A NEW METHOD IN NDT OF WOOD: THERMAL CONDUCTIVITY

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Abstract: NDT (Non-Destructive Testing) is a analysis technique of materials without causing damage. Common techniques of NDT are ultrasonic, acoustic emission, penetrometer, radiography etc. This methods depends on distinctive features of materials. NDT is used in a variety of settings that covers a wide range of industrial activity, with new NDT methods and applications, being continuously developed. Non-destructive testing methods are routinely applied in industries where a failure of a component would cause significant hazard or economic loss, such as in transportation, pressure vessels, building structures, piping, and hoisting equipment. Thermal conductivity is a inherit feature of wood material and it is related with density. In this study, a developed thermal conductivity based NDT device will be introduced and it's reliability will be exhibited.

Keywords: Non-Destructive Testing, Wood Material, Thermal Conductivity

Introduction

Wood is an engineering material with these known properties; lightweight, durable, easily worked, ecological, stylish, natural, versatile, low-density, cellular, hygroscopic, polymeric, and composite. Thanks to this excellent properties, woodcan potentially be used for a large variety of applications such as traditional buildings, earthquake resistant buildings, flooring, roofing, utensils, indoor and outdoor furniture, boat and shipbuilding, bridges, sport equipment, etc.

The using of wood as construction material is nearly as old as the history of mankind. In addition, wooden houses are already in existence. Wooden houses still subsist and widely preferred especially in many countries in Europe and United States. Turkey has wooden and half-masonry structures built especially during the times of Ottoman Empire. However, only a part of these structures remain standing from past to the present as cultural heritages reflecting the related period. Maintenances and restorations of this structures have a critical importance for their transfer to the next generations. Today, the tests of these structures are performed with visual inspection by the relevant institutions. Recently, in parallel with technological developments, some non-destructive testing methods have been developed for testing the durability of historical wooden house's constructions. The most important methods among them are penetrate, acoustic, microwave, electricity and magnetic assessment methods.

Wood has an historical impact on the life and cultural development process of human (Erdin, 2003). The using of wood material as a construction material has started too many years ago and this process has extended until today with the technological developments (Korkmaz, 2012). In America, especially in California, which is located on the seismic zone, approximately 90% of houses were made of wood (Mcrea et al, 2001). However, some disadvantages of wood, for example, bad dimensional steadiness, relatively low strength,easy worm-eaten and decay, and bad fire resistance, prevent wood extensive usages. These disadvantages limits to expected life of the wood material (Yalınkılıç, 1992).

Non Destructive Testing (NDT) covers a wide group of examination methods used to assess the properties of a material, part, product, weld, or system without causing harm. It is a commonly-used instrument in mechanical engineering, forensic engineering, civil engineering, mechanical engineering, aerospace and aeronautical engineering and medical applications. This term can also be used as Non Destructive Inspection (NDI), and Non Destructive Evaluation (NDE) in literature. Visual assessment and classification of wood which is one of the oldest forms of non-destructive testing needs another method to verify reliability of findings. Visual assessment is totally subjective and directed by the performer. Non-destructive testing methods provide an opportunity to get more reliable results (Bodig and Jayne, 1982). According to Youngquist and Hamilton (1999), NDT is a method which is needed to focus on in the 21 century.

Heat is the total energy of molecular motion in a substance while temperature is a measure of the average energy of molecular motion in a substance. Heat energy relies on the speed of the particles, the quantity of particles (the size or mass), and the kind of particles in an object. Temperature does not rely on the size or type of object. Heat exchange is the transfer of thermal energy between physical systems. The rate of heat exchange is reliant on the temperatures of the systems. The direction of heat exchange is from a region of high temperature to another region of lower temperature. On a microscopic scale, heat conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy (heat) to these neighboring particles. In other words, heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact.

Thermal conductivity can be expressed in terms of a coefficient of thermal conductivity (k). According to Fourier's law, in steady state condition, this is the measure of the rate of heat flow through one unit thickness of a material subjected to a temperature gradient, i.e., k is measured in $W \cdot m^{-1} \cdot K^{-1}$ (Kollmann and Cote 1968; Lienhard IV znd Lienhard V 2011). When heat is applied to a body, the vibratory energy of its molecules in that vicinity is increased. These molecules collide with neighboring molecules and, in so doing, transmit to them a part of their newly acquired energy. These neighboring molecules then in turn transmit a part of their newly acquired energy to still other molecules farther from the center of the disturbance (Brown et al. 1952).Due to the connections between atoms, the displacement of one or more atoms from their equilibrium positions will give rise to a set of vibration waves propagating through the lattice, and heat transfer in a dielectric solid occurs through elastic vibrations of the lattice.

The solid may be a crystal or it may be amorphous, but each atom has afixed equilibrium position, and the thermal vibrations can thus be resolved into normal modes. For a perfect crystal, these normal modes are plane travelling waves. Departures from the perfect lattice result in interactions, which are responsible for the statistical equilibrium between the normal modes. The thermal conductivity at liquid helium temperatures is due solely to phonons of the longitudinal mode of vibration (Debye 1912;Pomeranchuk 1941; Klemens 1951; Stephens 1973; Pohl et al. 1999).Jayne (1959) proposed in his well-known hypothesis for NDE of wood-based materials that energy storage and dissipation properties of wood-based materials are controlled by the same mechanisms that determine static behavior of such materials.

The above differential equation, when integrated for homogeneous material of 1-D geometry between two endpoints at constant temperature, gives the heat flow rate as:

$$\frac{\Delta Q}{\Delta T} = -kA \frac{\Delta T}{\Delta x}$$

Where
A is the cross-sectional surface area,
ΔT is the temperature difference between the surfaces,
Δx is the distance between the surfaces.

Density one of the major factor of the thermal conductivity with material's atoms and molecules are bonded together and their arrangement.

Materials and Methods

In this study, a portable machine which gives an idea about the strength of the wooden material depending on it's the rate of thermal conductivity was used. With the help of this machine, it is aimed to manufacture an alternative portable testing machine to acoustic and microwave testing systems. With this machine, especially in historical wooden houses, acceptable strength values of column-row systems will be determined through thermal conductivity coefficient without damaging the structure. Also, by using this machine it will be provide that defining the thermal conductivity values of facade systems of houses that are being used or ongoing construction. For the determination of strength values, thermal conductivity was defined on same test samples via new designed portable machine.

This machine consists of a terminal board, a heater and a thermo probe. Terminal board communicates with computer by USB serial. Also, the software was developed which process data comes from terminal board. A plate type sensor board was developed as probe with dimension of 50 mm * 70 mm. This sensor board was connected to terminal board with 3.5 mm jack and supplied with 3.5 V (DC). On the terminal board, Atmega 328 microcontroller was used. Because this microcontroller was used in arduino systems, the software of microcontroller was developed on Arduino platform.

A plate type resistance was used as heater with dimension of 100 mm * 70 mm. This resistance was supplied with 24V (DC) constant supply by a transformator. The surface of heater resistance was packaged with insulation materials to prevent heat escape and to provide reliability in experiments. The surface of sensor board was packaged with insulation materials to provide reliability. In order to measure the heat flow on the wood material, the temperature data were carried to the computer via USB bus using two meter sensor cable. Software of device takes data from sensors placed on the sensor board. This data processed in background and showed on the interface as a curve chart. When the test was finished, the results saved into the CSV file. The testing assembly shown in figure 1.

Figure 1: The testing assembly

In this study, 30 samples with a dimension of 2x5x10 cm obtained from Uludağ fir (*Abies bornmulleriana Mattf.*) wood were used. These samples separated into 3 equal groups. One of these groups was undensified, the others were densified at 25% and %50 ratio. Timbers were supplied as logs from a lumber yard in Düzce, Turkey. The sapwood was cut from the logs with an automatically controlled band saw. Rough-scale planks were formed, the cuts being determined by considering the annual rings parallel to the surface (tangent section) and the sample dimensions. Attention was paid to ensure that no rot, knot, crack, color, or density differences were present in the samples (TS 2470, 1976). The samples were initially subjected to natural drying to approximately 12% moisture content. Before the densification process, the samples were held in a conditioning cabin with a relative humidity of 65 ± 3%, and a temperature of 20 ± 2 °C until they reached a stable weight (TS 2471, 1976).

Results and Discussion

The air-dry density values of samples were determined. The average oven-dry density and air-dry density of Uludağ fir samples were given in Table 1.

Table 1. Oven-dry densities of Uludağ fir samples

Densification	Sample Number									
	1	2	3	4	5	6	7	8	9	10
Undensified	0,4103	0,3952	0,4214	0,4242	0,3856	0,3696	0,4263	0,4010	0,4123	0,4413
25% Densified	0.5715	0,5521	0.5817	0.5762	0.5561	0.5427	0.5884	0.5587	0.5709	0.6123
50% Densified	0.6689	0.5721	0.8121	0.7123	0.7434	0.7929	0.7672	0.8550	0.7659	0.8120

The air-dry thermal conductivity values of samples were determined. The average oven-dry density and air-dry density of Uludağ fir samples were given in Table 1.

According to Table 1, it can be said that the density values of samples increase with densification. It is expected that this situation affects the thermal conductivity values of samples. For that reason, the thermal conductivity values of samples were measured with designed thermal conductivity testing machine. These results were given in Table 1.

Table 1. Thermal conductivity values of Uludağ fir samples

Densification	Sample Number									
	1	2	3	4	5	6	7	8	9	10
Undensified	0.1216	0.1152	0.1274	0.1282	0.1137	0.1114	0.1238	0.1196	0.1203	0.1312
25% Densified	0.1417	0.1377	0.1521	0.1532	0.1503	0.1522	0.1604	0.1531	0.1590	0.1612
50% Densified	0.1689	0.1621	0.1772	0.1782	0.1743	0.1739	0.1912	0.1735	0.1765	0.1942

According to this results, as would be expected, it can be said that there is a significant interaction between thermal conductivity and density of wood. And this values can be determined with designed device. In the next step of study, obtained data will compare with data will be obtained from QTM 500 Quick Thermal Conductivity Meter. CTC tests have a good potential to be used as an alternative in situ NDE method to assess density and residual strength of wood. CTC test have a good potential to be used as an alternative NDT method to assess density and residual strengt of wood.

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