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Strength properties of composites from biobased and synthetic fibers

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ABSTRACT

Biobased composites have been produced from esterified aspen fibers with either a thermosetting (phenol-formaldehyde, PF) or thermoplastic (polypropylene) matrix material. The polypropylene was incorporated in fibrous form. The level of esterification of the wood fibers had the greatest effect on the strength properties of PF bonded fiberboards, while the type of esterifying agent, acetic anhydride, maleic anhydride or succinic anhydride, had little or no effect. Acetylation of aspen fibers did not appear to increase the compatibility of the aspen fibers with polypropylene.

INTRODUCTION

Interest in fiber-reinforced and fiber-based composites has increased dramatically in recent years. Particularly notable is the increasing emphasis on biobased fibers such as wood, pulp, bagasse, jute, etc. as major components of these composites because of the low cost and high perfomance characteristics of these fibers. However, there are several important problems with the biobased fiber-plastic composites which have not yet been solved; notably the poor compatibility between biobased and synthetic materials, the poor dimensional stability of the natural fibers and the very limited plasticity. We are addressing all of these problems in a broad-based cooperative project on biobased composites between our institutions. In this paper we will give a brief report on our work related to strength properties of mixed fiber composites and describe a new technique we have developed to evaluate the interfacial shear strength of wood-thermoplastic systems.

EXPERIMENTAL

Acetylation was performed on attrition-milled aspen fiber with neat acetic anhydride (AA) with the technique developed by Rowell (1). Modification of the fibers with maleic anhydride (MA) and succinic anhydride (SA) was performed in hot xylene at reflux temperature. Excess anhydride was removed by Soxhlet extraction with xylene for 4 hours as described previously (2). The analysis of the modified products was carried out using the techniques of Matsuda (3) and Clemons et al. (2). The molar gains for aspen fiber esterified with acetic, maleic and succinic anhydrides are shown in Figure 1.

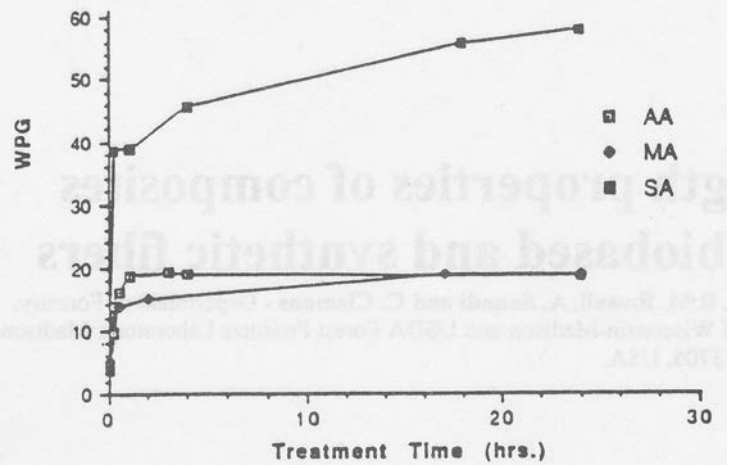

Figure 1. Weight Gains for Aspen Fiber Esterified with Acetic, Maleic, and Succinic Anhydrides.

Fiber mats were formed by sprinkling fiber onto a 15 x 15 cm screen. For treatment with a thermosetting resin, a liquid phenol-formaldehyde (PF) dry process hardboard resin (GP 2341, 50% aqueous solution) was sprayed on the fibers. Boards were made with a level of adhesive of 5, 8 or 12% based on the dry weight of the fiber. For incorporation of a thermoplastic material, a fibrillated form of polypropylene (PP) fiber from Hercules, Inc. (Pulpex, grade AD-H) was premixed with the wood fiber at levels of 0, 3, 10, 25 and 50% before sprinkling on the screen. The boards were bonded at elevated temperatures and pressures in a Carver press.

RESULTS AND DISCUSSION

Compression-shear tests were performed on fiberboards of esterified fiber bonded with phenol-formaldehyde resin. The compression shear test was used instead of the more traditional internal bond (IB) test because of the speed and simplicity of the procedure. The compression shear test has been shown to correlate well with the IB strength with similar or slightly lower variability (4).

As shown in Figure 2, the compression shear strength was found to increase when the extent of the esterification was increased, regardless of the type of esterifying reagent used for the modification. The type of fiber modification

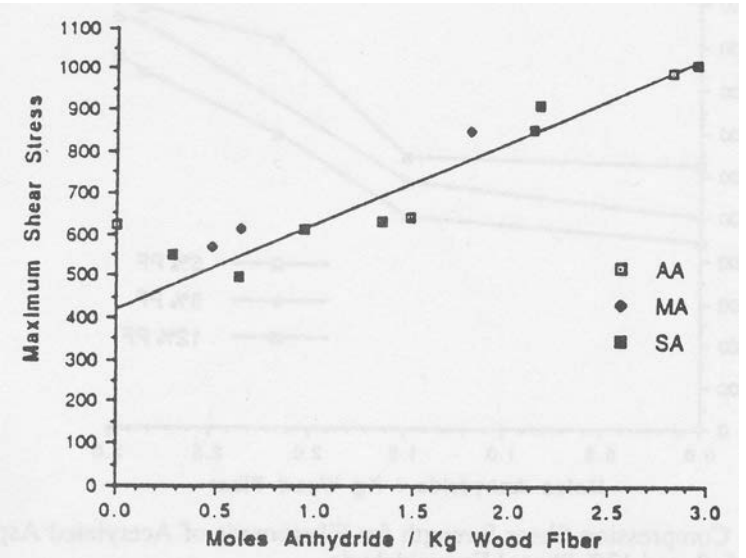

Figure 2. Compression-Shear Strength for Fiberboards of Acetic, Maleic, and Succinic Anhydride Modified Fiber and 5% Phenol Formaldehyde.

(AA, MA or SA) had no significant effect on the compression shear strength of the phenol-formaldehyde (5%) fiberboards. It was noted in our previous work (2) that at the higher levels of esterification the surfaces of the fibers became thermoplastic and exhibited flow at elevated temperatures and pressures. The increase in the maximum shear stress at higher levels of substitution could be due to the increased thermoplasticity of the esterified fiber since this would improve the fiber-to-fiber contact and subsequently the adhesion of the fibers in the boards.

An increase in the amount of PF resin deposited on the fibers was also found to increase the compressive shear stress of the fiberboards. As shown in Figures 3 and 4, when the PF resin content was raised from 5% to 12%. there was a corresponding increase in the strength. However the increase in board strength as a result of increased levels of PF resin (22-32%) were not nearly as great as the strength improvement realized from increased levels of esterification (135%). Thus, increased levels of esterification rather than further additions of PF resins are recommended for strength enhancement of these types of composites.

The equilibrium moisture contents (EMC) of the fiberboards made from aspen fibers modified with AA, MA and SA were reduced as compared to control boards; but similar to the strength properties of control boards, there was little effect of the type of esterifying agent on the final EMC. The same effect was noted in previous work for modified aspen fibers which had not been bonded into fiberboards (2).

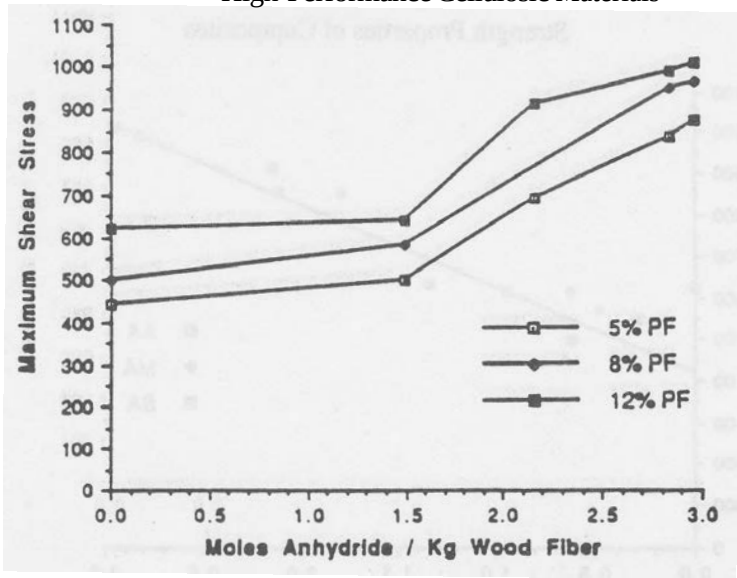

Figure 3. Compression-Shear Strength for Fiberboards of Acetylated Aspen Fiber and 5, 8, and 12% Phenol Formaldehyde.

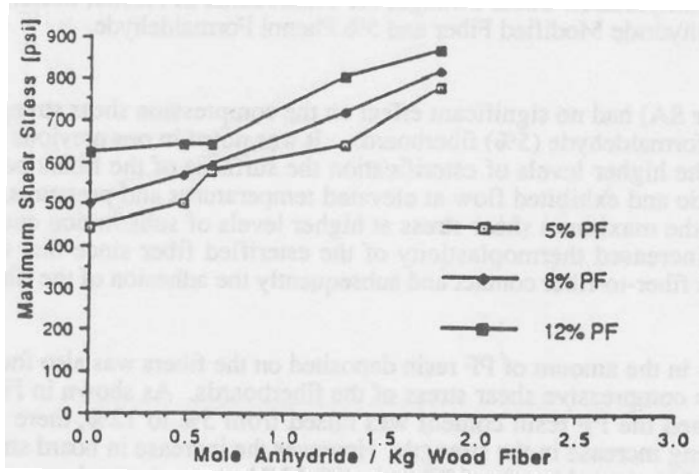

Figure 4. Compression-Shear Strength for Fiberboards of Maleic Anhydride Modified Aspen Fiber and 5, 8, and 12% Phenol Formaldehyde.

Composite boards from combinations of modified wood fibers and polypropylene were also evaluated. It was hoped that acetylation of the hydrophilic wood fibers would improve the compatibility with the polypropylene to give improved properties to the final composite board. Figures 5 and 6 show the density and internal bond strength of the composites from both unmodified and acetylated aspen fiber and polypropylene. Since the IB strength is very dependent on the density, it is not surprising that the two figures show curves of the same shape. The lower IB strength and density of the acetylated fiber composites at low levels of PP (0-10%) is probably due to both the poor compatibility adhesion of the modified wood fibers with PP and

the increased stiffness of the acetylated fiber. Since water acts as a plasticizer for wood fibers and acetylated wood fiber has a lower EMC, the result is a stiffer AA modified fiber with reduced IB strengths.

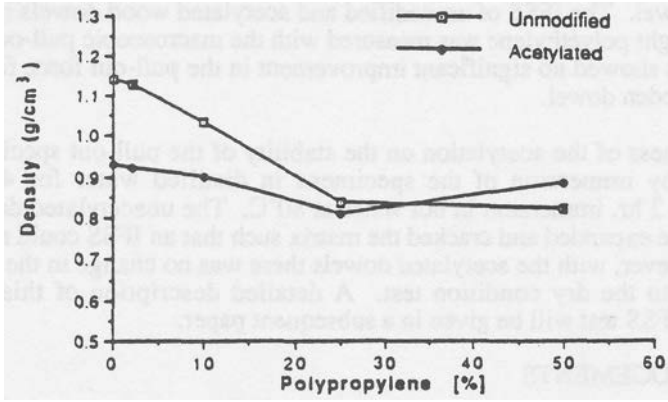

Figure 5. Densities of Aspen Fiber or Acetylated Aspen Fiber and Polypropylene Composites.

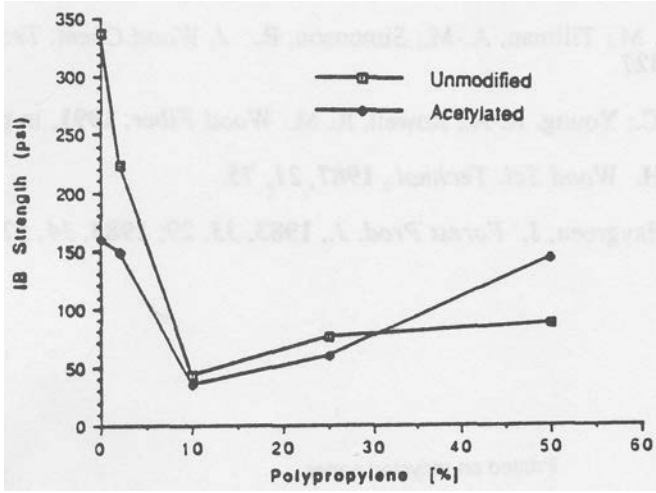

Figure 6. IB Strengths of Aspen Fiber or Acetylated Aspen Fiber and Polypropylene Composites.

The acetylation treatment provided no improvement in the strength properties of the composites. The increase in density and strength of the composites at PP contents greater than 10% were attributed to the flow and film formation of the PP in the composite structure. As reported previously, both an increase in the PP content and acetylation of the wood fibers resulted in significant improvements in the EMC of the composites.

A new technique for determination of interfacial shear strength (IFSS) has also been developed to aid in the evaluation of strength improvement modifications for composites. The method involves measurement of the force required to pull a small wooden dowel from a thermoplastic matrix formed as a small plug around the dowel. The IFSS of unmodified and acetylated wood dowels in low molecular weight polyethylene was measured with the macroscopic pull-out test and the results showed no significant improvement in the pull-out force for the acetylated wooden dowel.

The effectiveness of the acetylation on the stability of the pull-out specimens was gauged by immersion of the specimens in distilled water for 48 hr. followed by a 2 hr. immersion in hot water at 80°C. The unacetylated dowels in polyethylene expanded and cracked the matrix such that an IFSS could not be obtained: however, with the acetylated dowels there was no change in the IFSS as compared to the dry condition test. A detailed description of this new macroscopic IFSS test will be given in a subsequent paper.

ACKNOWLEDGEMENTS

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