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THERMAL INSULATION PROPERTIES OF KENAF AND COTTON NONWOVEN COMPOSITESFOR AUTOMOTIVE APPLICATION

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Abstract

There is good potential for use of vegetable fibers such as kenaf, ramie, jute, flax, and cotton in moldable nonwoven composite materials for automotive applications. Variety of automotive parts, such as headliner, wall panels, trunk liners, parcel shelves, and hood sound insulators with excellent shape stability can be manufactured by conventional techniques. The composites of these fibers have high tensile and flexural properties, coupled with economic and environmental benefits. Four sets of nonwoven materials were produced from refined kenaf fibers, other vegetable fibers and their blends with recycled polyester and polypropylene. The thermal insulation properties of the nonwoven composites were determined by the steady-state heat flow method, in accordance with ASTM C518, using the new thermal conductivity meter. The experimental data show that thermal insulation properties of the nonwoven 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 current annual world production (by regions) and sales of cars and light trucks is around 56 million units (Table I) and predicted to reach up to 60 million units of total vehicle production in 2008 (Böttcher 2003). Commonly, consumption of textile products in each car is around 20 kg, among which nonwoven materials account for 11% (WTP Ltd. 1999). Estimated yearly demand for nonwoven materials in the automotive interior applications is approximately 120 kt., including North America, which shares approximately 30% of this global market.

Table 1. Global Auto Production (million units).

Area	1998	2001
North America	14.7	16.7
Europe	18.2	19.2
Central/South America	2.3	2.2
Asia/Pacific	16.7	18.0
Africa	0.5	—
Total	**52.4**	**56.1**

At the end of life cycle the metal parts of disposed cars are scrapped and recycled; however, non-metal components are usually disposed in waste landfills. It takes a long time for nonwoven automotive fabrics to degrade under ambient conditions, thus creating 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 kenaf, cotton, ramie, 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 objective of this study was to examine thermal conductivity of various nonwoven materials manufactured from selected cellulosic fibers and combinations with thermoplastic synthetic fibers.

Experimental

Materials

Kenaf fibers used in this study were from different places, such as Shandong China, Mississippi State University, and University of Arkansas. Ramie fiber that was used to make blends with kenaf was also provided by a U.S. company. Greige cotton fibers were obtained from Veratec, Colrain, MA. 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. Two different types of binders were used for kenaf fiber bonding. Tables 2 and 3 summaries the specification of samples of nonwoven fabric manufactured from these fibers.

Table 2. List of samples of nonwoven composites (automotive headliner).

Sample		ρ Density (kg/m^3)	λ (W/mK)	λ/ρ
Carded	1	0.159	0.0210	0.132
	2	0.158	0.0216	0.137
	3	0.148	0.0217	0.147
	4	0.135	0.0197	0.146
	5	0.154	0.0276	0.179
	6	0.148	0.0205	0.139
	7	0.168	0.0202	0.120
	8	0.124	0.0151	0.122
	9	0.157	0.0223	0.142
Airlaid	100 Kenaf	0.119	0.0208	0.174
	70/30 K/R	0.140	0.0218	0.156

Table 3. List of samples of nonwoven composites (trunk interiors).

Sample	Sample Description	Components weight ratio (%)	ρ Density (kg/m^3)
C20-1	Carded; needlepunched 4 times; kenaf + recycled PE + PP; on PET scrim	35:35:30	93.9
C20-2	Carded; needlepunched 4 times; jute + recycled PE + PP; on PET scrim	35:35:30	92.7
C20-3	Carded; needlepunched 4 times; cotton fines + recycled PE + PP; on PET scrim	35:35:30	94.7
C20-4	Control sample; recycled PE + PP	70:30	78.7
D20-1	Carded; needlepunched 2 times; kenaf + PP	50:50	78.9
D20-2	Carded; needlepunched 2 times; jute + PP	50:50	71.0
D20-3	Carded; needlepunched 2 times; flax + PP	50:50	68.4

Nonwoven Composites

Nine carded nonwoven kenaf/ramie samples and two airlaid nonwoven samples (automotive headliner; table 2) were produced in the LSU Textile Processing Laboratory. The kenaf fiber was cleaned by cotton cleaner and mixed with the ramie fiber in a ratio of 70% kenaf and 30% ramie. The kenaf/ramie blend was fed into a lab-scale carding machine twice to obtain uniform fiber web. A Morisson Benkshire needle-punching machine was used for mechanically bonding the kenaf/ramie web. The needle-punching machine ran at a feeding speed of 5.4 feet/min and punching rate of 228 strokes/min. The needle-punched web was further bonded with 10% PVA solution that was prepared from granulated PVA powder and applied to the nonwoven by a padding machine (Birch Brother Inc.). The padded nonwoven was then dried in an oven. Fabrication of the airlaid nonwoven was a continuous procedure, including carding, airlaying, padding, and drying. Two airlaid nonwoven samples were used in this study including one pure kenaf and the other is 70/30 kenaf/ramie nonwoven.

In addition, two different sets of needlepunched carded nonwoven fabrics (trunk interiors) with densities of ~ 20 oz/yd^2) were fabricated in SRRC Nonwoven Laboratory. Samples were manufactured from various cellulosic fibers in combination with recycled polyester and polypropylene fibers with/without Fradenberg PET scrim (Table 3). Special 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. All fibers were opened in an Uster Spinlab Fiber Opener/Blender and blended in accordance with the predetermined weight percent ratio. Blended, carded webs of vegetable fibers with PE and PP fibers were run through a Morrison-Berkshire needlepunch loom. The needle-punching machine ran at a feeding speed of 6.0 feet/min and punching rate of 228 strokes/min.

Thermal Testing

After evaluation of various techniques for measurement of thermal insulation 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 (ASTM 2001). 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. This instrument held its internal calibration very well when compared to a NIST standard sample (Canaday and Brown 2000).

The thickness of the nonwoven samples was measured in accordance with standard ASTM D 5736-95. Before conducting measurements, all samples of non-woven composite materials were conditioned at standard textile conditions (20°C ± 2°C, 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 non-woven samples was found to be better then 1%, repeatability – 0.2% and reproducibility – 0.5% (Zarr and Lagergren 1999).

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 °C and textile fibers have an order of magnitude of higher conductivity then still air (Dean 1992). 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, irradiative 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 non-woven composites make direct measurement of the thermal conductivity of these materials the only viable option.

Thermal Insulation Properties of Cellulosic-Based Nonwoven Composites

The experimental data on thermal conductivity (λ) for the carded/airlaid nonwovens (**automotive headliner**) is listed in Table 2 and Figure 1. Because all tested samples had slightly different density and/or different kenaf/Ramie blending ratio, it was important to compare the thermal properties of these samples in a way that eliminates these effects. This was accomplished by normalizing the measured value of specific thermal conductivity of the sample (λ) by density coefficient (**ρ**). Normalized thermal conductivity (**λ/ρ**) provides a better means for comparison of thermal properties of non-woven composite materials by excluding variations in density caused by manufacturing and/or finishing processes. It also provides a better evaluation tool for these types of materials in light of their possible automotive application as thermal/sound insulators because more lightweight nonwovens would warrant better fuel efficiency. Experimental data indicates that all nine carded samples for automotive headliner (except #5) have a significantly lower thermal conductivity than the airlaid samples. This means the carded samples can perform as a much better thermal insulation material in auto applications.

Figure 2 presents data on normalized thermal conductivities of two sets of carded/needlepunched composites **(trunk interiors**) made from various cellulosic fibers in two vegetable/synthetic fiber ratios (35/35/30 and 50/50). Experimental data indicates that all cellulosic-based composites (samples C20-1, 2 and 3) showed significantly better thermal insulation properties (~13-18%) compared to the control sample (C20-4). All samples with 50/50 vegetable/synthetic fiber ratio (D20) were more conductive to heat then C20 samples. This is probably because of the difference in the manufacturing process (no PE scrim; needlepunched twice). Figure 3 presents the specific thermal conductivities of the 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 (Morris 1953), but in a recent publication, the authors (Jirsak et al., 2000) 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.

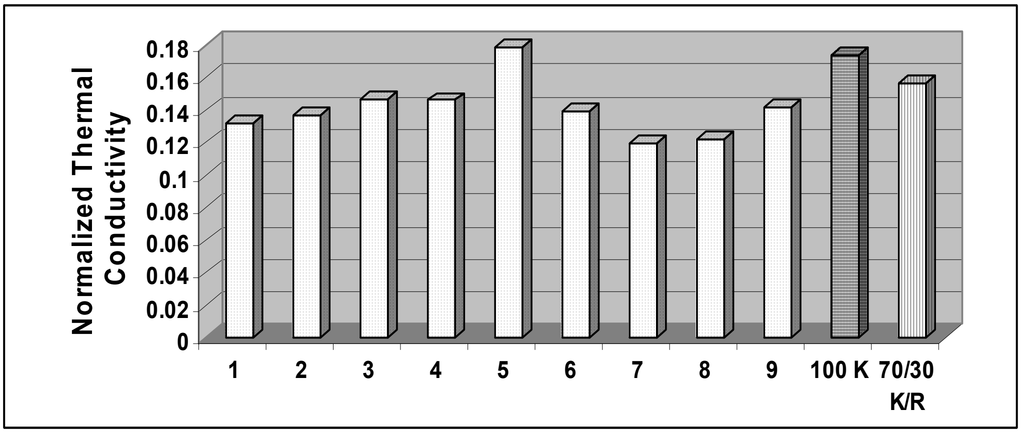

Figure 1. Normalized thermal conductivity of carded/airlaid nonwoven composites (automotive headliner).

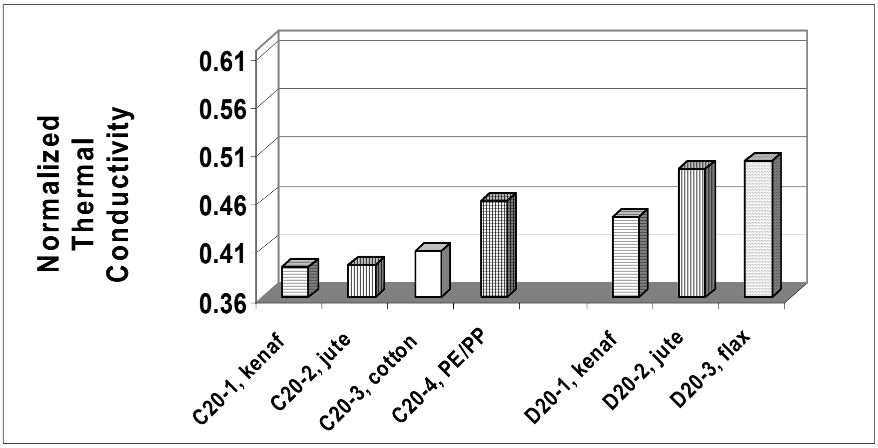

Figure 2. Normalized thermal conductivity of carded nonwoven composites (trunk interiors) made from vegetable fiber/recycled PE/PP in two ratios of 35/35/30 and 50/50.

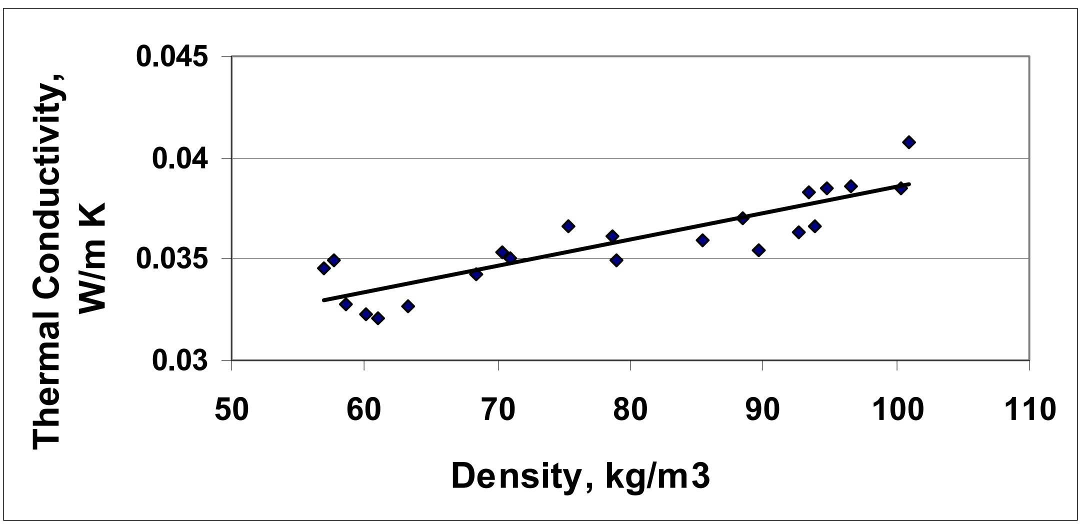

Figure 3. Specific thermal conductivities (λ) of carded nonwoven composites vs. their calculated densities (ρ).

Summary

- Variety of cellulosic-based nonwoven composites, suitable for automotive application, was fabricated from kenaf, ramie, cotton, jute, flax, and recycled polyester/substandard polypropylene.
- The data indicate that carded, needlepunched nonwoven composites would be better thermal insulators than the airlaid nonwovens.
- Thermal conductivity of cellulosic-based nonwoven composites varies 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.

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