2002 BELTWIDE COTTON CONFERENCES, ATLANTA, GA – JANUARY 8-12

THERMAL INSULATION PROPERTIES OF MOLDABLE NONWOVEN, CELLULOSIC COMPOSITES FOR AUTOMOTIVE APPLICATION

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Abstract

There is considerable potential for use of vegetable fibers such as kenaf, jute, flax, and cotton (cotton fines, waste fiber) in moldable thermoplastics for automotive applications. The composites of these fibers have high tensile and flexural properties, coupled with economic and environmental benefits. Needlepunched nonwoven fabrics were produced using refined kenaf fibers and other vegetable fibers in intimate blend with recycled polyester, and polypropylene (PP) in weight percent ratio of 35:35:30. Composites in the ratio of 35:35:30 were also produced on spunbonded polyester scrim. Composites of vegetable fibers with PP in the weight ratio of 50:50 were also produced.

The thermal conductivity of the nonwoven composites were determined by a steady-state heat flow method, in accordance with ASTM C518, using a new thermal conductivity meter, the Fox 200 of LaserComp Corporation. Average thickness of the samples was measured in accordance with the standard ASTM D 5736-95, and air permeability was determined by ASTM D 737-96 method. The test results show that thermal insulation properties of the composites vary significantly, depending on the type of cellulosic fiber, the pretreatment of fibers, ratio of cellulosic to synthetic fibers, and overall densities of the composite.

Introduction

The annual production and sales of cars and light trucks in the US is expected to reach 15.9M in 2001and it is predicted to be close to that average in upcoming years according to an editorial in "Business Day". Commonly, about twenty square meters of various types of nonwoven fabrics from synthetic fibers are used in the interior and trunk of an average car. The metal parts of disposed cars are scrapped and recycled; however, non-metal components are usually disposed of in waste landfills. It takes a long time for thermoformable nonwoven automotive fabrics to degrade under ambient condition. This creates significant environmental problems. The solution to the problem could be partial replacement of the synthetic fibers with cellulosics, which are abundant in supply, renewable and readily biodegradable. In combination with thermoplastic synthetic fibers, certain natural cellulosic fibers such as cotton, kenaf, jute and flax could be suitable starting materials for development of low cost nonwoven composites for automotive interiors. Incorporating cellulosic fibers in nonwoven composites for automotive interiors will dramatically improve their biodegradability while maintaining required acoustical/thermal insulation properties. The acoustical performance of various cellulosic nonwoven composites was described in an earlier publication. The objective of this study was to examine thermal conductivity and heat transmittance of needlepunched nonwoven materials manufactured from selected cellulosic fibers and combinations with thermoplastic synthetic fibers.

Experimental

Materials

All natural fibers used to manufacture sets of nonwoven composites were grown and purchased from domestic sources. Greige cotton fibers were obtained from Veratec, Colrain, MA. Scoured and bleached cotton fines (waste from cotton swab manufacturing) were obtained from American White Cross, Dayville, CT. Tainung-2 (T-2) kenaf fiber stocks were obtained in 400 lb. bales from Mississippi State University. Everglades 41 (E-41) kenaf bast fiber ribbons (40-50 inch length) were obtained from the University of Arkansas. Janesville & Co., Norwalk, OH, donated flax fibers and Clark, Cutter and McDermott Company, Franklin, MA, donated jute fibers. Clark, Cutter and McDermott also donated recycled polyester fibers and substandard polypropylene fibers. Freudenberg, Durham, NC, donated Substandard 56-11 spunbonded polyester scrim (130 gsm) that was used for reinforcement of some needlepunched batts.

Nonwoven Composites

Four different sets of needlepunched carded nonwoven fabrics with densities of ~ 20 - 30 oz/yd^2 were fabricated from various cellulosic fibers in combination with recycled polyester and polypropylene fibers with/without Fradenberg PET scrim.

The first set of needlepunched nonwoven batts (samples A-1, 2 and 3; A-4 is the control) were fabricated from jute, kenaf (T-2) and bleached cotton fines along with recycled polyester (PE) and polypropylene (PP) fibers in a weight percent ratio of 35:35:30. The second set (samples B-1, 2, and 3; B-4 is the control) was prepared from kenaf (T-2) fibers that underwent combined soap finishing & caustic pretreatment (1, 2 and 4 hr.) and greige cotton fibers in weight percent ratio of 20:80. The third set of needlepunched nonwovens with target densities of 20 and 30 oz/yd^2 (samples: C20-1, 2, 3 and C30-1, 2, 3) was fabricated from the jute, kenaf (E-41) and greige cotton fibers in blending with recycled PE and PP fibers on Fradenberg PET scrim in weight percent ratio of 35:35:30. The similar sets of needlepunched nonwovens (D-20 and D-30) were fabricated from the same jute, kenaf (E-41) fibers along with flax fibers in combination with recycled PE and PP fibers in weight percent ratio of 50:50. Additional sets of samples (controls) were made from "pure" recycled polyester and polypropylene fibers in weight percent ratio of 70:30 and they were used for comparative evaluations. The list of samples together with their descriptions and selected samples properties are presented in Tables 1 and 2.

Thermal Testing

After evaluation of various techniques for measurement of thermal properties of poorly conductive materials, such as needlepunched nonwoven composites, we selected the static method based on a heat flux sensor, which is comparable to ASTM C518 Standard Test Method. The Heat Flow Test Method C 518 covers determination of steady-state thermal transmission properties through flat slab specimens using a Heat Flux Meter apparatus. Measurements of specific thermal conductivity* of cellulosic-based nonwoven composites were performed using a newly developed thermal conductivity meter, the FOX 200, which was designed and manufactured by LaserComp Corporation (Figure 1). This instrument held its internal calibration very well when compared to a NIST standard sample (high-density glass-fiber board).

The thickness of the nonwoven samples was measured in accordance with standard ASTM D 5736-95. Air permeability of samples was measured on a Frazier permeability tester in accordance with ASTM D 737-96 Standard Test. Tensile properties of samples were measured in accordance with ASTM D 5035-89 and bursting strength was measured with ball burst apparatus on an Accutest tensile tester with the crosshead speed of 12 inches/min in accordance with ASTM D 3878-89 Standard Test.

Before conducting measurements, all samples of non-woven composite materials were conditioned at standard textile conditions (20 $^oC \pm 2^oC$, 65 % ± 2 % RH) for 24 hours. The average of three measurements for each sample was used to calculate mean values of specific thermal conductivity for each nonwoven specimen. The overall accuracy of the measurements of thermal conductivity of nonwoven samples was found to be better then 1 %, repeatability – 0.2 % and reproducibility – 0.5%.

Results and Discussion

Heat Transfer Mechanism in Nonwoven Composites

The thermo-conductive properties of cellulosic-based, needlepunched nonwoven fabrics depend on the nature and fineness of fibers, inter fiber pore size, distribution of fibers in the composite and overall material bulk density. A porous medium, such as nonwoven composites, can be treated as a combination of a solid substance and still air that fills its pore space. It is well known that still air has very low thermal conductivity of 0.0245 $W \cdot m^{-1} \cdot K^{-1}$ at 20-30 ^oC and textile fibers have an order of magnitude of higher conductivity then still air. There are three fundamental ways by which heat energy can be transferred through the material – conduction, convection and radiation. Depending on the fiber's specific thermal conductivities or the size and configuration of the space between fibers in the nonwoven sample, heat-transport mechanisms - conductive, radiative and convective will provide different contributions to overall heat transfer throughout the sample. Very complex interactions and contributions of various heat-transfer mechanisms in overall thermal insulation properties of nonwoven composites make direct measurement of the thermal conductivity of these materials the only viable option.

Thermal Insulation Properties of Cellulosic-based Nonwoven Composites

The objective of this study was to determine specific thermal conductivity and thermal transmittance of nonwoven composite materials made from a combination of various vegetable fibers, such as kenaf, jute, cotton and flax, and recycled polyester/substandard polypropylene fibers. The experimental results are presented in Figures 2-6.

The data indicate that among the samples of air-laid, needlepunched (2 times) composites (A-1, 2 and 3) the cotton-based composite had the highest thermal conductivity, and the jute-based material had the least conductivity (Figure 2). Thermal insulation properties of the jute-based sample were practically identical to that of the control sample from "pure" recycled polyester/substandard polypropylene fibers.

Figure 3 shows the thermal conductivities of kenaf/greige cotton composites manufactured from T-2 kenaf fibers that underwent various degree of preparation treatment (caustic boil; 1, 2 and 4 hours). The data indicates that the longer caustic boil insured greater refining of kenaf fibers and accordingly more dense packing of these fibers in the composite. This results in higher thermal conductivity relative to the control sample that was manufactured from unfinished kenaf fibers.

Figures 4 and 5 present data on thermal conductivities of four sets of samples of carded and needlepunched (4 times) nonwoven composites made from various cellulosic fibers in two vegetable/synthetic fibers ratios (35:35:30 and 50:50) with target densities of around 20 and 30 oz/yd^2. Similarly to the air-laid samples (Figure 2) the cotton-based composite (C20-3) showed the highest thermal conductivity and the jute-based (C20-2) the lowest. For samples with 50:50 vegetable/synthetic fibers ratio the thermal insulation properties of the flax-based sample (D20-3) were the best. Likewise, among samples with target densities approximately 30 oz/yd^2 the highest thermal conductivity was observed for the cotton based sample (C30-3). Among 50:50 samples the kenaf-based sample (D30-1) had the lowest value. Comparison of specific thermal conductivities of 20 oz/yd^2 samples (Figure 4) versus 30 oz/yd^2 samples (Figure 5) indicates that samples with lower densities have significantly better thermal insulation properties. Figure 6 presents the specific thermal conductivities of all measured samples versus their calculated densities. The graph clearly shows the pronounced trend of an increase of thermal conductance of samples with an increase in the sample's density. A similar trend was reported in the literature, but in a more recent publication, the authors [9] observed an opposite trend for samples of perpendicular and cross-laid lofty nonwoven fabrics. These contradictory reports could be explained by variability in the nature and fineness of the used fibers, and also by variations in the manufacturing process and measurement techniques.

Conclusions

Cellulosic-based nonwoven composites, suitable for automotive application, were fabricated from kenaf, jute, flax, and waste cotton using recycled polyester and substandard polypropylene. These low cost nonwoven composite materials with excellent thermal insulation properties have good tensile and flexural strength, excellent shape stability and enhanced biodegradability.

Thermal conductivity and thermal transmittance of cellulosic-based nonwoven composites vary significantly, depending on the type of vegetable fibers, the ratio of vegetable fibers to synthetic fibers, and the resulting bulk density of the composite.

Data also show that addition of vegetable fibers significantly improved thermal insulation properties of needlepunched composites compared to those made from synthetic fibers only.

Disclaimer

Specific company, product, and equipment names are given to provide exact description of experimental details. Their mention does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Acknowledgements

The authors wish to thank Farrell Screen for his help in sample preparation.

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Table 1. List of samples of nonwoven composites, their descriptions and basic properties.

Sample	**Sample Description**	**Components weight ratio, %**	**d, thickness, cm**	**ρ, density, kg/m^3**
A-1	Air Laid; kenaf (T-2) + recycled PE + PP	35:35:30	1.93	70.4
A-2	Air Laid; cotton fines + recycled PE + PP	35:35:30	1.16	75.3
A-3	Air Laid; jute + recycled PE + PP	35:35:30	1.42	57.7
A-4	Control sample; recycled PE + PP	70:30	1.31	57.0
B-1	Carded; needlepunched twice; kenaf (T-2) + greige cotton; 1hr. treatment	80:20	0.41	60.1
B-2	Carded; needlepunched twice; kenaf (T-2) + greige cotton; 2hr. treatment	80:20	0.45	58.6
B-3	Carded; needlepunched twice; kenaf (T-2) + greige cotton; 4hr. treatment	80:20	0.46	63.2
B-4	Control sample, kenaf not finished; kenaf (T-2) + greige cotton	80:20	0.42	61.0
C20-1	Carded; needlepunched 4 times; kenaf (E-41) + recycled PE + PP; on PET scrim	35:35:30	0.76	93.9
C20-2	Carded; needlepunched 4 times; jute + recycled PE + PP; on PET scrim	35:35:30	0.76	92.7
C20-3	Carded; needlepunched 4 times; cotton fines + recycled PE + PP; on PET scrim	35:35:30	0.80	94.7
C20-4	Control sample; recycled PE + PP	70:30	0.94	78,7
C30-1	Carded; needlepunched 4 times; kenaf (E-41) + recycled PE + PP; on PET scrim	35:35:30	1.08	96.6
C30-2	Carded; needlepunched 4 times; jute + recycled PE + PP; on PET scrim	35:35:30	1.06	100.4
C30-3	Carded; needlepunched 4 times; cotton fines + recycled PE + PP; on PET scrim	35:35:30	0.99	101.0
C30-4	Control sample; recycled PE + PP	70:30	1.13	93.4
D20-1	Carded; needlepunched 2 times; kenaf (E-41) + PP	50:50	0.89	78.9
D20-2	Carded; needlepunched 2 times; jute + PP	50:50	1.04	71.0
D20-3	Carded; needlepunched 2 times; flax + PP	50:50	1.03	68.4
D30-1	Carded; needlepunched 4 times; kenaf (E-41) + PP	50:50	1.01	89.7
D30-2	Carded; needlepunched 4 times; jute + PP	50:50	1.20	85.4
D30-3	Carded; needlepunched 4 times; flax + PP	50:50	1.12	88.5

Table 2. Selected sample properties.

Sample	Weight, Kg/m^2	Air Permeability, ft^3/min/ft^2	Bursting Strength (Ball Burst), lb$_f$	Tensile Strength, lb$_f$		Elongation, %	
				MD	CD	MD	CD
B-1	0.255	391.0		0.639	0.148	48.4	96.5
B-2	0.262	384.8		0.540	0.194	38.3	74.2
B-3	0.290	240.2		0.787	0.277	31.0	45.3
B-4	0.255	272.0		0.687	0.203	34.4	54.9
C20-1	0.700	89.9	385.1				
C20-2	0.679	91.0	389.8				
C20-3	0.740	38.3	434.6				
C20-4	0.736	82.6	418.4				
C30-1	1.063	67.2	288.1				
C30-2	1.018	68.6	391.5				
C30-3	1.018	29.7	517.4				
C30-4	1.013	57.0	420.0				

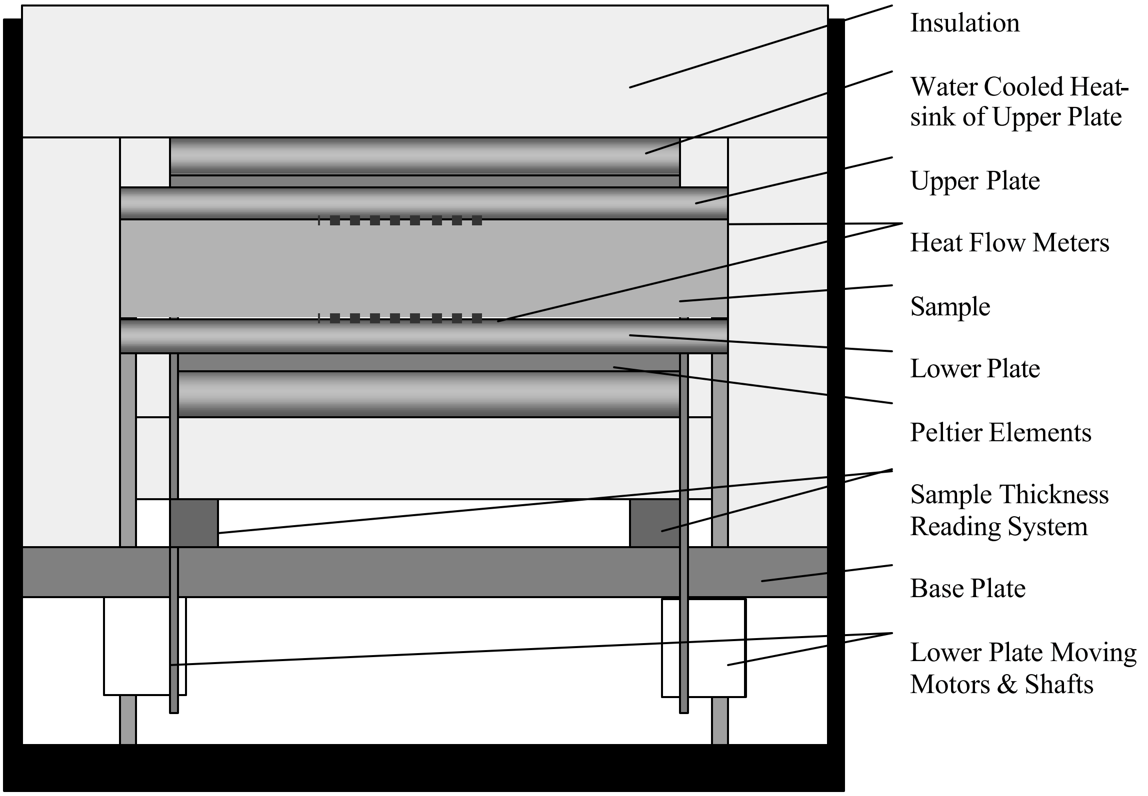

Figure 1. Schematic diagram of FOX-200 Heat Flow Meter.

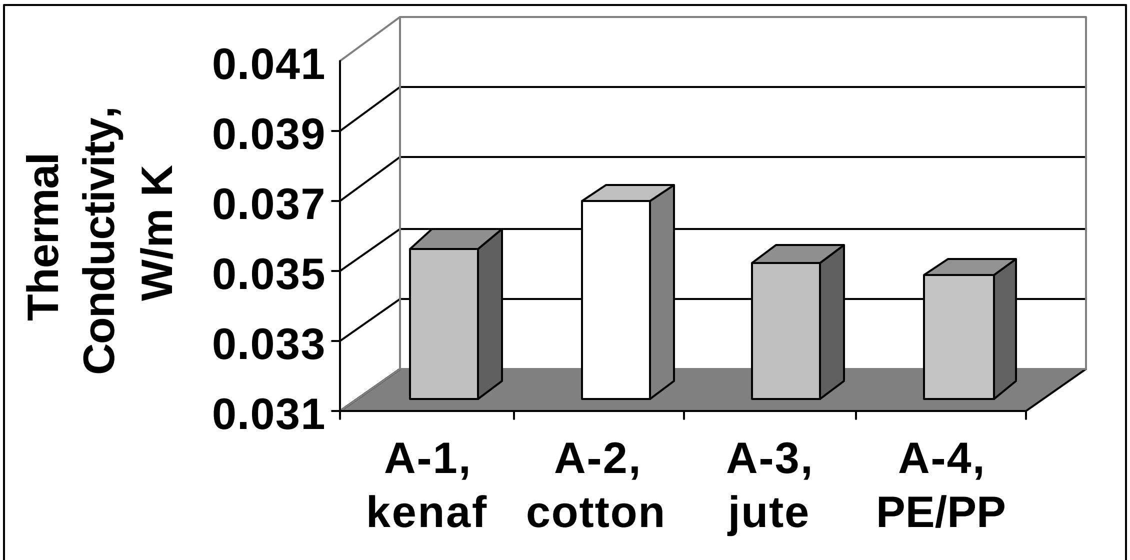

Figure 2. Thermal conductivity of air-lade, nonwoven composites made from vegetable fiber/recycled PE/PP; 35:35:30.

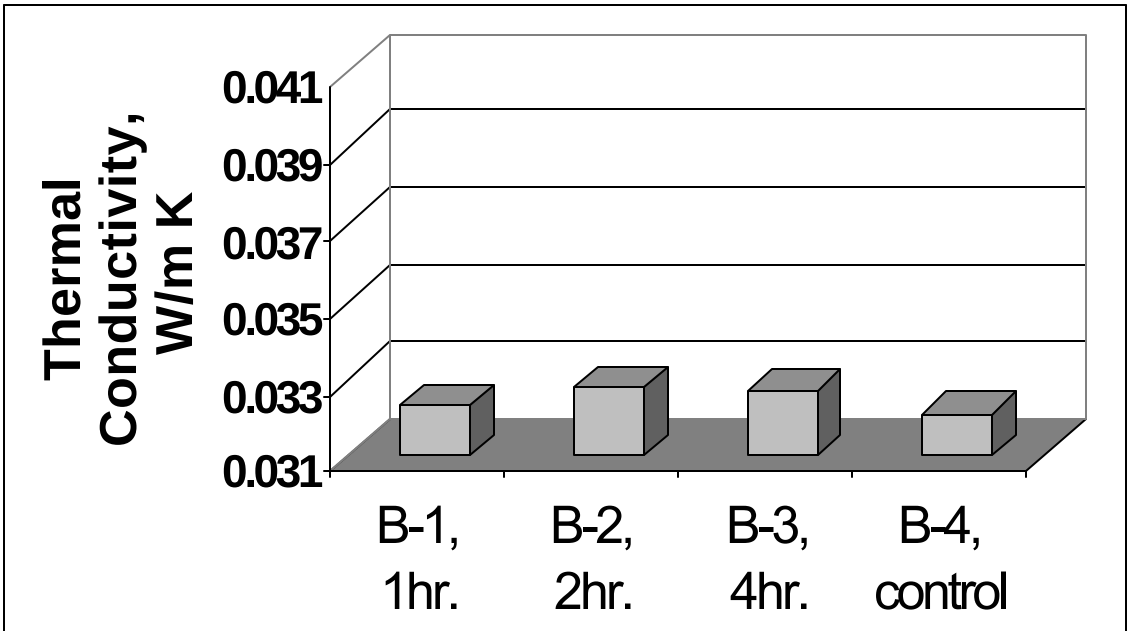

Figure 3. Thermal conductivity of carded, nonwoven composites made from kenaf /greige cotton after various degree of preparation of kenaf (T-2) fibers; 80/20.

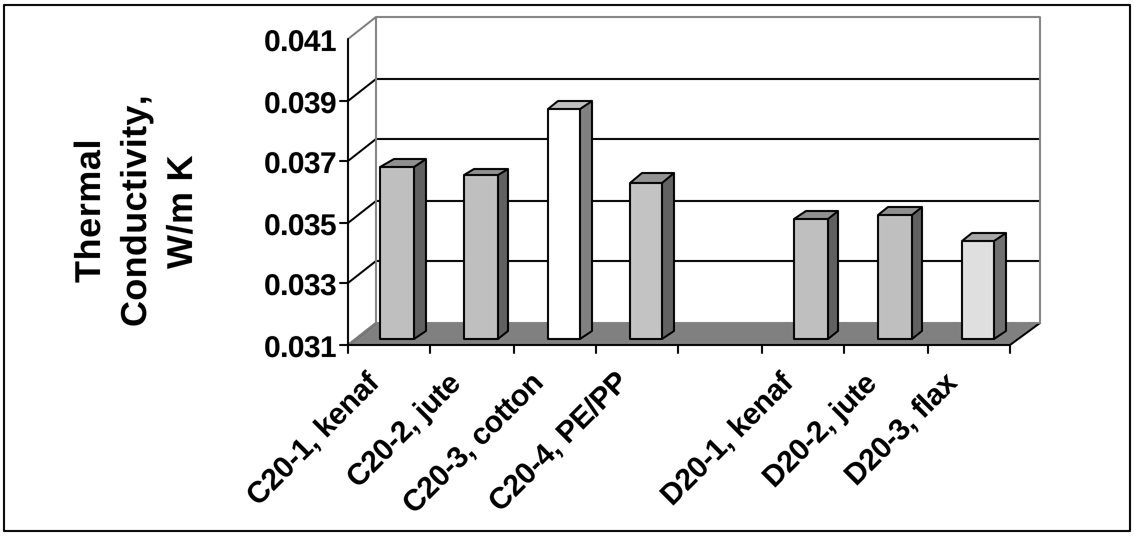

Figure 4 Thermal conductivity of carded, nonwoven composites made from vegetable fiber/recycled PE/PP and vegetable fiber/PP in two ratios (35:35:30 and 50:50) with target density approximately 20 oz/yd^2.

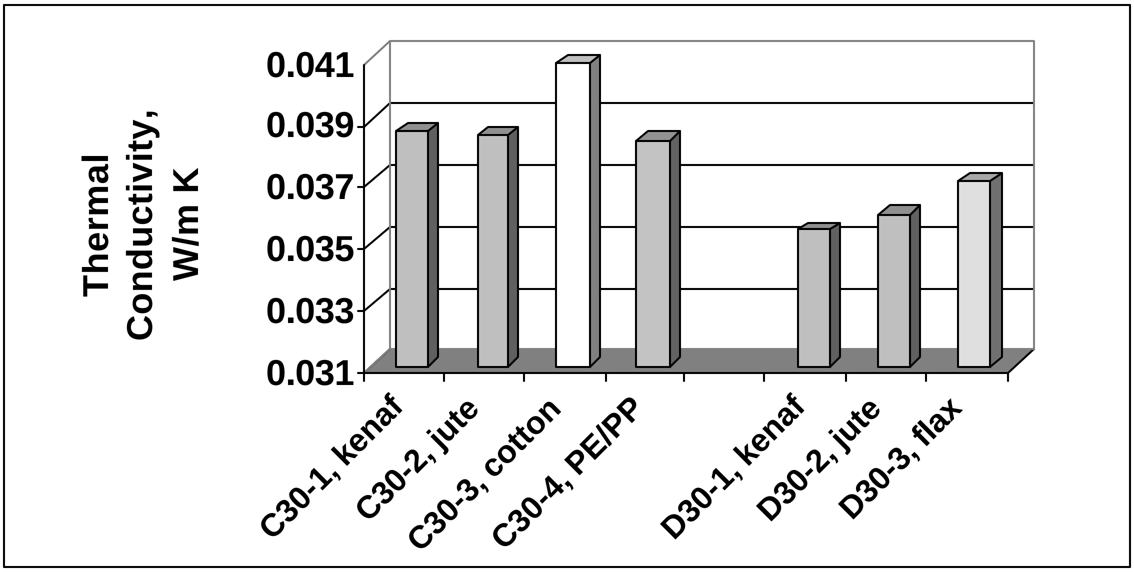

Figure 5. Thermal conductivity of carded, nonwoven composites made from vegetable fiber/recycled PE/PP and vegetable fiber/PP in two ratios (35:35:30 and 50:50) with target density approximately 20 oz/yd^2.

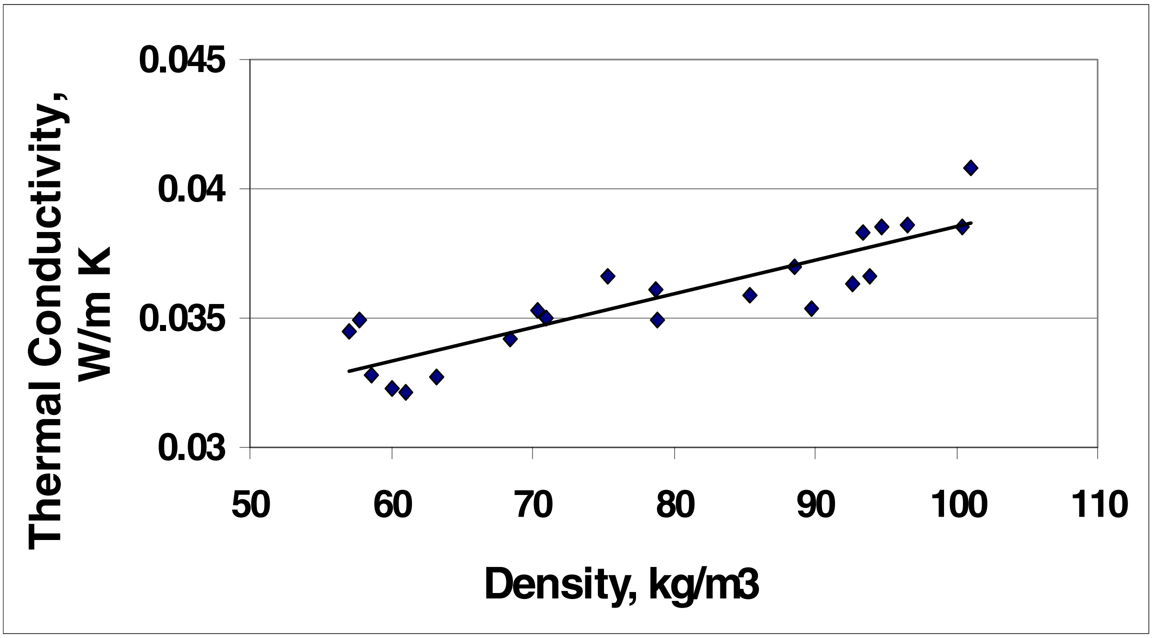

Figure 6. Specific thermal conductivities of all measured samples (λ) versus their calculated densities (ρ).