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EFFECT OF DRYING TYPES AND POLYSTYRENE DENSITY ON THERMAL CONDUCTIVITY OF POLYSTYRENE COMPOSITE PARTICLEBOARD

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Abstract

Thermal conductivity of wood material is superior to other building materials because of its porous structure. Thermal conductivity is a very important parameter in determining heat transfer rate and is required for development of drying models in industrial operations such as adhesive cure rate. Thermal conductivity is used to estimate the ability of insulation of material. Thermal conductivity of wood material has varied according to wood species, direction of wood fiber, resin type, and addictive members used in manufacture of wood composite panels.

The aim of the study is to produce a new wood composite material with insulating properties by using insulating material called as polystyrene instead of formaldehyde based adhesives as bonding material. Five different wood species (beech, poplar, alder, pine, spruce), six different polystyrene species with different density values were used in this study and three layers particleboard in 18 mm thickness was produced. Urea formaldehyde resin (UF) was used in conventional panels manufacturing as adhesive. Technical drying was applied half of the test groups, while the other group was conditioned until reach to 12% equilibrium moisture content at room temperature as natural before manufacturing process to determine the effect of drying. The thermal conductivity of new composite panels were determined according to ASTM C 518 & ISO 8301.

According to the results from the study, thermal conductivity values obtained from natural drying were found to be higher than technical drying. The type of binder that gives the lowest thermal conductivity values among tree species in natural drying is generally S5. The lowest values in technical drying were obtained from panels bonded with XPS.

Keywords: Thermal Conductivity, Polystyrene Composite Particleboard, Drying Types, UF,

1. Introduction

Reducing energy consumption of buildings is required in order to counteract global warming induced by carbon dioxide, and thermal insulation of a building is an important part of this process. One of the development concepts used in the design of insulation materials is to aim to achieve a low thermal conductivity (k-value). An alternative development concept is to aim to use environmentally friendly products. One aspect of being environmentally friendly is effective utilization of unused resources. Using agricultural wastes, forest product wastes, textile wastes, and so on, as the raw materials of thermal insulation products is favourable for working towards a sustainable society based on resource recycling (Sekino, 2016). Many types of insulation materials are available which differ with regard to thermal properties and many other material properties as well as cost. Current thermal insulation materials in the construction market are generally inorganic materials e.g. extruded polystyrene (XPS), expanded polystyrene (EPS), polyisocyanurate and polyurethane foam (Cetiner and Shea, 2018). Expanded polystyrene is proved to be an excellent insulating medium which exhibits consistent thermal performance over the range of temperatures normally encountered in buildings (Lakatos and Kalmar, 2012). Expanded polystyrene has a thermal conductivity coefficient λ=0.03 w/mK, which has led to the wide use of polystyrene panels for the rehabilitation and thermal insulation of buildings (Claudiu et al., 2015). Expanded polystyrene, commonly known as styrofoam, is a polymer material present in a wide variety of

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products used in daily life, ranging from disposable goods to construction materials, due to its low cost, durability, and light weight (Jang et al., 2018). Its manufacture involves the heating of expandable beads of polystyrene with steam, and the placement of these heated expanded polystyrene beads into moulds to create prismatic blocks of EPS (Horvath, 1994). EPS has a very low density. An individual bead of EPS would be approximately spherical and contains only about 2% of polystyrene and about 98% of air (Dissanayake et al., 2017). The EPS is a chemically inert material not biodegradable, ie, it does not decompose, does not disintegrate, does not disappear in the environment and does not contain CFCs, consequently the EPS does not chemically contaminate the soil, water or air. However it can be an environmental problem if not recycled because it is considered an eternal material and it takes up too much space (due to its low density) (Schmidt et al., 2011.). Hence, reuse of EPS is beneficial in terms of environmental protection (Fernando et al., 2017). Wood–styrofoam composite (WSC) panels may be a very suitable solution for environmental pollution caused by styrofoam waste and also formaldehyde released from wood based panels (Demirkir et al., 2013).

Due to the increasing demand for wood products and the decreasing in the quality and presence of wood raw materials, the importance of composite wood products has increased steadily. This has led to an enormous increase in the use of adhesives in the forest products industry and has improved the use of wood raw materials resources. It is stated that adhesives used in about 70% of application in forest product industry (Aydin et al., 2010). Among the wide range of adhesives/resins employed in the wood industry, the most important are the amino resins. These include urea-formaldehyde (UF) resins, melamine-formaldehyde (MF) resins and melamine-urea-formaldehyde (MUF) resins. Their widespread use is due mainly to low cost and good performance. UF resins are commonly used in the manufacture of wood products, especially PB and MDF, due to their high reactivity, low cost and excellent adhesion to wood (Gonçalves et al., 2018). Over 90% of particleboard panels are bonded with urea formaldehyde resin which provides strong and durable bonds at a low cost (Nemli and Ozturk, 2006). The major disadvantages are the low moisture resistance and formaldehyde emission during the production and life time of the panels (Gonçalves et al., 2018). Formaldehyde is one of the most ubiquitous and priority pollutants indoors. Numerous studies have verified that short-term exposure to formaldehyde could cause eye, nose and throat irritation (Liang et al., 2016). The International Agency for Research on Cancer (IARC) classified formaldehyde as carcinogenic to humans, which led to stricter regulations on the emissions of formaldehyde (Resetco et al., 2016). Due to this carcinogenic nature, alternative, non-formaldehyde based adhesives, have been under intensive investigation to mitigate the emission problem (Sulaiman et al., 2018). Although some of these new adhesives have already been used in industrial applications, their supply is limited which may be due to the high modification costs or some their poor properties, for example, low wood resistance (Frang et al., 2013). Therefore, the chemicals and adhesives will use are both cheap and easily accessible and its technological properties qualify according to usage of wood based panels (Colak et al., 2016).

WSC can be manufactured without synthetic resins such as urea-formaldehyde or phenol-formaldehyde. Therefore WSC manufacturing can be suitable for both environmental and economic perspective. WSC manufacturing process also does not need a gluing machine or the preparation of glue mixture. So, the production process has been simplified (Demirkir et al., 2013).

The objective of this study was to investigate the thermal conductivity properties of particleboard manufactured with polystyrene instead of formaldehyde based adhesives used in particleboard production.

2. Materials and Methods

Beech (*Fagus orientalis Lipsky*), poplar (*Populus deltoides I-77/51*), alder (*Alnus glutinosa subsp. barbata*), pine (*Pinus sylvestris*) and spruce (*Picea orientalis L.*) wood particles, were used in the manufacture of particleboards. They were chipped using a hacker chipper before the chips were reduced into smaller particles using a knife ring flaker. First, the wood particles were screened using a horizontal screen shaker. The chips that pass through a 3 mm mesh screen and leave on a 1.5 mm mesh screen are classified in the middle layer and the chips that pass through a 1.5 mm mesh screen and leave on a 0.5 mm mesh screen are classified in the outer layer for use. After these processes, technical drying was applied half of the test groups (particles were dried using a lab-customized hot air-dryer at 90°C to 3% moisture content) while the other group was conditioned until reach to 12% equilibrium moisture content at room temperature as natural before manufacturing process to determine the effect of drying. Six different polystyrene species with different density values (10, 16, 20, 24, 30, 30-32 kg/m^3) instead of formaldehyde based adhesives were used in the manufacture of particleboards as bonding material. Urea formaldehyde resin (UF) was used in conventional panels manufacturing as adhesive. It was used urea formaldehyde resin with a solid content of 55%. Based on oven-dry particle weight, 8% and 10% resin were applied using an atomizing spray gun for the core and face layers, respectively. The ratio of the face thickness to the total thickness of a panel known as the shelling ratio was 0.40 for all samples. 20% solution of ammonium chloride (NH_4Cl) as a hardener was added at 1% in oven-dry-weight basis to resin.

In the production of polystyrene composite particleboard (PCP); the waste fragments of each polystyrene species were broken in a size of 1.5 - 3 mm in a polystyrene crusher. After these processes, the polystyrene chips were mixed homogeneously with 10% polystyrene for the outer layer and 8% for the middle layer based on the particle weight. It was formed PCP panel drafts. Polystyrene composite particleboards manufactured with 3 layer as shown in Figure 1. No hardener was used in the production of PCP panels.

Figure 1. Polystrene composite particleboards draft

Conventional and PCP panels were manufactured at a pressure of 23-25 kg cm2 at 150°C for 10 min. The ratio of the face thickness to the total thickness of a panel known as the shelling ratio was 0.35 for all specimens. The dimensions and target density of particleboards were 55 cm × 55 cm × 1.8 cm, and 0.68 gr/cm3, respectively. After pressing, panels were conditioned at a temperature of 20°C and 65% relative humidity for three weeks. Two panels for each panel type were produced. Types of test panels as well as bonding types are given in Table 1.

Table 1. Form of the groups according to bonding types

Groups	**Bonding Types**	**Density (kg/m^3)**
Conventional (Control)	Urea Formaldehyde (UF)	-
S1	Expanded Polystyrene (EPS)	10
S2	EPS	16
S3	EPS	20
S4	EPS	24
S5	EPS	30
S6	Extruded Polystyrene (XPS)	30-32

The thermal conductivity of the panels were determined according to ASTM C 518 & ISO 8301 (2004). Sample size required is 300 x 300 x 18 mm. Two specimens were used for each test group. The Lasercomp Fox-314 Heat Flow Meter shown in Fig. 1 was used for the determination of thermal conductivity. The top and lower layers of it was set for 20°C and 40°C for all specimens, respectively. The panels temperature during the measurement of the thermal conductivity was maintained to these constant temperatures.

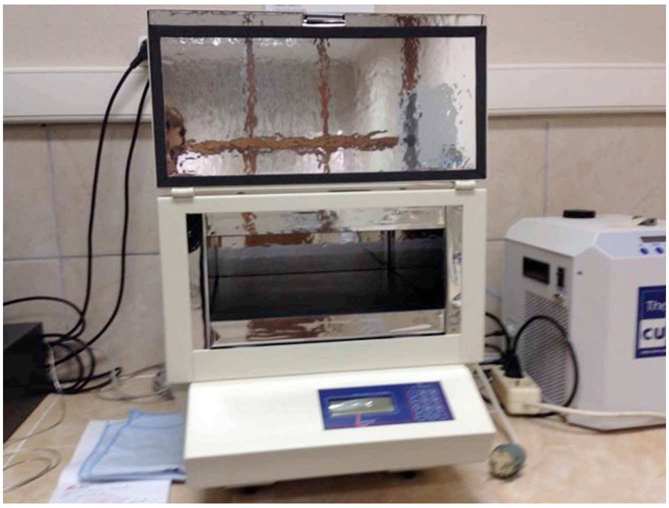

Figure 2. Lasercomp Fox-314 heat flow meter

3. Results and Discussion

Average values of thermal conductivity of conventional particleboard (control) and polystyrene composite particleboard are given in Table 2. In Figure 3, it is shown that the effect of wood species, bonding types and drying technique on thermal conductivity of panels.

Table 2: Average values of thermal conductivity of panels (W/mK)

Drying Type	Wood Species	Control (UF)	S1	S2	S3	S4	S5	S6
Natural Drying	Beech	0,1048	0,1008	0,09891	0,09413	0,09467	0,09245	0,09945
	Poplar	0,0939	0,1004	0,09266	0,09276	0,09307	0,09529	0,09385
	Alder	0,1003	0,09674	0,09700	0,09668	0,09664	0,09385	0,09446
	Pine	0,1042	0,09705	0,09578	0,09482	0,09802	0,09428	0,09616
	Spruce	0,1047	0,1011	0,1023	0,09794	0,09739	0,09692	0,1017
Technical Drying	Beech	0,1048	0,08995	0,08742	0,09167	0,08866	0,08621	0,08221
	Poplar	0,0939	0,08250	0,08316	0,08443	0,08239	0,08461	0,08423
	Alder	0,1003	0,08642	0,08662	0,08957	0,08783	0,08398	0,07904
	Pine	0,1042	0,08128	0,08679	0,08602	0,08441	0,08557	0,07907
	Spruce	0,1047	0,09318	0,09075	0,08788	0,08783	0,08673	0,08266

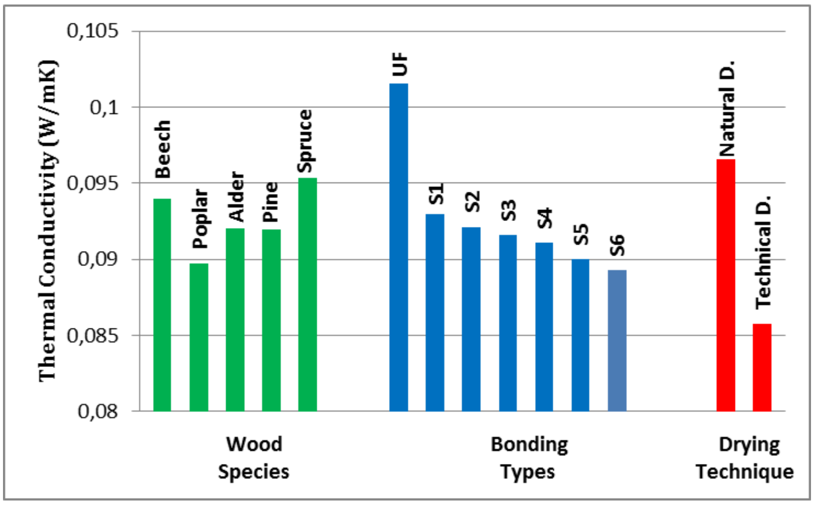

Figure 3. Effects of wood species, bonding types and drying technique on the thermal conductivity of particleboard (W/mK)

The heat conductivity of wood is dependent on a number of factors of varying degrees of importance. Some of the more significant variables affecting the rate of heat flow in wood are the following: (1) density of the wood; (2) moisture content of the wood; (3) direction of heat flow with respect to the grain: (4) kind, quantity, and distribution of extractives or chemical substances in the wood. Such as gums, tannins, or oils: (5) relative density of springwood and summerwood; (6) proportion of springwood and summerwood in the timber; (7) defects, like checks, knots, and cross grain structure (MacLean, 1941). Several studies about thermal conductivity of wooden materials showed that thermal conductivity was influenced from the thickness of composite materials, density, moisture content, the ratio of early and late wood zones, temperature, and flow direction of heat (Suleiman et al., 1999; Bader et al., 2007; Sonderegger and Niemz, 2009; Demirkir et al., 2013).

As can be seen from Table 2, the thermal conductivity values of conventional particleboards manufactured with urea formaldehyde adhesive were found to be higher than those of PCP panels. Generally, the lowest thermal conductivity values were obtained from the polystyrene composite particleboard bonded with S5 and XPS in the natural and technical drying, respectively.

According to the results from the study, thermal conductivity values obtained from natural drying were found to be higher than technical drying. In literature, the effect of the temperature on thermal conductivity of wood varied. Zhou et al. (2013) indicated for the MDF panels that thermal conductivity increased with the temperature up to 50°C and then decreased with increasing temperature in the range of 50°C to 100°C. On the other hand, it was stated that thermal conductivity of wood increases as temperature of the wood increases (Counturier et al., 1996). Tenwolde et al. (1988) also reported that the conductivity increased approximately 10 percent for every 50°C increase in temperature. The density of air filling the voids in the wood decreases as temperature increases, and this causes lower heat conduction through the voids (Suleiman et al., 1999; Aydin et al., 2015).

As shown in Figure 3, the usage of high density polystyrene in the manufacturing of PCP panels caused an decrease in thermal conductivity values. The panels manufactured from spruce gave the highest thermal conductivity values. The lowest values were found in the panels manufactured from poplar. It is known that density and moisture content have increasing effect on thermal conductivity of wood. As can be seen from Fig. 3, the lowest thermal conductivity values were determined for the panels obtained from poplar. The highest thermal conductivity values were obtained from spruce and beech. It was stated that the thermal conductivity of wood-based composites, as for wood, are strongly dependent on density and thermal conductivity of wood increases as density of the wood increases (Kamke and Zylkowski 1989; Kol and Altun 2009; Aydin et al., 2015). Also the extractive contents of spruce wood may have an increasing effect on the thermal conductivity of spruce particleboard panels. Simpson and Tenwolde stated that extractive content and a number of checks and knots in wood also play an important role on thermal conductivity (Demirkir et al, 2013).

4. Conclusion

The aim of the study was to investigate those effects of wood species, bonding types and drying technique on thermal conductivity properties of polystyrene wastes in particleboard production as a bonding material. Thermal conductivity values of traditional particleboard panels with urea formaldehyde adhesive were found to be higher than those of PCP panels. This study showed that particleboards produced from polystyrene wastes can be used as an alternative insulation material for internal use.

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