PRELIMINARY DESIGN OF SIDE DOOR IMPACT BEAM FOR PASSENGER CARS USING ALUMINIUM ALLOY

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ABSTRACT

The growing demand for more fuel efficient vehicles to reduce energy consumption and air pollution provides a challenge for the automotive industry. The best way to increase fuel efficiency, without sacrificing safety, is to employ aluminium alloy within the body of cars, due to its higher strength to weight ratio than that of conventional steel. In this study, during the early design stage, structural modifications were studied using Finite Element Analysis (FEA), to determine a suitable cross-section shape for the side-door impact beam. The impact energy absorption characteristics of aluminium alloy and high-strength steel were investigated using a Charpy impact test. The fracture and surface contour of both materials were observed after impact testing. The preliminary results showed that a square hollow cross-section type was suitable for side-door impact beam use, due to its yield at the highest bending load. Both materials exhibited differential fractures and surface contours after impact testing, which directly indicates that aluminium alloy experienced a ductile fracture and had higher impact energy absorption than the high-strength steel.

KEYWORDS: *Side-door impact beam, Finite element analysis, Impact energy absorption, Aluminium alloy*

1.0 INTRODUCTION

Side-door impact beams are mounted on the door panels of passenger cars to guarantee passenger's safety from side-impact damage. Door stiffness is an important factor of a side-impact. Impact beams are required to have large static strength and high-impact energy absorption capabilities; properties that are seldom possessed simultaneously by conventional metals, because metals with high-strength usually have low toughness and vice versa (Lim and Lee, 2002). To meet these required properties of high-strength and high-toughness, high-strength metals are used to replace conventional steel for use in side-door impact beams. Weight reduction of cars is currently of great concern to manufacturers, due to the international movement of regulations; in terms of fuel efficiency and gas emissions of passenger vehicles.

In order to reduce weight, there are two important methods (Zhang et.al., 2006). One of these methods is to redesign automobiles parts to optimize their structure. By using thinning, hollowing, minitype, and compound parts, car weights can be reduced. The other method is to replace traditional materials, like mild steel, with lightweight materials, such as aluminium alloy, high-strength steel, and composites (Zhang et.al., 2006). Of these two methods, material replacement is generally more effective in achieving a lightweight automobile than structural modification.

In this study, the structural modification and impact energy absorption of materials was investigated simultaneously using Finite Element Analysis (FEA) and Charpy impact tests, respectively; in order to design a new side-door impact beam.

The best way to reduce the structural weight of an impact beam, without sacrificing safety, is to employ aluminium alloy, due to its higher strength to weight ratio than that of conventional steel. Aluminium alloys are widely used in aerospace and automotive industries; especially in structural applications. Therefore, they are a useful new candidate material for side-door impact beams, in order to improve impact energy absorption capacity and resistance to plastic deformation.

2.0 METHODOLOGY

2.1 Material preparation

In this study, aluminium alloy was selected as a potential material for side-door impact beams, due to its higher strength to weight ratio than that of conventional steel (i.e., high-strength steel). Table 1 shows the mechanical properties of aluminium alloy (Alloy 6061 T6) and high-strength steel (AISI 4340), used for side-door impact beams.

TABLE 1
Mechanical properties of aluminium alloy and high-strength steel

Mechanical properties	Aluminium alloy	High-strength steel
Young's modulus E, GPa	70	210
Density ρ, kgm^{-3}	2700	7850
Yield strength Y, MPa	276	470

2.2 Determination of a suitable cross-section for side-door impact beams.

Besides material selection, other design parameters (such as the shape and thickness of cross-sections) should be determined during the early stages of design.

In this study, the dimensions of a side-door impact beam were based on that of a Proton Wira, which is a Malaysian manufactured car. Figure 1 shows the side-door impact beam of a Proton Wira, with a hollow circular cross-section. The outside and inside diameters of the impact beam are 40.2 mm and 34.2 mm, respectively. The length of the impact beam was 830mm.

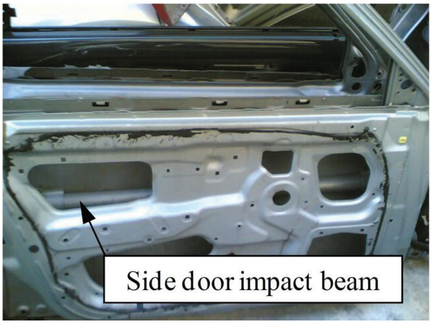

FIGURE 1
Photograph of the side-door impact beam of a Proton Wira.

Four different types of side-door impact beam cross-sections were selected, as shown in Figure 2. The thickness and length of each cross-section was 3mm and 830mm, respectively

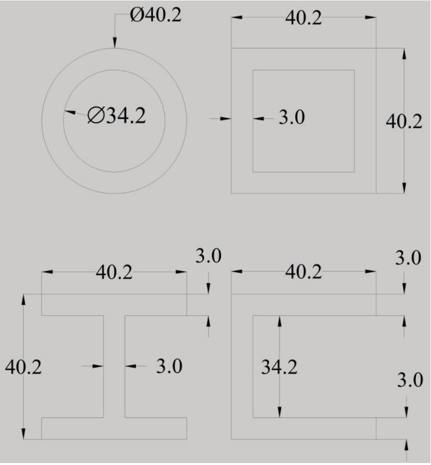

FIGURE 2
Different cross-section types of side-door impact beams
(All dimension in millimetres).

The side-door impact beam was simplified into a Beam 2D, and analysed using FEMLAB, which is part of the FEA software. As shown in Figure 3, a beam with equal thickness and length was modelled as a simple beam, supported by pins at both ends, and subjected to a load at the centre. In this analysis, the maximum bending load, *F* for four different cross-section types, was investigated by examining the Von Mises stress of all beams.

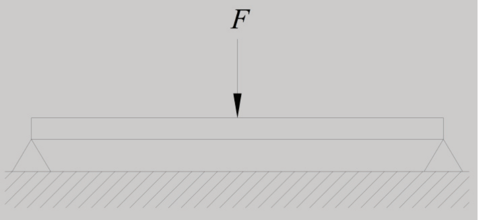

FIGURE 3
Simple beam subjected to a load at its centre.

2.3 Charpy impact test

Impact energy absorption was evaluated using a Charpy impact test, using a universal impact tester. Figure 4 shows the configuration of the impact tester, with the distance to the centre of strike, S = 1 m and the angle of fall, β = 120°. The impact speed was constant and the employed hammer's mass was 15.35kg. In this study, the notched specimens were prepared according to ASTM standards, with a dimension of 10 mm x 10 mm x 55 mm, as shown in Figure 5 (ASTM, E23-02a:158-184). After impact testing, the fractures and surface contours of the aluminium alloy and the high-strength steel were observed using a Sony digital camera, model T50.

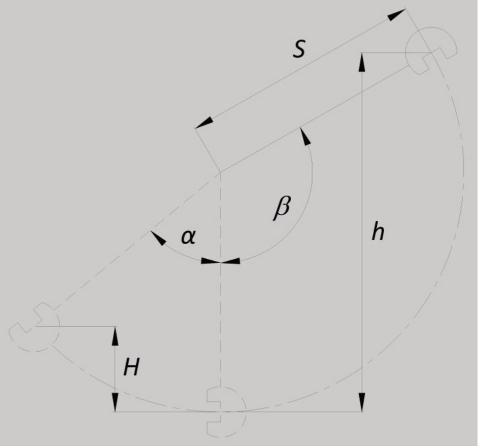

FIGURE 4
Charpy impact tester configurations.

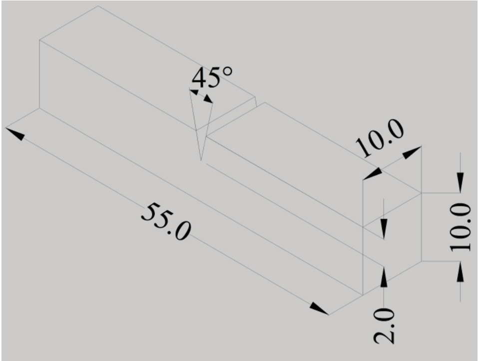

FIGURE 5
Standard specimen for the Charpy impact test (All dimension in millimetres).

Figure 4 shows that the impact speed was 5.42ms-1; calculated using the following equation:

$$v = \sqrt{2gh} \qquad (1)$$

Where, *g* is the acceleration of gravity. The impact energy absorption of both materials can be calculated as follows:

$$U = mg\left(S\cos\alpha - S\cos\beta\right) \qquad (2)$$

3.0 RESULTS AND DISCUSSION

Figures 6 and 7 show the results of the FEA. It was found that the square hollow cross-section type of aluminium alloy and high-strength steel side-door impact beams could be sustained at the highest bending load, just before yielding because the contact area is large. The larger the contact area, the larger the load which beams can be sustained before yielding. The square hollow cross-section types of aluminium alloy and high-strength steel were able to resist 6869 N and 11705 N, respectively. However, the hollow circular cross-section type yielded at the lowest bending load.

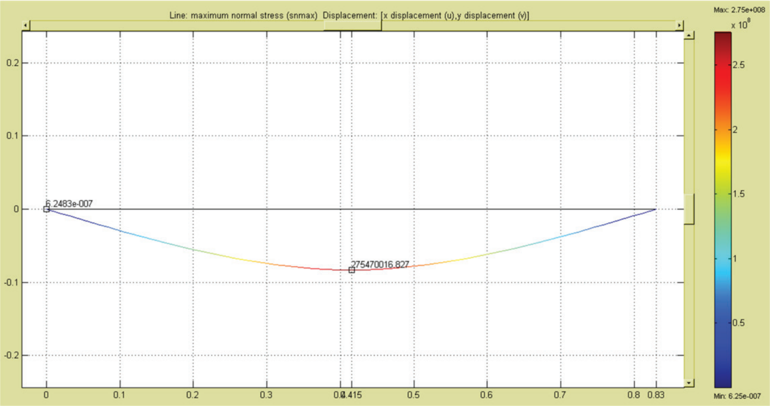

FIGURE 6
The value of maximum stress is almost the same as the yield strength of aluminium alloy for the square hollow cross-section type of impact beam, when loaded at 6869 N

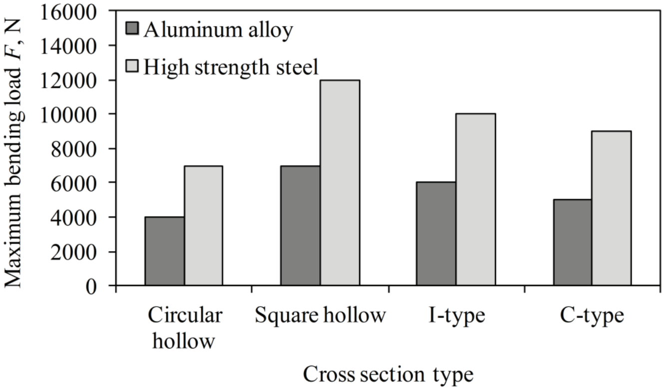

FIGURE 7
Maximum bending loads (at yield point) for various cross-section types of side door impact beams

Figure 7 shows that the maximum bending load (at yield point) for each cross-section type of high-strength steel was definitely larger than that of the aluminium alloy, because of its higher modulus of elasticity. However, the strength to weight ratio of aluminium alloy is higher than that of high-strength steel.

As impact beams undergo dynamic loads during a car crash, the impact energy absorption capability of the impact beam is more significant (Cheon et.al., 1997). Figure 8 shows that the average impact energy absorption characteristics of aluminium alloy and high-strength steel is 125 J and 78 J, respectively. This result shows that aluminium alloy exhibits a superior ductility to that of high-strength steel, because aluminium alloy has a face-centered cubic (fcc) crystal structure. Fcc alloys generally show a ductile fracture mode during Charpy impact testing (Shackelford, 2005), where more energy is needed to break the material. Figure 9 clearly shows that the aluminium alloy fractured in a ductile fracture profile, whilst the high-strength steel fractured in a brittle fracture profile after impact testing. Ductile fracture has a characteristic surface contour, which is termed as a cup-and-cone fracture, because one of the mating surfaces is cup-shaped and the other is cone-shaped (Callister, 2007).

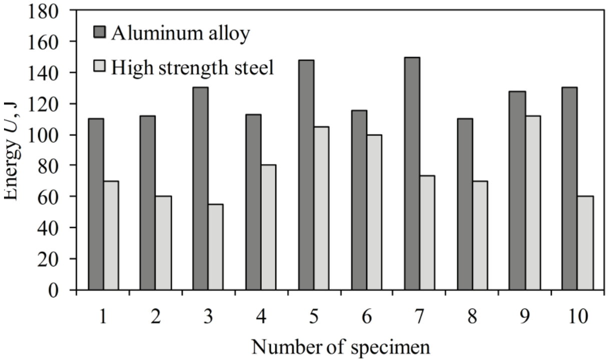

FIGURE 8
Impact energy absorption - evaluated using a Charpy impact test.

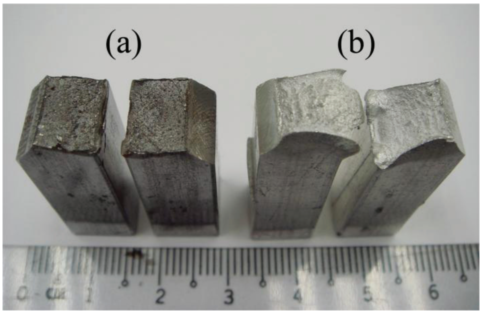

FIGURE 9
Photograph of the fractures and surface contours of aluminium alloy and high-strength steel.

4.0 CONCLUSIONS

In this study, an aluminium alloy side-door impact beam, for passenger cars, was designed to reduce weight, as well as to improve impact energy absorption. Structural modifications were studied using FEA, in order to determine a suitable cross-section for the side-door impact beam. Furthermore, the impact energy absorption characteristics of aluminium alloy and high-strength steel were also investigated using a Charpy impact test.

The FEA showed that the most suitable shape of a side-door impact beam is a square hollow cross-section type, because it yielded at a higher bending load than the I-type, C-type, and the circular hollow cross-section type.

The Charpy impact test results showed that the impact energy absorption of aluminium alloy was higher than that of high-strength steel, due to its superior ductility. Observation of the fractures and surface contours of both materials, after the Charpy impact test, clearly showed that aluminium alloy experienced a ductile fracture profile with a cup-and-cone surface contour, whilst the high-strength steel fractured in a brittle fracture profile.

5.0 ACKNOWLEDGEMENT

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