Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 8 (2018) 102–117

Structural Integrity Procedia

www.elsevier.com/locate/procedia

AIAS 2017 International Conference on Stress Analysis, AIAS 2017, 6-9 September 2017, Pisa, Italy

Axial crushing of metal-composite hybrid tubes: experimental analysis

Simonetta Boria[a,*], Alessandro Scattina[b], Giovanni Belingardi[b]

[a]*School of Science and Technology, University of Camerino, 9 Madonna delle Carceri, Camerino 62032, Italy*
[b]*Department of Mechanical and Aerospace Engineering, Politecnico di Torino, 24 Duca degli Abruzzi, Torino 10129, Italy*

Abstract

In the automotive sector, special attention is paid to the study of the behavior of the structural components that make the car bodies. The continuous demands on the weight saving imply the car bodies to be assembled with components made in different materials and using different manufacturing processes. Considering the making of the sacrificial structures aimed to the energy absorption, composite materials are increasingly used to replace conventional metal materials. However, the use of composites is accompanied with a change in the type of deformation obtained during the impact phenomenon. Usually, with the conventional metal materials, the crushing behavior is a progressive buckling whereas the composite materials are characterized by a brittle fracture. The combination of the traditional metal materials with the composite ones can represent a good solution to obtain high levels of performance.

In this context, the structural performance of metal-composite hybrid tubes subjected to quasi-static axial crushing is experimentally evaluated in this work. The specimens, with circular cross section, were obtained with tubes made in a fully thermoplastic composite internally reinforced with aluminum tubes. The composite material used were made in polypropylene both for the matrix and for the reinforcing fibers. This material has a good axial absorption capacity but irregular behavior during crushing. The addition of a conventional material as reinforcement allowed to increase the absorption capacity by ensuring a more progressive and controlled crush. The analysis was carried out by evaluating, for various geometric configurations, different parameters (mean load, average stress, specific energy, efficiency). The results, discussed in the work, showed how the energy absorption performance of a hybrid structure are higher than the sum of the performance of the single materials.

Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis

* Corresponding author. Tel.: +39-0737402503.
E-mail address: simonetta.boria@unicam.it

Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis
10.1016/j.prostr.2017.12.012

Keywords: axial crushing; energy absorption; circular hybrid tube; thermoplastic composite

1. Introduction

The demand to improve the crashworthiness efficiency of vehicles has been raising up in the last years in order to decrease the injuries due to the crash events, considering also the increasing speed of vehicles. Therefore, the interest to use energy absorber devices with higher energy absorption capacity has increased along the years. Circular metal tubes are one of the most common shapes of tubular devices for energy absorption. These devices, called also crash box, absorb the kinetic energy of an impact by collapsing in a progressive and controlled way. The so called concertina and diamond modes are the two main crushing behaviors that can be obtained, with this type of specimens, under quasi-static and dynamic axial loading conditions (Eyvazian et al. (2017)). In the last decades, few methods were suggested to improve the energy absorption capability of these kind of structures. One of this is the expansion of metal tubes using rigid rings on the tube to activate the axisymmetric plastic buckling mode (Shakeri et al. (2007)). Another interesting solutions are the use of filler substances such as metal and polymeric foams (Santosa et al. (2000), Kavi et al. (2006), Peroni et al. (2008), Avalle et al. (2014), Pandarkar et al. (2016)) or to apply an external reinforcement made in composite materials (Wang et al. (1991), Hanefi et al. (1996), Song et al. (2000), Bouchet et al. (2002), Mirzaei et al. (2012), Kim et al. (2014)).

Many researchers studied the axial crushing of metal tubes reinforced by composite layers, called also hybrid tubes, from the experimental (Wang et al. (1991), Kim et al. (2014), Zhu et al. (2017)) and numerical (El-Hage et al. (2006), Huang et al. (2012)) point of view. The results of these researches showed that various parameters could contribute in collapsing and affect the crashworthiness characteristics (absorbed and specific energy, mean and peak load, crush force efficiency). The crushing behaviors of metal/composite hybrid structures can be affected by geometry, lay-up sequence of composite, surface treatment, strain rate, etc. The idea to improve the energy absorption capability of metal tubes through composite reinforcement was introduced for the first time by Wang et al. (1991). Song et al. (2000) studied, from an experimental point of view, the effects of many factors like the strain rate, the composite wall thickness, the fiber ply orientation in pattern and the mechanical properties of metal tube subjected to impact load. They obtained four main collapse modes for hybrid tubes including: compound diamond, compound fragmentation, delamination and catastrophic failure. Watanabe et al. (1991) investigated energy absorption capacity of steel tube wrapped in fiber reinforced composites and they showed that energy absorption is positively related to composite thickness, but decreases with the reduction of fiber orientation angle. Bouchet et al. (2002) analyzed the effect of reinforcement and different surface treatments of metal tubes in order to improve the practical adhesion between the composite and the metal tube. The obtained values of the specific energy absorption suggest that the influence of surface treatments of multi-material structures was not a significant contribution, whereas the application of the reinforcement can increase the crashworthiness performance if the same crushing mode was maintained. For the thinner aluminum alloy tube, with or without the fiber reinforced plastic composites, a diamond mode was observed. On the contrary, from a concertina mode obtained with the thicker tube without reinforcement, a diamond mode is observed with the reinforced one. As the crushing mode changed, the reinforcement applied onto the aluminum tube decreased the capacities of the tested structure to absorb energy. On the other hand, the reinforcement applied onto the thinner tube increased the SEA of the tube. Bambach et al. (2009) carried out experimental tests to explore the crushing behaviors of steel square hollow sections strengthened with CFRP. They found that application of CFRP could increase the axial loading capacity providing constraints to the development of elastic buckling deflections and thus delaying local buckling. Kim et al. (2014) investigated the collapse modes and crash characteristics of an aluminum/CFRP hybrid column subjected to dynamic axial load by considering the influence of fiber orientation and lay-up sequence. El-Hage et al. (2006) and Huang et al. (2012) studied the axial crushing of circular and square hybrid tubes from a numerical point of view. They showed that for [±θ] ply pattern, the best angle of orientation is hoop reinforcement.

On the contrary, analytical models to predict the collapse behavior of hybrid tubes under axial loading are very restricted (Hanefi et al. (1996), Wang et al. (2002), Song et al. (2000), Shin et al. (2002), Akbarshahi et al. (2011)). Hanefi et al. (1996), based on Alexander's model and considering effective crushing length, presented the first analytical model to predict the mean crushing load of circular hybrid tubes that are reinforced with unidirectional