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Simulation Study on Structure Bumper Beam using Finite Element Analysis

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ABSTRACT

One of the main parts of the automotive bumper system is the bumper beam. A bumper beam is a safety feature of a car where it functions to absorb impact energy during a collision. It is important to improve the bumper beam design to improve vehicle safety. The objective of the paper is to investigate the most suitable bumper beam cross-section at the conceptual design stage using finite element analysis (FEA). There are five (5) conceptual designs with different types of cross-sections that have been proposed to evaluate its energy absorption analysis through ANSYS LS DYNA software. The indicators considered in evaluating and determining the best design are energy absorption, specific energy absorption (SEA) and deformation of the bumper beam after crashed. For the selection process, six bumper beam structures have been considered. Analytical hierarchy process and Technique for Order of Preference by Similarity to Ideal Solution (AHP-TOPSIS) method was employed to determine the best design through identified product design specification (PDS) of frontal low-speed impact low carbon steel bumper beam. Through the seven elements identified in product design specification (PDS) using the AHP-TOPSIS method, conceptual design 4 (CD-4) bumper beam was the best bumper beam design with a Relative closeness coefficient (Ci) value of 0.564.

Keywords: Bumper beam, energy absorption, Finite Element Analysis (FEA)

1. INTRODUCTION

The bumper system is a car component located at the front and back of a car which is the function to protect the car body and passengers during a crash. A front bumper system consists of three main components which are namely fascia, absorber and bumper beam as shown in Figure 1 [1]. The fascia cannot tolerate impact energy, so it is considered a non-structural component. It is usually used for aesthetics and for decreasing the aerodynamic drag force. The absorber is designed to dampen a portion of the kinetic energy from a collision. The bumper beam is a key structure that helps to absorb the kinetic energy from a high-impact collision and to provide bending resistance in a low-impact collision [2]. It absorbs the impact collision energy in a controlled manner before the energy gets transferred to the passenger compartment.

Nowadays vehicles are used extensively thus the research related to the crash safety issue in the automotive industry is explored by many researchers. The crash safety issue is the main contribution of the bumper beam structure study. When the vehicle is suspended to sudden or

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impact loads by any collision, then a bumper beam is used to absorb that impact energy and is helpful for the safety of the passengers as well as for the vehicle. Godara and Nagar [3] investigated the structure of the bumper beam by designing eight different types of cross-sections. The crash safety issue of bumper beam structure is also addressed by Zhu *et al*. [4] and Godara and Nagar [5]. The cross-section structure of the bumper beam affects the performance of the bumper beam in absorbing the impact energy. The effect of the bumper beam cross-section structure for the bumper beam in absorbing the energy to protect the vehicle during the crash, however, is also less discussed.

Structural crashworthiness is an essential requirement in the design of automobiles. Crashworthiness refers to the response of a vehicle when it is involved in or undergoes an impact. A good crashworthiness performance is where less damage to the vehicle and passengers after a crash. Analyzing the energy absorption in real impact is quite complicated. Finite element analysis (FEA) is a suitable method to analyze the energy absorption during impact to determine the approximate impact behavior deflection during an impact. Park *et al*. [6] compared intermediate response surface modeling (IRSM) with a finite element model. The studies developed an optimized bumper beam cross-section that satisfies both the safety requirements for a front rigid-wall impact and lower leg injuries in a pedestrian impact test and the results obtained between the two models did not exceed 3% error of maximum displacement.

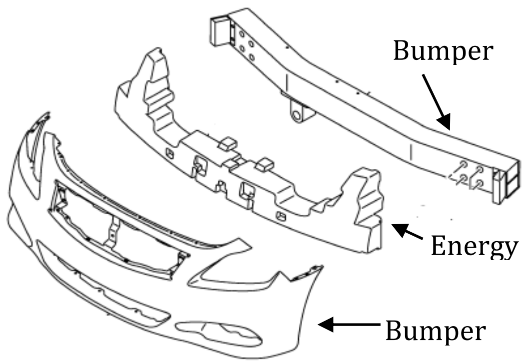

Figure 1. Bumper system [1].

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FEA analysis is performed before conducting the real test performance of impact test in which this can save the time, cost and speed up an engineering change of an existing product problem or optimize the design. The result obtained by simulation also agrees fairly with the results obtained from the experimental [7,8]. Zhang *et al*. [9] studied the overall deformation of the finite element model and experiments in terms of collapse mode and number of folds is in good agreement.

The studies have proven foam-filled thin-walled composite structures to be an ideal energy absorber for their extraordinary energy absorption ability and lightweight features. Kathiresan *et al*. [10] studied the crashworthiness of glass fibre/epoxy laminated thin-walled composite. The results showed that energy absorption predicted by numerical analysis or finite element analysis (FEA) mostly matched with experimental results. Hosseinzadeh *et al*. [11] studied impact modelling of a commercial front bumper beam made of glass mat thermoplastic (GMT) using ANSYS LS-DYNA 5.7 subjected to low-velocity impacts. Wang and li [12] studied by changing the material and thickness of bumper beam to improve the crashworthiness performance in low-velocity impact simulation based on finite element analysis. Ranjithkumar and Ramesh [13] studied four variables namely material, structures, shapes and impact conditions for analyzing the bumper beam during a collision to improve the crashworthiness using Pro/Engineer software.

Energy absorption, specific energy absorption and deformation are the factors considered in determining the best design concept of the bumper beam. Energy absorption ability is a very important factor in designing bumper beam. During the impact, energy absorption occurs where the kinetic energy changes form into the internal energy of a system. Deformation of the bumper beam is the result of energy being absorbed by the bumper beam during the impact process. Specific energy absorption (SEA) is an indicator used to measure crashworthiness [10]. It denotes the energy absorbed per unit mass of the absorber, which can be calculated as as $\mathrm{SEA} = \frac{\mathrm{EA}}{\mathrm{M}}$where M represents the total mass of the structure and EA represents the Energy absorption. Energy absorption capability is better when the value of SEA is higher [12].

2. MATERIALS AND METHOD

2.1 Bumper Beam Design - Existing design

The bumper beam part consists of the beam and two holders, which help the beam attach to the mainframe of the vehicle body. The material of the bumper beam was made of low carbon steel with 1.2 mm thickness and the designs of the beam are open section. The 3D modeling of bumper beam design was remodelled as similar as possible using Solidworks software as depicted in Figure 2.

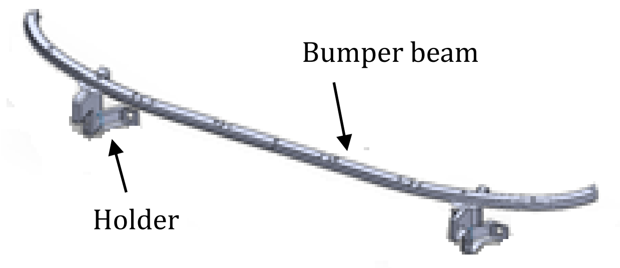


Figure 2. Existing bumper beam.

2.2 Conceptual Design Bumper Beam

There are five conceptual designs (CD) of bumper beams were proposed as shown in Figure 3. All the conceptual design of the bumper beam was designed with curved from end-to-end to allow deflection when impact without damaging the structure behind the bumper beam.

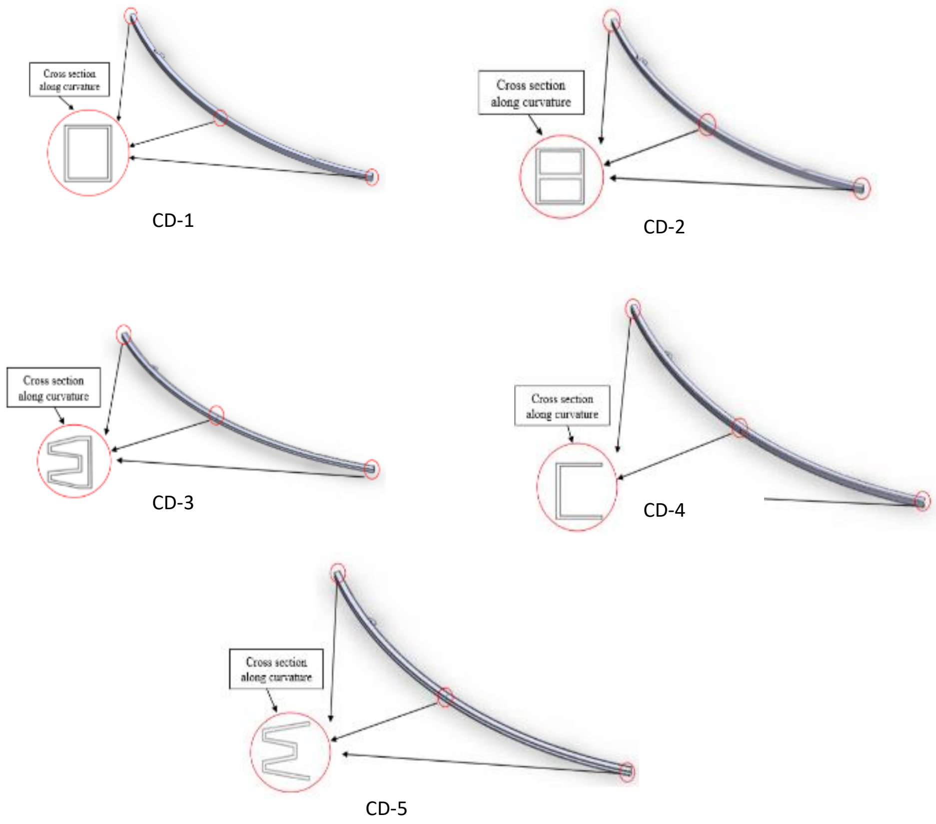


Figure 3. Five conceptual designs (CD) of bumper beams.

Table 1 Bumper Beam Design Profile

Conceptual Design (CD)	Cross-Section	Type of Cross-Section	Weight (kg)	Description
CD-1		Closed section	1.3659	Rectangular shape cross section bumper beam. The design does not require reinforcement inserts to enhance crash performance.
CD-2		Closed section	1.4834	Double rectangular shape cross- section bumper beam. The design does not require reinforcement inserts to enhance crash performance.
CD- 3		Closed section	1.641	B-shaped cross-section bumper beam. The design does not require reinforcement inserts to enhance crash performance.
CD-4		Open section	0.9705	C shaped cross-section bumper beam. The design does not require reinforcement inserts to enhance crash performance.
CD-5		Open section	1.3029	Double C shaped cross-section bumper beam. The design does not require reinforcement inserts to enhance crash performance.

The 3D modeling of the conceptual design of bumper beams was designed using Solidworks software then exported to ANSYS LS DYNA software to simulate the frontal low-speed impact. Table 1 shows the summary of the bumper beam design profile of the conceptual design of the bumper beam with the different types of the cross-section.

2.3 Simulation

The simulation of frontal low-speed impact consists of three parts which are bumper beam, holder and impactor. The bumper beam is attached to the two holders. Figure 4 shows the impact layout of the simulation. An impactor with a weight of 1000 kg and a speed of 4 km/h impact was applied at the middle of the bumper beam with a thickness of 1.2 mm. The frontal low-speed impact simulation was simulated according to Economic Commission for Europe (ECE) Regulation No 42 using ANSYS LS DYNA software [15]. According to the ECE regulation, the mass of the impactor should be equal to the mass of a car. Therefore, the density of steel for the impactor and holder has been modified to make it equal to the mass of a car. To determine the energy absorption of the bumper beam, the impactor and holder were modelled as rigid structures without energy absorption capability. The model design of the bumper beam in this study was made of low carbon steel material and both holder and impactor were made of steel. Table 2 shows the materials properties of steel and low carbon steel. The flow of simulation using finite element analysis is depicted in Figure 5.

Table 2 Material Properties of Steel (ANSYS library) and Low Carbon Steel [16]

Components	**Materials**	**Density (kg/m3)**	**Young Modulus (GPa)**	**Poisson's Ratio**	**Shear Modulus (GPa)**	**Bulk Modulus (GPa)**
Bumper beam	Low carbon steel	7872	205	0.29	79	167
Impactor and holder	Steel	17387	210	0.3	80.769	175

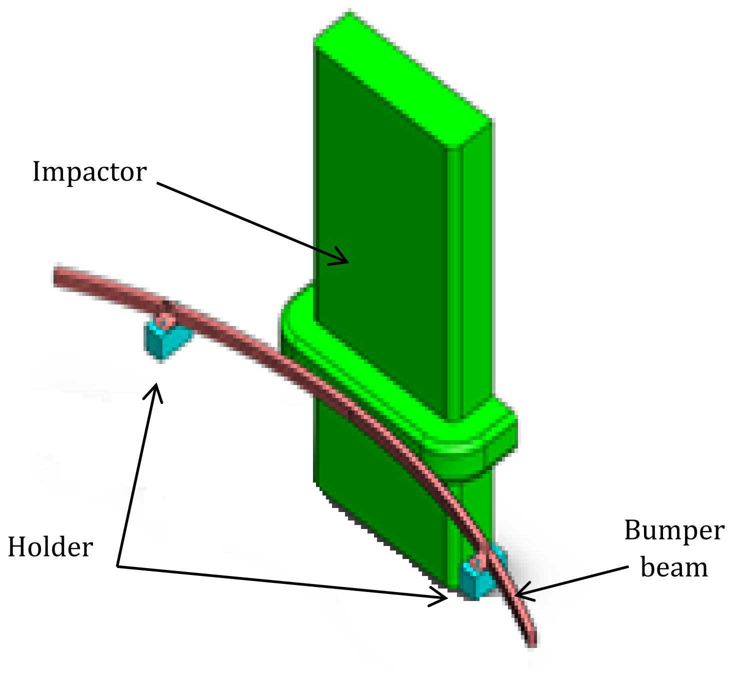


Figure 4. Low speed impact layouts.

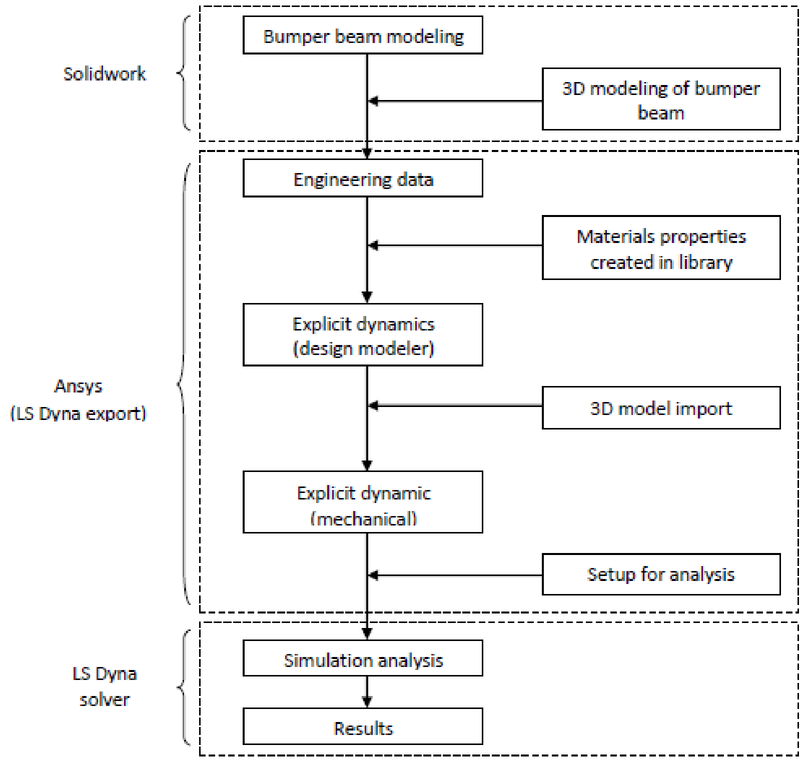


Figure 5. Flow of finite element analysis.

2.4 Concept Selection

A new product design specification (PDS) list for the automotive composite bumper beam was identified through journals, patents and safety standards for crash impact. Product design specification (PDS) contained the information for the development and selection of the best design concept of the bumper beam. Seven (7) elements of the product design specification (PDS) were considered in the design of the automotive bumper beam which are performance, weight, standard, size, shape, patent and materials.

The integrated method of AHP-TOPSIS was applied to select the best bumper beam design. Weights for selected criteria are determined using the AHP method, and then using the TOPSIS method to rank the alternatives. Figure 6 shows the process of the AHP-TOPSIS method to evaluate and select the best design. The steps of the concept selection are as follows:

Step 1 : Define criteria and sub-criteria
Step 2 : Construct a hierarchy decision model for the problem.
Step 3 : Determine the comparison matrix to obtain the weight of each criterion and sub-criteria using the AHP technique.
Step 4 : Determine the global weight by normalizing the local weight.
Step 5 : Use the TOPSIS technique to assess the alternatives where the most appropriate one can be easily selected.
Step 6 : Select the best alternative.

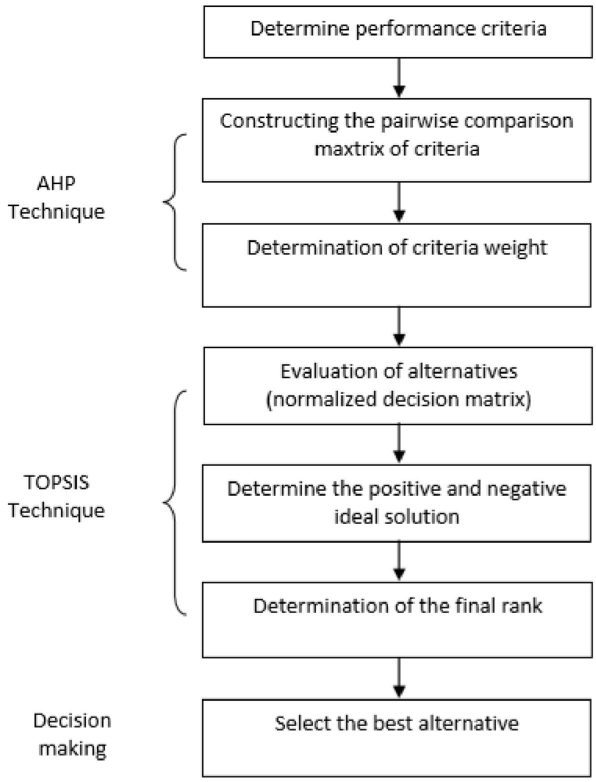
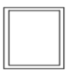
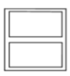
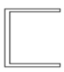


Figure 6. Process of the AHP-TOPSIS method to evaluate and select the best design.

3. RESULTS AND DISCUSSION

Table 3 shows the summary of results obtained of frontal low speed impact simulation for low-carbon steel bumper beam.

Table 3 Summary Results

Bumper Beam Design	Cross Section	Cross Section Type	Energy Absorption (J)	Weight (kg)	SEA (J/kg)	Deflection (mm)
CD-1		Closed section	509.96	1.3659	373.35	9.61
CD-2		Closed section	485.58	1.4834	327.34	9.58
CD-3		Closed section	491.98	1.641	299.80	11.46
CD-4		Open section	487.89	0.9705	502.81	12.18
CD-5		Open section	500.75	1.3029	384.33	12.10
Existing (CD-6)		Open section	569.79	1.14	499.82	13.76

In this study, the existing design bumper beam is better in absorbing the impact energy. The existing bumper beam absorbs 92.5% (569.79 J) of kinetic energy throughout the impact process. Energy absorbs by the conceptual bumper beam are 78 % to 83 % of the total kinetic energy throughout the impact process. Compared with the conceptual bumper beam, the closed section bumper beam is slightly better at absorbing the impact energy. Closed section bumper beam absorbs the highest impact energy. From an engineering standpoint, the closed section bumper beam is more rigid and capable of absorbing more energy on impact whereas the open section bumper beam is less rigid. Open section bumper beam is prematurely deformed during impact where it spread apart and its structure starts changing shaped upon impact [17]. Conceptual design 1 (CD-1) is the best design concept among the five conceptual designs. CD-1 low carbon steel bumper beam absorbs 82.79 % (509.96 J) of the impact energy. Figure 7 shows the results of energy absorption and their percentage.

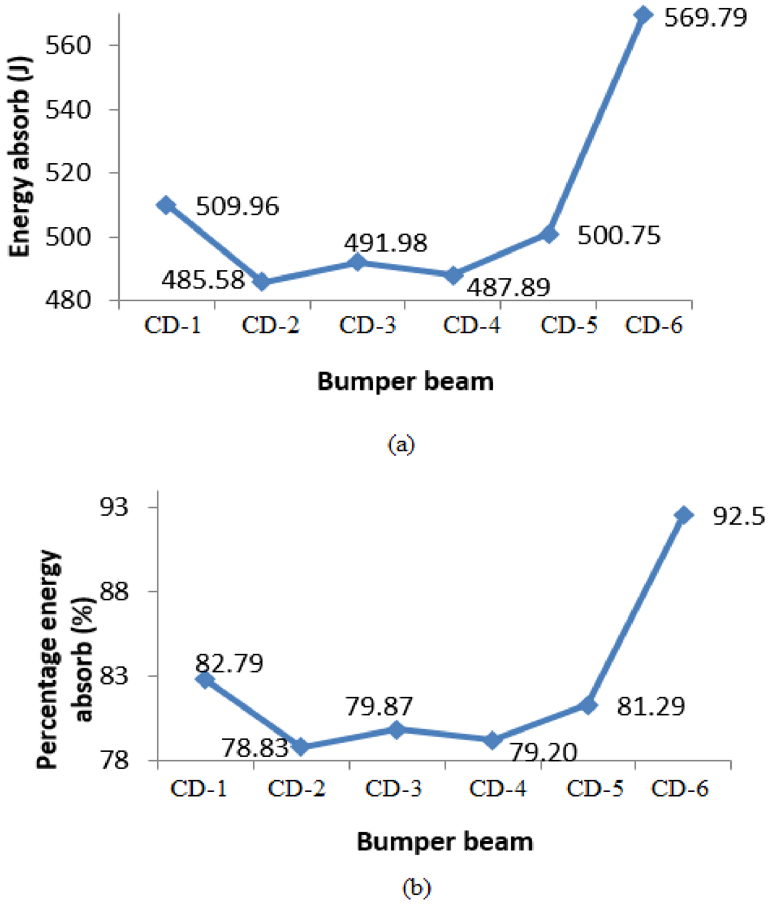


Figure 7. (a) Energy absorption (b) Percentage of energy absorb.

Another indicator to determine the effectiveness of energy absorption is specific energy absorption (SEA). Energy absorption of the bumper beam is measured by specific energy absorption (SEA), which is the total energy absorbed per unit mass. Figure 7 shows the results of specific energy absorption (SEA) for each bumper beam. Open section C4 bumper beam has the highest specific energy absorption (SEA) compared to the rest of the bumper beam designs. From the lightweight scope, conceptual design 4 (CD-4) design of low carbon steel is the best design in absorbing impact energy because of the lightest in weight compared to the other bumper beam designs.

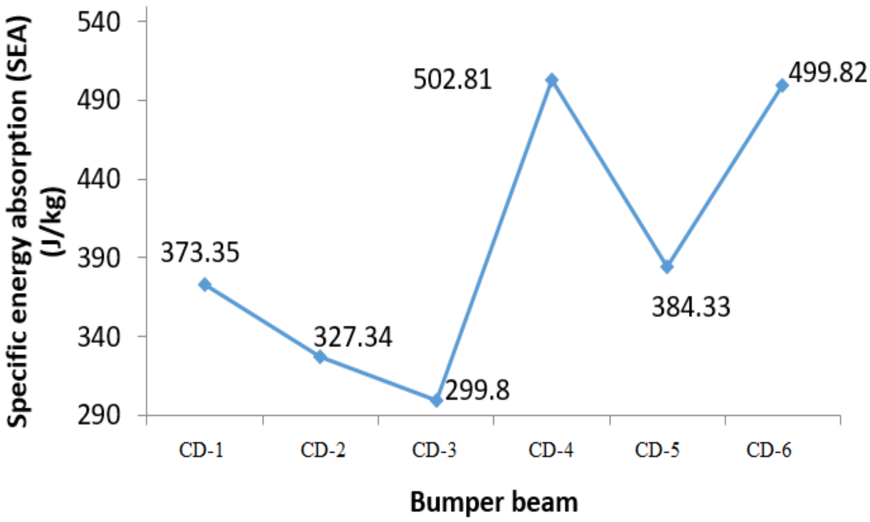


Figure 7. Specific energy absorption (SEA).

In general, local bending is experienced in Region A; deformation occurs at Region B. Figure 9 shows an example deformation of the bumper beam at the maximum deflection. Both open and closed section bumper beams deform during impact where the structure starts deflecting inward as the impact occurs (Region A), but for the open section, the bumper beam starts to crumble near the holder (Region B). The closed section bumper beam does not show visible deformation area in Region B because the structures of the bumper beam have to provide support and prevent deformations.

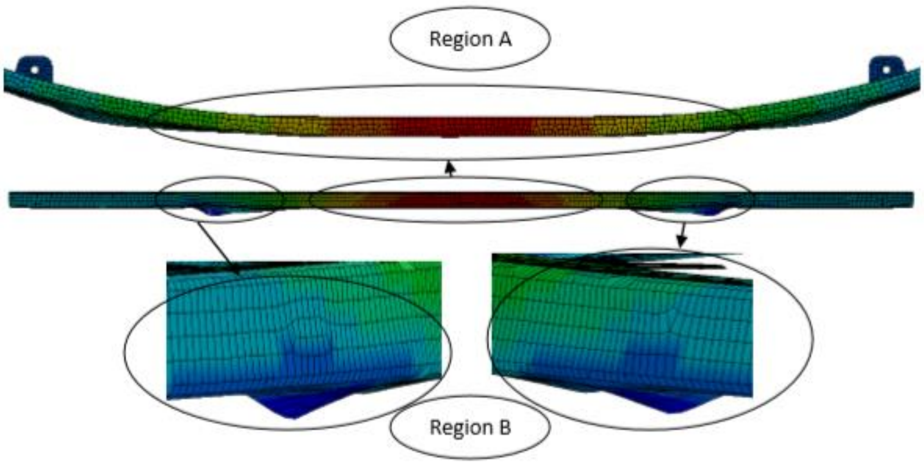


Figure 9. Deformation area of CD-4.

Figure 10 shows the deflection results of the impact simulation. The existing bumper beams have the highest deflection compared with the conceptual design of the bumper beam. All the bumper beams are deflecting within the limit set.

Through product design specification (PDS) criteria, the best conceptual design of the automotive bumper beam is determined using the AHP-TOPSIS method. The first stage is to define criteria and sub-criteria which consists of seven main criteria; performance, weight, standard, size, shape, patent, material and their sub-criteria are defined. The second stage is to construct a hierarchy decision model for the problem. The mentioned seven main criteria are segregated into sub-criteria as shown in Figure 11.

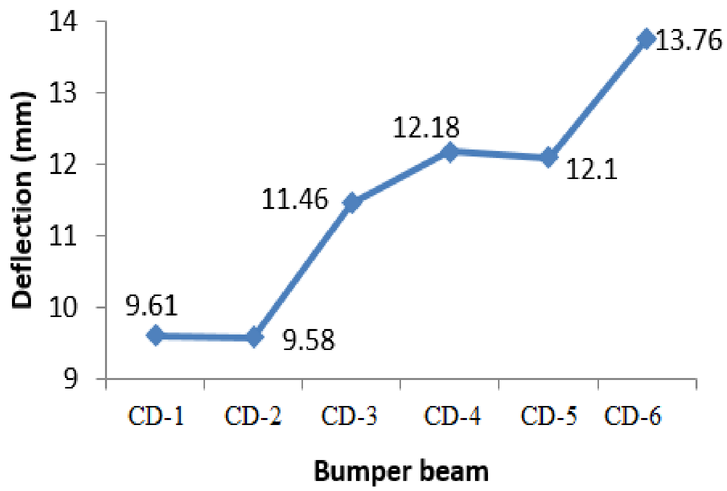


Figure 10. Bumper beam deflection.

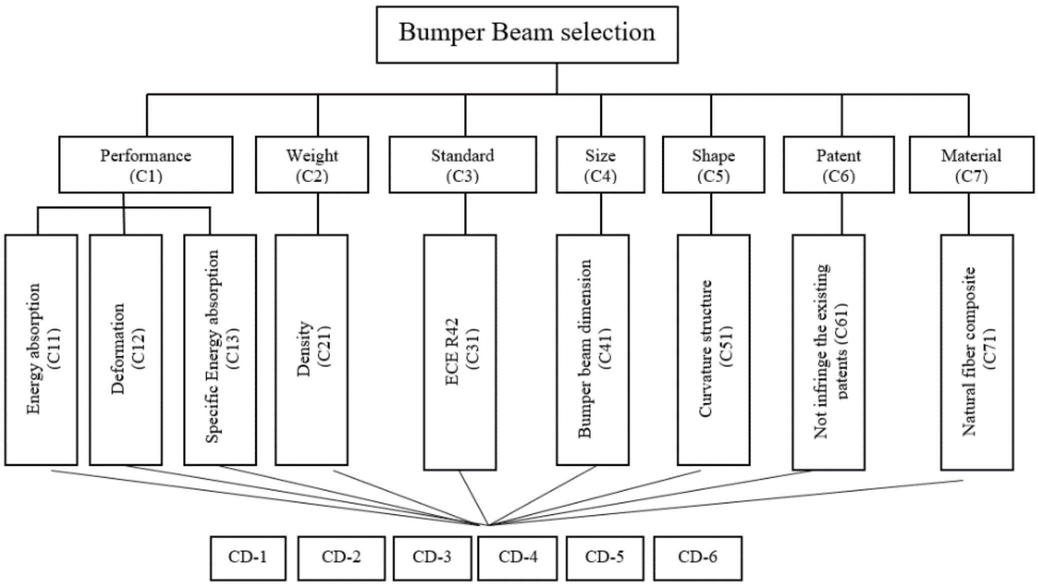


Figure 11. Hierarchy model of bumper beam selection.

The third step is to determine the comparison matrix to obtain the weight of each criterion and sub-criteria using AHP technique. Once the hierarchy has been constructed, the next step is to obtain the weights of elements at each level of the hierarchy. A set of comparison matrices of all elements for each level of the hierarchy with respect to the elements of the higher level are determined. The decision-makers are identified using Saaty scale [18] as shown in Table 4. The initial pairwise comparison matrix for the main criteria is presented in Table 5. Pairwise comparison starts by comparing the relative importance of two selected items. To do pairwise comparison, for example, as shown in Table 5, if C1 is strongly more essential over C2, then the value is equal to 5. Reciprocals are automatically assigned to each pairwise comparison. Table 6 shows the synthesized matrix for the criteria results.

Table 4 Scale of Pairwise Comparison for AHP [18]

Relative Intensity	Definition
1	Equally important
3	Weakly important
5	Strongly important
7	Very strongly important
9	Extremely important

Table 5 Pairwise Comparison of Criteria with Respect to Overall Goal

Goal	C1	C2	C3	C4	C5	C6	C7
C1	1	5	5	5	3	3	3
C2	1/5	1	3	3	3	3	1
C3	1/5	1/3	1	3	3	1	1/3
C4	1/5	1/3	1/3	1	1	1	1/3
C5	1/3	1/3	1/3	1	1	1/3	1
C6	1/3	1/3	1	1	3	1	1
C7	1/3	1	3	3	1	1	1
Total	2.600	8.333	13.667	17.000	15.000	10.333	7.667

Table 6 Synthesized Matrix for The Criteria

Criteria	C1	C2	C3	C4	C5	C6	C7	Total Row	Weight
C1	0.385	0.600	0.366	0.294	0.200	0.290	0.391	2.526	0.361
C2	0.077	0.120	0.220	0.176	0.200	0.290	0.130	1.214	0.173
C3	0.077	0.040	0.073	0.176	0.200	0.097	0.043	0.707	0.101
C4	0.077	0.040	0.024	0.059	0.067	0.097	0.043	0.407	0.058
C5	0.128	0.040	0.024	0.059	0.067	0.032	0.130	0.481	0.069
C6	0.128	0.040	0.073	0.059	0.200	0.097	0.130	0.727	0.104
C7	0.128	0.120	0.220	0.176	0.067	0.097	0.130	0.938	0.134
								∑	1

The weight can be calculated using equation;

$$W_i = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ij}}{\sum_i^n a_{ij}} \quad (1)$$

For example, the calculation for the first weight is as followed.
Firstly, $\sum_i^n a_{ij}$ hence, 1 + 1/5 + 1/5 + 1/5 +1/3 + 1/3 + 1/3 = 2.600.

Secondly, $\frac{a_{ij}}{\sum_i^n a_{ij}}$ hence, 1/2.600= 0.385.

Thirdly, $\sum_{j=1}^n \frac{a_{ij}}{\sum_i^n a_{ij}}$ hence, 0.356 + 0.051 + 0.119+ 0.119+ 0.119+0.119 = 2.526.

Finally, divide this sum by the number of elements (n = 7) hence, 2. 526 /7 = 0.361.

To guarantee the judgments are consistent, a consistency ratio (CR) is determined. Consistency ratio (CR) is the ratio of consistency index (CI) to random index (RI) for the same order matrices. The CR can be calculated using the formula:

CR = CI/RI (2)

CI= $(\lambda_{max} - n)/(n-1)$ (3)

To calculate $\boldsymbol{\lambda_{max}}$, multiply on the right matrix of judgements by the weight, obtaining a new weight. Calculated new weight is shown in Table 7. Table 8 to Table 11 show the calculation and the results for C1 sub-criteria.

Table 7 Consistency Test for the Criteria

Goal	C1	C2	C3	C4	C5	C6	C7	Weight	New Weight	New Weight /Weight		
C1	1	5	5	5	3	3	3	0.361	2.943	8.156	Consistency index CI = (λmax −n)/(n−1)	0.122
C2	1/5	1	3	3	3	3	1	0.173	1.375	7.929		
C3	1/5	1/3	1	3	3	1	1/3	0.101	0.760	7.527		
C4	1/5	1/3	1/3	1	1	1	1/3	0.058	0.439	7.550	Consistency Ratio CR = CI/RI	0.092
C5	1/3	1/3	1/3	1	1	1/3	1	0.069	0.507	7.385		
C6	1/3	1/3	1	1	3	1	1	0.104	0.781	7.518		
C7	1/3	1	3	3	1	1	1	0.134	1.078	8.042		
								Total		54.106		
								λmax		7.729		

Table 8 Pairwise Comparison of Criteria with Respect to Sub-criteria C1

Criteria (C1)	C11	C12	C13
C11	1	7	5
C12	1/7	1	1
C13	1/5	1	1
Total	1.343	9.000	7.000

Table 9 Synthesized Matrix for the Criteria

Criteria (C1)	C11	C12	C13	Total Row	Weight
C11	0.745	0.778	0.714	2.237	0.746
C12	0.106	0.111	0.143	0.360	0.120
C13	0.149	0.111	0.143	0.403	0.134
				∑	1

Table 10 Calculation to Get a New Weight

							New Weight
0.746	1	0.120	7	0.134	5	=	2.258
	1/7		1		1		0.361
	1/5		1		1		0.404

Table 11 Consistency Test for the Criteria

Criteria (C1)	C11	C12	C13	Weight	New Weight	New Weight /Weight		
C11	1	7	5	0.746	2.258	3.028	CI = (λmax − n)/(n−1)	0.006
C12	1/7	1	1	0.120	0.361	3.005		
C13	1/5	1	1	0.134	0.404	3.005	CR = CI/RI	0.011
					Total	9.038		
					λmax	3.013		

Step 4: Determine the global weight by normalizing the local weight.

The global weight by normalizing the local weight is determined as depicted in Table 12.

Table 12 The Normalized Sub-Criteria Weightings

Criteria	Level One	Sub Criteria	Level 2
Performance (C1)	0.333	Energy absorption (C11)	0.248
		Specific energy absorption (SEA) (C12)	0.040
		Deformation (C13)	0.045
Weight (C2)	0.186	Density (C21)	0.186
Standard (C3)	0.118	ECE R42 (C31)	0.118
Size (C4)	0.076	Dimension (C41)	0.076
Shape (C5)	0.096	Curvature (C51)	0.096
Patent (C6)	0.096	Not infringe the existing patent (C61)	0.096
Material (C7)	0.096	Composite material (C71)	0.096

Step 5: Use the TOPSIS technique to assess the alternatives where the most appropriate one can be easily selected. The weighted from AHP method is used in TOPSIS in order to determine the best alternatives. Normalized decision matrix was obtained by calculating divided input value with $\sqrt{\sum_{i=1}^{m}[g_{\mathrm{i}}(a_i)]^2}$ each column. Table 13 to Table 15 show the calculated normalized decision matrix. Then, weight normalized decision matrix are obtained by multiply normalized decision matrix and weight. Table 16 shows the calculated weight normalized decision matrix. Positive (D_i^*) and negative (D_i^-) ideal solutions are then determined by using

$D_i^* = \sqrt{\sum_{j=1}^{n}\left(e_{ij}^* - e_{j*}\right)^2}$, $D_i^- = \sqrt{\sum_{j=1}^{n}\left(e_{ij}^* - e_{j*}\right)^2}$, and the results as depicted in Table 17 and Table 18.

Table 13 Input Values of the TOPSIS Analysis

Criteria	Weight	A1	A2	A3	A4	A5	A6
C11	0.248	9	9	8	8	8	9
C12	0.040	7	7	6	9	7	8
C13	0.045	9	9	7	7	7	6
C21	0.186	7	7	6	9	7	7
C31	0.118	9	9	9	9	9	9
C41	0.076	9	9	9	9	9	9
C51	0.096	9	9	9	9	9	9
C61	0.096	9	9	9	9	9	9
C71	0.096	9	9	9	9	9	9

Table 14 Input Values of the TOPSIS Analysis

Criteria	Weight	A1	A2	A3	A4	A5	A6
C11	0.248	81	81	64	64	64	81
C12	0.040	49	49	36	81	49	64
C13	0.045	81	81	49	49	49	36
C21	0.186	49	49	36	81	49	49
C31	0.118	81	81	81	81	81	81
C41	0.076	81	81	81	81	81	81
C51	0.096	81	81	81	81	81	81
C61	0.096	81	81	81	81	81	81
C71	0.096	81	81	81	81	81	81
	$\sum$	665	665	590	680	616	635
	$\sqrt{\sum_{i=1}^{m}[g_{\mathrm{i}}(a_i)}$	25.7876	25.7876	24.2899	26.0768	24.8193	25.1992

Table 15 The Normalized Decision Matrix

Criteria	A1	A2	A3	A4	A5	A6
C11	0.349	0.349	0.329	0.307	0.322	0.357
C12	0.271	0.271	0.247	0.345	0.282	0.317
C13	0.349	0.349	0.288	0.268	0.282	0.238
C21	0.271	0.271	0.247	0.345	0.282	0.278
C31	0.349	0.349	0.371	0.345	0.363	0.357
C41	0.349	0.349	0.371	0.345	0.363	0.357
C51	0.349	0.349	0.371	0.345	0.363	0.357
C61	0.349	0.349	0.371	0.345	0.363	0.357
C71	0.349	0.349	0.371	0.345	0.363	0.357

Table 16 The Weight Normalized Decision Matrix

Criteria	A1	A2	A3	A4	A5	A6		A+	A-
C11	0.087	0.087	0.082	0.076	0.080	0.089	+	0.089	0.076
C12	0.011	0.011	0.010	0.014	0.011	0.013	+	0.014	0.01
C13	0.016	0.016	0.013	0.012	0.013	0.011	+	0.016	0.011
C21	0.050	0.050	0.046	0.064	0.052	0.052	+	0.064	0.046
C31	0.041	0.041	0.044	0.041	0.043	0.042	+	0.044	0.041
C41	0.027	0.027	0.028	0.026	0.028	0.027	+	0.028	0.026
C51	0.033	0.033	0.035	0.033	0.035	0.034	+	0.035	0.033
C61	0.033	0.033	0.035	0.033	0.035	0.034	+	0.035	0.033
C71	0.033	0.033	0.035	0.033	0.035	0.034	+	0.035	0.033

Table 17 Determine Separation from Ideal Solution

Criteria	A1	A2	A3	A4	A5	A6
C11	0.00000527	0.00011458	0.00005151	0.00016344	0.00007962	0.00000007
C12	0.00000983	0.00000075	0.00001692	0.00000003	0.00000735	0.00000167
C13	0.00000015	0.00002133	0.00000963	0.00001590	0.00001142	0.00002857
C21	0.00018371	0.00001977	0.00032741	0.00000002	0.00013424	0.00015317
C31	0.00000874	0.00000000	0.00000018	0.00001164	0.00000184	0.00000399
C41	0.00000172	0.00000048	0.00000011	0.00000258	0.00000007	0.00000047
C51	0.00000265	0.00000014	0.00000019	0.00000399	0.00000011	0.00000072
C61	0.00000265	0.00000014	0.00000019	0.00000399	0.00000011	0.00000072
C71	0.00000265	0.00000014	0.00000019	0.00000399	0.00000011	0.00000072
$\sum_{j=1}^{n}\left(e_{ij}^{*}-e_{j*}\right)^2$	0.00021735	0.00015732	0.00040633	0.00020556	0.00023484	0.00019010
$\sqrt{\sum_{j=1}^{n}\left(e_{ij}^{*}-e_{j*}\right)^2}$	0.01474275	0.01254279	0.02015767	0.01433744	0.01532465	0.01378763

Table 18 Determine Separation from Negative Ideal Solution

Criteria	A1	A2	A3	A4	A5	A6
C11	0.00011458	0.00011458	0.00003390	0.00000005	0.00001662	0.00016203
C12	0.00000075	0.00000075	0.00000001	0.00001454	0.00000166	0.00000732
C13	0.00002133	0.00002133	0.00000360	0.00000103	0.00000263	0.00000012
C21	0.00001977	0.00001977	0.00000001	0.00032905	0.00004114	0.00003163
C31	0.00000000	0.00000000	0.00000663	0.00000017	0.00000271	0.00000100
C41	0.00000048	0.00000048	0.00000546	0.00000016	0.00000300	0.00000172
C51	0.00000014	0.00000014	0.00000591	0.00000000	0.00000281	0.00000133
C61	0.00000014	0.00000014	0.00000591	0.00000000	0.00000281	0.00000133
C71	0.00000014	0.00000014	0.00000591	0.00000000	0.00000281	0.00000133
$\sum_{j=1}^{n}\left(e_{ij}^{*}-e_{j*}\right)^{2}$	0.00015732	0.00015732	0.00006734	0.00034499	0.00007618	0.00020781
$\sqrt{\sum_{j=1}^{n}\left(e_{ij}^{*}-e_{j*}\right)^{2}}$	0.01254279	0.01254279	0.00820616	0.01857390	0.00872797	0.01441572

Step 6: Select the best alternative.

Relative closeness coefficient (C_i) of the alternative to the ideal solution using $C_i^* = \frac{D_i^-}{D_i^+ + D_i^-}$ and rank all alternatives based on decreasing values of C_i and selecting the optimal one. Table 19 shows the final evaluation and ranking of alternatives. The best alternative is CD-4 with the shortest distance to the positive ideal solution and with the longest distance to the negative ideal solution. The proposed model results show that Design concept 4 (CD-4) bumper beam is the best design with C_i value of 0.564.

Table 19 The Final Evaluation and Ranking of Alternatives

	D+	D-	Ci	Rank
CD-1	0.015	0.013	0.460	4
CD-2	0.013	0.013	0.500	3
CD-3	0.020	0.008	0.289	6
CD-4	0.014	0.019	0.564	1
CD-5	0.015	0.009	0.363	5
CD-6	0.014	0.014	0.511	2

4. CONCLUSION

Integrated AHP and TOPSIS were explored in this paper. Four criteria that influence the energy absorption were considered which are cross-section, material, wall thickness and rib. These four criteria were employed to come out with six different types of the cross-section of bumper beam design. The designs were simulated according to the Economic Commission for Europe (ECE) Regulation No 42. Specific energy absorption (SEA) was used to observe the energy absorption. The best conceptual design of the automotive bumper beam was determined using the integrated AHP-TOPSIS method. The result showed that conceptual design 4 (CD-4) with a Relative closeness coefficient (C_i) value of 0.564. was the best design as it has the highest C_i compared to the others bumper beam design.

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