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ORIGINAL PAPER

The presentation of an agro-environmental nanocomposite: the study of its acoustic, physical and mechanical properties

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Abstract Nanocomposites can be used as an acoustic panel to adsorb noise. The aim of this study was to evaluate: (1) acoustic, (2) physical, and (3) mechanical properties of agro-environmental nanocomposites. To prepare the nanocomposites, wood flour, PVA glue, and aluminum nanoparticles (between 1 and 4 %) were hardly mixed and heated at near 220 °C for 120 min. In the next step, sound absorption coefficient, transmission loss, water absorption percentage, thickness swelling percentage, density, flexural strength, flexural modulus, tensile strength, and tensile modulus of nanocomposites were measured. This study showed that the increase in nanoparticle percentage led to the increase in flexural strength, flexural modulus, water absorption percentage, thickness swelling percentage, density, and sound absorption coefficient. But, the increase in nanoparticle percentage led to the decrease in tensile strength, tensile modulus, and transmission loss. The authors think that the nanocomposites are suitable as an agro-industrial nanocomposite to reduce noise.

Keywords Aluminum nanoparticles · Nanocomposite · Sound absorption

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Introduction

In the recent years, noise control from living environment has been highly attended (Wang et al. 2014). Importantly, noise is undesirable for human health and may cause increased blood pressure, sleep disorders, etc. These effects of noise can be so severe, i.e., it may cause a permanent memory loss or a mental disorder (Jiang et al. 2004; Singh and Davar 2004). There are two main methods to control noise, e.g., separation and adsorption. Theoretically, the physical laws governing the separation and absorption are quite different. Interestingly, the material that is a good isolator is a weak absorbent, and vice versa (Cox and D'Antonio 2009). Sound absorbers can be divided into three main groups, including porous materials, membranes, and panels (Charles 1998).

Today, composite materials are extensively used in building industry (Harris et al. 2002). Moreover, these can be used as acoustic panels to adsorb noise (Ismail et al. 2010). Nowadays, thin, lightweight, and low-cost composites are desperately needed to absorb sound waves in the wide range of frequencies (Byakova et al. 2014). Wood is the best choice to build advanced composites, because of high availability and durability. For many applications, wood has been used without any modification, but in some cases, it needs some modifications to improve its functional properties. Two important characteristics of the wood composites are density and modulus of elasticity. These parameters directly affect sound properties (Krokhin et al. 2003; Monties 1991; Saheb and Jog 1999).

Both alumina and aluminum can be used as an additive in wood composites, because of its low price, light weight, high corrosion resistance, good thermal and chemical stability, and acceptable mechanical properties. The most fundamental acoustic property of wood composites is their sound absorption coefficient (Krokhin et al. 2003). The property is increased with the decrease in pore size and of sample thickness. It has been found that aluminum with a porosity of 75 to 80 % has the best sound absorption (Guiping et al. 2001). Although the use of nanoparticle is very fantastic (Pourdanesh et al. 2014), there are some toxic effects (Barkhordari et al. 2014; Jebali et al. 2014).

The aim of this study was to evaluate acoustic, physical, and mechanical properties of some nanocomposites, based on wood flour, PVA glue, and aluminum nanoparticles. Moreover, the relationship between these parameters was studied.

Materials and methods

Materials

Aluminum nanoparticles were purchased from the Litotech Company, Germany. Their size distribution was near 50–100 nm, and their surface area was approximately 300 m^2/g. Wood flour from poplar and walnut was provided by a carpentry located in Yazd province. Polyvinyl acetate (PVA) glue was sourced from Glue Iran complex, Iran. Note that its density was near 0.8 gr/cm^3 and its pH was approximately 6.7.

Preparation of nanocomposites

To prepare nanocomposites, 70 g wood flour and 70 g PVA glue were hardly mixed. Then, aluminum nanoparticles at different contents (between 1 and 4 %) were added (Table 1). After mixing, all were separately held in two specific casts, including 98 mm × 10 mm and 28 mm × 10 mm. Then, they were heated at near 220 °C for 120 min. After heating, all casts were cooled at room temperature, and then all nanocomposites were separated.

Mechanical properties

After synthesis of nanocomposites, both tensile strength and tensile modulus of elasticity were measured according to ASTM-D1037 standard by Instron 6025 computer-controlled screw-driven mechanical testing machine. Also, both flexural strength and flexural modulus of elasticity were evaluated according to ASTM-D1037 standard. These parameters were measured by extensometer, which was attached to the specimen gauge length.

Physical properties

To calculate the density of nanocomposites, their weight was first measured by a digital balance and their volume was calculated by a ruler. Then, the density of each nanocomposite was obtained by formula 1.

$$\text{Density} = \text{m/v} \quad (1)$$

where m is weight and v is volume.

Water absorption percentage and thickness swelling percentage were also measured, according to with ASTM-D1037 standard. First, all nanocomposites were dried in an oven at 100 °C, and then their weight and thickness were calculated by a digital scale and a micrometer, respectively. In the next step, the samples were horizontally immersed in distilled water for 24 h. Then, all of them were removed, and the excess water was wiped by a tissue. Finally, their weight and thickness were recorded again, and the water absorption percentage and thickness swelling percentage were calculated using formulas 2 and 3.

$$\text{WA}_{24} = (W_{24} - W_0) \times 100/W_0 \quad (2)$$

$$\text{TS}_{24} = (T_{24} - T_0) \times 100/T_0 \quad (3)$$

where WA_{24}, W_{24}, and W_0 are water absorption percentage, nanocomposite weight after water immersion, and nanocomposite weight before water immersion, respectively. TS_{24}, T_{24}, and T_0 are thickness swelling percentage, nanocomposite thickness after water immersion, and nanocomposite thickness before water immersion, respectively.

Sound adsorption coefficient and transmission loss

In this study, the sound absorption coefficient was measured by acoustic tube, Brüel & Kjær, Germany. Four frequencies, including 250, 500, 1000, and 2000 Hz, were investigated. The sound absorption coefficient and transmission loss were defined, based on Eqs. 4 and 5, respectively.

$$\text{Sound absorption coefficient} = \alpha = 1 - (V/I) \quad (4)$$

$$\text{Transmission loss} = -10\text{Log}\alpha \quad (5)$$

Table 1 Content of aluminum nanoparticles, glue, and wood flour used in the nanocomposites

Wood flour weight (g)	Glue weight (g)	Nanoparticle weight (g)	Weight percentage (%)
70	70	1.4	≈1
70	70	2.8	≈2
70	70	4.2	≈3
70	70	5.6	≈4

where V is reflected sound intensity and I is incident sound intensity. Reflected and incident sound intensities were measured by an acoustic tube.

Statistical analysis

All tests were performed 3 times, and the results are shown as the mean ± standard deviation (SD). Parametric test (ANOVA) was applied to detect the significant difference. This test was carried out by SPSS software (V.16.0 for Windows; SPSS Inc., USA), and $P < 0.05$ was considered as a significant difference.

Results and discussion

Mechanical and physical properties

Table 2 shows flexural strength and flexural modulus of nanocomposites used in this study. As seen, the highest flexural strength and the highest flexural modulus were seen for nanocomposite 4: wood flour/PVA glue/aluminum nanoparticle 4 %. Both flexural strength and flexural modulus were increased with the increase in nanoparticle percentage. Table 3 shows tensile strength and tensile modulus of nanocomposites used in this study. As demonstrated, the highest flexural strength and the highest flexural modulus were observed for nanocomposite 1: wood flour/PVA glue/aluminum nanoparticle 1 %. Both flexural strength and flexural modulus were decreased with the increase in nanoparticle percentage. Table 4 shows water absorption percentage, thickness swelling percentage, and density of nanocomposites used in this study. As seen, the highest water absorption percentage, thickness swelling percentage, and density were seen for nanocomposite 4: wood flour/PVA glue/aluminum nanoparticle 4 %. Overall, all physical properties of nanocomposites were increased with the increase in nanoparticle percentage.

Acoustic properties

Table 5 shows sound absorption coefficient and transmission loss of nanocomposites used in this study. The highest sound absorption coefficient and the least transmission loss were seen for nanocomposite 4: wood flour/PVA glue/aluminum nanoparticle 4 % at frequency of 2000 Hz. On the other hand, the highest transmission loss and the least sound absorption coefficient were observed for nanocomposite 1: wood flour/PVA glue/aluminum nanoparticle 1 % at frequency of 500 Hz. As seen, sound absorption coefficient was increased with the increase in nanoparticle percentage. Moreover, transmission loss was decreased with the increase in nanoparticle percentage.

Table 6 shows the correlation between acoustic properties and physico-mechanical parameters of nanocomposites. The increase in nanoparticle percentage led to the increase in flexural strength, flexural modulus, water absorption percentage, thickness swelling percentage, density, and sound absorption coefficient. On the other hand, the increase in nanoparticle percentage led to the decrease in tensile strength, tensile modulus, and transmission loss.

The important and high correlations:

Between TL500 and TM, D, WA, and TS, R-square was 0.99, 0.90, 0.95, and 0.99, respectively.
Between TL1000 and NPP and FS, R-square was 0.91 and 0.94, respectively.
Between TL2000 and FS, R-square was 0.90.

Table 2 Flexural strength and flexural modulus of aluminum nanocomposites used in this study

Nanocomposites	Flexural strength (Mpa)	Flexural modulus (MPa)
Wood flour/glue/aluminum nanoparticle 1 %	5.46 ± 0.1	261.64 ± 10
Wood flour/glue/aluminum nanoparticle 2 %	7.81 ± 0.3	262.09 ± 8
Wood flour/glue/aluminum nanoparticle 3 %	9.63 ± 0.5	248.86 ± 9
Wood flour/glue/aluminum nanoparticle 4 %	10.93 ± 0.5*	405.53 ± 20*

* $P < 0.05$ compared with others, $n = 5$

Table 3 Tensile strength and tensile modulus of aluminum nanocomposites used in this study

Nanocomposites	Tensile strength (Mpa)	Tensile modulus (MPa)
Wood flour/glue/aluminum nanoparticle 1 %	2.9618 ± 0.1*	143.9585 ± 7*
Wood flour/glue/aluminum nanoparticle 2 %	1.1982 ± 0.05	133.7984 ± 6
Wood flour/glue/aluminum nanoparticle 3 %	0.7808 ± 0.03	56.7864 ± 3
Wood flour/glue/aluminum nanoparticle 4 %	1.2337 ± 0.04	54.25,609 ± 3

* $P < 0.05$ compared with others, $n = 5$

Table 4 Water absorption percentage, thickness swelling percentage, and density of aluminum nanocomposites

Nanocomposites	Water absorption percentage (%)	Thickness swelling percentage (%)	Density (g/cm^3)
Wood flour/glue/aluminum nanoparticle 1 %	179.2331 ± 9	1 ± 0.05	0.528571 ± 0.02
Wood flour/glue/aluminum nanoparticle 2 %	180.3685 ± 9	1 ± 0.05	0.542857 ± 0.02
Wood flour/glue/aluminum nanoparticle 3 %	201.5113 ± 10	50 ± 2*	0.571429 ± 0.02
Wood flour/glue/aluminum nanoparticle 4 %	208.8136 ± 11*	50 ± 3*	0.585714 ± 0.02

* $P < 0.05$ compared with others, $n = 5$

Table 5 Sound absorption coefficient and transmission loss of aluminum nanocomposites

Nanocomposites	Frequency (Hz)	Sound absorption coefficient	Transmission loss (dB)
Wood flour/glue/aluminum nanoparticle 1 %	250	0.5 ± 0.001	3.0103 ± 0.15
	500	0.30 ± 0.01	5.238787 ± 0.2
	1000	0.5 ± 0.001	3.0103 ± 0.15
	2000	0.45 ± 0.02	3.467875 ± 0.15
Wood flour/glue/aluminum nanoparticle 2 %	250	0.55 ± 0.02	2.596373 ± 0.1
	500	0.31 ± 0.01	5.228787 ± 0.2
	1000	0.55 ± 0.02	2.596373 ± 0.1
	2000	0.65 ± 0.03	1.870866 ± 0.1
Wood flour/glue/aluminum nanoparticle 3 %	250	0.55 ± 0.02	2.596373 ± 0.1
	500	0.35 ± 0.02	4.55932 ± 0.2
	1000	0.56 ± 0.02	2.51812 ± 0.1
	2000	0.7 ± 0.03	1.54902 ± 0.01
Wood flour/glue/aluminum nanoparticle 4 %	250	0.56 ± 0.2	2.51812 ± 0.1
	500	0.35 ± 0.02	4.55932 ± 0.2
	1000	0.58 ± 0.02	2.36572 ± 0.2
	2000	0.75 ± 0.03	1.249387 ± 0.1

Between SAC500 and TM, D, WA, and TS, R-square was 0.99, 0.90, 0.95, and 0.99, respectively.

Between SAC1000 and NPP and FS, R-square was 0.91 and 0.94, respectively.

Between SAC2000 and FS, R-square was 0.93.

Nowadays, nanocomposites are extensively used in different applications (Harris et al. 2002). It has been found that composite materials can be used as an acoustic panel to reduce noise (Ismail et al. 2010). Importantly, thin, lightweight, and low-cost nanocomposites are highly needed to absorb sound waves (Byakova et al. 2014). We believe that wood is the best choice to synthesize advanced nanocomposites, because of high availability and durability. Wood nanocomposites must have higher physical and mechanical properties, compared with wood panels alone. These parameters directly affect acoustic properties (Krokhin et al. 2003; Monties 1991; Saheb and Jog 1999). The aim of this study was to evaluate: (1) acoustic, (2) physical, and (3) mechanical properties of nanocomposites. Moreover, the correlation between these parameters was investigated. These nanocomposites were from wood flour, PVA glue, and aluminum nanoparticles. It must be mentioned that aluminum nanoparticles were variable among them from 1 to 4 %. Here, different parameters, including sound adsorption coefficient, transmission loss, density, water absorption percentage, thickness swelling percentage, and mechanical properties of these nanocomposites, were investigated.

Although nanoparticles can change physical and chemical properties of nanocomposites, matrix substance and nanoparticle type are two important factors (Balazs et al. 2006). Which nanoparticles and which matrixes are good are two important questions. To build acoustic panels, there is no enough information about matrix and nanoparticle type. In this study, both wood flour and PVA glue were used as matrix, and aluminum nanoparticles were applied as additive. We found that the complex of wood flour and PVA glue led to the increase in physical and chemical properties. The authors and other researchers think that the matrix is suitable for manufacturing of acoustic panels (Chauve et al. 2005). Among different types of nanoparticles, aluminum nanoparticles were used in this study. This nanoparticle has small size and high surface/volume ratio. Moreover, it has low density and high specific

Table 6 Correlation between acoustic properties and physico-mechanical parameters of aluminum nanocomposites

	NPP	TS	TM	FS	FM	*D*	WA	TS
TL250	0.827	0.891	0.493	0.815	0.201	0.649	0.456	0.405
TL500	0.75	0.409	0.992	0.786	0.258	0.9	0.959	0.99
TL1000	0.911	0.805	0.658	0.94	0.337	0.82	0.648	0.573
TL2000	0.502	0.886	0.636	0.906	0.235	0.772	0.595	0.55
SAC250	0.830	0.886	0.497	0.82	0.208	0.654	0.462	0.409
SAC500	0.75	0.409	0.992	0.786	0.258	0.9	0.959	0.99
SAC1000	0.916	0.79	0.667	0.947	0.335	0.831	0.662	0.582
SAC2000	0.57	0.854	0.675	0.935	0.276	0.814	0.644	0.59
NPP	1	0.602	0.056	0.962	0.342	0.982	0.776	0.75

TL transmission loss, *SAC* sound absorption coefficient, *NPP* nanoparticle percentage, *TS* tensile strength, *TM* tensile modulus, *FS* flexural strength, *FM* flexural modulus, *D* density, *WA* water adsorption, *TS* thickness swelling

surface area (Park et al. 2005). It must be mentioned that different parameters, including size, shape, surface/volume ratio, type of nanoparticles, type of matrix, and the proportion of matrix/additive, are important and affect acoustic, physical, and mechanical properties of nanocomposites. Here, different percentages of aluminum nanoparticles (1–4 %) were used, but other percentages must be evaluated in future studies.

After the synthesis of nanocomposites, both sound absorption coefficient and transmission loss were recorded by an acoustic tube at 250, 500, 1000, and 2000 Hz. These frequencies are octave bands and are important in sound studies. This study showed that the increase in nanoparticle percentage led to the increase in flexural strength, flexural modulus, water absorption percentage, thickness swelling percentage, density, and sound absorption coefficient. On the other hand, the increase in nanoparticle percentage led to the decrease in tensile strength, tensile modulus, and transmission loss. The authors hypothesize that this phenomenon is due to molecular interaction between nanoparticle, wood flour, and PVA. The increase in mechanical properties of these nanocomposites makes them suitable for building industry. Since these nanocomposites may be used in different temperatures, both contraction and expansion are also important and must be investigated in other studies.

Asmatulu et al. worked on electrospun nanofibers (ESNF) to reduce noise. They showed that ESNF has high absorption coefficient (Asmatulu et al. 2009). Lee et al. synthesized polyurethane/silica nanocomposite. They declared that sound absorption was increased by the increase in silica content. On the other hand, the decrease in isocyanate index and the increase in density led to the increase in sound absorption (Lee et al. 2012). Gayathri et al. prepared a new polyurethane-based porous composite, based on silica and clay nanoparticles. They found that this nanocomposite was a good sound adsorbent. Its sound absorption coefficient was found to be increased with the increase in frequency (Gayathri et al. 2013). Bahrambeygi et al. synthesized polyurethane nanofibers. They declared that they led to a considerable improvement of sound absorption (Bahrambeygi et al. 2013). Mahrholz et al. synthesized epoxy–silica nanocomposites as a new type of matrix for fiber-reinforced polymers (FRP). Depending on the silica content of the composite, its stiffness, strength, and toughness can be increased significantly compared with neat resin. Epoxy–silica nanocomposites are now proven to be a new high-performance polymer matrix for FRP structures manufactured (Mahrholz et al. 2009). Koizumi et al. used a natural resource, bamboo fiber, to manufacture sound-absorbing material. The results showed that the bamboo fiber material has acoustic properties equivalent to those of glass wool. The sound absorption coefficient increased with an increase in density (Koizumi et al. 2002).

Conclusion

Taken together, the agro-environmental nanocomposite, containing wood flour/PVA glue/aluminum nanoparticle, has good acoustic, physical, and mechanical properties. We found that the increase in nanoparticle percentage led to the increase in flexural strength, flexural modulus, water absorption percentage, thickness swelling percentage, density, and sound absorption coefficient. But, the increase in nanoparticle percentage led to the decrease in tensile strength, tensile modulus, and transmission loss.

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Compliance with ethical standards

Conflict of interest There was no conflict of interest.

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