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Evaluation of the mechanical properties of carbon fiber after electron beam irradiation

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Abstract

Carbon fibers are used as reinforcement material in epoxy matrix in advanced composites. An important aspect of the mechanical properties of composites is associated to the adhesion between the surface of the carbon fiber and the epoxy matrix. This paper aimed to the evaluation of the effects of EB irradiation on the tensile properties of two different carbon fibers prepared as resin-impregnated specimens. The fibers were EB irradiated before the preparation of the resin-impregnated specimens for mechanical tests. Observations of the specimens after breakage have shown that EB irradiation promoted significant changes in the failure mode. Furthermore, the tensile strength data obtained for resin-impregnated specimens prepared with carbons fibers previously irradiated presented a slight tendency to be higher than those obtained from non-irradiated carbon fibers.

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

1. Introduction

Composite materials are systems composed of two or more constituents differing in form and/or material composition that are essentially immiscible in each other [1]. Polymeric composites are made of a polymeric matrix (resin) and a reinforcement material (fibers). Important factors for its performance are: orientation, length, shape and composition of the fiber, mechanical properties of each component and fiber–matrix adhesion [2]. Therefore, the behavior of a carbon fiber/epoxy

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matrix depends on the adhesion between these components, which have different chemical structure. It is also important to consider the sizing material on the fiber surface, which plays an important role in the adhesion process.

Electron beam (EB) radiation processing is being used for cross-linking of such composite matrices [3,4]. Main advantages of this process are: low temperatures, fast reaction time, low emission of volatile materials and a product with improved mechanical properties. The action of EB radiation on polymeric materials promotes mainly two processes: (a) cross-linking, that is the formation of chemical links between molecular chains, and (b) degradation or scission of polymer chains, which destroys its molecular structure. These chemical transformations result in changes in the physical and mechanical properties of the polymers. Although these effects occur simultaneously, one plays a dominating role depending on the chemical structure of the polymer, radiation dose and overall experimental conditions. Cross-linking improves mechanical properties whereas scission leads to a deterioration of the irradiated material. In addition, EB radiation also promotes excitation reactions on the fiber/matrix interface resulting in improved adhesion property [5].

The aim of this paper was to evaluate the effects of electron beam radiation on the tensile properties of two different carbon fibers used for structural applications containing different sizing material and number of filaments per roving. For this propose, the experiments were carried out using resin-impregnated specimens prepared using carbon fibers previously irradiated.

2. Experimental

2.1. Samples

Two different commercial carbon fibers roving of high tensile strength were studied. One carbon fiber roving contained 6000 filaments (6k) and the other 12000 (12k), each one had a different sizing material. The content of sizing material on both carbon fibers was of about 1.5 wt%.

2.2. Fourier transform infrared analysis (FTIR)

Identification of the sizing materials was carried out by FTIR analysis. Sizing was removed from the carbon fiber surface by dissolution in acetone at room temperature. For this procedure, it was used three meters of fiber and about 50 mL of acetone. Fibers and solvent were left in contact for about five hours and after this period, the acetone was evaporated from the solution at room temperature and the residue obtained was analyzed in an FTIR equipment model Nexus (Nicolet) from 4000 to 400 cm^{-1}.

2.3. EB irradiations

EB irradiations were carried out at the IPEN-CTR facilities using a 1.5 MeV and 37.5 kW Dynamitron Electron Accelerator model JOB-188. Irradiation conditions were: energy 0.555 MeV, electron-current 6.43 mA and dose rate 44.81 kGy s^{-1} to reach overall doses of 50, 100, 200 and 300 kGy.

2.4. Mechanical tests

Tensile properties of the fibers were determined as resin-impregnated specimens thermal cured according to ASTM D4018 [6]. The specimens for testing were prepared after EB irradiation of the carbon fibers. The resin formulation for the impregnation was a conventional epoxy for thermal cure at a maximum temperature of 130 °C for 8 h. Tensile measurements were carried out in an Instron Universal testing machine model 4206 with an extensometer in accordance to ASTM E 83 [7]. Experimental data obtained for each type of fiber were load and elongation at breakage. Volumetric fiber densities of 6k and 12k roving had been previously determined by a liquid displacement technique [8] and, from these values, it was calculated the fibers linear densities. From the load and elongation results and linear and volumetric density values, tensile strength (TS) and Young's modulus (E) were calculated for the test specimens. A set of resin-impregnated specimens of each carbon fiber roving as received (without having been EB irradiated) was prepared and used as blank.