Eco-friendly, effective, and inexpensive making technique of an alternative insulation building material based on wood foam

Tehnică ecologică, eficace și ieftină de producere a unui material de construcție izolator alternativ pe bază de spumă de lemn

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DOI: 10.37789/rjce.2026.17.2.13

Abstract. *An alternative heat-insulating building material based on wood foam was tested. The adopted wood type was oak wood unused until now, according to data from the literature. The work objective was replacing plastics, commonly used in manufacturing insulating materials. The mixture included ground wood waste, an adequate surfactant (sodium dodecyl sulfate), and distilled water. The obtained wet suspension was expanded by stirring and dried at 80 ℃. The physical-thermal properties were remarkably performant, while compressive strength reached only low values, but acceptable for the desired purpose. Results were similar to those reported in the literature regarding other wood foam types.*

Key words: *wood foam, oak wood, surfactant, low density, heat conductivity.*

Rezumat. *A fost testat un material de construcție alternativ termoizolant pe bază de spumă de lemn. Tipul de lemn adoptat a fost lemnul de stejar, neutilizat până în prezent, conform datelor din literatura de specialitate. Obiectivul lucrării a fost înlocuirea materialelor plastice, utilizate în mod obișnuit la fabricarea materialelor izolatoare. Amestecul a inclus deșeu de lemn măcinat, un surfactant adecvat (dodecilsulfat de sodiu) și apă distilată. Suspensia umedă obținută a fost expandată prin agitare și uscată la 80 ℃. Proprietățile fizico-termice au fost remarcabil de performante, în timp ce rezistența la compresiune a atins doar valori scăzute, dar acceptabile pentru scopul dorit. Rezultatele*

The article was received on 17.06.2025, accepted on 27.05.2026 and published on 12.06.2026

au fost similare cu cele raportate în literatura de specialitate pentru alte tipuri de spumă de lemn.

Cuvinte cheie: spumă de lemn, lemn de stejar, surfactant, densitate mică, conductivitate termică.

1. Introduction

In the last decades of the previous century, the global oil crisis exhibited intensely [1], implying the need to develop and apply some plans for the conservation of energy sources at the level of the entire planet. By default, the effectiveness of thermal insulation materials of buildings has become an important objective of researchers and builders and this concern is still relevant at the beginning of the 21st century.

Currently, the main materials applied in the thermal insulation process of buildings are still plastic materials: polyurethane foam, expanded polystyrene, or glass wool. Although very effective practically, these material types can affect human health (through the possible inhalation of fine fibers) and, on the other hand, they are difficult to recycle at the end of the normal life cycle [2].

Substituting plastics with eco-friendly materials, without affecting the quality of polymer-based heat insulators by adding biomaterials or natural raw materials are interesting versions [2]. As an example, sintered polyurethane with biomaterials-based polyols [3] and polyurethane foams with polyols derived lignin [4] were produced with similar characteristics by comparing with traditional polyurethane.

The introduction of a gaseous phase in polymeric liquids or molten plastics during the synthesis process (similar to the production of polyurethane foam and, respectively, polystyrene or polyolefin) is known as the method of obtaining polymeric foams. The manufacture of cellulose fiber foams can be achieved by drying method of aqueous foam [5]. Blowing air into aqueous dispersion fibers in the presence of surfactant facilitates the formation of wet foams, that are then dried in the oven [6, 7].

In terms of quality, the production of a thermal insulator requires the adequate distribution of its structure to avoid heat circulation. Practically, insulating materials can be made from different types of cellulosic masses containing microfibrillated cellulose [8], cellulose nanocrystals [9], cellulose nanofibres [10], bacterial cellulose [11], and regenerated cellulose [12]. Cellulose-based materials made by lyophilization, supercritical drying or spray drying facilitate obtaining very low thermal conductivity values (0.013-0.075 $W{\cdot}m^{-1}{\cdot}K^{-1}$) similar to those of polyurethane foams and silica aerogels [13].

An interesting method of manufacturing wood foam using a residual pine wood (originally from North America) was applied by [2]. Polyvinyl alcohol was used as a binder. Also, sodium dodecyl sulfate, sodium bicarbonate as surfactants, and deionized water were introduced into the mixture. After drying in the oven at 70 ℃, excellent values of density (0.12-0.14 $g{\cdot}cm^{-3}$) and heat conductivity (0.042 $W{\cdot}m^{-1}{\cdot}K^{-1}$) were obtained.

Some thermal insulation materials are made of wood fiber and are already applied in construction, but their main disadvantage is the low dimensional stability. Also, the insulation degree achieved with wood fiber is lower (heat conductivity within the limits of 0.038-0.043 $W \cdot m^{-1} \cdot K^{-1}$) by comparison with the level obtained by petrochemical products [14].

Specialists from the German Fraunhofer Institute are currently performing research to create wood foam with excellent heat-insulating properties. According to [15], finely ground beech wood was expanded with suitable surfactants, then the suspension was dried and hardened into an isolated room free from moisture. The foamed wooden product had density values between 0.04-0.28 $g \cdot cm^{-3}$ and can be processed in the form of boards or elastic foam.

Wood-furanic foam was made using a fine wood powder [16]. The preparing method of wood foam was chemical foaming, the expanding agent being diethyl ether. Low values of density and thermal conductivity due to the porous structure with closed cells and variable sizes were the main characteristics of this wood foam.

The authors' team of this work previously gained experience on wood foam production domain by removing the lignin from the wood (oak) composition [17]. The adopted method was taken over from the pulp and paper making technique by removing the lignin for other technological purposes. The wood chemical treatment with an aqueous solution including NaOH, $Ca(OH)_2$, and distilled water was adopted. Low values of density (0.024 $g \cdot cm^{-3}$) and heat conductivity (0,031 $W \cdot m^{-1} \cdot K^{-1}$) ensuring excellent thermal insulating properties, despite the relatively low value (900 kPa) of compressive strength, were features of wood foam.

The current paper presented below constitutes a contribution of the Romanian authors to the preparation of wood foam with excellent heat-insulating properties. The technique currently developed by the Fraunhofer Institute, superior in quality terms to the technique based on removing the lignin (previously experienced by the authors' team), was adopted by testing a type of wood unused until now through the new technique researched by the German institute (oak wood).

2. Methods and materials

The wood chosen for this experiment (oak wood) was recycled in the form of sawdust from a Romanian wood-working workshop. The wooden waste was ground under pre-wetting conditions in a little laboratory knife-grinding equipment. Over the ground wood (grain size in the range of 100-500 μm selected after sieving) a suitable surfactant was introduced in very low ratios in order to decrease the surface tension of the wet suspension and to facilitate forming the foam. Among the known surfactants, sodium dodecyl sulfate (known as SDS) with high purity of over 99 % was chosen.

The expansion of suspension was performed in an electric homogenization device by stirring at 750 rpm for no more than 10 min, until increasing the foam volume was no longer observed. After finishing the foaming process, the wet foam was loaded into parallelepipedal stainless metal moulds and subjected to drying and hardening in an electric oven at 80 °C for 10 hours.

The materials used in this experiment were oak wood waste as the wooden material, sodium dodecyl sulfate as a surfactant, and distilled water for the wet suspension generation.

The most recent worldwide tests for the manufacture of high-performance wood foam did not include oak wood. As mentioned above, this wood type was tried by the paper's authors using the technique of removing lignin (usually applied in the pulp and paper industry) to obtain a wood foam with weaker thermal insulation properties. Now, oak wood waste was tested for the first time through the more effective method of chemical foaming currently being researched. The wood, recycled in the form of sawdust, was ground to sizes below 500 µm.

It has been found that an essential method for the generation of wood foam is reducing the solvent surface tension, that can be achieved by using surfactants. They facilitate the foam generation and enter into the composition of its membranes, giving them viscosity and surface elasticity properties [18]. The surfactant type adopted in this experiment was sodium dodecyl sulfate (SDS) with the purity over 99 % and having the following chemical formula $C_{12}H_{25}NaO_4S$. Available on the market in crystalline or powder state [19], the powder state was chosen by the authors.

The composition of the material mix for producing the wet suspension was adopted in four experimental versions, detailed in Table 1. According to the data in this table, the surfactant amount had variable values in the range of 16-28 mg, while the wet suspension was maintained at the constant value of 200 g.

Table 1

Wet suspension composition

Composition	Sample 1	Sample 2	Sample 3	Sample 4
Oak wood waste (g)	38	38	38	38
Surfactant SDS (mg)	16	20	24	28
Distilled water (g)	162	162	162	162
Wet suspension (g)	200	200	200	200

Methods for investigating the sample features are indicated below. Archimedes' principle was used to measure the apparent density of wood foam samples. Using ASTM C642-97 standard, the apparent porosity was determined by dividing the difference between wet and dry weight by the difference between wet weight and suspended weight of the sample. Heat conductivity was measured at room temperature using the HFM448 Lambda heat-flow-meter (SR EN 1946-3:2004). Measuring the compressive strength was performed using a universal testing machine. The samples were comprissed at 1.4 $mm \cdot min^{-1}$ (ASTM D695) and the compressive resistance was determined at 10 % compression (ASTM D1621-16). The microstructural appearance of foams could be investigated with the Biological Microscope MT5000 model, 1000 x magnification. Water uptake was determined by maintaining wood foam samples in humidity chamber at 85 % humidity for 30 days according to ASTM C272/C272M-18.

3. Results and discussion

After drying and hardening the wet suspensions at 80 °C for 10 hours, characteristics of wood foam samples, shown in Fig. 1, were investigated using the methods noted above. Results of these investigations regarding to physical, thermal, mechanical, water-absorbing features, and microstructural peculiarities are exposed further in Table 2.

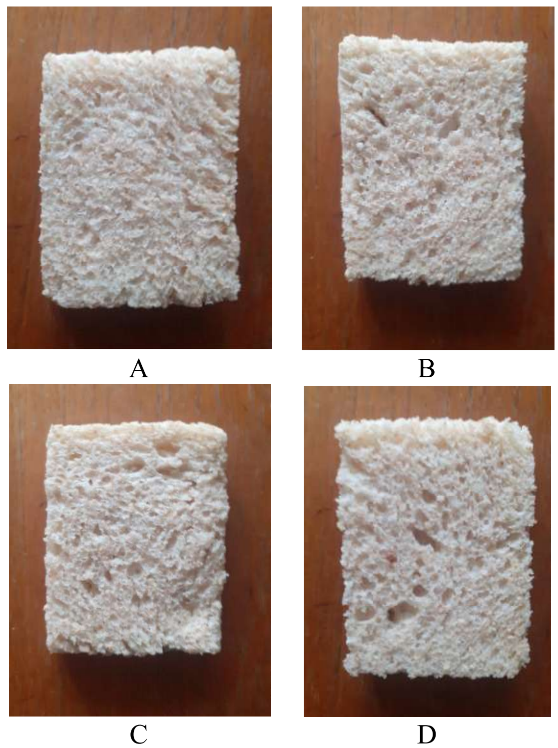


Fig. 1. Appearance of wood foam samples
A – sample 1; B – sample 2; C – sample 3; D – sample 4.

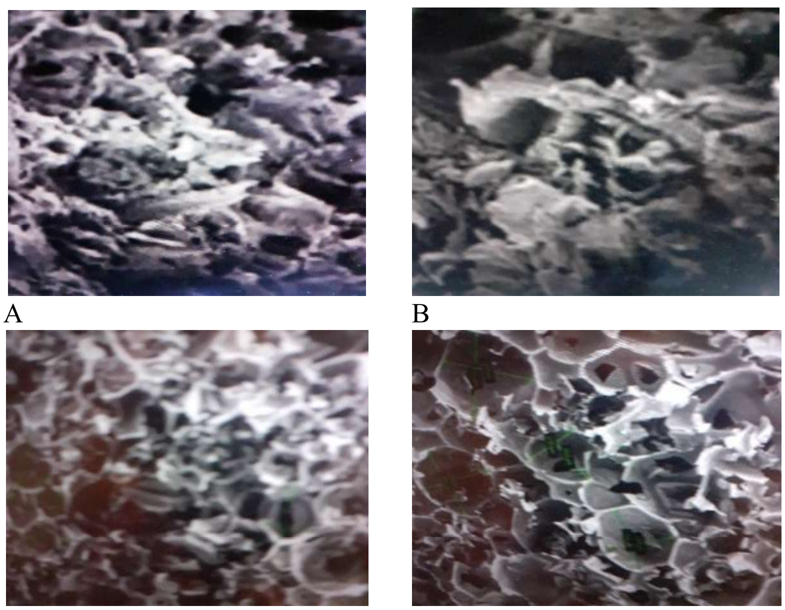
Table 2

Feature and peculiarities of wood foam samples

Feature	Sample 1	Sample 2	Sample 3	Sample 4
Apparent density ($g \cdot cm^{-3}$)	0.11	0.08	0.06	0.05
Apparent porosity (%)	88.9	89.6	90.7	91.3
Heat conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.051	0.042	0.038	0.033
Compressive strength (kPa)	865	800	743	735
Water uptake (wt. %)	5.8	5.0	4.9	4.5
Pore size (mm)	0.6-1.1	0.6-1.5	1.0-1.7	1.3-2.0

The experimental results contained in Table 2 indicate remarkable thermal insulating properties of the expanded products, especially of those made using the highest amount of surfactant (version 4). Thus, apparent density decreased up to 0.05 $g{\cdot}cm^{-3}$ and heat conductivity decreased also up to 0.033 $W{\cdot}m^{-1}{\cdot}K^{-1}$. The compressive strength was normally influenced by the very porous structure of material, decreasing to 735 kPa, but this value is satisfactory for applications in the thermal insulation of the building. The level of water absorption measured by maintaining these products into a chamber with constant high humidity (85 %) for 30 days was within the normal limits for this type of material (4.5-5.8 wt. %).

The microstructural appearance of wood foam samples is shown in Fig. 2.



A B C D **|--------| 2 mm**

Fig. 2. Microstructural aspect of wood foam samples
A – sample 1; B – sample 2; C – sample 3; D – sample 4.

Examining the pictures in Fig. 2, the pore dimension could be determined. The largest pore sizes (1.3-2.0 mm) were identified in the case of the sample corresponding to experimental sample 4. In addition, the porous structure of the foam is partially characterized by the existence of open cells. Approximately similar structural characteristics were also noted in the case of the sample corresponding to experimental variant 3. The pore size range valid for this sample was 1.0-1.7 mm.

The remarkable results obtained by research teams from the Fraunhofer Institute for Wood Research (Germany) [15] on the apparent density (up to 0.04 $g{\cdot}cm^{-3}$) and heat conductivity (under 0.04 $W{\cdot}m^{-1}{\cdot}K^{-1}$) of beech wood foams, at a comparable value level to those of polystyrene and wood fibre thermal insulating panels, have were almost replicated in the experiment presented in this work using oak wood waste and a surfactant (sodium dodecyl sulfate) recommended in the case of cellular concrete preparation [18], to form the required wet suspension in the presence of distilled water.

It should also be mentioned the performances reported by [2] on the preparation of a pine wood foam under the conditions of using a residual wood available in North America, sodium dodecyl sulfate, sodium bicarbonate, polyvinyl alcohol, and deionized water, the apparent density being lowed up to 0.12-0.14 $g \cdot cm^{-3}$ and heat conductivity to 0.042 $W \cdot m^{-1} \cdot K^{-1}$.

Different species of poplar wood were also used as feedstock in other experiments mentioned in the literature.

In principle, in the world, the research for manufacturing wood foam as a substitute for heat-insulating materials based on polymers is in full ongoing. Researchers from the Fraunhofer Institute investigate the possibility of also applying other lignocellulosic materials and consider that in a few years the wood foam manufacture could reach an industrial level.

6. Conclusions

The paper objective was making an alternative heat insulation material suitable for building construction based on the advanced technique of expanding wood waste. The new material type should have the capacity of replacing the current thermal insulating products based on plastics applied in construction. In present, researchers in construction field are testing different making techniques and more types of wood waste, the results being promising, but the optimal technical decision for manufacturing on an industrial-scale has not yet been reached. This paper aimed at experimentation an oak wood waste, un-used in previous tests reported in the literature in order to obtain wood foam with physical, mechanical, thermal, and morphological performance features adequate for use as an excellent insulating material in the building sector. The results showed remarkable values of apparent density (0.05-0.11 $g \cdot cm^{-3}$), heat conductivity (0.033-0.051 $W \cdot m^{-1} \cdot K^{-1}$), water-absorbing (4.5-5.8 wt. %) as well as a low but acceptable level of the compression resistance (735-865 kPa). The material obtained through the optimal testing version having a density of 0.05 $g \cdot cm^{-3}$, thermal conductivity of 0.033 $W \cdot m^{-1} \cdot K^{-1}$, water-absorbing of 4.5 wt. %, and the compressive strength of 735 kPa proved the reaching of value level of the material type produced so far in experiments presented in the literature. Taking into account the current trend of replacement the plastic-based materials, as in the case of thermal insulation materials usually applied in construction, as well as the continuation of the global research for this goal, the authors' team of the current paper have as future concern developing the own research on this investigation topic.

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