Laboratory Tests on the Natural Durability of Six Different Wood Species after Hygrothermal Treatment

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ABSTRACT

From several commercial heat treatment technologies with different, hardly comparable process parameters the positive effects on durability are described and well known. The objective of this study was to evaluate the efficacy of a hygrothermal treatment (WTT, Wood Treatment Technology, Denmark) on the biological resistance of six different wood species. The treatment was carried out at two temperature levels of 160 and 180 °C. The biological resistance against softrot fungi and other soil borne microorganisms was assessed by laboratory soil bed tests according to the European standard ENV 807. In addition, single fungi tests were performed with reference to EN 113 and CEN/TS 15083-1, respectively, using five different test fungi. All samples of each species had been leached according to EN 84 before testing. The laboratory tests on natural durability show a significantly reduced mass loss for hygrothermally treated samples. Thereby, the enhancement of the resistance against decay was predominantly better for hardwood than for softwood samples. However, practical experiences with terrace floorings showed further needs for process and quality improvements.

INTRODUCTION

Numerous studies have been carried out on the topic of heat treatment and its influence on primary wood properties. Beside physical and mechanical wood properties, the change of biological resistance after treatment is one of the most interesting issues. To obtain reliable results about biological resistance, long-term field tests are necessary and are supposed to produce more relevant results than laboratory tests. On the other hand, laboratory tests give an indication in quite a short time whether an intended increase of natural durability has been achieved or not. From several commercial heat treatment technologies with different, hardly comparable process parameters the positive effects on durability are described and well known (e.g. Tjeerdsma et al., 1998; Rapp and Sailer, 2001; Bächele et al., 2004; Scheiding et al., 2007). After an assessment of the physical and mechanical properties of a hygrothermal treatment in a high-pressure autoclave from WTT (Wood Treatment Technology, Denmark), the efficacy on the biological resistance of six wood species should be evaluated in this study.

EXPERIMENTAL

Kiln-dried sawn timber of medium quality was selected from following wood species: European Ash (*Fraxinus excelsior L.*), European Beech (*Fagus sylvatica L.*), Oak (*Quercus* sp. *L.*), Norway Spruce (*Picea abies L.*), Scots Pine (*Pinus sylvestris L.*) as well as Silver Fir (*Abies alba Mill.*). According to EN 350-1, the samples were cut from sap- and heartwood boards coming from three different trees (Table 1). The boards with lengths between 3.500 and 4.000 mm were cut into three pieces corresponding to the three different treatment variants. The treatment was carried out in a pressure autoclave at two temperature levels of 160 and 180 °C holding a pressure between 7 to 12 bars for a specific time, depending on e.g. wood species or entrance moisture content. All samples of each species had been weathered according to EN 84 before testing. After incubation, samples were cleaned from adherent mycelium, weighed, dried at 103 °C to mass constancy, and secondly weighed to determine the mass loss of each specimen based on the initial dry weight. The mass loss (ML) of each specimen is shown as a percentage of the initial dry mass.

Table 1: Sample size for the laboratory tests acc. to ENV 807/EN 113

wood species	control		160°C		180°C	
	heart	sap	heart	heart	sap	heart
European Beech	27/ 60	27/ 63	27/ 60	27/ 60	27/ 63	27/ 60
European Ash	18/ 40	18/ 40	18/ 40	18/ 40	18/ 40	18/ 40
Oak	27/ 57	27/ 0	27/ 56	27/ 57	27/ 0	27/ 56
Norway Spruce	26/ 58	27/ 64	27/ 58	26/ 58	27/ 64	27/ 58
Scots Pine	24/ 60	25/ 50	26/ 60	24/ 60	25/ 50	26/ 60
Silver Fir	27/ 37	27/ 61	26/ 37	27/ 37	27/ 61	26/ 37
Total	**300/ 645**		**303/ 651**		**259/ 551**	

Laboratory soil tests

The biological resistance against softrot fungi and other soil borne microorganisms was assessed by laboratory soil tests according to the European prestandard ENV 807. A number of about 140 samples with dimensions of 100 x 10 x 5 mm were prepared from sap- and heartwood of each wood species after treatment. The samples were placed in a soil bed under controlled climate conditions at 27 ± 2°C and 70 ± 5% relative humidity (RH). Soil substrate used in the study was a natural top soil from a test field in Freiburg, Germany. After 32 weeks test duration, mass loss of treated samples was determined and compared to the untreated samples. The statistical analysis was performed by means of an univariate analysis of variance (ANOVA) with repeated measurements for the results of the soil bed tests.

Single fungi tests

A total number of almost 2000 thermally treated and non-treated wood specimens with dimensions of 25 x 15 x 50 mm^3 were prepared according to EN 113. After weathering acc. to EN 84 and sterilisation with gamma irradiation, samples were exposed to 5 brown- and white-rot basidiomycetes for 16 weeks at 22 °C and 70 % RH in a climate chamber (Table 2). For statistical evaluation, a one-way analysis of variance (ANOVA) of the recorded mass losses was performed with the significance level set at $P<0.05$. A Tukey HSD post hoc test was run to demonstrate differences in means.

Table 2: test fungi for single fungi tests acc. to EN 113

name	origin	remark
Coniophora puteana (Schum.: Fr.) Karst.	(BAM Ebw. 15)	
Coriolus versicolor (L.:Fr.) Quél.	(isolate no. EMPA 159),	tested only on hardwood
Gloeophyllum trabeum (Pers.: Fr.) Murrill	(isolate no. EMPA 100)	
Poria placenta (Fr.) Cooke	(isolate no. EMPA 229),	tested only on softwood
Serpula lacrymans (Wulfen: Fr.) Schroeter	(BAM Ebw. 315)	

RESULTS AND DISCUSSION

Laboratory soil tests

The results show a significantly reduced mass loss for thermally treated specimens over all tested wood species after exposure to fungi and soil-borne organisms. After 32 weeks exposure in soil beds the highest relative mass loss was obtained for untreated hardwood samples. For the treatment variant 160 °C a reduction in fungi-related mass loss up to 60 % could be observed. Temperature variant 180 °C showed a further increase of the resistance against fungi and microorganisms, with a reasonable further increase for the hardwood samples. The samples hydro-thermally treated at 180 °C showed an average mass loss of less than 3 percent for almost every wood species after 32 weeks exposure to soil bed (Figure 1). Thereby for beech wood, the most effective reduction of mass loss was obtained for the hygrothermally treated samples. The difference between the average mass losses of the treatment variants is significant for almost every species. Only for spruce and pine, the lower mass loss of variant 160 °C was not significant. The cross-sectional zone of the log – heart- and sapwood – affects the results for some of the tested species. This was significant for all 3 treatment variants of ash and for the control variant of pine. Contrary to this, no statistical significant differences between heart- and sapwood were observed for beech, spruce and fir. The obtained results are generally in line with former laboratory studies according to ENV 807 (Tjeerdsma *et al*. 1998; Scheiding *et al*. 2007).

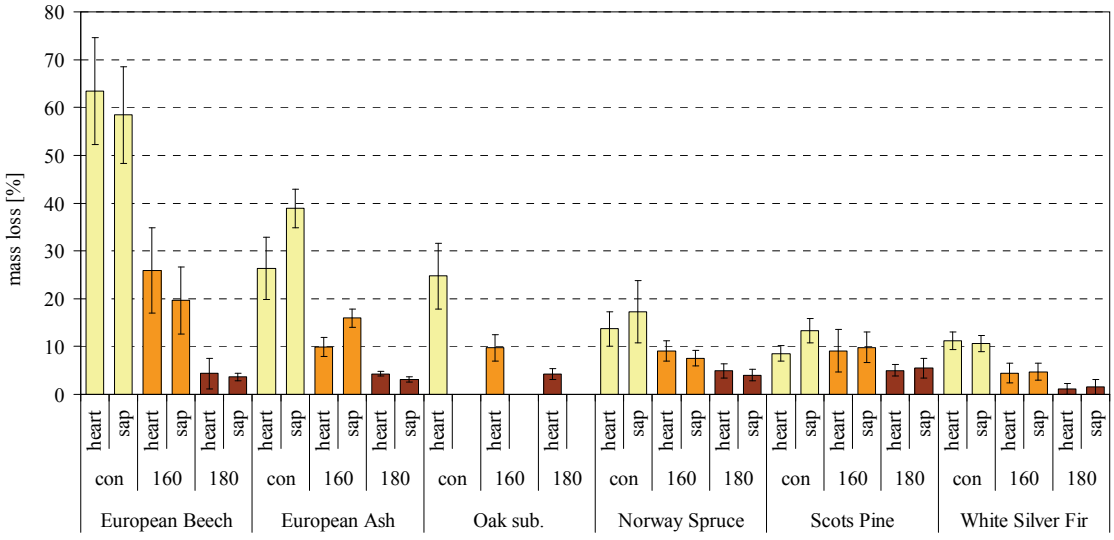

Figure 1: Mass loss [%] of treatment variants (con = control, 160°C and 180°C) after 32 weeks exposure in soil bed acc. to ENV 807. Bars show standard deviation.

Single fungi tests

In comparison to controls, softwood thermally treated at the temperature level of 180 °C showed after a 16-week exposure to wood destroying basidiomycetes a significant reduction of mass loss over most tested wood species and fungi (Figure 2). Overall, thermally treated silver fir showed better decay resistance against the fungi tested than pine and spruce. Same effect could be observed for tested hardwood species with the exception of oak (Figure 3). Here, two test fungi caused higher mass losses on the thermally treated samples than on the controls. *Coriolus versicolor* – the only tested white-rot fungus- caused on hardwood species over all treatment levels the highest degradation up to 36 % after 16 weeks. Treatment variant 160 °C resulted – as expected – predominantly in mass losses between those of untreated controls and specimens treated at 180 °C. An exception to this could be seen at two hardwood species exposed to the brown-rot fungus *Serpula lacrymans* where the medium treatment level (160 °C) showed higher weight losses than the untreated pendants. Decay results of the resistance of all wood species against *Coniophora puteana* could not be presented yet as the tests were still ongoing on the submission date of this paper.

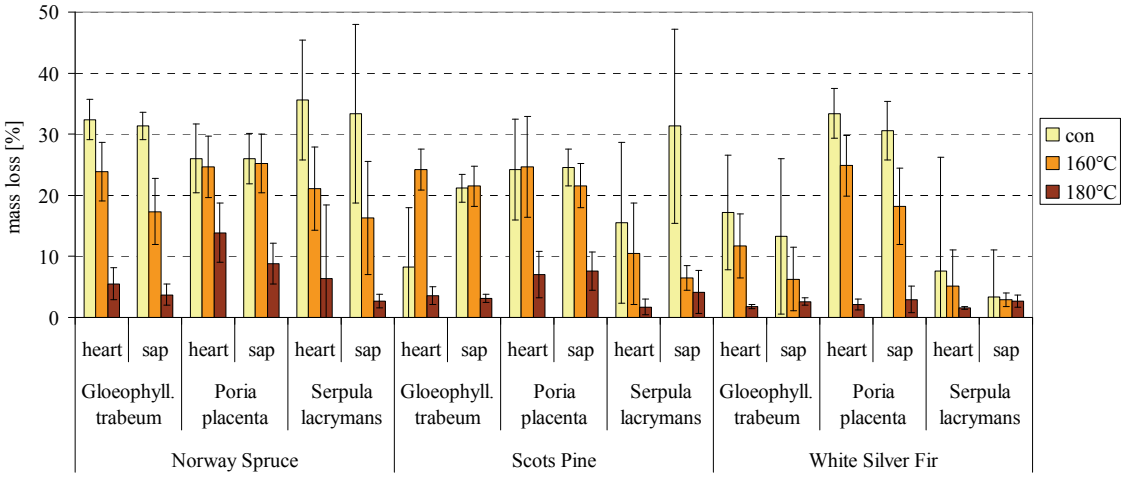

Figure 2: Mass losses of softwood blocks untreated and thermally treated (con = control) after 16 weeks exposure to wood destroying basidiomycetes acc. to EN 113. Bars show standard deviation.

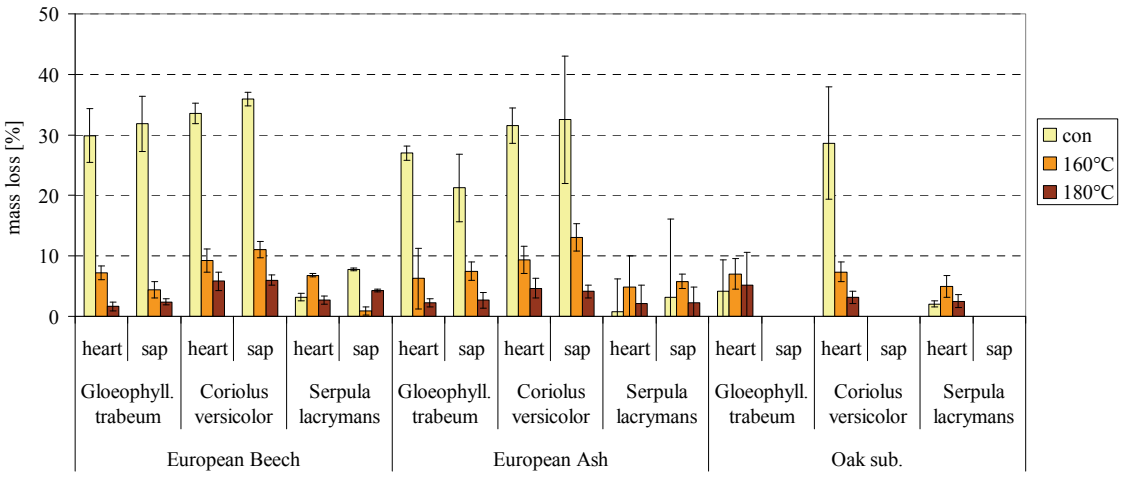

Figure 3: Mass losses of hardwood blocks untreated und thermally treated (con = control) after 16 weeks exposure to wood destroying basidiomycetes acc. to EN 113. Bars show standard deviation.

Natural durability classification

Coniophora puteana is an obligatory test fungus acc. to CEN/TS 15083-1 as well as EN 113 as it is known for its severe wood destroying ability. Since the results of decay resistance against this fungus were not available on the submission date of this paper, the categorisation of the thermally treated wood species into natural durability classes based on the single fungi tests could not be conducted yet. Based on the median mass loss of the soil bed tests, a preliminary classification of the natural durability of hygrothermally wood acc. to CEN/TS 15083-2 has been done. The classification is only given for information, since the test was performed according to the slightly differing prestandard ENV 807 (Table 3).

Table 3: Effect of hygrothermal treatment (WTT) on the classification of natural durability acc. to CEN/TS 15083-2:2005

wood species	Durability class		
	control	160°C	180°C
European Beech	5	2	1
European Ash	4-3	3-2	2-1
Oak sup.	3	1	1
Norway Spruce	4	3	1
Scots Pine	5	3	1
White Silver Fir	3	2	1

Laboratory results versus practical experience

Currently, there is a considerably demand for terrace floorings made from thermally modified timber. Due to its remarkable increase of dimensional stability as well as natural durability observed in laboratory tests, especially thermally treated European beech was supposed to be suited for outdoor applications. However, those terrace floorings revealed an unsatisfying quality after several months outdoor exposure. Under service conditions short term cycling of temperature, humidity and direct sunlight led to an accelerated weathering and fissuring of the decks. Especially, shakes parallel to grain direction and along the pith support moisture infiltration into the plank (Figure 4). Although thermally treated timber showed a lower water sorption than untreated timber, the problem of case hardening still remained.

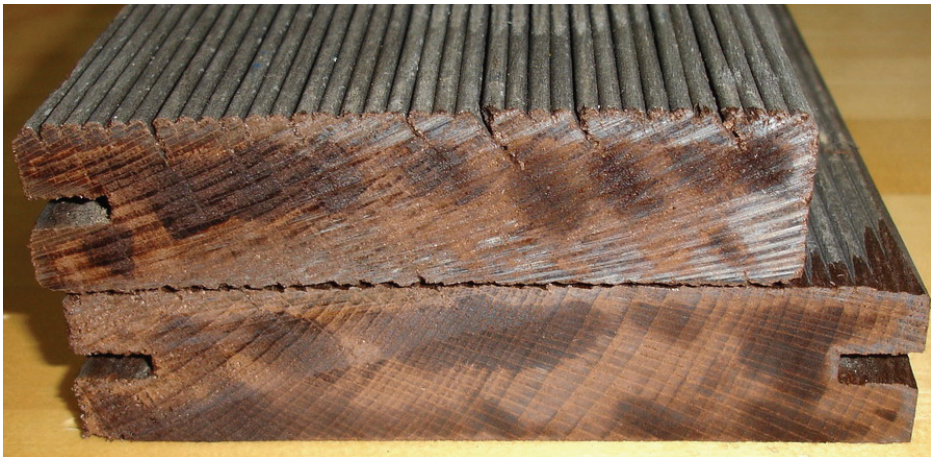

Figure 4: cross-sections of terrace planks (25 mm thickness), after one-year outdoor exposure – dark-stained areas show higher moisture content.

CONCLUSIONS

Significant effects of hygrothermal treatment on biological resistance of hard- and softwood species were observed. The results confirm findings from other studies that with an increasing treatment temperature a higher decay resistance can be achieved. Whereas hardwoods show significant effects already at temperature level of 160 °C, a significant improvement for softwoods was obtained not before treatment level 180 °C. Although laboratory tests are an approved test method to indicate natural durability of wood, the results have to be confirmed through long-term field tests in different climate regions. Especially, cycling temperature and humidity in service conditions associated with direct sunlight may lead to lower resistance or quality of TMT-products as indicated by results determined on small and defect free samples in laboratory tests. Additional effects, such as decreased strength properties, come along with a thermal modification of wood, and may therefore restrict the range of applications. Future work will be to optimise the treatment process in order to increase product quality. Additional hydrophobizing (e.g. with oil or resin) seems to be necessary for thermally treated beech to reduce the effect of case hardening. However, increased manufacturing costs make thermally treated timber even more to a product destined for the premium sector.

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