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Improvement of carbon fiber surface properties using electron beam irradiation

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Abstract Carbon fiber-reinforced advance composites have been used for structural applications, mainly on account of their mechanical properties. The main factor for a good mechanical performance of carbon fiber-reinforced composite is the interfacial interaction between its components, which are carbon fiber and polymeric matrix. The aim of this study is to improve the surface properties of the carbon fiber using ionizing radiation from an electron beam to obtain better adhesion properties in the resultant composite. EB radiation was applied on the carbon fiber itself before preparing test specimens for the mechanical tests. Experimental results showed that EB irradiation improved the tensile strength of carbon fiber samples. The maximum value in tensile strength was reached using doses of about 250 kGy. After breakage, the morphology aspect of the tensile specimens prepared with irradiated and non-irradiated carbon fibers were evaluated. SEM micrographs showed modifications on the carbon fiber surface.

Keywords EB irradiation, Carbon fiber, Composites, Tensile strength, SEM

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1 Introduction

Carbon fiber-reinforced advance composites have been used for structural applications, mainly on account of their mechanical properties, and additional features, such as high strength-to-weight ratio, stiffness-to-weight ratio, corrosion resistance, and wear properties. The main factor for a good mechanical performance of a carbon fiber-reinforced composite is the interfacial interaction between its components, which are carbon fiber and polymeric matrix [1].

The greatest challenge is to improve adhesion between components having elasticity modulus which differ by orders of magnitude and furthermore they are immiscible in each other. Another important factor is the sizing material on the carbon fiber, which protects the carbon fiber filaments and must be compatible with the matrix material to improve the adhesion process [2, 3].

The interaction of ionizing radiation from an electron beam can induce in the irradiated material the formation of very active centers and free radicals. Further evolution of these active species can significantly modify structure and properties not only in the irradiated polymeric matrix, but also on the fiber surface. Hence, fiber and matrix play an important role in the production of chemical bonds, which promote better adhesion between both materials improving the composite mechanical performance [4, 5].

The aim of this study is to improve the surface properties of the carbon fiber using ionizing radiation from an electron beam to obtain better adhesion properties in the resultant composite.

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2 Experimental

2.1 Samples

Commercial carbon fiber roving of high tensile strength with 12,000 filaments, named 12 k, containing epoxy resin, modified by ester groups as sizing material, was studied. The amount of sizing material on the carbon fiber was about 1.5 wt %.

2.2 EB irradiation

EB irradiation has been carried out at the Institute for Nuclear and Energy Research (IPEN-CTR) facilities using a 1.5 MeV and 37.5 kW Dynamitron Electron Accelerator model JOB-188. Roving of carbon fiber with 1.78 $g \cdot cm^{-3}$ density and 0.13 mm thickness were irradiated with 0.555 MeV, 6.43 mA, and dose rate of 44.81 $kGy \cdot s^{-1}$ to obtain equal entrance-equal exit dose in the sample thickness. Overall doses applied were 20, 50, 80, 100, 200, 300, 400, and 500 kGy. EB radiation was applied on the carbon fiber itself before preparing test specimens. Blank samples for the mechanical test were made with a carbon fiber roving not previously irradiated.

2.3 Mechanical tests

Tensile strength measurements were carried out with resin-impregnated thermal cured specimens according to ASTM D4018 [6], to overcome the difficulties of performing mechanical tests directly with carbon filaments. For carbon fiber impregnation, the thermally cured resin formulation was composed of a commercial epoxy, a hardener, and an accelerator. Tensile measurements were performed using an Instron Universal testing machine model 4206 with extensometer in accordance to ASTM E 83 [7].

2.4 Scanning electron microscopy (SEM)

SEM micrographs of fiber surfaces from fractured samples were obtained using a scanning electron microscope model JXA-6400 (JEOL). Nonconducting coating material was used on the samples before examination.

3 Results and discussion

Experimental results have shown that EB irradiation improved the tensile strength of carbon fiber samples. The behavior of the mechanical performance as a function of the radiation dose is presented in Fig. 1. The maximum value in tensile strength (7%) was reached at about 250 kGy, when compared with the tensile strength of carbon fiber roving samples without irradiation. For samples irradiated with doses of over 250 kGy, the values of tensile strength decreased, possibly on account of degradation of the sizing material. These results indicated modifications on the carbon fiber surface characteristics and improvement in the fiber-matrix adhesion properties.

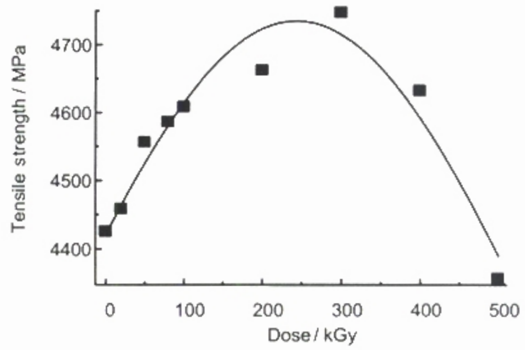

Fig.1 Tensile strength behavior of 12 k carbon fiber roving samples as a function of radiation dose applied.

After breakage, the morphology aspect of the tensile specimens prepared with irradiated and nonirradiated carbon fibers were evaluated. Test specimens from nonirradiated carbon fibers presented a highly scattered aspect with many separated filaments giving a very disorderly aspect. On the other hand, test specimens prepared from irradiated carbon fiber have shown a more organized morphology, with a high number of fragments containing some bonded filaments. This behavior can be attributed to a better adhesion between fibers and matrix [8].

SEM micrographs from samples after breakage, prepared with nonirradiated (a) and irradiated with 300 kGy (b) carbon fibers confirmed these observations (Fig. 2). Nonirradiated samples presented a separated fiber distribution, indicating a poor adhesion between them and the matrix. On the other hand, in the irradiated sample, micrograph (b), the amount of matrix material around the carbon fibers was much higher than on those prepared from nonirradiated fibers. SEM micrographs information also indicated that EB-irradiation produced modification on the carbon fiber surface, improving, in this way, the fiber-matrix adhesion.

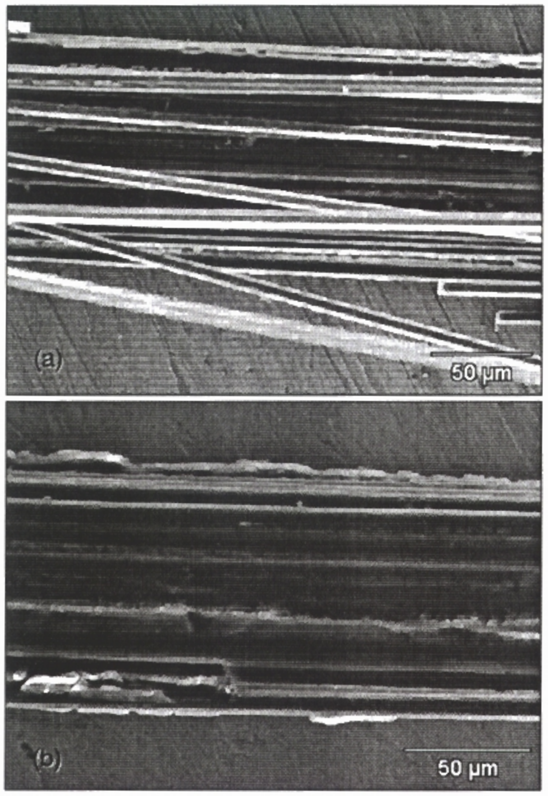

Fig.2 SEM micrographs of 12 k carbon fibers after breakage for (a) nonirradiated and (b) irradiated with 300 kGy samples.

4 Conclusions

The experimental results have shown that EB irradiation promotes modifications on the carbon fiber surface. It was indicated by the improvement of the tensile strength of samples prepared from irradiated carbon fiber roving and by the amount of matrix material around the carbon fibers present in SEM micrographs obtained from the fractured samples prepared from irradiated carbon fiber, compared to the behavior of specimens prepared from nonirradiated carbon fiber. These modifications on the carbon fiber surface improved the fiber-matrix adhesion, which was important for the composite mechanical performance.

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