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Material properties

Mechanical properties of preferentially aligned short pineapple leaf fiber reinforced thermoplastic elastomer: Effects of fiber content and matrix orientation

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ABSTRACT

Composites of preferentially aligned pineapple leaf fiber (PALF) and Santoprene, a thermoplastic elastomer, were studied. PALF filled Santoprene composites were first prepared by melt mixing on a two-roll mill with different PALF contents. Then, the molten mixture was sheeted out using a narrow nip with some stretching to give prepregs with PALF preferentially aligned along the machine direction. These prepregs were then stacked and compression molded at 175 °C and 195 °C to form composite sheets. Wide angle x-ray scattering patterns revealed that the prepregs had matrix orientation which still remained after molding at 175 °C but not at 195 °C. Tensile and tear properties in directions parallel and perpendicular to the fiber axis were measured. Modulus at 10% strain and tear strength in the longitudinal direction increased significantly with increasing PALF content (up to 15%), while tensile strength and elongation at break decreased. The effect of PALF content was less significant in the transverse direction. In addition, compression molding temperature also affected all these properties but to different extents. The two most affected properties were modulus and tear strength in the longitudinal direction. Composites prepared at 175 °C displayed significantly higher modulus and tear strength than that prepared at 195 °C with the same PALF content. This was attributed to the remnant matrix orientation.

1. Introduction

Fiber-reinforced rubbers have been used in many applications such as automotive parts, tyres, hoses, etc. In these systems, continuous cord or fabric of different textile fibers, both natural and synthetic, is used as reinforcement. This usually requires special machinery and additional steps in the product fabrication. To avoid such problems, short fiber reinforcements are employed. The use of short fibers in rubber provides several advantages including design flexibility, high low-strain modulus, anisotropy in technical properties and stiffness, ease of processing and production economy. Many types of fibers including cotton linters, cellulose, polyester, nylon and aramid are used [1–4]. In addition, natural fibers such as jute, sisal, flax, coir, oil palm, silk and pineapple leaf fiber (PALF) have also been studied for rubber reinforcement [5–9].

Thermoplastic elastomers (TPE) are elastomers that can be processed like a thermoplastic. They do not require a complex system of chemicals for crosslinking as do normal rubbers and can be recycled. Properties of thermoplastic elastomer can also be improved by the addition of different

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fibers. A review on short fiber- reinforced TPEs, with the main focus on thermoplastic polyurethane elastomer, can be found in [10]. There are many types of TPE. One type, which will be used in the present study, is based on thermoplastic-rubber blends such as Santoprene.

Recent environmental awareness and concerns have brought greater interest than ever in using bio-derived products into research communities. This has attracted the community to revise the use of bio-derived materials for rubber reinforcement. One of most widely studied materials is cellulose from natural fibers [11] and its derivatives such as cellulose nanowhiskers and cellulose nanofibers [12–14]. However, natural fibers have broad size distribution of relatively large diameter, for example, up to 200 μm for jute and 450–500 μm for coir and oil palm. This is much larger than the size of failure initiation sites in rubbers [15–16] and this limits the achievable reinforcement, thus making them less attractive. A simple and novel method to extract fiber from pineapple leaves has recently been presented [17]. PALF obtained by this method has a greater fraction of fine fibers as compared to that prepared by conventional methods. Although the current trend has focused on nanocrystalline cellulose or cellulose nanowhiskers and cellulose nanofibers [12–14] as reinforcement, the process presented here is much simpler and does not require any chemicals [17]. It has been shown to be quite effective in reinforcing acrylonitrile butadiene rubber (NBR) [18], and has also been shown to work well with PP without the need of surface modification [17]. Therefore, it would be interesting to see if PALF reinforced Santoprene (San-PALF) composites with improved properties could be produced since Santoprene has polypropylene (PP) as the minor and continuous phase. Although different natural plant fibers have been studied for the reinforcement of blends of polypropylene (PP)/ethylene–propylene–diene monomer (EPDM), see [19–20] for example, these blends have a relatively high proportion of PP and are hard plastic not rubber. In the present work, the effect of fiber content and compression molding temperature on tensile and tear properties of the composites in two directions (longitudinal and transverse) were investigated. Particular attention is paid to the anisotropic mechanical behavior in the low strain region.

2. Experimental

2.1. Materials

The matrix was Santoprene thermoplastic elastomer grade 691-73W175 from Advance Elastomer Systems (Newport, USA). The elastomer contains 18 wt.% PP and 82 wt.% EPDM (ethylene propylene diene monomer). Pineapple (*Ananas comosus*) leaves were collected from cultivation areas in Kok Kwai District, Amphor Ban Rai, Uthai Thani Province, Thailand. Pineapple leaves were removed from the stem and washed. Whole leaf was used for PALF separation. PALF was separated from pineapple leaves by the milling technique developed in this laboratory [17]. In essence, leaves were cut perpendicular to their long axis into 6 mm pieces, ground with a disc mill into paste, washed, dried and sieved to separate the PALF. The method yields PALF of 6 mm long with a range of diameters from 3 up to 80 μm. About 65% of PALF have diameter in the range of 3–20 μm [17].

2.2. Composite preparation

2.2.1. Mixing

PALF filled Santoprene composites with different PALF contents were prepared by melt blending on a two-roll mill (Collin W100T) at 180 °C. Santoprene was first melted on the mill and a uniform band was formed. PALF was gradually added and mixing continued until a uniform mixture was obtained. Total mixing time was approximately 20 min.

2.2.2. Prepreg preparation

When a uniform mixture was obtained, the mixture (in cylindrical shape with diameter of approximately 25 mm and length of 150 mm) was sheeted out using 0.5 mm nip gap and a drawing speed of about 1 m/min. The drawing speed was slightly greater than the speed of the roller to keep the fibers preferentially aligned in the longitudinal direction to form the prepreg. With 58 g mix for each batch, prepreg sheet with a thickness of approximately 380 μm and a length of 115 cm was obtained.

2.2.3. Compression molding

Compression molded sheets were prepared by stacking three layers of prepreg in a mold to form a sheet of 1 mm thickness at temperatures of 175 °C and 195 °C. Composites are designated as SanXPALF, where X is the content in weight percentage of PALF.

2.3. Composite characterization

2.3.1. PALF orientation

A piece of prepreg was extracted with toluene in a Soxhlet apparatus over night to remove the matrix. The specimens were observed under an optical microscope.

2.3.2. Crystalline structure and orientation

SAXS and WAXS were performed at Beamline BL 2.2 at the Synchrotron Light Research Institute (Public Organization) (SLRI), Thailand. X-ray energy was 8 keV. The patterns were recorded with a Mar detector and data analysed according to standard procedure with a self-developed program, *Saxsit* [21].

2.3.3. Morphology

The shape and size of PALF and fractured surfaces of the composites were observed with a scanning electron microscope (SEM) (Hitachi Tabletop Microscope; model TM 1000, Japan).

2.3.4. Modulus and Strengths

Samples of appropriate shape were punched out from molded sheets with the sample's long axis either parallel or perpendicular to the fiber orientation axis (termed longitudinal and transverse direction, respectively). For tensile tests, the sample was dumb-bell-shaped according to ISO 37, Type 2, and for tear tests the crescent test piece of ISO 34. Both tests were carried out on a universal testing