Evaluation of the Acoustic Properties of Wood-Plastic-Chalk Composites

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***Abstract*—Wood-plastic composites are a new group of materials that can be used in construction instead of wood and plastic. They are used in various industries due to features such as sound and water absorption, among others. This article aims to study the acoustic properties of wood-plastic composites made of wood flour, low-density polyethylene, and chalk. In this study, 6 combinations were made with different material percentages. Acoustic tests were performed for frequency ranges of 125, 250, 500, 1000, and 2000 Hz. The results of this study showed that the maximum amount of sound absorption was observed at a frequency of 2000 onwards. At the frequency of 25 to 2000, no remarkable change in sound absorption was recorded. At the 2000 to upper frequencies, one of the samples displayed the maximum amount of sound absorption. In terms of water absorption, a significant variation was reported in three samples with passing time (2, 24, 48 and 72 hours).**

Keywords-wood-plastic composites; low-density polyethylene; chalk, poplar wood; maleic anhydrite polyethylene; sound absorption.

I. INTRODUCTION

To cope with noise pollution, materials such as rock wool, glass wool, and asbestos were used as sound-absorbers in past decades. These materials are harmful both for manufacturers and for consumers and could endanger human health [1, 2]. Moreover, pure chalk panels, which are used a lot in construction, have a small sound absorption coefficient. In fact, the sound is reflected by them. Researchers have recently suggested the use of natural lignocellulosic materials in the manufacture of sound absorbing composites. Hemp is a lignocellulosic material whose wastes can be used in the construction of sound-absorbing panels [3-5]. Such materials can be used in interior and exterior areas. In general, the main markets of this material include the automotive industry, military industry, urban furniture, and construction services. Some of the products that are made with these compounds are internal components of cars, office and home furniture, kitchen cabinets, railings and flooring, acoustic insulation, window and door frames, skate boards, lumber and prefabricated roofing boards, boxes and pallets of cargo, containers, etc.

The products have some nice features such as dimensional stability, resistance to water absorption, low thickness swelling, resistance to decay due to lack of water absorption, high thermal expansion coefficient, high elastic modulus, low combustion speed, very good thermal properties, high compressive strength, recyclability, etc. Wide ranges of polymers such as polypropylene, polyethylene, polyvinyl chloride and so on are used in the manufacture of wood-plastic composites. Composites made with natural fibers have grown increasingly in a variety of industrial applications due to high resistance to weight ratio, low volumetric mass, low cost, and easy processing as well as being inexpensive and biodegradable. Lignocellulosic materials are used in the manufacture of wood-plastic composites as natural fillers and reinforcements in the form of powder or fibers [6].

Environmental compatibility, recyclability, and low cost are factors that result to the growing application of natural fillers. The lack of good adhesion between the surfaces of fibers and polyme is one of the main disadvantages of using lignocellulosic fibers in wood-plastic composites because it reduces the final product features. Poor adhesion of reinforcements with polymer causes weak distribution reinforcements in molten thermoplastic materials; it creates weak intermediate phase between the reinforcements and matrix. Both factors have great impact on physical and mechanical characteristics of composites. Reinforcements must make a strong connection with the polymer to be effective. The bonding agents are used to increase affinity of reinforcements with polymer. Bonding agents are substances with one non-polarized end and one polarized end. Thus, they act as a bridge between polarized reinforcements and non-polarized polymers. Isocyanates alkoxy silanes and anhydrides such as phthalic anhydride and maleic anhydride are important connector factors [7].

The main purpose of the production of composite products with minerals connector is the combination of organic particles such as wood and lignocellulosic materials with mineral connectors such as cement, chalk, magnesite, etc. Other fibers such as fiberglass resistant to alkalis can be used in this process. In addition, other inorganic materials such as gravel, sand, and perlite can also be used. The main fibers in the composition of the panel may be on a regular basis (arrow) or random mode. Wood- chalk was produced for the first time in Scandinavia by the semi-dry method. This method has advantages because it makes the use of industrial chalk possible in the production process; this chalk may be achieved by various chemical processes. In general, there are two main sources to obtain chalk: natural plants and industrial boilers' flue gases. The chalk available in exhaust gasses is created from entering chalk into the combustion process to reduce the emissions of sulfur dioxide. The modulus of rupture of wood-chalk is generally higher than chalk-reinforced fiber or wood-plastic; it is also lower than wood-cement or boards that have been produced using synthetic adhesives. Reinforced chalk panels, which are produced with a density of 1000 to 1200 kg/m^3 and with smooth and adjustable surfaces, have suitable properties for structural purposes. The stability of these products and their resistance to fire and biological agents are high; they have high thermal and sound insulation features. For interior purposes while emissions of formaldehyde gas is of utmost importance, panels with mineral fasteners have wide application as they are used for flooring, inner lining walls, ceilings, and separating walls (partitions). In comparison to wood-base panels, wood-chalk has better linear stability and represents better performance than other composite boards when it is exposed to fire.

II. Research Background

In [8], authors studied high-density polyethylene-based composites and rice husk flour with 4 loading levels 2, 2, 4, and 6 phr. The results showed that crystallization temperature, enthalpy of crystallization and crystallization level increase with increasing nanoclay to 2 phr; then, it reduces. Composites will improve by with the addition of nano storage fillers and losing modulus. X-ray diffraction patterns revealed the formation of the central composite. Moreover, morphological findings showed that samples containing 2-phr nanoclay have regular formation. It seems that a full morphological cutting can be made by increasing maleic anhydride polyethylene coupling agent. Therefore, thermal and rheological properties of composites of rice husk with high-density polyethylene have been improved by increasing the amount of maleic anhydride polyethylene. In [9], authors investigated the impact of adding compatibilizers on mechanical properties of polypropylene and wood flour. They concluded that the weakness of mechanical properties of unmodified composites is due to weak connections between the polymeric matrix and wood fibers; tensile modulus, tensile strength, and impact resistance increase with addition of linked maleic anhydride with polypropylene.

In [10], high-density polyethylene and polypropylene grafted with maleic anhydride was used to make composites containing wood chips. The results showed that the use of maleic anhydride leads to better fiber wetting by the matrix; it increases adhesion at the interface between matrix and fibers. In order to evaluate mechanical properties of polypropylene and poplar wood fibers, authors in [11] prepared a sample with 0, 30, 40, 50, 60 percent fiber weight, and 2 percent maleic Ayndryd grafted with polypropylene. In [12], the humidity properties of wood-plastic composites made of poplar-polypropylene fiber were discussed. Pure polypropylene is regarded as control samples; the produced samples were made of 4 variable level of 30, 40, 50, 60% fibers, 3% maleic anhydride, and zero maleic anhydride. In [13], authors reviewed the mechanical properties of composites made from recycled high-density polyethylene and laminated poplar. They concluded that tensile strength of these composites improves by increase in fiber. Thus, development of composites containing natural fibers and recycled plastic is an opportunity to use an abundant natural substance and a new method for reducing the serious problem of plastic wastes. In [14], authors examined the dimensional stability and mechanical behavior of wood-plastic composites made based on high-density recycling polyethylene. This research examined dimensional stability, mechanical properties, and microscopic structure of composites. With the addition of maleic anhydride polypropylene at levels 3 to 5 wt percentage to the composite, a significance improvement is observed in dimensional stability and mechanical properties of composites. Microscopic analyses of the fracture surface of maleic anhydride-modified polypropylene composites confirm improvement in binding of the molecular chain. In [15], authors conducted a research about the dimensional stability of composites made of fiber of old papers and thermo-mechanical pulp and paper (pp). The results showed that alkylation of fiber and the use of coupling auxiliaries increases dimensional stability of the wood composites or wood pp fiber.

III. Materials and Methods

A. Materials and Equipment

Raw materials used for the research are poplar wood, low-density polyethylene, chalk powder, and malic anhydride polyethylene. The list of devices and equipment used in the project are stated in Table I.

TABLE I. DEVICES AND EQUIPMENT USED IN THE PROJECT, ALONG WITH THEIR PROPERTIES

Device Name	General Properties
Non-collimator 2-screw extruder choline	Speed: 70 rpm Temperature 140 to 165 °C Made in Germany 1990 Brand: Collin
Semi-industrial mill	Made in Germany 1989 Brand: Wieser
125-grams injection machine	Temperature capability: 150, 155, 160, 170 ° C. Load speed: 60 Cooling temperature: ambient temperature Made in Iran 1997 Brand: Iman Machine
Curing presses (Blister)	Has 2 Jaw Temperature capability: 200 ° C

B. Research Variables and Samples

Six samples were prepared in this research. The percentage of components is shown in Table II. 800 grams raw material has been used for each combination. Six combinations were made of different percentages of wood, low-density polyethylene, and chalk. In the first three combinations, the fixed amount of low-density polyethylene was 50 percent, compatibilizer amount was 0 percent, and the amounts of poplar wood flour and chalk varied (with the decrease in the percentage of wood, application of chalk increases). The amount of chalk is zero in the control sample; then it reaches to 5 and 10 percent. In the next three combinations, the fixed amount of low-density polyethylene is 47 percent, compatibilizer amount is 3 percent, and the amounts of poplar wood flour and chalk varied (with the decrease in the percentage of wood, application of chalk increases). The amount of chalk is zero in the control sample; then it reaches to 5 and 10 percent.

C. The process of mixing and preparing boards

Low-density polyethylene, maleic anhydride polyethylene coupling agent, poplar wood flour and, chalk 2 are mixed in 2-screw extruder with a speed of 50 rpm for 10 minutes at 180 ° C. Then, rod-shaped pasty mixture exits from the the mixer, kept in cool water, and converts to granule. Granules are dried at 105 °C for 24 hours (Figure 1). Finally, boards are prepared from granules by molding at a temperature of 175 ° C and a pressure of 10 Mpa.

TABLE II. PERCENTAGE OF COMPONENTS

Sample	Wood flour (wt %) Variable value	Low- density polyethylene, (wt %) Fixed value	Compatibilizer (wt %) Fixed value	chalk (wt %) Variable value
1	50% (400grams)	50% (400grams)	0% (-)	0% (-)
2	45% (360 grams)	50% (400grams)	0% (-)	5% (40 grams)
3	40% (320 grams)	50% (400grams)	0% (-)	10% (80 grams)
4	50% (400grams	47% (375 grams)	3% (25 grams)	0% (-)
5	45% (360 grams)	47% (375 grams)	3% (25 grams)	5% (40 grams)
6	40% (320 grams)	47% (375 grams)	3% (25 grams)	10% (80 grams)

IV. RESEARCH FINDINGS

A. Measuring sound absorption coefficient of samples

In order to test sound absorption, two discs of each sample (one with a diameter of 100 mm and another with a diameter of 30 mm) are prepared. The prepared samples are transferred to Physics Laboratory to measure sound absorption coefficients. Standard ISO-10534-1 is used to measure the adsorption coefficient of sound. Absorption coefficients of the boards are measured using standing waves device (standing waves tube method) by software Cool Edit. Moreover, acoustic test is performed with a frequency range of 125, 250, 500, 1000 and 2000 Hz (Figure 2).

B. Test measuring sound absorption coefficient of samples

First, the sample is placed inside an impedance tube. One side of the tube is a loudspeaker that is connected to the signal generator. Another side of the tube is stalemate; thus, a standing wave is formed inside the tube. There are an incident wave and a reflected wave in; indentations and protrusions were found on the standing wave. Indentations represent decrease in the domain of signal and protrusions show increase in the domain of signal (Figure 3). A microphone placed inside the tube to discover indentations and protrusions. In fact, microphone is moved inside the tube; the microphone shows maximum and minimum pressures. The maximum and minimum can be read from the analyzer; finding maximum and minimum, we can calculate absorption coefficient as follows:

$$n=(A+B)/(A-B)$$
$$\alpha= 4N/(1+n)^2$$

where A=energy radiated, B=reflected energy, $A+B$=protrusions, B=indentations, α=sound absorption coefficient.

Fig. 1. Granules obtained from sample preparation

Fig. 2. Samples used in acoustic testing (left) and press machine for constructing the acoustic samples (right)

Fig. 3. Measuring instrument for sound absorption.

C. Statistical Analysis

Analysis of the results is performed in a completely randomized design and factorial analysis using the two-factor ANOVA by SPSS software. Then, averages are compared by LSD post hoc test with 95% confidence level.

1) Descriptive statistics of the amount of water absorption

The results of this test showed that water absorption after 72 hours after testing samples is significant. Moreover, the maximum amount of water absorption belongs to the sample 4 and minimum amount of water absorption belongs to sample 3 (Table III and Figure 4).

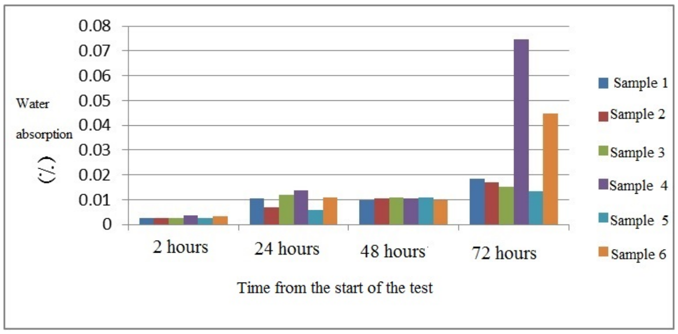

Fig. 4. The results of water absorption

TABLE III. STATISTICAL INDICES DESCRIBING THE AMOUNT OF WATER ABSORBED BY THE SAMPLE

Time (hours)	Sample	Minimum (%)	Maximum (%)	Average (%)	Standard deviation
2	1	0.0026	0.0027	0.0026	0.0000
	2	0.0025	0.0026	0.0025	0.0000
	3	0.0025	0.0026	0.0025	0.0000
	4	0.0026	0.0052	0.003	0.0014
	5	0.0025	0.0025	0.0025	0.0000
	6	0.0025	0.0049	0.0032	0.0013
24	1	0.0105	0.0107	0.0106	0.0000
	2	0.0051	0.0079	0.0068	0.0015
	3	0.0101	0.0129	0.0118	0.0015
	4	0.0103	0.0207	0.0138	0.0059
	5	0.0025	0.0102	0.0059	0.0038
	6	0.0075	0.0149	0.0107	0.0037
48	1	0.0079	0.0107	0.0097	0.0015
	2	0.0076	0.0132	0.0103	0.0028
	3	0.0075	0.0151	0.0109	0.0038
	4	0.0103	0.0105	0.0103	0.0001
	5	0.0076	0.0127	0.0109	0.0029
	6	0.0098	0.0100	0.0099	0.000
72	1	0.0160	0.0238	0.0185	0.0042
	2	0.0127	0.0203	0.0171	0.0039
	3	0.0075	0.0283	0.0152	0.0113
	4	0.0205	0.159	0.0747	0.0744
	5	0.0101	0.0152	0.0135	0.0029
	6	0.0050	0.1163	0.0445	0.0622

2) Statistical indices describing sound absorption of samples at different frequencies

The results of this test showed that the highest sound absorption is observed at frequency 2000 onwards. At the frequency of 25 to 2000, there was not a remarkable change in sound absorption. At the 2000 to upper frequencies, the maximum amount of sound absorption can be seen in the sample No. 6 (Table IV, Figures 5-7).

TABLE IV. STATISTICAL INDICES DESCRIBING SOUND ABSORPTION OF SAMPLES AT DIFFERENT FREQUENCIES

ength (nano meter)	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Sample 4 (%)	Sample 5 (%)	Sample 6 (%)
250	0.0059	0.019	0.0268	0.0325	0.0195	0.038
315	0.0292	0.040	0.0103	0.0272	0.038	0.026
400	0.0438	0.039	0.0406	0.0428	0.039	0.050
500	0.090	0.031	0.0105	0.0304	0.019	0.032
800	0.0487	0.029	0.0343	0.0466	0.038	0.054
1000	0.050	0.031	0.040	0.0507	0.027	0.041
1250	0.037	0.032	0.041	0.0362	0.033	0.045
1600	0.135	0.080	0.148	0.133	0.078	0.123
2000	0.0140	0.037	0.123	0.138	0.137	0.130
2500	0.0178	0.149	0.167	0.171	0.164	0.149
3150	0.171	0.162	0.199	0.169	0.148	0.176
4000	0.204	0.281	0.195	0.204	0.281	0.332
5000	0.362	0.285	0.216	0.357	0.293	0.369
6300	0.040	0.181	0.234	0.344	0.255	0.371

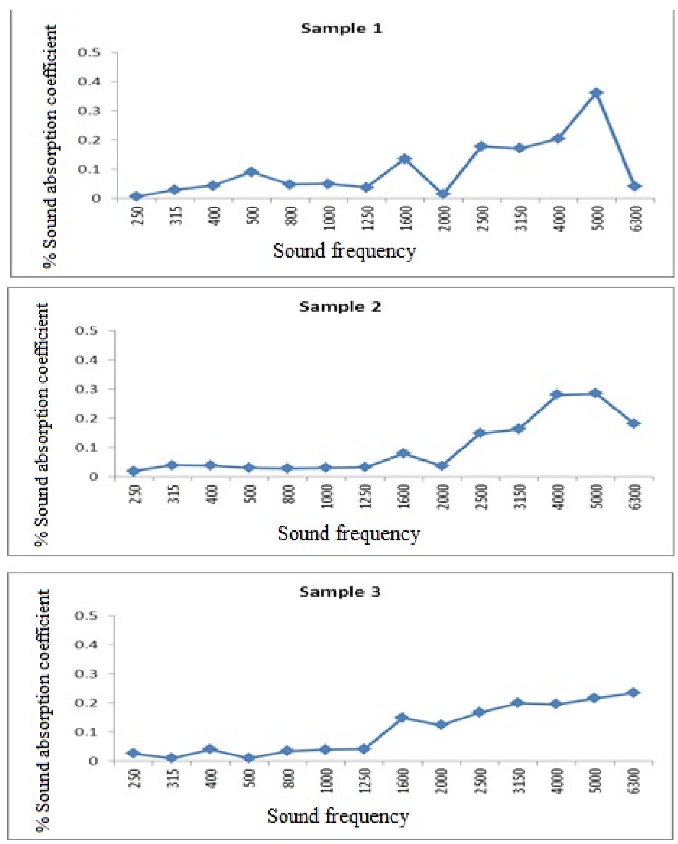

Fig. 5. Sound absorption coefficient for samples 1 to 3

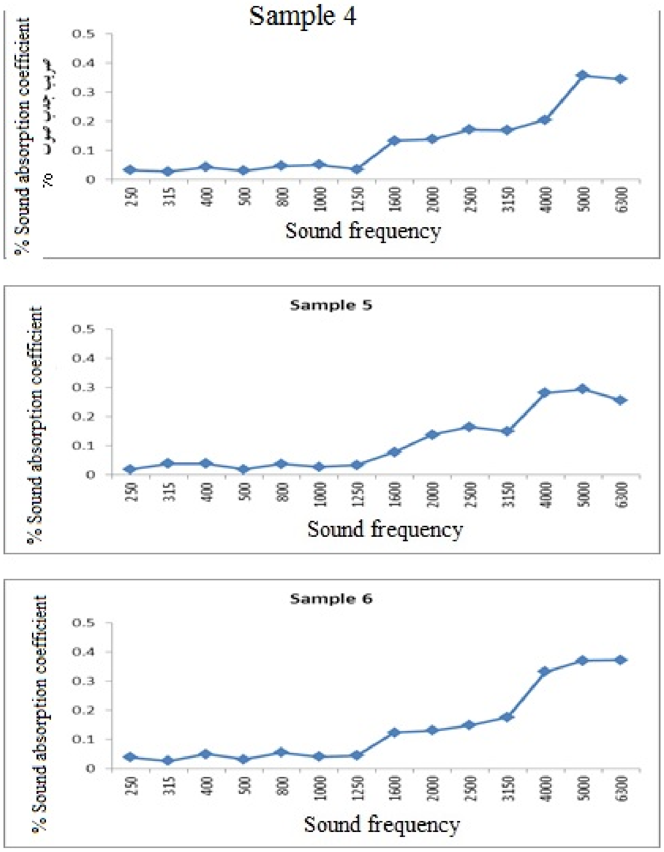

Fig. 6. Sound absorption coefficient for samples 4 to 6

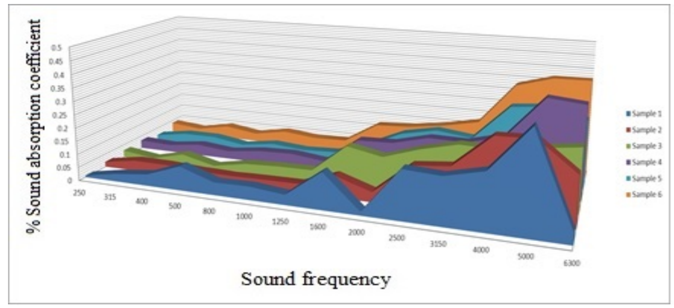

Fig. 7. Overview of sound absorption

D. Analysis of variance of sound absorption test

The results of analyzing variance of sound absorption test are presented in Table V. As seen, there are differences among sound absorption of samples at different frequencies (250, 500, 1000, 2000, 4000, and 6300). There is no significant difference among frequencies of 250, 500, and 1000; but there are significant differences among frequencies 200, 4000, and 6300 (sig. <0.05).

V. CONCLUSION

This research aims to study the acoustic properties of wood-plastic composites made of poplar wood flour, low-density polyethylene, and chalk. In this study, 6 combinations were made of different percentages of wood, low-density polyethylene, and chalk. The results of this study showed that the maximum amount of sound absorption was observed at frequencies of 2000 onwards and that a certain mix (which had 3% compatibilizer and 10% chalk) presented the best results. Regarding water absorption, it was shown that three mixes revealed significant difference at 2, 24, 48 and 72 hours.

TABLE V. VA TEST FOR COMPARISON OF MEAN SOUND ABSORPTION IN SAMPLES AT DIFFERENT FREQUENCIES

Test type		Sum of squares	Degrees of freedom	Mean squares	F	Significance
Frequency 250	Between groups	0.010	5	0.005	22.26	0.70
	Within groups	0.022	12	0.012		
	Total	0.011	17	-		
Frequency 500	Between groups	0.001	5	0.000	17.32	0.22
	Within groups	0.021	12	0.000		
	Total	0.020	17	-		
Frequency 1000	Between groups	0.021	5	0.010	2.42	0.78
	Within groups	0.010	12	0.005		
	Total	0.011	17	-		
Frequency 1000	Between groups	0.011	5	0.005	2.34	0.002
	Within groups	0.021	12	0.000		
	Total	0.011	17	-		
Frequency 4000	Between groups	0.010	5	0.005	8.96	0.005
	Within groups	0.020	12	0.010		
	Total	0.020	17	-		
Frequency 6300	Between groups	0.033	5	0.015	1.06	0.002
	Within groups	0.002	12	0.000		
	Total	0.001	17	-		

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