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Concept Generation of Sugar Palm / Glass Fiber Reinforced Thermoplastic Polyurethane Hybrid Composite Automotive Crash Box

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ABSTRACT

This paper presents a hybrid method of design technique introduced in development of conceptual design of sugar palm polymer composite Automotive Crash Box (ACB). Integration of theory of inventive problem solving (TRIZ), How-How diagram, Morphological Chart (MC) and Ishikawa method is applied in development of concept design of sugar palm polymer composite automotive crash box ACB. The important requirements of the function specification and failure mode analysis as well as geometry specification are considered. The aim of this paper is to produce a new concept design of sugar palm polymer composite ACB was determine and add into consideration of limitation from the material properties that are different with the conventional steel ACB. The selected final concept design of sugar palm polymer composite ACB has covered element of low cost, avoid complex manufacturing process to reduce the cost and efficient performance of ACB to absorb energy during collision.

1. Introduction

Concept generation is a process getting the ideas, starting with a set of customer needs and target specifications, the process concludes a selection of alternatives solutions until a final design is selected. There are multiple steps involved in the generic concept generation process, as well as various approaches. Hambali *et al.*,[1] applied analytical hierarchy process to generate idea for automotive composite bumper beam. Sapuan [2] using integration method of morphological chart, extension of search space, gallery method and voice of customer to generate concept design for the polymeric based composite automotive pedals. Mansor [3] using hybrid method of TRIZ, Morphological Chart and Analytic Hierarchy Process method for concept generation on kenaf

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Fiber polymer composite automotive parking brake lever. Currently, the conceptual generation method which is theory of inventive problem solving (TRIZ), How-How diagram, Morphological Chart (MC), Functional Analysis Diagram FAD and Ishikawa method selected in this paper have not implement by any researcher to generate idea in conceptual development process.

2. Methodology

Method of research in this study are using Technical FAD method to understand the technical aspect of a specific portion of a total product. Ishikawa method used to minimize the possibility of failure, mechanical failure happens once some components in the system unable to perform its operation sufficiently owing to the bound condition such as assembly errors, manufacturing defect or design deficiencies [4]. Then, Triz method provided general principal solution in conceptual idea generation, referring to the selected solution taken from TRIZ inventive principle, how-how morphology diagram method introduce to propose initial ACB conceptual design. How-how morphology is a hybrid method between how-how technique with morphological chart.

2.1 Functional Analysis Diagram (FAD)

In this study, automotive crash box (ACB) is a component that installed in a vehicle to absorb kinetic energy during low speed collision. Function analysis is a technique for analysing and developing a perform structure. Perform structure is an abstract model of the new product, while exclude the material options as well as the dimensions. It describes the function for each devices, elements and indicates the mutual relations. The underlying plan is that a perform structure is also designed up from a restricted range of elementary functions on a high level of abstraction. Functions is an abstractions of what a product ought to do. Being forced to consider the product in an abstract method stimulates creativeness, and prevents the designer from jumping to a solutions immediately on the first idea that comes to mind, which may not be the best. There are two types of FAD which is technical FAD and customer FAD.

2.2 Ishikawa Diagram

There are two major concerns within the style of automotive structures for crash energy management which is absorption of the kinetics energy of the vehicle and therefore the crash resistance or strength to sustain the crush method or maintain rider compartment integrity. As for energy absorption, two basic modes or mechanisms found in automobiles which is axial collapse and bending. Pure axial collapse will provide most effective mechanism for energy absorption to the ACB but very difficult to achieve while bending collapse will form a local hinge and the structure of ACB could failed in this mode [5]. At this point, Ishikawa method selected to be applied in order to identify the cause of the failure ACB producing axial collapse mode during collision. Thus, action of prevention will be taken at the earlier production stage to avoid any repeated failure.

2.3 TRIZ Method

The crash box idea is driven by the large amount of car crashes taking place at low speed impact which is velocities below 40 km/h. The aim of the conceptual design for ACB is to absorb maximum energy during collision, hence to obtain an axial collapse. According to Liu *et al*.,[6], Tarlochan *et al*.,[7] and Li *et al*., [8], beside the material properties (consider to use similar material for all conceptual design which sugar palm glass fiber reinforced thermoplastic polyurethane composite) influence the effectiveness of ACB, shape of geometry and density of the part criteria will affect the efficiency of ACB to obtain maximum energy absorption.

2.4 How-How Morphological Diagram Method

Final decision to select ACB conceptual generation idea before producing initial design model of ACB are using hybrid method of how-how morphological diagram method. How –how diagram is an interactive method use to explore relationship underlying a particular problem, where morphological method is a technique to consider all the possible solution for a multi-dimensional and non-quantified complex problem.

3. Results and Discussion

In this study, automotive crash box (ACB) is a component that installed in a vehicle to absorb kinetic energy during low speed collision. Generally the function of crash box to absorb maximum impact energy by deform prior to the other parts during the crash event to minimize the repair cost and ensure safety of the passengers' life as mentioned by Nasir Hussain et al. [9]. Figure 1 illustrated ACB system consists of Bumper rails at the most front of the crash system, bumper assemble to the automotive crash box and then crash box fix to the front rail. All parts hold at the position by using screw and bushing. The crash system receive kinetic energy from the impact load during the collision. Each operate segment in Figure 1 painted as an arrow within the diagram because the thick line represents the excessive operate, broken line represents an inadequate operate and thin line represents the traditional operate of the elements. As the structure of ACB would be made by composite material, the structure may not be able to absorb maximum kinetic energy to perform its general function adequately. Thus, in the next stage, the design process of ACB would be focused on the ACB structure for seeking a possible solution of this problem.

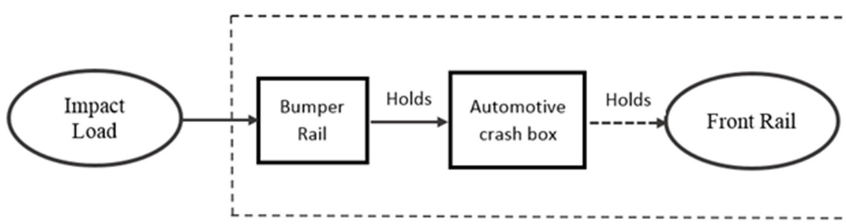

Fig.1. FAD for automotive crash box

3.1 Cause and Effect Analysis for ACB using Ishikawa Diagram

Nakazawa *et al*. [10] summarize force analysis to improve the impact energy absorption or to obtain an axial collapse base on three main points which is high buckling load at the ridge lines, minimize of buckling cycle time and minimization of load fluctuation. Free body diagram FBD shows in Figure 2 illustrate the folding process for ACB, folding start at certain compression area of the ridge line, that compression area then arise plastic buckling known as wrinkle.

Subsequently, wrinkle will fold and create another wrinkle at the ridge line under the above wrinkle. From the beginning, the load continuously increase until reaching the maximum value point. The load return back to the minimum value once the wrinkle absolutely fold, the following deformation will repeat the same process causing fluctuation load throughout the collapse, hence provide and axial collapse. Figure 3 illustrated the factor of failure to obtain an axial collapse by using

Ishikawa diagram. The most right box is a place to state an effect of the cause failure, the other boxes is a main cause contribute to the failure, then its followed by the details of failure cause for each roots.

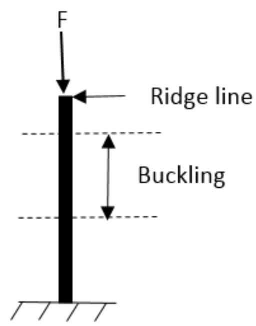

Fig. 2. ACB analysis force against displacement

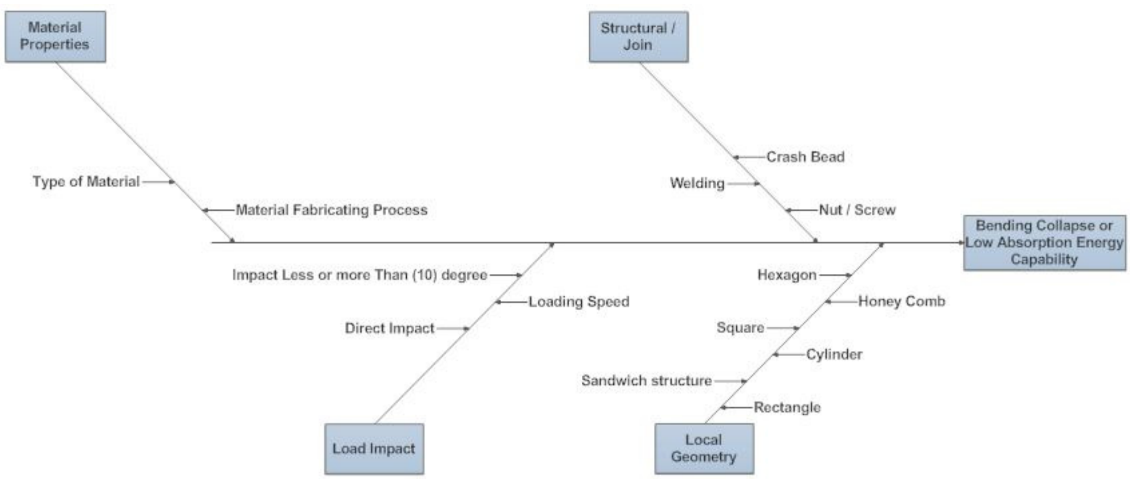

Fig. 3. Cause and Effect Analysis for ACB using Ishikawa Diagram [5,6,7].

According to the Ishikawa diagram in Figure 3, the failure might come from the structural or joint between crash box and bumper or front rail. Improper installation for ACB using nut and screw could provide misalignment, thus lead load impact smash the ACB slanting to the side way. Besides that, Crash box without crash bead will not provide any fluctuation load, hence provide a bending collapse. In addition, welding join with 6 mm diameter spot at the central of the flange width and 30 mm of the spot pitch will attain a constant progressive axial collapse [11]. Material properties is another cause of ACB failure to absorb maximum energy, the properties for materials various depends on types of materials and manufacturing process [12]. The most material selected by the automotive manufacturer which have high absorption capabilities is steel and aluminium. Material like synthetics composite or natural fiber composite which more user friendly also have a potential to replace aluminium and steel as ACB structure material due to the high toughness property. Equally important is manufacturing process, material such as Aluminium Carbon fiber reinforced polymer (Al/CFRP) manufactured using hybrid casting joining technology could increase the specific energy Absorption

SEA up to 38% for certain lay-up sequence. Load impact are related to the loading speed and degree of load impact to the ACB structure. The designing of crash box must engage with Federal Motor Vehicle Safety Standard (FMVSS) part 581 bumper test, and the Research Council for Automobile Repairs (RCAR) test to fulfill the strength requirement of the frontal structure [13].

3.2 TRIZ Method

TRIZ method presenting contradiction matrix and suggested inventive principle for ACB concept design. In this case, principle use are "the thickness, stiffness and size of the structure increase could improve energy absorption but it will increase more weight".

Table 1
Contradiction matrix and suggestion inventive principle for ACB concept design

	Worsening Parameter / Feature to Improve	Weight of Stationery	Inventive Principles
14	Strength	40,26,27,1	#40 Composite Material #26 Copying #27 Cheap short-living object #1 Segmentation
2	Area of Stationary	35,30,13,2	#35 Parameter change #30 Flexible shell and thin film #13 The other way round #2 Taking out

Table 1 presents the principle analysis, the best general suggestion that considered as most appropriate solutions are "# taking out" is defined as an undesirable component or part is disconnected from an object by pull out the only required component or part of an object. "# Parameter change" describe to change from uniform parameters to multiple parameters where each of it particular have own functional requirements.

3.3 How-How Morphological Hybrid Method

The hexagonal shape selected as geometry for ACB design in this study due to the benefits offers better than other geometry such as, high performance to absorb energy, easy to manufacture as well as will reduce the cost. ACB Structural selected to assemble using nut and screw due to the benefits offer better than welding such as easy to substitute the damage part, only need well train worker instead of specialist worker, hence reduce the manufacturing cost. The decision made also support by the earlier research such as Liu [14] present the design matrix of crashworthiness for the part with equal geometry could provide higher specific energy absorption SEA for the lightweight part. Moreover, Duddeck *et al*.,[15], Jiga *et al.*,[16] and Tanlak *et al.*,[17], present the hexagonal for ACB structure will perform better SEA value compare with rectangle and square geometry structure.

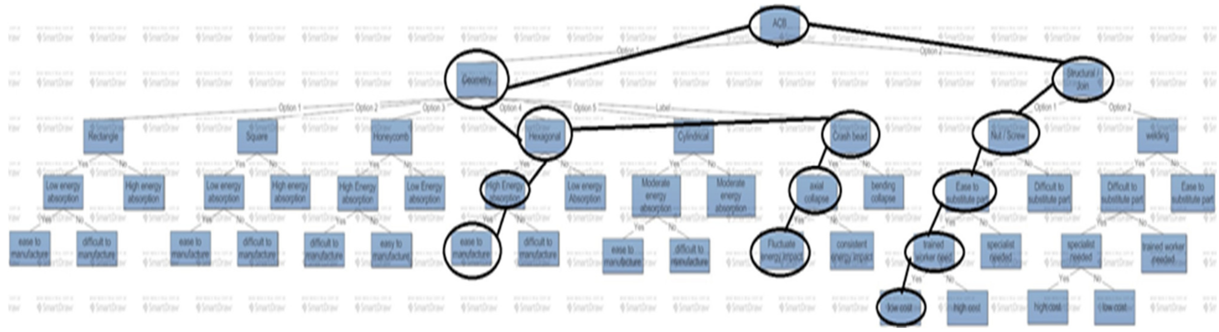

Fig. 4. How-How Morphology Diagram To Propose The ACB Conceptual Design

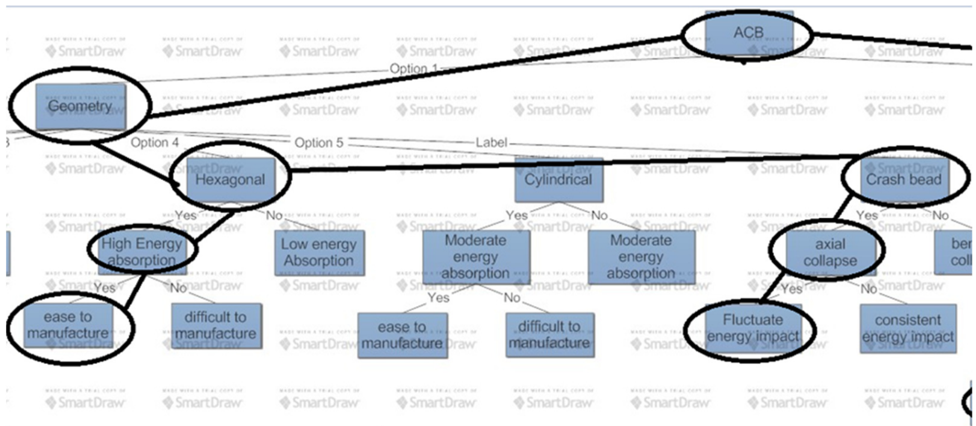

Fig. 5. Close up solution decision for requirements 1 (geometry)

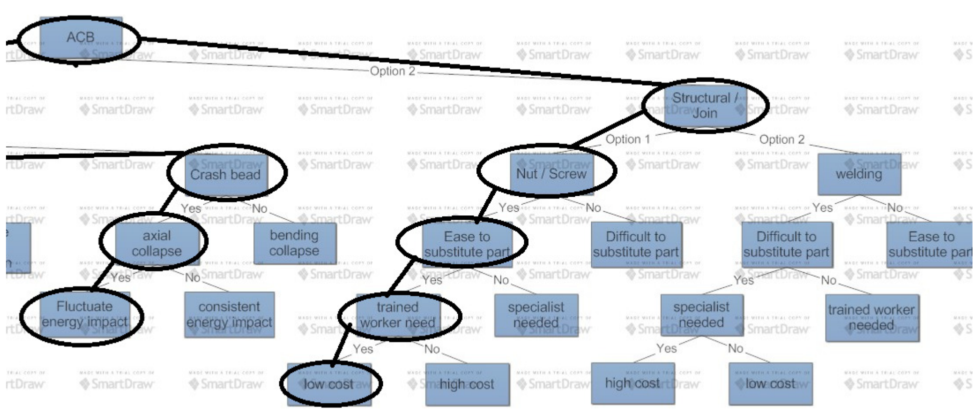

Fig. 6. Close up solution decision for requirements 2 (structural / join)

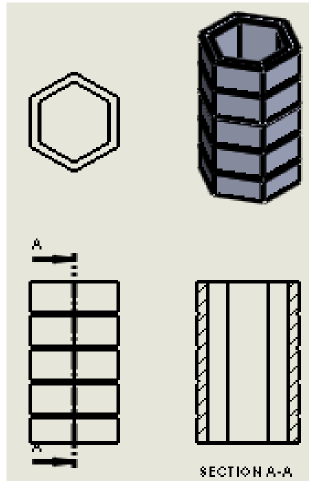

Fig. 7. ACB Conceptual Design

Figure 7 shows drawing of final conceptual design selected after undergo selection process, the model shows the hexagonal geometry with hollow structure and crash bead to fluctuate the load impact hence generate axial collapse as well as to efficiently absorb maximum kinetic energy.

4. Conclusion

Development of ACB had gathered useful method to satisfy the design requirements and technical design specification. Combination TRIZ, How-How diagram and Morphological chart could generate more concept design which would help design engineers to be more creative technically. However, the final ACB conceptual design selected in this study will undergo several alteration for assembly and manufacturing purposes.

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