Thin-Walled Structures 100 (2016) 180–191

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Effect of heat treatment on the blast loading response of combined geometry shell core sandwich structures

Alper Tasdemirci *, Ali Kara, Kivanc Turan, Selim Sahin, Mustafa Guden

Dynamic Testing and Modeling Laboratory and Department of Mechanical Engineering, Izmir Institute of Technology, Gulbahce, Urla, Izmir, Turkey

ARTICLE INFO

Article history:
Received 3 June 2015
Received in revised form
11 December 2015
Accepted 11 December 2015
Available online 22 December 2015

Keywords:
Sandwich structures with combined geometry shell cores
Heat treatment
Energy Absorption
Blast loading
CONWEP
Finite Element Method

ABSTRACT

The effect of heat treatment on the dynamic crushing and energy absorption behavior of combined geometry shell cores (hemisphere and cylinder) of sandwich structures were investigated both experimentally and numerically. The applied heat treatment on the combined geometry shell cores relieved the stress caused by deep drawing, diminishing the peak transmitted forces. The verified numerical models of the as-received and heat-treated combined geometry shells were used to model blast loading of various sandwich configurations and the additional sandwich configurations of reversing the cylindrical side of the cores to the impacted side. Both the applied heat-treatment and the reversing process decreased the magnitude of the force transmitted to the protected structure. The applied heat treatment increased the arrival time of blast force wave to the protected structure, while the reversing resulted in opposite.

1. Introduction

Energy absorbing structures are widely used in vehicle crashworthiness, highway safety, sacrificial claddings and armor protections. These are mostly the thin-walled structures of cylindrical, square and hexagonal tubes, cones and spheres with comparable high strength/weight ratios. The energy absorption characteristics of these structures can be tailored with the various combinations of simple geometries such as cylindrical, spherical and conical shapes, which have already been employed in aerospace, automotive and marine industries. The superior energy absorption characteristics of combined geometry shells lie in the deformation and collapse behavior of their constituents.

Gupta et al. [1] analyzed the collapse behavior of a combined geometry shell of a frusta and a hemispherical cap. The global deformation of the shell was progressive and the deformation mode of conical frusta part was found to be different from that of the geometry without a cap [2]. Niknejad and Tavassolimanesh [3] investigated the inversion process of an end-capped frusta. The end-capped frusta were treated as a special case of combined geometry. Gupta [4] studied the axial crushing of a metallic frusta with varying wall thicknesses, treated as the combinations of constant wall thickness frusta of infinite number. Gupta [5] and Gupta and Gupta [6] investigated the axial collapse of behavior of the combined tube-cone geometry. The collapse behavior changed with the dimensions of conical portion and the deformation mode and the region of fold formation changed with the thickness. Ghamarian and Abadi [7], Ghamarian et al. [8] and Ghamarian and Zarei [9] investigated the energy absorption characteristics of empty and foam-filled circular and conical end-capped tubes and showed that the absorbed energy increased with increasing impact velocity. Ghamarian et al. [10] showed that the crush force efficiency and absorbed energy of shallow spheres as end-cap in conical tubes increased with increasing spherical cap radius. Shojaeefard et al. [11] showed that the absorbed energy of combined tubes were higher than those of individual components of the same length. Shahi and Marzbanrad [12] investigated the crushing behavior of segmented thin walled tubes. Sahu and Gupta [13] studied the large deformation of a combined geometry consisting of three individual geometries, namely an end-capped cylinder, a frusta, and a spherical crater. The increase in the thickness of shell resulted in higher buckling loads and changed the location of fold initiation and the fold thicknesses varied with the friction coefficient. Gupta and Gupta [14] and Gupta [15] investigated the effect of heat treatment and size of cutouts on the collapse behavior of aluminum and mild steel thin walled tubes. Annealing caused the change the deformation mode of aluminum tubes from diamond to ring and steel tubes from concertina to diamond mode. Gupta and Gupta [16] investigated the collapse of metallic hemispherical shells compressed with hemispherical nose indenter and showed that specimens tested in as-received condition absorbed more energy than the annealed condition, resulting from reduced yield strength after annealing. No noticeable change was

* Corresponding author.

http://dx.doi.org/10.1016/j.tws.2015.12.012
0263-8231/

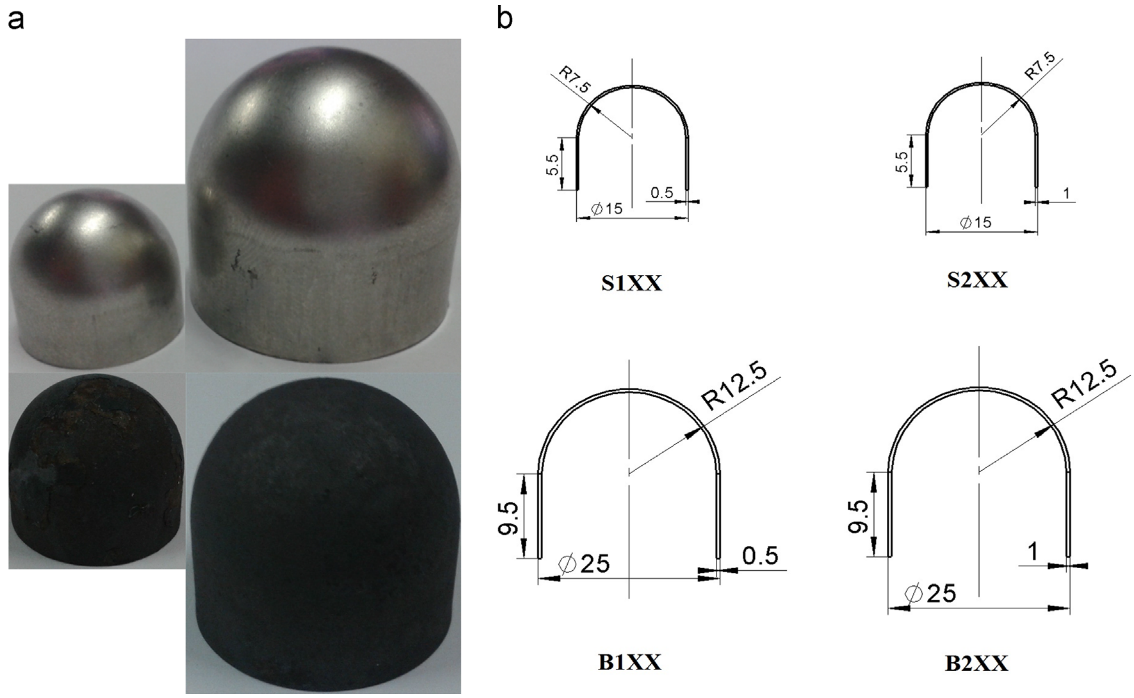

Fig. 1. (a) As received and heat-treated combined geometry shells and (b) the geometrical parameters.

observed in the collapse mode as lower amount of plastic deformation was induced during the spinning process.

Various types of sandwiches with different core materials and topology have also been designed and suggested, including metallic foams [17,18], metallic honeycombs [19–21], and corrugated structures [22,23]. Alberdi et al. [24] evaluated the performance of sandwich structures against blast using CONWEP functions [25] incorporated in LS-DYNA [26]. The folded core topologies exhibited superior blast performance than honeycomb topologies considering their lower back plate deflections, lower transmitted forces to the back plate, and higher energy dissipation. Palanivelu et al. investigated recycled beverage cans for low velocity impact applications [27] and the use of their arrangements for a macro foam as sacrificial cladding [28] against blast loading.

The aim of the current study is to determine the effect of heat treatment on the crushing behavior and energy absorption characteristics of the combined geometry shells (hemispherical cap and cylindrical segment) at quasi-static and high strain rates. The quasi-static and dynamic deformation behavior of the tested as received combined geometry shells and their sandwiches were recently investigated in Refs. [29] and [30] by the same authors. Previous results revealed that failure/fracture of few specimens occurred during crushing, imparting the energy dissipating capability. Therefore, heat treatment was presented in this study as a stress relieving procedure to induce more ductile material behavior in order to increase absorbed energy without failure/fracture. Current study also utilized numerical approach in order to determine dynamic crushing behavior of sandwiches with cores of as-received and heat-treated combined geometries and their configurations under blast loading conditions.

2. Manufacturing of combined geometry shells and heat treatment

The investigated combined geometry shells were formed by deep-drawing 0.5 and 1 mm thick AISI 304L stainless steel sheet blanks. The tooling for the deep-drawing process was machined locally for the current study. The edge of the deep drawn cylindrical segment on the bottom side formed during the forming process was trimmed by a cutting tool on a CNC lathe. The prepared specimens of various configurations commonly consisted of a hemispherical cap and a cylindrical segment. Four different combined geometry shell configurations were tested and modeled. The coding of the configurations is as follows: S1XH, S2XH, B1XH and B2XH. The first letters, S and B, refer to the sample's radius. The samples 15 mm in diameter are coded as S (small) and the samples in 25 mm diameter as B (big). The numbers after the first letters, 1 and 2, refer to the sample thickness of 0.5 and 1 mm, respectively. The last number in the coding, X, represents the type of the test applied. The quasi-static test is coded as 1 and drop-weight test as 2 [29]. In this study, the last letter H was introduced which refers to heat-treatment. The code of B12H, for example, refers to a heat treated sample with 25 mm diameter and 0.5 mm thickness, tested in drop-weight. The numerical and measured thickness vs. distance from apex graphs of deep drawn S2X and B2X samples were previously shown in Ref. [29]. The deep drawing process caused slight or no increase in the thickness of the cylindrical segment while the thickness decreased in the hemi-spherical cap. For example, the hemi-spherical cap thickness reduced to 0.8 mm on the average after deep drawing, while the thickness of the cylindrical segment remained almost the same for a blank thickness of 1 mm.

The heat treatment process consisted of two steps: annealing at 1100 °C, followed by an immediate air quenching. The optimum heat treatment route was determined by varying the annealing times: 0.5, 2.0, and 4.0 h and an annealing time of 2 h was determined to be optimum (no change in mechanical behavior after 2 h). The annealing time strongly depends on the amount of plastic deformation induced during deep-drawing. Comparable results were also reported for a similar material by Weber et al. [31]. The pictures of the prepared small and big radius as-received and heat-treated combined shells and the geometrical parameters of the samples tested are shown in Fig. 1a and b.