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Short Communication

Low-velocity impact response of woven Kevlar/epoxy laminated composites reinforced with multi-walled carbon nanotubes at ambient and low temperatures

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ABSTRACT

In this article, the low-velocity impact response of woven Kevlar/epoxy laminated composites enhanced with different weight percentages (⩽1%) of multi-walled carbon nanotubes (MWCNTs), was investigated under ambient (27 °C) and low temperature (−40 °C) conditions. Energy profile diagrams (EPDs) were employed to determine the penetration threshold of Kevlar/epoxy laminated composites. In addition, the effect of MWCNTs on laminate composites was evaluated by subjecting all specimens to the same level of energy, 45 J. The time history of absorbed energy, deflection and velocity are measured and some parameters such as stiffness bending, penetration limit and maximum deflection, for both composites and nanocomposites at ambient and low temperatures are reported. Results showed a remarkable dependency of damage formation on temperature and contents of MWCNTs. It was concluded that the MWCNTs was improved the impact response and was restricted the damage size in the woven Kevlar fiber composites at ambient and low temperature. The addition of 0.5% MWCNTs resulted in about 35% increase in energy absorption at ambient temperature, and the addition of 0.3% MWCNTs increased the absorbed energy capability about 34% at low temperature.

1. Introduction

Laminated polymer-based composite materials have been assigned a wide range of aspects of research in many advanced technologies, such as aerospace, military, marine and automotive industry, due to their high strength, great stiffness and low density. However, laminate composite structures have many superior advantages, the high susceptibility of damage to high-velocity or low-velocity impact is a conventional character of these materials. Hence, many investigations on the impact behavior of laminated composites at ambient or low temperature conditions have been performed [1–7]. Low-velocity impact is the source of various types of damages such as matrix cracking, delamination, fiber breakage and even perforation of fiber–matrix surface [8] in laminated polymer matrix composites. For this reason, although there exist some researches about the effect of high velocity impact on laminated composite materials, most of them focused on low-velocity impact of these materials. For instance, Aktas et al. [9] experimentally investigated the effect of different fabric layers on impact and after impact behavior of layer fabric composites subjected to low-velocity impact. They determined the perforation threshold of E-glass/epoxy composite plates containing different layer fabrics as plain weave (1D), double (2D), and triple (3D) layer fabrics. Another research was performed by Atas et al. [10] who carried out an experimental investigation on low velocity impact of composite plates prepared by vacuum assisted resin infusion molding (VARIM) and hand lay-up processes. It was found that the perforation threshold of intact samples is higher than the repaired samples.

Furthermore, there are some researches on the effect of low velocity impact at low temperature conditions such as Gómez-del Río et al. [11]. Who examined the response of carbon fiber-reinforced epoxy matrix (CFRP) laminates with different stacking sequences to impact loading in low temperature conditions [11]. Impact and post impact response of laminated composites at low temperature was obtained by Ibekwe et al. [12] who showed the significant role of temperature on the low velocity impact responses. Icten et al. [13] studied the effect of low temperature on impact response of quasi-isotropic glass/epoxy laminated plates. In addition, Salehi-Khojin et al. [14] investigated the role of temperature (from −50 °C to 120 °C) on low velocity impact properties of Kevlar/fiber glass composite laminates. Also, Sayer et al. [15] presented an experimental investigation on the impact responses of hybrid composites (carbon–glass fiber/epoxy) under

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various temperatures from −20 °C to 60 °C until complete perforation.

Few works have been performed concerning to nanoparticles effect on low-velocity impact of laminate composite materials. Avila et al. [16] considered the behavior of nanostructured laminate plates under low-velocity impact loading. It was found that the presence of intercalated nanoclays into laminates led not only to an enhancement on stiffness but also an increase on impact resistance/fracture toughness. In addition, they showed failure mechanisms, were changed from interlaminar to intralaminar [16]. Hosur et al. [17] presented a low-velocity impact response of woven carbon/epoxy–nanoclay composites. It was showed that all the nanophased composites exhibited lower level of impact damage when compared with the control samples even though there was not much change in the impact response [17]. Iqbal et al. [18] investigated the influence of nanoclay on the impact damage resistance of carbon fiber-epoxy composites using the low-velocity impact and compression after impact (CAI) tests. It was found that adding nanoclay in the matrix improved the impact damage size and shear stiffness of the matrix material, giving rise to a higher resistance to fiber buckling under a unidirectional compressive load. Reis et al. [19] performed an experimental study on the impact behavior as well as damage tolerance of Kevlar/filled epoxy matrix. Two different fillers, cork powder and nanoclays Cloisite 30B, were used in order to improve the impact response of these laminates.

In recent years, carbon nanotubes (CNTs) received much attention of scientists and industries due to their high aspect ratio and excellent mechanical, electrical, and thermal properties [20,21]. CNTs are considered to be one of the most effective reinforcing fillers in fabricating high strength, light weight polymer composites because of low density, as well as superior strength and Young's modulus [22,23]. Therefore, there are some studies on the effect of CNTs on low-velocity impact of laminated composites. Kostopoulos et al. [24] investigate the influence of multi-wall carbon nanotubes (MWCNTs) on the impact and after impact behavior of carbon fiber reinforced polymer (CFRP) quasi-isotropic laminates and reported no radical difference for the delamination area or the absorbed energy per unit delamination area. The low-velocity impact response of thin carbon woven fabric composites reinforced with different weight percentages of multi-walled carbon nanotubes was investigated. It was observed that the MWCNTs enhanced the impact response, limited the damage size and energy absorption in the woven carbon fiber composites [25].

Regarding to the previous studies on low-velocity impact of laminated nanocomposites, to the best of authors' knowledge, there is no report on the effect of nonoparticles on the impact response of these materials at low temperatures. Therefore, in the present study, the effect of different percentages of MWCNT on the impact response of woven Kevlar/epoxy composites at ambient and low temperatures is investigated. The energy profile diagram was plotted for identifying the penetration threshold of Kevlar/epoxy composites. MWCNTs were dispersed in the epoxy resin by sonication technique and the samples were fabricated by hand layup laminating procedure. Scanning electron microscopy (SEM) was utilized to characterize nanostructure and microstructure. The energy–time, velocity–time and force–deflection plots were presented for both temperatures conditions. The

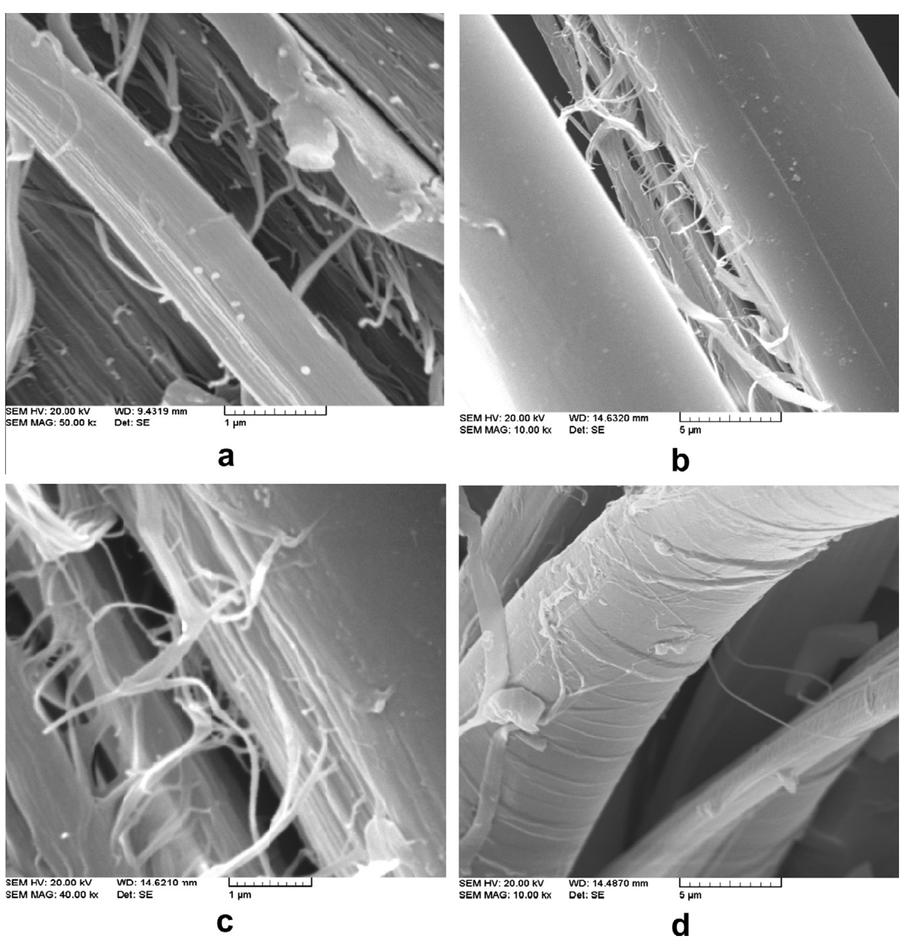

Fig. 1. SEM images of the fracture surface in MWCNTs/Kevlar/epoxy nanocomposites containing (a) 0.3 wt.% (b and c) 0.5 wt.% (d) 1.0 wt.% of MWCNTs.