THERMAL CONDUCTIVITY OF LAMINATED VENEER LUMBERS BONDED WITH VARIOUS ADHESIVES AND IMPREGNATED WITH VARIOUS CHEMICALS

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In this study it is aimed to describe the effects of adhesives (PVAc-Desmodur VTKA and Urea formaldehyde) on wooden materials (Scotch pine and oriental beech) cut tangentially and radially impregnated with Tanalith-C, creosote, and sodium silicate in layer (3, 4, 5) of laminated veneer lumber (LVLs) on thermal conductivity. The lowest thermal conductivity of 0.103 Kcal/mh°C was obtained in Scotch pine, cut tangentially, impregnated with creosote, bonded with urea formaldehyde, and 3 layer LVL. The highest thermal conductivity of 0.185 Kcal/mh°C was obtained in oriental beech, cut radially, impregnated with Tanalith-C, bonded with PVAc, and 5 layers LVL. Consequently, oriental beech wood cut radially and impregnated with Tanalith-C, bonded with PVAc adhesive and 5 layers in LVL can be used as a material in construction where the thermal conductivity is required. Scotch pine wood cut tangentially and impregnated with creosote, bonded with urea formaldehyde adhesive and 3 layers in LVL can be used as a material in construction where the insulation is required.

Keywords: Laminated Veneer Lumber; Adhesive; Impregnated; Thermal Conductivity

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INTRODUCTION

Wood is an extremely versatile material with a wide range of physical and mechanical properties among the many species of wood. It is also a renewable resource with an exceptional strength-to-weight ratio. Wood is a desirable construction material because the energy requirements of wood for producing a usable end-product are much lower than those of competitive materials, such as steel, concrete, or plastic (Winandy 1994).

Thermal conductivity is expressed by the coefficient of thermal conductivity (*k*). This is a measure of the quantity of heat in calories that will flow during a unit of time (s) through a body 1-cm thick with a surface area of 1 cm2, when a difference of 1 ºC is maintained between the two surfaces, i.e. *k* is measured in (kcal m / h ºC) (Kollmann 1968).

The thermal conductivity of wood is affected by a number of basic factors: density, moisture content, extractive content, grain direction, structural irregularities such as checks and knots, fibril angle, and temperature. Thermal conductivity increases as density, moisture content, temperature, or extractive content of the wood increases. Thermal conductivity is nearly the same in the radial and tangential directions with respect to the growth rings. Conductivity along the grain has been reported as 1.5 to 2.8 times greater than conductivity across the grain, with an average of about 1.8, but reported values vary widely. For moisture content levels below 25%, approximate thermal conductivity k across the grain can be calculated with a linear equation of the form where M is moisture content (%) (Simpson and TenWolde 1999).

Thermal conductivity (*Tc*) is influenced by various factors, such as wood structure, density, moisture, temperature, extractives, and defects (checks, knots, cross grain) (Steinhagen 1977). According to Kollmann, when moisture is increased or reduced below the fibre saturation point (FSP) by 1%, *Tc* is increased or reduced from 0.7% to 1.18%. However, above the FSP, the increase or reduction is somewhat higher, and in general wood with an MC higher than 40% has an approximately 1/3 higher conductivity than dry wood (Kollmann 1951). Furthermore, *Tc* is affected by temperature. Kanter determined the k(kcal m / h ºC) for birch at temperatures between 20 and 80 ºC at different MCs, and found variations from 0.17 to 0.21 at 20% MC and from 0.22 to 0.27 at 40% MC (Kanter 1957).

In general, the thermal conductivity of wood is low because its structure is porous. Dry wood is one of the poorest conductors of heat due in part to the low conductivity of the actual cell wall materials, and in part to the cellular nature of wood, which in its dry state contains within the cell cavities a large volume of air – one of the poorest conductors known (Desch and Dinwoodie 1996).

The demand for engineered wood products such as oriented strand board, glulam, and laminated veneer lumber - LVL has increased due to a constant increase in the global population. The grain of each layer of veneer assembled into LVL runs parallel with each adjacent ply (Badwin 1995; Kurt 2006; Uysal 2005). Being a homogeneous and dimensionally stable building material, LVL can be used where strength and stability are required (Colak et al. 2004).

Since there has not been enough study on the thermal conductivity of LVL's, the aim of this study was to compare the effects of adhesives (PVAc- D-VTKA and urea formaldehyde) on wooden materials (Scotch pine, oriental beech) cut tangentially and radially impregnated with Tanalith-C, creosote and sodium silicate and layers (3, 4, 5) of LVL's.

EXPERIMENTAL

Materials

Scotch pine (*Pinus sylvestris L.*) and oriental beech (*Fagus orientalis L.*) were chosen randomly from timber suppliers of Ankara, Turkey. A special emphasis was put on the selection of the wood material. Accordingly, non-deficient, whole, knotless, normally grown (without zone line, reaction wood, decay, insect or fungal infection) wood materials were selected.

Adhesives

Three different types of the following adhesives were used in this experiment: PVAc, (Polyvinyl acetate) an odorless and non-flammable adhesive can be used in cold temperatures and solidifies quickly. The application of this adhesive is very easy and it does not damage the tools during the cutting process. However, mechanical resistance of PVAc adhesive decreases by increasing the heat. It loses its bonding resistance capacity over 70°C. Using 170–180 g/m^2 adhesive seems to be suitable when it is applied to only one surface (Ors 1987). TS 3891 standard procedure was used for applying PVAc adhesive. The density of PVAc should be 1.1 g/cm^3, the viscosity 16.000±3.000 mPa.s, th pH value 5, and the ash ratio 3%, respectively. A pressing time of 20 min for the cold process and 2 min at 80°C are recommended with 6–15% humidity for the jointing process. After a hot-pressing process, the materials should be attended until its normal temperature is reached (TS 3891 1983). PVAc adhesive was supplied from POLISAN, a producer firm in İzmit, Turkey.

Producer firm describes Desmodur-VTKA as a one-component polyurethane-based and widely preferred adhesive for the assembly process in the furniture industry. It has one component, as a solvent-free adhesive. It is used for gluing wood, metal, polyester, stone, glass, ceramic, PVC, and other plastic materials. Its application is specially recommended in locations subject to high-level humidity. The gluing process was carried out at 20 ^{o}C and 65 % relative humidity. According to the producer firm's advice, adhesive was applied 180-190 g/m^2 to the surfaces. Its viscosity was -14 000 ± 3000 mPa.s. at 25 ^{o}C; density 1.11 ± 0,02 g/cc at 20 ^{o}C, and it had resistance against cold air (Producer firm 1999).

Urea and formaldehyde are combined in a reactor into UF resin. It is shipped to engineered wood product plants as a colloidal aqueous solution with a solids content of about 65%. This liquid is odorless, slightly opaque, and, of course, not flammable. When shipped, the UF resin is already polymerized and cross-linked to a certain degree. Urea-formaldehyde reacts with a wooden cell wall hydroxyl groups. Adhesive is usually applied on the surfaces at 100–150 g/m^2. If cold pressing is applied at 20 °C, the period of pressing is 3–5 h. In hot press, this period decreases to 3–5 min (Çolakoglu 1998).

Impregnated Materials

The creosote, a mixture of different distillation fractions of hard coal tar, consists of many polyaromatic and heterocyclic compounds. The main components according to GC/MSD identification were naphthalene, quinoline, acenaphthene, dibenzofurane, fluorene, phenanthrene, anthracene, fluoranthene, and pyrene (Becker 1997).

In this study, Tanalith-C (copper chromium arsenic) was used at a 4 % concentration. Pressure impregnation (PI) of timber using waterborne preservatives such as Tanalith-C or copper chromium arsenic (CCA) by the full-cell process is an important method to increase the natural durability of wood against deteriorating organisms, and hence, increase its service life. Efficient penetration and uniform distribution of the preservative salt is achieved by PI, as the preservative is driven into the wood via the wood capillary system. Factors of prime consideration governing the flow are the amount of pressure, fluid viscosity, solvent contact angle, wood pore radius, and wood capillary length (Siau 1971).

CCA stands for Chromated Copper Arsenate, a wood preservative formulation containing copper, chromium, and arsenic. The copper acts as the main fungicide and also provides some protection against termites. Arsenic provides protection against termites and copper-tolerant decay fungi. Chromium helps to bond and "fix" the chemical components to the wood (www.tretewood.com).

Sodium silicate, also known as water glass or liquid glass, available in aqueous solution and in solid form, is a compound used in cements, passive fire protection, refractories, textile, and lumber processing. Sodium carbonate and silicon dioxide react when molten to form sodium silicate and carbon dioxide. Sodium silicate is a white solid that is soluble in water, producing an alkaline solution. There are many kinds of this compound, including sodium orthosilicate, Na_4SiO_4; sodium metasilicate, Na_2SiO_3; sodium polysilicate, $(Na_2SiO_3)_n$; sodium pyrosilicate, $Na_6Si_2O_7$, and others. All are glassy, colourless and dissolve in water (www.answers.com).

Determination of Density

Wood materials were kept in the room at 20 ± 2°C and 65 ± 3 % relative humidity until their weight became stable (TS 2471 1976). Air dry densities of wood materials before and after impregnation, used for the preparation of treatment samples, were determined according to TS 2472 (1976). Afterwards, the dimensions of wood materials were measured by a compass of ±0.001 sensitivity, and volumes were determined by a stereo-metric method. The air dry density (δ_{12}) was calculated by the following equation:

$$\delta_{12} = M_{12}/V_{12} \ \text{g/cm}^3 \qquad (1)$$

where M_{12} is the perfect air dry weight (g) and V_{12} is the volume (g/cm^3) of the wood material.

Preparation of Experimental Samples

The wood samples cut from sap wood were conditioned at 20 ± 2°C and 65± 3% relative humidity until they reached constant weight by holding them for 3 months in a climatization room. Air-dry specimens with a dimension of 4, 5, 7 mm±0.3 x 50 x 100 mm were cut from the drafts for impregnation. Impregnation processes as specified in ASTM D 1413-76 (ASTM-D 1413-76 1976), TS 344 (TS 344 1981) and TS 345 (TS 345 1974) were applied to the prepared test samples. For this aim, the samples were dipped into the impregnation solution (having packing viscosity) for 48 h for long-term dipping, provided the samples passed over. Before the impregnation process all samples were weighed and then kiln dried at the temperature of 103 ± 2°C until they reached constant weight. Then, the samples were weighed in an analytic balance with 0.01-g sensitivity. After impregnation, all impregnated samples were held for 15 days in circulating air for evaporation of the solvent. Impregnated test samples were kept at the temperature of 20 ± 2°C and 65 ± 3% relative humidity until they reached constant weight.

After this period the impregnated samples were kiln dried at 103 ± 2°C until they reached constant weight. After cooling, all dried samples in the desiccator were weighed on the scale. The dry weights of the samples were determined and recorded. The amount of retention (*R,*kg/m) and ratio of retention (*R,* %) were calculated as follows:

$$R = \frac{GxC}{V} 10^{3} \quad kg/m^3 \tag{2}$$

$$R(\%) = \frac{Mdi - Md}{Md} 100 \tag{3}$$

$$G = M_2 - M_1 \tag{4}$$

where G is the mass of the sample after impregnation (M_2, kg) minus the mass of the sample before impregnation (M_1, kg), Mdi is the dry mass after impregnation (kg), Md is the dry mass before impregnation (kg), V is the volume of the sample (m^3), and C is the concentration of the solution (%).

The characteristic features of the impregnation chemicals were determined before and after the impregnation processes. All processes were carried out at 20 ± 2°C. Impregnated test samples were kept at 20 ± 2°C and 65 ± 3% relative humidity until they reached constant weight. Afterward, approximately 180 g/m^2 of adhesive was applied to the bonding surfaces of samples, based on TS 5430 (1988). Bonding was obtained with 0.5 N/mm^2 press pressure and 24-h pressing time. Press temperatures were applied at 110 °C for UF adhesive by taking the general curing temperatures recommended by their manufacturers into consideration. LVL's were prepared in a way to enable 3, 4, and 5 layers. There were 1920 test samples with 12 % average moisture with dimensions of 20 x 50 x 100 mm according to the procedure of ASTM C 177/C 518 for each wood species (ASTM C 177/C 518 2004).

Execution of the Test

A quick thermal conductivity meter based on ASTM C 1113-99 hot-wire method was used (ASTM C1113-99 2004). Variac (power supply) was used to supply constant electrical current to the resistance. QTM 500 device is a product of Kyoto Electronics Manufacturing, Japan. Measurement range is 0.0116–6 W/mK. Measurement precision is F5% of reading value per reference plate. Reproducibility is F3% of reading value per reference plate. Measurement temperature is -100 to 1000 °C (external bath or electric furnace for temperature other than room). Sample size required is 20 x 50 x 100 mm. Measuring time is Standard 100 –120 s (Sengupta et al. 1992).

Data Analyses

By using three different types of glue, three impregnation chemicals and one control sample, one kind of process, two wood types, directions (tangentially and radially), and three differences of layer (3, 4, 5), and unprocessed wood (control) as parameters, a total of 1920 samples (3 x 4 x 2 x 2 x 4 x 1 0) were prepared using 10 samples for each parameter. Multiple analyses of variance were used to determine the differences between the thermal conductivity of the prepared samples.

RESULTS

The averages of density are given in Table 1.

Table 1. Average Values of Density (g/cm^3).

Wood type	Grain Orient.	Adhesives	Layer	Tanalith-C	Creosote	Sodium Silicate	Control
Scotch Pine	Radial	PVAc	5	0.694	0.739	0.660	0.649
			4	0.683	0.716	0.705	0.616
			3	0.638	0.582	0.604	0.593
			Control	0.560	0.537	0.526	0.514
		D-VTKA	5	0.638	0.660	0.638	0.616
			4	0.616	0.571	0.627	0.548
			3	0.619	0.527	0.518	0.526
			Control	0.560	0.537	0.526	0.514
		Urea form.	5	0.672	0.728	0.683	0.649
			4	0.649	0.694	0.660	0.593
			3	0.593	0.560	0.560	0.571
			Control	0.560	0.537	0.526	0.514
	Tangential	PVAc	5	0.862	0.887	0.772	0.722
			4	0.806	0.844	0.828	0.716
			3	0.739	0.806	0.716	0.660
			Control	0.705	0.660	0.672	0.627
		D-VTKA	5	0.772	0.784	0.772	0.660
			4	0.739	0.795	0.761	0.649
			3	0.749	0.683	0.649	0.639
			Control	0.705	0.660	0.672	0.627
		Urea form.	5	0.806	0.840	0.840	0.761
			4	0.761	0.817	0.806	0.705
			3	0.750	0.739	0.660	0.672
			Control	0.705	0.660	0.672	0.627
Oriental beech	Radial	PVAc	5	0.907	0.862	0.873	0.862
			4	0.828	0.640	0.817	0.784
			3	0.739	0.806	0.694	0.694
			Control	0.672	0.705	0.694	0.616
		D-VTKA	5	0.806	0.761	0.817	0.705
			4	0.761	0.683	0.739	0.716
			3	0.660	0.683	0.638	0.628
			Control	0.672	0.705	0.694	0.616
		Urea form.	5	0.840	0.795	0.828	0.761
			4	0.795	0.784	0.784	0.750
			3	0.728	0.784	0.716	0.694
			Control	0.672	0.705	0.694	0.616
	Tangential	PVAc	5	0.873	0.930	0.907	0.862
			4	0.851	0.929	0.873	0.840
			3	0.806	0.907	0.817	0.739
			Control	0.728	0.750	0.739	0.716
		D-VTKA	5	0.817	0.817	0.806	0.761
			4	0.772	0.806	0.784	0.761
			3	0.638	0.806	0.672	0.660
			Control	0.788	0.750	0.739	0.716
		Urea Form.	5	0.817	0.851	0.851	0.784
			4	0.817	0.795	0.862	0.828
			3	0.795	0.761	0.862	0.739
			Control	0.728	0.750	0.739	0.716

The highest density (0.930gr/cm^3) was obtained in oriental beech prepared tangentially, impregnated with creosote, bonded with PVAc and 5 layer LVL. The lowest density (0.514gr/cm^3) was obtained in Scotch pine prepared radially, unprocessed impregnated, unprocessed wood (control).

The highest retention amounts are given in Table 2.

Table 2. Amount of Retention (kg/m^3).

Chemicals	Wood species	Grain orientation	Mean	Max	Min	S.Dev.	Variance
Tanalith - C	Scotch pine	Radially	0.8	1	0.6	0.1641	0.027
		Tangentially	0.78	1	0.6	0.1514	0.022
	Oriental beech	Radially	0.75	0.85	0.65	0.1114	0.012
		Tangentially	0.66	0.75	0.58	0.1058	0.011
Creosote	Scotch pine	Radially	65.9	71.5	60.2	4.7841	22.88
		Tangentially	61.2	67.1	56.8	4.3574	18.98
	Oriental beech	Radially	42.8	46	38.9	2.7893	7.780
		Tangentially	41.4	44.2	38	2.5997	6.758
Sodium Silicate	Scotch pine	Radially	41.8	46.9	36.8	4.5893	21.061
		Tangentially	36.9	40.3	31.7	4.1247	17.013
	Oriental beech	Radially	31.2	33	29.8	1.5475	2.395
		Tangentially	27.7	29.8	25	1.4714	2.165

The highest retention amounts 68.1 kg/m^3 for Scotch pine, and 45 kg/m^3 for oriental beech were determined in both wood species prepared radially with creosote impregnation chemicals. Creosote is heated electrically to reduce viscosity and improve penetration (Kurt 2006; Richardson 1993; Bergman 2003).

The thermal conductivity values of Scotch pine (Kcal/mh°C) are given in Table 3. The highest thermal conductivity of 0.176 Kcal/mh°C was obtained in Scotch pine, cut radially, impregnated with Tanalith-C, bonded with PVAc, and 5 layer LVL. The lowest thermal conductivity of 0.103 Kcal/mh°C was obtained in Scotch pine, cut tangentially, impregnated with creosote, bonded with urea formaldehyde, and 3 layer LVL.

The thermal conductivity value of oriental beech (Kcal/mh°C) is given in Table 3. The highest thermal conductivity of 0.185 Kcal/mh°C was obtained in oriental beech, cut radially, impregnated with Tanalith-C, bonded with PVAc, and 5 layers LVL. The lowest thermal conductivity of 0.134 Kcal/mh°C was obtained in oriental beech, cut tangentially, impregnated with creosote, bonded with D-VTKA, and 3 layer LVL.

Table 3. Average Values of Thermal Conductivity Coefficients (Kcal/mh°C).

Wood type	Grain Orienta-tion	Adhesives	Layer	Tanalith -C	Creosote	Sodium Silicate	Control
Scotch Pine	Radial	PVAc	5	0.176	0.126	0.132	0.126
			4	0.144	0.121	0.149	0.119
			3	0.124	0.119	0.120	0.118
			Control	0.131	0.123	0.124	0.118
		D-VTKA	5	0.143	0.115	0.124	0.123
			4	0.138	0.112	0.124	0.115
			3	0.135	0.112	0.121	0.109
			Control	0.131	0.123	0.124	0.118
		Urea form.	5	0.140	0.123	0.117	0.117
			4	0.139	0.109	0.119	0.114
			3	0.114	0.105	0.122	0.110
			Control	0.131	0.123	0.124	0.118
	Tangential	PVAc	5	0.157	0.124	0.142	0.125
			4	0.141	0.115	0.134	0.118
			3	0.121	0.113	0.118	0.115
			Control	0.124	0.120	0.121	0.115
		D-VTKA	5	0.134	0.114	0.124	0.120
			4	0.133	0.112	0.117	0.111
			3	0.130	0.110	0.115	0.105
			Control	0.124	0.120	0.121	0.115
		Urea form.	5	0.130	0.113	0.121	0.114
			4	0.124	0.109	0.117	0.114
			3	0.110	0.103	0.115	0.115
			Control	0.124	0.120	0.121	0.115
Oriental beech	Radial	PVAc	5	0.185	0.154	0.161	0.159
			4	0.156	0.145	0.158	0.157
			3	0.149	0.153	0.159	0.157
			Control	0.155	0.160	0.159	0.149
		D-VTKA	5	0.158	0.154	0.157	0.155
			4	0.153	0.148	0.154	0.151
			3	0.158	0.140	0.152	0.151
			Control	0.155	0.160	0.159	0.149
		Urea form.	5	0.159	0.155	0.157	0.154
			4	0.152	0.148	0.157	0.150
			3	0.150	0.147	0.151	0.150
			Control	0.155	0.160	0.159	0.149
	Tangential	PVAc	5	0.158	0.148	0.155	0.154
			4	0.153	0.145	0.155	0.154
			3	0.149	0.145	0.157	0.152
			Control	0.155	0.147	0.148	0.141
		D-VTKA	5	0.158	0.152	0.158	0.149
			4	0.146	0.145	0.148	0.149
			3	0.147	0.140	0.148	0.146
			Control	0.155	0.147	0.148	0.141
		Urea Form.	5	0.155	0.151	0.160	0.152
			4	0.150	0.139	0.145	0.151
			3	0.148	0.138	0.144	0.148
			Control	0.155	0.147	0.148	0.141

The multi-variance analyses applied on the data obtained from the thermal conductivity test is given in Table 4.

Table 4. Multi-variance Analysis for the Effect of Wood Type, Grain Orientation, Adhesive Type, Chemicals, and Layer on Thermal Conductivity

Source	Type II Sum of Squares	df	Mean Square	F	Significance
A	6.361E-04	2	3.181E-04	2.159	0.116
B	0.223	1	0.223	1511.711	0.000
C	2.910E-03	1	2.910E-03	19.754	0.000
D	1.201E-02	3	4.004E-03	27.182	0.000
E	2.607E-02	3	8.689E-03	58.989	0.000
A*B	4.728E-03	2	2.364E-03	16.050	0.000
A*C	6.252E-06	2	3.126E-06	0.021	0.979
B*C	2.164E-03	1	2.164E-03	14.690	0.000
A*B*C	1.974E-04	2	9.869E-05	0.670	0.512
A*D	1.168E-03	6	1.946E-04	1.321	0.245
B*D	1.755E-03	3	5.848E-04	3.970	0.008
A*B*D	2.438E-03	6	4.063E-04	2.759	0.012
C*D	1.856E-03	3	6.187E-04	4.200	0.006
A*C*D	9.934E-04	6	1.656E-04	1.124	0.346
B*C*D	4.102E-04	3	1.367E-04	0.928	0.426
A*B*C*D	4.331E-04	6	7.219E-05	0.490	0.816
A*E	3.726E-03	6	6.209E-04	4.215	0.000
B*E	1.201E-02	3	4.004E-03	27.184	0.000
A*B*E	1.337E-03	6	2.229E-04	1.513	0.170
C*E	9.074E-04	3	3.025E-04	2.053	0.105
A*C*E	1.051E-03	6	1.752E-04	1.190	0.309
B*C*E	9.712E-04	3	3.237E-04	2.198	0.087
A*B*C*E	3.187E-04	6	5.312E-05	0.361	0.904
D*E	1.542E-02	9	1.713E-03	11.630	0.000
A*D*E	8.180E-03	18	4.545E-04	3.085	0.000
B*D*E	7.336E-03	9	8.152E-04	5.534	0.000
A*B*D*E	3.524E-03	18	1.958E-04	1.329	0.161
C*D*E	1.572E-03	9	1.747E-04	1.186	0.300
A*C*D*E	3.099E-03	18	1.722E-04	1.169	0.280
B*C*D*E	1.553E-03	9	1.725E-04	1.171	0.310
A*B*C*D*E	1.277E-03	18	7.097E-05	0.482	0.966

Factor $_A$ = Adhesive type (PVAc, D-VTKA and UF)
Factor $_B$ = Wood species (Scotch pine and oriental beech)
Factor $_C$ = Grain orientation (Radial, Tangential)
Factor $_D$ = Layer (3, 4, 5)
Factor $_E$ = Impregnated material (Tanalith-c, creosote, sodium silicate, control)

According to the variance analysis, the effects of grain orientation, wood species and the effects of grain orientation, wood species and impregnation material were statistically significant. On the other hand, according to the variance analysis, the effects of adhesive type were not statistically significant.

DISCUSSION

The thermal conductivity of oriental beech is higher than Scotch pine. Sova et al. (1970) stated that *Tc* increases proportionally with wood density, moisture content (MC), and temperature.

According to the interaction given in Figs. 1 and 2 between the adhesive types and grain orientation, urea formaldehyde adhesive and cut tangentially gave the lowest result in Scotch pine and oriental beech.

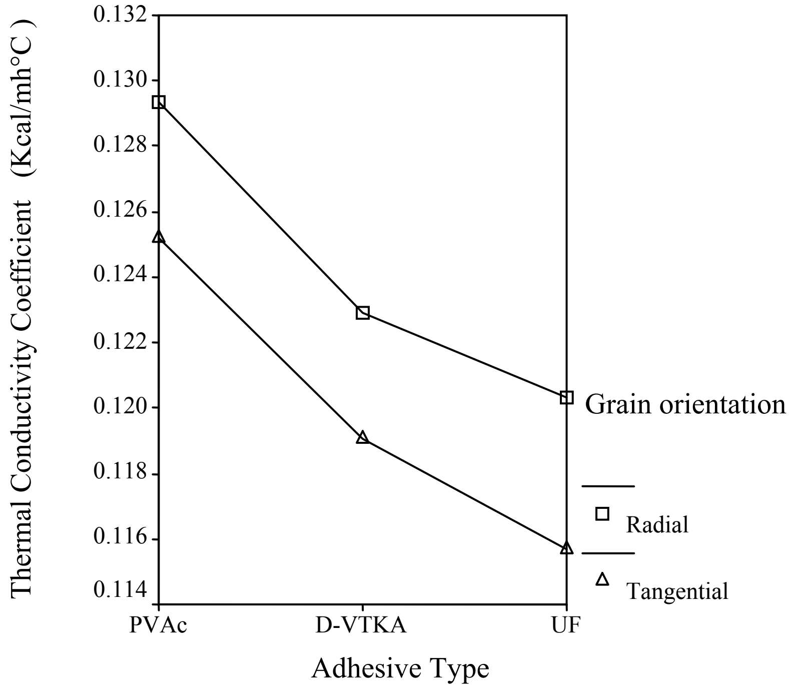

Figure 1. Effect of types of adhesives and grain orientation on thermal conductivity in Scotch pine

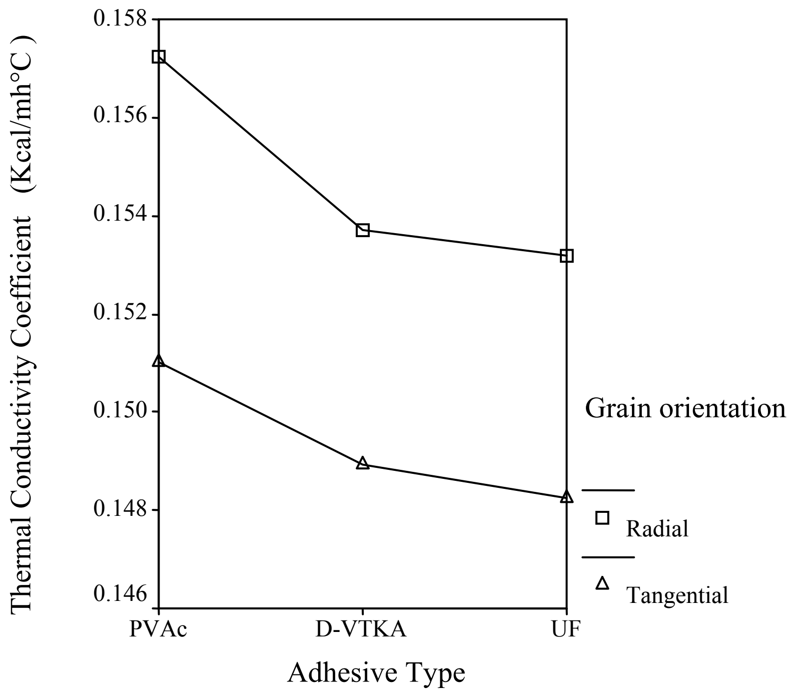

Figure 2. Effect of types of adhesives and grain orientation on *Tc* in oriental beech; thermal conductivity in radial direction are at average 5- 10 % higher than the ones in tangential direction (Ors and Keskin 2001).

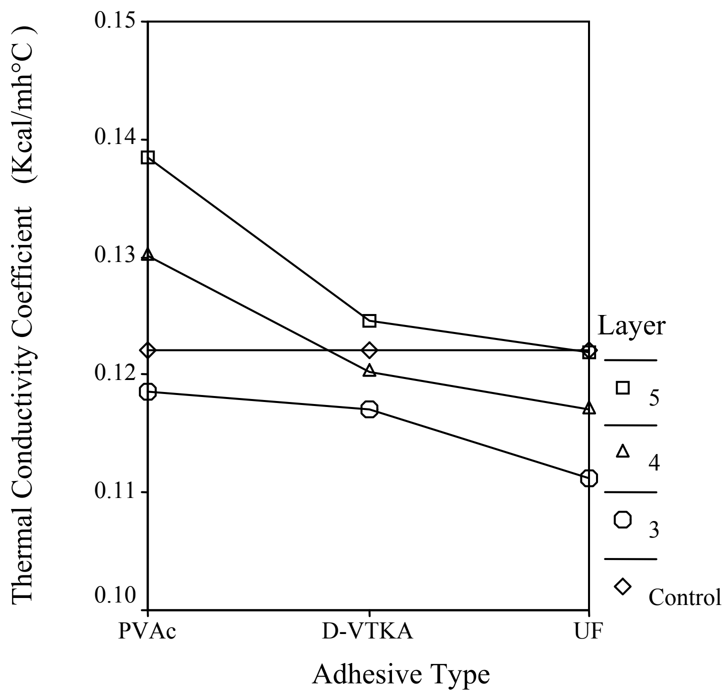

Figure 3. Effect of types of adhesives and layer in LVL on TC in Scotch pine

According to the interaction given in Figs. 3 and 4, considering the adhesive types and layers in LVL, urea formaldehyde adhesive and 3 layer LVL gave the lowest result in Scotch pine and oriental beech.

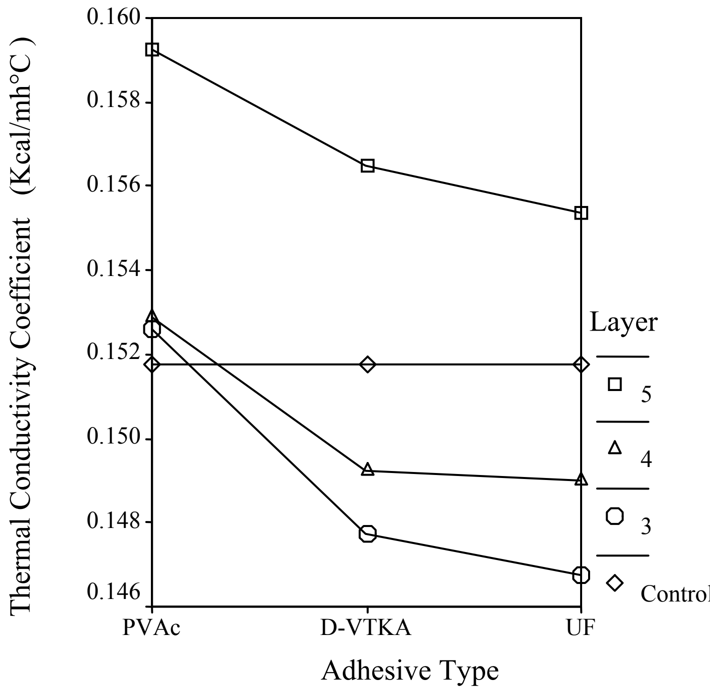

Figure 4. Effect of types of adhesives and layer in LVL on TC in oriental beech

According to the interaction given in Figs. 5 and 6, among the adhesive types and impregnated materials, D-VTKA adhesive and impregnation with creosote gave the lowest result in Scotch pine and urea formaldehyde and creosote in oriental beech.

CONCLUSIONS

1. Oriental beech wood cut radially and impregnated with Tanalith-C, bonded with PVAc adhesive and 5 layers in LVL can be used as a material in construction where the thermal conductivity is required.
2. Scotch pine wood cut tangentially and impregnated with creosote, bonded with urea formaldehyde adhesive and 3 layers in LVL can be used as a material in construction where the insulation is required.

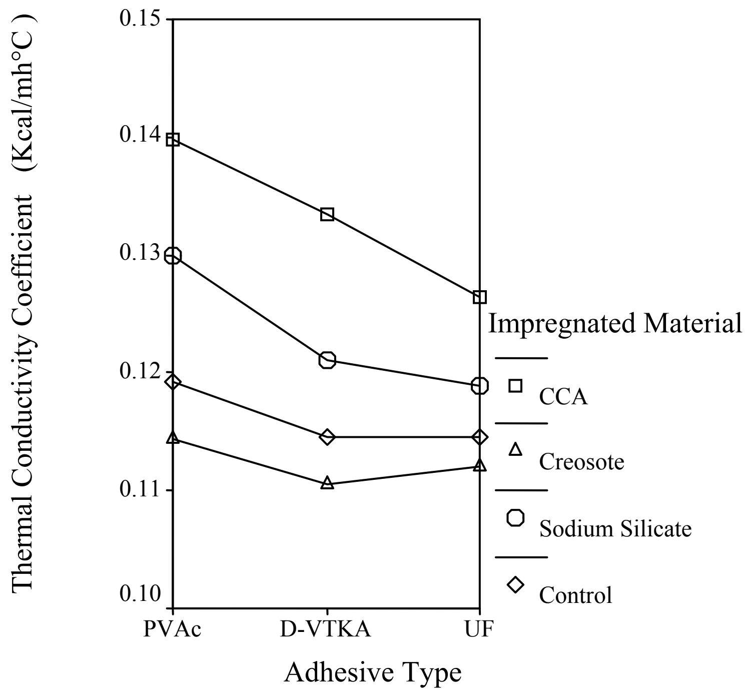

Figure 5. Effect of types of adhesives and impregnated material on TC in Scotch pine

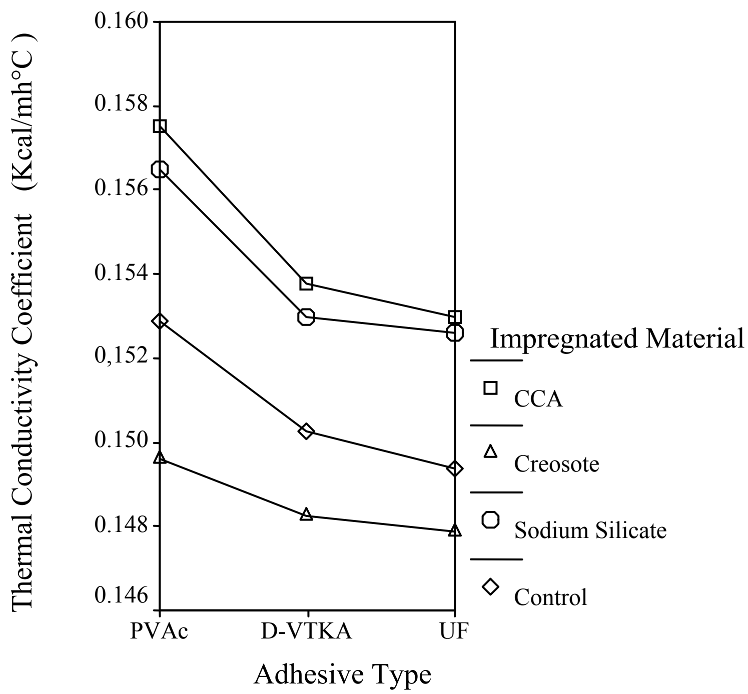

Figure 6. Effect of types of adhesives and impregnated material on TC in O. beech

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