Simulation of Square Beam Subjected to Side Impact

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***Abstract*— Increasing energy absorption is an significant parameter in vehicle design. Absorbing more energy result in decreasing occupant damage. The limitation of deflection in side impact result in decreasing energy absorption (SEA) and increasing peak load. Hence high crash force is jeopardized passenger safety and the vehicle integration. This paper is aimed to introduce a configuration design of square beam with proper material to obtain less deflection and high SEA at same time. These contract objectives are achievable by analyzing the proper material of applied rib inside the square beam. There are comprehensive comparative steps to prove that the aluminum square beam by applied aluminum rib can be a good choice to get less deflection as well as high level of SEA.**

***Key words*—crashworthiness, energy absorption, simulation, square beam, side impact**

I. INTRODUCTION

Global accident statistics demonstrate that nearly 30% of accidents and 35% of fatalities are caused by side impact [1, 2] Side impact is more significant than frontal impact because there is less crash zone to absorb the energy compared with the rear and front structures [3, 4]. Hence there is not a sufficient safety region when a passenger is completely subjected to impact, which results in severe injuries [5, 6]. Thus, increasing the crash zones is essential but this may increase the weight of the vehicle. The crashworthiness performance of automobile components under crash conditions is very important for the vehicle occupants [5] . On the other hand, the weight reduction of the automobile is needed to improve fuel efficiency. Reducing the vehicle weight by about 10% results in a fuel saving of about 3-7% [7] .

In recent years a lot of research work on vehicle crashes has been carried out. Cui [8] investigated lightweight multi-material components of automobiles with some new materials for enhancing crashworthiness. However, this study did not consider the side impact on the square beam. Most of the research has analysed an axial crash on the square beam but neglected lateral crashes, which are analysed in this research. Niknejad [9] studied the fold creation in square columns under axial loading. Kill-sung [5] investigated the energy absorption of thin-walled square tubes under impact loading. The effect of web corrugation under bending was investigated by C. L. Chan [10] Sahari et al. investigated crash analysis of a front natural gas vehicle platform with a tank mounting structure.

Many crash studies have been done considering rib structure [11, 12] but without an adequate focus on analysing the combination of different kinds of materials and structure reinforcement. In the present research, improved SEA and reduced deflection are considered in the crash analysis. Many crash analyses have been done on the materials' crashworthiness. For instance, steel is a significant material due to its reduced deflection. However, high impact force and lower SEA are disadvantages of high strength materials such as steel. On the other hand, aluminium is a good choice due to its high SEA, but the high deformation of aluminium structures under impact may mean it is not the right choice. We need a structure design that gives us less deflection and high SEA. In this paper, the modelling, meshing and crash analyses were done using the LS-DYNA suite of programs, and at a crash speed of 8 m/s. The thickness of the square beam is 1 mm. Figure 1 shows the dimensions of the structure and the condition of the impactor. This condition of the square beam simulation could be a simplified representation of a front side sill door beam, as illustrated in Figure 2. For this reason, in this research a side impact crash is considered. Two steps in this research are considered. In the first step, magnesium, aluminium and steel are considered to analyse the level of energy absorption and the amount of deflection. In the second step, two structures which are made of steel and aluminium are considered with two different rib materials.

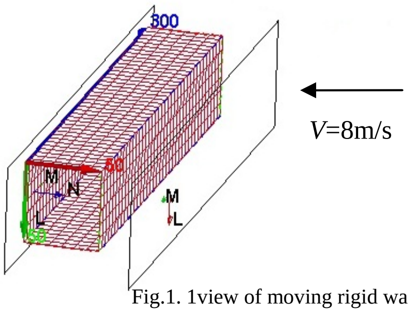

Fig.1. 1view of moving rigid wall

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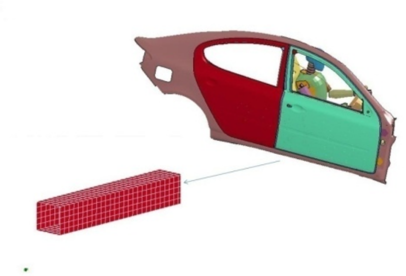

Fig.2 simplified beam of front side sill door

II. METHODOLOGY

A. Specific Energy Absorption

The energy E which is absorbed by the objects during the collision can be obtained from the following equations (NB: elastic displacement is neglected):

$$E = \int_{0}^{\delta} P(\delta)d\delta \qquad (1)$$

The specific energy absorption (SEA), which is the energy absorbed per unit mass of the structure part, can be defined by:

$$SEA = \frac{E_{total}}{M_{total}} \qquad (2)$$

where E_{total} is the whole energy and M_{total} is the total mass of the impactor .

B. Finite Element Modelling

The CAD data of the square beam is modelled, meshed and simulated using LS-DYNA 3.1 Beta software from LSTC Co. In the analysis, the side door beam is constrained with a rigid wall on one side, while the other side is impacted by a rigid wall of 10 kg mass moving with a constant velocity of 8 m/s. The four-node quadrilateral element (Belytschko-Tsay) is chosen because of its appropriate application in shell elements with the formulation of 3 integration points to mesh the model [15].

C. Materials Properties

The properties of aluminium, steel and magnesium are assigned to the front side sill door. The mechanical properties of the material are given in Table 1.

TABLE I
PROPERTIES OF MATERIALS

Material types	E (Gpa)	Poisson's Ratio	Yield stress(Mpa)	Ultimate stress(Mpa)	Strain at failure	Density (kg/m^3)
Aluminum 3105-H18	68.94	0.33	193	214	0.03	2720
Magnesium AZ31B	45	0.35	190	275	0.1	1740
Commercial steel bare-c	207	0.3	190	320	0.3	7860

III. RESULTS AND DISCUSSION

Fig. 3 shows the lateral deflection for the square beam made of different materials. The maximum deflection occurs at 0.012, 0.006 and 0.0055 s, with deflections of 43, 30, 21 mm, for magnesium, aluminium, and steel respectively. The minimum deflection occurs with the steel. Fig. 4 shows the impact force for these three materials. Steel has the greatest crash force of about 158532 N due to its greater rigidity compared to aluminium and magnesium. Fig. 5 shows the comparison of SEAs. It can be seen that the maximum SEA occurs with magnesium, which is about 29.3403E08 N.mm/ton. Thus, magnesium and steel are not a good choice due to their large deflection and low SEA respectively.

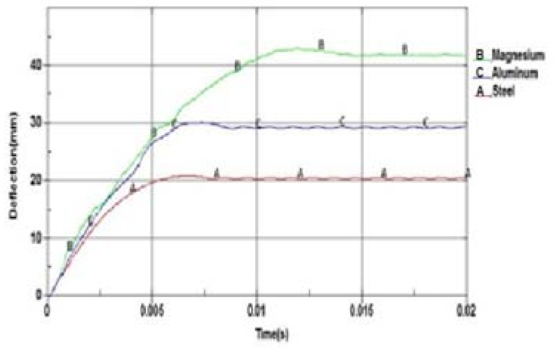

Fig.3 magnesiuman, aluminum and steel square beam deflection

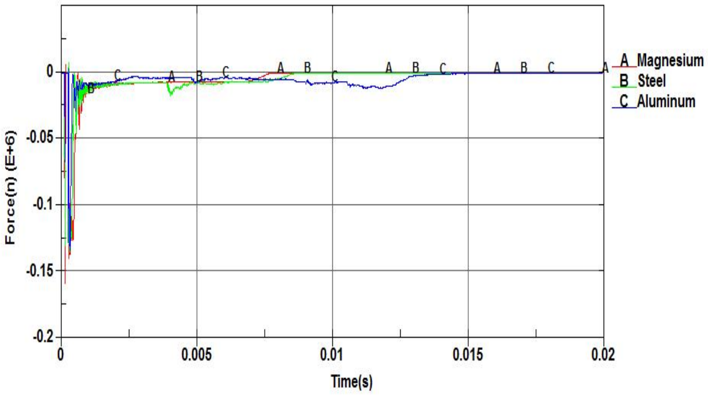

Fig.4 impact force in three case studies of square beam

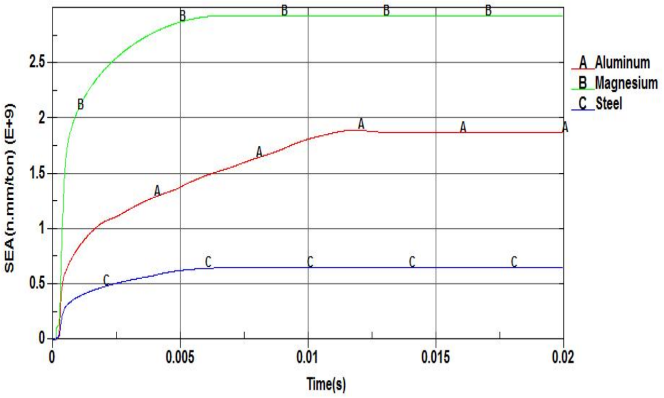

Fig.5 specific energy absorption for three case studies

IV. IMPACT BEHAVIOR OF MATERIAL FOR STRUCTURE AND RIB

In this study, we consider placing two different material ribs in the aluminium and steel square thin-walled structures. The mechanical properties for the ribs and square beam structure are given in Table 1. The rib is placed horizontally in the middle lateral surface of the square beam structure, as illustrated in Fig. 6. The thickness of the rib and structure is 1 mm. The effects of the impact behavior are investigated in three steps.

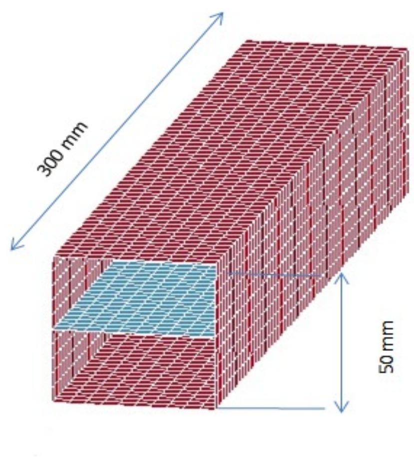

Fig.6 Thin wall structure with rib

A. *Steel Structure*

The thin-walled structures made of a steel square-cross section with 2 different rib materials, aluminium 3105 and steel, are compared with each other. Figures 7, 8, and 9 show the distribution of SEA, deflection, and impact force for the two cases studied. Fig. 7 shows that the steel structure with an aluminium rib has the maximum SEA, amounting to 5.89304e8 N.mm/ton, and Fig. 8 shows the amount of deflection, which is approximately the same for ribs of both materials. Meanwhile, the steel rib is more rigid than the aluminium rib. Fig. 9 shows that the steel structure with a steel rib has the maximum impact force, which amounts to 189139 N. In this phase, it is observed that the rigidity of the rib material does not play an important role in the amount of deflection.

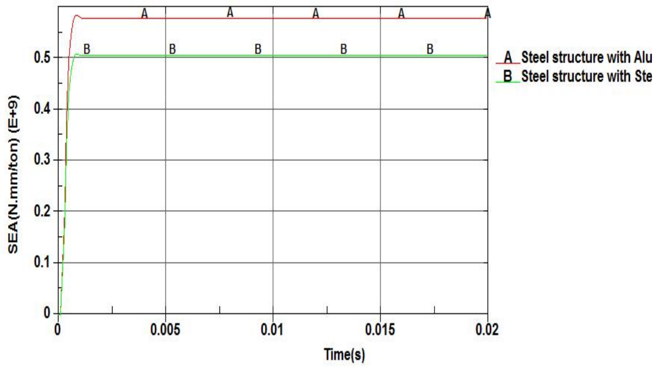

Fig.7 SEA for steel structure with aluminium and steel rib

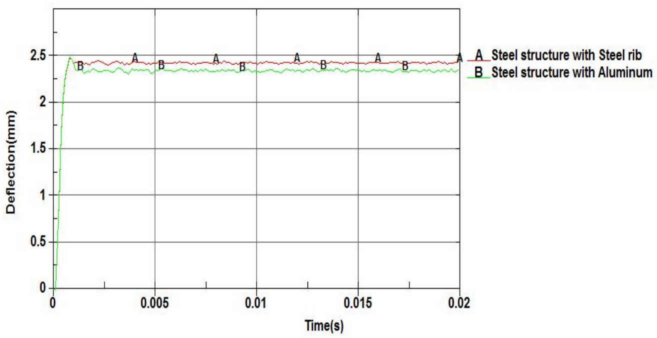

Fig.8 Deflection for steel structure with aluminum and steel rib

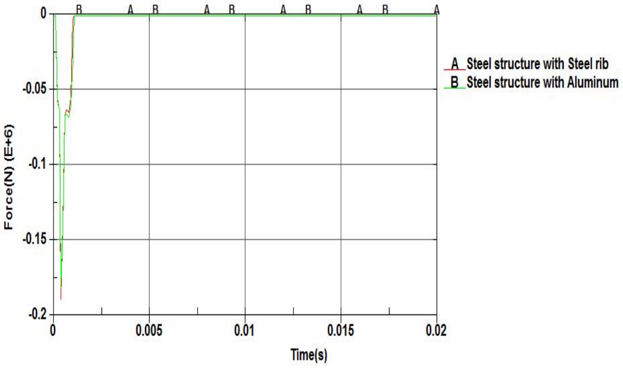

Fig.9 Impact force for steel structure with aluminum and steel rib

B. *Aluminium structure*

Figs, 10 and 11 show the impact behaviour for the aluminium structure with two different rib materials, aluminium and steel. The mechanical characteristics are shown in Table 1. It can be seen in Fig. 10 that the aluminium structure with an aluminium rib has the maximum SEA, which is about 15.0827e8 N.mm/ton. On the other hand, Fig. 11 shows that the amount of deflection is approximately the same for the aluminium structure with both aluminium and steel ribs, which is about 3.3 mm. Hence it is again observed that the type of rib material is not a significant factor in the amount of deflection. However, the rigid rib (steel) results in lower SEA and a high impact force.

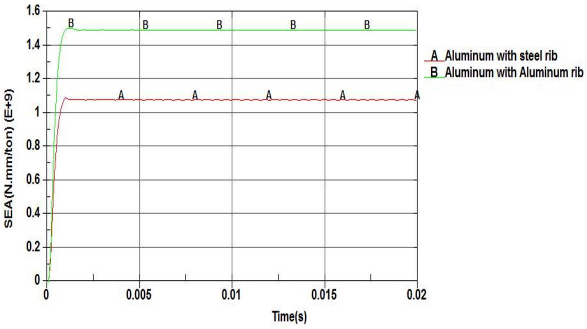

Fig.10 SEA for aluminum structure with aluminum and steel rib

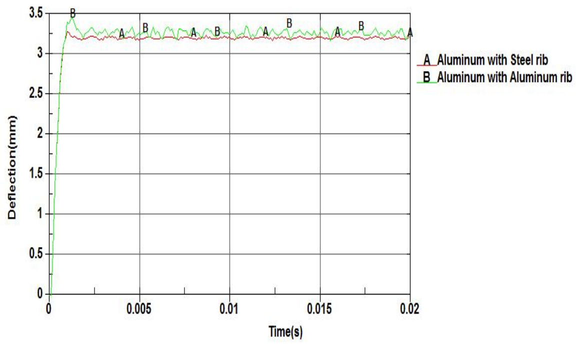

Fig.11 Deflection for aluminium structure with aluminium and steel rib

C. *Aluminium Rectangular Rib*

In the third phase, the appropriate material structure including aluminum rib is analysed. Figs. 12, 13 and 14 show the SEA, deflection and impact force for steel and aluminium structures with aluminium ribs. Fig. 13 shows that there is not much difference between the amount of deflection for both cases of study, which are 3.46 mm and 2.5 mm for the aluminum structure with an aluminum rib and the steel structure with an aluminum rib respectively. Meanwhile, Figs. 12 and 14 show that the aluminum structure with an aluminum rib has the maximum level of SEA and minimum impact force, at about 15.0827e8 N.mm/ton and 176822 N respectively. This phenomenon is due to the location of the rib, which is horizontal in the lateral section of the square beam. This configuration results in distributing the impact force over the surface and reinforcing the integrity of the structure.

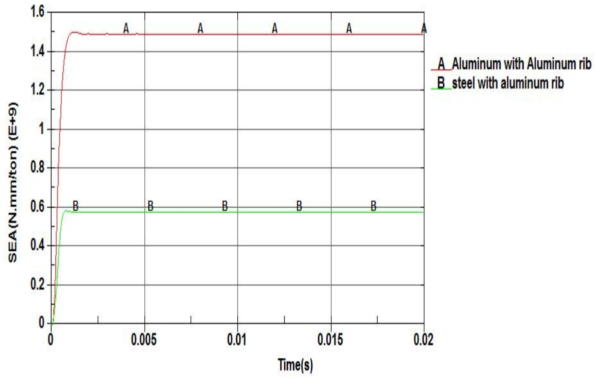

Fig.12 SEA for aluminium and steel structure with aluminium rib

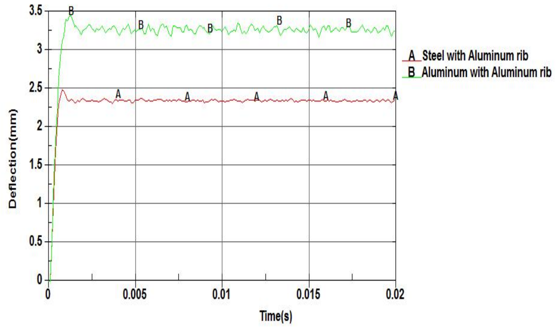

Fig.13 Deflection for aluminium and steel structure with aluminum rib

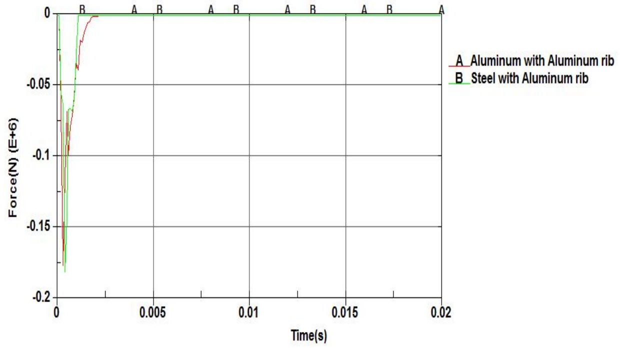

Fig.14 Impact force for aluminium and steel structure with Aluminum rib

V. CONCLUSION

The results obtained from this study of a square beam considering its impact performance, lead to the following conclusions:

1. Low stiffness materials give more energy absorption and lead to good impact performance. On the other hand, in the side impact the amount of deflection is another significant factor. Hence, aluminium is a good choice of material.
2. Rigid rib materials do not have much effect in reducing the deflection. The aluminium-reinforced structure results in a reasonable SEA compared to the other, due to the lesser mass of aluminium. In addition, using an aluminium rib caused much less deflection than magnesium. Furthermore, the impact force of the aluminium structure with an aluminium rib is much less than the steel structure with aluminium or steel ribs. Thus the shape, material and the location of the ribs and the type of configuration could contribute to increasing the SEA and decreasing the deflection.
3. In the automobile industry, steel is commonly used in the structural design for side impact, such as for the front side sill door. The reduced deflection of this material makes it important. Meanwhile, steel results in increasing the impact force and decreasing SEA. This research has proved that applying an aluminium square beam which has rib material inside can be a good choice to increase SEA and decrease deflection.

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