DEVELOPMENT OF CONCEPTUAL DESIGN OF AUTOMOTIVE BUMPER BEAM AT THE CONCEPTUAL DESIGN STAGE

[1] Hambali, A, [2] Sapuan, S.M, [3] Tajul A.A and [4] Taufik

[1,3,4] Department of manufacturing design,
Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia, Melaka

[2] Department of Mechanical and Manufacturing Engineering,
Universiti Putra Malaysia, 43400 UPM,
Serdang, Selangor, Malaysia.

Author's Email: Hambali@utem.edu.my

ABSTRACT: Development of a given engineering automotive component is a crucial process. Determining various factors that influence the development process of product is very important. This paper presents the development of automotive bumper beam at the conceptual design stage. The total design approach was employed to generate and design the conceptual design of automotive bumper beam. Analytical hierarchy process (AHP) was used to assist designers in determining the most appropriate decisions at the conceptual design stage. The paper reveals that the design concept 6 (DC-6) with a weight of 0.191 (19.1%) is the most appropriate decision during the development process at the conceptual design stage.

Keywords: Automotive bumper beam, conceptual design stage, integrated method

1.0 INTRODUCTION

Bumper systems are the first safety systems encountered during front and rear collisions. Automotive bumper systems are designed to protect or reduce physical damage to the front and rear ends of passenger motor vehicles in low-speed collisions (Mohapatra, 2005). In general, the bumper system is divided into four basic components namely bumper fascia, energy absorber, bumper beam and bumper stay (Lee and Bang, 2006). However, in this paper, the focus is only on the development of automotive bumper beam. The development of automotive bumper beam is important because it plays the important role in absorbing the bulk of energy and providing protection to other part of the vehicle during collision (Yim et al., 2005). The development of automotive bumper beam in terms of its initial shape or conceptual design is less explored by researchers in the literature. Many researchers have addressed the development of automotive bumper beam at the detail stage in the literature. Cheon et al. (1995) described the development of the composite bumper beam for a passenger car. In their work, various design activities which normally carried out at the detail stage such as 3D modeling, design analysis using finite elements software and mould analysis were performed to investigate the parameters that used to develop composite bumper beam. Yamaguchi et al. (2008a) and Yamaguchi et al. (2008b) developed automotive bumper beam by improving its cross-sections in order to improve a bending strength while minimizing the increase in weight. Hosseinzadeh et al. (2005) and Marzbanrad et al. (2009) studied and analyzed various parameters including material, thickness, shape and impact condition during the development of automotive bumper beam in order to improve the crashworthiness design in low-velocity impact. The articles discussed above presented that the development of automotive bumper beam have focused on the development of automotive bumper beam at the detail stage for improving impact performance without presenting any initial designs or conceptual designs.

The development of automotive composite bumper beam by considering the right material has been discussed by many researchers in the literature. However, more works focused in the development of automotive bumper beam from metal materials such as aluminium and steel (Schuster, 2006). Using composite materials in the development of automotive bumper beams is also discussed. Mohan (1987) used glass fibre reinforced polypropylene in the development of automotive bumper beam. Clark et al. (1991) used 40 % glass fibre reinforced polypropylene and described their extensive work on the stress contour of the bumper beams design. Cheon et al. (1995) developed the composite bumper beam for a passenger car using glass fibre epoxy composite material with the exception of the elbow section. The elbow section was made of carbon fibre epoxy composite materials. According to Murphy (1998), front and rear bumper beams of some General Motors models are generally made of 60% glass fibre vinylester SMC, reinforced with a newly developed chopped and continuous strand glass fibre giving strength in all directions. Moinar (1987) employed composite material namely glass fibre embedded with a thermosetting isopolyester resin matrix to produce the composite bumper beam. Kelman and Nelson (1998) used composite materials consist of fibreglass preform and two-component urethane based resin polyol and isocyanate to manufacture the composite bumper beam. Okumura et al. (1989) developed automotive bumper beam using high-strength sheet moulding compound to reduce weight and improve toughness of bumper beam. Many papers are also discussed the use of several composite process in the literature. Mohan (1987) discussed the use of structural reaction injection moulding (SRIM) composite in producing automotive bumper beam. Lee and Suh (2006) cited that reinforced plastic bumper beam made by compression moulding with sheet moulding compound (SMC), resin transfer moulding (RTM), and reaction injection moulding (RIM) have been successfully employed.

Schmachtenberg and Töpker (2004) developed composite bumper beam under resin transfer moulding process. Crand et al. (1997) described the method used by Hutchinson and Peugeot in manufacturing of bumper beam that is structural reaction injection moulding (SRIM). Jula and Butterfield (1992) briefly discussed the use of compression moulding and injection moulding in manufacturing of automotive bumper beam.

Even though a good number of research work has been carried out in the past on the development of automotive bumper beam, there is limited study has focused on the development of automotive composite bumper at the conceptual design stage. Thus, the development of composite bumper system is addressed in this paper by looking into the conceptual design aspects.

2.0 METHODOLOGY USED TO DEVELOP AUTOMOTIVE BUMPER BEAM

Basically, the design flow used in this study is based on total design method or integrated method (Pugh, 1991). The design flow used in this research is only covered the development of a product which is initially started from, market investigation, product design specification (PDS) stage and ends at conceptual design stage as shown in Figure 1.

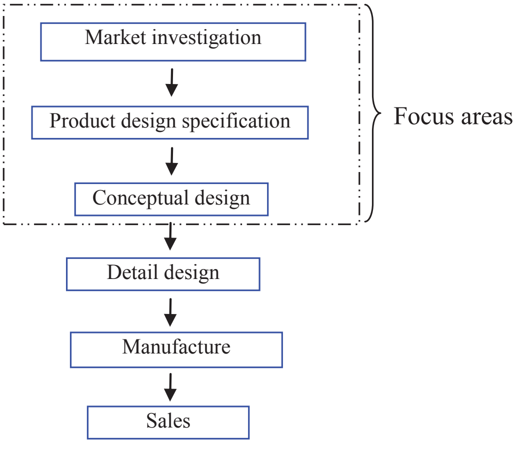


Figure 1: Design flow used in this research (Pugh, 1991)

2.1 Market investigation

The first activity of product development process is market investigation. The scope of market investigation in this research is focused on design requirements that influence the selection process during development of the automotive bumper beam. This stage is carried out based on various sources such as journals, books, magazines, technical reports, patents and factory that related to the development of automotive bumper beam.

2.2 Product design specification (PDS)

The second stage of the product development process in this research is product design specification (PDS). To generate the PDS list for the automotive composite bumper beam, investigation of existing automotive composite bumper beams through patents, journals and safety standard requirements such as CFR, NHTSA and CMVSS were used. From market investigation stage, it was revealed that only 12 elements of the PDS were considered in the design of automotive composite bumper beam as depicted in Figure2. 12 elements of the PDS were considered because they are the most important elements that need to be considered during development process of automotive bumper beam.

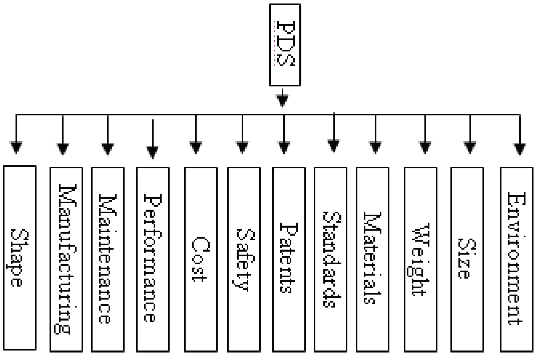


Figure 2: Elements of PDS for development of automotive bumper beam

2.3 Conceptual design stage

The development of automotive bumper beam is performed at the conceptual design stage.

2.3.1 Concept generation

Bumper beam is a complex shape, thus, all the proposed conceptual design or design concepts are assumed as curve flat-faced (a zero (0) sweep). It is because the actual shape of bumper beam is based on the shape of bumper fascia, energy absorber and bumper stay and how they are attached to each other. To design automotive bumper beam, generally, a convenient way of defining the degree of roundness is to use the concept of sweep (Bernert et al., 2006). Sweep expresses the degree of curvature of the outer bumper face, or the face farthest removed from the inside of the vehicle as shown in Figure 3. Depth of draw is often used to describe the amount of rounding and wrap around on a bumper section as shown in Figure 4. Depth of draw is the distance, Y, between the extreme forward point on a bumper and the extreme aft point on a bumper (Bernet et al., 2006). The proposed conceptual design of automotive bumper beam is based on the dimension as shown in Table 1.

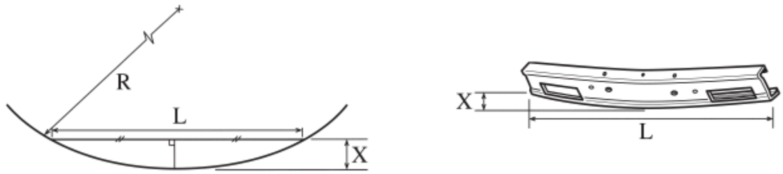


Figure 3: Definition of sweep (Bernert et al., 2006)

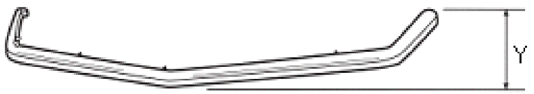


Figure 4: Definition of the depth of draw (Bernert et al., 2006)

Table 1: Dimension of bumper beam

Dimension	Unit (mm)
Circle of radius (R)	1908
Chord length (L)	1524
Sweep in the camber (X)	159
Depth of draw (Y)	210
Width	120
Thickness	2

In order to generate ideas to meet the product design specification (PDS) in the development of automotive composite bumper beam, brainstorming approach was employed. Brainstorming is used to generate new idea by freeing the mind to accept any idea that is thought.

2.3.2 Conceptual design of automotive composite bumper beam

There are eight sketches of automotive bumper beams have been carried out. All the sketches were then translated to the 3D drawing using SolidWorks and they are briefly described as follows:

2.3.2.1 Design concept 1

This proposed design concept 1 (Figure 5) is a tubular or hollow and has a square or rectangular in cross section which results in high strength and dimensional stability. The bumper beam is curved from end-to-end to allow deflection when impact without damaging structure behind the bumper beam. The design has a 2 mm thickness of cross-section. The bumper beam is symmetrical so that the left-side part is constituted similarly as right-side part.

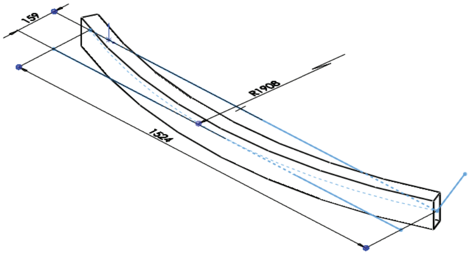


Figure 5: Design concept 1

2.3.2.2 Design concept 2

This proposed design concept 2 of bumper beam (Figure 6) has a substantially rectangular or square hollow cross section defined by front side portion and extended laterally curve. The bumper beam is curved from end-to-end to allow deflection when impact without damaging structure behind the bumper beam. The design has a 2 mm thickness of cross-section. The bumper beam is symmetrical so that the left-side part is constituted similarly as right-side part.

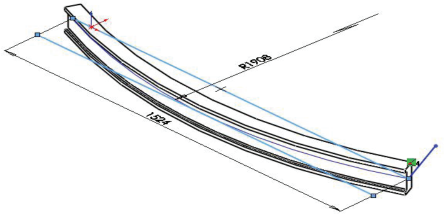


Figure 6: Design concept 2

2.3.2.3 Design concept 3

This conceptual bumper beam 3 has a C-shaped cross section with a vertical base wall and upper and lower flanges extending rearwardly as depicted in Figure 7. The bumper beam is curved from end-to-end to allow deflection when impact without damaging structure behind the bumper beam. The design has a 2 mm thickness of cross-section. The bumper beam is symmetrical so that the left-side part is constituted similarly as right-side part.

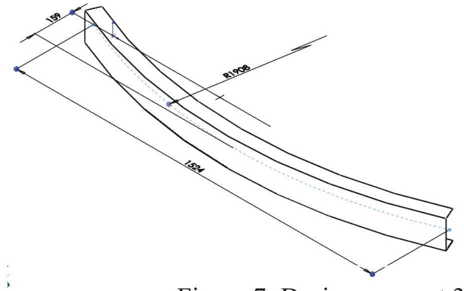


Figure 7: Design concept 3

2.3.2.4 Design concept 4

This design concept 4 is similar to design concept 1. The different is an inner portion of the upper wall and lower wall is angled (tapered) upwardly and downwardly respectively. The bumper beam has a good roundness formed and aerodynamic shape which determine the impact-absorbing performance and air flow to the engine compartment. In general, this design concept of bumper beam is low in maintenance requirement.

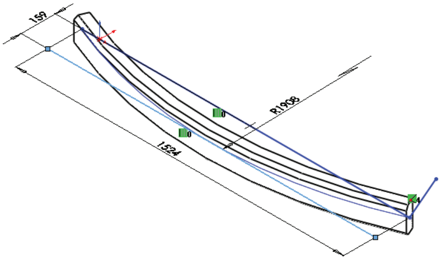


Figure 8: Design concept 4

2.3.2.5 Design concept 5

In general, this design concept 5 has cross-sectional view of the D-shape as illustrated in Figure 9. The bumper beam has a good roundness formed and aerodynamic shape which determine the impact-absorbing performance and air flow to the engine compartment. In general, this design concept of bumper beam is low in maintenance requirement.

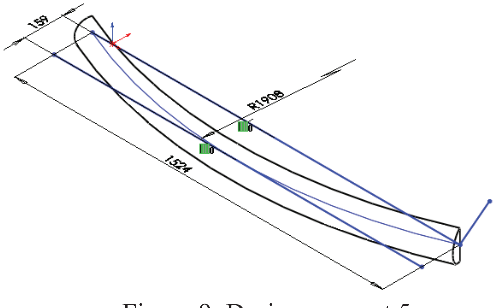


Figure 9: Design concept 5

2.3.2.6 Design concept 6

This conceptual bumper beam 6 has a hat-box cross-section as depicted in Figure 10. The bumper beam is curved from end-to-end to allow deflection when impact without damaging structure behind the bumper beam. The design has a 2 mm thickness of cross-section. The bumper beam is symmetrical so that the left-side part is constituted similarly as right-side part. The bumper beam has a poor roundness formed and aerodynamic shape which determine the impact-absorbing performance and air flow to the engine compartment. In general, this design concept of bumper beam is low in maintenance requirement.

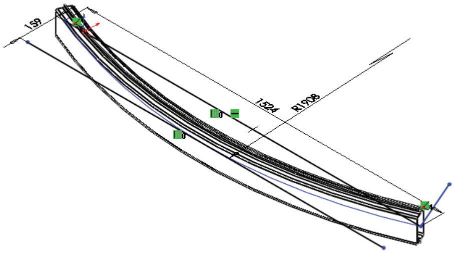


Figure 10: Design concept 6

2.3.2.7 Design concept 7

In general, the design concept 7 has X-ribbing pattern and 3 mm thickness distributed evenly to whole bumper beam as illustrated in Figure 11. The structure of bumper beam is strengthened by ribs in specific places in order to form a more rigid and stabilized structure. The ribs can be arranged in any pattern or orientation which provides support to the front wall. A cross or X-shaped pattern is designed to provide the maximum support for the wall and maximum torsional stiffness.

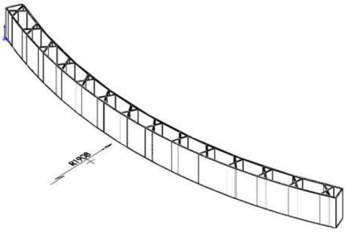


Figure 11: Design concept 7

2.3.2.8 Design concept 8

The shape of the design concept 8 is rectangular cross-section with the gap between the front wall and rear flat surface area as depicted in Figure 12. This design concept is poor in curvature shape due to flat surface or straightens can cause the beam mount is pushed outwards. This outward motion puts the energy absorbing structure into bending and so energy may not be absorbed efficiently. The bumper beam has a good roundness formed but poor in aerodynamic shape which determine the impact-absorbing performance and air flow to the engine compartment. In general, this design concept of bumper beam is low in maintenance requirement.

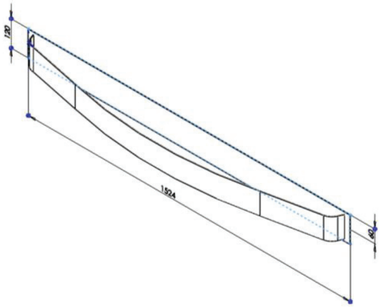


Figure 12: Design concept 8

3.0 FINAL DESIGN CONCEPT OF AUTOMOTIVE BUMPER BEAM AT THE CONCEPTUAL DESIGN STAGE

The best design concept of automotive bumper beam must be determined during concept selection process at the conceptual design stage.

3.1 Selection process using analytical hierarchy process

AHP was used to determine the most appropriate design concept. Generally, AHP consists of three basic steps namely decomposition, comparative judgement, and the synthesis (Saaty and Vargas, 2001, Adhikari, et al., 2006 and Cheng et al., 2007). These steps can be elaborated by structuring them in a more encompassing nine steps process (Hambali et al., 2008). Various input parameters that influence the selection process are then translated into a hierarchical structure as depicted in Figure 13.

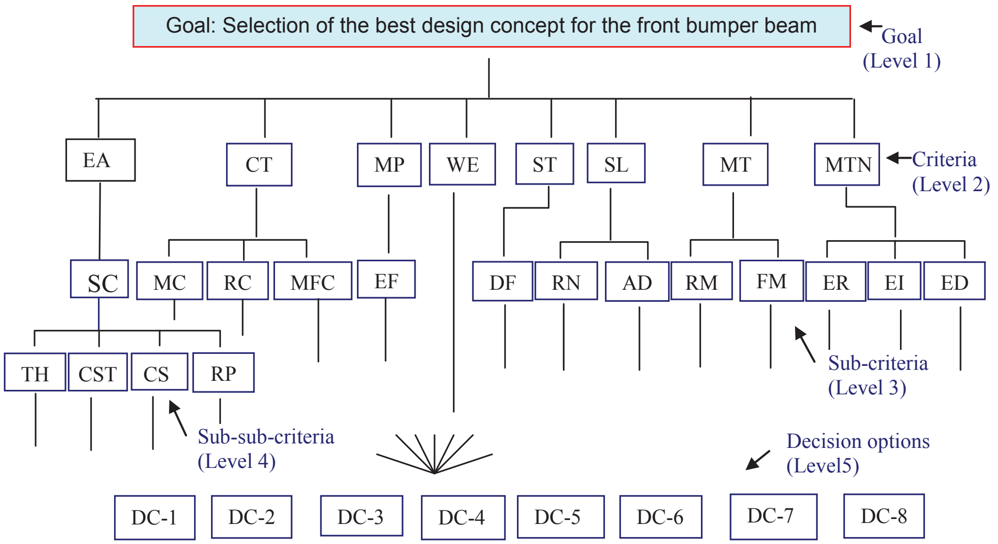


Figure 13: The hierarchy model represents the criteria and sub-criteria affecting the selection of design concepts for automotive bumper beam

Pairwise comparison begins with comparing the relative importance of two selected items. To perform the judgement of pairwise comparison, a scale pairwise comparison was employed as shown in Table 2. The values as shown in Table 3 are assigned based on the authors' experience and knowledge.

Table 2: Scale for pairwise comparisons (Saaty, 1980)

Relative intensity	Definition	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favours one requirement over another
5	Essential or strong value	Experience strongly favours one requirement over another
7	Very strong value	A requirement is strongly favoured and its dominance is demonstrated in practice
9	Extreme value	The evidence favouring one over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals	Reciprocals for inverse comparison	

Table 3: Pairwise comparison of the main criteria with respect to the goal

Goal	EA	CT	MP	WE	ST	SL	MT	MTN
Energy absorption (EA)	1	7	7	5	5	8	5	8
Cost (CT)		1	1	1/3	1/3	4	1/3	4
Manufacturing process (MP)			1	1/3	1/3	4	1/3	4
Weight (WE)				1	1	5	1	5
Strength (ST)					1	5	1	5
Styling (SL)						1	1/5	1
Material (MT)							1	5
Maintenance (MTN)								1

After implementing various steps in AHP method, the overall priority vectors is depicted in Table 4

Table 4: Consistency ratio and priority vectors for the main factors, sub factors and alternatives

	Priority vectors																
Main Factor	EA				CT			MP	WE	ST	SL		MT		MTN		
	0.434				0.062			0.062	0.131	0.131	0.025		0.131		0.025		
	CR=0.04																
Sub-Factor	SC				MC	RC	MFC	EF		DF	RN	AD	RC	FM	ER	EI	ED
Sub-Sub-Factor	TH	CST	CS	RP	0.258	0.105	0.637	1.0		1.0	0.750	0.250	0.250	0.750	0.238	0.625	0.137
	0.095	0.249	0.560	0.095	CR=0.04						CR=0.0		CR=0.0		CR=0.02		
	CR=0.02																
Alternative																	
DC-1	0.100	0.136	0.132	0.100	0.053	0.125	0.053	0.218	0.053	0.157	0.086	0.083	0.125	0.218	0.125	0.125	0.125
DC-2	0.100	0.136	0.037	0.100	0.033	0.125	0.033	0.078	0.034	0.034	0.036	0.083	0.125	0.078	0.125	0.125	0.125
DC-3	0.100	0.136	0.092	0.100	0.229	0.125	0.229	0.218	0.217	0.108	0.086	0.083	0.125	0.218	0.125	0.125	0.125
DC-4	0.100	0.136	0.052	0.100	0.078	0.125	0.078	0.078	0.090	0.073	0.223	0.250	0.125	0.078	0.125	0.125	0.125
DC-5	0.100	0.136	0.227	0.100	0.130	0.125	0.130	0.218	0.135	0.227	0.223	0.250	0.125	0.218	0.125	0.125	0.125
DC-6	0.100	0.136	0.385	0.100	0.052	0.125	0.052	0.078	0.053	0.327	0.036	0.083	0.125	0.078	0.125	0.125	0.125
DC-7	0.300	0.136	0.055	0.300	0.019	0.125	0.019	0.078	0.023	0.050	0.086	0.083	0.125	0.034	0.125	0.125	0.125
DC-8	0.100	0.045	0.020	0.100	0.406	0.125	0.406	0.033	0.396	0.024	0.223	0.083	0.125	0.078	0.125	0.125	0.125
CR	0.0	0.0	0.06	0.0	0.05	0.0	0.05	0.01	0.02	0.03	0.01	0.0	0.0	0.01	0.0	0.0	0.0

3.2 Selection of the Best Design Concept

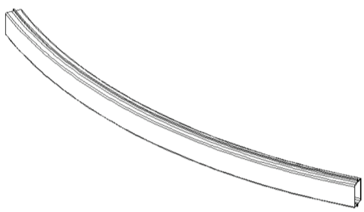
The ranking of the design concept decisions is shown in Table 5. The first choice of conceptual design automotive bumper beam is design concept 6 (DC-6) with a weight of 0.191 (19.1%). While DC- 8 with a weight of 0.064 (6.4%) is a last choice of decision making results.

Table 5 Result of selection

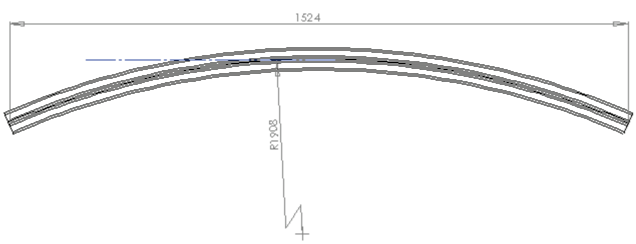
No.	Best Selection	
1	DC-6	**0.191**
2	DC-5	0.182
3	DC-3	0.145
4	DC-1	0.130
5	DC-8	0.118
6	DC-4	0.087
7	DC-7	0.082
8	DC-2	0.064

3.3 Final conceptual design of automotive bumper beam

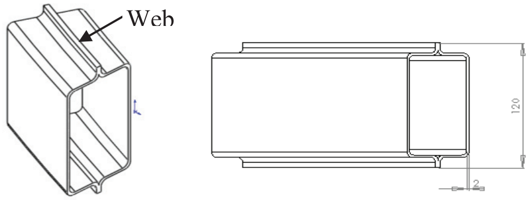
Figure 14(a)-(c) show an isometric view, top view, front view and side view of final design concept of automotive bumper beam at the conceptual design stage. In general, the design concept has a hollow and hat-box cross-section with the two webs or flanks as depicted in Figure 14 (c). Its design is curved from end-to-end to allow deflection when impact without damaging structure behind the bumper beam as depicted in Figure 14 (b). This design has a 2 mm thickness distributed evenly to whole bumper beam as illustrated in Figure 14 (c).



(a) 3D solid modelling of the bumper beam (isometric view)



(b) Top view



(c) Side view

Figure 14: Final design concept of automotive bumper beam

4.0 CONCLUSIONS

The paper presents the development of automotive front bumper beam at the conceptual design stage. The use of analytical hierarchy process for determining the most appropriate decision on design concept during concept selection at the conceptual design stage was discussed in this paper. Various input parameters that need to be considered for the design concept selection in the development of automotive front bumper beam. AHP reveals that design concept 6 (DC-6) with a weight of 0.191 (19.1%) was chosen as the first choice. The paper reveals the importance of considering the right decision on design concept at the early stage of design process. For future work, detail design of automotive bumper beam should be carried out and design analysis should be performed using finite element analysis software.

ACKNOWLEDGMENTS

The authors wish to thank Universiti Teknikal Malaysia Melaka (UTeM) for supporting this research.

REFERENCES

Adhikari, I.; Kim, S.Y. and Lee, Y.D., 2006. Selection of appropriate schedule delay analysis method: Analytical Hierarchy Process (AHP). Proceedings of the Technology Management for the Global Future, 483 – 488.

Bernert. W.; Bulych, S.; Cran J.; Egle, D.; Henseleit, K.; Hersberger, T.; Kantner, C.; Koch, M.; Kudelko, C.; Mihelich, M.; Mohan, R.; Stokfisz, S.; Tang, M.; Vikstrom, T.; Welte, E. and Zabik, B., 2006, American Iron and Steel Institute: Steel Bumper Systems for Passenger Cars and Light Trucks, Revision number three, June 30, 2006. http://www.bumper.autosteel.org, accessed on 6 February, 2008.

Cheng, S.C.; Chen, M.Y.; Chang, H.Y. and Chou, T.Z., 2007, Semantic-based facial expression recognition using analytical hierarchy process. Expert Systems with Applications: An International Journal, 33(1): 86–95.

Cheon, S.S.; Choi, J.H. and Lee, D.G., 1995, Development of the composite bumper beam for passenger cars. Composite Structures, 32(1): 491-499.

Clark, G.L.; Bals, C.K and Layson, M.A., 1991, Effects of fibre and property orientatation on 'C' shaped cross sections. *SAE Technical Paper No* 910049.

Crand, E.; Choumer, S. and Fromentin, B.,1997, High-performance front bumper beams. *SAE technical paper No*. 190043.

Hambali, A.; Sapuan, S.M.; Ismail, N and Nukman, Y., 2008, Use of analytical hierarchy process (AHP) for selecting the best design concept. Jurnal Teknologi, 49 (A): 1-18.

Hosseinzadeh, R.; Shokrieh, M.M. and Lessard, L.B., 2005. Parametric study of automotive composite bumper beams subjected to low-velocity impacts. Composite Structures, 68(4): 419–427.

Jula, J. and Butterfield, L., 1992, Blow molded vehicle bumper beams. (Blow Molding) Plastics Engineering, 48: 21-24.

Kelman, J and Nelson, G.V., 1998, Composite motor vehicle bumper beam. United States Patent: Patent No. 5804511.

Lee, D.G. and Suh, N.P., 2006, Axiomatic Design and Fabrication of Composite Structures: Applications in Robots, Machine Tools, and Automobiles. New York: Oxford University Press.

Lee, K.H. and Bang, K.I., 2006, Robust design of an automobile front bumper using design of experiments, Proc. IMechE Part D. Journal of Automobile Engineering, 220(9): 1199-1207.

Marzbanrad, J.; Alijanpour, M. and Kiasat, M.S., 2009, Design and analysis of an automotive bumper beam in low-speed. Thin-Walled Structures, 47: 902–911.

Mohan, R., 1987, SIRIM composites for automotive structural applications. Proceedings of the 3rd Annual Conference on Advanced Composites, 57–62.

Moinar, A.A., 1987, Bumper Beam. United States Patent: Patent No. 4671550

Mohapatra, S. 2005. Rapid design solutions for automotive bumper energy absorbers using morphing technique. Proceedings of the Altair CAE User Conference, 1-6.

Murphy, J. 1998. The Reinforced Plastics Handbook. New York: Elsevier.

Okumura, H.; Okura, K.; Aihara, K and Terae, Y. 1989. H-Smc Bumper Beam Endured 5 Mph Impact. *SAE Technical Paper No*. 890339

Pugh, S. 1991. Total Design: Integrated Methods for Successful Product Engineering. Wokingham: Addison Wesley Limited.

Saaty, T.L. 1980. The Analytic Hierarchy Process. New York: McGraw-Hill.

Saaty, T.L. and Vargas, L.G. 2001. Models, Methods, Concepts & Applications of the Analytical Hierarchy Process. Boston: Kluwer Academic Publishers.

Schmachtenberg, E. and Töpker, J. 2004. Resin transfer moulding for railway industry: Development and processing of a composite front end bumper. Journal of Polymer Engineering, 24: 243-258.

Schuster, P.J. 2006. Current trends in bumper design for pedestrian impact. *SAE Technical Paper No*. 2006-01-0464.

Yamaguchi, T.; Nakagawa, T.; Kinefuchi, M.; Watanabe, K.; Tachibana, M. and Hashimura, T. 2008a. Automobile bumper beam. JP Patent: Patent No. 2008-023967.

Yamaguchi, T.; Nakagawa, T.; Kinefuchi, M.; Watanabe, K. 2008b. Bumper beam. JP Patent. Patent No. 2008-045913.

Yim, H.J.; Kim, M.S.; Park, J. and Heo, S.J. 2005. Shape optimization of bumper beam cross section for low speed crash, society of automotive engineers, Inc. *SAE Technical paper No.* 2005-01-0880.