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Mechanical and thermal properties of carbon fiber/polypropylene composite filled with nano-clay

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ABSTRACT

The effect of organoclay on the mechanical and thermal properties of woven carbon fiber (CF)/compatibilized polypropylene (PPc) composites is investigated. Polypropylene–organoclay hybrids nanocomposites were prepared using a maleic anhydride-modified PP oligomer (PP-g-MA) as a compatibilizer. Different weight percentages of Nanomer® I-30E nanoclay were dispersed in PP/PP-g-MA (PPc) using a melt mixing method. The PPc/organoclay nanocomposite was then used to manufacture plain woven CF/PPc nanocomposites using molding compression process. CF/PPc/organoclay composites were characterized by different techniques, namely; dynamic mechanical analysis (DMA), fracture toughness and scanning electron microscope. The results revealed that at filler content 3% of organoclay, initiation and propagation interlaminar fracture toughness in mode I were improved significantly by 64% and 67% respectively, which could be explained by SEM at given weight as well; SEM images showed that in front of the tip, fibers pull out during initiation delamination accounting for fracture toughness improvement. Dynamic mechanical analysis showed enhancement in thermomechanical properties. With addition 3 wt.% of organoclay, the glass transition temperature increased by about 6 °C compared to neat CF/PPc composite indicating better heat resistance with addition of organoclay.

1. Introduction

There are increasing interests in using thermoplastics to replace thermosets for laminate fabrication due to their advantages such as high toughness, shorter manufacturing cycles, no refrigeration storage required and reprocessing possibilities [1]. Carbon fiber or glass fiber reinforced thermoplastic laminates in matrices such as polyetherimide (PEI), polyetheretherketone (PEEK) and polyphenylene sulfide (PPS) have already been used extensively in the aerospace sector due to their excellent mechanical properties, heat stability and low flammability [2,3]. These matrices are, however, expensive and difficult to process due to the high processing temperature and pressure.

Among the available thermoplastic polymers, polypropylene (PP) is considered a good candidate as thermoplastic composite matrix. Polypropylene is a semi-crystalline engineering thermoplastic and is known for its balance of strength, modulus and chemical resistance [4]. Polypropylene has many potential applications in automobiles, appliances and other commercial products in which creep resistance, stiffness and some toughness are demanded in addition to weight and cost savings. However, the CFRP fabrication from neat PP resin cannot meet the industrial requirements due to its low mechanical properties especially toughness and low thermal resistance. To improve the strength and thermal properties of CF composites, various types of nano-filler (such as clay, silica, graphene, and CNT) have been incorporated into the thermosets and thermoplastics matrices. The incorporation of inorganic particulate as well as fiber fillers has been proved to be an effective way to improving the physical and thermal properties [5–18].

Nanoclay, an inexpensive natural mineral, has been reported by many studies as one of the potential candidates for nanocomposite and CFRP preparations because of its large value of aspect ratio, diameter in nanometer range and thermal resistivity [19,20]. In most cases, in order to provide a better physical and chemical environment for the polymer, clay is organically modified through an ion exchange reaction between organic cations and inorganic cations,

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to change the clay from hydrophilic to organophilic and to increase interlayer spacing of clay [21].

Polypropylene–clay based nanocomposites are of tremendous research interest due to the improved properties with low clay content as well as the clay serving as a valuable cost effective additive. In general, 0–5 wt.% of organically treated clay is added in PP polymer matrix. The addition of the nanoclay in the PP matrix increases the thermal stability in air medium, increases physical properties (dimensional stability), improves flame retardant properties (increased thermal-oxidative stability and reduced Heat Release Rate), improves mechanical properties, fracture properties and gas barrier properties. Several studies were conducted with various types of organoclays, clay concentrations and compatibilizers [22–24,10].

To the best of our knowledge, the effect of organoclay on the mechanical properties of CF/PPc composites has not been studied yet. In the present study, thermal and mechanical behavior of CF/PPc composites filled with organoclay were investigated. Polypropylene–organoclay hybrids nanocomposites were prepared using a maleic anhydride-modified PP oligomer (PP-g-MA) as a compatibilizer. Different weight percentages of Nanomer® I-30E nanoclay, a surface modified montmorillonite mineral, were dispersed in PP/PP-g-MA (PPc) using melt mixing method. The PPc/clay nanocomposites were then used to manufacture plain weave carbon/PP nanocomposites using molding compression process. CF/PPc/organoclay composites were characterized by different techniques, namely; bending, dynamic mechanical analysis (DMA), fracture toughness, and scanning electron microscope. Also, PPc/organoclay nanocomposites were characterized by X-ray diffraction (XRD), Differential Scanning Calorimeter (DSC), and tensile tests.

2. Experimental

2.1. Materials

Polypropylene (Novatec SA08 containing 1% MA-g-PP with MFR 75 g/10 min) was purchased from Polypropylene Japan Co., Montmorillonite clay (Nanomer® I.30E, a surface modified montmorillonite mineral) containing 25–30 wt.% octadecylamine with bulk density 200–500 kg/m^3 was purchased from sigma Aldrich Japan.

2.2. Preparation of PPc/organoclay nanocomposite and CFRP laminates

PPc and organoclay were dry blended prior to melt-blending on a twin-screw extruder until the mixture was evenly mixed. The mixture was then taken out and molded into sheets of 0.1 mm thickness by a hot press at 180°C and 3 MPa for 5 min using a hydraulic hot press machine, then, cooled to room temperature at the same pressure. The sheets were prepared for structure and mechanical characterization. The PPc/organoclay nanocomposites were then used to manufacture plain weave carbon/PP nanocomposites using molding compression process.

Carbon fiber laminates were manufactured by stacking the pre-impregnated carbon fabric with the fabricated PPc/organoclay attending the reinforcement/matrix volume fraction of 52/48 ± 2 (v/v).

2.3. Hot compression molding

The composite laminate consolidation process using the compression molding was carried out in a steel mold with dimensions of 200 × 220 mm. Firstly, the composite laminate was heated up to 200 °C at 10 °C/min, holding at this temperature for 10 min. Afterwards, the composite laminate was cooled down to the desired compressing temperature of 160 °C at 10 °C/min and consolidated under 15 MPa of pressure. The mold was cooled to room temperature by cooling system. Fig. 1 shows the heating cycle process.

2.4. Characterization

2.4.1. X-ray diffraction (XRD)

The structure of the nanocomposites was studied by using XRD. A Philips PW1050 diffractometer was used to obtain the X-ray diffraction patterns using Cu Kα lines ($\lambda = 1.5406$ Å). The diffractrograms were scanned from 2.1° to 35° (2θ) using a scanning rate of 2°/min. X-ray diffractrograms were taken on organoclay particles and on PPc/organoclay nanocomposites.

2.4.2. Differentials scanning calorimeter (DSC)

A DSC-2910 apparatus made by TA Instrument Inc. (USA) was used for investigating crystallization process of PPc and PPc/organoclay nanocomposites. All measurements were carried out in room temperature. Ten milligrams of the polymer sample was weighed very accurately in the aluminum DSC pan and placed in the DSC cell. The sample was heated from room temperature to 200 °C. The sample was cooled to 30 °C at a constant rate of 10 °C/min, and the heat flow curve was recorded as a function of temperature.

2.4.3. Tensile tests of PPc/organoclay nanocomposites

The tensile tests for PPc/organoclay nanocomposites were carried out using Universal Testing Machine (Shimadzu, AG-X) at a crosshead speed of 1 mm/min with gauge length 50 mm at room temperature according to ASTM D-638. Five samples of each category were tested and their average values were reported.

2.4.4. Dynamic mechanical analysis of CF/PPc/organoclay nanocomposites

RSAIII instrument was used to perform the DMA studies in order to evaluate the storage modulus and tan δ. The CFRP laminates samples with dimensions 50 mm long × 6.5 mm wide × 2 mm thick were tested in three-point bending at varying temperatures between −45 °C and 200 °C at a heating rate of 3 °C/min and a frequency of 1.0 Hz. The glass transition temperatures, T_g, of nanocomposites were also determined from the maxima of the tan δ curves.

2.4.5. Fracture toughness test of CF/PPc/organoclay nanocomposites

The double cantilever beam (DCB) mode I fracture specimen (ASTM D 5528-01) was employed to characterize the delamination resistance of CFRP laminates. The corrections for the end-block,

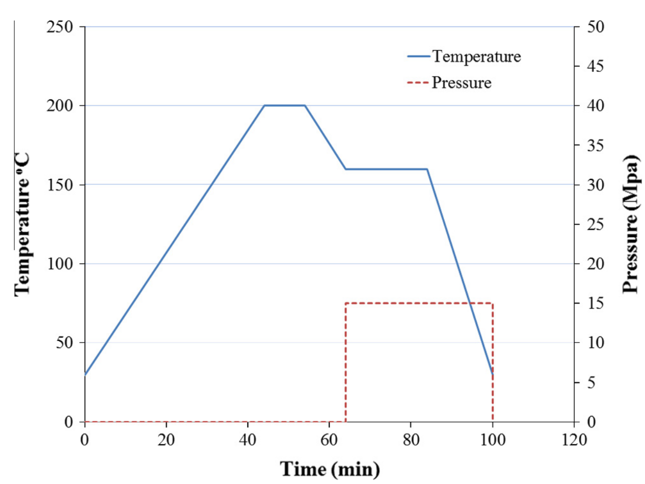

Fig. 1. Heating cycle used in the hot molding compression for PP/CF/organoclay composites.