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SCIENCE DIRECT®
Composites Science and Technology 65 (2005) 525–535
COMPOSITES SCIENCE AND TECHNOLOGY
www.elsevier.com/locate/compscitech

Modified polyester resins for natural fibre composites

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Received 7 October 2003; received in revised form 21 July 2004; accepted 4 August 2004
Available online 5 November 2004

Abstract

Unsaturated polyester resin, which is commonly used as the matrix in synthetic glass fibre composites, has been modified to make it more compatible with cellulose fibres. Long kenaf fibres were alkalized with a 6% NaOH solution, combined with four different polyester resin formulations, A, B, C and D, and hot-pressed to form natural fibre composites. Polyester resin A was a conventional unsaturated polyester resin in styrene monomer, Crystic 2-406PA. The molecular structure of polyester B was based on polyester A, modified to make it more polar in nature to better react with the surface of natural fibres, and this modification resulted in the best mechanical properties. The flexural modulus and flexural strength of polyester B composites gave the highest values and the unmodified polyester resin (polyester A) gave the lowest. The opposite trend was obtained for the impact test as expected. Dynamic mechanical analysis (DMA) showed that polyester B composites gave the highest storage modulus (E') values and the lowest $\tan\delta$ values. Scanning electron microscope (SEM) micrographs of impact fracture surfaces performed on the polyester B composites clearly demonstrated better interfacial adhesion between fibre and matrix. A moisture absorption test also showed that polyester B composites gave the most superior bonding and adhesion of all the other polyester–kenaf composites.

Keywords: Modified polyester resins; B. Mechanical properties; D. Scanning electron microscopy; D. Differential scanning calorimetry

1. Introduction

Unsaturated polyesters are extremely versatile in properties and applications and have been a popular thermoset used as the polymer matrix in composites. They are widely produced industrially as they possess many advantages compared to other thermosetting resins including room temperature cure capability, good mechanical properties and transparency. Curing of unsaturated polyester is due to a polymerization reaction that causes crosslinking among individual linear polymer chains. In contrast to other thermosetting resins, no by-product is formed during the curing reaction, hence resins can be moulded, cast and laminated at low pressures and temperatures. The reinforcement of polyesters with cellulosic fibres has been widely reported. Polyester–jute [1,2], polyester–sisal [3], polyester–coir [4], polyester–banana-cotton [5], polyester–straw [6], polyester–pineapple leaf [7] and polyester–cotton-kapok [8] are some of the promising systems.

Kenaf, *Hibiscus cannabinus* L, a member of the hibiscus family is a biodegradable and environmentally friendly crop. It has been found to be an important source of fibre for composites and other industrial applications. However, being hydrophilic, natural fibres need to be treated first to make them more compatible with hydrophobic thermosets and thermoplastics. It has been reported by several authors that modification of fibres improved the mechanical properties of composites [7,9–13]. Mwaikambo and Ansell [14] treated hemp,

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doi:10.1016/j.compscitech.2004.08.005

jute, sisal and kapok fibres with various concentrations of NaOH and found 6% to be the optimized concentration in terms of cleaning the fibre bundle surfaces yet retaining a high index of crystallinity. In this work, kenaf fibres were treated at this concentration.

Four types of polyester resin were used in this study. The first one, labelled type A with the commercial product name Crystic 2-406PA, was a conventional unsaturated polyester resin in styrene monomer. Three more unsaturated polyester resins were specifically formulated for this work for use with natural fibres. The second resin type, B had a polymer structure modified to make it more polar in nature, making it more hydrophilic and therefore it could interact or bond better to the OH groups on the surface of the natural fibres. The third resin C contained an additional monomer, 2,3-epoxypropyl methacrylate, besides styrene. This monomer contained polar groups designed to interact or even possibly to bond to the OH groups on the surface of the natural fibres. The fourth resin D also contained an additional monomer, 2-hydroxyethyl methacrylate, which was also designed to interact better with natural fibres.

The objective of this paper is to study the effect of the chemically modified polyester resin on the mechanical properties of the natural fibre composites and its compatibility with natural fibres. A thorough study of the mechanical behaviour of the composites in flexure and impact is presented here. Results of dynamic mechanical analysis (DMA) are also examined in order to understand the influence of polyester resin chemistry on the formation of bonds at the fibre–matrix interface.

2. Experimental methods

2.1. Materials

A Japanese company supplied the straight Chinese kenaf fibre used in this work. Crop was hand-harvested and separated mechanically and the fibres bundles were of the order of 50 μm in "diameter". The Scott Bader Company Limited, Wollaston United Kingdom supplied the four types of polyester resin. Sodium hydroxide pellets of 98% strength were supplied as general laboratory reagents. The mould release agent used, PAT 607/PCM was supplied by Chemical Release Company Limited, Harrogate, UK.

2.2. Fibre treatment

Fibres were soaked in 6% NaOH solution in a water bath where the temperature was maintained throughout at 19 ± 2 °C for 48 h. The fibres were rinsed and left to dry at room temperature before being put in an oven for 5 h at 110 °C.

2.3. Composite manufacturing methods

Composites were made using a stainless steel mould measuring $240 \times 60 \times 40$ mm length, width and depth, respectively. A releasing agent PAT 607/PCM was sprayed onto a laboratory tissue and smeared evenly onto the surface of the mould. Resin was poured onto each layer of unidirectionally oriented fibre in a zig-zag configuration to ensure even delivery of the resin and the procedure repeated for each layer of fibre. About six to seven layers of fibre were laid up uni-directionally in the mould and resin was poured onto each layer except for the top layer. The layers of the wetted fibres in the mould were then placed between the electrically heated platens of a hot press at 50 °C. The mould was heated for 25 min at a moulding pressure of 6 MPa. The composites were post-cured at 80 °C overnight in an oven.

2.4. Measurements

Three-point bend tests were performed using an Instron model 1122. The width and thickness of the specimens were measured and recorded. The specimen had a span to depth ratio of 16:1. Samples were tested at a crosshead speed of 1 mm/min. The tests were carried out in accordance with ASTM D 790. The flexural modulus and flexural strength were calculated from this test.

Charpy impact tests were performed using an Avery Denison impact tester. The width and thickness of the unnotched specimen were measured and recorded. The tests were carried out in accordance with ASTM D 256. The work of fracture values were calculated by dividing the energy in kJ recorded on the tester by the cross-sectional area of the specimen.

Scanning electron microscope (SEM) micrographs of fractured surfaces following impact were taken using a scanning electron microscope Model JEOL 6310. Prior to SEM evaluation, the samples were coated with gold using the plasma sputtering apparatus Edwards sputter coater model S150B.

DSC was used to evaluate the glass transition temperature (T_g) of a partially and post-cured polyester resin A. Samples weighing between 5 and 10 mg were placed in a hermetic pan and sealed. A TA Instruments DSC 2910 was operated in a dynamic mode with a heating scheme of 0–200 °C and heating rate of 10 °C/min in a nitrogen environment purged at 25 ml/min. The thermograms were analyzed for an estimation of the T_g of the resin.

The dynamic mechanical properties of the four types of polyester resin and the composites were measured using a Tritec 2000 DMA. The samples were cut to size using a diamond cutter. A single cantilever test was used for testing with a span of 16 mm, and sample width and