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MICROWAVE DRYING OF WOOD-CEMENT COMPOSITES

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ABSTRACT

In the paper the microwave drying of wood-cement composite boards of the densities 400 kg.m^{-3}, 700 kg.m^{-3} and 1100 kg.m^{-3} was studied. The wood-cement boards were both without admixtures and with the admixture of carbon. High power density of the electromagnetic field was used. The drying speed varied between 1.7 and 14 (%.min^{-1}). No damages such as cracks, shape changes, or decrease of mechanical strength at the bend were observed. It may be stated that by means of microwave drying, it is possible to reduce the time of finalizing wood-cement boards without any noticeable changes in their quality.

KEY WORDS: wood-cement composite, microwave drying, drying speed, carbon wood cement composites

INTRODUCTION

Wood-cement composites (WCC) are used mostly as a building material – as both exterior and interior wall claddings, as well as ceilings and floors claddings. Their desirable basic qualities are: heat-resistance, insect and fungi resistance, toughness, high absorption of sound, and low thermal conductivity. If appropriate electro-conductive admixtures are used, it is possible to increase the attenuation characteristics of WCC and to use them for shielding electromagnetic fields.

The necessary element included in the technology process of the WCC production is water. It enables the hydration of mineral binder – cement. At the end of the technology process, a redundant water remains in WCC, which is removed by natural drying in the air, with simultaneous stiffening of the cement paste. This process is lengthy, it lasts approximately 28 days. The aim of the study was to test the possibility of fast drying of WCC using the microwave type of heating.

The issue of microwave drying of wood has been treated with a considerable attention, see e. g. works of (Babiak et al. 2000, Cividini and Travan 2003, Perré and Turner 1999, Lee and Hong 1987, Zemiar et al. 2009). To a certain extent, it was also the case with e. g. heated gluing of particleboard materials and fibreboards. The drying of composite materials is not generally required in the technology process, with the exception of conventional heating during the process of pressing the mat of wood particles.

Water is an essential element in the process of the WCC production, being necessary for hydrating cement. The portion of water to cement, i. e. water coefficient, is a significant factor affecting the strength of WCC. The optimal portion necessary for hydrating cement is practically unachievable, due to several reasons. In the production of WCC, water is added alongside with other input raw materials, and water exists in wood wool, as well. With regards to the changes in the composition of raw materials that contain water, and sometimes also to the needs to increase the content of water because of the function of technological junctions and reology of the mat of wood wool, cement and admixtures on the production line, at the end of the WCC production process, they contain redundant water.

The quickest method of heating wood materials is the microwave heating. With a low diffusional resistance of the dried material, this way of heating enables even the highest speed of heating. Wood-cement composites represent polar dielectric materials. With respect to a good permeability for a liquid water and also for steam, the best conditions are achieved for the application of microwave method of drying WCC.

A demerit of the application of microwave heating of materials in ventricular resonators may be an irregularity of the heating, which is caused by non-homogenity of electro-magnetic fields.

The microwave system used for drying WCC in our experiments includes the resonator, in which the operational box containing material moves within the scale of half a wave length during heating. In this way, the irregularity of heating in the dried material, and consequently, also of non-homogeneous thermal field, is reduced.

The intensity of absorption of dielectric heating in electromagnetic fields depends, with a given frequency, on the intensity of electric element of the field, and on the loss number ε'' of dried material. The loss number of material is predominantly affected by moisture.

Specific volumetric power is expressed by the relation

$$p = \omega \varepsilon_0 \varepsilon'' E^2 \tag{1}$$

where ω is an angular speed,
ε_0 is the permitivity of vacuum,
ε`` is the loss number of material,
E is the intensity of electric field.

Generally, for a considered volumetrical element of wood, there is an equation for thermal conductance

$$div[-\lambda grad(\vartheta)] + c\rho \frac{d\vartheta}{dt} = p \tag{2}$$

where λ is the coefficient of thermal conductivity,
ϑ – temperature,
c – specific heat capacity,
ρ - density,
t – time.

The first element of the equation represents the heat conducted away to the environment for a unit of time, the second element – the output of heat consumed to increase the temperature, heating a particular element of wood, and the right side represents the inner source of heat, the output of heat of the element.

For the sake of practical usage, it is important to know the total time of drying. The time needed for heating of material may be calculated from the relationship:

$$t_h = \frac{m.c.(\vartheta_1 - \vartheta_2)}{p.V} \tag{3}$$

where c is the specific heat capacity
ϑ_1 – temperature at the beginning of heating
ϑ_2 – temperature at the beginning of intensive evaporation of water
m – weight of material
V – the volume of heated material

The time needed for heating may be determined from the relationship:

$$t_{su} = \frac{m_{H_20}.r}{p.V} \tag{4}$$

where m_{H2O} is the weight of evaporated water
r – evaporation heat of water

From the equations (3) and (4) the total time of drying may be obtained, but only under generalized preconditions that the process is adiabatic and parameters of equations are constant. In fact, it is only approximately true, and thus these relations may be used only for an approximate estimation of the drying time. It is especially difficult to ascertain specific output of heat, as the absorption of electromagnetic energy by dried material depends on electrophysical properties of the material and, at the same time, there emerges also the reflection of electromagnetic waves.

MATERIAL AND METHODS

Samples of wood-cement boards of various densities 400, 700 and 1100 kg.m^{-3}, which we produced in the laboratory by pressing wood-cement matt under various pressures, were used for drying WCC. Measurements were taken from samples of boards of dimensions 150 x 300 mm. As we used three different values of pressure, the samples of different values of thickness were obtained. After pressing, they were 23 mm, 13 mm and 9 mm thick. The pressing of each sample lasted 24 hours.

There realized 12 measurements with various concentrations of carbon: 0, 5, 10 and 25 (wt.%) and of three densities: 400, 700, 1100 kg.m^{-3}.The each measurement was perforated on six samples.

The samples of boards were prepared out of spruce wood-wool consisting of the stripes of geometrical dimensions 500 x 5 x 0,3 (mm).

The prescriptions of WCC prepared in the laboratory were identical for all kinds of samples: 200 ml of water, 100 g of Portland cement, 100 g of wood wool, 4 g of calcium chlorid $CaCl_2$ and carbon powder 0, 5, 10 and 25 (wt. %).

In Fig. 1, there is a design of the resonator of a microwave system, as well as of the operational box with the position of installed magnetrons (MG1 to MG10) and a dried sample of wood-cement composite WCC.

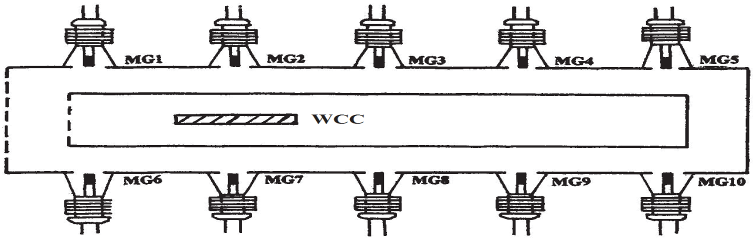

Fig. 1: Design of the resonator of a microwave system with the position of installed magnetrons (MG1 to MG10), and a dried sample of wood-cement composite, (WCC).

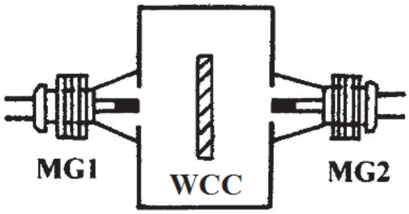

Fig. 2: View at a microwave system with the operational box and a wood-cement board

Drying was carried out in the operational box installed movably in the resonator of a microwave system in the shape of ashlars with the parameters in the Tab. 1 (Makovíny 2009).

Tab. 1: Basic technical parameters of microwave system

Input power (W)	12000
Output vhf power (W)	7000
Number of magnetrons	10
Frequency (GHz)	2.45
Size of rezonator (mm^3)	300x250x1500
Size of operational box (mm^3)	190x230x1400
Weight (kg)	70

The achieved specific volumetric power was of the value p = 6 $kW.m^{-3}$. Drying was taking place under atmospheric pressure and relative moisture of air 90 %. It was carried out immediately after pressing, i.e. 24 h later.

At certain intervals during the process of drying, we weighed the samples and also took the surface temperature. The surface temperature of samples was measured by pyrometer GIM 530 MS at five places, to obtain the average temperature. Moisture was determined by means of gravimetric method.

The quality of drying was assessed macroscopically, evaluating the occurrence of boundary, internal and surface cracks, or, as the case may be, of a collapse.

RESULTS AND DISCUSSION

The results of the experiment are summarized in (Fig. 1 - 8, and in Tab. 2). Moisture curves representing the dependency of moisture of wood-cement composite samples of different density and without the admixture of carbon on the time interval of drying are depicted in (Fig. 3a - Fig. 6a).

The initial moisture both with content of WCC, both with and without the admixture of carbon, was decreasing with increasing density of WCC.

The growth of density was achieved through increasing pressure with the same proportion of elements of composites, hence, in the case of the samples of the densities 700 and 1100 ($kg.m^{-3}$), a part of water was pressed off the matt.

Since the moisture of WCC decreased approximately linearly with the time of drying, the speed of drying may be considered constant within the whole moisture content interval.

The wood-cement boards with the carbon admixture of the concentrations 5, 10 a 25 (%) behaved similarly to the carbon-less samples.

The speed of the drying of samples (Tab. 2) depended on the initial moisture but also on the density of the samples. The speed of drying is from 1.7 – 14 ($\% .min^{-1}$).

Tab. 2: The drying speed of WCC by different density ρ concentration of carbon C and initial moisture w_i

C (%)	0			5			10			25		
ρ ($kg.m^{-3}$)	400	700	1100	400	700	1100	400	700	1100	400	700	1100
w_i (%)	94	45	20	78	41	38	76	40	34	75	49	26
v ($\%.min^{-1}$)	14	4.3	1.7	11.7	4.2	4.4	12	4.2	3.2	15	4.9	2.9

Despite the high drying speed, there was no occurrence of internal or surface cracks observed when assessing the quality of drying.

The thermal characteristics (Fig. 3b-6b) correspond to the moisture characteristics (Fig. 3a-6a).

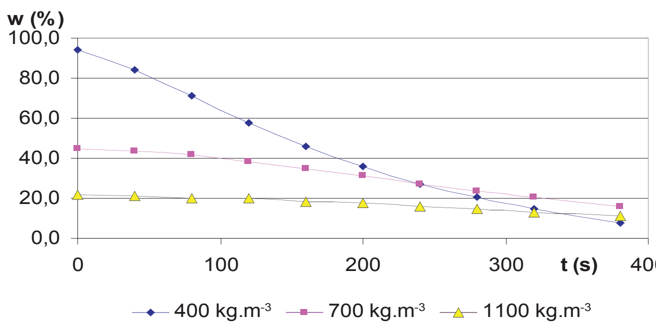

Fig. 3a: Dependence of moisture content in WCC, from the time when microwave drying three boards density 400, 700, 1100 $kg.m^{-3}$ after 24 h pressing the boards at carbon concentration 0 (wt.%)

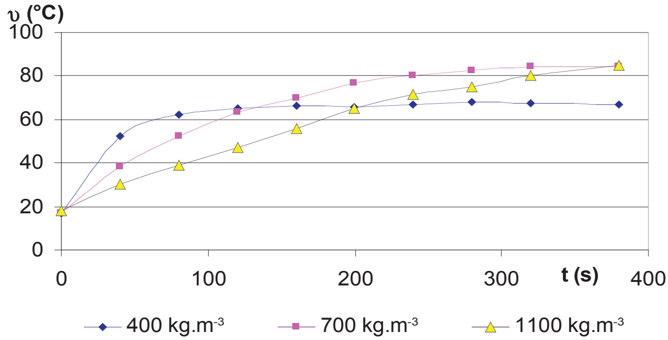

Fig. 3b: Temperature dependence WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after 24 h pressing the boards at carbon concentration (wt.%)

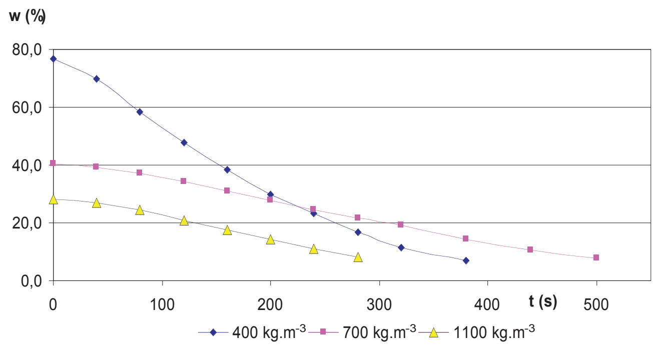

Fig. 4a: Dependence of moisture content in WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after 24 h pressing the boards at carbon concentration 5 (wt.%)

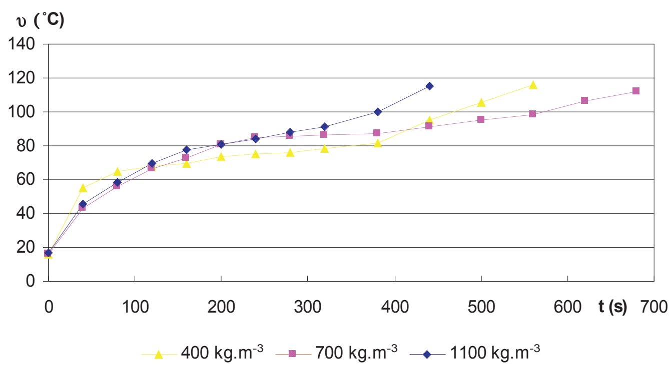

Fig. 4b: Temperature dependence WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after 24 h pressing the boards at carbon concentration 5 (wt.%)

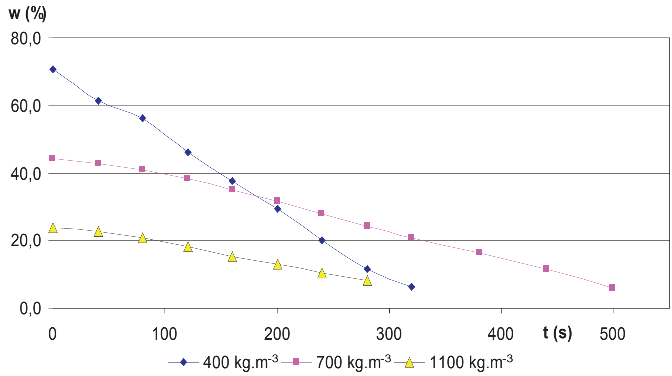

Fig. 5a: Dependence of moisture content in WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after one day pressing the boards at carbon concentration 10 (wt.%)

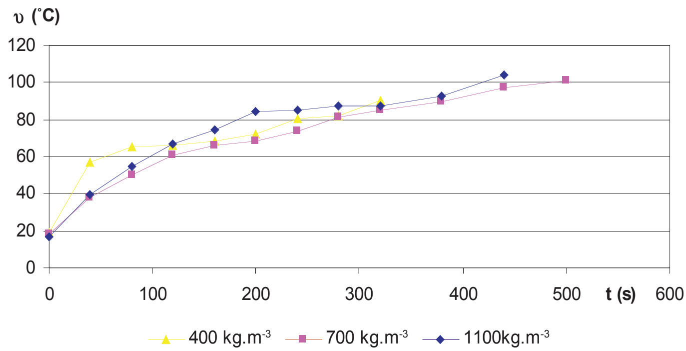

Fig. 5b: Temperature dependence WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after one days pressing the boards at carbon concentration 10 (wt.%)

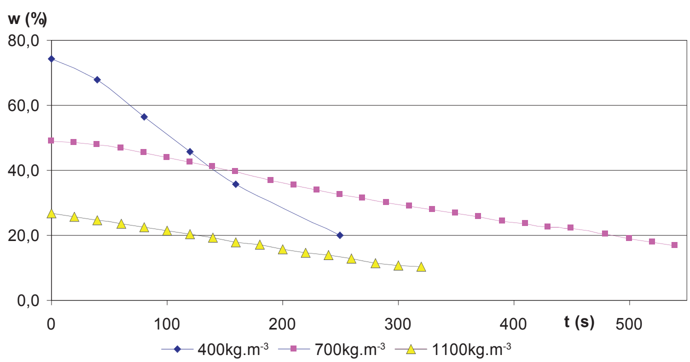

Fig. 6a: Dependence of moisture content in WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after one day pressing the boards at carbon concentration 25 (wt.%)

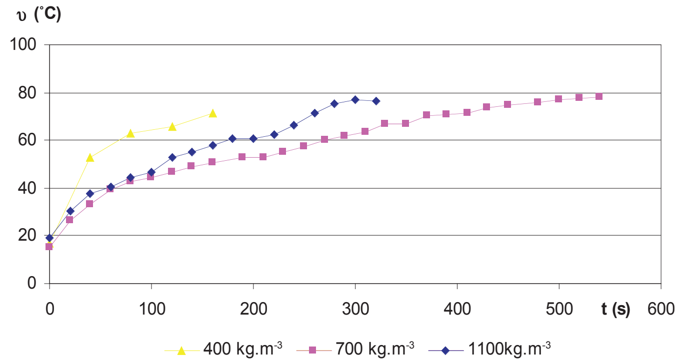

Fig. 6b: Temperature dependence WCC, from the time when microwave drying three boards density 400, 700, 1100 kg.m^{-3} after one days pressing the boards at carbon concentration 25 (wt.%)

The changes of temperature, except for the samples of WCC with the lowest density 400 kg.m^{-3} at 0 (wt.%) carbon concentration, did not have any significant distilling horizontals, which appear during the dielectric heating of wood at the moisture over FSP, when the free water is evaporating. The increased temperature accelerates the course of chemical reactions of the hydratation of cement. Portland cement is not a pure material but rather a multiphasic material whose composition varies at a wide range. A series of chemical reactions proceeds in it. In general, conditions for hydrating may vary depending on admixtures, however, there was not determined any definite influence of the carbon concentration.

However, Aitcin (2005) states that during the acceleration of the process of hardening the concrete by means of heat, the initial hardness of concrete increases, while the final strength of concrete decreases. We assume that due to a good access of water to cement, contrary to concrete, the most of cement grains hydrate at increased temperature in a short time interval, i. e. still during pressing-in within the first 24 hours, (Makovíny 2009, Lee and Hong 1987, Moslemi and Pfister 1987).

The influence of the concentration of carbon on thermal curves was ambiguous. There appeared problems at the edges of boards with the highest concentration (C = 25 %) and the highest density (ρ = 1100 kg.m^{-3}) when the temperature started to rise to an excessive degree after a certain time of heating.

CONCLUSION

It was discovered that it is possible to dry with microwave heating the wood-cement composites of the densities 400, 700 and 1100 kg.m^{-3} without the admixture of carbon and with various concentrations of carbon with a high quality and a high speed of drying at the same time. The drying speed depended on initial values of moisture and density of WCC, varying within the interval of 1.7 – 14 %.min^{-1}. The higher values of drying speed correspond to the higher values of initial moisture content WCC. The drying speed was practically constant during the process of drying. It is possible to reduce the time of finalizing wood-cement composites by means of microwave drying without any marked changes of their quality. Hence it is possible to consider the microwave way of drying wood-cement boards suitable for industrial usage to reduce the time of storing because of the maturing of cement, and to reduce the moisture. At present, the storing time of 4 weeks is a usual practice in the production of WCC.

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