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Improving Sound Absorption Property of Polyurethane Foams by Adding Tea-Leaf Fibers

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The sound absorption property of polyurethane (PU) foams loaded with natural tea-leaf fibers and luffa cylindrica (LC) has been studied. The results show a significant improvement in the sound absorption property parallel to an increase in the amount of tea-leaf fibers (TLF). Using luffa-cylindrica as a filler material improves sound absorption properties of soft foam at all frequency ranges. Moreover, an increase in the thickness of the sample resulted in an improvement of the sound absorption property. It is pleasing to see that adding tea-leaf fibers and luffa-cylindrica to the polyurethane foam demonstrate a significant contribution to sound absorption properties of the material and it encourages using environmental friendly products as sound absorption material in further studies.

Keywords: fibers, polymer-matrix composites, sound absorption, tea-leaf, luffa-cylindrica.

Notations

PU – Polyurethane,
TLF – Tea-Leaf Fibers,
MOCA – Methylene-bis-ortho-chloroanilline,
PET – Polyethylene terephthalate,
ISO – International Organization for Standardization,
ASTM – American Society for Testing and Materials.

1. Introduction

Polymer-based foams are widely used in industry to benefit from their mechanical, electrical, thermal and acoustic properties (Verdejo *et al.*, 2009). Polyurethane (PU) is one of the polymers with the largest and most versatile applications having the ability to easily change its properties by changing the chemical composition or adding filler reinforcement agents. It is commonly used as adhesives to join different materials in the footwear and automotive industry.

There are many studies of PU composites involving the use of synthetic fibers such as glass, carbon, boron, nylon, and kevlar. The tensile properties of polyurethane foams can be increased using polyester, glass, Kevlar-49 aramid fiber (Chen, Ma, 1992a; 1992b; 1994; Vaikhanski, Nutt, 2003a; 2003b), carbon nanotubes (Verdejo *et al.*, 2009), multi-walled carbon nanotubes (Chen *et al.*, 2006), methylene-bis-ortho-chloroanilline (MOCA)-grafted carbon nanotubes (Xiong *et al.*, 2008), SiO_2 (Yang *et al.*, 2004), silexil (Saliba *et al.*, 2005), post-consumer PET (polyethylene terephthalate) (Mello *et al.*, 2009), and mineral fillers such as calcium carbonate and crystallized silica particles (Saint-Michel *et al.*, 2006). Pure carbon nanotubes (Kucerova *et al.*, 2009), multi-walled carbon nanotubes (Chen *et al.*, 2006), and silexil (Saliba *et al.*, 2005) contribute to the Young's modulus of PU foam composites.

Using synthetic fibers as reinforcement agents in PU foam composites produces some disadvantages such as slow deterioration, higher cost, and consumption of nonrenewable resources. On the other hand, biodegradability and low cost properties of renewable natural materials has attracted the attention of many researchers (Demir, 2006; Yalinkilic *et al.*, 1998).

Among the coconut and woven sisal fabric mixed PU composites, alkali-treated coconut fibers exhibit the best fracture toughness (Silva *et al.*, 2006). Among the pine wood and hemp fibers used to reinforce microcellular cross-linked PU synthesized from a castor oil-based polyol, hemp fibers provide the best dynamic flexibility, modulus and toughness characteristics (Aranguren *et al.*, 2007). Abrasive properties of PU foam can be increased by adding garnet particles into the mixture (Jang *et al.*, 2001). Stacking hardwood-based cellulose fiber mats between polyurethane films and using compression molding improves the tensile strength and modulus properties (Seyidbeyoğlu *et al.*, 2008). Among the cotton, bamboo and wool fibers mixed with polyurethane foam, cotton fibers result in the best sound absorption properties (Büyükakinci *et al.*, 2011).

Sound absorption constitutes one of the major requirements for human comfort today, especially in automobiles and manufacturing environments. These applications create a higher sound pressure and thereby the need to develop more efficient and economical ways of producing sound absorption materials. Industrial applications of sound absorption generally includes the use of materials such as glass wool, foam, mineral fibers and their composites. Using a laminated polyester fabric composed of different layers bonded by polyurethane adhesive doped with a removable salt are already studied to determine the sound permissibility levels in automobiles (Mahmoud *et al.*, 2011). Also, a laminated composite consisting of three different layers of tea-leaf fiber waste materials with and without backing were studied experimentally (Ersoy, Küçük, 2009) in order to determine their sound absorption properties. In this study, a single layer of woven textile cloth provides backing.

This study investigates the effect of tea-leaf fibers and luffa-cylindrica as agents on sound absorption properties of polyurethane foam. The reason of selecting tea leaf as a material in the production of sound absorbing composites is that tea was the second most popular drink in the world, after water. For a number of developing countries, it is also an important commodity in terms of jobs and export earnings. Tea production is labor intensive and the industry provides jobs in remote rural areas. Worldwide, the sector provides employment to millions of people. Tea production and export is a vital part of the economy for tea producing countries in terms of employment in remote and poor rural areas. The global tea production reached 3.5 million tons in 2006, while tea is produced in more than 35 countries. Turkey is the fifth biggest producer (142,000 tons) by having 4 percent share of the tea sector and the value of exports (5,500 tons) has reached 6,300,000.00 USD (Wal, 2008). Therefore, tea leaf (TLF) is actually a waste material and is easy to find. Luffa-cylindrica (LC) is a plant which has a hard spongy structure and other than wiping or cleaning purposes it does not have a significant commercial benefit. Due to its insignificant economics here we decided to utilize luffa-cylindrica for sound absorption purposes.

This study will investigate the reusability of wasted TLF and LC. Different compositions of TLF and LC with PU are used in the development of a new sound absorbent material. Two different foam types are used as matrix material. Tea-leaf fibers are added in these matrix materials in three different weights among which 24% weight tea-leaf composition has given the best properties. Later soft foam and LC combination was examined for sound absorption properties.

2. Experimental setup

2.1. Material

Two different PU foam types (isocyanate mixed with H 1710/6 polyol (PU1-rigid foam) and that one with H2411/1 polyol (PU2-soft foam)) are used as matrix materials. The compositions of the polymers are given in following table.

Table 1. Properties of H 1710/6 Polyol and Isocyanate components.

Physical properties	Unit	Polyol	Isocyanate
density (20°C)	g/cm^3	1.1	1.230
viscosity (20°C)	mPa·s	–	210
NCO content	%	–	31.5
Storage life	Month	6	6

Table 2. Properties of H 2411/1 Polyol and Isocyanate components.

Physical properties	Unit	Polyol	Isocyanate
density (20°C)	g/cm^3	1.01	1.24
viscosity (20°C)	mPa·s	400	300
NCO content	%	–	31.5
Storage life	Month	3	6

The PU foam was prepared by mixing the polyol and isocyanate at a 1:1 ratio. Tea-leaf fiber wastes, whose lengths changed between 1–5 mm, were prepared as an additive. A stainless steel die is used to prepare samples of the PU foam composite for acoustic measurements.

2.2. Preparation of TLF mixed PU samples

Composite samples are prepared by mixing TLF with a polyurethane formulation including isocyanate and forms of polyol. At the beginning of the study it was necessary to define different weight ratios of TLF in PU. For this purpose the maximum weight ratio must be defined. In order to determine the maximum amount of TLF that can be added to PU, many samples having different TLF weight ratios are produced. Then, the maximum weight ratio is obtained. The range of weight ratio of TLF varies between zero and the maximum weight ratio. Weight ratios are determined in this range and samples are prepared. H 2411/1 polyol samples are prepared heavier as it has lower density and have tendency to be more ductile. Tables 3 and 4 show the weight ratios of the first samples.

Table 3. H 1716/6 polyol and isocyanate with TLF (total 150 g).

Sample	TLF		Polyol		Isocyanate	
	% w	g	% w	g	% w	g
PU1TLF20	20	30	40	60	40	60
PU1TLF15	15	22.5	42.5	63.75	42.5	63.75
PU1TLF10	10	15	45	67.5	45	67.5
PU1	0	0	50	75	50	75

Table 4. H 2411/1 polyol and isocyanate with TLF (total 200 g).

Sample	TLF		Polyol		Isocyanate	
	% w	gr	% w	gr	% w	gr
PU2TLF24	24	48	38	76	38	76
PU2TLF16	16	32	42	84	42	84
PU2TLF8	8	16	46	92	46	92
PU2	0	0	50	100	50	100

Polyol and isocyanate are mixed with TLF at determined weight ratios. After pouring the mixture into the die, a driller with a mixer tool was used to bring the composition up to 2000 rpm in order to obtain a homogeneous compound. From each mold, 5 different samples with diameter of 100 mm for large tube measurements (Fig. 1a) and a smaller round piece with a 29 mm diameter for small tube measurements (Fig. 1b) were obtained.

a)

b)

Fig. 1. Samples prepared for sound absorption measurements: a) sample for the large tube, b) sample for the small one.

2.3. Preparation of luffa cylindrica mixed PU samples

Luffa cylindrica is a natural spongy and matrix structure which can be used as filler in PU. The luffa filler is cut half from the surface to the center parallel to its longitudinal axis and laid flat (Fig. 2).

a) b)

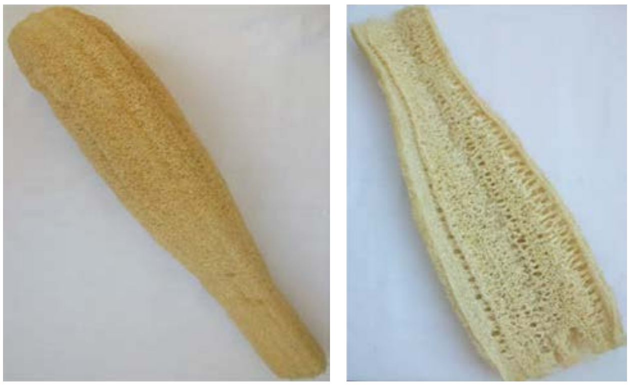

Fig. 2. Luffa cylindrica: a) natural, b) half-cut.

The samples of 100 mm diameter and 2 cm thickness were cut from raw flat luffa material (Fig. 3a). After mixing H 2411/1 polyol and isocyanate, luffa samples were immersed into the mixture before the formation of foam structure within pores of the filler. For small tube measurements, samples of 29 mm diameter are cut from large tube samples (Figs. 3b, c).

a)

b)

b)

Fig. 3. Luffa cylindrica and foam composites samples: a) luffa large tube sample, b) luffa small tube sample, c) foam-luffa small tube sample.

2.4. Measurements of acoustic properties

The testing apparatus is part of a complete acoustic material testing system featuring a Brüel& Kjær PULSE^{TM} interface (Fig. 4). In this study only an impedance tube kit 4206 was used.

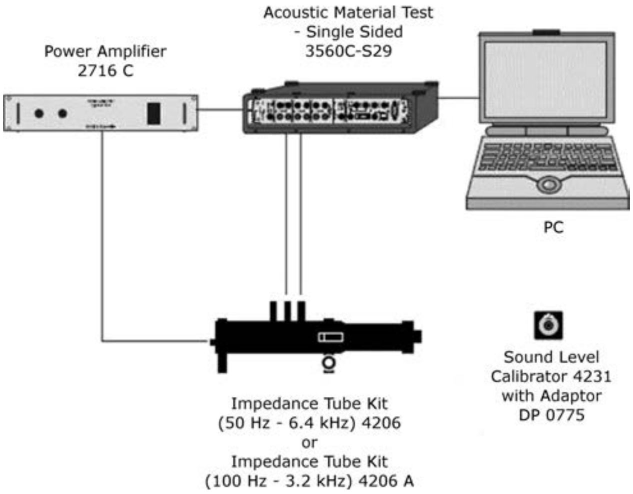

Fig. 4. Measurement tester of acoustic properties (courtesy of Brüel & Kjaer).

The sound absorption measurements were performed according to ISO 10534-2 and ASTM E1050-98 international standards for horizontally mounted orientation-sensitive materials using a two-microphone transfer-function method. The small impedance tube kits consisted of a 29 mm diameter tube (small tube), a sample holder, and an extension tube of the same diameter. The large impedance tube kit consisted of a similar tubular apparatus with a diameter of 100 mm. The small and large tube setups were used to measure different acoustical parameters and then large and small tube measurements were combined to determine the sound absorption coefficient for the frequency range of 50–6300 Hz.

3. Results

PU1 foam and Tea-Leaf Fiber composites are produced and sound absorption coefficients are measured for five times. The average values are plotted as graphs to make a comparison. PU1 Foam and Tea-Leaf Fiber composites are produced at two different thicknesses to see the effect of thickness on sound absorption property as well. The sound absorption coefficient values btained are plotted for the composite of H 1710/6 Polyol Foam (PU1) and the TLF. The samples have 2 cm (Fig. 5) and 1 cm thicknesses (Fig. 6). The absorption coefficient values are also plotted for the second composite of H2411/1 Polyol Foam (PU2) and the TLF (Fig. 7) and PU2 foam and LC (Fig. 8).

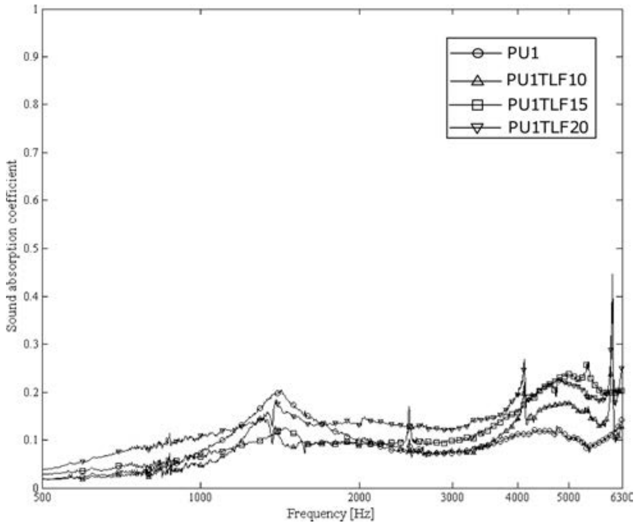

Fig. 5. Sound absorption of the PU1 foam and TLF composites (2 cm thickness).

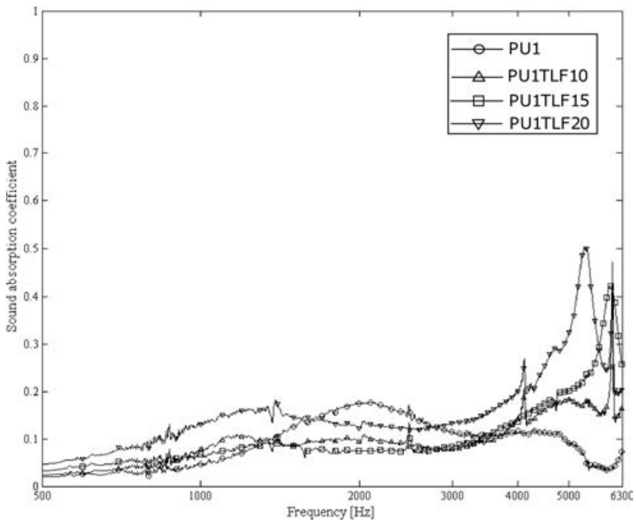

Fig. 6. Sound absorption of the PU1 foam and TLF composites (1 cm thickness).

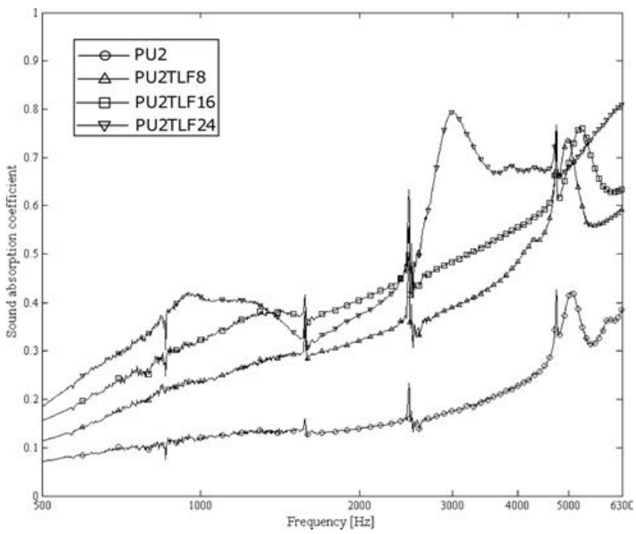

Fig. 7. Sound absorption of the PU2 foam and TLF composites (2 cm thickness).

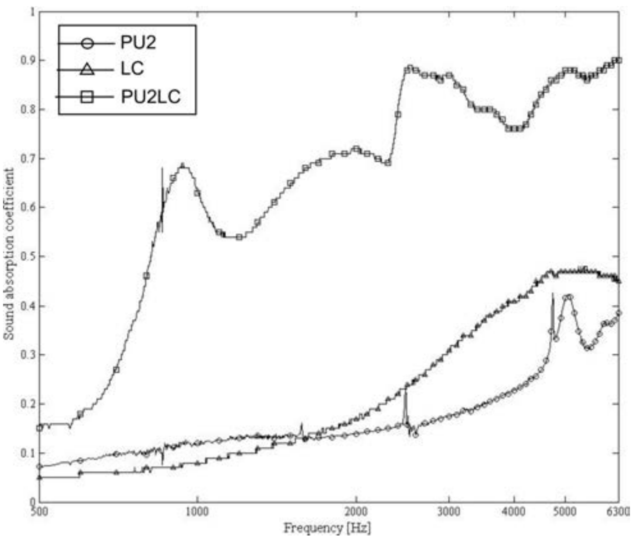

Fig. 8. Sound absorption of the PU2 foam, LC and PU2LC composites (2 cm thickness).

The sound absorption of pure LC is below PU2 between 0.5–1.5 kHz frequencies. However above 1.5 kHz until high frequency ranges sound absorption of LC progress higher than PU2 with a maximum of twice of PU2 at certain frequencies. Using LC as a filler in PU2 (PU2LC) results in exceptional sound absorption properties for all frequency ranges. In the mid frequency ranges sound absorption properties of PU2LC is more than 4 times higher than PU2.

4. Discussion

The sound absorption measurements of PU1 results in a maximum of 0.2 at 1.5 kHz for the case of 2 cm thickness of the samples. It is seen that all PU1 composites have at least two times better sound absorption characteristics between the frequencies 3.5–6 kHz. Also, an increase in the weight ratio results in a better sound absorption characteristic. PU1TLF15 has a 50% increase in the sound absorption compared to PU1TLF10 in the same frequency range, while PU1TLF20 has a 50% increase in sound absorption between the frequencies 0.05–4.25 kHz compared to PU1TLF15.

Decreasing the thickness of the PU1 samples from 2 cm to 1 cm results in a frequency shift at which the maximum sound absorption occurs. The sound absorption of the pure PU1 foam is very low at 50 Hz with a steady increase up to 0.2 at 2 kHz and then a steady decrease occurs down to 0.1 at frequencies between 5–6.3 kHz.

PU1TLF10 does not change sound absorption characteristics significantly compared to PU1. Also, increasing the TLF content to 15% does not make a noticeable change in the sound absorption characteristics. PU1TLF20 results in sound absorption twice as much as that indicated for PU1TLF15 in the frequency range of 0.5–5.5 kHz. However for higher frequencies, sound absorption of PU1TLF20 tends to be lower than that of PU1TLF15.

Sound absorption measurements for PU2 reveals a steady increase in sound absorption with an ultimate value of 0.39 at 6.3 kHz. There is a slight peak value of 0.42 in sound absorption at 5 kHz. Mixing 8% TLF into PU2 results in an increase as much as 80% in sound absorption compared to pure PU2. Increasing the TLF content to 16% results in a 25% increase in sound absorption compared to PU2TLF8 except the frequency range 4.75–5 kHz. The 24% TLF content in the PU2 matrix increases the sound absorption characteristics of the composite as much as 60% between the frequencies of 2.5–6.3 kHz.

Additionally using luffa-cylindrica does make a significant contribution to low frequency sound absorption properties. However between frequencies 1.5 kHz–6.3 kHz LC yields better sound absorption values compared to soft foam. Impregnating LC into soft foam improves sound absorption properties at all frequencies.

Using luffa-cylindrica as a sound proofing material improves sound absorption properties in the mid-to high frequency ranges. Adding luffa as a filler into polyurethane foam results in exceptional sound absorption properties. Especially in the mid frequency ranges the increase in sound absorption is more than four times of soft polyurethane foam.

5. Conclusions

The increased agricultural production and the development of agro-based industries in many countries of the world have brought about the production of large quantities of agricultural wastes, most of which are not adequately managed and utilized. Agricultural wastes were used for animal feed, fertilizer and fuel for energy production, but little work has been carried out to develop utilization of these wastes in the production of industrial materials. This study tried to fill this gap and showed an area to reuse wasted TLF.

The TLF mixed polyurethane-based composites are developed and acoustic measurements are performed to determine their sound absorption properties. TLF is a wasted by product of tea processing, extracted after drying and chopping of the leaves. Also, the TLF is hygienic, a product of renewable bio-resources, and is biodegradable. Using a novel natural fiber improves the sound absorption properties and causes lessening the environmental impact and reducing the cost of the developed material.

Including tea-leaf-fibers into PU1 improves the sound absorption properties significantly. The sound absorption results for PU2 indicate a steady increase at the frequencies between 1.6–6.3 kHz. Sound absorption of PU2 is four times greater than for PU1 at certain frequencies. Including 8–16% TLF improves the sound absorption values for all frequency ranges. Increasing the tea-leaf-fibers in the foam matrix to 24% improves the sound absorption properties in the mid-frequency ranges.

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