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Enhancing the Energy Absorption Characteristics of Multi-Cell Square Tubes under Lateral Impact

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Abstract: Thin-walled tubular components have been broadly utilized in energy absorption applications, to improve the crashworthiness of the structure and to mitigate the impact kinetic energy through progressive plastic buckling. The extensive usage of cylindrical tubes as impact energy attenuators is owing to their superior crashworthiness behaviour, easy fabrication, less cost, and light-weight efficacy. The current paper examines the lateral impact behaviour of thin-walled aluminum multi-cell square tubes of different configurations using numerical simulations. These non-linear impact simulations were performed on multi-cell square tubes using finite element ABAQUS/CAE explicit code. From the overall results obtained, the crashworthiness performance of multi-cell square tubes of various configurations were compared. Moreover, multi-cell square tube of first type were recognized as most prominent for better energy absorption. This type of tubes was found to be effective one to improve the lateral crashworthiness performance

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

I. INTRODUCTION

During the last three decades, huge efforts have been performed by scientists to improve the Energy Absorbing Characteristics (EAC) of thin-walled tubular structures through experimental, theoretical, and finite element simulation techniques [1, 2]. Deformation performance of multi-cell tubular structures, particularly in cases of axial and lateral loading have gained considerable attention in research owing to the potential applications in crash box. Chen and Wierzbicki [3] is the pioneer in examining the axial deformation behaviour of multi-cell tubular structures subjected to high speed impact. Regarding lateral deformation, Gupta et al. [4] performed the experimental and numerical crashworthiness characteristics of polygonal tubes subjected to quasi-static lateral compression. They reported that the square section absorbs superior energy related to the rectangular section of same mass, and the tube sections deformed owing to the development of two pair of plastic hinges.

Multi-cell tubular components are described by a number of stiffeners linked with each other at various angles and with different linking of edges. Concerning multi-cell tubular components exposed to lateral loads various experimental and numerical research studies have been conducted [5-7]. Wang et al. [8] examined the transverse loading resistance of square section multi-cell tubes. The results obtained revealed the significance of the number of stiffeners on the EAC. Huang [9] investigated the EAC and design optimization of square section multi-cell tubular structures. The influence of various configurations on the deformation characteristics were analyzed. Estrada et al. [10] examined the influence of the various cross-section on deformation and EAC of multi-cell configurations numerically. The finite element simulations estimated the efficiency of cylindrical multi-cell configuration to absorb impact energy by progressive plastic deformation [11]. Hence, the computational investigation of multi-cell tubular structure is a significant topic of research. Nevertheless, most of the research studies have concentrated on the numerical deformation behaviour of cylindrical cross-sections but not on square section multi-cell tubes. Thus, in the present research, the lateral impact behaviour of thin-walled aluminum multi-cell square tubes of different configurations using numerical simulations. These non-linear impact simulations were performed on multi-cell square tubes using finite element ABAQUS/CAE explicit code. From the overall results obtained, the crashworthiness performance of multi-cell square tubes of various configurations were compared.

II. MATERIALS AND TUBE CONFIGURATION

In this research work, multi-cell square tubes were made of aluminium alloy and this material was chosen owing to its common utilization in automotive structures. Mechanical properties of the aluminum material are estimated from standard tensile testing of specimens pierced from the tubes. The influence of strain rate was not considered in the current simulation owing to the insensitivity of aluminum alloy. Material properties of the model could be modeled as elastoplastic using isotropic elasticity, and von mises yield criterion. The yield stress and plastic strain values were obtained and are presented in Table 1.

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Table 1: Inelastic characteristics of aluminum alloy

Yield stress (MPa)	68	78	125	148	155	165	170
Plastic strain	0	0.001	0.03	0.06	0.08	0.16	0.19

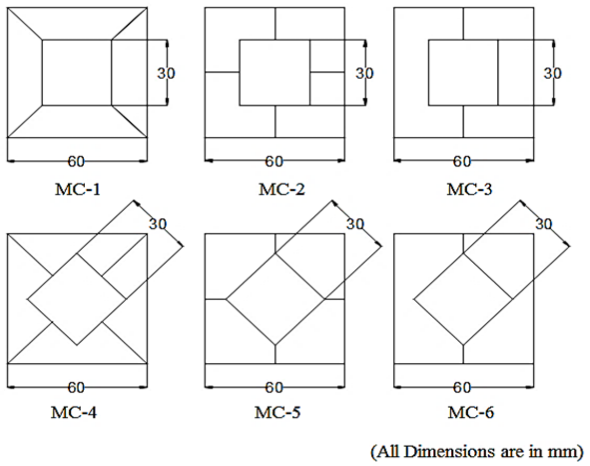

Fig.1 Cross-sectional configurations of multi-cell square tubes

III. FINITE ELEMENT MODELING

The finite element ABAQUS/Explicit software was employed to numerically calculate the lateral crushing response of the multi-cell square tube which was subjected to impact loading. Figure 2 shows the Finite Element boundary conditions of multi-cell square tube structures simulated under lateral impact loading. For lateral crushing simulation, a square tube is placed between two rigid walls, the lower plate is fixed and the movable plate is constrained in all degrees of freedom except the lateral displacement. A mass of 50 kg is assigned to the movable plate and an impact velocity is defined for the movable plate. The element size of 1 mm for multi-cell square tube is obtained after performing the mesh sensitivity study. Four noded shell elements are used to model the multi-cell square tube and the plates are modeled with a four-noded rigid element. The comparison of lateral deformation characteristics of multi–cell square tubes subjected to lateral impact loading in Table 2.

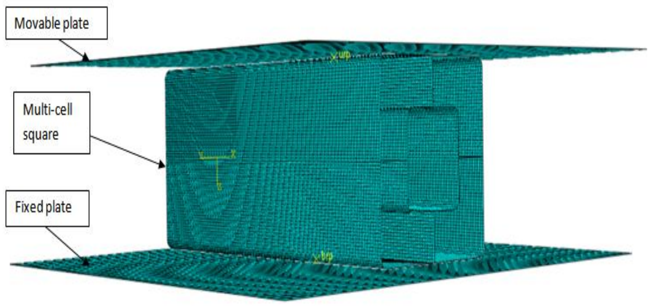

Fig.2 Finite Element boundary conditions

Table 2 : Lateral deformation charecteristics under impact loading

Specimen geometry	Thickness (mm)	Velocity (m/s)	Crush length (mm)	Initial peak force (KN)	Mean crush force (KN)	Energy (joules)
MC1	2	7	50	49.48	20.30	1023.27
MC2	2	7	39	20.89	26.89	1061.26
MC3	2	7	52	27.26	20.66	1081.90
MC4	2	7	82	34.49	29.30	648.21
MC5	2	7	43	39.08	25.51	1105.49
MC6	2	7	57	31.27	18.27	1033.89

The cross-sectional configuration of multi-cell square tubular structures simulated under lateral impact loading is shown in Figure 1. The tube samples are specified using codes for better understanding, identifications and comparison. These codes comprise two alphabets and one number. The first letter represents the section and the subsequent number indicates the type of tube sample. In multi-cell square tubes six different types of patterns were utilized. MC1- Multi-cellular square tube of type one, MC2- Multi-cellular square tube of type two, MC3- Multi-cellular square tube of type three, MC4- Multi-cellular square tube of type four, MC5- Multi-cellular square tube of type five, MC6- Multi-cellular square tube of type six.

IV. RESULT AND DISCUSSION

In this research article, the lateral impact deformation and the EAC characteristics of multi-cell square tubes were investigated using Finite Element simulation technique. When the lateral impact force is applied to the multi-cell square tubes, initially the outer square section buckled in the middle segment and further, the profile of ‘8’ type was attained in the inner square. The typical progressive buckling of multi-cell square tubes at four different crushing values (for every 10mm) exposed to lateral impact force is illustrated in Figure 3. It is witnessed that the variation of stiffener positions highly influenced the deformation profile and EAC characteristics.

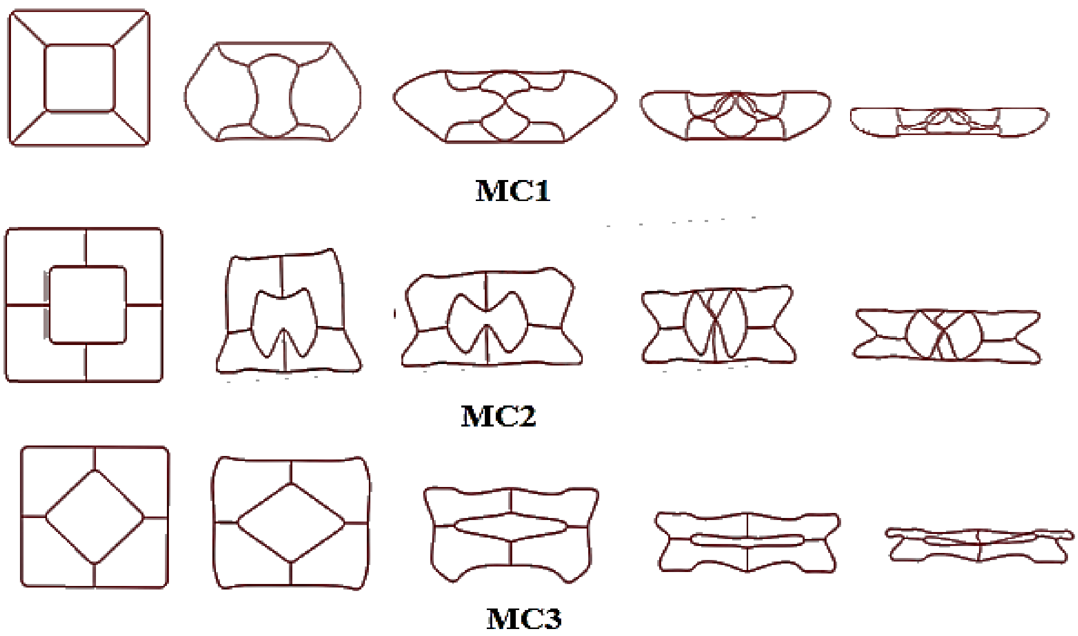

Fig.3 Comparision of Lateral crushing of multi-cell square tubes

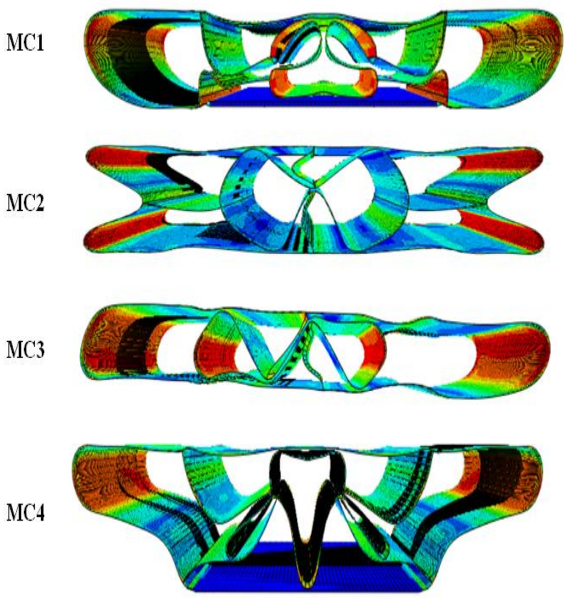

Fig.4 Comparision of Lateral crushing of multi-cell square tubes

The comparision of final crushed profiles of multi-cell square tubes exposed to lateral impact force is presented in Figure 4. It is perceived from the figure that all the proposed tube configurations resisted the crushing force effectively and deformed with different modes of irregular pattern. However the aborption energy is better than the conventional bitubular structures. Among all the configurations considered, MC4 tube deformed to a final crush length of 82 mm which is more than that of other tubes. These multi-cell square tubes performed better crashworthiness characteristics and experienced uniform stable deformation behaviour.

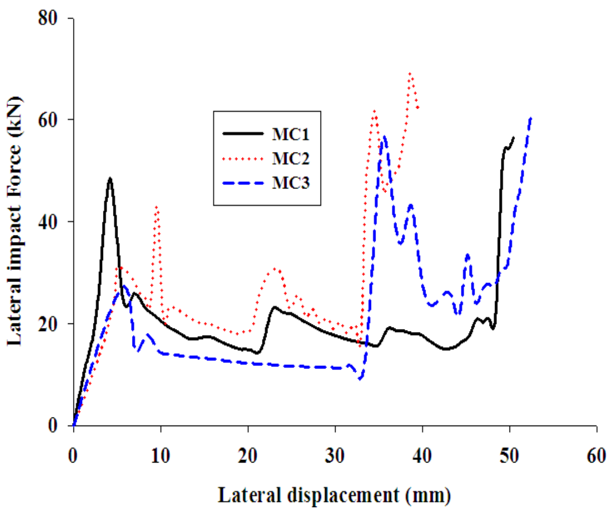

Fig.5 comparision of Lateral impact force displacement characteristics of
(a) MC-1 (b) MC-2 (c)MC-3

Figure 5 shows the comparision of lateral impact force–displacement charecteristics of multi-cell square tubes subjected to lateral force. It is observed that the peak crushing force is formed initially when the impactor touches the outer square section followed by smooth curve. When the load reaches the inner square tube, again a peak force is obtained followed by progrssive deformation. Finally the densification is percieved which leads to high increase in crushing force. Similar deformation response is attained in all three types of tube configurations considered.

However this reponse leads the tube to absorb more impact energy than the conventional tubes. The comparision of lateral impact force – displacement characteristics of multi-cell square tubes are presented in Figure 6. Similar deformation response were achieved for the MC4, MC5 and MC6 like the previous tube configurations but with increased magnitude. The crush length of MC6 configuration is more when compared to the other two configurations.

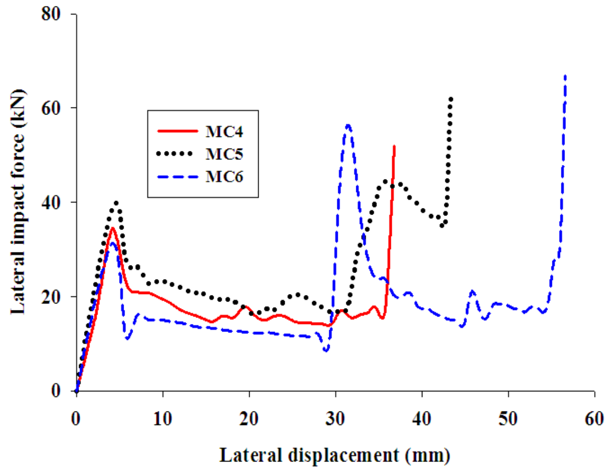

Fig.6 Comparision of Lateral impact force – displacement characteristics of (a) MC4 (b) MC5 (c) MC6

The comparitive plot of EAC of multi-cell square tubes with various configurations is shown in Figure 7. It is noted from the plot that the MC4 configuration showed very less EAC performance than the other tubes simulated. This is due to the irregular deformation pattern which occurred rapidly and the stiffeners were placed in the corners which is unable to withstand the impact force. Among all the tube configurations, MC5 tube configuration absorbed more impact energy about 1105 joules owing to the reason that the stiffeners are in both horizontal and vertical direction which withstands more impact force. All the other four tube configurations absorbed impact energy in the range of 1023-1082 joules. These tubes were recommnded as impact energy absorbing componenets in modern automotive vehicles or high spped race cars.

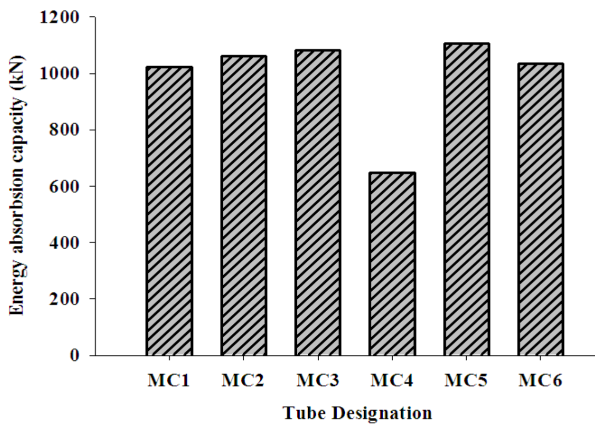

Fig.7 Comparision of EAC of multi-cell square tubes

V. CONCLUSION

The Energy Absorption Characteristics of the conventional bitubular square structures is enhanced by Multi-Cell Square Tubes under Lateral Impact force. The various deformation profiles and the corresponding modes of failure and Lateral impact force – displacement characteristics were extracted from Finite Element simulations. The EAC of all the tube configuration were determined with the obtained Lateral impact force – displacement. All the proposed multi-cell square tubes show similar trends in an impact force – displacement curve, but the proposed tubes have a higher MCF and better EAC than the conventional bitubular square tubes. Among all the tube configurations, MC5 tube configuration absorbed more impact energy about 1105 joules owing to the reason that the stiffeners are in both horizontal and vertical direction which withstands more impact force.

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