Aerospace Science and Technology ••• (••••) •••–•••

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Experimental and numerical investigations of the effect of cellular wired core on the ballistic resistance of sandwich structures

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ARTICLE INFO

Article history:
Received 19 November 2016
Received in revised form 15 May 2017
Accepted 12 August 2017
Available online xxxx

Keywords:
Energy absorption
Ballistic limit velocity
Wired core

ABSTRACT

Sandwich structures usually are of particular importance in different industries including aerospace, marine and automotive due to their high performance and high energy absorption. In this research, the ballistic limit velocity of sandwich panels with wired core and aluminum face-sheets in normal impact with flat head cylindrical projectile has been investigated numerically and experimentally. It was also evaluated the effect of wire diameter and type of layout on the ballistic limit velocity of the panels. The diameter of wires was 4.44, 6, 8 and 10 mm and they were applied as core in 7 types of different layouts. Flat head steel projectiles with mass of 8.6 grams, diameter of 8 mm and length of 22 mm were impacted on the targets at velocities of 250–450 m/s. Results of this research showed that for the panels with the same mass, firstly, the ballistic limit was increased by reducing the wires diameter and increasing the number of their rows; secondly, reducing the distance between the wires also led to increase in ballistic limit and thirdly, the ballistic limit velocity of sandwich panel showed 45% increase with respect to a single-layer target with the same type and mass.

1. Introduction

Sandwich panels are made of two thin and stiff face-sheets and a thick and light core. According to the interesting properties, these structures are widely used in many industries such as transportation and aerospace. Face-sheets can be made of metallic materials such as aluminum, steel, titanium and non-metallic materials including glass fiber, carbon and Kevlar [1,2]. Ben-Dor et al. studied analytically the influence of air gaps between the plates and the order of plates on the ballistic limit velocity of a multi-layered shield against conical shaped impactors, and the results are summarized in [3–5]. Børvik et al. [6] presented finite-element calculations for rigid, conical nose rods that perforate 5083-H116 aluminum armor plates. Børvik et al. [7] presented an experimental and analytical study to understand the mechanisms and dominant parameters for ogive-nose rods and 7.62 mm APM2 bullets that perforate 5083-H116 aluminum armor plates. Deng et al. [8] studied the ballistic performance of single, two, three and four-layered steel plates impacted by ogival-nosed projectiles. They showed that the thin monolithic targets have greater ballistic limit velocities than multi-layered targets if the total thickness is less than a special value, and also the ballistic limit velocities of multi-layered targets decrease with the increase of the number of layers. Li et al. [9] presented the recent progress in formulating and modeling local impact effects in concrete targets struck by hard missiles. Greenhalgh et al. [10] reported fractographic observations on laminates which have been exposed to ballistic impact. They showed the sequence of failure modes (and their interaction), such as delamination, ply splitting and fiber kinking, through the laminate during the impact event have been deduced, and the influence of processing conditions and target response on the damage processes have been gleaned. Hoo Fatt et al. studied analytically deformation and resistance to penetration of sandwich panels with honeycomb core under quasi-static loads and high velocity impact of projectiles. They used lumped spring-mass system to predict the impact response [11,12]. Hanssen et al. studied a bird impact to sandwich panels made of aluminum foam core with aluminum face-sheets both experimentally and numerically [13]. Zhao et al. investigated the perforation of sandwich structures with aluminum foam core and aluminum alloy face-sheets by Hopkinson pressure bar and determined their load-displacement curves [14]. Yamashita and Gotoh evaluated experimentally the behavior of AL-5052 honeycomb panels with different thicknesses against high speed impact [15]. Alavi Nia and Liaghat studied the behavior of aluminum honeycombs subjected to quasi-static and dynamic loads [16]. Alavi Nia and Kazemi studied analytically the effect of high speed impact on sandwich panels with metal face-sheets and foam core in normal impact of a cylindrical projectile [17]. They showed that the proposed analytical method has acceptable accuracy to determine the residual velocity of the projectile in impact with panels with polymer and metal foam cores and with different relative densities. Heimbs et al. studied experimentally

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http://dx.doi.org/10.1016/j.ast.2017.08.015

Please cite this article in press as: A. Alavi Nia et al., Experimental and numerical investigations of the effect of cellular wired core on the ballistic resistance of sandwich structures, Aerosp. Sci. Technol. (2017), http://dx.doi.org/10.1016/j.ast.2017.08.015

and numerically the mechanical behavior of sandwich structures with composite cores and carbon fiber reinforced face-sheets under pressure and impact loads [18]. Tan and Akil evaluated experimentally the impact properties of sandwich beams with composite face-sheets and polypropylene honeycomb core and showed that the first failure modes of the structure under low velocity impact were delamination of layers and global bending of the structure [19]. Goldsmith and Moriaty examined dynamic energy absorption properties of cylindrical sandwich shells with aluminum honeycomb core and Nomex HRH-10 and thick face-sheets made of aluminum and ABS plastic subjected to impact of heavy masses [20]. Zhibin et al. investigated the penetration and failure of sandwich panels with composite face-sheets and aluminum foam core under quasi-static loading and low velocity impact and evaluated the effect of parameters such as impact energy, core thickness, face-sheets thickness, core density and geometry of projectile nose on behavior of the panel [21]. Manalo et al. examined the bending of a new generation of sandwich beams with fiber composite face-sheets and modified phenolic core [22]. They performed four point bending tests in two modes in the transverse and through the thickness of beams. They showed that the loaded beams in the thickness direction have failed at larger force with less deformation. Kazem Ahvazi et al. examined impact properties of sandwich structures with composite wavy cores [23]. They studied experimentally dynamic response of four different composite wavy cores with the same projectile in velocity range of 10 to 50 m/s. Weihong et al. studied experimentally the ballistic behavior of sandwich panels with metallic face-sheets and aluminum foam core. They evaluated the effect of parameters such as projectile velocity, face-sheet thickness, thickness and density of foam core as well as projectile shape on ballistic limit and energy absorption of [24].

Dean et al. [25] studied energy absorption through penetration of projectile into the sandwich structure with the steel fiber core numerically and experimentally. Their experimental results showed that the rate of energy absorption had the highest value at velocities close to the ballistic limit and it was reduced by increasing projectile velocity. Also, their numerical investigations indicated that this increase was due to the kinetic energy of separated particles and influence of strain rate. Nasir Zadeh and Sabet investigated the ballistic limit and energy absorption of sandwich structures with polyurethane foam core; they also studied the effect of Nano clay in polyurethane foam core on the impact properties of sandwich structure [26]. Ghalami Choubor and Sedighi studied numerically and experimentally the effect of parameters of projectile velocity, core density, core thickness, face-sheet thickness and orientation of fibers on ballistic limit and energy absorption of sandwich structures with polyurethane foam core and aluminum and composite face-sheets [27].

Cao et al. examined the performance of shock energy absorption in sandwich structures with aluminum combined honeycomb core under impact and quasi-static loads. They showed that the combined honeycomb structure has higher rate of energy absorption than the single honeycomb [28].

In this research, we have investigated experimentally and numerically the normal impact of flat head steel cylindrical projectile with sandwich panels with cellular wired core and aluminum face-sheets. We have also evaluated the effect of parameters such as reducing diameter and increasing the number of wires' row and also reducing the distance between the wires on the ballistic limit velocity of the panels.

Fig. 1. A view of the projectile used in experimental tests.

Table 1
Mechanical properties of projectiles.

Poisson's ratio ν	Young's modulus, E (GPa)	Density (kg/m^3)
0.29	210	7800

Fig. 2. Tensile test samples.

2. Experimental tests

2.1. Materials

Projectiles: the projectiles used in experimental tests of penetration are made of steel with hardness of HRC 58. The projectile was flat head cylindrical shape with a mass of 8.6 grams, diameter of 8 mm and length of 22 mm (Fig. 1). Mechanical properties of projectiles are given in Table 1.

Aluminum face-sheets: face-sheets are made of 1100-H14 aluminum. Tensile test was performed based on the ASME-E8 standard on three samples in order to determine stress–strain curve of aluminum sheet. Tensile tests were done using STM 150 device with loading rate of 10 mm/min. Samples of tensile test are provided in Fig. 2 and also mechanical properties of the sheets obtained from the test are given in Table 2.

Aluminum wires: the wires used in this research are made of 1350-O aluminum with diameters 4.44, 6, 8 and 10 with a length of 100 mm. Tensile test was performed on them based on the standard ASME-E8 to determine stress–strain curve. Tensile test was performed using STM 150 apparatus with a speed of 10 mm/min. Samples of tensile test are given in Fig. 3 and also mechanical properties obtained from the test are listed in Table 3.

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