Design & Analysis of Multi-Cell Square Thin Walled Sandwitch Panel In Bumper To Improve Crash Worthiness

Athithh A. Kamble[1],Dnyanesh P. Chaudhari[2], Madhu V. Dora[3], Harshal M. Pagare[4]
[1, 2, 3, 4] Dept of Mechanical Engineering
[1, 2, 3, 4] G. N. Sapkal College of Engineering, Nashik, Maharashtra

Abstract- *Over the past twenty years, enormous efforts have been made by the academia and industry to understand the role of bumper system as energy absorber in high as well as low impact. The crashworthiness of the vehicle and bumper system, which identifies the safety and performance of the vehicle in response to impact load, is a challenging issue. The effective parameters of structural energy absorption are longitudinal curvature, cross-section profile, strengthening ribs, thickness, and the overall dimensions of the cross-section. The most popular form of stacking energy absorbers, that are widely used to absorb the kinetic energy and to improve the crashworthiness behavior of a structure, is multi-cell Thin Walled (TW) structures. In this project, multi-cell square thin walled structure having different configuration are to be studied numerically and to be validated experimentally.*

Keywords- Bumper, crashworthiness, Multi-cell, Thin-walled structure, Square tube

I. INTRODUCTION

Design is the preliminary stage of product development and analysis. The embodiment stage of the design process fairly predicts the failure(s), if any, before mass production. Passenger vehicles make up over 90% of the fleet of registered vehicles. In 2009 it was estimated that 9,640,000 vehicles were involved in police-reported crashes, 95% (9,161,000) of which were passenger vehicles. Furthermore, there, 45,435 vehicles of these were involved in fatal crashes and eighty percent of which (36,252) were passenger vehicles. More than 23,000 passenger vehicle travelers lost their lives in traffic crashes in 2009 and an estimated 1.97 million persons were injured

In most of the accidents, the bumper system is the first vehicle part that receives the collision and which may to some extent protect the car body and passengers. This system comprises three main parts: fascia, energy absorber, and bumper beam. The fascia is a non-structural aesthetics component that reduces the aerodynamic drag force while the energy absorber dissipates part of the kinetic energy during collision. The bumper beam is a structural component which absorbs the low-impact energy by bending resistance and dissipates the high-impact energy by collision. There are some investigations of new material development, property improvement, and FEA of bumper beam structures by researchers and car manufacturers. These parties are mainly interested in substituting the conventional material with lighter and stronger material.

II. LITERATUREREVIEW

M. M. Davoodiet. al. reviews the development process of bumper beam of passenger car, states recent safety regulations about bumper system conditions besides the automaker environmental regulations made it quite difficult and more costly for the design of the construction to achieve all wide requirements. Finding the best suitable technique for bumper beam development poses extra loads on the designer and can influence his/her performance. Previous research considered the design process, material selection, analysis and verification of the developed product functionality by FEM tools. But there is limited data about the approaches to bumper system development. The present study focussed on bumper beam development process based on conclusions of previous data. It analysed sufficient information to determine the best method for bumper beam development. To categorize the settings for the effective structural variables (rib strength thickness, cross section and frontal arc) favourable to the finest bumper beam strength. Strengthening beam plays an active role in safety. It will be interpreted through the finite element analysis (FEA) with experimental tests before mass production. With the cautious design and analysis of the bumper beam operative parameters can be improve strength, decrease the weight, increase the possibility of operating decomposable and biodegradable resources to reduce the environmental contamination. [1]

Ahmad Baroutajiaet. al. reviews that over the past several decades, a noticeable volume of research efforts has been directed to minimising injuries and death to people inside a structure that is subjected to an impact loadings. Thin walled (TW) tubular components have been widely hired in energy absorbing structures to enhance the harmful effects of an impact loading during a collision event and thus enhance the crashworthiness performance of arrangement. Various configurations of multi-cell columns are used are shown in fig.1

.

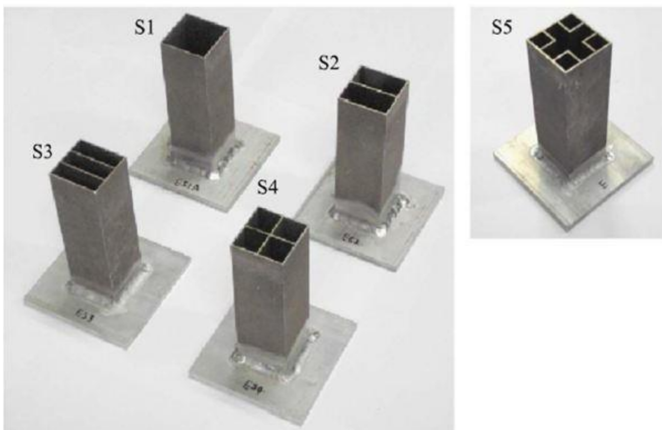

Fig. 1 various configurations of multi-cell columns

Comprehensive information of the material properties and the structural behaviour of various TW components under various loading conditions is important for designing an effective energy absorbing system. In this paper, based on a wide survey of the literature, a comprehensive overview of the recent developments in the area of crashworthiness performance of TW tubes is given with a distinct focus on the topics that emerged in the last years such as crashworthiness optimisation design and energy absorbing responses of unconventional TW components including multi cells tubes, functionally classified thickness tubes and functionally graded foam filled tubes. Due to the vast number of studies that analysed and assessed the energy absorption behaviour of various TW components, review of the crashworthiness behaviour of the components that can be used in vehicles structures with hollow and foam-filled TW tubes under lateral, axial, oblique and bending loading. [22]

R. V. Patilet. al. worked on the Aluminium Honeycomb Sandwich Panel in Bumper Beam as shown in fig.2. Honeycomb mostly known for is high strength to weight ratio. Its sandwich structure is made from three layers, first and third layer is skin, made of metal, alloys of metal or may be from the composite material like fiberglass, high pressure laminate. This light weight structure is mostly part of aerospace industries. Its high impact absorbing capacity concerned many researchers to investigate the effect of core between two skins. This paper aims to analyse impact absorbing capacity of the specimen. Impact absorbing capacity of the specimen is determined up to the full penetration by experimental drop weight test. The Core hexagonal cell configurations with difference in their cell size has been considered

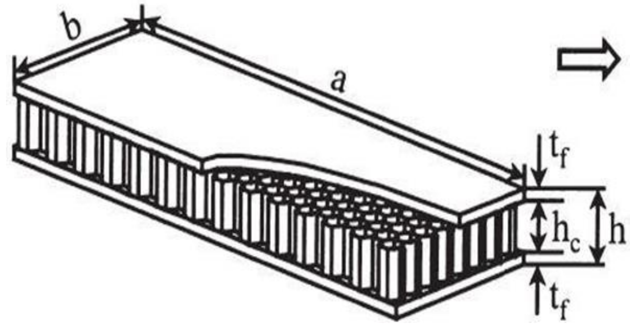

Fig. 2 Schematic representation of the equivalent single skin approach

The six specimens was tested to determine the relation between force and deformation by considering peak and puncture factors for force and deformation. The variations in cell size discloses that 40% energy absorbing capacity increase in the results. The maximum deformation was obtained 12.52mm by Finite Element analysis, while experimentation the impact analysis has made 8.81mm by experimentation. In Finite Element analysis, the equalisation of beam eliminate the plane material properties for the reason of drop the strength of the model. Original orthotropic model using out of plane material properties produced variations in the results and it also shows that to increase in face sheet thickness, the impact strength of bumper beam is also increases. The experimental analysis shows that the upper face sheet supported by core and lower panel are additional resistance to penetration. The increase in thickness of upper face sheet has expected to improve the improved results. [23]

From the above literature survey, we can conclude that the gain in specific energy absorption can be achieved increasing with the number of cells. Behaviour of an advanced twelve edge criss-cross sectional tubes such as star shaped proved its superior crashworthiness performance, in terms of greater specific energy absorption (SEA) and crush force efficiency (CFE), over conventional cross-sectional profiles such as square, hexagonal, octagonal profiles. Crashworthiness behaviour of the multi- cell square tubes with four different shapes are more effective than the star shaped polygons with and without foam filled. Theoretical models for calculating the mean crush force for each configuration was derived for the multi cell tubes. Numerical simulations of the multi-cell structures are effective energy absorbers where their energy absorption efficiency was about 50–100% more than that of foam-filled tubes. It suggests that increasing the number of corners is not always effective. To break through this limitation of multi corner cross-section with a large number of corners is introduced with angle elements (i.e. internal webs) in the cross section. Crush behaviour of an angle element or thin multi tube walled tubes can influenced by the number of panels and the angle between neighbouring flanges. Specific energy absorption increases as the number of plates increases.

Problem definition - The numbers of vehicles are increasing day by day and numbers of accidents are also increased due to vehicles operating under high velocities. The injuries to pedestrians and / or passengers and damage to vehicle is unavoidable in the event of accident. The role of Bumper is becoming very crucial during last few years and role is shifting from just as an aesthetic part to safety component in car. Hence, the bumpers capacity to absorb the maximum energy during collision will help to reduce damage to vehicle as well as minimize the injury to pedestrians and passengers. The most popular form of stacking energy absorbers, that are widely used to absorb the kinetic energy and to improve the crashworthiness behaviour of a structure, is Thin Walled (TW) structures. The design and analysis of an TW energy absorber are normally performed using experimental and computational techniques, such as finite element method (FEM).

1. Objectives

- To determine specific energy absorption (SEA) of multi-cell square thin walled structure.
- To determine mean crushing force (MCF) of multi-cell square thin walled structure.
- Selection of optimized multi-cell square thin walled structure within configurations.
- To validate the results experimentally.
- To improve the crashworthiness of bumper of a car.

2. Scope

- To complete computational simulation of multi square array thin walled structure.
- To validate the result of FEA analysis by experimental test.
- To prevent injury and damage at higher operating speeds in passenger cars.
- To improve strength to weight ratio of the structure.

3. Organization of Dissertation

- Literature survey
- Creating the CAD model of Multi-square tube structure using Catia V5 software.
- Computational FE Analysis of Multi-square tube structure using Ansys Workbench 19.1
- Manufacturing prototype model of Multi-square tube welded structure from Aluminium Tubes and plates.
- Experimental set up and testing
- Result analysis based on Numerical andexperimentalmethods.
- Discussion and Conclusion
- Future scope
- References

III. DESIGN OF MULTI-CELL THIN-WALLED SQUARE TUBES

1. Design Consideration

The aim of the project is to analyse crashworthiness of multi-cell square thin walled structure. The common use of TW components as energy absorbing devices is due to many important aspects including superior performance under dynamic loading, cost effective, high efficiency, ease of manufacturing and installation. The principal factors that affect the energy absorption capability of such TW components are material, structural geometry and loading type.

2. Material

The maximum used materials for manufacturing the thin-walled energy absorbers are metallic, such as aluminium alloy, mild steel, and Fibre Reinforced Composites (FRCs). The energy dissipating mechanisms of metallic are considerably different as the ductility nature of metallic structures allows them to dissipate energy through progressive plastic deformation. The selection of material is governed by various parameter like low density, modulus of elasticity, cost, availability, formability, strength to weight ratio etc.

Table No.1 Material Selection & Its Properties

Component	Material	Density, Kg/m^3	Tensile Strength, MPa	Modulus of Elasticity, GPa
Top Plate & Bottom Plate	Structural Steel	7850	460	200
Core Structure	Aluminum Alloy	2770	310	71

3. Numerical Analysis

Finite element models are introduced in the given section and numerical simulations are carried out to analyse the deformation modes, Von-mises stresses and energy absorptions characteristics of multi-cell square tube structure. Firstly, static structural FE analysis was performed to numerically simulate the quasi-static loading. Furthermore, three different configurations are imported in Ansys workbench model and materials is assigned as mentioned above. Hex dominant mesh method is inserted and liner types of element are chosen for element order. In addition to this, boundary condition like fixed support at bottom plate is applied with quasi-static axial compressible load of 150 KN at the top plate. In the solution section, deformation, Von-mises stresses and strain energy are called for evaluation.

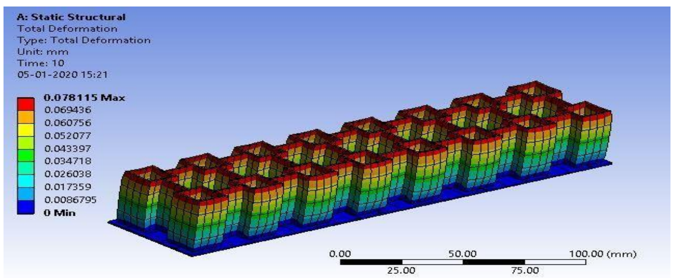

Fig.(a) Total Deformation

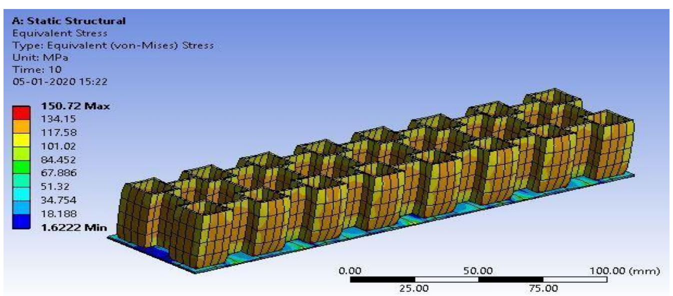

Fig (b) Von-Mises Stresses

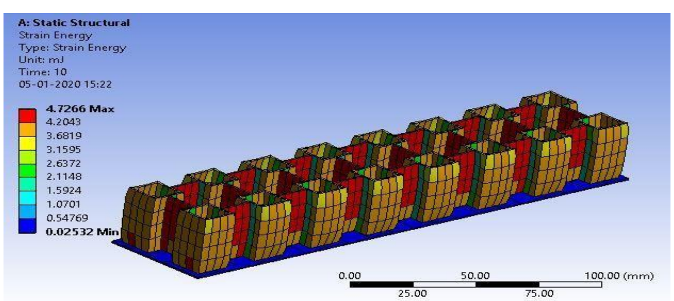

Fig (c) Strain energy for model C1

In fig a, b, c observed that maximum deformation in model C1 is 0.078115 mm and maximum von mises stresses is 150.72 MPa; whereas energy absorption is 4.7266 mJ. Ribs which are joining the square tubes are absorbing maximum energy than square tubes. Hence the cross-section may need some geometry modifications to have uniform energy absorption capacity.

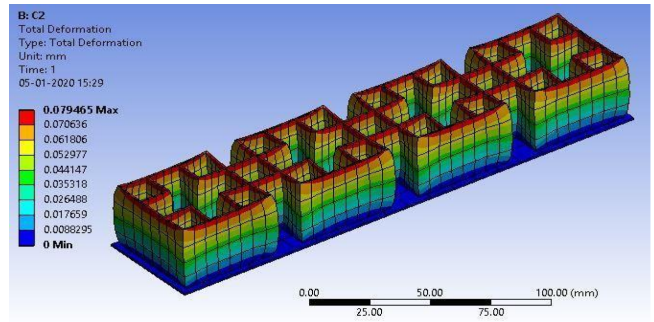

Fig (a) Total Deformation

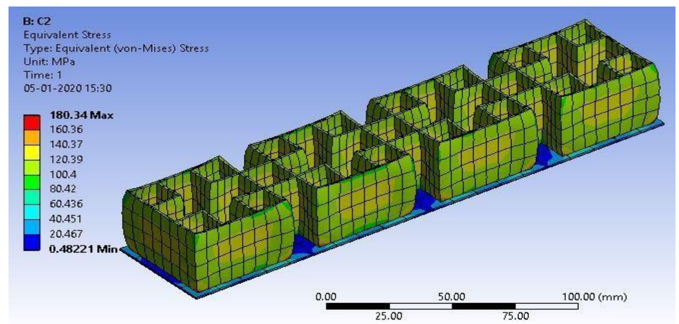

Fig (b) Von-Mises Stresses

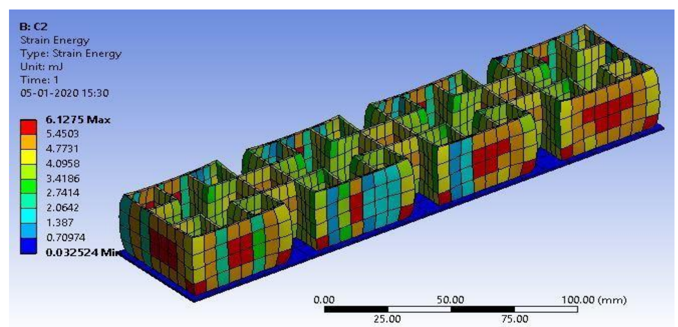

Fig (c) Strain energy for model C2.

From figure a, b, cit is observed that maximum deformation in model C2 is 0.07946 mm and maximum von-mises stresses is 180.34 MPa; whereas energy absorption in this case has been increased to 6.1275 mJ compare to C1 configuration. In this case energy absorption is more evenly distributed across the configuration than C1 & C3 configurations.

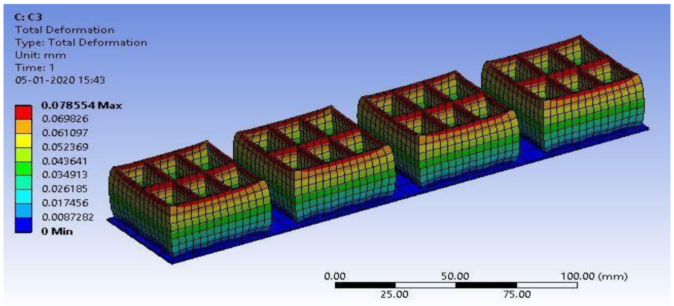

Fig (a) Total Deformation

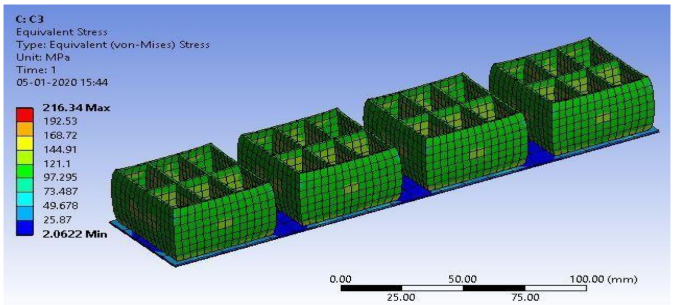

Fig (b) Von-Mises Stresses

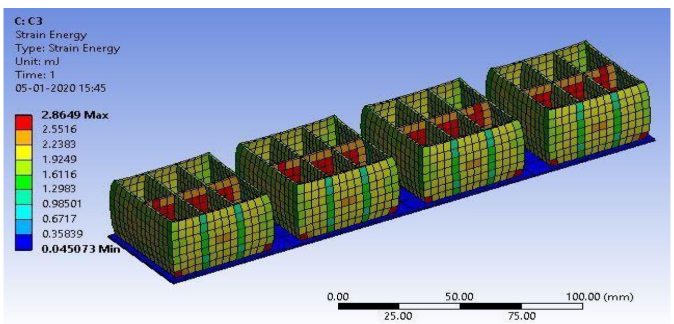

Fig (c) Strain energy for model C3

From figure a, b, c, it is observed that maximum deformation in model C2 is 0.07855 mm and maximum von-mises stresses is 216.34 MPa; whereas energy absorption in this case has been reduced to 2.8649 mJ compare to C1& C2 configuration. Horizontal single Rib is absorbing maximum energy than square tubes. Hence the cross-section may need some geometry modifications to have uniform energy absorption capacity Comparative numerical analysis result is settled in table 2 below.

Model	Deformation, mm	Von-Mises Stress, MPa	Strain Energy, mJ
C1	0.078115	150.72	4.7266
C2	0.07946	180.34	6.1275
C3	0.07855	216.34	2.8649

From the table 2 , it is observed that the strain energy in configuration C2 is 6.1275 mJ which is almost 30 % and 113% higher than C1 and C3 configuration respectively. Similarly, deformation in C2 configuration is slightly higher that other two configurations. In addition to this, Von-mises stresses developed in configuration C2 is in between rest of two configuration.

IV. EXPERIMETAL ANALYSIS

To perform experimental analysis, we need to prepare the three different model as finalized for our model. The standard shape of this models was not available and hence we have to fabricate it into college workshop. Axial quasi static loading of samples can be carried out using Instron 8503 apparatus. This apparatus has two jaws: the upper one is stationary and the lower one is moveable. The sample is set between two jaws vertically and is compressed axially. Since the upper and the lower jaws of the apparatus are stationery and moveable, respectively, the upper and the lower ends of the specimen are named ‘‘fixed end’’ and ‘‘moving end,’’ respectively. The rate of loading was decided 100 mm/s and the stroke is considered equal to 90 mm. This stroke is given so that all of the samples can absorb the maximum energy. During the test, it is possible to get the load–displacement curve for the sample.

Fig 1.Instron Apparatus for Compression test

In the experiment values of the maximum and the average forces in tests can be listed, the samples crushing length at the end of loading.

Due to this pandemic situation this work of experiment has not been carried out. Only we have the results of FEA analysis.

V. FUTURE WORK

Following work will be undertaken step by step as follows:

- Explicit dynamic computational FE Analysis of Multi-square tube structures using Ansys Workbench 19.1
- Manufacturing prototype model of Multi-square tube welded structures from Aluminium Tubes and plates.
- Experimental set up and testing
- Result analysis based on Numerical and experimental methods.
- Discussion and Conclusion

VI. CONCLUSION

Based on the FE static analyses, results obtained are concluded are as follow:

- As per static structural analysis results, configuration C2 appears to be more effective in one of the energy absorption parameters.
- Strain energy distribution in configuration C2 is nearly uniform and also maximum amongst the three configurations.
- The strain energy in configuration C2 is 6.1275 mJ which is almost 30 % and 113% higher than C1 and C3 configuration respectively.
- However quasi static results seem to be oriented towards configuration C2, explicit dynamic analysis and experimental testing needed to be carried out.
- According to Ahmad Baroutaji et.al. has revealed that SEA increased with the number of cells and around 100% gain in SEA could be achieved in multi-cell tubes (configuration C1)[22].
- Based on the literature of Xiong Zhang et.al. the SEA goes upto 220% higher than simple square tube for multi-cell S5 design which is C2 configuration in this case [19].
- Based on previous research for the similar configurations and FE static analysis results, it can be expected that configuration C2 will have better results than C1 & C3 configuration in numerical and experimental test.
- With this structure the crashworthiness of bumper system will enhance.

REFERENCES

[1] M. M. Davoodi, S. M. Sapuan, A. Aidy, N. A. Abu Osman, A. A. Oshkour,W.A.B. Wan Abas, Development process of new bumper beam for passenger car: A review, Materials and Design 40 (2012) 304–313.

[2] SahilGoyal, Anand C.S., Sunil Kumar Sharma, RakeshChandmalSharmab, Crashworthiness analysis of foam filled star shape polygon of thin-walled structure Thin-Walled Structures 144 (2019) 106312.

[3] M. Ali n, E. Ohioma, F. Kraft, K. Alam, Theoretical, numerical, and experimental study of dynamic axial crushing of thin walled pentagon and cross-shape tubes, Thin –Walled Structures 94 (2015) 253–272

[4] Gang Zheng, Suzhen Wu, Guangyong Sun, Guangyao Li, Qing Li, Crushing analysis of foam-filled single and bitubal polygonal thin-walled tubes, International Journal of Mechanical Sciences 87 (2014) 226–240.

[5] JiantaoBai, GuangweiMeng, Hong Wu, WenjieZuo, Bending collapse of dual rectangle thin-walled tubes for conceptual design, Thin-Walled Structures 135 (2019) 185–195.

[6] X. Zhang, G. Cheng, H. Zhang, Theoretical prediction and numerical simulation of multi-cell square thin-walled structures, Thin-Walled Structures 44 (2006) 1185– 1191.

[7] H.R. Zarei, M. Kröger, Bending behavior of empty and foam-filled beams: structural optimization, International Journal of Impact Engineering 35 (2008) 521–529.

[8] Chang Qi, Yong Sun, Hai-Tao Hu, Da-Zhi Wang, Guang-Jun, Cao and Shu Yang, On design of hybrid material double-hat thin-walled beams under lateral impact, International Journal of Mechanical Sciences 118 (2016) 21–35.

[9] SuchaoXie, Weilin Yang, Ning Wang, Haihong Li, Crashworthiness analysis of multi-cell square tubes under axial loads, International Journal of Mechanical Sciences 121 (2017) 106–118.

[10] HeeChul Kim, Dong Kil Shin, Jung Ju Lee, Jun Beom Kwon, Crashworthiness of aluminum/CFRP square hollow section beam under axial impact loading for crash box application, Composite Structures 112 (2014) 1–10.

[11] Ali AlaviNia, Jamal Haddad Hamedani, Comparative analysis of energy absorption and deformations of thin walled tubes with various section geometries, Thin-Walled Structures 48 (2010) 946–954

[12] A. AlaviNia, M. Parsapour, An investigation on the energy absorption characteristics of multi-cell square tubes, Thin-Walled Structures 68 (2013) 26–34.

[13] A. AlaviNia, M. Parsapour, Comparative analysis of energy absorption capacity of simple and multi-cell thin-walled tubes with triangular, square, hexagonal and

octagonal sections, Thin-Walled Structures 74 (2014) 155–165.

[14] Zong Wang, Zhenhuan Li, Xiong Zhang, Bending resistance of thin-walled multi- cell square tubes, Thin-Walled Structures 107 (2016) 287–299.

[15] NiyaziTanlak, Fazil O. Sonmez, Optimal shape design of thin-walled tubes under high-velocity axial impact loads, Thin-Walled Structures 84 (2014) 302–312.

[16] Weigang Chen, Tomasz Wierzbicki, Relative merits of single-cell, multi-cell and foam-filled thin-walled structures in energy absorption, Thin-Walled Structures 39 (2001) 287–306.

[17] Zonghua Zhang, Shutian Liu, Zhiliang Tang, Design optimization of cross- sectional configuration of rib-reinforced thin-walled beam, Thin-Walled Structures 47 (2009) 868–878.

[18] Jianguang Fang, YunkaiGao, Guangyong Sun, Na Qiu, Qing Li, On design of multi-cell tubes under axial and oblique impact loads, Thin-Walled Structures 95 (2015) 115–126.

[19] Xiong Zhang, Hui Zhang, Energy absorption of multi-cell stub columns under axial compression, Thin-Walled Structures 68 (2013) 156–163.

[20] Ali Najafi, MasoudRais-Rohani, Mechanics of axial plastic collapse in multi-cell, multi-corner crush tubes, Thin-Walled Structures 49 (2011) 1–12.