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Effect of water absorption on the dynamic mechanical properties of composites used for windmill blades

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ABSTRACT

Glass fiber/unsaturated polyester composites (with and without nanofiller) were produced by using the VARI (vacuum assisted resin infusion) technique. These materials will be used in windmill blades and, therefore, they are expected to be exposure to high humidity environments. The fabricated specimens were immersed in water at 80 °C for different periods of time. DMA (dynamic mechanical analysis) technique was employed to investigate the matrix degradation and interfacial debonding of the aged specimens. The gradually decreased T_g (glass transition temperature), E' (storage modulus), and the increased $\tan\delta$ (energy dissipation) with extended exposure time indicated that both the matrix and the interface had been deteriorated by the water. While matrix degradation occurs in a short period of time, composites degradation takes place gradually, showing that the degradation of the interphase in composites is the limiting step for the whole degradation process. Nanoclays were incorporated to the UP (unsaturated polyester) matrix showing a detrimental effect in degradation resistance, probably because of the degree of hydrophilicity of the selected clay, which produces a weak interphase with the polymeric matrix.

1. Introduction

During the last decades, fiber-reinforced plastics have been an alternative to other materials such as metal and steel in several applications, because this kind of materials exhibits high specific tensile and compressive strength, good fatigue and corrosion resistance being appropriateness for the manufacture of complex-shape components in shorter times. Besides them, glass fibers ones (GRP) display a really high cost effectiveness [1–3]. But wide-scale usage of GRP is seriously hindered by the lack of experimental data and understanding of durability aspect in the different environments [4–8]. To assume long-term durability, a fundamental understanding of the degradation processes is essential in terms of strength evolution. Wind energy is one of the fields in which long-term durability is required and exposure to aggressive environments is common. Offshore mills are exposed to high humidity that could affect the integrity of the composites blades (Fig. 1), reducing the lifetime of the components. Moreover, the inspection and reparation operations are more difficult in those conditions, which impose the need of using materials that could withstand the hygrothermal degradation. It has been reported that water absorption can affect the mechanical performance of turbine blades, especially fatigue, which is the most common failure mode in these components [9,10]. Shan and Liao [11] studied the effect of water absorption in glass and carbon reinforced composite for wind blades, and found that the fatigue life is reduced when measuring immersed samples, especially when loading at lower percentages of the ultimate tensile stress.

The sensitivity of the fatigue life to hygrothermal aging has also been stated elsewhere [12,13]. In general, water can penetrate into the composites by three main mechanisms: diffusion of the water through the matrix, capillary flow and diffusion along the fiber/matrix interface and percolating flow and storage of water in micro-cracks [14]. In the case of glass/polyester composites, they have shown to be affected by water uptake, with reduction in strength mainly due to fiber/matrix deterioration [15–19]. Mandell et al. [15] studied the effect of water immersion on the mechanical properties of iso and orthophthalic polyester composites. They determined that composites made with orthophthalic polyester are much more sensitive to water absorption than isophthalic polyester composites. By means of SEM (scanning electronic microscopy), Fraga et al. [16] observed that the immersion of isophthalic polyester/glass composites in water at 80 °C produced a degradation of the fiber/matrix interphase due to oligomer extraction and hydrolysis of silane coupling agent of the fibers. In the same kind of composites, Mouzakis et al. [17] observed the presence of micro cracks in the surface of samples exposed to hygrothermal degradation. Also, the damage produced by water

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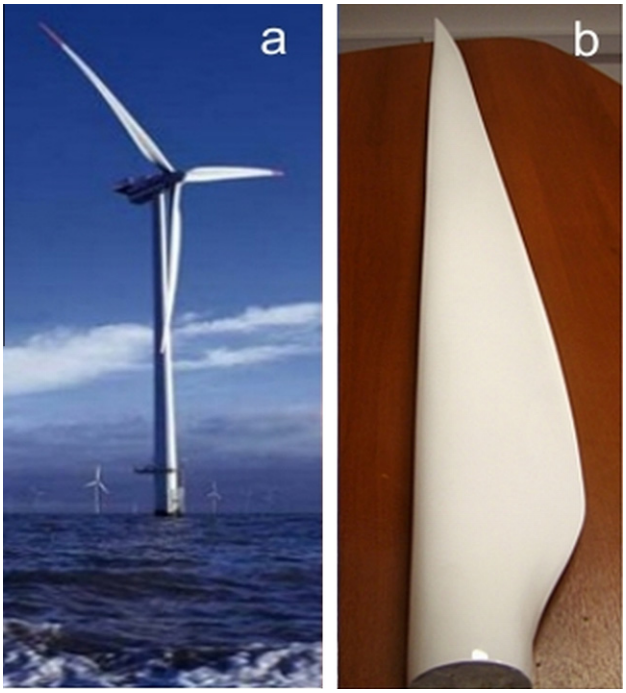

Fig. 1. (a) Typical windmill blade application exposed to high humidity environment and (b) small scale prototype made in our lab with the materials studied in this work.

can be severely increased in the presence of a cyclic sorption and desorption process [20], as is in the case of windmill blades. Besides, the amount of water uptake and its effect in the mechanical properties of the composites can be affected by the type of environment. Akil et al. [21] studied the aging degree of UP/glass composites immersed in distilled water, seawater and acidic solution. The higher impact of hygrothermal effects on mechanical properties was found for the distilled water immersed composites.

Regarding the incorporation of nanoclays to UP composites, Abu-Jdayil et al. [22] showed that humidity and water absorption can be reduced by the incorporation of bentonite. But long term hygrothermal aging information in UP/glass composites is still scanty in the literature. Although previous studies of the effect of water on the mechanical properties of UP/glass fibers composites were carried out, none of them have reported the effects of clay incorporation and hygrothermal aging on the dynamic mechanical properties of these materials, using models to predict the variation of the mechanical properties as a function of temperature, which is essential due to severe conditions in which these materials could be used.

The main objective of the present work was to establish the effect of absorbed water in dynamical–mechanical behavior of UP/glass fibers composites used for windmill blades. Glass fiber reinforced laminates were fabricated by using the vacuum infusion technique. After immersion in distilled water, the weight change and the dynamical–mechanical of the samples were measured and analyzed. SEM images of the broken section of the original and exposure samples was taken and evaluated. Models were use to predict the behavior of storage and loss modulus as a function of temperature. Finally, the effect of clay incorporation to the UP resin on the aging behavior is studied.

2. Experimental procedure

2.1. Materials

UP resin was used as a matrix. It was purchased from Carmas Composites (Buenos Aires, Argentina). Its properties were given in the technical sheet (density: 1.8–2.2 g/cm^3; viscosity: 300–400 CPs and 32–42% of styrene). The total reaction heat was determined from a test in a scanning electron calorimetry (DSC-50 Shimadzu) and it was190 J/g.

A chopped strand mat of glass fibers (M123, from Saint Gobain) was used as reinforcement. The measured surface density was 484 ± 34 g/m^2. In this kind of mats, the fibers are treated to enhance their compatibility with the polyester resins.

The clay used in this work is bentonite and it was supplied by Minarmco S.A. (Neuquén, Argentine). The bentonite was used as received.

2.2. Samples preparation

Plaques of 15 cm × 15 cm × 3 mm (length, width, thickness) of UP matrix were prepared by casting using 1.2% of MEKP (Methyl ethyl kentone peroxide), 0.4% of NapCo (cobalt naphtanate) and 0.1% DMA (dimethyl aniline). The curing was carried out in an oven at 70 °C for 90 min and a post-curing at 120 °C for another 90 min.

Composites with six piles of glass fiber mat were prepared by vacuum infusion using the same matrix/catalyst/accelerator relation as for matrix. Plaques of 30 cm × 30 cm × 3 mm were obtained. Incineration of plaques showed that the fibers content was 70 wt.%. They were left 24 h at room temperature for curing process. Post-curing was carried out in an oven at 120 °C for 90 min.

Complete curing of both, matrix and composites, was confirmed by DSC (DSC-50 Shimadzu), running from room temperature to 250 °C at 10 °C/min in nitrogen atmosphere.

Both unfilled and bentonite filled (5 wt.%) resin were used. The later was obtained by stirring the mixture in an ultrasonic bath at room temperature for the time needed to obtain a homogeneous dispersion. The nomenclature used in this work is summarized on Table 1.

2.3. Methods

2.3.1. Water absorption

Samples of matrix and composites were immersed in distilled water at 80 °C. They were removed from the bath at several times and it was carefully dried with a tissue paper. After equilibrium water content was reached, the samples were dried until constant weight in order to determine the dynamical–mechanical properties. The properties of the initial samples (before immersion) were also determined.

2.3.2. Dynamic mechanical analysis (DMA)

Rectangular specimens having a size of 65 × 12 × 3 mm^3 were used for the dynamic mechanical experiments. The dynamic storage modulus (E'), loss modulus (E'') and loss factor ($\tan\delta$) of the specimens were measured as a function of temperature (0–200 °C) at a frequency of 1 Hz using a Dynamic Mechanical Thermal Analyzer (Mettler Toledo DMA 86E) at maximum amplitude of 5 N and at heating rate of 5 °C/min. Three samples have been tested for each scan and the error was less than 2%.

2.3.3. Scanning electron microscopy (SEM)

The dispersion of fibers on a microscopic scale was examined using SEM (Hitachi model S3400N). Specimens were cooled in liquid air and then broken.

2.3.4. Transmission electron microscope (TEM)

A JEOL CX II equipment with an acceleration voltage of 80 kV was used to observe the dispersion of clay platelets within the polymer chains.