Crashworthiness Behaviour on Aluminum Foam Bumper Beam and Side Member System under Oblique Impact

F. Djamaluddin, S. Abdullah, A. K. Arrifin and Z. M. Nopiah

Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

*Corresponding author : fauzanman_77@yahoo.com, shahrum.ukm @ gmail.com

Abstract

This paper presents the simulation of crush behavior for side members and bumper beam under axial and angular impact loading. Recent issues of automotive industry are to reduce weight and to improve occupant safety. Aluminum foam as a lightweight material was selected due to its excellent energy absorption capacity. Various parameters have been considered, such as angles of load, geometry and the material selection, aluminum alloy (AA6063 and AA6060) . Bumper beam connected two side members were impacted load angles of 0˚ to 30˚ from longitudinal axis. The finite element analysis approach using the specific software package has determined the crashworthiness parameters, that were specific energy absorption (SEA) and crush force efficiency (CFE). The outcome of this study have formulated functions for calculating of crush parameters.

Keywords: Aluminum foam, bumper beam, crashworthiness, oblique impact, side member

Bumper beam side members system is main part of vehicle in absorbing of the kinetic energy under frontal impact. Figure 1. shows position of the bumper beam and side member system in the automobile.

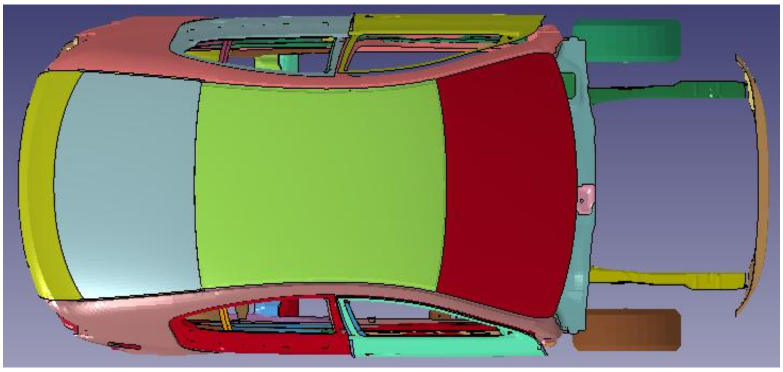

Figure 1. Position of bumper beam and side member system at automobile

During the accident, this system not only endures a bending effect, but also a combination of bending and collapsing, especially under angle load. In this paper, we studied the combination of axial and angle loads of the system, which consists of two side members connected at the bumper beam. In accordance with standard safety regulations driving of the vehicle and federal safety standards (FMVSS), the loading angular is from 0° to 30° for rigid barrier tests at 48 km/h velocity.

Celullar material, such as foam, is used to fill thin-walled column. This column is expected to increase ability of the material energy absorption without adding excessive weight. Hansen et al (2000). have conducted experimental tests to find effective crushing distance in aluminum foam square and cylindrical column. Ahmad et al.(2010) studied whether the aluminum foam-filled conical tubes can improve energy absorption in their experiment test. Research on oblique impact on structure is limited. However, this load occurs in many vehicle accidents. Certain research, such as Reyes et al. (2002), Nagel et al. (2006), and Ahmad et al.(2010), have conducted oblique loading using experiment test.

This work determines crush behavior by considering a numerical solution. Finite element model set up used was ABAQUS software. Finally, we find correlation between crash behavior of bumper beam and side member system and their different parameters, such as length and thickness.

Theory Background

Some parameters are applied to determine the ability to absorb energy of the material or structure. The specific energy absorption (SEA) and the crush force efficiency (CFE) are two parameters used to calculate the absorption level of material and structures. For this study, we focused on square columns filled with aluminum foam.

Mean crush load

we used mean crush load to calculate capability of material for energy absorption. In this study, displacement is used to determine the value of energy absorbed. In the numerical result, displacement is given by the node at the top end of the aluminum foam tube.

$$Pm = \frac{Ea}{\delta} \tag{1}$$

where δ deformation of structure that the time after reach mean crush load . Peak crushing force should reduce energy and increase level of occupant safety in automotive accidents (Kurata et al. 2002).

Specific energy absorption (SEA)

SEA shows energy (*Ea*) per unit mass (*m*) or,

$$SEA = \frac{Ea}{m} \tag{2}$$

Crush force efficiency (CFE)

CFE is the ratio of the mean crush load to the peak crush load

$$CFE = \frac{Pm}{Pmax} \tag{3}$$

Model of Finite Element

By considering the dynamic numerical solution, the model of simple bumper beam side members system under loading angle was formed, as seen in Figure 1. Both bottom parts of the side members was clamped, whereas the top left corner of the bumper beam under angle load had a velocity of 10 m/s.

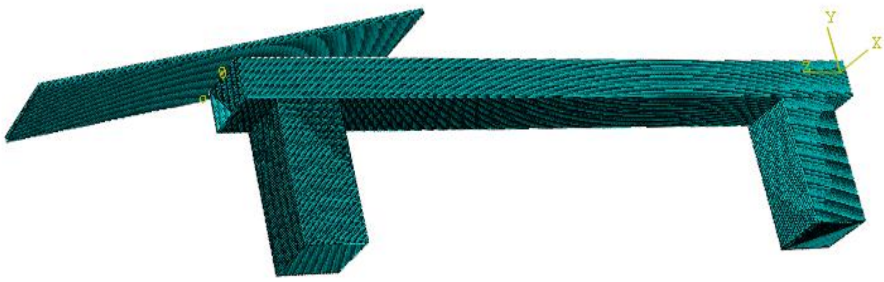

Figure 2. Simple model of aluminum foam bumper beam side member system under oblique impact

Model and simulation used the ABAQUS explicit finite element code. The mechanical properties of the materials were obtained from experiments with the engineering curve of stress-strain, as shown in Figures 2 and 3. Model of the system formed a square aluminum column using the Belytschko-Tsay. Deshpande and Fleck (2000) developed the crushable foam model for the foam core. The aluminum foam has mechanical properties such as Young's modulus E=64.8 GPa, rate sensitivity damping coefficient is 0.05, Poisson's ratio of 0.01, and rate sensitivity damping coefficient of 0.05 (Song et al. 2005). The mechanical properties of AA6063 and AA6060 can be referred to in the table below.

Table 1. Mechanical Properties of aluminum alloy

PARTS	MATERIAL	ν	ρ (kg/m3)	σu (N/mm2)	σy (N/mm2)
Bumper beam	AA 6060	0.33	2700	160	120
Side member	AA 6063	0.30	2700	215	160

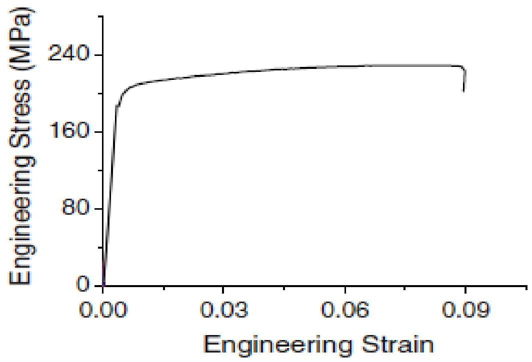

Figure 3. Stress – strain curve of AA 6063 (Guo et al. 2011)

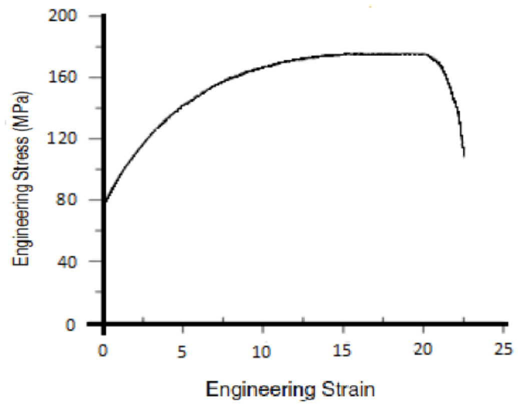

Figure 4. Stress – strain curve of AA 6060 (Reyes et al. 2002)

Result and Discussion

Square column geometries effect of bumper beam side members system

The geometry of the model can be seen in Fig. 5, where the bumper beam length is 960 mm and cross-sectional area is (80 mm x 65 mm). Side member length is 120 mm and cross-section area is (80 mm x 80 mm). Parameters on the bumper beam are assumed constant.

However, the length and thickness of the side member were different. Length varies from 120 mm to 180 mm and the thickness varies from 2.5 mm to 4 mm.

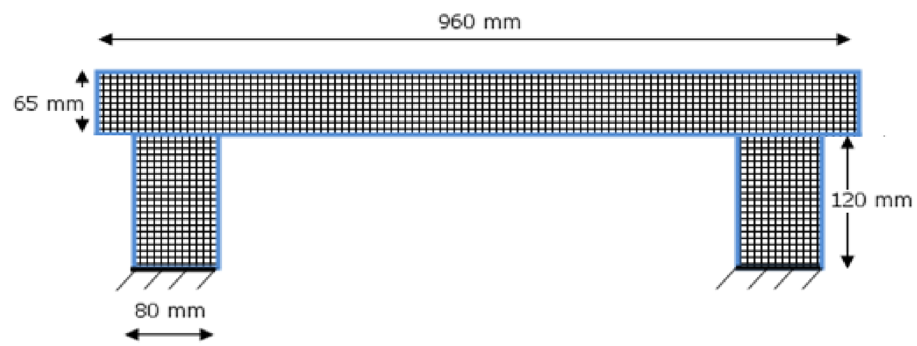

Figure 5. Geometry of simple bumper beam side member system

Column length effect of side members

Fig. 6 shows the SEA- angle of loading response of aluminum foam filled square columns of bumper beam side member system with varying lengths.

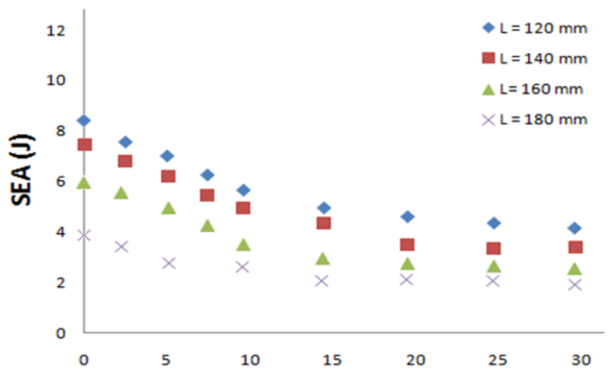

Figure 6. SEA versus angle of loading with different length

The numerical simulation result indicates that shorter columns are more mass efficient in absorbing energy. Loading angle increases, but column SEA decreases. This case suggests that load angle promotes local bending to dominate collapse behavior.

Figure 7 shows the CFE versus angle of loading response of aluminum foam square columns with varying lengths.

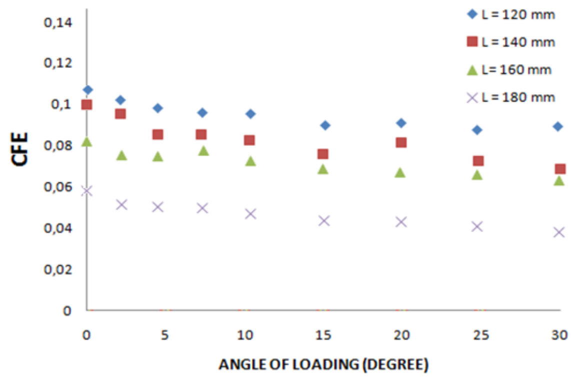

Figure 7. CFE versus angle of loading with different length

Unlike SEA, CFE increases because of increase in column length. This was caused by a considerably different value between mean crush load and peak crush load. Hence, the value of CFE becomes relatively small. Apart from these, the addition of the load angle decreases CFE.

Column thickness effect of side member

Fig. 8 shows the SEA-load angle response of aluminum foam of square columns side members with varying thickness.

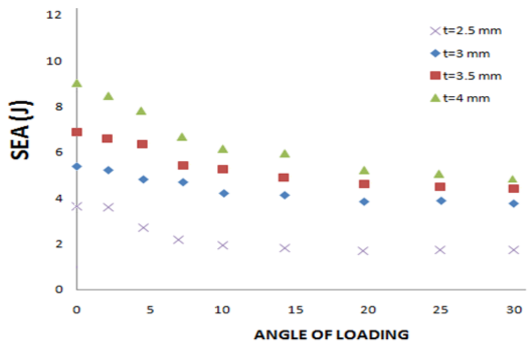

Figure 8. SEA versus angle of loading with different thickness

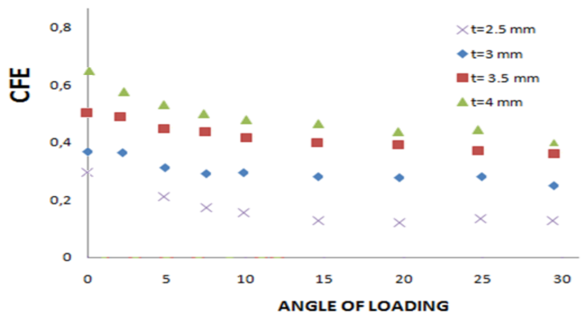

Figure 9. CFE versus angle of loading with different thickness

The thin walled column was increased from 2.5 mm to 4 mm. SEA increase is caused by increased wall thickness deformation corresponding with additional column thickness. On the other hand, CFE is reduced because of the effect of peak load crash.

Table. 2. SEA and CFE of column under 30˚ loading angle

Length (mm)	SEA					CFE				
	Thickness (mm)					Thickness (mm)				
	2	2.5	3	3.5	4	2	2.5	3	3.5	4
120	3.23	3.56	4.12	4.45	4.67	0.53	0.40	0.34	0.21	0.18
140	2.32	2.45	2.65	2.87	3.12	0.47	0.38	0.31	0.18	0.15
160	1.65	1.76	1.98	2.09	2.14	0.45	0.36	0.30	0.15	0.12
180	0.56	0.97	1.20	1.32	1.53	0.42	0.34	0.28	0.12	0.10

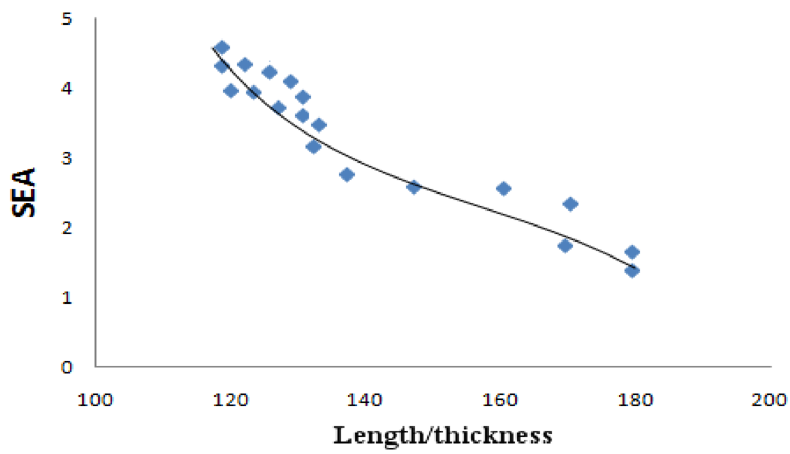

Figure 10. SEA versus length/thickness under 30˚ loading angle

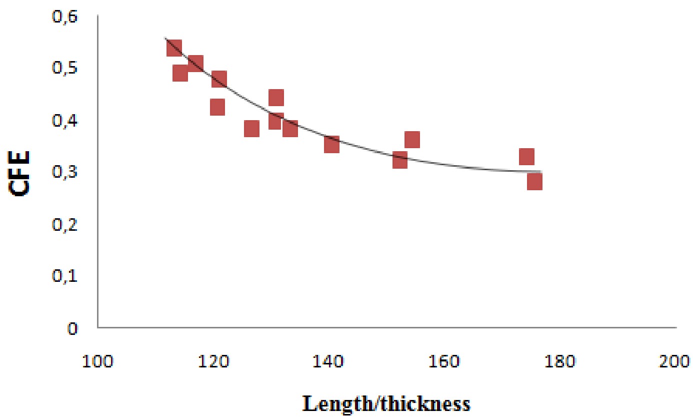

Figure 11. CFE versus length/thickness under 30˚ loading angle

Table 2 describes the numerical results for SEA and CFE under a load of 30˚ for the aluminum foam bumper-beam side-member system. The results can be plotted to determine relationship between the SEA of the aluminum foam column and the length-to-thickness ratio. Based on Figure 10, the equation can be written as

$$SEA = 64.85\left(\frac{l}{t}\right)^{-0.64} \tag{4}$$

where t denotes the thickness, and l denotes the length of the aluminum foam column. Similarly, the CFE versus length-to-thickness ratio is given by

$$CFE = 6.319\left(\frac{l}{t}\right)^{-0.75} \tag{5}$$

The SEA and CFE of the aluminum foam columns depend on the value of the length-to-thickness ratio. Automotive design parameters must consider both the thickness and length of the column to achieve the optimal weight and stability of the structure.

Conclusion

This paper facilitated understanding and provided an analysis of column behavior under an oblique impact of 0° to 30°. Different thin-walled column parameters, including length and thickness, induced SEA and CFE effects. Changes in these parameters and the loading angle resulted in the variance of SEA and CFE values.

The SEA and CFE results were plotted to determine the effect of the length-to-thickness ratio of the side member on the properties of the aluminum foam bumper-beam side-member system. The numerical result of CFE and SEA versus the variations of the length-to-thickness ratio can serve as reference for the selection of appropriate parameters for columns made of an aluminum foam bumper-beam side-member system.

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