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CONTROL OF HOUSE LONGHORN BEETLE (*HYLOTRUPES BAJULUS*) LARVAE BY MICROWAVE HEATING

Ivan Makovíny, Ladislav Reinprecht, Monika Terebesyová
Technical University in Zvolen
Zvolen, Slovak Republic

Pavel Šmíra
Thermo Sanace, s.r.o.
Ostrava – Kunčičky, Czech Republic

Anna Součková
Timber Institute, s.p.
Product and Testing Laboratory
Březnice, Czech Republic

Ľubomír Pavlík
Institute of Materials and Machine Mechanics
Slovak Academy of Sciences - INOVAL
Žiar nad Hronom, Slovak Republic

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ABSTRACT

The purpose of the study was to examine the conditions of microwave (MW) sterilization of Scots pine (*Pinus sylvestris*) sapwood containing larvae of the house longhorn beetle (*Hylotrupes bajulus*). Pine blocks with dimensions of 150 x 100 x 25 mm containing larvae were heated in special wooden matrices so that heating of wooden beams could be simulated. A microwave emitter with a frequency of 2.45 GHz and a surface heating power density of 1.0 $W.cm^{-2}$ was used. The efficiency of MW sterilization was assessed from two viewpoints: - the effect of the distance of the larvae from the MW heater (i.e. the block with larvae was moved inside the wooden matrix - "model beam" - between 0 and 150 mm from the heater); - the effect of the MW heating mode (i.e. different durations and numbers of stages of heating, as well as durations and numbers of stages of pauses were tested). The microwave treatment of wood containing the house longhorn beetle larvae was efficient as soon as the average temperature inside wood near the larvae reached 50°C (41-50-60°C) held for 34 minutes in the heating stages and pauses, or 65°C (60-65-68°C) held for 19 minutes.

KEYWORDS: Wooden structures, sterilization, microwaves, wood borers, *Hylotrupes bajulus*.

INTRODUCTION

Microwave technology has been successfully used for several years for treatment of wood attacked by insects (Fleming et al. 2005, Kisternaya and Kozlov 2007) and fungi (Bech-Andersen et al. 2001, Terebesyová et al. 2010). It can effectively destroy the microfauna of wood pests. MW heating is one of the fastest and most efficient physical methods of sterilization of wooden products. Its advantage consists in the fact that heat is formed within the whole volume of wood by absorbing the electromagnetic field energy, regardless of the thermo-technical properties of the wood.

The principle of MW treatment against wood boring insects in attacked wood lies in the fact that microwaves heat not only the wood, which is composed of polar molecules of cellulose, hemicellulose and lignin together with absorbed molecules of bound water, but also the insects – their eggs, larvae, pupae, and adults, because these are also composed of polar substances such as water, proteins, chitin, etc. In the electromagnetic field a polarization process takes place, as a result of which heat is formed. When MW heating is applied, the thermal field in the heated object (e.g. a wooden beam) is non-homogeneous, both in the cross-section and along the surface. MW heating can be performed in a resonator chamber or by means of an applicator, e.g. a horn antenna (Belanis 1997). As wider practical use of the microwave treatment is planned, increased attention is now being given to the research of one-sided MW heating using a horn antenna. As a first approach, it can be assumed that during such MW heating, the absorption law applies and the temperature decreases in the direction from the heated surface to the centre of wood.

It is known from the literature that for killing the individual development stages of most kinds of wood borers (eggs, larvae, pupae, adults), elevated temperatures between 45°C and 65°C are required; the insects or the whole cross-section of the attacked wood must be exposed to these temperatures for several minutes up to tens or even hundreds of minutes (Becker and Loebe 1961, Strang 1992, Reinprecht 2008). High temperatures have different effects on different insect development stages; there are also apparent differences between younger and older larvae with higher weight.

Killing insects by heat is based on denaturation of their proteins and damaging of the structure of their enzymes. However, it must be kept in mind that at temperatures above 50°C there is a hazard of softening of natural waxes and damaging of glues and paints on polychromed sculptures, old furniture, wood panel paintings, etc. (Beiner and Ogilvie 2005). Museums currently use the Thermo Lignum® pest control treatment, which consists in accurate regulation and control of air temperature and relative humidity in special chambers, whereas inert gases may also be used (Nicholson and von Rotberg 1996).

A certain risk of thermal sterilization of some kinds of wood at temperatures around 100°C is the formation of attractants, i.e. substances that can attract certain species of termites or other wood borers to the treated wood (Doi et al. 2001).

According to Morell (1995), wood borers can be killed by heating the wood they are in to 52°C for 30 minutes. However, at the same time the author states that, according to other publications, a minimum lethal temperature of 67°C being held of up to 75 mines may be required. Dwinell (1990) has found that lethal temperatures for insects in a classical hot air dryer are usually higher than 60°C.

It is also important to know the relationship between the lethal temperature and the time it is held for. There is a predominant view that it is more advantageous to use higher temperatures and shorter exposure times. This method is more efficient than when the wood is exposed to lower temperatures for a longer time (Morell 1995). Sutter (2002) states the sensitivity of larvae of some important indoor wood borers (*Hylotrupes bajulus* – house longhorn beetle, *Lyctus brunneus* – lyctus powderpost beetle, and *Anobium punctatum* – common furniture beetle) to high temperatures. The larvae of these species were exposed to hot air. Clearly the most resistant were the larvae of the house longhorn beetle (*H. bajulus*), their lethal temperatures and exposure times being the following: 50°C / 300 minutes; 52°C / 150 minutes; 54°C / 90 minutes; 56°C / 65 minutes; 60°C / 50 minutes. The larvae of *A. punctatum* and *L. brunneus* were killed at more moderate conditions, e.g. at 56°C / 20 to 25 minutes.

If the wood is wet, longer exposure is required to kill the insects at the same MW source output, because the radiation is damped and the temperature rise in the direction towards wood centre is slower. Andreuccetti et al. (1995) experimented with *Hylotrupes bajulus* larvae and found out that at a very low wood moisture content of 10 % the larvae are heated by MW radiation more quickly than the surrounding wood.

Using a MW emitter with a frequency of 2.45 GHz, Kisternaya and Kozlov (2007) managed to heat timber of bigger cross-sections to temperatures of 53 to 55°C, which are lethal temperatures for insect larvae, in approx. 120 to 240 minutes, but the temperatures then had to be held for another 30 minutes in order for the larvae to die. Fleming et al. (2005) studied the lethal effects of microwave heating in common commercial MW ovens on the larvae of *Bursaphelenchus xylophilus*, whereas 100 % mortality of larvae was reached at the temperature of 62°C or, in case of uniform MW heating, already at lower temperatures of 46 or 53°C. Lewis et al. (2000) studied the mortality of termites *Incisitermes minou* in laboratory conditions in Douglas fir wood using commercial MW ovens with outputs of 500, 1000 and 2000 W and a frequency of 2.4 GHz at time intervals of 20 to 150 s. The final 84 to 100 % mortality of termites was reached with higher MW outputs, whereas a 100 % lethal effect was reached with the exposure times being as short as a little more than 1 minute.

Currently, it is also possible to use the heating effects of the electromagnetic field in the high frequency zone from 100 kHz to 300 MHz for pest control. Dwinell et al. (1994) performed experiments in a high frequency vacuum dryer and found that temperatures above 56°C had sufficient effect.

It can be seen from the above-mentioned literature that for sterilization of wood attacked by a certain species of wood borer to be efficient and successful, it is important to optimize the two basic factors which are temperature and exposure time; these are directly dependent on the dimensions and moisture content of timber. From the technological point of view, the information currently available about times and temperatures necessary to kill individual wood boring species by microwave heating are only partial and need to be extended.

The goal of this experiment was to optimize the technological conditions of MW sterilization of pine sapwood attacked by larvae of the house longhorn beetle (*Hylotrupes bajulus* L.).

MATERIAL AND METHODS

Wood material with wood borer larvae

17 test blocks made of Scots pine sapwood (*Pinus sylvestris* L.) were prepared for the experiment according to EN 1390. The dimensions of the blocks were 150±2 x 100±2 x 25±1 mm (Fig. 1). Each block contained 6 holes drilled from both frontal surfaces, into which 2-year-old larvae of the house longhorn beetle (*Hylotrupes bajulus* L.) were inserted, i.e. 6 larvae into each block. A total of 102 larvae were used; they were selected from a stock colony provided by the Timber Institute in Březnice, based on sufficient viability and weight. The pine blocks with

inserted larvae were transported to Technical University in Zvolen, where they were exposed to different doses of MW radiation. The heating power surface density was 1.0 W.cm^{-2}. Before MW heating, each test block (150 x 100 x 25 mm) was inserted into a hole in a pinewood base matrix (250 x 200 x 50 mm), onto which other solid timber matrices with a thickness of BH_1 = 0 to 150 mm were placed. In this way, sterilization of a real wooden beam was modelled (250 x 200 x BH mm; BH – beam height = BH_1 + 50 mm (Fig. 2, Tab. 1). Initial moisture content of the pine test blocks and timber matrices varied from 12 to 15 %. After MW heating, the mortality of larvae inside the test block as well as the amount of their caking was examined.

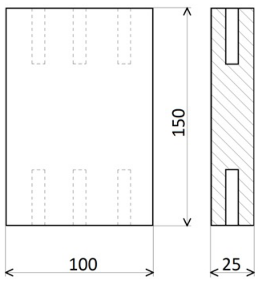


Fig. 1: Test block of pine sapwood 150 x 100 x 25 mm with 6 drilled holes for 6 larvae of the house longhorn beetle according EN 1390 (side and top view).

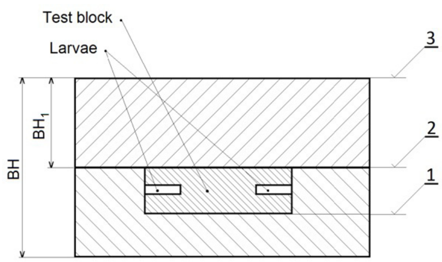


Fig. 2: Test block with 6 larvae placed into a wooden beam model matrix. The test block is exposed to MW heating from the top through wood layer BH_1 = 0, 15, 20, 40, 50, 100 or 150 mm (Tab. 1).

1 - temperature measured on the bottom surface of the test block
2 - temperature measured on the top surface of the test block
3 - temperature measured on the top surface of the wooden matrix.

Microwave system radiating into a free space inside a shielded chamber

For examining the effects of MW treatment on the larvae of *Hylotrupes bajulus* a microwave system with a horn antenna was used. The system makes it possible that microwaves are radiated into the chamber where the conditions of free space radiation are simulated. The device allows for one-sided heating of loss materials including wood. It is composed of two main parts – shielding chamber with internal dimensions of 400 x 600 x 550 mm and MW radiation source with a horn antenna with dimensions of 240 x 230 mm. The internal sides of the chamber are covered with high-absorption (anechoic) material for maximum absorption of the stray MW field that has reflected from the surface of the heated material or gone through the heated material. The connection of the microwave source is standard – it includes a magnetron, a horn antenna, a supply circuit, and protection, switching, and control elements. The antenna was designed for a frequency of 2.45 GHz using a theory according to Belanis (1997). The MW device used for the experiment is demonstrated on Fig. 3.

Measurement of temperature field and temperature

The temperature field, and the average, minimum and maximum temperatures were measured using thermovision camera FLIR B425. The camera has the following basic parameters: resolution of 50 mK, IR picture 320 x 240 pixels, temperature range from -20 to +350°C. This infrared camera makes it possible to display the overall temperature field and, in addition to that,

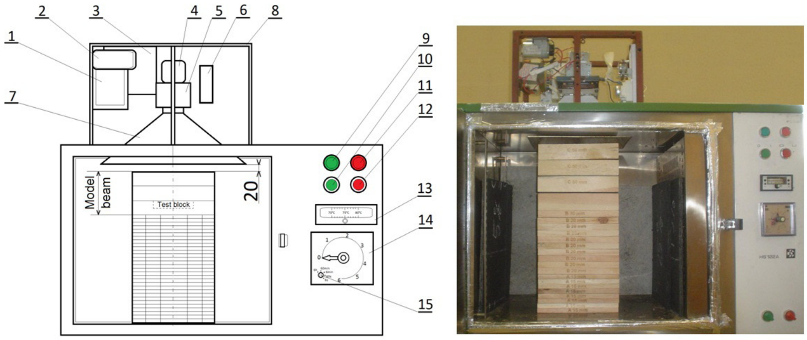


Fig. 3: Device for microwave heating (see experiment no. 4, at BH = 150 mm – Tab. 1, i.e. the test block with larvae is situated in a pinewood base matrix above which are two 50 mm timber matrices).
A) Technical parameters of the microwave source: Supply voltage (230 V, 50 Hz), Maximum input power (1250 W), Maximum output of the MW emitter (750 W), Frequency of the MW emitter (2.45 GHz)
B) Description of the MW device: 1 – Transformer; 2 – Filter condenser; 3 – Supply circuit; 4 – Magnetron; 5 – Magnetron cooler; 6 – Fan; 7 – Horn antenna; 8 – Frame; 9 – Switch-on indication; 10 – ON button; 11 – Switch-off indication; 12 – OFF button; 13 – Thermostat; 14 – Timer; 15 – Timer setting; 16 – Model beam.

to measure the temperature at selected points and to find the minimum and maximum temperatures in a selected temperature field area (Fig. 4).

The average temperatures from the experiments as listed in Tab. 1 were calculated from 2 x 15 measured points each for the bottom and top surfaces of the pine test blocks; the points were evenly distributed in a square grid on the surface of the test block. Tab. 1 also lists the minimum and maximum temperatures from the thermovision pictures made at different time intervals at the ends of the heating periods (H).

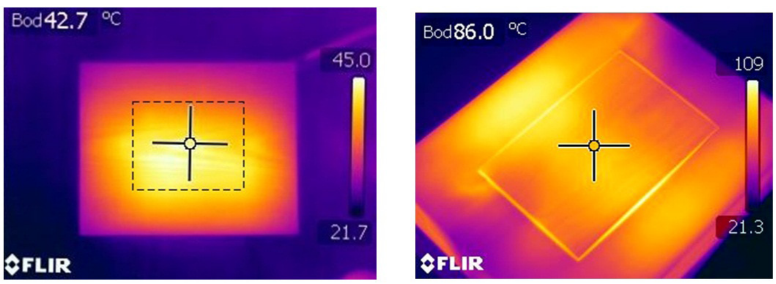


Fig. 4: A thermovision picture of the wood surface – pine test block.

The effects of MW heating on the mortality of wood borer larvae

The examination of effects of MW heating duration and temperature on the mortality of larvae focused on the effects of different intervals of MW heating (H) and pauses (P) as well as on the effects of different distances (BH_1) of the pine test blocks with longhorn beetle larvae from the external surface of the model beam matrix exposed to MW radiation (Fig. 2, Tab. 1).

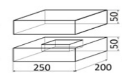
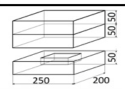
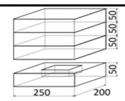
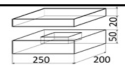
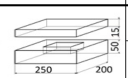
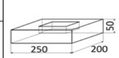
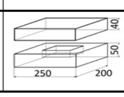
The test blocks with the house longhorn beetle larvae remained in the model beam matrix after the MW heating was terminated. This method was selected with regard to practical applications of MW treatment on timber structures, roofs and ceilings, but also on wooden cladding, furniture, etc. Thus, the duration of exposure of insect larvae to elevated temperatures was correspondingly longer. It is connected with the fact that if a test block was placed in a matrix (model wooden beam), its cooling period after MW heating was longer than the cooling period of a separate test block (Fig. 5).

The viability, mortality and condition of the larvae in the pine blocks after the experiments were assessed visually according to EN 1390.

RESULTS AND DISCUSSION

The minimum, maximum and average temperatures during MW heating, measured just above and just below the surface of pine test blocks with the house longhorn beetle larvae, are listed in Tab. 1. The table also includes the numbers of dead (D) and live (L) larvae in the pine blocks that were found 2 days after the MW heating was terminated.

Tab. 1: Effects of MW heating on the larvae of the house longhorn beetle (Hylotrupes bajulus).

Experiment no.	Location of test block in model beam	Time intervals (min) H – heating P – pause	Temperature (°C) min – max average	Number of larvae	Condition of larvae after MW heating
1.		H = 10´; P = 5´; H = 10´	72 – 110 92	5	D (C)
				1	D (PC)
2.		H = 5´; P = 5´; H = 5´; P = 5´; H = 5´	61 – 100 90	3	D (C)
				3	D (N)
3.		H = 5´; P = 10´; H = 5´	51 – 90 77	3	D (C)
				3	D (N)
4.		H = 10´; P = 15´; H = 10´	54 – 78 65	3	D (C)
				3	D (N)
5.		H = 10´; P = 15´; H = 10´; P = 15´; H = 10´	59 – 75 65	2	D (C)
				1	D (PC)
				3	D (N)
6.		H = 3´; P = 5´; H = 3´; P = 5´; H = 3´; P = 5´; H = 3´	60 – 74 68	1	D (C)
				5	D (N)
7.		H = 3´; P = 5´; H = 3´; P = 5´; H = 3´	60 – 68 65	6	D (N)
8.		H = 5´; P = 10´; H = 5´	59 – 86 70	2	D (C)
				1	D (PC)
				3	D (N)
9.		H = 5´; P = 5´; H = 2´; P = 5´; H = 2´	50 – 75 68	1	D (C)
				5	D (N)
10.		H = 10´; P = 5´; H = 2´	71 – 88 79	2	D (C)
				4	D (N)
11.		H = 3´; P = 15´; H = 1´; P = 15´; H = 1´	33 – 59 40	1	D (N)
				5	L
12.		H = 2´; P = 10´; H = 2´	31 – 54 50	6	L
13.		H = 3´; P = 10´; H = 2´; P = 5´; H = 1´	33 – 62 50	1	D (PC)
				4	D (N)
				1	L
14.		H = 4´; P = 10´; H = 2´; P = 10´; H = 2´; P = 5´; H = 1´	41 – 60 50	1	D (C)
				5	D (N)
15.		H = 20´	75 – 90 85	3	D (C)
				1	D (PC)
				2	D (N)
16.		H = 30´; P = 5´; H = 10´	90 – 130 100	6	D (C)
17.		H = 30´; P = 5´; H = 10´	70 – 130 95	6	D (C)

Note: L = live larvae; D = dead larvae; D (N) = non-caked dead larvae; D (PC) = partially caked dead larvae; D (C) = brown-caked dead larvae.

The effects of temperature and duration of MW heating

The temperature and duration of MW heating occurred as the deciding factors for its sterilization effect. This result is in accordance with knowledge of other researches (Strang 1992, Lewis et al. 2000, Sutter 2002, Fleming et al. 2005, etc.). At average temperatures for pine test block surfaces of 40 to 50°C near the larvae and at exposure durations of these temperatures from 14 to 35 minutes, the larvae were killed only in some cases (Tab. 1 – experiments no. 11, 12, and 13). After this, so-called moderate MW heating many larvae in the test blocks remained viable. However, all larvae were killed at average temperature of 50°C lasting 34 minutes (Tab. 1 – experiment no. 14). Similar result obtained Morell (1995), by which wood borers can be killed at 52°C lasting 30 minutes.

Higher average wood temperatures above 50°C, e.g. from 65 up to 100°C, caused 100 % killing of all larvae as well as at shorter times (Tab. 1). As the duration of MW heating increased, the number of non-caked dead larvae gradually decreased (Tab. 1 – experiments no. 7 and 8), and the number of totally brown-caked dead larvae increased (Tab. 1 – experiments no. 1, 16, and 17). The condition of dead larvae "D" after MW treatment, i.e. brown-caked (C), partially caked (PC) or non-caked (N), might be partially dependent on their location in the test block with regard to the unevenness of the MW heating. On the other hand, the larvae development stage and their weight were not considered as only homogenous groups of larvae of equal weight and age (2-year-old) had been selected for the experiment.

The effects of duration and temperature of MW heating (H) of test blocks in model beams were also analyzed in connection with pauses (P) between heating periods. The pause factor was not dominant as the temperature of the test blocks was sinking only a little during the few-minute pauses and reached the required value again during the following MW heating period (Tab. 1).

The effect of the orientation of the test block inside the matrix (model wooden beam) on the prolonging of high temperature hold in the cooling period after MW treatment is shown in Fig. 5 for the case of BH_1 = 0 mm.

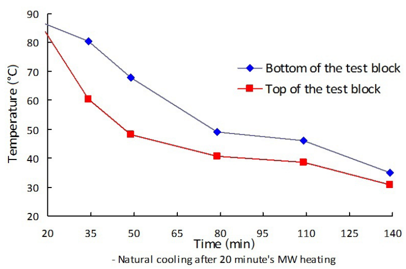


Fig. 5: Curves of cooling temperatures (from 20 to 140 minutes) on the top surface of the pine block contacting with air and on its bottom surface contacting with base matrix (according to Fig. 2). The measurements were performed after a 20-minute MW heating period with a heating power density of 1.0 W.cm^{-2} (experiment no. 15 according to Tab. 1).

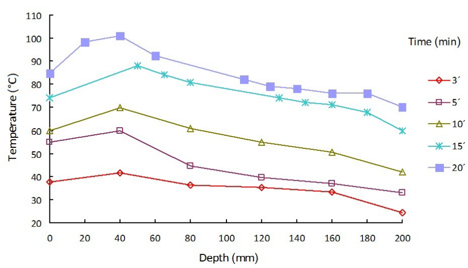


Fig. 6: Dependence of temperature at different depths of the pine model beam with a thickness of 200 mm on time of continuous MW heating – 3, 5, 10, 15, and 20 minutes at 1.0 W.cm^{-2} heating power density.

The effects of distance from the MW emitter – test block depth in the model beam

The effect of the distance of the test pine block with inserted larvae of the house longhorn beetle from the top surface of the model beam exposed to one-sided MW radiation with pauses (Fig. 2; see BH_1 = 0, 15, 20, 40, 50, 100 or 150 mm) turned out to be significant (Tab. 1). E.g. the average lethal temperature of 65°C was reached after 9 minutes of MW heating if the distance was BH_1 = 15 mm (experiment no. 7), after 20 minutes if the distance was BH_1 = 100 mm (experiment no. 4), and even after 30 minutes if the distance was BH_1 = 150 mm (experiment no. 5); and this only applies if the heating periods (H) without pauses (P) are considered.

In supplementary experiments, in which the model beams were heated continuously without pauses, the time periods necessary to reach the required temperatures were considerably shorter than those with interrupted heating. For example, the temperature of 70°C in the depth of beam BH_1 = 150 mm was reached as early as after 15 minutes (Fig. 6); or the temperature of 60°C was reached after 12.5 minutes of MW heating (Fig. 7). It can also be seen from Fig. 6 that adequately higher average temperatures in model pine beams with a thickness of 200 mm were reached with the lengths of the time periods of MW heating being 3 to 20 minutes. This results well correspond with the work of Kisternaya and Kozlov (2007) by which the time of MW heating of bigger cross-section timbers needed for achieving of the borer's lethal temperatures can last several minutes or even hours.

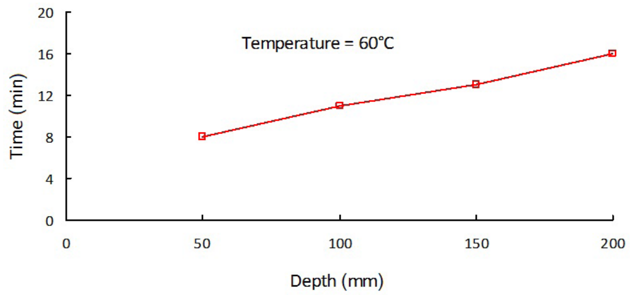


Fig. 7: Dependence of time of reaching the temperature of 60°C on depth in the pine model beam with a thickness of 200 mm at continuous MW heating with 1.0 W.cm^{-2} heating power density.

CONCLUSIONS

In the work it was found that at an average wood temperature of 40°C (experiment no. 11: 33-40-59°C) lasting 35 minutes (taking into account both the heating and pause times of MW heating) was insufficient for killing of larvae of the house longhorn beetle (*Hylotrupes bajulus*).

On the other hand, microwave heating can be successfully used for killing all house longhorn beetle larvae in wooden beams if an average temperature of 50°C is held for 34 minutes (e.g. experiment no. 14: 41-50-60°C), or an average temperature of 65°C is held for 19 minutes (e.g. experiment no. 7: 60-65-68°C). This applies if the MW radiation power density on the surface of treated wooden beams is at least 1.0 W.cm^{-2}.

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Ivan Makovíny, Ladislav Reinprecht, Monika Terebesyová
Technical University in Zvolen
T. G. Masaryka 24
960 53 Zvolen
Slovak Republic
Corresponding author: reinprecht@tuzvo.sk

Pavel Šmíra
Thermo Sanace, s.r.o.
Chamrádova 475/23
781 00 Ostrava – Kunčičky
Czech Republic

Anna Součková
Timber Institute, s.p.
Product and Testing Laboratory
Praha, S.P.
Borská 471
262 72 Březnice
Czech Republic

Ľubomír Pavlík
Institute of Materials and Machine Mechanics
Slovak Academy of Sciences - INOVAL
Priemyselná 12
965 01 Žiar nad Hronom
Slovak Republic