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Lateral Crushing and Energy Absorption Behavior of Multicellular Tube Structures

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***Abstract**: Thin-walled metallic tubular elements are extensively employed as an impact energy attenuator in modern vehicles owing to light weight, easy fabrication and average cost. Besides, the novel multi-cell tubular structures have superior energy absorption characteristics related to a conventional simple cell tube. In this research article, the finite element simulation of thin-walled aluminium alloy extruded multicellular structure under lateral impact loading is investigated. Nonlinear impact simulations were performed on multicellular tubes of various configurations using finite element ABAQUS/CAE explicit code. From the outcomes attained, the energy absorption capability of various multicellular tube structures were compared and it shows that multicellular tubes have more remarkable than that of traditional simple cell tubes. Moreover, square shaped multicellular structure tube were retained as most prominent for higher energy absorption. This type of multicellular tubes was found to be effective one to improve the lateral crashworthiness performance.*

***Keywords**: Lateral load, multi-cell tube, crashworthiness, collision, Computation, Simulation.*

I. INTRODUCTION

Thin-walled metallic tubular structures which have superior energy absorbing capability and crashworthiness characteristics are efficient energy absorbing devices during the axial impact collisions [1]. However, few research studies have reported that most of the structural components deformed in bending buckling pattern [2]. Hence, it is significant to enhance the energy absorbing capability (EAC) and crashworthiness characteristics under lateral or transverse impact load [3]. Previously, the B-pillar and side-door panels were employed to dissipate impact energy in the event of vehicle collisions to safeguard the occupants and the vehicle parts, but they couldn’t perform significantly [4]. Thus, numerous scientists and researchers have put much effort to study the lateral deformation performance of thin-walled tubular structures [5]. In this regard, thin-walled multi-cell tubular structures have been proposed as lateral energy absorbers in automotive vehicles owing to their superior EAC and light-weight capacity [6].

Furthermore, from the earlier research studies on multi-cell tubular components [7, 8] it is found that that the EAC of the multi-cell tubular structures are superior to that of the single-cell tubes under lateral dynamic load. Wang et al. [9] examined the crushing characteristics and EAC of various polygonal section multi-cell tubes and reported that the IPF and EAC could be enhanced when the number of cells increases. Yin et al. [10] examined the deformation behaviour of multi-cell tubes of six various configurations using the LS-DYNA code. The outcomes revealed that the multi-cell tube with nine cells absorbed more impact energy among all the considered cases. Therefore, the EAC of the multi-cell tubular structures is very likely to be superior to that of the conventional single-cell tube. Nevertheless, to author’s understanding, there are limited literature existing that discusses the crashworthiness performance and EAC of multi-cell tubular structures under lateral loading condition.

Hence, this research paper aims to examine the deformation characteristics and EAC of multi-cell tubular structures subjected to lateral impact loads. Nonlinear impact simulations were performed on multicellular tubes of various configurations using finite element ABAQUS/CAE explicit code. Multi-cell tubes of five different configurations are proposed in this study to compare their crashworthiness performance. Square shaped multicellular tubes were retained as most prominent for higher energy absorption and found to be effective one to improve the crashworthiness performance in lateral impact collisions.

II. MATERIALS AND TUBE CONFIGURATION

In this study, multicellular tubes where made of AA6061 alloy this material was selected due to its wide applications in vehicle structures. Mechanical characteristics of the material are calculated from tensile test of samples pierced from aluminum tubes. The influence of strain rate was not considered in this numerical simulation due to the insensitivity of aluminum alloy. For aluminium tubes, material properties of the model could be modeled as elastoplastic and von mises yield criterion. The plastic yield stress and effective plastic strain values of the aluminium metal is presented in Table 1.

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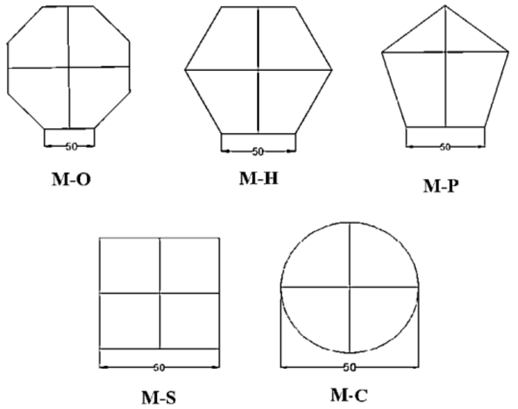
Table 1 Plastic characteristics of aluminium alloy

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

Figure 1 shows the dimensions of proposed multicellular structures tested under lateral impact loading. The tube specimens are specified using codes for better understanding, identification and comparisons. These codes comprise two alphabets. The first letter represents the geometry and second letter indicates the shape of the tube. In multicellular structures five different shapes are used. M-C represents multicellular structure of octagon, M-H represents multicellular structure of hexagon, M-P represents multicellular structure of pentagon, M-S represents structure of square, M-C represents multicellular structure of circle.



(All dimensions in mm)

Fig. 1.Dimensions of proposed multicellular structures

Table- 2 Lateral deformation characteristics under impact loading

Specimen geometry	Thickness (mm)	Velocity (m/s)	Crush length (mm)	Initial peak force (KN)	Mean crush force (KN)	Energy (joules)
M-O	2	7	98	43.03	10.68	1043.63
M-C	2	7	42	55.00	27.88	1172.51
M-P	2	7	57	54.24	21.02	1194.83
M-H	2	7	70	53.75	17.09	1197.64
M-S	2	7	92	54.33	18.42	1701.06

III. FINITE ELEMENT SIMULATION

The lateral crushing of multicellular tubes were numerically simulated by the developed Finite Element models using the ABAQUS code. Figure 2 shows the finite element model of multicellular structure simulated under lateral impact loading. For lateral simulation, multicellular structural tube is positioned between the movable plate and rigid plate, the lower rigid plate is stationary and the movable top plate is inhibited except the axial translation. A mass of 50 kg is attached and velocity of 7 m/s is defined to the movable plate. An element size of 1 mm is adapted for multicellular structure after executing the mesh sensitivity study. The contact between the moving plate and the multicellular tube is a node-to-surface contact with friction coefficient of 0.2. The tube is assigned with (S4R) Four noded shell elements and both the plates are assigned with a (R3D4) four-noded rigid plate. Table 2 displays the comparative results of lateral deformation characteristics of multicellular structures under impact loading

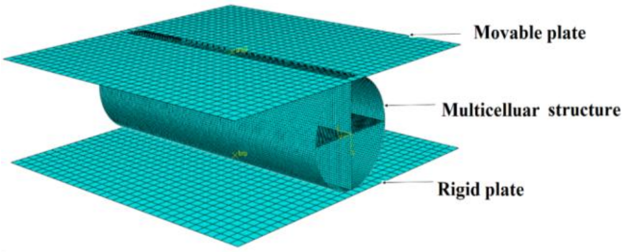


Fig. 2. Finite element model of multicellular structure

IV. RESULTS AND DISCUSSION

In this study, the numerical simulation of lateral crushing behaviour and the EAC characteristics of multi cellular tube structures were analyzed using ABAQUS code. When an impact load is applied laterally, the tubes deformed initially at the middle portion followed by the development of hinge and later it changed into irregular deformation pattern irrespective of the configurations examined. The typical progressive crushing of multi cellular tube structures at four different crushing values (for each 10mm) of lateral impact is shown in Figure 3.

In all the simulated tube configurations, hinges about both the parallel and perpendicular stiffeners were witnessed. The progressive crushing continued with the formation of the inelastic hinges, with a final deformation about 80% decrement.

The comparison of final crushed profiles of various multi cellular tube structures in two different views subjected to lateral impact loading is displayed in Figure 4. From the figure, it is witnessed that the stiffeners resists the. Figure 5 illustrates the comparison of lateral crushing force-displacement curves of various multicellular tubes when subjected to same impact loading. The examination of the multi cellular tube structures showed impact load and restricts the buckling of tubes.

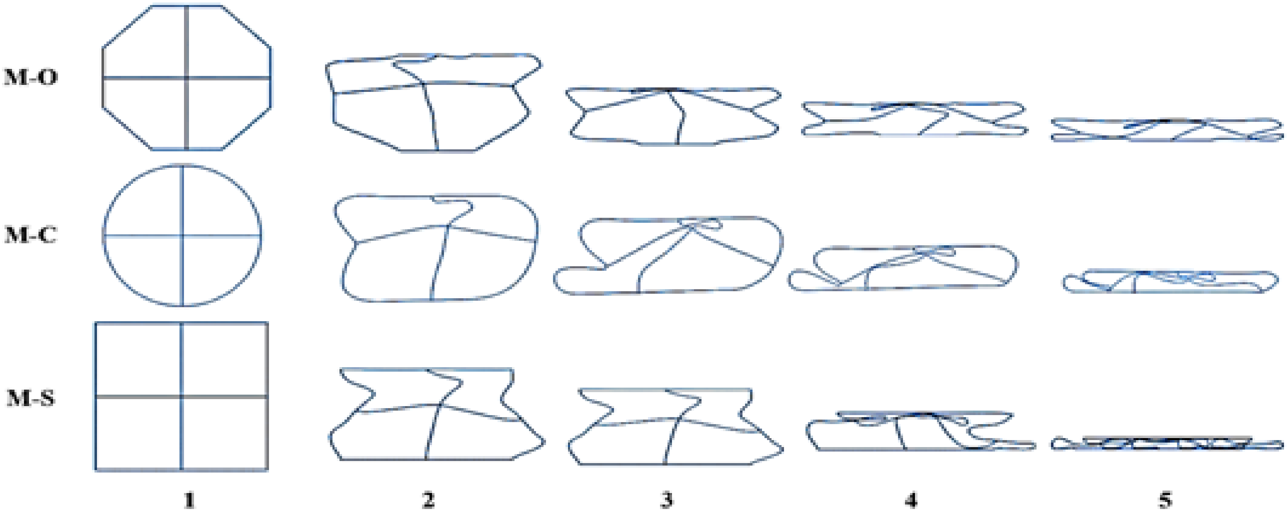


Fig. 3. **Progressive crushing of multi cellular tubes**

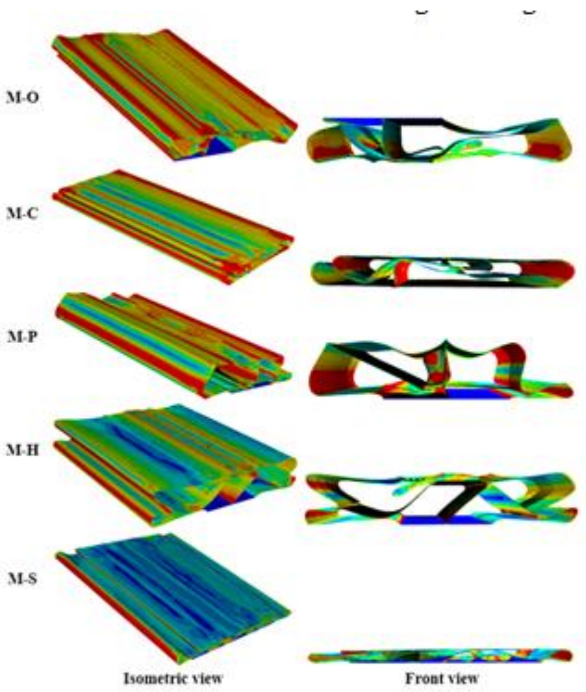


Fig. 4. **Comparison of lateral crushed profiles multi cellular tubes**

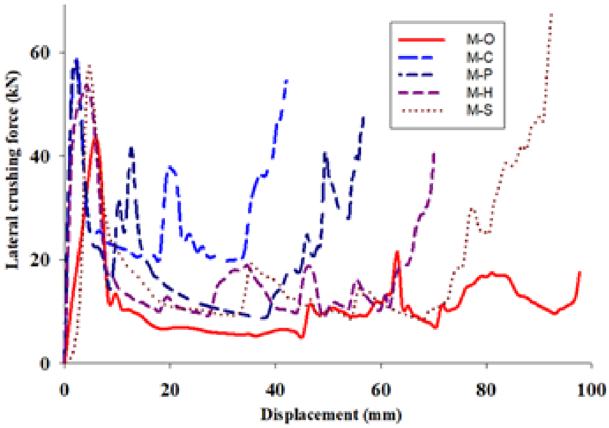


Fig. 5. **Lateral crushing force-displacement curves**

However the tube with octagonal section deformed rapidly and absorbed very less impact energy than all the configurations considered that the crushing behaviour of the proposed tubes had been changed primarily by the existence of the horizontal and vertical stiffeners. For the tube with cylindrical cross section, the predicted initial peak crushing force is 55kN, with the crush length of 42 mm owing to inelastic crushing. Similar results with equivalent value were witnessed for the investigated tubes with other polygonal sections except the octagonal section.

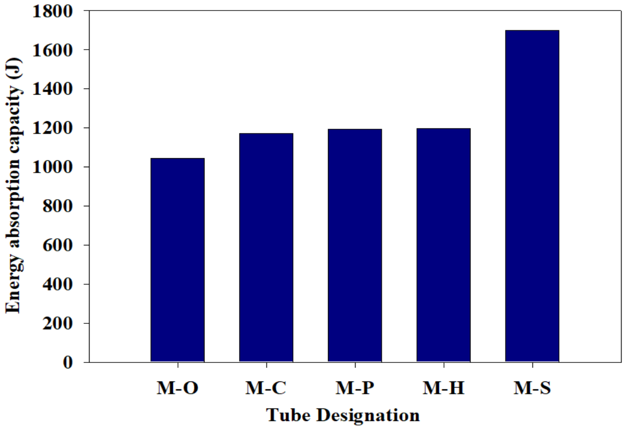


Fig. 6. Comparison of EA characteristics of multi cellular tubes

Figure 6 illustrate the comparative plot of EA characteristics of multi cellular tubes when subjected to same impact loading. The obtained EA results revealed that the multicellular tube with square section absorbed more impact energy of 1701 Joules by progressive plastic deformation till the final crush length of 92 mm. In the contrary, multicellular tube with octagonal section deformed to the crush length of 98 mm with very less energy absorption of 1044 joules. This is due to the reason that the more number of edges restricts the formation of uniform plastic hinges and makes the tube deform irregularly in a rapid manner. All the other tube configurations examined show similar energy absorption capacity with different crush lengths.

V. CONCLUSION

The crushing behaviour and EA characteristics of the multi cellular aluminium tubes of various cross-sections were investigated by numerical technique. The patterns of deformation and lateral crushing force-displacement curves were extracted from numerical simulations. The multicellular tube with cylindrical section shows higher MCF, higher IPF than the other configurations considered. However multicellular tubes with square section absorbs more impact energy when compared to the conventional simple geometry tubes. These multicellular tubes could be applied as energy absorbing devices in modern vehicles for crashworthiness applications.

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