Materials Letters 179 (2016) 142–145

Contents lists available at ScienceDirect

Materials Letters

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

# Indentation experiments on novel sandwich composite tubes

Abbas Niknejad [a,*], Alireza Moradi [a], Niloofar Beheshti [b]

[a] Mechanical Engineering Department, Yasouj University, P.O. Box: 75914-353, Yasouj, Iran
[b] Civil Engineering Department, Yasouj University, P.O. Box: 75914-353, Yasouj, Iran

ARTICLE INFO

*Article history:*
Received 29 February 2016
Received in revised form
22 April 2016
Accepted 7 May 2016
Available online 9 May 2016

*Keywords:*
Agglomerated cork
Composite materials
Indentation process
Energy absorption
Sandwich tubes
Porous materials

ABSTRACT

This article introduces a novel energy absorber of sandwich tube with the agglomerated cork core and the composite tube during the indentation process under the applied quasi-static lateral loading by a solid cylindrical rigid indenter. Also, the corresponding cork specimens and the empty composite tubes are tested, too. The solid cylindrical cores made of agglomerated cork are prepared by punching a cork sheet with 200 kg/m$^3$ density and positioned into the composite tubes to manufacture the cork-filled tubes. The results show that the cork-filled composite tubes have an energy absorption capacity up to 5.65 times of the corresponding cork sample and up to 6.06 times of the corresponding empty tube. Also, it is found that total absorbed energy by a cork-filled composite tube is 174% higher than summation of absorbed energy by the corresponding empty tube and the cork sample. Also, specific absorbed energy by all the specimens is discussed.



## 1. Introduction

Energy absorption is an interesting concern for many researchers and it relates to safety of some engineering structures. Porous materials are one of suitable selections as energy absorber, so, some previous papers investigated mechanical behavior of different porous materials such as scaffolds [1], metal foams [2] and agglomerated cork [3]. Sanchez-Saez et al. [4] studied multi-impact behavior of agglomerated cork, experimentally. Gameiro and Cirne [5] studied dynamic crushing of agglomerated cork-filled tubes. Some articles discussed effects of porous polyurethane foam as the filler into composite [6,7] and metal tubes [8]. Also, Morris et al. [9] and Hafeez and Almaskari [10] studied indentation process on circular metal and composite tubes, respectively.

This article introduces a novel composite sandwich tube as the new energy absorber during the indention process, using rigid solid cylindrical rods with different diameters. On the other hand, some solid cylinders made of agglomerated cork are laterally compressed and also, similar cork specimens are positioned into cylindrical composite tubes as the filler and the achieved sandwich tubes are laterally tested and their energy absorption behavior under the applied quasi-static lateral loading is discussed.

## 2. Experiments

This article studied energy absorption by some agglomerated cork specimen, hollow composite tubes, and agglomerated cork-filled composite tubes during the indentation process. For this purpose, three solid cylindrical rods with different diameters of 10.0, 20.0 and 30.0 mm were machined from hardened steel to consider them as rigid material, comparing with the experimental specimens; and they were used as indenter. Length of the indenters was selected equal to 50.0 mm; while lengths of all the specimens were 40.0 mm. In each test, the specimen was positioned between a rigid platen and a rigid indenter in a DMG machine, model 7166. The indenter was positioned parallel to specimen axis. Three different groups consist of solid cylindrical agglomerated cork specimens, hollow composite tubes, and agglomerated cork-filled composite tubes were prepared and tested according to Fig. 1. In each group, there were three similar specimens with the same corresponding characteristics and they were laterally compressed by three different indenters of 10.0, 20.0 and 30.0 mm diameters. All the agglomerated cork specimens and fillers were in solid cylindrical form with 41.6 mm diameter; and they were produced by punching a sheet of agglomerated cork with 10.0 mm thickness and density of 200 kg/m$^3$. Four pieces of the punched cork were affixed by the thin layer of Pattex glue to produce the cork cylinder with 40.0 mm length. The tubes were made of woven E-glass fiber and epoxy resin with the same inner diameter of 41.6 mm and wall thickness of 3.0 mm. The fiber fabric was weaved at a $+15/-15$ configuration respect to the tube cross-

* Corresponding author.
*E-mail address:* Aniknejad@yu.ac.ir (A. Niknejad).

http://dx.doi.org/10.1016/j.matlet.2016.05.041
0167-577X/

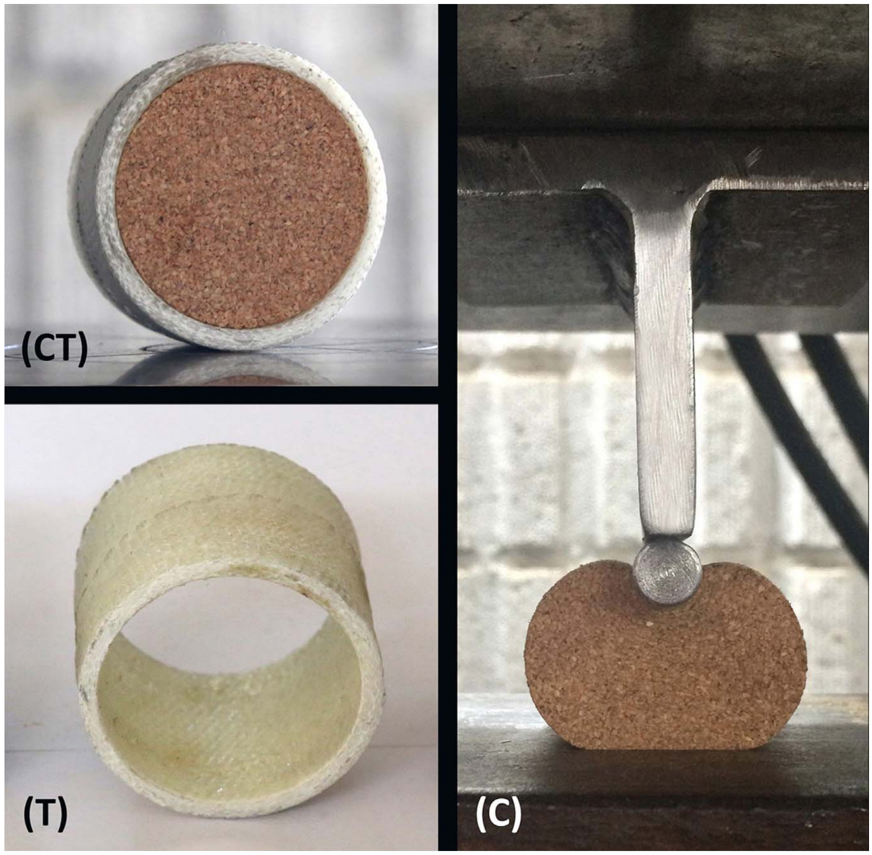


**Fig. 1.** Three different specimens consist of a solid cylindrical agglomerated cork specimen (C), a hollow composite tube (T) and a cork-filled composite tube (CT).

section. Code of each specimen consists of two parts: a number, and one or two letters. The number indicates diameter of the indenter; and the C, T and CT show cork specimen, empty composite tube and agglomerated cork-filled composite tube, respectively (Fig. 1).

## 3. Results and discussion

Fig. 2a and b compares total absorbed energy (TAE) and specific absorbed energy (SAE) by all the specimens during the indentation process, respectively. Fig. 2a and b illustrates that when indenter diameter increases, TAE and SAE (total absorbed energy per specimen mass) by the agglomerated cork specimens, empty composite tubes, and cork-filled composite tubes increase, too. The figure shows that by enhancing the indenter diameter from 10.0 mm to 30.0 mm, TAE and SAE by the agglomerated cork specimens increases, intensively. It is due to applying the external load on a limit zone of the cork specimens. On the other hand, during the indentation process on the solid cylindrical cork specimens, due to the almost zero value of the cork Poisson ratio, the external load is applied on the cork particles that are positioned under the indenter along the loading direction. Therefore, in the indentation progress on the cork samples, just some cork particles associate in the deformation and energy absorption process. Thus, by increasing the indenter diameter, volume of the cork that contributes in the deformation progress increases; consequently, TAE and SAE of the cork samples enhances, intensively. The cork specimens were tested up to the fracture. The same trend is not considered in the cork-filled tubes. In other words, although, by

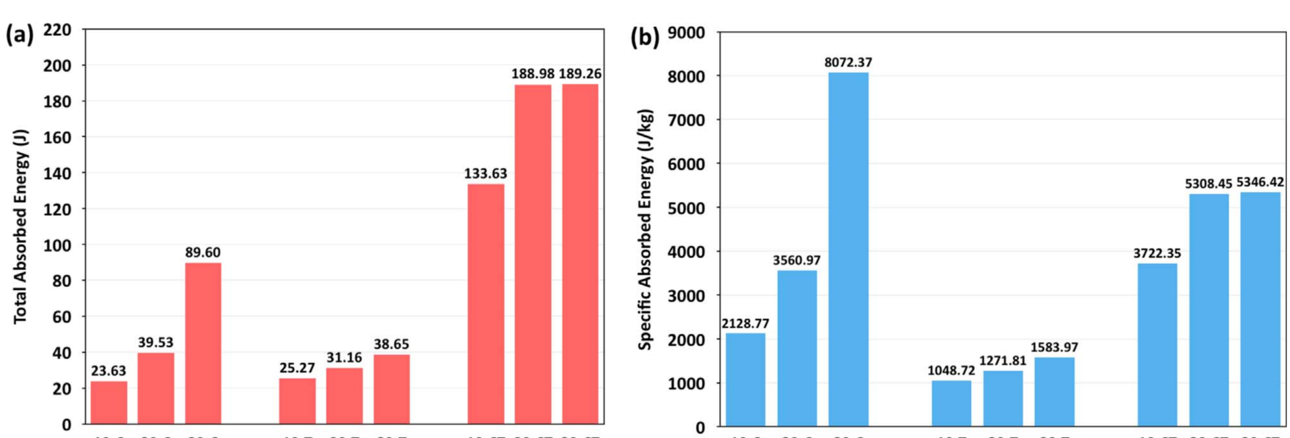


**Fig. 2.** Total absorbed energy (a) and specific absorbed energy (b), by all the specimens during the indentation process.