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High-energy radiation technique treat on the surface of carbon fiber☆

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Abstract

Co^{60} γ-ray irradiation as a novel method for modification of carbon fiber (CF) surface was introduced in this paper. After surface treatment by mutual irradiation the interlaminar shear strength (ILSS) of CF/epoxy composites was enhanced by about 37%. Surface elements of CF were determined by XPS analysis, which indicated that the oxygen/carbon ratio increased rapidly. Fitting the C 1s spectra demonstrated that two new photopeaks were emerged which was indicated −C=O and plasmon, respectively. Surface topography of carbon fibers was analyzed by atomic force microscopy (AFM). It could be found that the degree of surface roughness was increased by lower absorbed dose (30 kGy), but excessive irradiation (>250 kGy) was not beneficial for mechanical interlocking between CF and epoxy resin. The impregnating performance of CF was also improved after irradiation.

Keywords: Carbon fiber; Surface treatment; Irradiation; XPS; AFM

1. Introduction

Carbon fibers are widely being used as reinforcing materials in both thermoset and thermoplastic matrix composites for their favorable strength and stiffness characteristics [1,2].

The mechanical properties of carbon fiber reinforced plastics (CFRP) are dependent on the properties of the CF and the matrix, especially on the effectiveness of the interfacial adhesion between the CF and the matrix [3–6]. A strong interface increases the structural integrity of the composites and transfers the stress efficiently from fibers through the matrix. For its surface inert characteristic, lots of surface treatments of carbon fibers have been used in order to improve the interfacial performance between fibers and matrix, such as thermally treatment [7], wet chemical or electrochemical oxidation [3,8–13], plasma treatment [4,6,14], gas-phase oxidation [15,16], ion or cluster bombardment, covalent linkage of bimolecular [17] and so on. The ultimate purpose of these treatments has been to increase the surface energy, induce chemical active functional groups, and corrode or change the microstructure of the carbon fiber.

In recent years, radiation treatment is being extensively investigated as a means of altering surface properties of polymeric materials, such as films, fibers, powders and molded objects [18]. An irradiation can induce chemical reactions at any temperature in the solid, liquid and gas phase without any catalyst; it is a safe method that could protect the environment against pollution; carbon fibers could be treated after departure from the production line; radiation process could reduce curing time and energy saving; it could treat a large and thick three-dimensional fabrics that need not consider of the shape of the samples [19–21]. For these unique advantages, the research of using radiation processing treat on CF surface was studied in this paper.

At present, the two main radiation types in industrial use are gamma and e-beam. Gamma rays are very penetrating because of energetic photons (1.17 and 1.33 MeV). Cobalt-60 was selected as the radiation facility in this work. The fiber surface composition and surface functional groups were examined by X-ray photoelectron spectroscopy (XPS). Deconvoluted peaks of the C 1s spectrum were also used to determine the surface oxygen functional groups content of the carbon fiber. The surface morphology of the fibers was observed and the surface roughness was calculated by atomic force microscopy (AFM). Different dose and dose rate influence on the interlaminar shear strengths (ILSS) of the carbon

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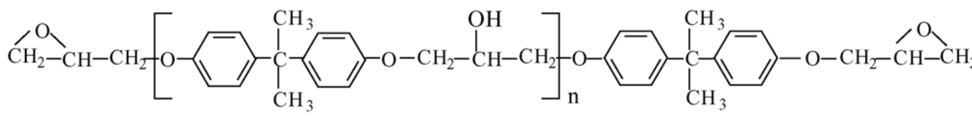

Fig. 1. Epoxy resin (E-618) structural formula.

fiber/epoxy composites were also analyzed by three-points short beam shear. The CF wetting abilities in water were also studied.

2. Experimental

2.1. Materials

The polyacrylonitrile (PAN) based carbon fibers investigated in current studies were manufactured by Jilin Carbon Factory of China (average diameter was 7 μm, 3×10^3 single filaments per tow, linear mass was 0.161 gm^{-1}). The matrix was an epoxy resin from Wuxi, China (E-618). Its structural formula is shown in Fig. 1.

2.2. Equipments

Harbin Rui Pu Irradiation New Technology Company of China provided the irradiation field. For commercial purpose, the Co^{60} γ-ray source has a high intensity that is 1.5×10^4Ci at this period of time. ESCA (Lab220i-XL) which made in V.G. Scientific Company, U.K., the XPS was equipped with a Al Kα (1.25 keV) radiation source generated at 12 kV and 20 mA, the pressure below the atmospheric range is 10–7 Pa. Atomic force microscope (Nanoscope-III) was made in America, Digital Instrument Company. The ILSS of CF/epoxy composite specimens was determined by a universal-testing machine (made in Changchun, China)

2.3. Methods

Several bundles of carbon fiber were wound up on a frame and placed in a glass container, which was full of chloroepoxy propane. It was then sealed tight. The arrangement is schematically illustrated in Fig. 2. The samples were deposited into the Co point-source radiator and irradiated by different absorption doses and dose rates, as shown schematically in Fig. 3.

After irradiation treatment, unidirectional composite specimens were fabricated by combining carbon fibers with E-618 through a compression molding processing method and compared with an untreated specimen. The resin/hardener mixture was thoroughly stirred for 15 min and deposited in a vacuum oven with the temperature at 50 °C for half an hour in order to degas. The termination products were cut into 22 mm length, 6.5 mm width and 2.0 mm thickness, respectively. The

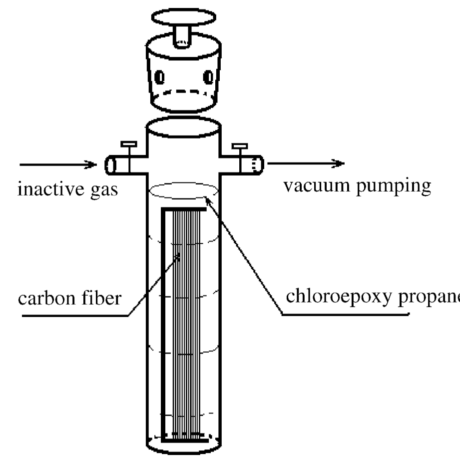

Fig. 2. Schematic of the irradiate instrument.

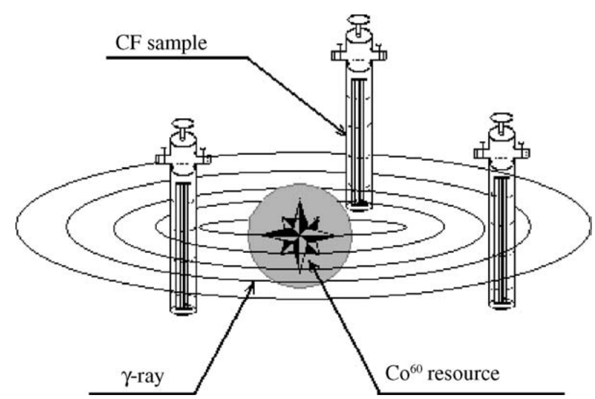

Fig. 3. The schematic plan of CF irradiate process by a point-source Co^{60} radiator.

ILSS of CFRP was determined according to ASTM D2344, with a crosshead speed 1.5 mm per minute and the span to thickness ratio greater than 5:1. The testing device of ILSS was shown in Fig. 4. The values of ILSS were calculated by Eq. (1)

$$\mathrm{ILSS} = \frac{3P_b}{4bh} \quad (1)$$

In this Eq., P_b is the load at the moment of break; b and h denote the width and thickness of the specimen, respectively.

Before XPS and AFM testing, treated and untreated carbon fibers were both extracted with acetone for 48 h in order to wash out impurities on their surface. Each sample was cut into a 1 cm length and carefully mounted on the spectrometer probe tip by means of double-sided adhesive tape.