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Use of round wood of chestnut tree coppices: crack risk and effects of a hot oil bath treatment

Pierre Berard · Thierry Laurent · Oliver Dumonceaud

Abstract The chestnut tree (*Castanea sativa* Mill.) presents good mechanical properties, when valorised in the form of round wood in small diameter. On the other hand, it is very sensitive to cracking during drying. The topic of this study is to optimize a hot oil bath treatment known from previous studies to reduce surface checking. Here, we compare the state of cracks of two series of chestnut tree logs: one is directly dried to 12% moisture content (MC), the other one is treated for one hour using a 130 °C oil bath first, then dried to 12% MC. This first experiment led us to study the evolution of the temperature in the log during the treatment and to propose a chart to determine treatment time in a 130 °C bath. This chart has been successfully tested on a second series of logs.

Verwendung von Kastanienrundholz mit kleinem Durchmesser: Rissbildung und Auswirkungen einer Heißölbehandlung

Zusammenfassung Kastanienrundholz (*Castanea sativa* Mill.) besitzt vor allem bei kleinen Durchmessern gute mechanische Eigenschaften, die das Rundholz aufwerten. Andererseits neigt das Holz jedoch während der Trocknung zu Rissbildungen. Ziel der vorliegenden Untersuchung ist die Optimierung einer Heißölbehandlung basierend auf vorherigen Untersuchungen, um Oberflächenrisse zu reduzieren. Die Rissbildung und -entwicklung bei Stammholz wurden anhand zweier Versuchsreihen verglichen: eine Versuchsreihe wurde direkt auf einen Feuchtegehalt von 12% heruntergetrocknet, die andere wurde zuerst einer 130 °C Ölbehandlung unterzogen und anschließend auf einen Feuchtegehalt von 12% heruntergetrocknet. Aus der ersten Versuchsreihe wurden Informationen über die Temperaturentwicklung im Stamm während der Trocknung gewonnen, um somit eine Vorhersage für die Dauer der 130 °C Ölbehandlung treffen zu können. Diese Ergebnisse konnten in einer zweiten Versuchsreihe erfolgreich angewandt werden.

P. Berard (✉) · T. Laurent · O. Dumonceaud
Laboratoire de Mécanique et Génie Civil, Université Montpellier 2,
Campus St Priest, 860 rue St Priest, 34090 Montpellier, France
E-mail: berardpierre@risc.kyoto-u.ac.jp

1 Introduction

There is a market for round wood products due to the ecological standards in various fields: – Urban development: bus stop structures, urban signalization – Material for public gardens: posts, stakes, tutors, edges of parks and gardens – Playgrounds for children. Currently this market is occupied to a large extent by resinous species treated with impregnation of copper-chromium-arsenic solutions. The presence of these heavy metals in such treated wood presents a problem at the time of their recycling. In addition, a recent European directive recommends banning these treatments apart from specific uses like electric or phone poles and railway sleepers.

An alternative solution consists in turning to small round wood, naturally resistant in outside use. The chestnut tree, for example, presents the advantage of both a good availability in the form of coppices (Bourgeois 1992) and interesting mechanical properties (Militz et al. 2003). It also shows a very thin part of sapwood, which limits the matter loss at the time of manufacturing (Dumonceaud 2001). Moreover, this species resists quite well while exposed to weather in outside, for example in the case of use for vineyard posts, thanks to the presence of tannins. However,

i) leaching of the tannins by water action reduces the naturally very high resistance to fungi of chestnut tree when used at ground contact.

This aspect has already been studied under different aspects: the CIRAD (Centre of International Cooperation in Agronomic Research for Development) has led some researches on impregnation of wood using two high temperature oil bath successive treatments: A green log is immersed in a first bath of vegetal oil, maintained between 110 and 210 °C for a short time. After that, the log is moved to another bath of oil or other liquid (this liquid can be used to impregnate wood, or as a vector to carry preservation products, for example), temperature ranging from 10 to 90 °C. The thermal gradient causes the condensation of the free water, creating a depression in the log. This depression

helps the liquid to impregnate the entire log, up to the deepest layers (Thevenon 2001).

On the other hand, another process using a single bath of hot vegetal oil (temperature ranging from 90 to 140 °C, for up to 7 hours for deep drying) has demonstrated a good efficiency to impregnate the peripheral layers of chestnut tree logs. This impregnation prevents the leaching of the tannins due to outdoor exposition and reinforces the naturally good durability of the chestnut tree (Dumoncaud 2001).

ii) The manufacturing of products using chestnut tree in round wood encounters a general problem which is a strong tendency to cracking, under either the action of growth or drying stresses.

Both growth stresses and hygrothermal recovery (HTR) of green wood for heated logs lead to a strong tendency of heart cracks at log ends, sometimes developing into severe splits of the end, in the veneer peeling industry for example (Jullien 1993). The propagation of these end cracks has previously been studied using the finite element method and an energetic propagation model coming from Griffith theory (Jullien 2003).

On the contrary, natural air drying of logs leads to more or less strong peripheral cracks, because of the anisotropy of the radial and tangential drying shrinkages.

These well known phenomena are linked to the occurrence of internal stresses described by Kübler (1987), growth stresses on one side with tangential compression in periphery and radial tension at heart, stresses due to the drying on the other side with the reverse stress distribution on log cross section. Both stress levels are proportional to the anisotropic difference between tangential and radial strains due to maturation, hygrothermal recovery or hygroscopic shrinkage (Gril et al. 1993b).

Thus, using hygrothermal treatment of green logs combined with natural air drying should be a way to use the antagonism along the cross section of these two anisotropic strain mechanisms to reduce the risk of final drying checks on log periphery.

In the case of chestnut tree logs, previous studies (Jullien 1995, Dumoncaud 2001) give useful information on the mean level of anisotropy for HTR (Fig. 1) and drying shrinkage between green state and standard air dry condition (12% MC):

$$\begin{aligned}(\alpha_T(\text{HTR}) - \alpha_R(\text{HTR})) &= 0.6\% \\(80\text{ }^\circ\text{C}/30\text{ minutes} - (\text{Jullien 1995})) \\(\alpha_T(\text{drying}) - \alpha_R(\text{drying})) &= -1.7\% \\(12\%\text{ moisture content} - (\text{Dumoncaud 2001}))\end{aligned}$$

The thus combined anisotropic strain difference should be at the end:

$$(\alpha_T - \alpha_R)(\text{Drying} + \text{HTR}) = -1.7 + 0.6 = -1.1\%$$

This negative value means that peripheral checks can occur at the end of the air drying process, but the rather low level of this can be sufficient to prevent these unwanted checks.

Taking this into account, this kind of oil bath treatment seems to be able to reduce the anisotropy of stresses coming from drying shrinkages. Thus, we propose to apply a single hot oil bath treatment to small round logs of chestnut tree (under $\varnothing 250$ mm),

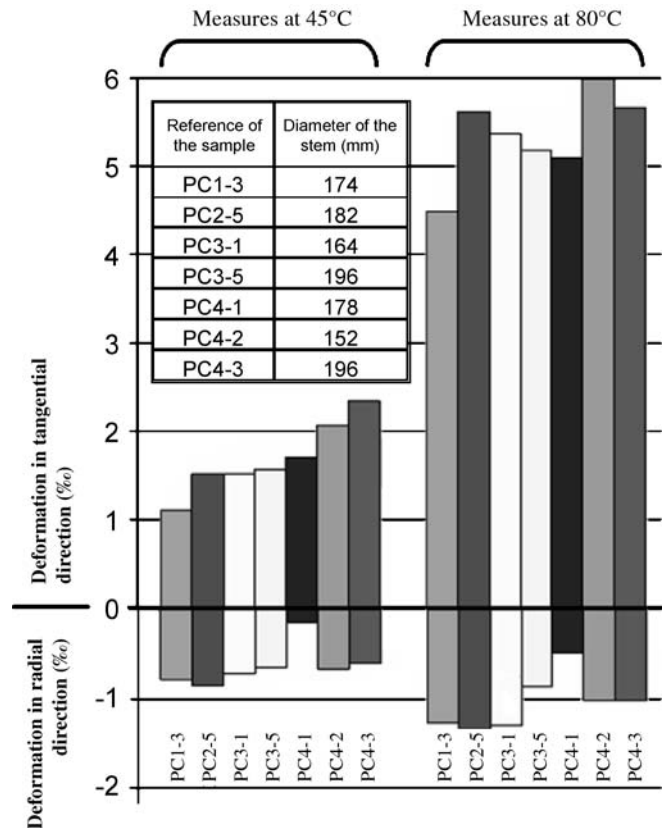


Fig. 1 Radial and tangential deformations due to HTR at 45 °C and 80 °C on slices coming from 7 different wet chestnut trees (*Castanea Sativa* Mill.) - Thickness of the slices: 8 mm - origin: Poitou-Charentes area, France (Jullien 1995)

Abb. 1 Verformungen in radialer und tangentialer Richtung bei 8 mm dicken Holzscheiben von 7 verschiedenen, frisch gefällten Kastanienbäumen (*Castanea Sativa* Mill.) aufgrund hygrothermischer Entspannung (HTR) bei 45 °C und 80 °C – Herkunft: Poitou-Charentes, Frankreich (Jullien 1995)

and to determine the treatment parameters (treatment time, temperature) that will prevent surface cracks due to drying shrinkages. If this can be performed, and knowing from previous studies the efficiency of this kind of treatment on the durability of such logs for outdoor use, then chestnut tree logs will be available for several industrial applications, as described above.

2 Materials and methods

2.1 Materials

Two series of 16 logs were taken from chestnut trees coming from coppices exploited by a sawing company based in the south of France (Charpentes et Sciages du Haut Languedoc, Courniou, Hérault). These green logs (between 55 and 75% of moisture content) were rounded at final diameter between 70 and 160 mm, stored in a cold room at 4 °C, after their ends were sealed with SERFIL, a product clogging the pores in order to prevent natural drying. Each one of these logs was then crosscut into paired small logs 400 mm long. Two series of 16 paired green logs were

constituted like this (a series of even numbers, and a series of odd numbers).

2.2 Oil bath treatment

The hot oil bath treatment (Fig. 2) was performed for 1 hour in a temperature regulated tank (capacity: 40 litres, temperature between 20 to 190 °C with 1 °C precision). The oil used was a rapeseed oil (density = 0.91, viscosity 98 cSt). Linseed oil (density 0.93, viscosity 45–50 cSt) has also been used in former experiments, but it was producing foam on the surface of the bath, so that the rapeseed oil was preferred. Both of these oils have boiling points near 400 °C. A calibrated thermometer placed in the bath near the logs controls the effective temperature which has been set to 130 °C (previous tests showed that lower temperature, around 110 °C, increases the shrinkage values, while higher, above 140 °C, leads logs to critical collapse). An interfaced balance allows following the water loss during the treatment.

2.3 Procedure

The even series have been placed in a moisture and temperature controlled room for three months (20 °C, relative humidity (HR) = 65%) to dry logs at about 12% of moisture content (MC). The odd series logs have been first immersed in the oil bath at 130 °C for 1 hour. Then, they were placed in the same room as the even series. In order to quantify cracking, the cumulated lengths of the cracks at log end and log periphery were measured on the two series, at the end of the drying period. These measurements were used to calculate a crack indicator in periphery (C_{Ip}) and a crack indicator at log end (C_{Ie}), by the following way:

C_{Ip}: peripheral crack indicator = \sum Length of the peripheral cracks / Length of the log

C_{Ie}: end crack indicator = \sum Length of the radial cracks / Radius of the log

2.4 Measurement of temperature in a log during oil bath treatment

Thermocouple transducers were positioned in five radial positions in the middle of a green log (Fig. 6), before immersing it

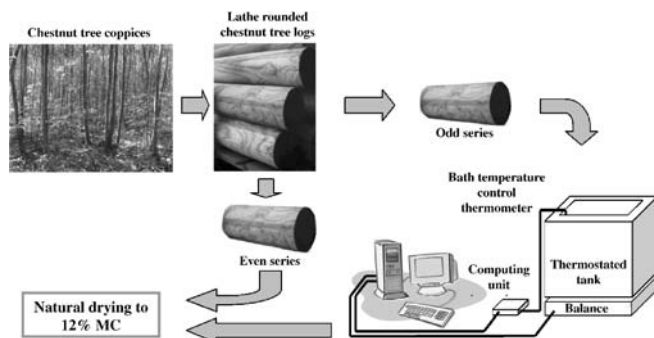


Fig. 2 Experimental process
Abb. 2 Versuchsablauf

during several hours in the heated oil bath (130 °C). From the measured values obtained by the thermometers, it was possible to establish cartography of radial evolution of the temperature in the central area of the log during treatment. Thus, we can have an estimation of the duration of treatment for the internal part of each log at a higher temperature than the target value.

3 Results

3.1 Comparison of end and peripheral cracking

Figure 3 shows cracking on parts of the log of the two series (even numbers: air dried logs; odd numbers: logs having undergone a 1 hour / 130 °C oil bath treatment before air drying). The samples shown here are representative for the entire batch. The treated logs present both a peripheral and a log end cracking much less important than the naturally dried logs as stated by the values of the crack index (Table 1). For both types of cracks, the difference between series is highly significant, although a rather strong dispersion of the values in the case of the treated logs appears.

3.2 Influence of log diameter

The diameters of the treated logs evolve from 70 mm to 160 mm. Figures 4 and 5 show the relation between log diameter and crack indicators for both series. There is always a positive significant relationship between crack index and log diameter. This is particularly true in the case of end crack indicators, when we consider the determination coefficient of 0.72. Similar results



Fig. 3 Photography of the end of paired logs after hot oil bath treatment, then drying (odd samples), or direct natural drying (even samples)
Abb. 3 Stirnseiten der Stammpaare nach einer Heißbehandlung mit anschließender Trocknung (Proben mit ungeraden Nummern) oder unmittelbarer Lufttrocknung (Proben mit geraden Nummern)

Table 1 End and peripheral crack indicators – comparison between natural air drying to 12% MC (even series) and 130 °C/1 hour oil bath treatment, then natural air drying to 12% MC (odd series) applied to green chestnut tree logs

Tabelle 1 Hirnholz- und Mantelrissindizes – Vergleich von 1 Stunde bei 130 °C im Ölbad behandelten (ungerade Probennummern) und unbehandelten (gerade Probennummern) Abschnitten von frisch gefällten Kastanienbäumen nach Lufttrocknung auf 12% Holzfeuchte

Series		Average value		Coefficient of variation (%)	Comments
Even series:	Peripheral indicator	3.02	1.26	42	
non treated logs	End indicator	8.97	2.79	31	
Odd series:	Peripheral indicator	0.61	0.58	95	Small diameter logs have undergone very few cracks, while greater diameter still presents surface checking. This explains the increase of the coefficient of variation compared to non treated logs
treated logs	End indicator	2.31	1.21	52	Same remark regarding the coefficient of variation of the end indicator

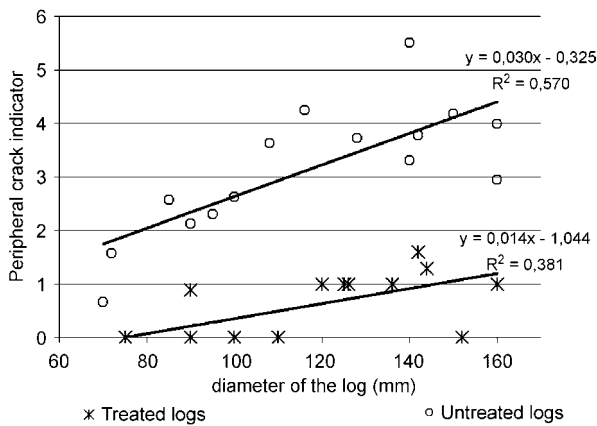


Fig. 4 Comparison of treated and non treated logs peripheral crack indicators

Abb. 4 Vergleich der Mantelrissindizes behandelter und unbehaltener Stammabschnitte

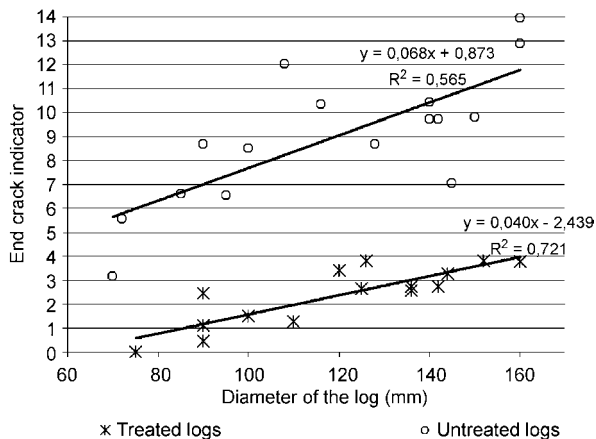


Fig. 5 Comparison of treated and non treated logs end crack indicators

Abb. 5 Vergleich der Rissindizes am Hirnholz von behandelten und unbehaltener Stammabschnitten

were found for log end cracking due to growth stresses, and can be explained using an energetic approach of stored elastic energy inside the log, compared to dissipating energy by crack propagation (Jullien 2003).

For the peripheral observations, there are nearly no cracks up to a 90/100 mm diameter, then only one crack on the whole length for the larger diameters.

The diameter/crack index relationships clearly show the treatment impact on the level of cracking since the curves are clearly shifted downwards in the case of the treated logs.

3.3 Temperature measurements in the log during the treatment

Figure 6 gives a presentation of temperature rise inside the log with the duration of heating up for 4 hours. Using this data, we can draw a cartographic representation (Fig. 7) of the evolution of the temperature in the central area during the treatment: this visualizes that it is necessary to immerse a 120 mm diameter log for nearly 3 hours so that its heart reaches the temperature of 70 °C which is believed necessary to fully express HTR, in the case of chestnut tree. This can explain why the largest diameters (> 90 mm) logs present peripheral cracks after only one hour treatment, in the former case, while small diameter logs have no peripheral cracks. In this case (ø 90 mm, 1 hour, 130 °C), the reached heart temperature at the end of the treatment is about 35 to 40 °C, the 70 °C temperature is only reached on a 15 mm thick external layer.

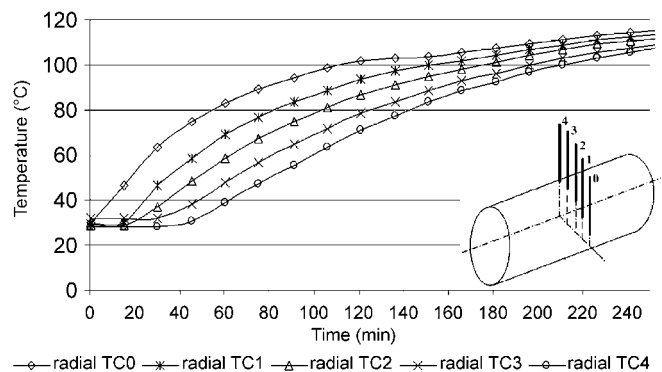
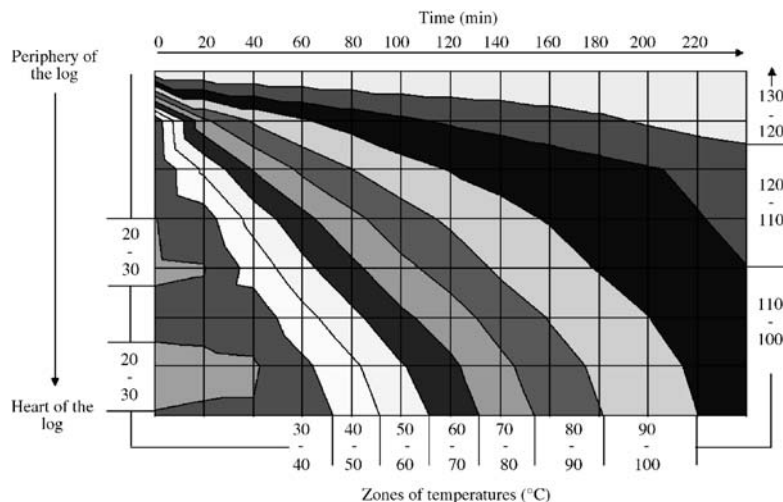


Fig. 6 Change of the radial temperature in a green log's median zone during a 130 °C oil bath treatment

Abb. 6 Temperaturänderung in radialer Richtung im Mittelbereich eines waldfrischen Stammabschnitts während einer Heißölbehandlung bei 130 °C

Fig. 7 Cartography of the evolution in the time of the temperature in the green log's median zone treated in a 130 °C oil bath

Abb. 7 Zeitlicher Temperaturverlauf im Mittelbereich eines waldfrischen Stammabschnitts während einer Heißölbehandlung bei 130 °C



3.4 Oil uptake

The oil uptake is very low during the treatment. After one hour, only the peripheral layer of the logs is impregnated, and the concerned thickness does not overcome 2 millimetres. Also the ends of the logs are not deeper impregnated than 5 millimetres.

4 Improvement of the treatment

Using these observations, we designed a chart (Fig. 8) in order to determine the treatment time of a wet log, in a way to be sure that activation temperature has reached the heart of the log, using 60 °C for the low limit, and 80 °C for the high limit of such a target temperature.

To verify this graph, a new set of wet green logs composed of 15 logs of varied diameter from 70 to 160 mm were used after

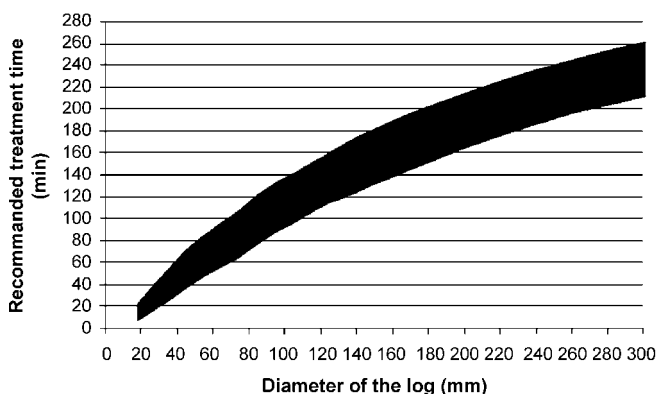


Fig. 8 Treatment time determination chart – for a given diameter, treatment time should be chosen in the dark area: 160 mm diameter log should be treated between 140 and 180 min at 130 °C

Abb. 8 Diagramm zur Bestimmung der Behandlungsdauer in Abhängigkeit des Durchmessers. Die Behandlungsdauer sollte entsprechend dem dunklen Bereich gewählt werden: zwischen 140 und 180 Minuten bei einem Stammabschnitt mit einem Durchmesser von 160 mm bei 130 °C

being rounded. Each log was crosscut into two logs of 400 mm length. The first set (odd numbered 1, 11, 21 ... to 141) was immersed in a hot oil bath at 130 °C. The treatment time was determined according to the graph (average zone, i.e., to reach 70 °C at log heart), from the value of log diameter. After the treatment, these logs were air dried to 12% moisture content in a regulated room for almost 3 months. The second set (even numbered 2, 12, 22 ... to 142) was air dried directly to 12% moisture content, as a control, in the same room, for the same time as the treated set.

Figures 9 and 10 show the visual results of this test. There are no visible cracks on periphery of the treated logs and only very narrow heart checks on log end, which are not reaching the log periphery, while directly air dried logs have overcome important cracks in both log end and periphery.

Values of crack index are clearly lower for treated logs (Table 2), as before in the first test, but there are no peripheral cracks anymore.

Figure 11 shows that the diameter effect observed in the results of the first test has almost disappeared with this second one on the peripheral side. On the other hand, Fig. 12 shows that for



Fig. 9 Logs series treated in a 130 °C oil bath – treatment time determined using the diameter-treatment time determination chart, before natural drying to 12% moisture content

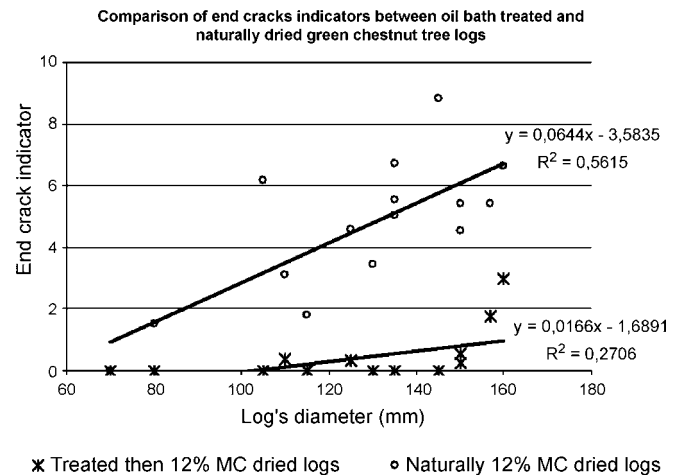
Abb. 9 In einem 130 °C heißen Ölbad behandelte Abschnitte: Behandlungsdauer nach Abb. 8 vor Lufttrocknung auf einen Feuchtegehalt von 12%

Table 2 End and peripheral crack indicators – comparison between natural air drying to 12% MC (even series) and 130 °C oil bath treatment (treatment time determined using the treatment time determination chart), then natural air drying to 12% MC (odd series) applied to green chestnut tree logs
Tabelle 2 Hirnholz- und Mantelrissindizes – Vergleich von im Ölbad bei 130 °C behandelten (Behandlungsdauer nach Abb. 8; ungerade Probennummern) und unbehandelten (gerade Probennummern) Abschnitten von frisch gefällten Kastanienbäumen nach Lufttrocknung auf 12% Holzfeuchte

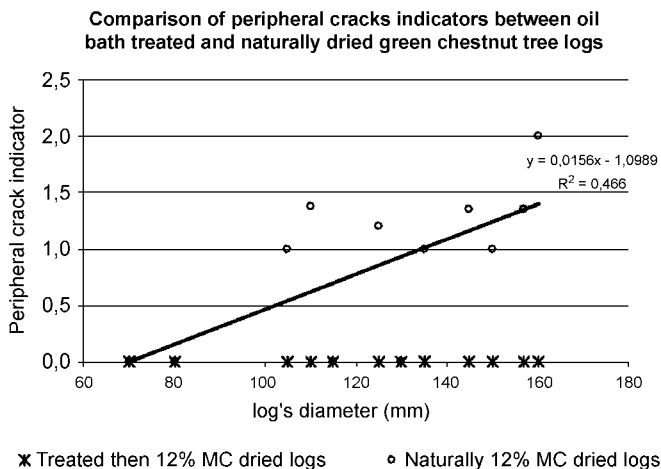
Series		Average value	Coefficient of variation (%)	Comments
Even series:	Peripheral indicator	0.89	0.61	69
non treated logs	End indicator	4.58	2.29	49
Odd series:	Peripheral indicator	0	0	0
treated logs	End indicator	0.42	0.85	204
				No cracks at all in periphery
				The two bigger logs have undergone narrow end cracks at heart. If we don't take them into account, the average CIE is 0.1, with a 164% coefficient of variation



Fig. 10 Paired logs series naturally dried to 12% moisture content
Abb. 10 Unbehandelte, auf 12% Holzfeuchte getrocknete Vergleichsproben



✱ Treated then 12% MC dried logs ○ Naturally 12% MC dried logs
Fig. 12 Comparison of treated (using treatment time determination chart) and non treated logs end crack indicators
Abb. 12 Vergleich der Rissindizes am Hirnholz von behandelten (Behandlungsdauer nach Abb. 8) und unbehandelten Stammabschnitten



✱ Treated then 12% MC dried logs ○ Naturally 12% MC dried logs
Fig. 11 Comparison of treated (using treatment time determination chart) and non treated logs peripheral crack indicators
Abb. 11 Vergleich der Mantelrissindizes behandelter (Behandlungsdauer nach Abb. 8) und unbehaltener Stammabschnitte

the higher diameter, we still observe some end cracks, but these cracks, as we said, are very narrow, and only located at heart.

Heart check is not a problem for the use as round wood, as for ring shake that sometimes appears in these chestnut logs. Moreover, this heart checking occurs during oil treatment, due to HTR phenomena, thus the surfaces generated by this checking process will be also protected against tannin leaching by a thin oil impregnation.

5 Conclusion

In this study, the hot oil bath treatment (treatment time: one hour) allowed a 75% reduction of the crack indicator value. But the efficiency was better for small diameter logs. A deeper study of temperature variation during the treatment shows that the time needed for complete HTR expression inside bigger logs was not reached. A treatment graph relating the log's diameter to the treatment time was then successfully tested on a 70 to 160 mm diameter range, which did not show any peripheral cracks at all after treatment and air drying to 12% MC. Only end cracks remain at heart, which are not a problem for the final expected use of these logs.

Taking into account this study, it seems possible, from a technical point of view, to enhance the use of chestnut tree coppices in round wood products for outdoor uses, because this species is not very sensitive to cracking in the small diameters usually observed in coppices and the heat treatment can drastically reduce this cracking risk, provided that diameter influence is correctly taken into account.

Moreover, in the young coppice logs, chemical ageing of heartwood bioactive metabolites is not present and the outside heartwood of these trees was found in the highest class of natural durability against fungi in standard tests (Dumoncaud 2001). Furthermore, oil treatment at temperature slightly above 100 °C is a good way to put oil inside the wood on all surfaces.

Anyway one can wonder whether only HTR/drying phenomena opposition explains the efficiency of the heat treatment. Indeed, it would also be necessary to hold account of the viscoelastic phenomena which affect wood at high temperature (Bardet et al. 2003). Moreover, it would be necessary to study the exact chronology of the phenomena in parallel with the evolution of the mechanical properties of wood according to its moisture content and temperature (Beauchêne 1996) to reach a better understanding of the concerned phenomena.

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