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Improvement of Carbon Fiber Surface Properties using Electron Beam Irradiation

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Abstract

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

Keywords: EB irradiation; Carbon fiber; Composites; Tensile strength; SEM

1. Introduction

Carbon fiber-reinforced advance composites has been used for structural applications, mainly due to 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 carbon fiber-reinforced composite is the interfacial interaction between the components that are 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 in order to improve the adhesion process [2, 3].

The interaction of ionizing radiation from 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. So that, fiber and matrix play an important role in the production of chemical bonds, which promotes better adhesion between both materials improving the composite mechanical performance [4,5].

The aim of this work was to improve the surface properties of the carbon fiber using ionizing radiation from an electron beam in order to obtain improvement of the adhesion properties in the resulted composite.

2. Experimental

2.1 Samples

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

2.2 EB irradiation

EB irradiation have 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. Rovings of carbon fibers with 1.78 g cm^{-3} density and 0.13 mm thickness were irradiated with 0.555 MeV, 6.43 mA and dose rate of 44.81 kGy 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 mechanical test were made with carbon fiber rovings that were 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 to perform mechanical tests directly with carbon filaments. For impregnation, the resin formulation was commercial epoxy, a hardner and an accelerator for thermally cured. 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). Non conducting 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 fibers samples. The behavior of the mechanical performance as a function of radiation dose is presented in Figure 1. The maximum value in tensile strength (7%) was reached at about 250 kGy, in comparison with the tensile strength of carbon fiber roving samples without irradiation. For samples irradiated with doses over 250 kGy the values of tensile strength decreases, possibly due to degradation of the sizing material. These results indicate modifications on the carbon fiber surface characteristics and improvement in the fiber-matrix adhesion properties.

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

SEM microghaphs from samples after breakage, prepared with non-irradiated (a) and irradiated with 300 kGy (b) carbon fibers confirmed these observations (Figure 2). Non–irradiated samples present 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 is much higher than on those one prepared from non-irradiated fibers. SEM microghaps information indicates also that EB-irradiation produces modification on the carbon fiber surface improving in this way the fiber-matrix adhesion.

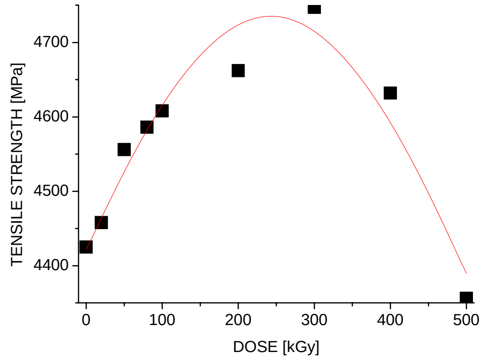

Fig. 1. Tensile strength behavior of 12k carbon fiber roving samples as a function of radiation dose applied.

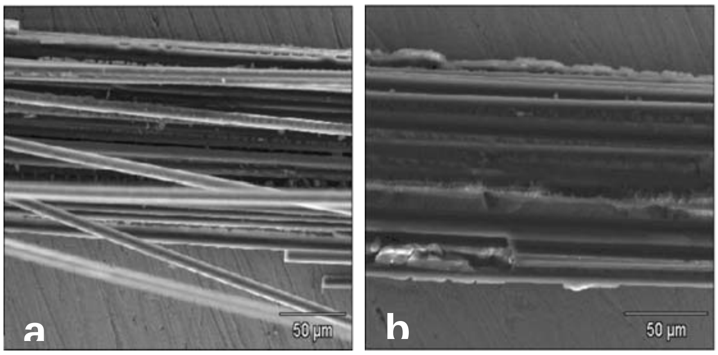

Fig. 2. SEM micrographs of 12k carbon fibers after breakage for non-irradiated (a) and irradiated with 300 kGy (b) samples.

4. Conclusion

The experimental results have shown that EB irradiation promotes modifications on the carbon fiber surfaces which were indicating by the improvement of the tensile strength of samples prepared from irradiated carbon fiber rovings, compared to tensile strength specimens prepared from non-irradiated carbon fibers. SEM micrographs information indicates also that EB irradiation produces modification on the carbon fiber surface improving in this way the fiber-matrix adhesion.

Acknowledgments

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