Concept Selection of a New Longitudinal Member Design with Developed Bi-Metallic Model

Karam S. Khalid, F. Tarlochan, Haidar Fadhil AL-Qrimli / Proceedings, CAN'2012 Eleventh AES-ATEMA International Conference Toronto, Canada, August 06 - 10, 2012, pp. 125 – 134.

ISBN 978-0-987945-1-6 / ISBN 978-0-9879945-2-3

AES

ATEMA'2012

Toronto, CA

CAN'2012 ELEVENTH AES-ATEMA INTERNATIONAL CONFERENCE

AES-ATEMA' 2012 Eleventh International Conference on Advances and Trends in Engineering Materials and their Applications

(Toronto, CANADA: August 06 - 10, 2012)

Concept Selection of a New Longitudinal Member Design with Developed Bi-Metallic Model

Karam S. Khalid[1*], F. Tarlochan[1], Haidar Fadhil AL-Qrimli[2]

[1] Graduate Student, Dept. of Mechanical Engineering, Universiti of Tenaga Nasional, Puchong, 43009 Kajang, Selangor, Malaysia

(Email: karamkhalid@ymail.com)

[2] Graduate Student, Dept. of Mechanical Engineering, The University of Nottingham, 43500 Semenyih, Malaysia

*Corresponding Author

Abstract

Steel material has a widely use in automotive applications for the high stiffness that could provide more safety for the passengers. On the other hand, the steel has quite a heavy weight due to its high density. A new longitudinal member design has been presented in order to give more safety in many crash situations. Two dynamic collision tests (frontal and oblique) have been simulated. The new design concept needs two separate components. An interior tube called the crash component. This component is simulated with a bi-metallic material (combination of steel and aluminum) to reduce the weight by up to 25 %. This interior tube controls the front crash test to exhibit a desirable energy. The outer part called the support component, contains four stiff tubes fitted to each other in order to slide over each other like a telescope. The outer component produces high bending resistance in the case of an oblique collision. There are five different concepts for the telescope (arc side, inside arc side, hat side, taper side and sharp side). The complex proportional assessment method (COPRAS) has been used for selecting the best design. Using the COPRAS method helps to meet the *satisfaction of engineering specifications and costumer needs. Six different criteria, which were specified as specific energy absorption, crash force efficiency for frontal and 30 degrees, cost and ease manufacturing, were analyzed to form the initial matrix. It is concluded that the sharp angle side can be used for the longitudinal member design with a mid car model.*

Keywords

Bi-metallic material, Selection of concept, COPRAS, PDS, Oblique crash

1. Introduction

There is a growing recognition of the importance of crashworthiness in aircraft and automobile transportation sector. Crashworthiness deals with the structural integrity of a vehicle during impact, especially as it relates to the safety of its passengers. The primary aim of a crashworthy vehicle design is to manage the rapid conversion of the kinetic energy in other forms (such as structural deformation) in a manner that attenuates effects of sudden decelerations (or accelerations) on occupants. Central to crashworthiness technology is the notion of energy absorption [1]. [2] observed the Increase of car accidents following an explosive increase of vehicles has brought casualties as well as enormous social and economic losses. When passengers of a car are fully subjected to collision energy at the time of collision accident, their safety is in great danger. To reduce such danger, it is necessary to lessen the impact of collision by absorbing the collision energy through deformation of vehicle structural member while securing space for passengers to survive. It is also necessary to devise safety measures for the vehicle structural member that can allow appropriate deformation for passenger's safety.

To design a safe frontal car structure it is necessary to improve the structure so that it absorbs enough energy in all crash situations. To prevent excessive deceleration levels, the available deformation distance in front of the passengers must be used completely for the crash velocity [3, 4]. The majority of accidents occur in partial overlapping in which only one longitudinal member is loaded, or in an off-axis load direction [5]. The longitudinal members fail with the bending mode rather than having much more energy absorbed with the progressive folding pattern. Presently, the problems above lead to two conflicts. The first conflict is to absorb enough energy during the partial overlapping of either one of the longitudinal member is loaded. The second conflict is that the desirable energy must be absorbed in the case of an off-axis impact angle collision [6,7].

To improve the front design crashworthiness of the car, it is necessary to come up with new design concept that must have the ability to exhibit energy in order to protect the passengers. [8,9] produced a method that solves the selection problems of engineering using the stepwise ranking and alternative procedure in terms of their significance. There are six criteria chosen for this study, specific energy absorption for the front and oblique crashes, crash force efficiency for both front and oblique crashes, cost and assembly.

This research focused on analyzing, evaluating and selecting the optimum concept among five different longitudinal member concepts. Based on the National Highway Traffic Safety Administration [10], the car longitudinal member low impact test was simulated by the finite element software, to address the highest energy absorption and maximum possible deflection. Finally, the decision matrix came up with five alternatives against five criteria. The COPRAS method was appointed for selecting the best concept of the longitudinal member profile through five different geometries.

2. Basic Design Procedure

2.1 Conceptual design of the longitudinal member

The development of a product depends preliminary on the conceptual design, which is derived from the customer's requirements. To improve the product cost, the engineering calculations must be precise. Material selection and design are important factors which must be taken into account. The designers have to select the best idea from different design concepts or material selection in each stage of the project to avoid rework problems. There are many methods of concept selection, which compromise different concepts with a variation of design parameters.

The Topsis technique is a method that has been used to deal with multi attributes or multi criteria selection problems. Its method is based on the ‟chosen alternative has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution''. It helps to organize problems, as well as compare and rank alternatives to carry out the analysis for better options [11]. [9] presented the evaluation of mixed data (EVAMIX) method. It is based on the determination of the dominance score of an alternative on criterion-by-criterion basis. This method is especially designed to deal with mixed (quantitative and qualitative) data. Another approach to material selection problems is the weighted property method (WPM) which is used when several properties should be taken into consideration. This numerical method ranks the candidate materials based on their performance indices, calculated from simple mathematics.

2.2. Product design specifications (PDS)

To perform the customer requirements and expectation to a detailed technical document called PDS. It is quite difficult to finish the exact PDS in the early stage of product development, while the knowledge of design requirements is imprecise and incomplete [12]. PDS originates by disorganized brainstorming team with various proficiencies, i.e. manufacturing, designing, selling, assembling, maintaining, and might be improved due to new product changes and manufacturing limitations. Safety was the main goal among different longitudinal member PDS specifications in this study.

Longitudinal member PDS consisted of safety, performance, weight, size, cost, environment issue, appearance. Whole PDS parameters can be classified into three main subdivisions such as material, manufacturing and design.

2.3. Effective parameters in longitudinal member energy absorption

To satisfy the customer needs and engineering specifications, the parameters must meet both requirements. The PDS originated from a disorganized brainstorming team with various proficiencies, i.e. manufacturing, designing, selling, assembling, maintaining, and might be improved due to new product changes and manufacturing limitations. Safety was the main goal among different bumper PDS specifications in this study.

1. Side curvature and sharp angle: the side curvature and angle increase the area between

the applied load point and the interior part. This apace gave enough time for the crashing until reach the crash component. The telescope starts to fail first with a slide backward due to the telescope nature, then the contact between the telescope sides curve or sides force the crash component to fail in a progressive way.

2. Cross section: the cross-section has a significant effect on the bending resistance and energy damping rate, the crash component cross-section remains same while the telescope side cross-section has been changed. In this research, five different telescope cross-sections have been investigated to select the optimum concepts in energy absorption and crash force efficiency for the dynamic test along with material weight, cost and easy manufacturing.

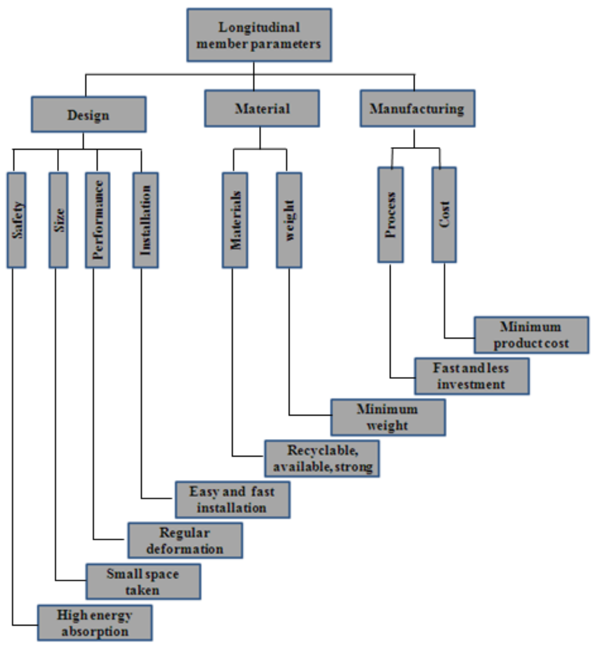


Figure 1. Longitudinal member design parameters

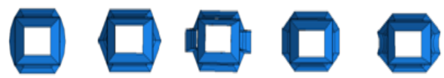
3. Manufacturing: to ease the manufacturing many parameters must be taken into account such as manufacturing process, machine used and assembly. Easy manufacturing values have been calculated depending on the expert to the converted qualified value to the quantify value and other applications.

4. Thickness: increasing the longitudinal member thickness has a significant effect on the specific energy absorption due to increasing the weight property. The thickness affect the stability of the deformed tubes, increasing the thickness produce a high structure disturbance and unstable force level. On the other hand, increasing the thickness improve the energy absorption ability.

5. Material properties: Material behavior, rigidity and ductility, has a great influenced in energy absorption. High rigidity increases the car protecting capability, but decreases damping capacity and causes impact load transmission to the compartment [13]. In dynamic test, the bi-metallic material has been used in order to increase the deformation length and time steps to reduce the load transmission. The telescope material is aluminum in order to reduce the total weight of the longitudinal member and increase the specific energy absorption.

In this study energy absorption abilities for the five concepts are originated by cross-section, material and manufacturing optimizations, which have less effect with weight factor have been employed. The crash force efficiency, cost, weight, and easy manufacturing criteria have included selecting the best design as shown in Table 1.

Table 1. Five concepts with five criteria



No.	Criteria	AS (Arc Side)	SS (Sharp Side)	HS (Hat Side)	TS (Taper Side)	ICS (Inside Curve Side)
1.	Energy Absorption	12751	12895	14428	13597	14613
2.	Crash Force Efficiency	0.32	0.41	0.36	0.32	0.37
3.	Cost	31.54	39.28	34.49	27.77	31.98
4.	Weight	2.09	2.49	2.34	2.15	2.16
5.	Easy Manufacturing	2	5	3	1	4

3. Material and Methods

The previous researchers used the metallic materials for the design of the longitudinal members. The metallic materials have the toughness and stiffness, which is able to exhibit high-energy absorption with progressive folding patterns [13]. The steel material is widely use for this application, but steel still has a high weight which cannot improve on the greenhouses gases and total front car weight [7,8]. Bi-metallic material has been used in this project to solve the weight problem; aluminum material has been combined with steel to reduce the weight by up to 25 % as compared with steel alone.

3.1. Geometrical 3D Model Development

A bi-metallic tube that is a combination of steel and aluminum materials has been modeled. A shell 3D steel tube has been modeled with a density of 7700 Kg/mm3 and young modulus of 205 GPa, while the aluminum with a density of 2700 Kg/mm3 and young modulus of 68 GPa has been combined with an offset of 0.1 mm. the Poisson's ratio for both materials is 0.3, the thickness ratio of the steel and aluminum tubes is 2/1, and the average perimeter for all geometries is 300 mm. the telescope has been modeled with a four aluminum tubes, these tubes are fitted to each other in order to slide over each other like a telescope. Figure 2 shows the longitudinal member dimensions.

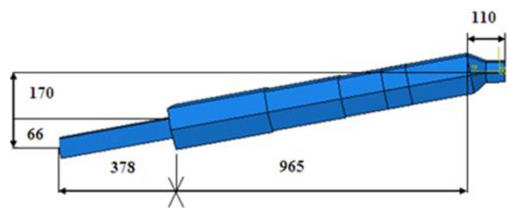


Figure 2. Shows the longitudinal member dimensions

3.2. Explanation of the Finite Element Method

A deformable shell element with a three dimensions was used to model the structure of the tubes, and rigid bodies with a planner (no thickness) were used to model the impactor and bottom unmovable wall. To accurately define the post-yield material response in the FE model, the tube stress strain curve was obtained by previous researches from tensile tests. The material assumed to have only isotropic strain hardening, and strain rate effects on the yield strength were neglected due to their low overall average load rate used in the tensile and tube tests [14].

Surfaces and sets were created to define the contact between the rigid bodies and the tube. The top and bottom parts of the tube were set to specify the node region to surface contact for the impactor and the top of the tube, and constrained (tie contact) for the bottom rigid wall and the bottom part of the tube. Self-contact was specified for the tube walls during collapse.

A quadrilateral shell element was defined to control the mesh with an approximately global size of five to divide the structure for thousands of nodes to ensure the accuracy of the results. Both the crash displacement-time and reaction force-time are insensitive to the mesh size [15]. The model can be shown in Figure 3.

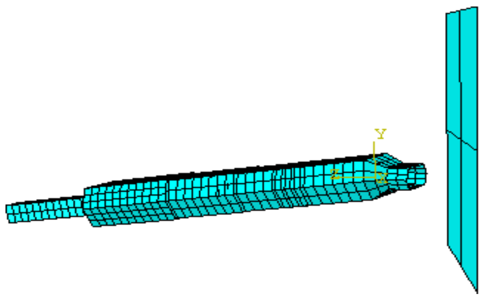


Figure 3. Finite element model

3.3. Impact Parameters

The design of the frontal car spectrum must be safe in all types of collisions, the possibility of more safety designs must be considered for the crash tests to improve a car's ability to absorb more energy during real accidents. [8, 12 and 28] provide the complete database of the crash parameters. The most important parameters of the car crashing test are the collision speed, obstacle type, impact direction and the impact location. From the database information above, collisions with different situations will be covered to have a comprehensive idea about the frontal car behavior. The following observations can be made:

1.At least 90 % of collisions take place with a speed of 54 km/h.

2.The number of different obstacle types is endless. The obstacles can be divided into three major types:

(i)Rigid wall (simulating buildings or heavy trucks)

(ii)The deformable barrier (simulating other vehicles)

(iii)The pole (simulating trees and pillars)

3.Frontal collisions are considered to have an incident angle for the impact direction varying from -30 to 30 degrees.

3.4. Complex Proportional Assessment Method (COPRAS)

The complex proportional assessment method (COPRAS) is an effective way for selecting the best alternative depending on the criteria that has been chosen considering the best and worst ideal solutions. [10 and 11] produced a method that solves the selection problems of engineering using the stepwise ranking and alternative procedure in terms of their significance.

The complex proportional assessment method (COPRAS) is a successful method to solve the problems of design selection in many fields like construction, project management, economy, this method consists of many steps, and they are explained as follows:

Step 1: Develop the initial matrix (X) and find the relative coefficient (R)

This step contains a matrix with values from 1 to 3; the decision is given according the importance of the factors as shown in the matrix below. The matrix is found to obtain the positive decision.

$$X = [x_{ij}]_{mxn} \qquad 1$$

Where x_{ij} is the performance value of the ith alternative on jth criterion, m is the number of alternatives compared and n is the number of criteria.

X_{ij} represents the positives for each criteria and

$\sum X_{ij}$ is the summation for a number of positives decisions.

$$R = [r_{ij}]_{mxn} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad 2$$

Step 2: Determine the weighted normalized decision matrix D.

$$D = [y_{ij}]_{mxn} = r_{ij} \times w_j \quad 3$$

w_j is the weight for each criteria; the summation of the normalized weight for each criteria is always equal to the weight of the same mentioned criteria. Now the new table for the normalized decision matrix must be tabled with a numbers depend on the equation above.

Step 3: Beneficial and non-beneficial attributes

The values of the normalized decision matrix contain beneficial and non-beneficial attributes. The next step is to separate them according to their importance. These two factors are formulated into two equations:

$$S_{+1} = \sum_{j=1}^{n} y_{+ij} \quad 4$$

$$S_{-1} = \sum_{j=1}^{n} y_{-ij} \quad 5$$

Where $y+_{ij}$ and $y-_{ij}$ are the beneficial and non-beneficial attributes respectively, the best alternative depends on the greater value as a beneficial and the lower value as a non-beneficial attribute. The summation of the minuses also represents attributes to help find the priorities.

$$S_{-} = \sum_{i=1}^{m} S_{-i} \quad 6$$

$$S_{+} = \sum_{i=1}^{m} S_{+i} \quad 7$$

The summation of S- and S+ always equals to one, and the separate summation is equal to the sums of the weight of the beneficial and non-beneficial attributes.

Step 4: Relative Significance or Priority (Q)

The priorities of the alternative have been calculated, the higher the value of Q_i, the greater the priority of an alternative. The alternative with the maximum relative significance Q_{max} is the best choice for the application design. The relative significance has been formulated as below:

$$Q_i = S_{+i} + \frac{S_{-min} \sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{i=1}^{m} (S_{-min}/S_{-i})} \quad 8$$

Step 5: Determine the Quantitative Utility (U)

The value of the quantitative utility is related directly to the relative significance; the values with the quantitative utility complete the ranking of the alternatives and can be denoted as the formula below:

$$U_i = \frac{Q_i}{Q_{max}} \quad 9$$

The maximum value of the relative significance is denoted as Q_{max}. The quantitative utility is directly proportionate to the relative significance and the utility value with 100 is considered to be the best design using this method.

4. Results

The most important criteria have been chosen with their weight factors are shown in Table 2; these five criteria are considered as parameters in selecting the longitudinal member design concept. The energy absorption (EA) and crash force efficiency (CFE) values for the oblique crash situation at 30 degrees have been derived from the simulated crash test. The other parameters have been calculated depending on the expert to the converted qualified value to the quantify value and other applications. These parameters created a decision matrix to comply with the other COPRAS method requirements.

Table 2. Evaluation matrix for select the best concept

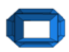
Concept	Name	Energy Absorption 0.3	Crash Force Efficiency 0.25	Weight 0.2	Cost 0.15	Easy Manufacturing 0.1
	AS	12751	0.32	2.09	31.54	2
	SS	12895	0.41	2.49	39.28	5
	HS	14428	0.36	2.34	34.49	3
	TS	13597	0.32	2.15	27.77	1
	ICS	14613	0.37	2.16	31.98	4

Table 2 showed the five criteria with the weighted factor which is resulting from the initial matrix as explained in step 1. The following tables represent the rest steps of the complex proportional assessment COPRAS method.

Table 3. The Weighted Normalized Decision Matrix

Criteria	EA	CFE	W	C	EM
AS	0.05602	0.04494	0.037222	0.028662	0.013[illegible]
HS	0.056654	0.05758	0.044346	0.035696	0.033[illegible]
NS	0.063387	0.05056	0.041674	0.031343	0.026[illegible]
SS	0.059737	0.04494	0.03829	0.025236	0.006[illegible]
TS	0.064201	0.05196	0.038468	0.029062	0.0[illegible]

Table 4. Beneficial and non-beneficial attributes

	Beneficial S_{+1}	Non-Beneficial S_{-1}	$\text{Min } S_{-1} / S_{-1}$
AS	0.138186	0.041996	0.76
SS	0.142971	0.031903	1
HS	0.158584	0.069029	0.462
TS	0.154636	0.049062	0.65
ICS	0.155623	0.05801	0.55
	ΣS_{+1} 0.75	ΣS_{-1} 0.25	$\Sigma (\text{Min } S_{-1} / S_{-1})$ 3.422

Table 5. Relative significance and quantitative utility with concepts ranking

Concepts	Relative Significance (Q)	Quantitative Utility (U)	Ranking
AS	0.193684	89.65746	4
SS	0.216027	100	1
HS	0.192347	89.0386	5
TS	0.202141	93.57208	2
ICS	0.1958	90.63695	3

Tables from 2 to 5 illustrate the steps of the Complex Proportional Assessment Method (COPRAS) with five concepts and five criteria. Firstly, the weight of each criterion has been found related to the decision matrix. Subsequently, the criteria are divided into beneficial and non-beneficial values according to their influence on the design. The relative significance (Q) and the quantitative utility (U) with their rankings are the last steps, which specify the best design concept. The rectangular B profile has been ranked as one; that is the best design among the six concepts.

5. Discussion

According to [3 and 4], the car must be safe during the crash at a speed of 56 km/h without serious damage and occupant injuries. Most of the front car designs use the square tubes in the longitudinal member application [16]. Steel is the major material selected to manufacture the longitudinal members. This project estimates the ability of different longitudinal geometries to exhibit energy in order to choose the best design that can produce more safety for the occupants. The thickness for the six profiles is the same 1 mm for steel and 1 mm for aluminum while the perimeter is 300 mm. [17,18] provide the complete database of the crash parameters. For a safer car design, two crash situations have been performed with the FEA with 30 degree oblique crash. A midsized car has been used in this research with a mass of 1000 kg [7].

Many parameters must be taken into account besides the energy absorption affect for the selection of the best concept. For the crash performance, the crash force efficiency (CFE) is an important criterion that must included. Based on section 2, the design, the material and the manufacturing are described to explain their importance along with this application. Cost is chosen as a criterion, cost estimation is a function by which the cost can be calculated for each geometry. Easy manufacturing is included with this cost criteria. Longitudinal member assembly is another criterion; the assessment is used to set a value for the concepts in the range of one to five. The weight parameter estimated for each concept according to the density and the cross-section perimeter.

The COPRAS (Complex Proportional Assessment method) is a mathematical way to select the best concept; this method is used to satisfy the engineering specifications and customer needs. The sharp side telescope has been selected using this method as explained in section 4. Among all the concepts, the sharp side telescope exhibits the best behavior during the oblique crashing with a 30 degree crash. This concept produces a regular folding patterns and stable energy during the first 10 ms of the crash deformation as shown in Figure 4. The bending failure started at 20 ms, but, the telescope process increase the bending resistance of the interior part. The crash continue with a same behavior until the step 50 ms which is the end of the crashing process.

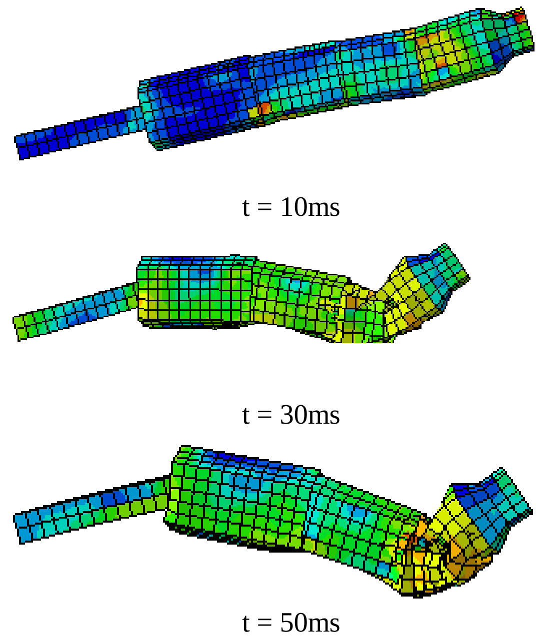


Figure 4. Sharp side concept deformation with five steps.

6. Conclusions

The FEA dynamic test using Abaqus software has been carried out with five different concepts. The bi-metallic material is the developed combination material design used in this project. The thickness ratio between the steel to aluminum is 2/1, which reduces the weight up to 25% compared with steel alone. The bi-metallic tube represent the crashing component of the present concept, while, the telescope with a four tubes represent the support part which produces more bending resistance for the crash component. The the telescope tubes has been simulated with aluminum material in order to reduce the total weight of the longitudinal member. The energy absorption cannot alone decide the best design to satisfy both: engineering specification and costumer needs.

Six parameters have been used: energy absorption (SEA), crash force efficiency (CFE), cost (C) and easy manufacturing (EM). The sharp side concept has been selected as the best design depending on the Complex Proportional Assessment method. The relative significance (Q) and quantitative utility (U) with ranking is the last steps of the COPRAS method, which specify the best design concept. The telescope technique produce more bending resistance for the crash component in order to exhibit more absorbed energy in the 30 degree crash situation.

References

[1] Junning sun, b.e.(2000). *Prediction of energy absorption of extruded tubes*, a Thesis Submitted to the Graduate Faculty of Texas Tech University.

[2] John F., (1996). *Handbook of Vehicle Design Analysis*. Society of Automotive Engineers Inc, pp. 9–12

[3] Naci, H., Chisholm, D., Baker, T.D., 2009. Distribution of road traffic deaths by road user group: a global comparison. *Inj. Prev*. 15: 55–59.

[4] World Health Organization, 2004. World Report on Road Traffic Injury Prevention, Geneva.

[5] S.C. Burgess, J.M.J. Choi, 2003. A parametric study of the energy demands ofcar transportation: a case study of two competingcommuter routes in the UK. *Transportation Research*. Part D 8, 21–36

[6] David W. Harless, George E. Hoffer, (2007). Do laboratory frontal crash test programs predict driver fatality risk? Evidence from within vehicle line variation in test ratings.*Accident Analysis and Prevention*, 39: 902–913

[7] G.M. Nagel, D.P. Thambiratnam (2006). Dynamic simulation and energy absorption of taperedthin-walled tubes under oblique impact loading.*International Journal of Impact Engineering.* 32: 1595–1620.

[8] Prasenjit Chatterjee, Vijay ManikraoAthawale, Shankar Chakraborty, 2011. Materials selection using complex proportional assessment and evaluationof mixed data methods.*Materials and Design*. 32: 851–860

[9] B. Dehghan-Manshadi, H. Mahmudi, A. Abedian, R. Mahmudi, 2007. A novel method for materials selection in mechanical design: Combination of non-linear normalization and a modified digital logic method. *Materials and Design*. 28: 8–15

[10] National Highway Traffic Safety Administration, 2003. NCAPdb.mdb, Washington, DC. ftp://ftp.nhtsa.dot.gov/NCAP [accessed August 4, 2003]. Also accessed http://www.safercar.gov/ and http://nhtsa.gov/cars/testing/ ncap/index.cfm, various dates, 2003–2006.

[11] Hwang Cm, Yoon K. Multiple attribute decision making: methods and applications: a state-of the-art survey, vol. 13. New York: Springer-Verlag; 1981.

[12] Shih H, Shyur H, Lee E. An extension of TOPSIS for group decision making. Math Comput Modell 2007;457–8:801–13.

[13] Farag M. Materials selection for engineering design. Prentice-Hall; 1997. p. 227–234.

[14] M.M. Davoodi, S.M. Sapuan, D. Ahmad, A. Aidy, A. Khalina, 2011. Concept selection of car bumper beam with developed hybrid bio-composite material. *Materials and Design. 32:* 4857–4865

[15]Wang L, Shen W, Xie H, Neelamkavil J, Pardasani A,2002. Collaborative conceptual design-state of the art and future trends. *Comput Aided Design*. 3413:981–96

[16] Automotive company 2009 [Online] Available at: http://www.csa.com/discoveryguides/archives/metals.php [Accessed:18th May 2009].

[17] Michael F. Ashby, (2009). *Materialsand the Environment: Eco-Informed Material Choice*. 1st edn. Canada: Elsevier Inc.

[18] Insurance Institute for Highway Safety, 2006. Vehicle ratings, Arlington, VA. http://www.iihs.org/ratings/default.aspx, [accessed various dates, 2003–2006].