector	New Vector
P	0.2671	1.0891
C	0.2671	0.25
W	0.2671	2.339
M	0.2671	0.4339
Consistency Test		
ƛmax		4.0683
CI		0.0228
RI		0.9000
CR		0.0253

The pair-wise comparison and consistency analysis were performed for the sub-criteria in the hierarchy model. Tables 9 and Table 10 represent the consistency test for sub-criteria with respect to their corresponding Performance and Manufacturing main criteria.

Table 9: Consistency test for sub-criteria of performance

Performance	UTS	YS	EB	YM	IP	CTE	PV	NV	NV/PV
UTS	1	1	6	1/3	1	3	0.1759	1.0805	6.1427
YS	1	1	6	1/3	1	3	0.1759	1.0805	6.1427
EB	1/6	1/6	1	1/7	1/3	1/2	0.0395	0.2383	6.0329
YM	3	3	7	1	3	4	0.3927	2.445	6.2261
IP	1	1	3	1/3	1	2	0.1436	0.8896	6.195
CTE	1/3	1/3	2	1/4	1/2	1	0.0724	0.4386	6.0586
Total (Σ)									36.798
Consistency Test									
λmax						6.1330			
CI						0.0266			
RI						1.2400			
CR						0.0215			

Table 10: Consistency test for sub-criteria of manufacturing

Manufacturing	ER	SHC	PV	NV	NV/PV
ER	1	1/3	0.2500	0.5000	2.0000
SHC	3	1	0.7500	1.5000	2.0000
Total (Σ)					4.0000
Consistency Test					
λmax				2.0000	
CI				0	
RI				0	
CR				0	

2.2 Stage 2: Ranking of Alternatives using TOPSIS Method

Step 1: Normalized decision matrix was calculated using

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x^2_{ij}}} \text{ where } i = 1,\ldots, m, \text{ and } j = 1,\ldots, \quad (5)$$

Where X_{ij} and n_{ij} are original and normalized score of decision matrix, respectively

First, modified decision matrix was calculated and shown in Table 11. The modified decision matrix for UTS sub-criteria was calculated as

$650^2+1100^2+338^2+290^2+55^2+53^2+267^2+175^2+49.8^2+54^2 = 1.94E+06$; $\sqrt{1.94E+06} = 1.39E+03$.

The normalized decision matrix for the sub-criteria was calculated and tabulated in Table 12. The normalized decision matrix for D600DP with the sub-criteria was calculated as

650/1.39E+03 = 0.4662; 400/9.98E+02 = 0.4007; 16/1.35E+02 = 0.1185;
207/3.12E+02 = 0.6639; 57.5/8.28E+01 = 0.6941; 10.8/1.56E+02 = 0.0694;
0.81/2.87E+01 = 0.0282; 7.87/1.22E+01 = 0.6442; 20/4.76E+20 = 4.29E-20;
460/4.02E+03 = 0.1144.

Step 2: Weighted normalized decision matrix was determined using

$$V = N_D . W_{n\times n} = \begin{vmatrix} V_{1i} & \cdots & V_{1j} & \cdots & V_{1n} \\ \vdots & & \vdots & & \vdots \\ V_{m1} & \cdots & V_{mi} & \cdots & V_{mn} \end{vmatrix} \tag{6}$$

The weighted normalized decision matrix (V) multiplied the normalized decision matrix (N_D) by the weighted priority (W_{nxn}) as shown in Table 13. The weighted normalized decision matrix for D600DP with the sub-criteria was calculated as

0.4662(0.0470) = 0.0219; 0.4007(0.0470) = 0.0188; 0.1185(0.0105) = 0.0012;
0.6639(0.1049) = 0.0696; 0.6941(0.0384) = 0.0266; 0.0694(0.0193) = 0.0013;
0.0282(0.0622) = 0.0018; 0.6442(0.5628) = 0.3626; 4.29E-20(0.0270) = 1.16E-21;
0.1144(0.0809) = 0.0093.

Step 3: Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) could be expressed as Equation (7) and Equation (8). PIS was the best solution and the NIS was the worst solution.

$$A^+ = \{(\max_j v_{ij}; i \in I)(\min_j v_{ij}; i \in J); i = 1, 2, \ldots, n\} \tag{7}$$
$$A^- = \{(\min_j v_{ij}; i \in I)(\max_j v_{ij}; i \in J); i = 1, 2, \ldots, n\} \tag{8}$$

For example, higher Ultimate Tensile Strength (UTS) was required for the automotive fender. A largest value of UTS was the best compared to a smallest value. Hence, PIS was the maximum value and NIS was the minimum value. However, lower Density (D) was required for a light weight automotive fender. A smallest value of D was the best compared to a largest value. Hence, PIS was the minimum value and NIS was the maximum value. The PIS and NIS values are shown in Table 14.

Table 14: PIS and NIS

Sub-Criteria	PIS	NIS
UTS	0.0371	0.0017
YS	0.0400	0.0025
EB	0.0094	0.0001
YM	0.0696	0.0007
IP	0.0266	0.0002
CTE	0.0013	0.0116
MC	0.0018	0.0441
D	0.0451	0.3626
ER	2.40E-22	0.0191
SHC	0.0342	0.0093

Table 11: Modified decision matrix

Sub-Criteria	UTS	YS	EB	YM	IP	CTE	MC	D	ER	SHC
D600DP	650	400	16	207	57.5	10.8	0.81	7.87	20	460
D1000DP	1100	850	7	207	57.5	11.7	0.85	7.87	23	486
AA2036T4	338	193	24	71	8.53	23.4	11.79	2.75	4.16	882
AA6010T4	290	170	24	69	8.53	24.8	12.68	2.71	4.4	890
PPE/PA/989	55	60	40	2.3	2.4	85	5.19	0.98	5.00E+09	1.70E+03
PPO/PA66	53	54	2.2	4.47	0.37	64.8	4.72	1.31	3.30E+20	1.63E+03
NY66/40CF	267	120	6.66	24.6	1.6	14.8	6.05	1.55	1.00E+14	1.52E+03
PPS/40CF	175	143	0.859	32.8	0.508	17.3	20.4	1.51	1.00E+06	1.33E+03
AR/PC	49.8	56.3	26.7	2.18	9.43	93.6	3.84	1.19	2.02E+10	1.58E+03
PC/PBT	54	58	120	3.8	2.5	46	2.69	1.3	3.30E+20	1.42E+03
ΣX^2_{ij}	1.94E+06	9.97E+05	1.82E+04	9.72E+04	6.86E+03	2.42E+04	8.25E+02	1.49E+02	2.18E+41	1.62E+07
$\sqrt{(\Sigma X^2_{ij})}$	1.39E+03	9.98E+02	1.35E+02	3.12E+02	8.28E+01	1.56E+02	2.87E+01	1.22E+01	4.67E+20	4.02E+03

Table 12: Normalized decision matrix

Sub-Criteria	UTS	YS	EB	YM	IP	CTE	MC	D	ER	SHC
D600DP	0.4662	0.4007	0.1185	0.6639	0.6941	0.0694	0.0282	0.6442	4.29E-20	0.1144
D1000DP	0.7889	0.8515	0.0519	0.6639	0.6941	0.0752	0.0296	0.6442	4.93E-20	0.1209
AA2036T4	0.2424	0.1933	0.1778	0.2277	0.1030	0.1503	0.4104	0.2251	8.91E-21	0.2194
AA6010T4	0.2080	0.1703	0.1778	0.2213	0.1030	0.1593	0.4414	0.2218	9.43E-21	0.2214
PPE/PA/989	0.0394	0.0601	0.2963	0.0074	0.0290	0.5460	0.1807	0.0802	1.07E-11	0.4229
PPO/PA66	0.0380	0.0541	0.0163	0.0143	0.0045	0.4162	0.1643	0.1072	0.7071	0.4055
NY66/40CF	0.1915	0.1202	0.0493	0.0789	0.0193	0.0951	0.2106	0.1269	2.14E-07	0.3782
PPS/40CF	0.1255	0.1432	0.0064	0.1052	0.0061	0.1111	0.7102	0.1236	2.14E-15	0.3309
AR/PC	0.0357	0.0564	0.1978	0.0070	0.1138	0.6012	0.1337	0.0974	4.33E-11	0.3931
PC/PBT	0.0387	0.0581	0.8890	0.0122	0.0302	0.2955	0.0936	0.1064	0.7071	0.3533

Table 13: Weighted normalized decision matrix

Sub-Criteria	UTS	YS	EB	YM	IP	CTE	MC	D	ER	SHC
Weight	0.0470	0.0470	0.0105	0.1049	0.0384	0.0193	0.0622	0.5628	0.0270	0.0809
D600DP	0.0219	0.0188	0.0012	0.0696	0.0266	0.0013	0.0018	0.3626	1.16E-21	0.0093
D1000DP	0.0371	0.0400	0.0005	0.0696	0.0266	0.0015	0.0018	0.3626	1.33E-21	0.0098
AA2036T4	0.0114	0.0091	0.0019	0.0239	0.0039	0.0029	0.0255	0.1267	2.40E-22	0.0178
AA6010T4	0.0098	0.0080	0.0019	0.0232	0.0039	0.0031	0.0274	0.1249	2.54E-22	0.0179
PPE/PA/989	0.0019	0.0028	0.0031	0.0008	0.0011	0.0106	0.0112	0.0451	2.89E-13	0.0342
PPO/PA66	0.0018	0.0025	0.0002	0.0015	0.0002	0.0080	0.0102	0.0604	0.0191	0.0328
NY66/40CF	0.0090	0.0056	0.0005	0.0083	0.0007	0.0018	0.0131	0.0714	5.78E-09	0.0306
PPS/40CF	0.0059	0.0067	0.0001	0.0110	0.0002	0.0021	0.0441	0.0696	5.78E-17	0.0268
AR/PC	0.0017	0.0027	0.0021	0.0007	0.0044	0.0116	0.0083	0.0548	1.17E-12	0.0318
PC/PBT	0.0018	0.0027	0.0094	0.0013	0.0012	0.0057	0.0058	0.0599	0.0191	0.0286

Step 4: The separation of each alternative from the ideal solution was given as Equation (9) and Equation (10).

$$d_{i^+} = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_{j^+}\right)^{1/2}; i = 1, 2, \ldots, m\right\} \tag{9}$$

$$d_{i^-} = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_{j^-}\right)^{1/2}; i = 1, 2, \ldots, m\right\} \tag{10}$$

Where, i= criterion index and j=alternative index
The separation from PIS was the distance of each alternative separate from the PIS value of each sub-criterion as shown in Table 15. Taking D600DP as an example, the separation from PIS and NIS was calculated as

di^+_{D600DP}
$= (0.0219-0.0371)^2+(0.0188-0.0400)^2+(0.0012-0.0094)^2+(0.0696-0.0696)^2$
$+(0.0266-0.0266)^2+(0.0013-0.0013)^2+(0.0018-0.0018)^2+(0.3626-0.0451)^2$
$+(1.16E-21-2.40E-22)^2+(0.0093-0.0342)^2$
$= 0.1021$

di^-_{D600DP}
$= (0.0219-0.0017)^2+ (0.0188-0.0025)^2+ (0.0012-0.0001)^2+ (0.0696-0.0007)^2$
$+(0.0266-0.0002)^2+(0.0013-0.0116)^2+(0.0018-0.0441)^2+(0.3626-0.3626)^2$
$+(1.16E-21-0.0191)^2+(0.0093-0.0093)^2$
$= 0.0084$

Table 15: Separation from PIS and NIS

Alternatives	Separation from PIS, di^+	Separation from NIS, di^-
D600DP	0.1021	0.0084
D1000DP	0.1014	0.0104
AA2036T4	0.0118	0.0572
AA6010T4	0.0118	0.0579
PPE/PA/989	0.0082	0.1028
PPO/PA66	0.0088	0.0931
NY66/40CF	0.0073	0.0868
PPS/40CF	0.0087	0.0868
AR/PC	0.0082	0.0969
PC/PBT	0.0086	0.0936

Step 5: Finally, the relative closeness *(cl_i)* to the ideal solution for every alternative was determined using Equation (11). The ranking of alternatives was finally made by ranking the preference in decreasing order based on the indices as shown in Table 16.

$$cl_{i^+} = \frac{d_{i^-}}{(d_{i^+} - d_{i^-})}, 0 \leq cl_{i^+} \leq 1; i = 1, 2, \ldots, m \tag{11}$$

The Relative Closeness of the alternatives was calculated as

0.0084/(0.1021+0.0084) = 0.0759; 0.0104/(0.01014+0.0104) = 0.0927;
0.0572/(0.0118+0.0572) = 0.8293; 0.0579/ (0.0118+0.0579) = 0.8310;
0.1028/(0.0082+0.1028) = 0.9259; 0.0931/(0.0088+0.0931) = 0.9137;
0.0868/(0.0073+0.0868) = 0.9223; 0.0868/(0.0087+0.0868) = 0.9084;
0.0969/(0.0082+0.0969) = 0.9220; 0.0936/(0.0086+0.0936) = 0.9158.

Table 16: Relative closeness

Alternatives	Relative Closeness	Ranking
D600DP	0.0759	10
D1000DP	0.0927	9
AA2036T4	0.8293	8
AA6010T4	0.8310	7
PPE/PA/989	0.9259	1
PPO/PA66	0.9137	5
NY66/40CF	0.9223	2
PPS/40CF	0.9084	6
AR/PC	0.9220	3
PC/PBT	0.9158	4

3.0 RESULTS AND DISCUSSIONS

The results of AHP analysis were obtained from Expert Choice ™ software. The pair-wise comparison of the main criteria with respect to goal is shown in Figure 2. The inconsistency value obtained was 0.03, which was less than 0.1, hence, the judgments were acceptable.

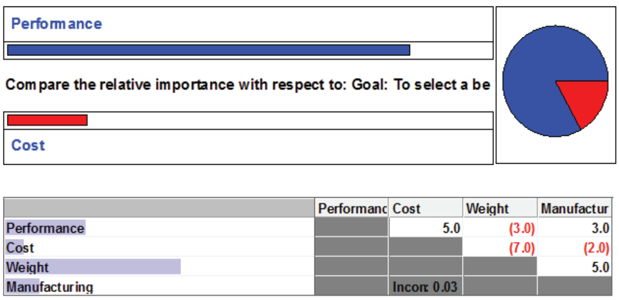

Figure 2: Pair-wise comparison of the main criteria in graphical

The pair-wise comparison for the sub-criteria of Performance and Manufacturing are shown in Figure 3 and Figure 4. The inconsistency values obtained were 0.02 and 0.00 respectively, which were less than 0.1, hence, the judgements were acceptable.

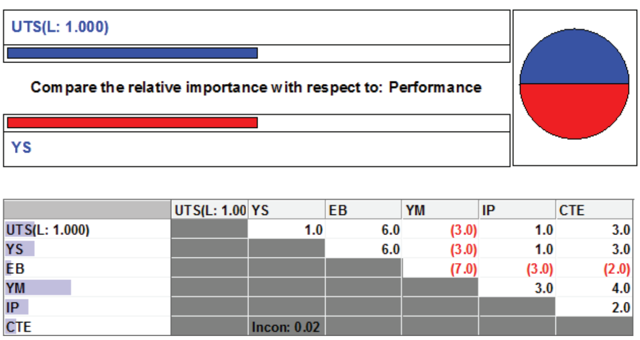

Figure 3: Pair-wise comparison of the Performance sub-criteria

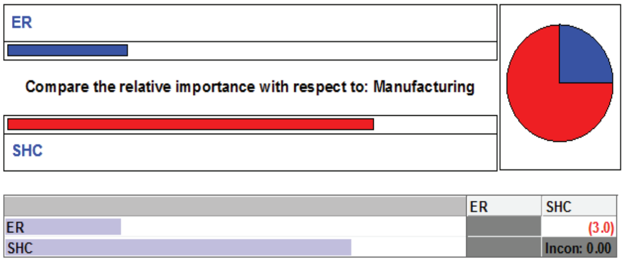

Figure 4: Pair-wise comparison of the Manufacturing sub-criteria

Local Weight (L) represented the priority of each sub-criterion with respect to their corresponding main criteria. Global Weight (G) represented the priority of each sub-criterion with respect to the goal. The Local Weight and Global Weight are shown in Figure 5.

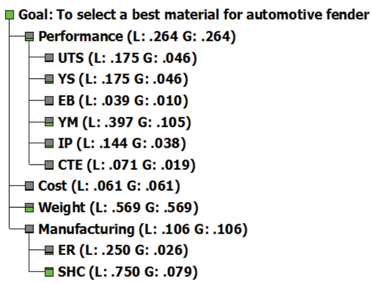

Figure 5: Global weight of the sub-criteria

The overall priority of sub-criteria with respect to goal were Weight (0.569), YM (0.105), SHC (0.079), Cost (0.0610), UTS (0.046), YS (0.046), IP (0.038), ER (0.026), CTE (0.019) and EB (0.010) as shown in Figure 6. The priority vector was the weightage of the sub-criteria with respect to the goal obtained in AHP analysis.

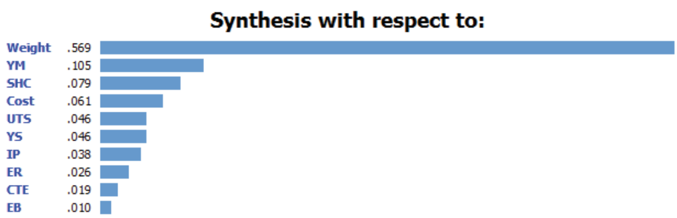

Figure 6: Priority of the sub-criteria with respect to the goal

Finally, the ranking of the alternatives using TOPSIS analysis is shown in Table 17. The alternative at the top of ranking was material PPE/PA/989 with the highest relative closeness of 0.9259. The ranking was followed by NY66/40CF, AR/PC, PC/PBT, PPO/PA66, PPS/40CF, AA6010T4, AA2036T4, D1000DP and D600DP.

Table 17: Ranking of alternatives

Alternatives	Relative Closeness	Ranking
PPE/PA/989	0.9259	1
NY66/40CF	0.9223	2
AR/PC	0.9220	3
PC/PBT	0.9158	4
PPO/PA66	0.9137	5
PPS/40CF	0.9084	6
AA6010T4	0.8310	7
AA2036T4	0.8293	8
D1000DP	0.0927	9
D600DP	0.0759	10

4.0 CONCLUSION

In conclusion, the material selection of the automotive fender was very important. A lightweight material used for the automotive fender could enhance fuel economy, lowered emission and improved driving performance of the automotive vehicle. There are ten (10) important criteria considered in the material selection of the automotive fender such as low weight, high stiffness, high specify heat capacity, low cost, high ultimate tensile strength, high yield strength, high impact strength, low electric resistivity, low coefficient thermal expansion and high elongation at break. Besides that, the integrated AHP-TOPSIS method is successfully proven in multi-criteria decision making processes which involve many criteria and alternatives in the material selection of the automotive fender. From the ten (10) proposed lightweight materials, the PPE/PA/989 resin is selected as the best alternative based on its performance, weight, cost and manufacturing perspective. Indeed, the PPE/PA/989 resin is selected as the best material for the automotive fender using integrated AHP-TOPSIS method.

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REFERENCES

[1] R.V. Rao, "A decision making methodology for material selection using an improved compromise ranking method". *Materials & Design,* Vol. 29, No. 10, pp.1949-1954, 2008.

[2] E.R. Fuchs, F.R. Field, and R.E. Kirchain, "Strategic materials selection in the automobile body: Economic opportunities for polymer composite design". *Composites Science & Technology*, Vol. 68, No. 9, pp. 1989-2002, 2008.

[3] L. Brooke and H. Evans, "Lighten up!". *Automotive Engineering International*, Vol. 117, No. 3, 2009.

[4] A. Mayyas, Q. Shen, A. Mayyas, A. Qattawi and M. Omar, "Using quality function deployment and analytical hierarchy process for material selection of body-in-white". *Materials & Design,* Vol. 32, No. 5, pp.2771-2782, 2011.

[5] T.L. Saaty, *The analytic hierarchy process: planning, priority setting, resources allocation.* New York: McGraw, 1980.

[6] F. Dweiri and F.M. Al-Oqla, "Material selection using analytical hierarchy process". *International Journal of Computer Applications in Technology*, Vol. 26, No. 4, pp. 182-189, 2006.

[7] M.R. Mansor, S.M. Sapuan, E.S. Zainudin, A.A. Nuraini and A. Hambali, "Application of Integrated AHP-TOPSIS Method in Hybrid Natural Fiber Composites Materials Selection for Automotive Parking Brake Lever Component". *Australian Journal of Basic & Applied Sciences*, Vol. 8, No. 5, pp. 431-439, 2014.

[8] C.L. Hwang and K. Yoon, "Multiple criteria decision making". Methods & Applications, Berlin Heidelberg New York, Spinger-Verlag, 1981.

[9] A. Jahan, S.M. Sapuan and F. Mustapha, "Material screening and choosing methods - A review". *Materials & Design*". Vol. 31, pp. 696-705, 2010.

[10] M. Behzadian, S.K. Otaghsara, , M. Yazdani and J. Ignatius. A state-of theart survey of TOPSIS applications". *Expert Systems with Applications*, Vol. 39, No. 17, pp. 13051-13069, 2012.

[11] R. Karim and C.L. Karmaker, "Machine selection by AHP and TOPSIS Methods". *American Journal of Industrial Engineering*, Vol. 4, No. 1, pp. 7-13, 2016.

[12] M. Hanine, O. Boutkhoum, A. Tikniouine and T. Agouti, "Application of an integrated multi-criteria decision making AHP-TOPSIS methodology for ETL software selection". *SpringerPlus*, Vol. 5, No. 1, 2016.

[13] M. C. Lin, C. C. Wang, M. S. Chen and C. A. Chang, "Using AHP and TOPSIS approaches in customer-driven product design process". *Computers in industry*, Vol. 59, No. 1, pp. 17-31, 2008.

[14] L.L.C. MatWeb, "MatWeb: Material Property Data," Available: http://www.matweb.com/