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THERMAL CONDUCTIVITY OF CROSS LAMINATED TIMBER (CLT) WITH A 45° ALTERNATING LAYER CONFIGURATION

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Abstract

Cross-laminated timber (CLT) has increasingly become a viable alternative to other structural materials, mainly because of its excellent properties related to sustainability, energy efficiency, and speed of construction. This has resulted in the recent emergence of a significant number of CLT buildings constructed around the world. Cross-laminated timber panels consist of lumber boards stacked and glued in layers, which run perpendicular to each other, making them dimensionally stable with high in- and out-of-plane strength and stiffness. 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 grain, specific gravity, moisture content, resin type, and addictive members used in manufacture of wood composite panels. The aim of this study is the comparison of two types of CLT panels consisting of boards either with grain direction aligned at 45° or at 90°, in terms of their insulation properties. In the study, spruce (*Picea orientalis L.*) was used as a wood species, and was used polyurethane for CLT panels. Thermal conductivity of CLT panels was determined according to ASTM C 518 & ISO 8301. As a result of this study, it was indicated that thermal conductivity values for 90° layers were higher than the values for 45° layers.

Keywords: Cross-laminated timber, grain direction, spruce, thermal conductivity

1. Introduction

In facing the global warming trend, there is a dire need for more effective measures to sustain comfortable temperatures in living environments. To sustain an indoor temperature that is independent of outdoor temperature fluctuations, materials are needed to be developed that have superior thermal insulation abilities (Kawasaki and Kawai 2006). Wood has been intensively used as residential construction material due to its natural beauty and great properties, such as high specific strength, thermal insulation, and ease of handling and processing (Kilic et al. 2006). For example, wood's low thermal conductivity and good strength make it of special interest for building construction, refrigeration, automobile applications, and cooperage, among others (Gu and Zink-Sharp 2005; Sahin Kol and Altun 2009; Aydin et al., 2015). Technological improvements in mass timber engineering have created a renewed sense of purpose and a more versatile use of wood as a building material. Combined with environmental issues, the importance of wood-based structures is becoming more evident compared with steel and concrete, which in turn will promote further advancements toward sustainable construction solutions (Fredriksson, 2003; Buck et al., 2016). 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 (Sekino, 2016).

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Timber constructions have undergone a revival of popularity over the last years; this positive trend is associated to a combination of several factors. Firstly, wood-based structural products generate fewer pollutants compared to the mineral-based building materials (e.g. steel and concrete) because they are obtained from sustainable and renewable resources. Secondly, timber structural elements are prefabricated off-site and transported to the building location, where they are quickly assembled. Finally, the high strength-to-weight ratio of wood is a great advantage for structures erected in seismic-prone areas, because it limits the total mass of the buildings (Izzi et al., 2018). Cross-laminated timber (CLT) is an innovative engineering wood panel product made from gluing layers of solid-sawn lumber at perpendicular angles. Owing to the excellent structural rigidity in both orthogonal directions, CLT becomes a preferred construction material for shear walls, floor diaphragms, and roof assemblies. CLT is normally made of Spruce-pine-fir (SPF) lumber or Douglas fir-Larch lumber (He et al., 2018). Cross-laminated timber (CLT) is an engineered wood product that is playing a major role in the worldwide push for wood buildings taller than the conventional limit of 5–6 stories for light-frame wood construction (Sullivan et al., 2018). It can also be combined with other mass timber produces such as glulam beams and columns (Bolvardi et al., 2018). The higher strength, stiffness, and solid wood volume of CLT, compared to conventional light frame construction, are the specific characteristics enabling the increased building heights of wood structures (Sullivan et al., 2018).

With the increasing adversity of climate changes from global warming, discussions within the international community for establishing an appropriate response policy have become more urgent (Seo et al., 2011). In facing the global warming trend, there is a dire need for more effective measures to sustain comfortable temperatures in living environments. To sustain an indoor temperature that is independent of outdoor temperature fluctuations, materials are needed to be developed that have superior thermal insulation abilities (Kawasaki and Kawai, 2006). Thermal conductivity is a very important parameter in determining heat transfer rate and is required for development of thermal insulation of materials (Sahin Kol and Altun, 2009). Several studies about thermal conductivity of composite materials showed that thermal conductivity was influenced thickness of composite materials, density, moisture content, temperature, material space ratio and flow direction of heat (Suleiman et al., 1999; Bader et al., 2007; Sonderegger and Niemz, 2009; Aydin et al., 2015).

The aim of this study is the comparison of two types of CLT panels consisting of boards either with grain direction aligned at 45˚ or at 90˚, in terms of their insulation properties. In the study, spruce (*Picea orientalis L.*) was used as a wood species, and was used polyurethane for CLT panels. Thermal conductivity of CLT panels was determined according to ASTM C 518 & ISO 8301.

2. Materials and Methods

In this experimental study, 20 mm-thick lumber with the dimensions of 100 mm by 100 mm were obtained from Spruce (Picea orientalis L.) logs. The average moisture content was 12±3% as determined by the oven dry method according to EN 322 (1999). Afterwards, the lumber processed both edgewise and flatwise through a jointer, the dimensions of each individual board were 16 mm in thickness and 85 mm in width. Three-layer-CLT panels with 48 mm thick were manufactured by using Polyurethane (PUR) glue resin. The glue was applied at rate of 160 g/m^2 to the single surfaces of lumbers. After gluing, it was formed CLT panel drafts. The draft of CLT panels is shown in Figure 1. Two types of CLT panels were produced: transverse layers at 45° and the conventional 90° arrangement. Press pressure was 8 kg/cm^2 while pressing time and temperature were 40 min and 40°C, respectively. Two replicate panels were manufactured for each test groups. Test samples were conditioned to achieve equilibrium moisture content at 20 °C temperature and 65% relative humidity prior to testing.

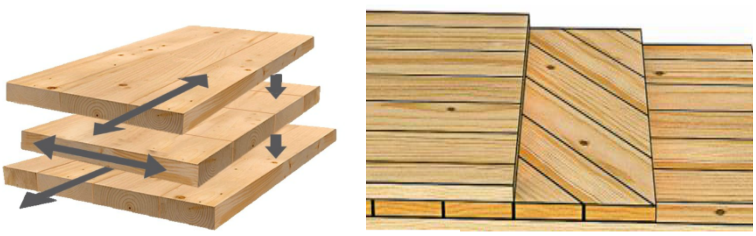

Figure 1: Draft of cross laminated timber

The thermal conductivity of the cross laminated veneer were determined according to ASTM C 518 & ISO 8301 (2004). The required sample size is 300×300×panel thickness mm. Two specimens were used for each group. The tests were made at laboratory of Forest Industry Engineering in KTU. The Lasercomp Fox-314 Heat Flow Meter shown in Figure 2 was used for the determination of thermal conductivity.

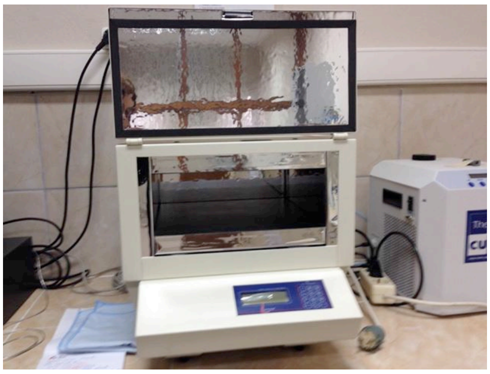

Figure 2: Lasercomp Fox-314 heat flow meter

3. Results and Discussion

As a result of this study, it was indicated that thermal conductivity values for 90˚ layers were higher than the values for 45˚ layers. The thermal conductivity values in the 45° alternating CLT layers was found to be 0,1015 W/mK and in the 90° alternating CLT layers it was found to be 0,1032 W/mK (Table 1). Wood is a hygroscopic, porous material. The unique structure of wood causes the anisotropic nature of wood in its mechanical and physical properties. Thermal conductivity of wood has been studied by many scientists (Festus et al., 2017). Several studies about thermal conductivity of composite materials showed that thermal conductivity was influenced thickness of composite materials, density, moisture content, temperature, material space ratio and flow direction of heat (Suleiman et al., 1999; Bader et al., 2007; Sonderegger and Niemz, 2009; Aydin et al., 2015). The thermal conductivity of wood varies in the three main directions of wood as they are usually referred to in the wood lumber industry – Longitudinal direction (parallel to the grain, along the length of a tree), Radial direction, (perpendicular to the grain, along the radius of the cross section) and Tangential direction (perpendicular to the grain, tangent to each growth ring) (Festus et al., 2017).

Table 1: Thermal conductivity values of CLT panels

Groups	Thermal Conductivity (W/mK)
45° alternating CLT	0,1015
90° alternating CLT	0,1032

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