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Effect of Microwave Treatment on Oak Compression Strength

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Abstract. Microwave (electromagnetic) energy is currently used in the treatment of biological damage, in the machine grading of timber and its use for timber drying is foreseen. The exposure of structural timber elements to microwaves, such as for other timber treatments (preservation or fire-retardant), implies analyzing its effect on the mechanical properties of the wood. This paper intends to contribute to this discussion, presenting a preliminary study on the effect of microwave exposure (during 5 and 10min) on compression parallel to grain strength of clear Oak wood. The results obtained show a clear loss of strength due to exposure and to an increase in the time of exposure. Considering the results obtained in this study and by other authors, it becomes clear that more thorough research is needed, bearing in mind the establishment of strength correction factors or rules towards the safe use of this technology for assuring the proper mechanical behaviour of timber.
Key words: oak; compression parallel to grain; microwave

Efeito na Resistência à Compressão do Tratamento de Madeira de Carvalho com Ultra-Sons

Sumário. A energia de microondas (electromagnética) é actualmente utilizada no tratamento de degradação biológica e na classificação mecânica de madeira e perspectiva-se a sua utilização na secagem de madeira. A exposição a microondas de elementos estruturais de madeira implica, tal como para outros processos de preparação da madeira (preservação ou tratamentos ignífugos), analisar o efeito dessa exposição nas propriedades mecânicas da madeira. O presente artigo pretende contribuir para esta discussão, apresentando um estudo preliminar sobre o efeito da exposição a microondas (durante 5 e 10min) na resistência à compressão paralela às fibras de madeira de Carvalho limpa de defeitos. Os resultados obtidos mostram uma clara perda de resistência com a exposição e aumento do tempo de exposição. Considerando os resultados obtidos no presente estudo e por outros autores, torna-se clara a necessidade de estudos mais exaustivos tendo em vista estabelecer possíveis factores de correcção ou regras de utilização segura desta energia de forma a garantir um apropriado comportamento mecânico da madeira.
Palavras-chave: carvalho; compressão paralela às fibras; microondas

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Effet du Traitement du Bois de Chêne par des Ultrasons sur la Résistance à la Compression

Résumé. L'énergie des micro-ondes (électromagnétique) est actuellement utilisée dans le traitement de dégradation biologique et dans le classement mécanique du bois et son utilisation dans le séchage de bois de construction est prévue. L'exposition d'éléments structurels en bois à des micro-ondes implique, comme pour d'autres traitements du bois de construction (conservation ou traitements ignifuges), l'analyse de l'effet de cette exposition sur les propriétés mécaniques du bois. Le présent article vise à contribuer à cette discussion, en présentant une étude préliminaire sur l'effet de l'exposition aux micro-ondes (pendant 5 et 10min) sur la contrainte de rupture en compression parallèle au fil du bois de Chêne sans défauts. Les résultats obtenus montrent une claire perte de résistance avec l'exposition et l'augmentation du temps d'exposition. En considérant les résultats obtenus dans la présente étude et par d'autres auteurs, la nécessité d'études plus exhaustives devient évidente en vue d'établir de possibles facteurs de correction pour la résistance ou des règles d'utilisation sûres de cette énergie de manière à garantir un comportement mécanique approprié du bois.
Mots clés: chêne; compression parallèle au fil; micro-ondes

Introduction

Microwave consists of electromagnetic energy (frequency band between 300MHz and 300GHz and wavelengths ranging from 1,0 meter to 0,1 centimetre). Microwave energy absorption produces random vibration of polarized molecules leading to an increase in temperature. Although water molecules are signifycantly affected, given its high dielectric permittivity, also other polar molecules existent in wood (as for instance cellulose, hemicellulose and lignin) could be affected (HANSSON and ANTTI, 2003).

Microwaves energy is being used nowadays in different fields of timber technology and engineering based on the modification of a measurable parameter of the wave (amplitude, phase and polarization) by a specific feature of wood (moisture content, knot, density, slope of grain) - strength grading machines (LEICESTER and SEATH, 1996) - or on the increase of temperature of timber due to microwave energy absorption – timber drying (ANTTI, 1995) or eradication of biological degradation (ANDREUCCETTI *et al.*, 1995).

Microwave treatment of timber degradation by insects (termites and beetles) is at the present time being carried out either in new timber or in timber elements in service. This kind of treatment solves problems regarding the new and frequent restrictions to the use of preservative treatments due to potential hazard associated with the active chemical elements of the products used.

ANDREUCCETTI *et al*. (1995) showed the possibility of using a commercial microwave oven for eradication of *Hylotrupes bajulus* L., supporting the development of a portable microwave disinfestation device. BECH-ANDERSEN and ANDERSEN (1992) claimed to eradicate dry rot in timber elements in service using a microwave device. The treatment consisted on the heating of timber elements until the least accessible areas have reached 50ºC.

Also microwave imaging is a recent non-destructive technique used for detection of internal features on planks, logs and wood-based panels (BUCUR, 2003).

The capacity of microwave energy to rapidly heat wood through its thickness was successfully attempted for a fast fixation of CCA preservative (SMITH *et* *al.*, 1996).

Microwave use on timber drying is based on having advantages over traditional drying techniques: being faster, showing minimal timber deterioration and no alteration of colour (HANSSON and ANTTI, 2003). However, unlike conventional drying where heat is transfer from the surface to the core of the timber element, microwave energy is absorbed throughout the volume. ZIELONKA and GIERLIK (1999) using a standard microwave oven (2,45GHz frequency and 250W power) showed that the rise of temperature inside the sample was much faster with microwave energy compared with conventional drying. The study showed also that whilst the shape of temperature curve inside the specimen during microwave drying is convex (peak temperature at some millimetres from the surface) during conventional drying is concave (peak temperature at surface of the specimen).

The use of microwave in the process of obtaining sawn timber for structural uses and also its use for eradication of biological degradation of timber elements in service is promising but its implication on mechanical properties of timber elements should be assessed. The lack of information still prevalent about the distribution of temperature inside timber planks during drying process raise some doubts about possible effect on mechanical properties unless development of precise monitoring of timber temperature and moisture content is established.

Traditionally the appraisal of timber's strength before application and in service is made by visual observation of wood features (knot, slope of grain) and characteristics (presence of juvenile wood, rate of growth), but more often attention is being paid to processing methods (type of drying, preservative treatment) influence on the mechanical design properties which are based on traditional processing and untreated timber. Modification of strength properties due to timber preservation ((WINANDY, 1995) and fire-retardant (WINANDY *et al.*, 1991) treatments are studied for sometime now and the necessity of being taken into account on design values for structural purposes seems essential in certain circumstances.

Possible thermal degradation of timber during exposure to microwave energy is an issue to take into account. SMITH *at al*. (1996) referred that since strength loss due to temperature, occurs as a cumulative process during time, the use of electromagnetic energy, being the exposure over a short period of time, would not adversely affect wood strength properties. No proof of this fact is however produced in his paper. It is generally accept that timber heated until 100ºC will recover its mechanical properties when cooled, not being expected any degradation of the chemical constituents of its cell wall or major structural degradation (fissures).

OLOYED and GROOMBRIDGE (2000) studied the effect of drying Caribbean pine timber using microwaves and concluded that microwave drying could reduce timber's strength by 60%. This result was contested by ANTTI *et al.* (2001) on the basis of uncontrolled drying coarse of events, test pieces not matched and not being appointed any reason for the strength reduction observed. Nonetheless TERZIEV (2002) after comparing conventional kiln drying, high temperature kiln drying (above 100ºC) and microwave drying, concluded, about the existence of chemical and structural changes in Scots pine (more severe in microwave than in high temperature) implying that eventual modification of mechanical properties should be study.

The objective of the present study is to provide additional information, using in this case a hardwood species (Oak), on the need for more thoroughly studies on the effect of timber mechanical properties when exposed to microwave energy.

Materials and methods

Twenty-eight small clear Oak (*Quercus pyrenaica* Wild.) wood specimens with dimensions 20x20x200mm were crosscut into three test pieces with 20x20x60mm dimensions, Figure 1.

The test pieces were placed on a climatic chamber at 20º±2ºC temperature and 65%±5% relative humidity until a variation of mass inferior to 0.1% was observed between two consecutive readings in a period of 2 hours.

The test pieces used as reference were not subject to microwave exposure. Test pieces subject to treatment 1 were exposed for 5 minutes to a microwave source of 550W and 2.45GHz frequency (wavelength of the order of 7cm). Test pieces subject to treatment 2 were exposed for 10 minutes to the same conditions. Microwave treatment was carried out using a commercial microwave oven.

The test pieces were weighted before and after the treatment. Before tested in compression parallel to grain test pieces were reconditioned for 20º±2ºC temperature and 65%±5% relative humidity until a variation of mass inferior to 0.1% was observed between two consecutive readings in a period of 2 hours.

The test pieces were tested in compression following ISO 3787 and the results adjusted for reference moisture content of 12%.

After tested in compression the moisture content at the different stages was assessed by determination of the oven dry mass following EN 13183-1.

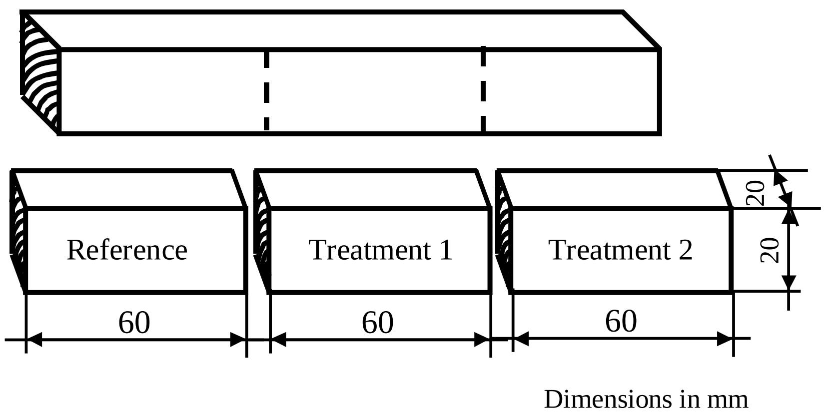


Figure 1 - Preparation of the test pieces from each wood specimen

Results

Variation of moisture content

Since it was not possible to measure the temperature at surface and core of the test pieces during microwave treatment the severity of the exposure was assessed by the determination of the degree of variation of moisture content (drying) of the test pieces.

As expected the degree of drying was more severe in the case of 10 minutes exposure as regards 5 minutes. In the former case an average decrease of 5% moisture content was observed against 2% in the case of exposure during 5 minutes, Figure 2.

A remarkable higher coefficient of variation (around 11%) is observed on sample containing the test pieces exposed for 10 minutes as regards a stable coefficient of variation of 4% observed at the other two samples (untreated and 5 minutes exposure). The reason for this sudden increase of variability could rely on the enhancing of differences between test pieces (density, distribution of moisture content, permeability) with increasing time exposure. The increase of variability, although slighter, is also observable in Table 1 regarding strength loss. This drying rates difference, enhanced by a higher time of exposure to microwaves, disappear after reconditioning before mechanical testing, showing at that time the sample a CV similar to the other two groups.

Variation of compression strength

The strength values obtained for treatment 1 and 2 were compared with the strength values obtained for the reference test pieces using eq. 1.

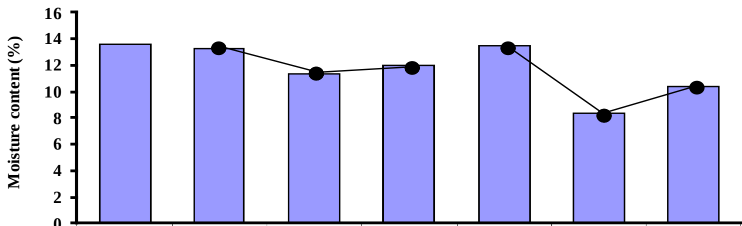
$$SV_t = \frac{\sigma_{c,0,t}}{\sigma_{c,0,r}} \qquad \text{Eq. 1}$$

Where:

SV_t – Strength variation exposure for a certain period of time t (5 or 10 min)

$\sigma_{c,0,t}$ – Compression parallel to grain after treatment for a period of time t (5 or 10min)

$\sigma_{c,0,r}$ – Compression parallel to grain for the reference test piece



	R	TR1/BMW	TR1/AMW	TR1/C	TR2/BMW	TR2/AMW	TR2/C
Mean (%)	13,6	13,2	11,3	12,0	13,5	8,3	10,4
St. Deviation (%)	0,52	0,53	0,47	0,48	0,40	0,95	0,45
CV (%)	3,8	4,0	4,2	4,0	3,0	11,4	4,4

Figure 2 - Variation of moisture content after each treatment. R: Reference; TR1: 5min exposure to microwaves; TR2: 10min exposure to microwaves; BMW: moisture before microwave exposure; AMW: moisture after microwave exposure; C: moisture at mechanical testing

There seems to be a clear negative effect on the compression parallel to grain strength due to the treatment with microwaves, Table 1. An average decrease of 0.12 times the original strength was observed in the case of the treatment for 5min, being that loss higher in the case of 10min (0.19 times de original strength).

Table 1 - Variation of compression parallel to grain strength for treatment 1 and 2 – eq. 1

Test Piece Identification	SV_5	SV_{10}
1	0.91	0.69
2	0.87	0.84
3	0.70	0.89
4	0.91	0.75
5	0.87	0.82
6	0.71	0.67
7	0.88	0.52
8	0.90	0.84
9	0.87	0.87
10	0.90	0.90
11	0.96	0.61
12	0.93	0.90
13	0.85	0.90
14	0.72	0.69
15	0.96	0.85
16	0.82	0.88
17	0.67	0.67
18	0.73	0.85
19	0.97	0.95
20	0.90	0.84
21	0.96	0.87
22	0.94	0.86
23	1.00	0.93
24	0.88	0.79
25	0.93	0.77
26	0.97	0.97
27	0.94	0.68
28	0.86	0.81
Mean	0.88	0.81
Standard deviation	0.09	0.11
Coefficient of variation (%)	10.3	13.5

Application of ANOVA, Table 2 and 3, shows that a significant difference (significance level = 0.05) exists between the three groups considered. The difference is clearly more significant (p value inferior to 0.00) when considering the three groups than when considering only the two microwave treated groups (p close to 0.05). This result can be seen also from Figure 3.

Table 2 – ANOVA results on differences of compression strength of the three groups considered

Variation Source	Degree of Freedom	MS	F	p
Between Groups	2	1112.93	18.42	0.000
Within groups	81	60.41		
Total	83			

Table 3 – ANOVA results on differences of compression strength of groups Exposure for 5 and 10 minutes to microwaves

Variation Source	Degree of Freedom	MS	F	p
Between Groups	1	252.94	4.11	0.048
Within groups	54	61.56		
Total	55			

The effect of the microwave treatment affects also the 5-percentile value of the strength distribution. A lognormal density function (eq. 2) was fitted to the strength values obtained for the different groups considered (not treated, treated during 5min and treated during 10min). This distribution was chosen given its generalize use for timber mechanical data related with reliability studies.

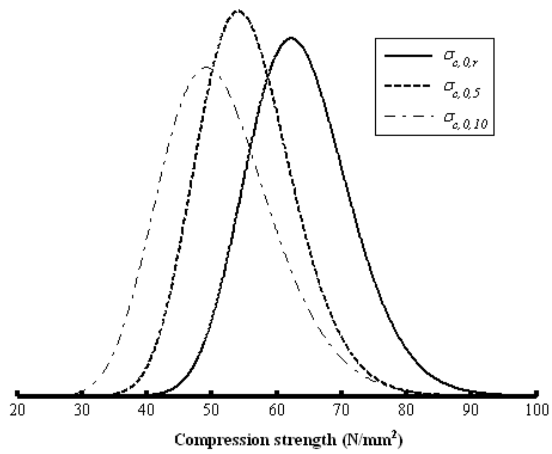


Figure 3 - Adjustment of a lognormal probability density function to the three groups

$$f_X(x) = \frac{e^{\left[-\frac{1}{2}\frac{(\ln x - \bar{x})^2}{\sigma^2}\right]}}{x\sigma\sqrt{2\pi}} (x > 0) \qquad \text{Eq. 2}$$

$\bar{x}$ - Mean

σ - Standard deviation

From Figure 3 it is clear that a loss of strength occurs as the duration of the microwave treatment increases.

Conclusions

Small Oak clear wood test pieces showed a significant loss of compression strength when exposed to microwaves (550W) for 5min and 10min. The loss increased with the time of exposure to microwaves from around 10% (5min exposure) to around 20% (10min exposure). At this stage it is not possible to conclude if in fact safety factors shall be applied to structural timber subject to microwave energy, due to only small test pieces were tested and since it was not possible to measure the temperature at surface and core of the test pieces during microwave treatment (control over drying intensity). Therefore, some critics made by ANTTI *et al.* (2001) to the work of OLOYEDE and GROOMBRIDGE (2000) are still applicable to the present work.

However the results now obtained, along with those of OLOYEDE and GROOMBRIDGE (2000) and TERZIEV (2002), encourage pursue of more thorough studies on possible mechanical deterioration of timber planks when prepared/treated using microwave energy.

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