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A Review on Impact Characteristics and Energy Absorption of Fibre Metal Laminate Tubes

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Abstract – *Laminated metal and composite shells are increasingly being used in various engineering applications including automotive, mechanical, and marine engineering. With the sensitivity to structural impact characteristics and energy absorption increased, research covering the crushing response of fibre metal laminates has received considerable attention. For better crashworthiness performance, vehicles must protect its occupants by maintaining structural integrity and converting the large amount of kinetic energy into other forms of energy in a controllable and predictable manner in a crash situation. In doing so, lower crushing force would provide better safety for the vehicle occupants. This paper reviews the response of fibre metal laminate tubular sections subjected to axial impact loads relevant to the field of structural crashworthiness. The various types of tube material and design shall reduce the maximum crush force, hence improving the energy-absorbing characteristics of tubular structures.*

Keywords: Crashworthiness, Tubes, Axial Impact Loading

1.0 INTRODUCTION

Ideally for the crash protection would be no crash at all. However the possibility to have no crash in the reality is haven't realize. Nonetheless, if someone is going to crash, the best chances to survive is the ability to absorb or diverting the kinetic energy. Different geometries and materials of tubular structural members have been widely used as energy absorbers. They have the ability to absorb and convert large amount of kinetic energy into plastic strain energy when deforming under compression in impact situations. Pugsley and Macaulay [1] and Alexander [2] pioneered the studies on the behaviour of thin-walled structures for their absorbing kinetic energy capabilities.

Later on the interest on the axial crushing behaviour of thin-walled structures has been continued and has been studied by Reid [3], Alghamdi [4] and Jones [5]. Reid [3] focused on the progressive buckling, inversion, and splitting of circular tubes. Alghamdi [4] briefly reviewed the common shapes of collapsible energy absorbers, such as circular tubes, square tubes, frusta, struts, honeycombs, and sandwich plates and their most common deformation shapes. Jones [5] discussed the dynamic plastic instability of different circular and square tubes subjected to large axial impact loads. Despite of the numerous experimental and theoretical studies on tubular structures material and shape, the study on fibre metal laminates thin wall structure tube has never been done.

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2.0 EXPERIMENTAL RESEARCH ON STRUCTURAL TUBES

Andrew et al. [6] and Guillow et al. [7] has classified the collapse mode based on the tube thickness, diameter and length ratio that a classification chart can be drawn up enabling modes of collapse to be predicted. The quasi-static collapse of axially compressed ductile tubes indicates the influence of tube length on collapse mode. Mamalis et al. [8] studied the crumpling of thin-walled frusta, under axial compression, in the concertina mode where the energy expended in bending at the plastic hinges and in stretching the metal between the hinges is minimized for the total decrease in height due to collapse. While Langseth et al. [9] investigate the behaviour of square thin walled aluminium extrusions in alloy AA6060 subjected to axial loading and the primary variables were the wall thickness and temper. Static test found that progressive symmetric deformation mode was independent of wall thickness and temper. While dynamic test found almost linear relationship between the impact energy and the permanent axial displacement for temper T4.

Guillow et al. [10] found that the ratio of $F_{MAX}=F_{AV}$ increased substantially with an increase in the D/t ratio where The average crush force, F_{AV}, was non-dimensionalised and an empirical formula established as $F_{AV}/M_P = 72.3(D/t)^{0.32}$. Al Galib et al. [11] conducted experimental and numerical study of the crash behaviour of circular aluminium tubes with D/t=14 of alloy A6060 T5, undergoing axial compressive loading static and dynamic tests. The numerical model well predicted the 1st peak load, the mean crushing force and the number of folds within 1% for the 1st peak load and 4% for the mean crushing force.

Foam-Filled Tubes is a form to stiff tubes. Tubes can be filled with cellular structures, such as honeycombs, wood, and foams. The compression characteristics of these materials show that they are good as energy absorber. According to Thornton and Dharan [12] and Gibson and Ashby [13], the cellular materials offer a distinct plateau of almost constant stress in the uniaxial compression stress-strain curve up to nominal strain values of 70–80%. Typical foam-filled specimens and material behaviour for aluminium extrusion in uniaxial tensile and aluminium foam in uniaxial compression, as obtained by Hanssen et al. [14]. The blend of tubular members and cellular filler material combines the crushing energy of both types of structures, which seem to be efficient with the filler material providing enhancements to the empty tube. The compression of the filler material and its interaction with the tube lead to higher energy dissipation provided the tube buckles progressively.

Hanfeng et al. [15] investigates the energy absorption characteristics of foam-filled multi-cell thin-walled structures (FMTS) by nonlinear finite element analysis through LS-DYNA, found that the FMTS with nine cells has the most excellent crash worthiness characteristics. Thus, the FMTSs with cell number n=9 are then optimized by adopting a multi-objective particle swarm optimization (MOPSO) algorithm to achieve maximum specific energy absorption(SEA) capacity and minimum peak crushing force (PCF).

3.0 RESEARCH ON FIBRE METAL LAMINATES

Shin et al. [16] investigated the energy absorption capability of axial crushed square aluminium/glass fibre reinforced plastic (GFRP) hybrid tubes. Glass fibre-epoxy composite pre-pregs were wrapped around an aluminium tube and cured completely in the autoclave. Bonding between composite and aluminium tubes was performed by excess resin extracted from the composite tube during curing process. The hybrid tube with the 90º ply orientation composite tube showed the best energy absorption capability among all kinds of hybrid tubes.

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During deformation of the aluminium tube, the composite material prevented the aluminium tube from folding. The failure of the hybrid tube was stable and progressive without any trigger mechanism because the inner aluminium tube could play the role of crack initiator and controller.

Hanefi and Wiezbicki [17] reported on the axial crush resistance and energy absorption of externally reinforced metal tubes. Classical Alexander's solution was modified to take into account the contribution of the compound metal composite wall. The mean crushing force and the length of local folding from the analysis were in good agreement with experimental data. El-Hage et al. [18] studied the quasi static axial crush behaviour of aluminium composite hybrid tube containing filament Wound E glass-fibre reinforced epoxy overwrap around an aluminium tube. The fibre orientation angle in the overwrap was 45º to the tube axis. It was found that the folding initiation force was lower with adhesive between the aluminium tube and composite overwrap than without adhesive. A high bond failure limit resulted in a lower folding initiation force and mean crush force.

M. Kathiresan [19] validated low velocity axial impact crush behaviours and energy absorption characteristics of thin-walled aluminium conical (AC) and E-glass/epoxy composite over-wrapped aluminium conical hybrid frustrated shells (CWAC) with 15º–24º semi-apical angled aluminium with finite element analysis (FEA) techniques of ABAQUS software in order to predict and compare the crashworthiness of each category of specimen model with experimental results. The obtained crashworthiness test results and collapse behaviours of FEA analysis are found in good agreement with the experimental results.

4.0 NUMERICAL STUDIES ON TUBE IMPACT

Finite element analysis has been widely applied to analyse the crushing of tubes, enabling parameters and boundary conditions, which are not accessible experimentally or analytically to be investigated. Consequently, the numerical tool has become an ideal instrument to gain a better understanding of the failure mechanism of the extrusions under compressive loading conditions.

A few examples of the different finite element codes used to investigate these characteristics include the work of Langseth et al. [20,21], Otubushin [22], and Marsolek and Reimerdes [23] who used LS-DYNA; Abah et al. [24] and Markiewicz [25] used PAM-CRASH; Miyazaki et al. [26] used MARC K6.2; Nannucci et al.[27] and Karagiozova et al. [28-31] used ABAQUS. In most of the studies, an explicit integration scheme was used. Four-noded shell elements with reduced integration, multiple integration points through the thickness of the element, and hourglass control were used.

Mamalis et al. [32], however, used an "implicit" finite element code, MARC, to simulate the crush behaviour of cylindrical thin wall composite tubes under static and dynamic axial compressions, in accordance with the progressive mechanism of failure. Finite element techniques have been further used for the optimization of different parameters with a view to obtain the ideal energy absorbers, with the aim to maximizing the specific energy absorption. Chiandussi and Avalle [33] and Nagel and Thambiratnam [34] optimized tapered tubular steel components to be used as an energy-absorbing device. Other algorithms to optimize the crashworthiness of tubular structures were carried out by Lust [35], Yamazaki and Han [36], and Avalle et al. [37,38] by applying structural optimization techniques using the response surface methodology. Kim [39] developed new types of trigger and multi cell profiles with specific energy absorption 1.9 times larger than conventional square tubes in terms of energy absorbed and weight efficiency. Theobald and Nurick [40,41] numerically investigated.

S.A. Yousefsani et al. [42] used numerical method with LS-DYNA software to simulate, the axial impact of metallic and hybrid energy absorbing thin-walled tubes with polygonal cross-section. To compare the results, all metallic tubes have identical thickness, length, and circumference. The hybrid tubes are made of the same metallic tubes which are reinforced with special composite overlays. The metallic energy absorbing thin-walled tubes shows that although the strength and Young's modulus have developing effects on the crush behaviour, the ass specific energy absorption (MSEA) significantly depends on the strength to weight ratio. Moreover, it can be concluded that, by correct reinforcing the metallic tubes with composite laminates, the mass specific energy absorption and also other crush behaviours can be significantly improved. Furthermore, it can be concluded that, some polygonal shapes with better crush behaviour, even 10% better than the circular ones, can be achieved.

5.0 CONCLUSION

The response of fibre metal laminate tubes thin-walled structures to axial impact depends on numerous common aspects of the tubes, such as geometry includes cross section, length, width, and thickness of the tube and its material properties such as elasticity modulus, yield stress, and strain hardening. Other common factors include the loading conditions like impact velocity that affects strain rate and inertia effects and the boundary conditions as clamped, pinned, or free. Varying the laminate layer and fibre directions or introducing fillers aluminium foam, wood densities and stiffeners frequency, types also affect the response of tubular sections to axial loading. Presented in this paper is an extensive literature review on the response of tubular structures subjected to axial loading. Modifying whether geometrical or material can be used to obtain a particular axial crush mode or modify certain crush characteristics of tubular structures.

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