Worakan Hosakun, Dániel Horváth, Zoltán Börcsök, Zoltán Pásztory

Innovation Center at University of Sopron

INSULATION BOARD MADE OF SAW DUST

correspondence: Dr. Zoltán Pásztory at pasztory.zoltan@uni-sopron.hu

ABSTRACT

Wood is a naturally renewable biocomposite raw material, which has potential in many applications such as structural, furniture, paper, sound, and thermal insulation through centuries. It can reduce CO2 emission and has enormous social value as well. To extend the application field the improvement of its composite properties (mechanical, thermal) is required. Focusing on structural applications the industry often demands materials with complex properties. In our research, the chemical inhomogenity of natural wood and its porosity is modified to achieve better thermal insulation attributes. To achieve homogeneous, thermal insulating board structure the surface activation of saw dust has been increased through hydrodynamic-mechanical pre-treatment. In order to characterize the boards, thermal conductivity measurement has been performed.

Keywords: hydrodynamic treatment, saw dust, sliced office paper, thermal properties, fibre boards

INTRODUCTION

Indoor thermal comfort condition in the buildings can be provided by insulators. Different types of sources and forms to produce insulating materials were used. These are for example wood boards, wood wool, rock wool, glass wool and other petrochemical based materials like expanded polystyrene foam (EPS), extruded polystyrene (XPS) and polyurethane (PU). However, these last materials have serious health and environmental impacts during production processes and could generate large quantities of toxic gases in incineration. Therefore, several studies were developed environmentally friendly insulating materials with excellent properties to replace the traditional materials. Thermal insulation panels, which were produced from natural sources gained more interest since the last decades. Natural-based insulation materials can be categorized into three types, which are animal-, plant- and mineral-based insulators. The use of these materials can enhance the energy efficiency of the buildings, reduce the amount of CO2 emission and relatively low in costs. The low-quality species of tree, sawdust, used furniture, agricultural wastes and other biomass products can be a raw material for thermal insulation boards in wood panel industry. The overall process expenses and environmental load can be reduced by utilization of these disposed wastes. Due to the limited availability of fossil resources and aggravated environmental problems it is necessary to develop new techniques to utilize lignocelluloses.

(1) Muthuraj et al. 2019 prepared bio-based composite from rice husk, wheat husk, wood fibres and textile wastes and studied the relation of thermal conductivity, density, and porosity. It was found that when the density increased and porosity of the specimens decreased, the thermal conductivity values was increased. Hussain et al. 2019 (2) also reported that enhancing the porosity of structure by increasing hemp shiv content leading to produce low density composites and reduce thermal conductivity value. Another study to confirm the relation between porosity and thermal insulation properties was investigated by Abbas et al. 2019 (3). A waste-derived silica aerogel was synthesized from rice husk for thermally insulating cement-based composite. In fact, aerogel has a highly porous structure which can produce an ultra-lightweight and insulating material. The obtained results obviously show that thermal conductivity coefficient will decrease when increasing aerogel content. The addition of aerogel content made air entrapped microstructure and increasing volume of pores in the matrix which means increasing porosity.

In this work, different wood species (spruce, poplar, beech, oak) in saw dust form, sliced office paper waste and unbleached wood fibres were treated hydrodynamically. During hydrodynamic treatment process, the wood particles sized are reduced and a chemically more homogeneous suspension was created. Then, thermal insulation boards were manufactured with increasing the porosity in several way. Thermal insulation parameter was finally investigated.

EXPERIMENTAL

Materials

Three different type of wood particle were used in this study: saw dust, sliced office paper waste and unbleached fibres. Four sawn wood saw dust for the insulating boards were made from spruce (Picea abies), poplar (Populus tremula), beech (Fagus sylvatica) and oak

(Quercus robur) received from Bakonyerdő Co. The particle size of spruce was > 0.2 mm, and the other three wood species < 0.2 mm. The wood saw dust were used as received. Sliced office paper stripes collected in the Financial department of University of Sopron. Unbleached wood pulp received from Robert Placzek GmbH. Sodium-dodecyl-sulphate was purchased from Merck KGaA, Darmstadt, Germany.

Sample preparation

The samples used for the insulating boards were hydrodynamically treated sawn wood dust particles, sliced office paper and spruce unbleached wood pulp with various thickness of 11 to 50 mm and manufactured in our laboratory. The sawn wood species for the insulating boards were made from spruce (Picea abies), poplar (Populus tremula), beech (Fagus sylvatica) and oak (Quercus robur) bonded through hydrodynamically activated wood particle surfaces. The insulating boards target, average, air-dried density was 250 kg/m3. The sawn wood dust particle was soaked in water for overnight and then treated in a laboratory disc refiner at 3-9 % consistency. The distance of the discs was changed from 5 to 0.1 mm. The sliced office paper was treated at 1.5% consistency and disintegrated in a laboratory vertical rotating plate pulper. The pulped office paper was then mixed with sodium-dodecyl-sulphate (SDS) at a concentration of 1.2 g office paper/L for 2 min in a separate container with a 2000 rpm mixer. The unbleached wood pulp was treated in a laboratory valley beater at 1.5% consistency for 10 min disintegration and 1 hour beating under 5 kg load. The grinded unbleached pulp was then mixed with sodium-dodecyl-sulphate (SDS) at a concentration of 1.2 g pulp/L for 2 min in a separate container with a 2000 rpm mixer. The hydrodynamically treated sawdust, the pulped office paper and grinded pulp were then poured into a round shaped mould with diameter of 30 cm and the bottom screen size was 50 μm, separately. The dewatering was done by gravitational force for overnight, then by vacuum sucking for 10 min. The mould was then removed, and the disc shape mats was placed into the oven to dry it at 40°C for 5 days. All the specimens were left in an air-dried laboratory condition until further processing.

To examine thermal conductivity values the surface of the insulating boards was sanded and measurement was performed on Lambda self-build instrument system. This instrument was designed for a method using heat-flow meter apparatus. In this measuring system, each specimen was set between the heating and cooling plates in an area of 50 cm by 50 cm square. A heat-flow meter in an area 10 cm square was attached to the hot plate. In the measurement the upper plate was constantly heated at 25°C and the lower, cooling plate was set to 15°C.

The temperature of the atmosphere around the specimen was controlled at 20°C, and the mean temperature (T) of each specimen was therefore kept around 20°C. The thickness values of the boards were recorded for each specimen into the software. Thermal conductivity values were calculated based on the stable and relaxed measurement method.

RESULTS AND DISCUSSION

Table 1 contain the thermal insulation values of the hydrodynamically treated sawn wood and wood pulps boards. It can be seen that unbleached wood pulp with foaming agent has the lower thermal insulation value among other boards. It can be concluded from these results that this board has the lowest density as well. In the last column of Table 1, a characteristic value was created to compare the different wood species and pulps as a type of normalization. The dimension of the characteristic value is m^4/s^3K, which clearly indicate the that thickness has the highest rate of influence on the thermal properties. Higher that characteristic value, higher the insulation performance. According to these values, it can be seen that sawn wood species has almost the same range between 2.1 to 2.7 and has an average around 2.4 with a standard deviation of 13%. Compare these values to commercially available low density wood and wood-based boards data value can be seen that for example low density wood has 2.6(4), plywood has 2.3, medium density fibreboard has 1.4 and oriented strand board has 1.8 characteristic value, respectively. It is obvious that these boards are made for structural applications and not thermal insulation, hence lower amount of air trapped – has lower porosity – inside their structure. The advantage of the present, hydrodynamically treated wood particles is that it has no artificial adhesive and has relatively high porosity. It also can be concluded that these characteristic values for these boards strongly depends on their density. The hydrodynamically treated sawn wood boards were advantageous for insulation over the commercial boards, due to their lower densities and higher porosity. The hydrodynamically treated sawn wood boards' characteristic values were approximately seven times lower compare to those of petrochemical based insulators, like 17.1 for expanded polystyrene foam, 16.3 for extruded polystyrene foam and 18.5 for fiberglass wool. That value for unbleached wood pulp is approximately 3 times lower only. There are no significant and clear differences between wood species in our measurement. The different treatment conditions were not resulted significant differences in the characteristic value as well.

Table 1. Characteristic thermal insulation values for the boards

Sample	Chemical	Hydrodynamic treatment method	*ρ (kg/m³)*	*Consistency (%)*	*λ (W/mK)*	*Characteristic value (λ/ρ)·10⁻⁴*
Spruce	-	disc-refiner	214	9	0.056	2.6
	-	disc-refiner	230	9	0.053	2.3
Poplar	-	disc-refiner	190	3	0.051	2.7
Beech	-	disc-refiner	315	3	0.067	2.1
Oak	-	disc-refiner	320	3	0.075	2.3
Sliced office paper	SDS	pulper	200	1.5	0.048	2.4
Unbleached wood pulp	SDS	valley beater	70	1.5	0.04	5.7

As it was introduced earlier the dimension of characteristic value is depends on the thickness in the highest rate. To show how the effect of thickness on the thermal insulation property, the characteristic value was normalized by the thickness. These values can be found in Table 2. Table 2 contain values from other insulation materials as well for comparison purposes. It can be concluded that with varying the thickness of one kind of material the thermal insulation properties can be fine tuning. For example, if the thickness of the hydrodynamically treated oak board can be increased, the thermal insulation properties can be better. However, the hydrodynamically treated oak saw dust thermal properties and the low-density solid wood thermal properties did not alter significantly, but they have the same density. The proper interpretation of this phenomenon can be found in the material structure itself. The cells, which is a chemical composition of cellulose, lignin and hemicellulose are connected chemically in the fiber and vessel elements in case of a solid wood, resulting inhomogeneous thermal conduction. Once the saw dust is treated hydromechanically, the homogeneity of its chemical structure is increased, the particles connect through less chemical sites and the thermal conductivity is reduced, which resulted better insulation properties. Moreover, reducing the particle size by hydrodynamic treatment can increase the porosity of the samples and the same time the heat transmission is reduced.

In case of petrochemical based or glass fibre insulation boards, the chemical homogeneity is very high and the same time the porosity as well. That high homogeneity, isotropy and micro-porosity together characterize the thermal insulation properties of a material.

In case of the thickness normalized characteristic values, the hydrodynamically treated wood saw dust has ten times lower thermal feature than conventional insulation materials (Table 2.). However, increasing further the porosity and homogeneity, isotropy, a better thermal insulation material can be reached. In this point it should be emphasize, that economy value or circular economy issue play a dominant role. Are we really want to have a better thermal insulation material from a relative low-cost saw dust with a high energy input or move ahead with a combined approach?

Table 2. Thickness normalized characteristic value of the hydrodynamic pre-treated boards and other materials

Sample	*ρ (kg/m^3)*	*λ (W/mK)*	*Thickness normalized characteristic value (1/s^{3}K)·10^6*
Spruce	214	0.056	0.2
Poplar	190	0.051	0.1
Beech	315	0.067	0.7
Oak	320	0.075	14.3
sliced office paper	200	0.048	6.5
unbleached wood pulp	70	0.04	0.02
low density wood	340	0.089	10.4
plywood	530	0.12	7.8
medium density fibreboard	690	0.10	19.1
oriented strand board	660	0.12	6.4
expanded polystyrene foam	22.0	0.037	2.1
extruded polystyrene foam	25.6	0.041	1.6
fiber glass wool	21.1	0.039	1.8

Figure 1. depict the relation between the density and thermal conductivity value, the two main factor, which influence the thermal feature. Figure 1. Right plot depicts a unique, but strong relation, how the normalized characteristic value can vary with board thickness value. This relationship sensitively correlates on the thickness to the fourth order, which means that a few more millimetre thickness can reduce thermal insulation value and increase the overall performance of the wood saw dust board. The thickness normalized characteristic value of thermal insulation board made from spruce saw dust is double than poplar, but the thickness difference is only 7 mm. The thickness normalized characteristic value of traditional insulting boards (EPS, XPS, FG) is one order of magnitude higher than the same thickness value spruce insulation board. This difference is due to the structural inhomogeneity of saw dust chemical composition.

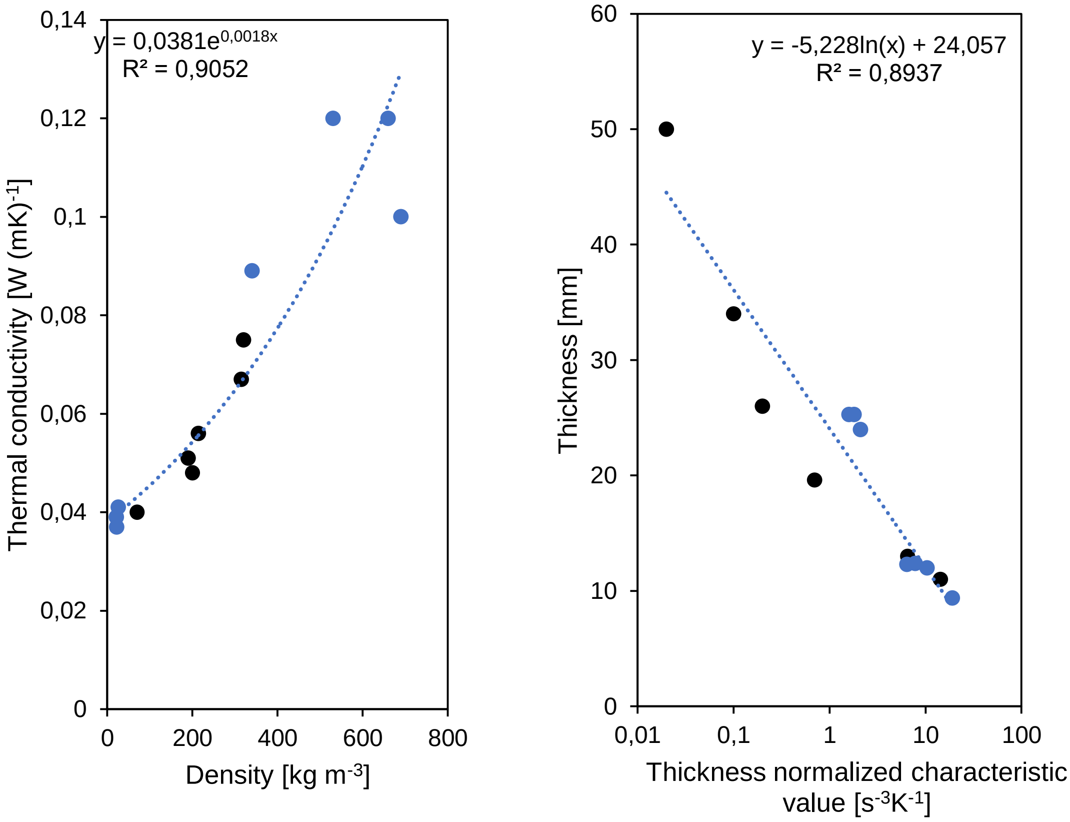

Figure 1. Left) Relation of density values versus thermal conductivity. Right) Relation of thickness normalized characteristic value versus board thickness. The highlighted blue circles refer the present measurement values.

Finally, the thermal conductivity measurement curves were analysed for the first time. The thermal conductivity measurement curves were smoothened by creating the average of 40 successive measured points from the instrument data and then a logarithmic curve fitting can tell us when the measurement start to be stable, approaching to the final value. It can be concluded from this comparison, that hydrodynamically treated beech (r2=0.98) and oak (r2=0.95) saw-dust relaxed at the same time rate, after 6 hours measurement. The beaten unbleached wood pulp (r2=0.94) with SDS relaxed at 11:40 hours rate, which is almost double than wood saw dust. It can be seen from these results, that the heat dissipation rate of pulp is much higher, because longer time need to be relaxed. In order to investigate further this phenomenon, more measurements and curves will be analysed.

CONCLUSION

Indoor thermal comfort condition in the buildings can be provided by insulators. These are for example wood boards, wood wool, rock wool, glass wool and other petrochemical based materials like expanded polystyrene foam (EPS), extruded polystyrene (XPS) and polyurethane (PU). In this work, different wood species (spruce, poplar, beech, oak) in saw dust form, sliced office paper waste and unbleached wood fibres were treated hydrodynamically and their thermal insulation properties were evaluated. During hydrodynamic treatment process, the wood particles size are reduced and a chemically more homogeneous suspension was created. It can be concluded that unbleached wood pulp with foaming agent has the lower thermal insulation value among other boards. A characteristic value was created to compare the different wood species and pulps as a type of normalization. The dimension of the characteristic value is m^4/s^3K, which clearly indicate that the thickness has the highest rate of influence on the thermal properties. The hydrodynamically treated sawn wood boards were advantageous for insulation over the commercial wood boards, due to their lower densities and higher porosity. There are no significant and clear differences between wood species in our measurement. The proposed thermal insulation mechanism of the wood saw dust boards can be approached from chemical and porosity perspective. The hydromechanically treated saw dust increased its chemical homogeneity and the thermal conductivity is reduced, which resulted better insulation properties.

ACKNOWLEDGEMENT

This work was carried out as part of the Sustainable Raw Material Management Thematic Network – RING 2017, EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realisation of this project is supported by the European Union, co-financed by the European Social Fund.

REFERENCES

1. **Muthuraj R, Lacoste C, Lacroix P, Bergeret A.** Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. Industrial Crops and Products. 2019;135.

2. **Hussain A, Calabria-Holley J, Lawrence M, Jiang Y.** Hygrothermal and mechanical characterisation of novel hemp shiv based thermal insulation composites. Construction and Building Materials. 2019;212.

3. **Abbas N, Khalid HR, Ban G, Kim HT, Lee HK.** Silica aerogel derived from rice husk: an aggregate replacer for lightweight and thermally insulating cement-based composites. Construction and Building Materials. 2019;195.

4. **Kawasaki T, Kawai S.** Thermal insulation properties of wood-based sandwich panel for use as structural insulated walls and floors. Journal of Wood Science. 2006;52(1).