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Composite Panels Made With Biofiber or Office Wastepaper Bonded With Thermoplastic and/or Thermosetting Resin

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Abstract

The purpose of this study was to evaluate two groups of composite panels made from two types of underutilized natural fiber sources, kenaf bast fiber and office wastepaper, for their suitability in composite panels. All panels were made with 5% thermosetting phenol-formaldehyde (PF) resin and 1.5% wax. Also, an additional 10% polypropylene (PP) thermoplastic resin was used in half the panels. The PP was added to determine the effect it had on the mechanical and physical properties of the panels. The resin and wax were applied with a pneumatic spray gun while tumbling the fiber in a rotary blender. All fibers were formed into non-woven air-laid mats and compression molded into 356- by 356-mm (14- by 14-in.) composite panels, cut into test specimens, and tested for mechanical and physical properties. All mechanical property values were below the minimum standard established by the American Hardboard Association for medium-density fiberboard and particleboard (AHA 1995). However, composites with PP had more short-term moisture resistance than did composites without PP. The poor mechanical test results were probably due to the PF resin being absorbed into the fiber rather than remaining on the fiber surface, insufficient cure of PF, and interference of the PP when used with the PF resin.

Keywords: kenaf, office wastepaper, polypropylene, phenolic

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Composite Panels Made With Biofiber or Office Wastepaper Bonded With Thermoplastic and/or Thermosetting Resin

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Introduction

Kenaf is an agricultural plant consisting of a long durable bast outer fiber with a relatively short, low-density core fiber (pith). The desirable properties of the bast fiber make it useful for many products, although paper is the primary use. The core fiber has very different properties that are not well suited to paper products, and thus it must be separated from the bast fiber. However, kenaf, even though it is an underutilized fiber source, has many desirable qualities that would make it suitable as a fiber source for composite panels. Some of these qualities are that it has low density, is nonabrasive, has high specific properties, is easily recyclable, can be formed over sharp contours, is biodegradable, generates rural jobs, and is low cost (Sanadi and others 1997).

Kenaf has a relatively short growing period, especially compared with trees. Plant maturity can be reached in only 5 to 6 months. Plants generally grow from 2 to 5 m high. Given the right growing conditions, kenaf can reach up to 6 m high, with the outer bast fibers making up to 20% to 25% of the stalk on a weight basis (LaMahieu and others 1991). Yield ranges from 6 to 10 tons per acre per year as far north as Illinois, with higher production rates farther south where the growing season is longer. Once mature, however, the entire crop must be harvested and stored, requiring extensive storage capacity. The rapid growth rate of kenaf provides farmers with potential income if sufficient markets can be developed. Trees, on the other hand, have a minimum rotation period of 7 to 20 years before harvesting. However, the advantage of trees is that they can be harvested year-round, thus requiring a relatively short storage period, and they do not require covered storage.

Kenaf bast fiber can be used alone, or it can be used as the primary component for a product and mixed with a shorter fiber material, such as wood fiber. This combination of materials is often used to make erosion control mats. In this type of product, kenaf bast fiber acts as a matrix fiber to impart strength and integrity (that is, resistance to tearing) to the mat. This integrity is also useful when making three-dimensional compression molded panels. Kenaf fiber can be compression molded into composite panels when combined with a thermoplastic that acts as the binder (English and others 1997). In a study involving fiberboard made with kenaf, Youngquist and others (1993) reported that properties could be achieved that were nearly equal or equal to the minimum standards set by the American National Standard Institute of the American Hardboard Association for basic hardboards.

Air-laid composites can be made from a variety of agricultural fibers, wastepaper, and waste plastic materials in the postconsumer waste stream. These composites exhibit a wide range of properties that should make them useful in numerous commercial applications and value-added products. Examples of potential products that can be made with the air-laid process include storage bins; furniture components; automobile and truck components; paneling for interior wall sections, partitions, and door systems; floor, wall and roof systems for light-frame construction; and packaging materials including containers, cartons, and pallets (Krzysik and Youngquist, 1991).

Office wastepaper is an abundant postconsumer waste product, and paper that is not repulped is normally sent to landfills. Any further use that can be developed for wastepaper could add value to it and would reduce the demand on landfills. Paper can be broken down into a variety of forms, which allows it to be suitable for numerous applications including composite panels made through the medium-density fiberboard (MDF) process or the air-laid nonwoven mat process.

Objectives

The objective of this study was to establish an understanding of processing and pressing techniques needed to make composites from kenaf fiber or recycled office paper. We will then use this understanding to further the development of the technology for combining waste plastic with agricultural kenaf fiber and shredded office paper to make durable composite panel products that are recyclable and environmentally friendly. Successful results will help broaden alternative markets for both underutilized biofiber and recycled office paper materials. Using wastepaper and plastic for value-added products decreases the amount of these materials entering the municipal solid waste stream. Increasing the potential uses for kenaf provides farmers with an alternative crop which would help increase farm income.

Table 1—Panel composition[a]

	Natural fiber content,%		Synthetic fiber content, %			
Panel	Kenaf	Office waste-paper	PP	PET	Phenolic resin[b] (%)	Wax[b] (%)
K	93.5	0	0	0	5	1.5
K–PP	83.5	0	10	0	5	1.5
OW–PET	0	83.5	0	10	5	1.5
OW–PP	0	83.5	10	0	5	1.5

[a]PP, polypropylene; PET, polyester; K, kenaf; OW, office wastepaper.
[b]Phenolic resin and wax are based on solids content.

Experimental Design

This research concentrated on testing compression molded panels made from nonwoven mats composed of kenaf stalk bast fiber and office wastepapers bonded with thermoplastic and thermosetting resins. The experiment consisted of four formulations: two with agricultural and synthetic fiber and two with paper and synthetic fiber. The weights were based on ovendry fiber weight. Panels containing different formulations were compared. The details of the experimental design are shown in Table 1.

Flat panels with a specific gravity of 1.0 and target thickness of 6 mm were produced for each experimental condition. Each of the four formulations was evaluated using five replicate panels. In total, 20 panels were made for this study.

Materials

The kenaf was grown on University of Illinois Experimental Station test plots on the Champaign–Urbana campus. The kenaf was planted in early June and harvested in late October after the first frost. By this time, the kenaf had reached a height of 4 to 5 m, and stalk diameter ranged between 25 and 35 mm, typical for a 175- to 185-day growing period. The harvest averaged a dry weight of 6 tons per acre.

The office wastepaper was collected from the USDA Forest Service, Forest Products Laboratory (FPL), paper recycling program. This provided a clean uniform source of paper consisting of discarded copy paper. Nearly all the paper had text on it from either a printer or a copier.

Two types of polymer fibers were used that were in the form of textile fibers: virgin polypropylene (PP) and recycled polyethylene terephthalate (PET) fiber. A virgin PP fiber was used for the nonwoven mat because a recycled PP fiber could not be located with the required specifications. The PP was provided by Hercules, Inc. (Norcross, Georgia), and had the following characteristics: 2.2 denier, 37 mm long, crimped, a density of 0.91 g/cm^3, and a melting point of 162°C. The PET fiber was provided by Wellman Co., Inc. (Johnsonville, South Carolina). It was spun from recycled soft drink containers and had the following characteristics: 6.00 denier, 51 mm long, and crimped. The PET fiber was not considered a binder in the office wastepaper (OW)–PET panels because its melting temperature was above the temperature used for hot pressing. The purpose of the PET was to act as a matrix fiber to help hold the office wastepaper fibers together within the formed mat.

The adhesive, Cascophen OS 707, obtained from Borden Chemical, Inc. (Sheboygan, Wisconsin), was a water-soluble, liquid phenol formaldehyde resin. It had a solids content of 56%, viscosity of 140 cps, pH of 9.5 to 11.5, and specific gravity of 1.233. The wax, Cascowax EW 58S, also obtained from Borden Chemical, Inc., had a solid content of 58%, viscosity of 131 cps, pH of 8.25 to 9.25, and specific gravity of 1.0. Both resin and wax contents were based on solids content of total board weight.

Process

Fibers

Following harvesting, the kenaf was cut into nominal 51-mm lengths and air-dried to approximately 15% moisture content (MC) to prevent it from rotting while being stored. After all the kenaf was harvested, the bark had to be separated from the core. This is most easily done when the kenaf is in the green state, but because it had been dried to prevent decomposition during storage, moisture had to be reintroduced. This was done by exposing the kenaf to a vacuum–pressure–soak cycle. The vacuum was for 15 min at 84.7 kPa (25 in. of mercury), and the water soak was for 30 min at 689 kPa. The kenaf was removed from the soak tank, the bark was removed from the core by hand, and then the kenaf was air-dried again, reducing the MC to 8%.

The office wastepaper was exclusively white copy paper obtained from the FPL paper recycling program. The paper had to be reduced to particle and fiber bundle form to be processed into a nonwoven mat. This was accomplished by hammermilling the paper with a screen opening of 9.6 mm. Following the hammer mill operation, the paper had an MC of 4%.

Wax and Adhesive

The wax and resin were sprayed onto kenaf or office wastepaper fibers in a drum-type blender using a single pneumatic spray gun applicator. The resin and wax were applied separately with the wax applied first. Enough fiber was blended in one batch so that all the panels for each board formulation could be formed from the one blending operation. During resin application, some balling of the kenaf fibers occurred as a result of the tackiness of the resin and the tumbling action of the rotating drum. One level of phenolic resin (5%) and wax (1.5%) was used in this study.

Mat Formation

The air-laid nonwoven mats used for this study were made on a 305-mm-wide, lab-scale, Rando-Webber (Macedon, New York) web forming machine. This was done in three stages. First, the kenaf or paper fibers were passed through a pin drum opener. This broke up any kenaf clumps or balls made during the resin blending operation and provided an initial blend with either the PP or PET plastic fiber. A second pass through the pin drum provided a more thorough, uniform blending of the kenaf or paper and plastic fiber. In the second stage, the blended fibers were elevated to feed rolls, transferred to a lickerin, and formed into a nonwoven mat on a fiber condenser belt. At this point, the nonwoven web had very low integrity and was easily damaged if handled. The third stage improved the density and integrity of the mat by passing it through a needler, which provided a vertical intertwining of the plastic fiber with the kenaf or paper fiber. It was then in a condition to be cut into strips and laid up into a mat for pressing. The mat made with recycled office wastepaper, but without PP fiber, had 10% PET fiber added to it. The PET was necessary to provide the mat with enough integrity to prevent it from falling apart when being handled, formed, and pressed.

Panel Pressing

Each 5-kg batch of blended kenaf, or wastepaper, was made into a nonwoven web 30 cm wide and approximately 15 m long and was then cut into 30- by 30-cm webs. Each web was weighed and put into like piles of webs that had a weight range of 10 g. The next step was to form a mat that would be pressed into a panel. A panel basis weight was calculated, and webs were removed from the piles and stacked to form a mat equal the basis weight of the pressed panel.

The theory behind the air-laid nonwoven mat forming technology is that the fibers are laid up into a continuous web in a completely random orientation. In reality, however, during web formation, the forming equipment provided slight alignment of the fiber in the machine direction, that is, parallel to the direction of movement of the web. Thus, when the webs were laid up into the mattress for pressing, they were placed so that the machine direction of each web was perpendicular to the machine direction of the previous web. This minimized any effect machine direction and cross machine direction might impart to the panel properties. Mat lay-up was also confounded by the wide variation in web density requiring from as few as two to as many as six webs to achieve the basis weight to make up a mat.

The mats were pressed in a manually controlled, steam-heated press with platen temperature held at 197°C. Mats were held under pressure for 3 min at a maximum pressure of 12.4 MPa for kenaf panels and 8.1 MPa for panels containing office wastepaper. This was the amount of time necessary to reach the melting temperature of the PP in the core of the panels. During this time, mat core temperature reached 100°C within 60 to 90 s, allowing more than sufficient time to cure the phenolic resin, that is, core temperature above 100°C for more than 60 s. A steel frame, 356 by 356 by 6 mm, was used to contain the composite panel during heating and to prevent over-pressing (that is, the frame also acted as press stops). One to two de-gassing cycles were made during the pressing cycle, depending on mat moisture content and amount of steam released during each de-gassing cycle. During the heating stage, the mat flowed to fill the steel frame. Nevertheless, the edges of the panel had lower density than the rest of the panel. Thus, the edges were trimmed off, and the final panel size was 305 by 305 mm. This allowed for less variability in density (hence properties) within each panel.

Tests

Mechanical and physical property tests were made on specimens cut from the experimental panels. Each panel was weighed and measured, and the specific gravity was calculated. All tests were done in conformance with the American Society for Testing and Materials (ASTM 1994, part B basic hardboard specifications) according to the specific test being done.

Prior to mechanical and physical property testing, the specimens were conditioned at 50% relative humidity and 20°C. Three-point static bending tests to get modulus of elasticity (MOE) and modulus of rupture (MOR), tension tests to get tensile strength, and internal bond (IB) tests were performed on a Tinius Olsen (Horsham, Pennsylvania) model 290 testing machine. Twenty-four hour thickness swell (TS) and water absorption (WA) measurements were at ambient temperature. Differential linear expansion (LE) tests were made

Table 2—Mechanical properties of air-laid panels made with phenolic resin[a]

Board formulation[c]	Properties[b]				
	Specific gravity	Static bending, N/mm² MOR	MOE	Tensile strength (N/mm²)	Internal bond (N/mm²)
K	0.88 (6.1)	31.6 (35.3)	4,094.9 (33.9)	21.4 (52.1)	0.086 (45.8)
K–PP	0.83 (5.8)	20.4 (42.7)	2,829.0 (38.8)	19.5 (10.7)	0.056 (59.4)
OW–PET	0.91 (5.9)	10.1 (28.4)	508.0 (30.3)	10.2 (5.5)	0.036 (38.1)
OW–PP	0.87 (13.0)	11.2 (53.8)	673.1 (78.2)	8.9 (23.7)	0.057 (52.0)
ANSI 208.2-1994 MDF standard	0.64–0.80	24	2,400		0.60

[a]K, kenaf; PP, polypropylene; PET, polyester; OW, office wastepaper; ANSI, American National Standards Institute; MDF, medium-density fiberboard; MOR, modulus of rupture; MOE, modulus of elasticity.

[b]Values in parentheses are coefficients of variation (%).

[c]All boards were formulated with 5% resin and 1.5% wax.

after equilibrating each specimen at 50% relative humidity (RH), 27°C, and then again at 90% RH, 27°C.

Results and Discussion

Mechanical and physical property data are presented in Tables 2 and 3. The results were statistically analyzed and are reported as the mean and coefficient of variation.

Kenaf Panels

We anticipated that the PP would help improve the mechanical and physical property values of the panels by assisting the PF resin in bonding the kenaf fiber together. However, this did not appear to be the case. The test results from the panels (Tables 2 and 3) were analyzed within their specific formulations. The mechanical properties of the kenaf only (K) panels were consistently higher than those of the kenaf and PP (K–PP) panels. The K panel MOR was 35% higher than the K–PP panel MOR. Similarly, MOE, TS, and IB values were 31%, 9%, and 35% higher, respectively, for K panels than for K–PP panels. This indicates that the addition of PP probably resulted in the reduction of mechanical properties. It may also suggest that the phenolic resin bonded well to the kenaf fiber but when 10% PP was added, there may have been some interference between the resin and PP or the PP may have absorbed latent heat energy in the mat that impeded PF resin cure. Since the PP is hydrophobic, the PF resin may not have bonded to the PP, preventing a good bond between the PP and kenaf thus causing weak areas in the panels at the PP–kenaf contact points. Furthermore, because kenaf is hydrophilic, the two materials have some difficulty bonding together in the first place. With only 10% PP fiber, there was probably insufficient PP to provide PP–PP bonding. Thus, only the PP and kenaf bonded. If a higher percentage of PP had been used allowing PP–PP bonding to occur, perhaps 20% to 30%, higher mechanical properties could possibly have been achieved compared with using 10% PP or none at all. The addition of PP reduced the values of each of the mechanical properties, even causing the MOR to drop below the American National Standards Institute (ANSI) standard (NPA 1994).

Conversely, the addition of PP enhanced some of the physical properties. The K–PP panels had 12% less TS and 2% less WA but 28% higher LE than the K panels. This may indicate that PP had some positive effect for improving short-term water resistance to the wood fiber–PP composite reducing its short term TS and WA. For LE though, the specimens were allowed to reach equilibrium. In these long-term tests, the moisture had time to fully penetrate all the kenaf fibers, ultimately causing higher LE in the K–PP panels. This indicates that PP impedes moisture sorption but does not prevent it. An additional factor possibly contributing to the reason the K–PP panels have better physical properties than the K panels is that the K–PP panels have less kenaf in them, having 10% replaced by the PP. Because the PP doesn't absorb moisture and swell, the K–PP panels will probably swell about 10% less.

The processing procedure could also have added to both the poor mechanical and physical property values. When the PF resin was applied to the kenaf fiber, sufficient fiber–resin was blended at one time to make all five panels in each board formulation to try to minimize board to board inconsistency. Following resin application, the fiber was processed into a continuous nonwoven mat requiring it to pass through various transfer steps involving high air flows. The continuous mat also had to be cut into 30- by 30-cm squares and sorted before pressing. Each step tends to dry the resin causing it to lose its tack, thus reducing its effectiveness as a binder.

Table 3—Physical properties of air-laid panels made with phenolic resin[a]

Board formulation[b]	Specific gravity	24-h water soak Thickness swell (%)	Water absorption (%)	Linear expansion (%)
K	0.88 (6.1)	172.8 (23.1)	172.2 (26.6)	0.39 (23.9)
K–PP	0.83 (5.8)	150.9 (15.7)	168.3 (14.4)	0.54 (15.1)
OW–PET	0.91 (5.9)	65.2 (7.0)	95.7 (4.5)	0.33 (29.7)
OW–PP	0.87 (13.0)	51.4 (15.7)	90.4 (18.4)	0.43 (8.8)

[a]K, kenaf; PP, polypropylene; PET, polyester; OW, office wastepaper. Values in parentheses are coefficients of variation (%).

[b]All boards were formulated with 5% resin and 1.5% wax.

Office Wastepaper Panels

Office wastepaper panels had substantially lower mechanical values than the kenaf panels although no direct comparison was made between the two formulations. As with the kenaf panels, we expected the addition of PP to improve both the mechanical and physical properties of the office wastepaper panels. With the PP melting point being below the pressing temperature, we thought the PP would aid in the bond strength of the OW–PP panels compared with that of the OW–PET panels. Because the melting point of the PET was above the pressing temperature, we didn’t expect that it would provide a bonding advantage. Although the mechanical values for both office wastepaper formulations were low, the panels with PP had higher values for MOR, MOE, and IB than the panels with PET. The values were 10%, 25%, and 37%, respectively. This was not the case for TS, however, where the panels with PET had 13% higher strength than the panels with PP (Table 2).

The physical properties for the office wastepaper panels were also considerably worse than the properties for the kenaf panels. The addition of PP to office wastepaper did reduce the TS and WA by 21% and 6%, respectively, but the OW–PET panels had 23% less LE than the OW–PP panels (Table 3).

Some of the poor performance of both the mechanical and physical properties of the office wastepaper panels could be attributed to the large flakes made by the hammer mill and used as furnish for the panels. These large flakes may not have been an optimum form to use. Another possible cause could have been that the resin may have soaked into the paper causing resin-starved bonding sites rather than remaining on the office wastepaper fiber surface where it would have been more effective. A third factor may be inequities in mat formation during pressing causing a difference in curing of the PF resin.

Conclusions

This study has helped set the baseline for future work on hybrid composites made from kenaf and recycled office wastepaper and using both thermoplastic and thermosetting resin. Two types of nonwoven mats were made with the air-laid process using kenaf for the main component in one set of panels and recycled office wastepaper in a second set. All panels had 5% thermosetting phenolic resin as the binder and 1.5% wax. Half the panels had 10% thermoplastic PP textile fiber added to them. In the case of the kenaf panels, the PP appeared to be detrimental to, or possibly interfere with, the bonding of the fibers because all the mechanical properties of the panels containing PP were lower than those without PP. For physical property tests, neither the PF resin nor the PP bonded the fibers well enough to prevent excessive swelling or expansion.

Composite panels made from recycled office wastepaper had lower mechanical properties when made with 5% phenolic resin and 10% PP compared with panels made from kenaf. However, these panels had enhanced short-term moisture resistance compared with kenaf panels.

The poor bonding performance of both the phenolic resin and PP was probably due to a number of reasons. The first is that the absorbent characteristics of both the kenaf fiber and office wastepaper drew the resin deeper into the fibers and away from the fiber surface. This was most likely the case more with the office wastepaper than with the kenaf. To obtain strong bonding characteristics, the resin must remain on the surface of the fiber and yet have a strong bond to that fiber. One way to prevent the resin from being absorbed into the fiber is to treat the fiber to keep the resin on the surface. Uniform resin blending is also critical for making strong fiber to fiber bonds. Fiber balling during blending starves the fiber in the center of the ball for resin and concentrates the resin on the fiber on the outside of the fiber balls, thus creating uneven resin distribution. Even though the fiber balls are broken up during mat forming, fiber with insufficient resin can cause low mechanical and physical property values. To achieve improved mechanical and physical property values, increased levels of PF resin and/or PP would be required as well as an improved method for blending the fiber and resin to prevent fiber balling. Further study should focus on the effects of pressing temperature and pressing duration on the process of mat consolidation and on the resin cure.

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