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An experimental study on low-velocity impact response of nanocomposite beams reinforced with nanoclay

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ABSTRACT

The low-velocity impact (LVI) response of the unidirectional glass/epoxy laminated composites, which were reinforced with various contents of nanoclay (i.e., 0, 3, 5 and 7 wt %) was performed using a drop-weight impact machine. The nanocomposite beams were fabricated using two different methods, including hand lay-up (HLU) and vacuum assisted resin transfer molding (VARTM) methods, to evaluate the effect of the manufacturing method on the impact response. In addition, the influence of the nanoclay type on the impact response was assessed by using Cloisite 30B and Cloisite 15A. The quasi-static and LVI responses of the nanocomposite beams were compared, and the effect of nanoclay on the delaminated area after impact was also discussed. The comparative results of the experiments indicate that the samples fabricated via VARTM method, have a smaller damage area and more energy absorption than the HLU types. However, the beams with 5 wt % nanoclay have the highest energy absorption in both manufacturing methods. Moreover, the mechanism of smaller delaminated area with increasing nanoclay contents is explained according to the impermeable nature of nanoclays.

1. Introduction

Among various types of loading which the structures may encounter during their service life, impact loadings are the most probable type. Impact can result from falling down a device or the striking of moving structures with small debris.

Nowadays, polymer-based composites are among the most commonly used materials in industry. Because of high mechanical properties and significant weight reduction in structural design, these materials can achieve significant attention in industries, particularly military, aircraft and aerospace applications. Unique properties such as high strength-to-weight ratio, fatigue and wear resistance [1,2] make composite materials a good alternative for traditional metallic alloys.

However, these widely used materials are more vulnerable than metallic alloys to damages resulting from impact loading. The situation becomes more critical when the low velocity impact (LVI) is conducted. Generally, the damages caused by the LVI can rarely be detected by visual inspections but can significantly decrease the strength of the materials [3]. As a result, investigation of the LVI response of composite structures is a crucial subject in structural mechanics.

It is generally accepted that during the LVI, the damage process is initiated by matrix cracks, which induce delamination at ply interfaces [4]. In addition, in the LVI, the matrix is overstressed and local sub-critical cracking is produced [5]. These micro-cracks are the main sources of stress concentration at the inter-ply regions and will lead to crack propagation, delamination and fracture of the structure. It is shown that one of the best methods to overcome this problem is adding small amounts of nanoparticles to the pure matrix [6].

Nanocomposites, which are the new class of materials, have attracted great attention over the past decades. The extremely large surface area is the most attractive feature of nanoparticles, which strengthens the matrix and nanoparticle bonding by creating a large interface area in a nanocomposite [7,8]. Nanoparticles can improve the strength of the neat matrix. Indeed, the important reason for adding nanoparticles to polymers is to improve the properties of the neat polymers [9–11].

Based on the previous descriptions, it can be said that the matrix in a composite is the primary source of damage initiation in the LVI. Thus, using nanoparticles may improve the matrix performance during the impact test and postpone the damage initiation.

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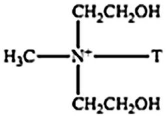
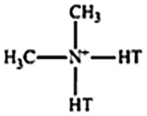
Table 1
Typical properties and structures of two types of nanoclay used in this study. (Information taken from the producer data sheets).

Trade name	Organic modifier	Modifier concentration [meq/100 g clay]	Density [g cm^{-3}]
Cloisite® 30B	 $\mathrm{H_3C{-}\overset{CH_2CH_2OH}{\underset{CH_2CH_2OH}{N^+}}{-}T}$	90	1.87
Cloisite® 15A	 $\mathrm{H_3C{-}\overset{CH_3}{\underset{HT}{N^+}}{-}HT}$	125	1.66

T: Tallow (~65% C18; ~30% C16; ~5% C14) and HT is hydrogenated Tallow.
Anion: chloride.

Numerous publications analyzed the LVI response of nanocomposite structures. However, to the best knowledge of the authors, all previous studies concentrated on the LVI response of nanocomposite plates for various types of nanoparticles. For example, for the LVI on composite plates that are filled with carbon nano tubes (CNTs), one can refer to the works of Taraghi et al.'s [12] and Soliman et al.'s [13]. Furthermore, the response of composite plates with nanoclay-filled epoxy matrix under the LVI was investigated in Refs. [6,14–18]. However, there are few studies regarding the dynamic response of nanocomposite beams [19–22]. It is important to note that all of these publications analytically investigate the vibration analysis of beams that are reinforced with carbon nano tubes (CNTs).

Hence, no experimentally published literature has addressed the response of nanocomposite beams under the LVI. The only available work on the LVI of nanocomposite beams is our previous work [2]. In that work, the LVI on nanocomposite beam was numerically performed. To analyze the LVI, Bernoulli-Euler beam theory, Hertz's contact law and Ritz's variational approximation method were simultaneously used to govern and solve the equations of motion with a numerical technique (Runge-Kutta fourth order) [2].

In this study, the LVI on glass fiber/nanoclay composite beams was performed using a drop-weight impact machine. Generally, four nanoclay contents of 0, 3, 5 and 7 wt % were used to fabricate the nanocomposites. In addition, quasi-static tests were performed to obtain a primary estimation of the energy absorption capacity of the composite/nanocomposite specimens and study the effect of nanoclay on the strain rate dependency of the beams. The effect of two common manufacturing methods (i.e., hand lay-up and vacuum assisted resin transfer molding methods) and two types of nanoclay (i.e., Cloisite 30B and Cloisite 15A) on the impact response of the nanocomposite beam were investigated. Moreover, the effect of the nanoclay content on the delaminated area after impact and the mechanism of this behavior were discussed in this study. In addition, the effect of the nanoclay content on the force-time and velocity–time histories of the samples was examined.

2. Experimental procedures

The nanocomposite fabrication involves two different steps: the nanoclay exfoliation procedure and the lamination practice [23]. These steps will be precisely described in the following subsections.

2.1. Exfoliation procedure and resin preparation

Before the fabrication of the nanocomposite laminates, nanoclay should be dispersed into the matrix. In the present study, a commercially produced epoxy resin based on Bisphenol (diglycidyl ether of bisphenol epoxy resin) and its related hardener (was purchased from Lavan Inc., Iran) were used and mixed in the ratio of 100:12 by weight. Two types of nanoclay, Cloisite 30B and Cloisite 15A, were applied separately into the neat epoxy matrix. Typical Properties of Cloisite 30B and Cloisite 15A as well as their structures are presented in Table 1.

First, to decrease the viscosity of the resin and obtain a better dispersion of nanoclays, the pure matrix was preheated. Next, the nanoclay was added to the epoxy resin and mechanically mixed with different contents of nanoclay (i.e., 0, 3, 5 or 7 wt %). Ultrasound sonication method, one of the most efficient methods to disperse nanoparticles into a polymer [24], was used to improve the nanoclay dispersion. In this study, Bandelin Sonopuls Ultrasonic Homogenizers, made in Germany, was used to obtain a better and more homogeneous mixture of epoxy and nanoclay. The translucent color of the epoxy/nanoclay mixture revealed a uniform distribution of nanoclay. The ultrasound sonication and mechanical mixing introduced air bubbles into the mixture. Because the air bubbles may weaken the high performance of the polymer/nanoclay mixture [9], the trapped air bubbles must be removed. Therefore, the solution was allowed to degas for an hour. After degassing, the mixture was cooled to room temperature, and the hardener was subsequently added to the mixture.

2.2. Lamination practice and manufacturing methods

In the previous section, the first step, preparation of epoxy matrix reinforced with nanoclay, was described. The next step, which is used for the nanocomposite fabrication, is described here.

Uni-Directional (UD) glass fiber (obtained from Mytex Turkey) with an areal density of 400 g/m^2 was used as the main

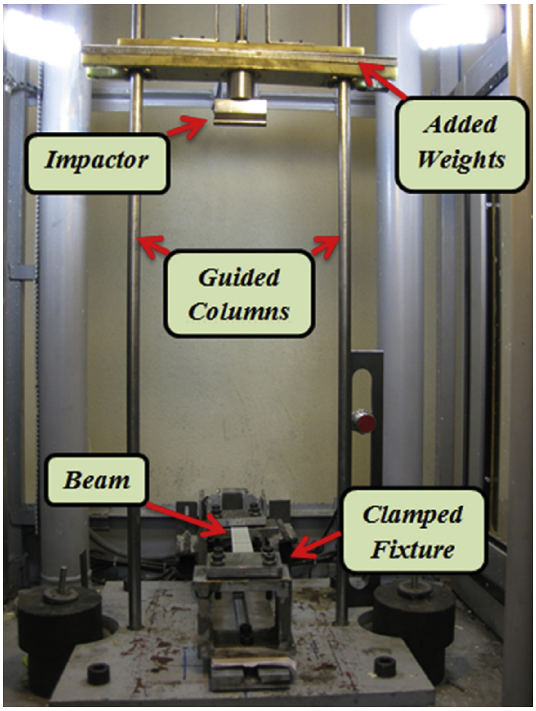


Fig. 1. Low-velocity impact test set up used in this study.