Mechanical Properties of Wood Fiber Composites Under the Influence of Temperature and Humidity

Yibin Xue, David Veazie, Cindy Glinsey, Meagan Wright, and Roger M. Rowell

Abstract

Woodfiber-thermoplastic composites (WPC) have received considerable attentions from the forest product industry for civil engineering applications due to its superior properties over wood and plastics alone. Particularly WPCs can be easily fabricated using traditional plastic processing techniques. The major limitation in the applications of WPCs is the poor understanding of their mechanical properties and especially the environmental impacts on these properties. The aim of this research is to systematically study the mechanical properties of aspen-fiber polypropylene composites (APCs), evaluate the typical temperature and humidity influences on the mechanical properties of APCs, and such find an optimal composition of APCs for high mechanical reliability and long life span in service conditions. This was accomplished by examining APCs of 30 and 50 weight percent wood fiber contents with/without 2 wt. % maleic anhydride grafted polypropylene MAPP additives. Specimens of these specially selected APCs were exposed for 7,000 hours to four temperature and moisture conditions, typically experienced by structures in domestic housing industry:

1. hot/dry (Arizona),
2. hot/wet (Florida),
3. cold/dry (Montana), and
4. cold/wet (Wisconsin).

Tensile and flexural tests according to ASTM specifications were used to evaluate the mechanical properties of these APCs after conditioning. Especially flexural strengths after conditioning were reported here at room, near zero (4°C), and elevated (40°C) temperatures. Large reductions in both tensile and flexure strengths of APCs were observed after 7,000 hours ageing at all four ageing conditions.

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Introduction

Woodfiber-thermoplastic composites (WPCs) have received considerable attention of forest product industry for civil engineering applications due to its many merits, which include increasing the durability of wood, requiring little maintenance during service, lower cost than plastics alone, and being able to be fabricated using traditional plastic/composite processing techniques (1,2). To fully realize the great potential of WPCs in domestic industry, WPC manufacturers and consumer product designers need a better understanding of the mechanical properties of the composite and environmental effects on these properties (3-5). Substantial research has been conducted on the interaction between wood fibers and amorphous polymers (6). It is concluded that the reinforcement of WPCs is not only a function of fiber tensile strength, fiber volume fraction, and matrix strength, all of which can be demonstrated using micromechanics theory (7), but also depends on the chemical and physical interactions between the woodfiber and the polymer matrix, along with the special treatment on the wood fibers and additives in the composites (6-10). Currently, the major limitation of using wood fibers for reinforcement is the poor interfacial adhesion between the polar-hydrophilic wood fibers and the non-polar-hydrophobic polymers (7). Maleated polypropylene (MAPP) has been used in WPCs to increase compatibility between polypropylene and the woodfiber (7).

Aspen fiber-polypropylene composites (APC) are newly manufactured wood-based composites used to prolong the longevity of wood structures (11-13). Polypropylene (PP), a semi-crystalline thermoplastic with low density that can be easily molded, is used as a matrix for the aspen fiber. The tensile and flexure properties of APCs at room temperature have been represented as a function of aspen fiber weight fraction by the authors (14). Changes to tensile and flexure properties were also observed when tested at elevated (40°C) and near frozen (4°C) temperatures (14). MAPP as an additive to the PP matrix was also found to increase tensile and flexure strengths of the composites. To continue this study on APCs, the aim of this research is to evaluate the temperature and humidity influences on the mechanical properties of the APCs. Selected APCs were exposed for 7,000 hours (about 10 months) to the following four temperature and humidity conditions, typically specified by the domestic housing industry as following:

1. hot/dry at 40°C and 30 percent relative humidity (RH) that mimics the summer in Arizona,
2. hot/wet at 40°C and 82 percent RH as summer in Florida,
3. cold/dry at 4°C and 30 percent RH as most weather in Montana, and
4. cold/wet at 4°C and 82 percent RH as in Wisconsin.

The APCs after the 7,000-hour ageing at the four temperature and humidity conditions demonstrate over 30 percent reduction in tensile strengths compared to the tensile strengths of APCs before the ageing process (15). In this paper, flexural strengths of APCs after the four-temperature and humidity conditions were evaluated at room, near zero, and elevated temperature. Over 80 percent reductions in flexural strengths were observed on APCs after 7,000 hours ageing at the four conditions.

Experimental

Materials and Specimens

Harvested from mature trees, aspen filaments approximately 15 to 20 cm long were chopped into lengths of approximately 1 cm. The fibers were not dried to remove the moisture present, resulting in a fiber moisture content varying from approximately 6 to 9 percent by weight. A PP homopolymer, Solvay 1602, was blended with the aspen fibers. Included in some of the blends was the coupling agent MAPP Batch blending of the formulations was performed at the Forest Products Laboratory in Madison, WI, in a 1-liter thermokinetic mixer (K-Mixer, Synergistics Ltd., Canada). The short fibers, PP and MAPP (if used) were compounded in a high intensity kinetic mixer where the only source of heat was generated through the kinetic energy of the rotating blades. The blending was accomplished at 4,600 rpm, which resulted in a blade tip speed of about 30 m/s. The blended mass was then automatically discharged at 190°C.

A total weight of 150 g was used for each batch, and about 1.5 kg of blended material was prepared for each set of experiments. The total residence time of the blending averaged about 2 minutes. The discharged mass was cooled by compression in a cold press and then granulated. The granules were then injection molded into ASTM standard specimens using a 33-ton Cincinnati Milacron injection-molding machine at 190°C. The specimens were then stored at 20 percent humidity and 32°C for at least 3 days before testing or conditioning.

Selected APCs of woodfiber weight percentages (wt. %) of 30 and 50 were studied to evaluate the influences of environmental conditionings on the mechanical properties of ACPs. As usual, the 2 wt. % of MAPP additive was introduced to the composite by replacing the corresponding PP in the composite. The APCs studied are listed in **Table 1.** The naming of composite is in such convention as APC-aspen fiber weight percentage-MAPP weight percentage. For example, APC-30-02 indicates an APC with 30 wt. % aspen fiber and containing 2 wt. % MAPP.

Temperature and Humidity Conditions

APCs were subjected to one of four forms of environmental exposures for 7,000 hours prior to testing. The isothermal 'hot/dry' environmental exposure was achieved in a convection oven with a digital controller. The 'hot/wet' environment exposure was accomplished using a Tenney Bench-Top Environmental Chamber with digital temperature and humidity controls. The isothermal 'cold/dry' environment exposure was conducted in a refrigerator with the temperature and humidity setting as that indicated previously. The 'cold/wet' environmental isothermal exposure was accomplished by suspending the specimens above a pool of distilled water inside a moisture chamber placed inside a refrigerator. The APCs were free standing while exposed to all the environmental conditions for 7,000 hours. The mechanical tests were conducted immediately after 7,000 hours conditioning.

Moisture absorption of the APCs resulted in slight weight gains by the specimens exposed to the 'hot/wet' and 'cold/wet' environments. The weight gain by the specimens following 7,000 hours exposure to the 'hot/wet' and 'cold/wet' environments was less than 0.1 percent.

Measurements

All mechanical tests were performed according to ASTM standards (ASTM D 790-92). Three-point bending setup was used and the tests were conducted using displacement-control. The loading rate is set at 1.25 mm/min., corresponding to an average strain rate of approximately 0.01 per minute (16).

All flexural tests were performed at atmospheric pressure on a 100 kN servo-hydraulic test frame equipped with digital controller and computer data acquisition. To reduce experimental error, at least five replicate tests were performed for each APC listed in **Table 1.** All the materials after subjected to the specific temperature and humidity conditions were tested in flexure at room temperature first. Then the same set of tests was conducted at the near frozen (4°C) and the elevated (40°C) temperature with the temperature control accomplished by conducting the test inside an environmental chamber mounted to the test frame. The elevated temperature was achieved with a traditional convention furnace while the near frozen temperature was achieved with a constant flow of liquid N_2 to the chamber. The temperature of the test chamber was digital controlled in a close loop. Prior to testing, the specimens were allowed to stabilize in the chamber at the desired temperature for 25 minutes.

Table 1. ~ *Composition of APCs.*

Material #	Aspen fiber	PP	MAPP
	- - - - - - - - -	(%)	- - - - - - - - -
APC-30-00	30	70	0
APC-30-02	30	68	2
APC-50-00	50	50	0
APC-50-02	50	48	2

Table 2. ~ *Tensile strengths of as-received APCs at 25°, 4°, and 40°C.*

	Flexural strengths (MPa)		
Materials	25°C	40°C	4°C
APC-30-00	49.93	29.89	39.77
APC-30-02	61.55	35.05	52.14
APC-50-00	51.40	29.39	56.84
APC-50-02	77.21	38.71	55.35

Results and Discussion

Results

APCs listed in **Table 1** were tested in three-point bending at room, near zero (4°C), and elevated (40°C) temperature as they were received (14). The average flexural strengths obtained are listed in **Table 2.**

Following exposure to one of the four temperature and humidity conditionings that have been previously specified, the APCs were test at room, near frozen, and elevated temperatures, respectively. **Figure 1** shows the tensile strength of the APCs after conditioning at room temperature. Ap-

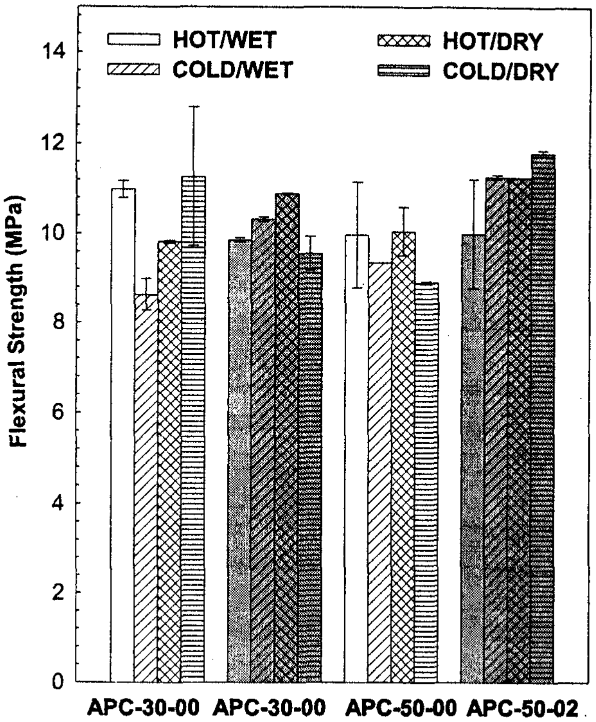

Figure 1. ~ *Flexural strengths of APC-30s and APC-50s tested at room temperature after 7,000 hours conditioning.*

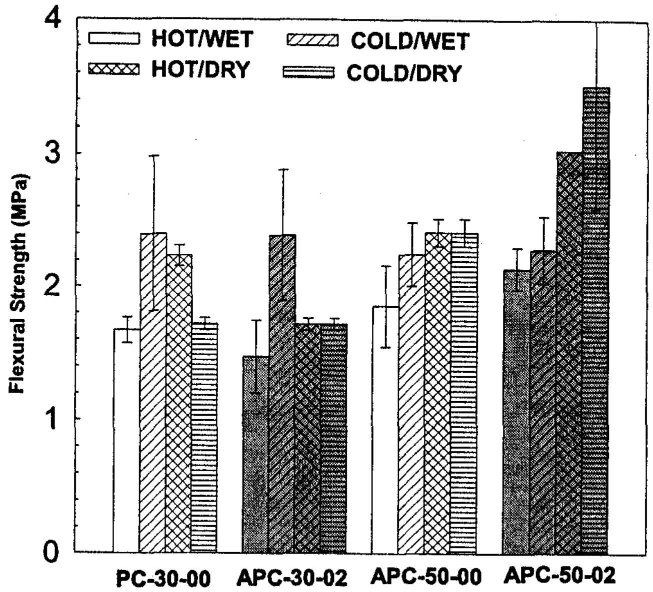

Figure 2. ~ *Flexural strengths ofApC-30s and APC-50s tested at nearfrozen temperature (4°C) after 7,000 hours conditioning.*

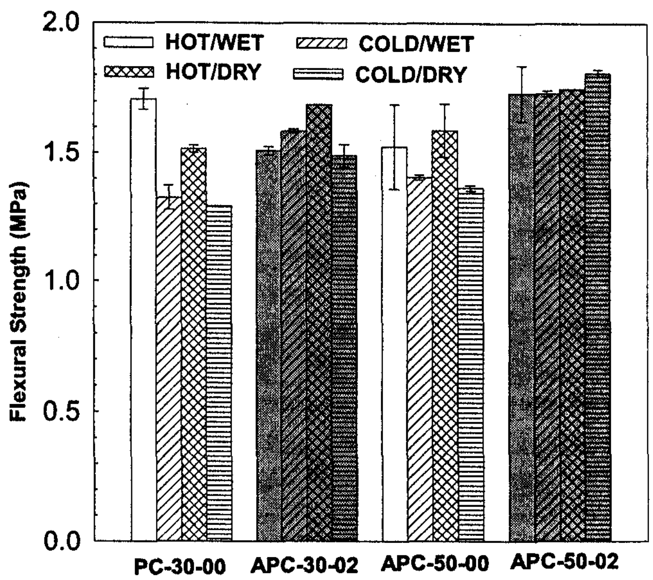

Figure 3. ~ *Flexural strengths ofAPC-30s and APC-50s tested at elevated temperature (40°C) after 7,000 hours conditioning.*

proximately 80 percent overall reduction in flexural strength was observed when compared to those of APCs tested as-received, listed in the first column of Table 2. APCs with MAPP showed more reduction in tensile strength than those without MAPP Figures 2 and 3 show the flexural strength of the APCs after the four conditionings tested at near frozen and elevated temperatures, respectively. It appears that the flexural strengths at the near frozen and elevated temperature are much lower than those at room temperature. It is believed that because of the thermal mismatch of the aspen fiber and PP matrix, there are large thermal stresses in the composite from fabrication, temperature/humidity conditioning, and at the test conditions. Therefore, it is suggested that a complete microscopic analysis be conducted to fully understand the variation of the APCs' flexural strength when tested at different temperatures.

Discussion

Unlike tensile experiments on APCs after conditionings, this set of flexural tests on APCs after conditionings did not demonstrate uniform effects from temperature and humidity conditions. The testing temperature showed strong effects on flexural properties of APCs. The flexural strengths of APCs tested at both elevated and near frozen temperatures appear to be lower than those at room temperature following the four temperature and humidity conditionings. The flexural strengths of conditioned APCs tested at near frozen temperatures are slightly higher than those tested at elevated temperature. This is consistent with results listed in **Table 2.** Further investigations would have to be conducted to fully explain the impact of environmental conditions on the mechanical properties of APCs.

Conclusion

Aspen fiber-PP composites of 30 wt. % and 50 wt. % aspen fiber with and without MAPP are evaluated using for flexural strength after 7,000 hours exposure to 40°C/82 percent RH, 4°C/82 percent RH, 40°C/30 percent RH, and 4°C/82 percent RH conditions. The APCs after conditioning, in general, were found to have approximately 80 percent reduction in flexural strengths when tested at room temperature. The tensile strengths of the conditioned APCs tested at near frozen and elevated temperatures were lower than those tested at room temperature.

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