Construction and Building Materials 78 (2015) 362–368

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical properties and energy absorption capability of thin-walled square columns of silica/epoxy nanocomposite

Mahmoud Shariati [a], Gholamali Farzi [b], Ali Dadrasi [c,*]

[a] Department of Mechanical Engineering, Ferdowsi University, Mashhad, Iran
[b] Department of Material and Polymer Engineering, Faculty of Engineering, Hakim Sabzevari University, Sabzevar, Iran
[c] Department of Mechanical Engineering, Shahrood University, Shahrood, Iran

HIGHLIGHTS

- Crashworthy capability of composite thin-walled square columns is investigated.
- Effect of nanosilica content, particle size and various combinations of epoxy/silica.
- Young's modulus, yield strength and specific energy absorption were investigated.
- Initiation of axial cracks at an early stage of the loading was observed.
- Shorter specimens have higher crashworthy capability in the same combination.

ARTICLE INFO

Article history:
Received 24 August 2014
Received in revised form 31 December 2014
Accepted 4 January 2015
Available online 17 January 2015

Keywords:
Particle size
Thin-walled structures
Energy absorption
Silica nanoparticles
Weight percent

ABSTRACT

In this paper, the effect of adding silica nanoparticle to epoxy, silica weight percent, particle size and various combinations of epoxy/silica on Young's modulus, yield strength and energy absorption capability of thin-walled square columns was investigated. Two different sizes of silica nanoparticles, nominally 17 nm and 65 nm in diameter, were used. Nanosilica particles were dispersed almost homogeneously in the epoxy resin from 1.5 wt.% to 6 wt.% in three series of composites. First and second series were composites reinforced with 17 nm and 65 nm particle size, respectively and third series were composites reinforced with combination of both particle sizes. All specimens were tested under quasi-static loading using a servohydraulic Instron machine. A scanning electron microscopy (SEM) was used for fracture surface studies. The results showed that when silica weight percent was increased, the Young's modulus increased, yield strength remained constant and energy absorption capability of columns decreased, and specimens collapsed under unstable and dangerous mode. It was observed that the reason for this type of collapse was initiation of axial cracks at an early stage of the loading and propagation along the specimen height. Energy absorption capability for columns with height of 60 mm and 90 mm was also investigated and results showed that this parameter for shorter specimens was higher in the same combination of a nanocomposite. Moreover, the effect of particle size on Young's modulus, yield strength and energy absorption capability was not considerable. Using both particles in a combination did not show any important synergy effect. And finally, fracture surfaces of the specimens showed that surface roughness was increased by increasing the silica nanoparticles.

1. Introduction

In recent decades, many thin-walled structures such as cylindrical, conical, square and dome shells have been investigated as energy absorbents by researchers, but traditionally metals have been extensively considered as crashworthy structures because of their good plastic deformation characteristics and facility in construction [1–3].

Energy absorbents are always one of the most important parameters in designing automobiles whose lightweight, high specific energy absorption and low cost of their production is crucial. These structures are designed to absorb the collision energy in a controlled manner in accidents before transferring the passenger compartment. The role of structures designed as energy absorbent is not only to reduce the energy exerting on the passengers inside the vehicle but also save pedestrians or cyclists.

* Corresponding author. Tel.: +98 9155717510; fax: +98 23 32300258.
E-mail address: ali.dadrasi@gmail.com (A. Dadrasi).

http://dx.doi.org/10.1016/j.conbuildmat.2015.01.031
0950-0618/© 2015 Elsevier Ltd. All rights reserved.

A crashworthy structural application is studied for polymer composites in [4]. The result of this paper showed that when polymer composite materials properly designed, absorb more energy per unit mass in comparison conventional metals [4].

Unique properties of polymers such as light weight and often flexible nature make them to be very attractive by many researchers, but some of their properties such as Young's modulus, yield strength, fracture toughness and energy absorption capability need to be strengthened by the addition of certain nanoparticles.

Study of the mechanical and physical properties of polymer and metal using organic and inorganic nanomaterials is very popular [5–9]. Among composite structures reinforced by different fillers, Silica nanoparticles are more considered for good mechanical properties and high thermal stability [10–12].

Energy absorption characteristics of nanocomposites can be evaluated by compression [13], flexural [14] and Charpy or Izod impact testing [15].

Several studies on the energy absorption capability of shells with square cross-section are performed. Mean crashing load of square columns under dynamic axial loading are calculated by Abramowicz and Jones [16]. Dadrasi and shariati [3] studied the energy absorption capability of one-cell and two-cell aluminum square columns numerically and reported optimized square side and thickness. A theoretical solution for square multi-cell columns was also developed by Zhang et al. [17]. They divided the section into three basic components and estimated the energy dissipated by each part with a simplified method.

There are a few reports about nanocomposite's energy absorbent and this is mainly due to difficulty in the production of this type of crashworthy structures. For these reasons, the relation between energy absorption capability and mechanical properties of a nanocomposite is not completely clear. So, based on the literature review, this report seems to be the first one on energy absorption capability of nanocomposite square columns.

In this paper, the effect of adding silica nanoparticles with two different diameters to epoxy resin on Young's modulus, yield strength and energy absorption capability of square cross-section columns has been investigated. Two heights of 60 mm and 90 mm were tested under the quasi-static loading.

2. Materials and methods

2.1. Materials

Epoxy resin was a standard diglycidyl ether of bis-phenol A (DGEBA) with an epoxy equivalent weight (EEW) of 189 g/mol., 'ML-504', supplied by Mokarrar, Iran. The spherical silica nanoparticles with a mean diameter of 17 and 65 nm and purity of more than 99.5% were provided by US-NANO, USA. It is necessary to mention that the range of particle size with a mean diameter of 17 nm is between 15 and 20 nm and for the particle with a mean diameter of 65 nm is between 60 and 70 nm. The curing agent, cycloaliphatic polyamine, HA-12, (Mokarrar, Iran.), was used nominally.

2.2. Sample preparation

The neat epoxy has been reinforced by adding 1.5–6 wt.% of silica nanoparticles. The epoxy resin is based on bis-phenol A, namely ML-504, with a relatively low viscosity that enables researchers to use it on sensitive molding systems without any defect in the final model. Material formulations were prepared by mixing resin with a certain weight percent of nanoparticles for about two hours. For better particle distribution in the resin, equal to one weight percentage of nanoparticles, Soya Lecithin was used as disperse agent. The mixture was degassed in vacuum for 10 min by a mechanical stirrer at 300 rpm and 50 °C. In continuation, the polyamine hardener, HA-12, was added to the mixture. After 5 min mixing, the compound was poured into release-coated molds. Finally, materials were cured at 160 °C for 6 h to remove any residual stress entered during the fabrication process.

All molded samples have the same cross section of inner side of 20 mm and thickness of 3 mm. In Samples coding, "NE" denotes neat epoxy samples and composites reinforced with 17 nm and 65 nm particle size are shown by "S" and "L" letters respectively. Bimodal particle size systems are shown by both letters. The number behind these letters also shows the weight fraction of silica nanoparticles.

2.3. Tension test

Uniaxial tensile tests were conducted in accordance with the ASTM D638 standard. For this purpose, an Instron 8802 with 5 mm/min crosshead speed was used. All samples were molded in a dog-bone form of dimensions 3 × 19 × 185 mm. Tests were performed on at least four samples for each material composition under ambient temperature. The longitudinal strain was measured by a 50 mm gauge length and the Young's modulus, E, was calculated. 0.2% offset strain was used for the catching of yielding.

2.4. Energy absorption test

As shown in Fig. 1, the quasi-static loading of samples was done using the Instron 8802 machine, too. To increase accuracy, a 25 kN load-cell was used and to ensure a good distribution of the loading, specimens were laid between two steel plates. Four iterations for each sample were tested at a crosshead speed of 5 mm/min.

3. Results

3.1. Young's modulus and yield strength

The Young's modulus and yield strength of the nanocomposite materials were measured using dog-bone shaped tensile specimens. The Young's modulus of each composition was obtained from the linear portion of the stress–strain curves and also a 0.2% offset strain was used for the catching of yielding. The Young's modulus and Yield strength average, standard deviation (numbers in the brackets) and coefficient of variation are shown in Table 1. The coefficient of variation is a criterion of dispersion of experimental iterations of a test. It is defined as the ratio of the standard deviation to the average value.

The obtained modulus for neat epoxy is 1521 Mpa. By adding silica nanoparticles, the Young's modulus clearly increases in both unimodal particle size and bimodal particle size composites, which is expected because of the higher modulus of silica compared to the epoxy matrix [18]. In all three series of composites, the Young's modulus also increases by increasing the nanoparticle's weight percent but this parameter was not affected by the particle size. Similar observations of the negligible effect of particle size on the Young's modulus are reported in literature [19,20]. Using both particle sizes in a composite did not show considerable synergy effects on Young's modulus.

From Table 1 also it can be found that in both unimodal and bimodal particle size systems, the yield strength is neither changed with the addition of silica nanoparticles nor with the nanoparticles weight percent. This trend is in line with the literature [20,21]. In

Fig. 1. A composite sample with 60 mm height under loading by an Instron 8802.