Axial Impact Crushing Performance of Bi-tubular Structures with Stiffeners

A. Praveen Kumar, L. Ponraj Sankar, D. Maneiah, M. Naveen

Abstract*: Thin-walled tube shaped components have been expansively utilized as an impact energy dissipating devices in modern vehicles in order to decrease fatalities and vehicle damage during accidents. The present article investigates the axial crushing performance of bi-tubular structures of various configurations. Nonlinear impact simulations were performed on the proposed bi-tubular structure using finite element ABAQUS/CAE explicit code. From the outcomes attained, the Energy Absorption Capability (EAC) of bi-tubular structures with stiffeners were compared and it confirmed that bi-tubular structures have more potential than that of traditional simple geometry tubes. Furthermore, bi-tubular structure of circle section enclosed with square type section were recommended as significant one for superior EAC. This kind of bi-tubular structures was found to be proficient energy absorbing elements in vehicles to improve the crashworthiness performance.

***Keywords* : Bitubular structures, Simulation, crashworthiness, crash box, Axial impact.**

I. INTRODUCTION

For the passenger safety and protection of vehicle structures during unexpected accidents, the kinetic impact energy need to be dissipated in a controlled manner [1]. Thin-walled (TW) metallic tubular structures draw more attention among researchers and are extensively employed in the crashworthiness design of automotive vehicles owing to its light-weight, less cost and superior energy absorption efficacy [2,3]. These structures has to be stiff enough to decrease intrusion, and provide appropriate progressive plastic deformation to reduce the impact force, acceleration transmitted to the passengers [4]. By modifying the geometric attributes of the structure, it would be feasible to attenuate the peak crushing force and enhance the Energy Absorption Capability (EAC) [5]. Several research studies have been conducted in the last four decades to gain better understating of the deformation behaviour of T-W tubular structures and calculation of their crashworthiness indicators under quasi-static and impact axial load [6-8].

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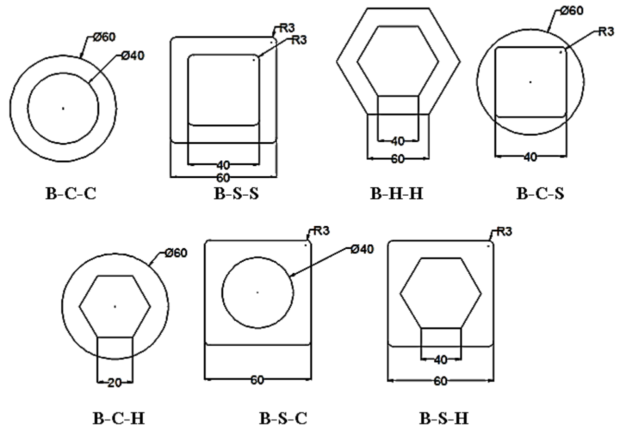
Bitubular components are one of the recently proposed energy absorbing structures for automotive vehicles and proper design of these tubes could control the deformation modes without compromising the EAC [9, 10]. Extrusion process is one of the potential manufacturing method to easily fabricate several prismatic structures with multi-cell cross-sections. Tang et al. [11] reported that the deformation performance of bitubular cylindrical tubes predominantly depends on the number of stiffeners and tube thickness. They concluded that the bitubular concentric cylindrical was the most appropriate among all the sections to enhance crashworthiness characteristics. Continuing with bitubular cylindrical sections, Ahmed et al. [12] examined the deformation characteristics of numerous tube configuration with curvy stiffeners under axial impact. Their outcomes showed the efficacy of curved stiffeners in enhancing the EAC of tubes. On the other hand, bitubular cylindrical tubes with curvy stiffeners exhibited superior stability to the lowest peak force compared to single-cell cylindrical tube.

Though crashworthiness performance of bitubular structures are gaining importance in recent research topics, still only cylindrical configurations under quasi-static loading is examined. In the current study, bitubular tubes research is further stretched for determining the deformation and EAC characteristics of such structures having similar and different outer and inner sections under axial impact. In this regard, the proposed bitubular structures are well-defined and deformed numerically for determining the crushing profiles and crashworthiness indicators such as Initial Peak Force (IPF), Mean Crushing Force (MCF), Crush Length (CL) and EAC and the results are compared with the single cell tubes.

II. MATERIALS AND TUBE CONFIGURATION

In this article, bi-tubular structures were made of aluminium AA6061 alloy, and this material was selected owing to its wide application in vehicle body panels and roof structures [13]. Mechanical characteristics of these tubes are calculated from typical uni-axial tensile testing of samples pierced from the tubes. The Modulus of elasticity is E=68000 MPa, Yield stress is 68 MPa. Ultimate tensile strength is 170 MPa, the density is $\rho = 2700$ kg/m^3 and the Poisson ratio is $\upsilon = 0.3$. The influence of strain rate was not considered in this study owing to the insensitivity of aluminum alloy. For aluminium tubes, material properties of the tube could be modeled using von Mises elasto-plastic criterion and an associated flow rule. The yield stress and effective plastic strain values were determined from the stress- plastic strain curves of the aluminium metal and are presented in Table 1. The dimensions of the proposed bi-tubular structures simulated under axial impact loading is shown in Figure 1.

The tube specimens investigated in this study are specified using codes for better understanding, identification and comparisons. These codes comprise three alphabets.



(All dimensions are in mm)

Fig. 1 . Dimensions of proposed bi-tubular structures

The first letter represents the type of tube while second and third indicates the section of the tube. In bi-tubular structures, different shapes are used. B-C-C represents the bi-tubular circle with circle, B-S-S represents the bi-tubular square with square, B-H-H represents the bi-tubular hexagon with hexagon, B-C-S represents the bi-tubular circle with square, B-C-H represents the bi-tubular circle with hexagon, B-S-C represents the bi-tubular square with circle, B-S-H represents the bi-tubular square with hexagon.

Table 1 Plastic properties of aluminium AA6061 alloy

Yield stress (MPa)	Plastic strain
68	0
78	0.0019
125	0.03
148	0.06
155	0.08
159	0.1
165	0.16
170	0.19

Table 2 Crashworthiness indicators of bi-tubular structures under axial impact

Specimen geometry	Thickness (mm)		Velocity (m/s)	CL (mm)	IPF (kN)	MCF (kN)	EAC (Joules)	Specimen geometry
	T1	T2						
B-C-H	2	2	12	165	87.011	37.55	6187.97	12
B-C-C	2	2	12	165	59.93	37.60	6199.11	12
B-S-H	2	2	12	140	142.67	48.92	6850.16	12
B-S-S	2	2	12	136	92.58	50.47	6892.91	12
B-S-C	2	2	12	135	85.66	51.38	6953.84	12
B-C-S	2	2	12	145	62.40	48.86	7093.10	12
B-H-H	2	2	12	108	77.16	65.51	7094.03	12

III.FINITE ELEMENTS SIMULATION

With the aim of performing the Finite Element (FE) simulations of axial deformation of the proposed bi-tubular structures under impact loading, the ABAQUS/Explicit FE code is utilized. For axial crushing simulation, a bi-tubular structure is placed between the upper plate and fixed plate, where the lower fixed plate is fully constrained and the upper plate is movable in axial direction. Figure 2 shows the boundary conditions applied to bi-tubular structures simulated under axial impact loading. A point mass of m=100 kg and an impact velocity of 10 m/s is defined for the upper plate. Based on the mesh sensitivity analysis, the element size for each bi-tubular structure is obtained as 1 mm which is sufficient to yield accurate results. Four noded shell elements (S4R) is used in the discretized model. The fixed plate is modeled with a four-noded fixed elements (R3D4). Table 2 displays the comparative results of various crashworthiness indicators of bi-tubular structures predicted numerically subjected to axial impact.

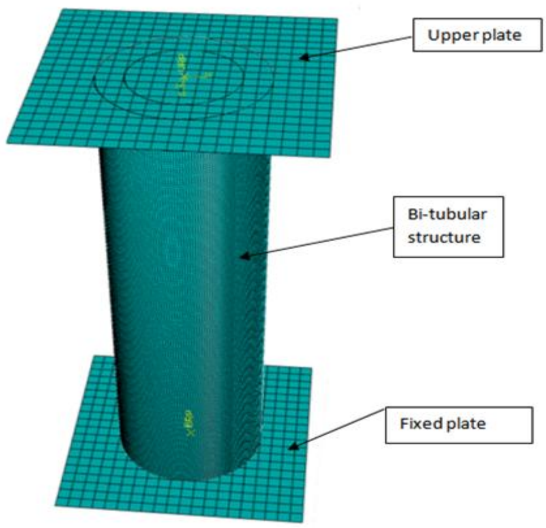


Fig. 2. Boundary conditions applied to bi-tubular structures

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IV. RESULTS AND DISCUSSION

The deformation behavior of the proposed bitubular structures is numerically simulated under axial impact loading conditions.

Since the buckling profiles of the simulated tubes were not symmetric in respect to an axis, all the tube configurations were numerically created in full geometry. The typical progressive crushing of bi-tubular structures at four different crushing deformation values (for every 40 mm) of axial impact is shown in Figure 3. It is perceived from Figure 3 (a) that the both the inner and outer cylindrical tubes deformed in concertina mode from the loading end to the final deformation which leads to absorb more impact energy and also noted that that the deformation is stable and progressive. Moreover the inner hexagon and outer square tube configuration as shown in Figure 3 (b) also deforms progressively with uniform subsequent folds until the final deformation length of 165 mm.

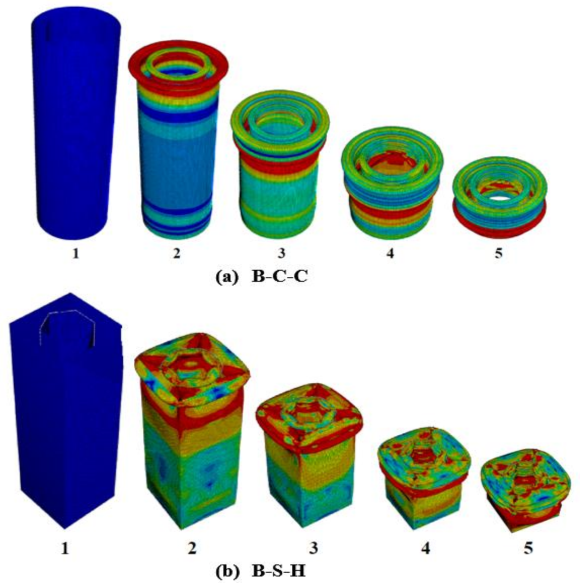

Fig. 3. Progressive crushing of bi-tubular structures

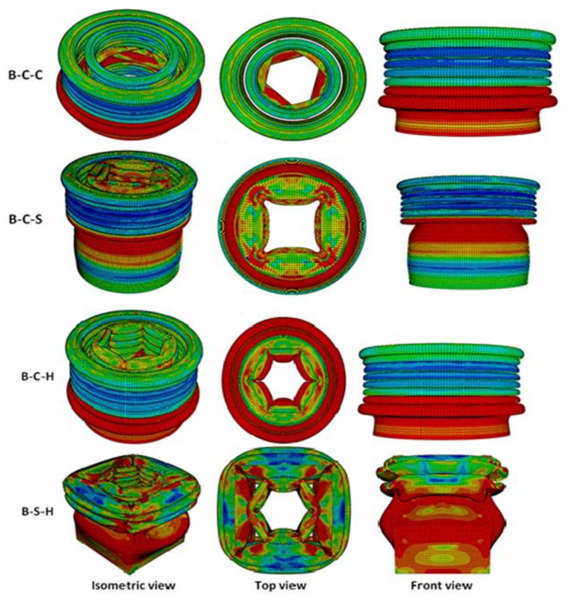

Fig. 4. Comparison of axial crushed profiles bi-tubular structures

Figure 4 shows the final crushed profiles bi-tubular of structures comparison in three different views exposed to axial impact loading. It is witnessed that the variation of geometric sections influenced the deformation behaviour by modifying the deformation profiles for each tube. In bitubular structures of similar section, B-S-S configuration deformed with less number of asymmetric folds whereas B-C-C type deformed with more number of symmetric nodes. Moreover in bitubular structures of different section, B-S-H configuration deformed with less number of asymmetric folds whereas B-C-H type deformed with more number of symmetric nodes. The results revealed that the square section in all the bitubular structure resists the deformation and increases the crushing force.

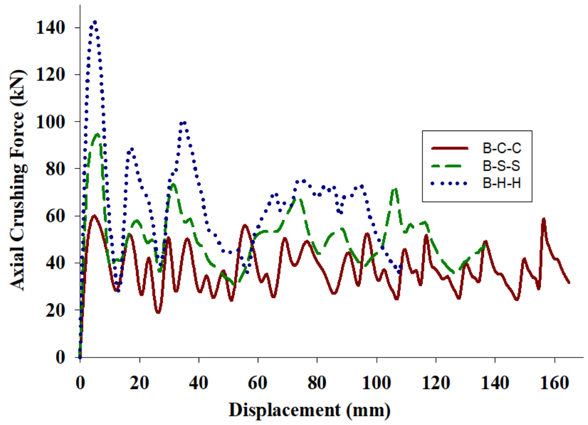

Fig. 5. Crushing force-displacement curves of bi-tubular structures of similar section

The crushing force-displacement curves of bi-tubular structures of similar section when exposed to same impact loading is displayed in Figure 5. It is witnessed that B-C-C tube experienced less IPCF with a final crushing length of 165 mm. Also the fluctuation height of the curve is less which in turn reduces the acceleration and transfers less force to the occupants. In case of B-S-S configuration, the initial peak crushing force is slightly high and absorbs more energy than the B-C-C tube and also the fluctuations are high. However when these sections are replaced with hexagonal shapes, the deformation behaviour differs and absorbs more impact energy than the other configurations considered.

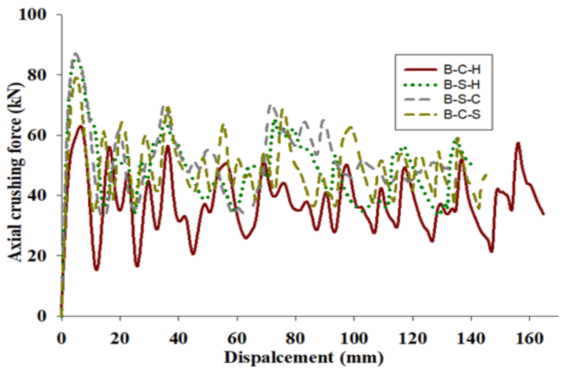

Fig. 6. Crushing force-displacement curves of bi-tubular structures of different section

Figure 6 illustrates the crushing force-displacement curves of bi-tubular structures of different section when exposed to same impact loading. It is observed from the figure that when different sections are used in bitubular structure, the deformation behaviour changes and the fluctuation height increases. This inturn leads to higher energy absorption but the acceleration will be more. Among all the configurations considered in this study B-H-H tube configuration absorbs more energy followed by B-C-S tube configuration. However the B-C-H tube configuration produces less initial peak crushing force followed by B-S-H tube.

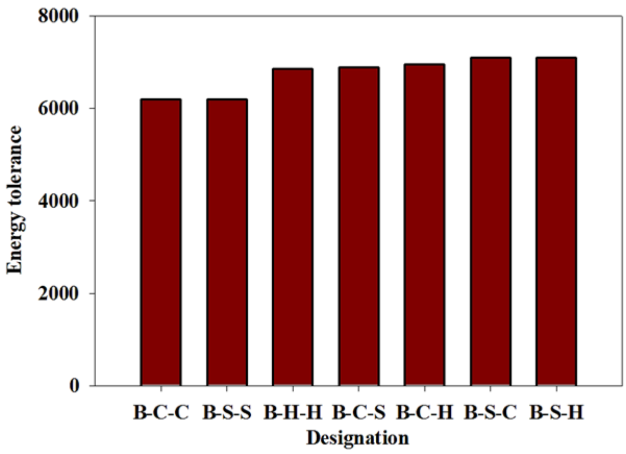

Fig. 7. Comparison of EAC characteristics of bi-tubular structures

The comparative plot of EAC characteristics of bi-tubular structures with various configurations is illustrated in Figure 7. The impact EAC of bi-tubular structures of different section tubes obtained was related with the erstwhile simulated results of bi-tubular structures of similar section. From the plot, it was witnessed that almost all of the simulated tube configurations absorbed similar amount of impact energy, however bi-tubular structures of different section absorbed comparatively more energy than the bi-tubular structures of similar section. Further, it was noticed that the hexagon sections deformed progressively and has better EAC characteristics than the square and cylindrical sections.

V. CONCLUSION

The deformation behavior and EAC characteristics of aluminium bitubular structures of similar and different sections were analyzed by numerical simulation. The various deformation modes and axial crushing force–deformation plots were extracted from numerical simulations. The EAC of all the tube configurations was determined from the obtained curves. Both the proposed bitubular structures of similar and different sections show similar trends in a crushing force–deformation curves, but the latter tubes have a higher IPF and greater average crushing force than the initial one. From the current research study, the proposed novel bitubular structures with hexagon section have better EAC than the other tubes. However bi-tubular structure of circle section enclosed with square type section were recommended as the most prominent for higher energy absorption and uniform crushing force.

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