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A note on the conceptual design of polymeric composite automotive bumper system

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Abstract

In this paper, a conceptual design approach to the development of polymeric-based composite automotive bumper system is presented. Various methods of creativity, such as mindmapping, product design specifications, brainstorming, morphology chart, analogy and weighted objective methods are employed for the development of composite bumper fascia and for the selection of materials for bumper system. The evaluation of conceptual design for bumper fascia is carried out using weighted objective method and highest utility value is appeared to be the best design concept. Polymer-based composites are the best materials for bumper fascia which are aesthetically pleasant, lighter weight and offer many more substantial advantages.

Keywords: Conceptual design; Polymeric composite; Automotive bumper system

1. Introduction

Product innovation is an important aspect for attaining a quality product [1]. Conceptual design, design concept or conceptualization is the beginning phase of the design process normally after the recognition of need. Creativity is related to conceptualization because conceptualization is a means to identify viable solutions by considering alternatives. Creativity is a means to generate alternative solutions [2].

Lightweight structure, resulting from the need to reduce fuel consumption and exhaust emissions, is the most important reason to use polymeric composites in automobile. An important component that uses polymeric composite material is a bumper system.

In the past, various works have been devoted on the development of composite bumper system for passenger cars [3,4]. Kelman et. al. [5] described their work on the design, development, prototype and testing of front end assembly using composite material. The performance of blow molded beams was compared with structural-reinforced injection moulding (SRIM) materials [6]. Maahs and Janowiak [7] also compared some of the materials available for manufacturing composite bumper beams. They carried out material selection task to decide the most suitable materials for bumper beam, which are categorized in three major groups, namely thermosetting, thermoplastics and structural reaction injection moulding (SRIM).

The development of bumper system using sheet moulding compound (SMC) for automobile was reported in the literature [8,9]. The composite material used was random chopped glass fiber. Mechanical properties of the material, such as tensile strength, tensile modulus and hardness were tested for acceptable performance of the material. Clark et. al. [10] described their extensive work on bumper beam using glass fiber-reinforced plastics to study the stress contour in the component. Recently, structural composite bumper for medium- and heavy-duty truck and bus has been developed using a hybrid glass fiber, which is lighter than its steel equivalent [11]. The impact energy absorption characteristics of

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glass fiber hybrid composites were investigated by Cheon et al. [12] and they found that the volume fraction of embedded materials have significant effects on energy absorption properties of composite structure. Mohan [13] discussed the use of SRIM composite in automotive bumper beams. The material used was glass fiber-reinforced polypropylene. The tooling cost was lower than that of metal processes because of the low moulding pressure used.

Polymeric materials are being applied in the automotive bumper system to satisfy stringent weight and performance requirements. Bumper system consists of three parts, such as fascia, energy absorber and bumper beam. Fascia is an aesthetic cover, which is usually flexible and non-structural component. If the car is light (under 2400 lb) and has low cost, where high performance is not necessary, the fascia is used with a foam energy absorber to support the fascia and to provide an inexpensive energy absorber [14]. Despite some work have been carried out on composite bumper, there is a very limited information on the conceptual design of polymer-based composite bumper system. Therefore, a study of conceptual design of composite bumper is presented in this paper.

2. Creativity methods in conceptual design for polymeric composite bumper fascia

The aim of this section is to describe the conceptual design stages of the development of the polymeric-based composite bumper fascia. The architecture of the conceptual design and final design is shown in Fig. 1. However, only conceptual design part is reported in this paper. The conceptual design is very important in designing activities because it forms the background work of the product design. The systematic conceptual design is important to enable designer to produce high quality design in the final design stage. The conceptual design results from a consideration of the design options and the number of components that constitute the product.

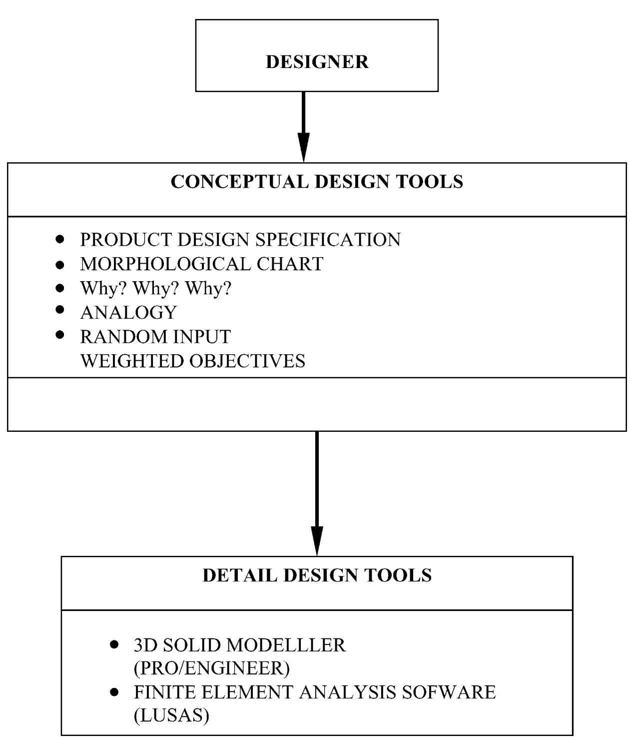

Fig. 1. The architecture of conceptual designs with other activities.

Creativity is related to conceptualization because conceptualization is a means to identify viable solutions by considering alternatives. During this phase of the process, the ideas and alternatives that have seemed most profitable to investigate are merged to form a useful solution to the identified problem [15]. Creativity is defined by Smith [16] as 'creativity is sinking down taps into our past experiences and putting these selected experiences into new patterns, new ideas and new products'. Behind the fascia, polyurethane form is attached to it. The concept of front end automotive bumper system consists of bumper fascia and energy absorber. The bumper fascia was made of "conventional" polyurethane. The energy foam made of polyurethane is attached to bumper fascia beam by means of adhesive.

2.1. Product design specifications

Product design specifications (PDS) are used for analysis, design, manufacturing and construction of a structure or a component in order to achieve a specified degree of safety, efficiency, performance or quality as well as a common standard of good design practice. Design specifications normally cover the following information [17]:

- product classification, scope of application, size range and condition, etc;
- allowable ranges of chemical composition;
- all physical and chemical properties necessary to characterize the product; and
- if applicable, other requirements, such as special tolerance and surface preparation, including instruction, etc are included in the specification.

PDS is a set of the requirements of the product that to be met at the end of the product development. Pugh [18] has listed 32 elements in the PDS. Out of 32 elements, only 10 of them were considered in designing bumper system.

2.2. Mindmapping

A mindmap of the design implications for a conceptual design of the front bumper system is shown in Fig. 2. The central 'topic' is expressed as a diagram that identifies those parts of the structure being considered. In addition to the central topic, sub-areas and their critical offshoots are circled to make them stand out. As well as identifying the issues to be dealt with, the map also records questions that

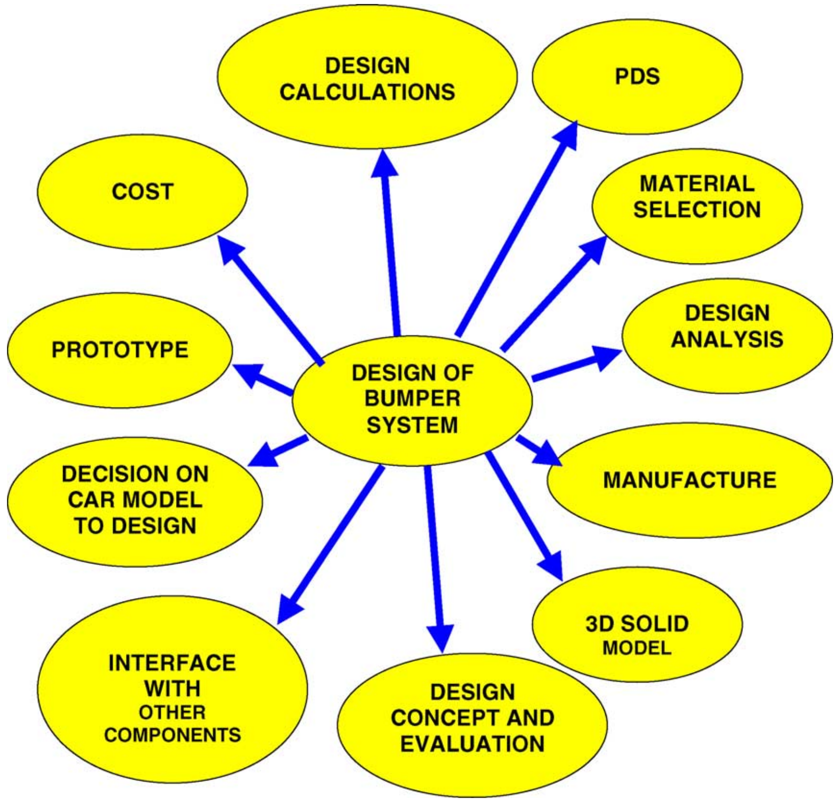

Fig. 2. A studied mindmap of the design implications for a conceptual design of front bumper system.

the designer needs to address before progress can be made [19].

2.3. Analogy in fascia design

This technique encourages the participants to see the similarities between the given design situation and another situation. The idea is that it may be easier to generate ideas for that other situation; some of which may be transferable to, or adapted for the present situation. A four-step approach to using analogies to generate design concepts is listed here [20]:

- state the need;
- generate the analogies by completing the phrase, "this situation is like. . .";
- solve the analogy; and
- transfer the analogy to the original problem.

2.4. Brainstorming in fascia design

Brainstorming was used to generate as many analogies as possible and as many as solutions to each analogy. In this project, a brainstorming session was undertaken by the authors to come up with the ideas. In the brainstorming section of producing ideas of bumper fascia, bunches of ideas are produced, those are combined and suited for the logical interconnection. From these combinations, several bumper fascia are created.

2.5. The morphology chart

The complete range of alternative design solutions for a product is generated, and hence, widens the search for potential new solutions. In this chart, the features or functions that are essential to the product are listed. For each feature or function, the means by which it might be achieved are listed. Finally, all the possible solutions are drawn in the chart. This morphology chart represents the total solution space for the product, made up of the combinations of sub-functions [20].

2.6. Final concepts

After much free-hand sketching using the combination of brainstorming, four new ideas were generated and modified and were then plotted with the help of a computer aided drafting as shown in Fig. 3. The four different concepts of bumper fascia were considered in the fascia design. The fascia design concept is based on the current design concept of bumper fascia of passenger cars. For the polymeric-based composite, the selection of bumper system is quite similar to the metallic bumper system developed by the car manufacturer [21].

2.7. Weighted objective method for evaluation of alterative concept of bumper fascia

The evaluation of bumper fascia conceptual design was carried out using the weighted objective method. This method

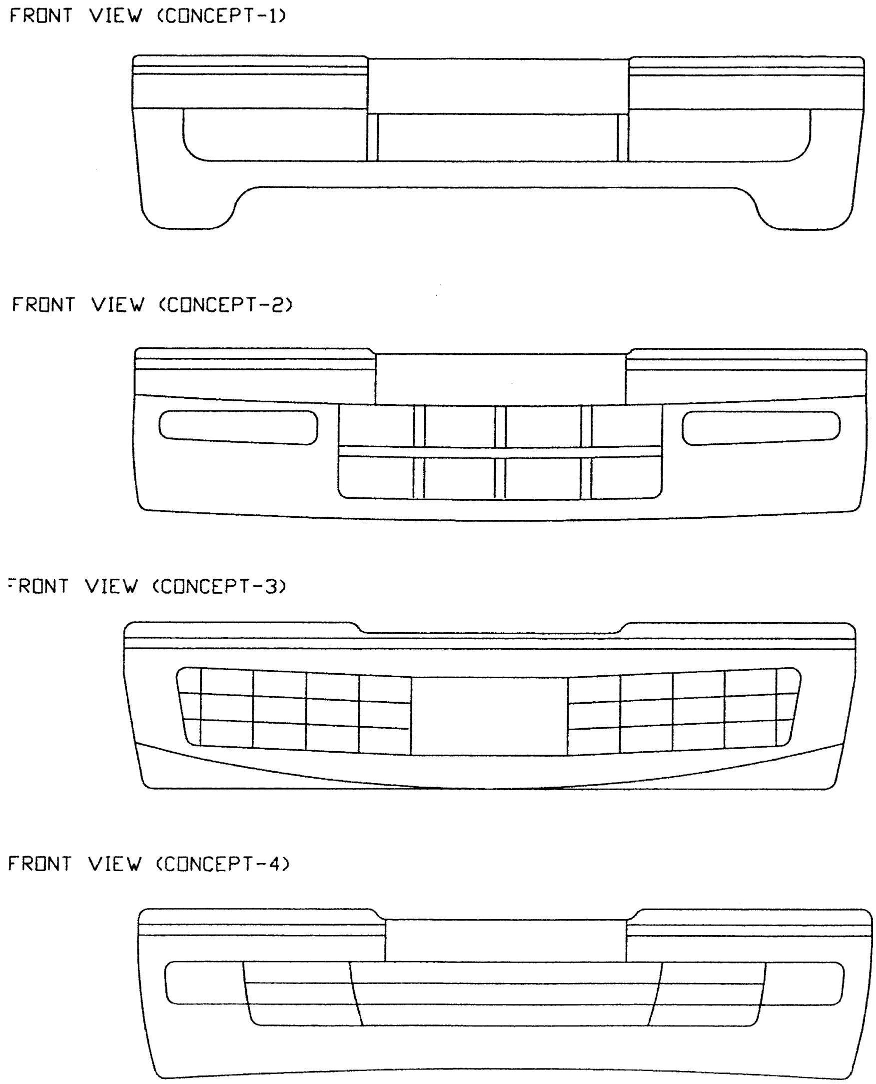

Fig. 3. Final concepts for bumper fascia.

is to compare the utility values of alternative design proposals, on the basis of performance against differential weighted objectives. In this method, the design objectives were listed and ranked. Relative weight was listed to the objectives. These numerical values should be on an interval scale; an alternative is to assign relative weight at different levels of an objective tree, so that all weight sum to 1.0. Performance parameter or utility values for each objective were established. The evaluation of utility values for four different concepts of bumper fascia is shown in Table 1. Given that all four concepts are fulfill the PDS. The following objectives are set:

- low cost;
- low weight;
- number of parts;
- material utilization; and
- manufacturability.

These are considered to have the respective weights of 0.25, 0.25, 0.1, 0.2 and 0.2. The entire concepts are assigned with values using 11-point scale. For each concept, the utility value for each objective was multiplied by the weight to give relative values. These values are sum up to get the overall utility values of each concept. The concept with highest values is selected. As shown in Table 1, the concept-3 gets the highest utility value compared to the other concepts; and hence, it is chosen as the best design concept.

2.8. Analogy method for material selection

Design involves choice, and choice from enormous banks of data and ideas. Among these is the choice of materials and processes [22]. The material selection procedure used in this research is employed analogy method. The management method of a company called Company ‘X’ is studied and its management style is adapted for the selection of material for bumper system based on the analogy principle. Company ‘X’ is an organization that is involved in manufacturing a certain

Table 1
Concept evaluation of utility values for bumper fascia

	SUB FUNCTION \ SOLUTION	1	2	3	4
1	MEANS FASCIA CONNECTION TO BRACKET	BOLTS AND NUTS	CLIPS	U-BOLTS AND NUTS	-
2	NUMBER OF PIECES	ONE	TWO	THREE	-
3	ATTACHMENT TO ENERGY ABSORBER (FOAM)	ADHESIVE	CIRCLIPS	U-BOTS AND NUTS	-
4	PLATE NUMBER PLACEMENT	UPPER AND CENTRE	CENTRE AND CENTRE	UPPER AND LEFT	UPPER AND RIGHT

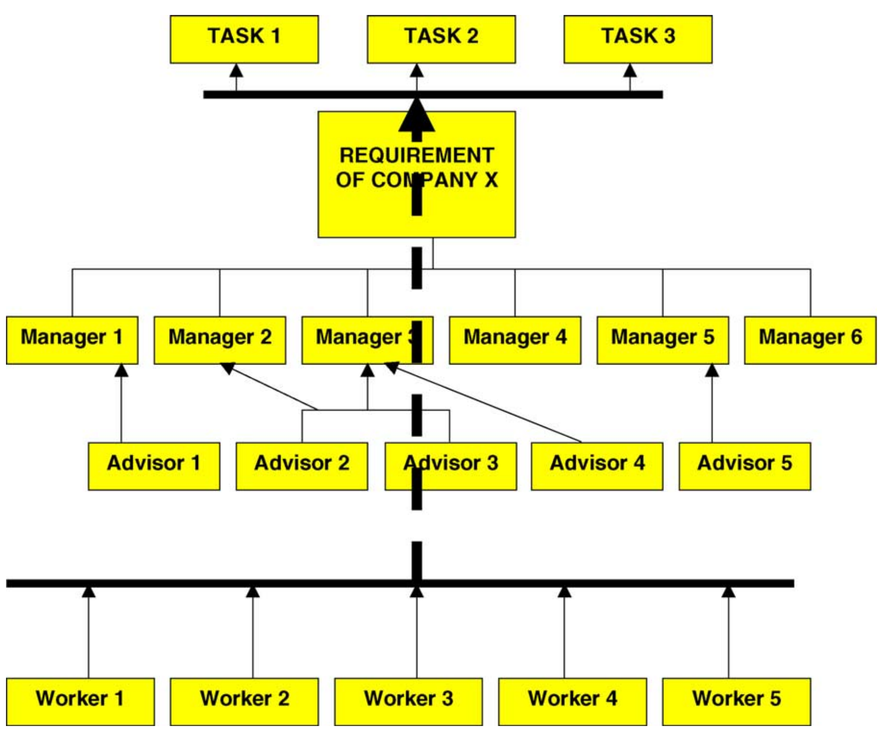

Fig. 4. The management style of company ‘X’ in executing three tasks.

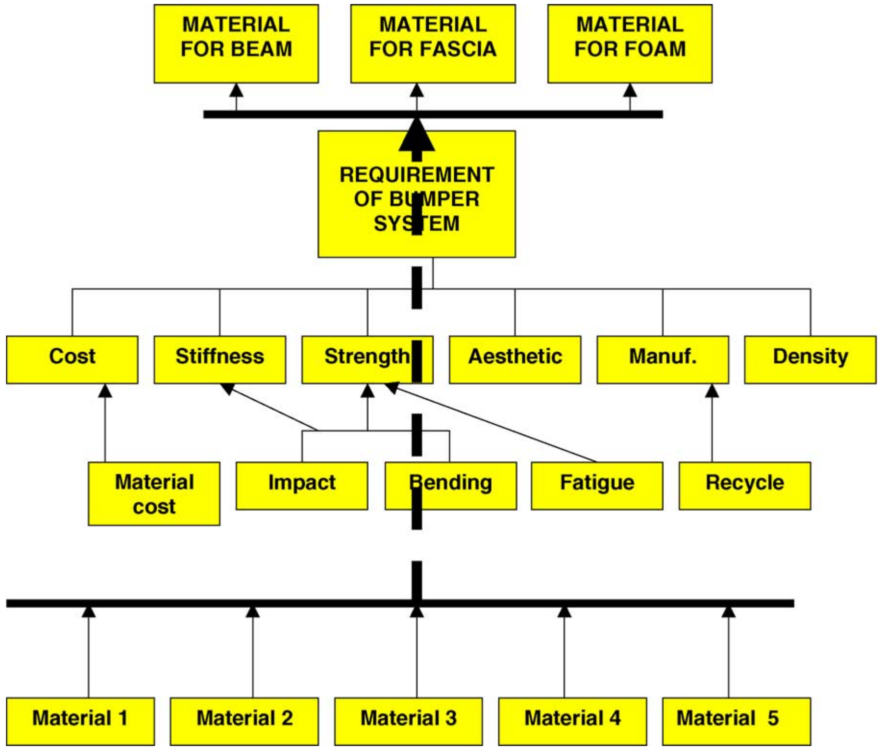

Fig. 5. A flowchart for material selection.

product. The management style of company 'X' in executing three tasks is shown in Fig. 4.

In the case of bumper fascia selection, Company 'X' is referred to bumper system. The three highly rewarded tasks are analogous to the most suitable materials of three main components of bumper system namely bumper beam, fascia and foam. Workers are equivalent to the candidate materials. In order for the candidates to become the most suitable materials for those three components, they have to satisfy certain constrains, such as cost, strength and other sub-constraints. The advisors are equivalent to sub-functions of the requirements.

The candidate materials should satisfy all the requirements and constraints. If any one of the requirements is not satisfied, the material is not selected for particular components. However, if a material satisfies all the requirements, it will become the candidate material for that component. In addition to the main requirements, sub-requirements may have to be satisfied by a material to be the most suitable for particular components. The flowchart in selecting the materials for three bumper components is shown in Fig. 5.

3. Conclusions

In the automotive industry, the properties of composite materials have their own place in advanced forms alongside metal. The development of composite bumper system has been given attention in this paper by looking into the conceptual design aspect.

Various proposed methods are appropriate for the design and selection of materials for automotive bumper system. Weighted objective method is the best method for evaluation of alternative concept of bumper system. This method shows that concept-3 is the best design among four different concepts.

Morphology chart, brainstorming, analogy and weighted objective method, etc. were used and they proved to be very efficient in generating ideas in the design process and selection of materials.

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