BRIEF ORIGINAL

Laboratory screening of thermo-mechanically densified and thermally modified timbers for resistance to the marine borer *Limnoria quadripunctata*

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Abstract

Thermo-mechanically densified material of five different wood species (English oak, European ash, European beech, Norway spruce, poplar) was subjected to three different vacuum-heat treatment processes (A: 230 °C / 20 % vacuum; B: 230 °C / 80 % vacuum; C: 240 °C / 20 % vacuum) and tested for its resistance against the marine borer *Limnoria quadripunctata* by comparing their faecal pellet production rates. The three different treatments caused a notable reduction of the feeding rates of up to 66 % indicating significantly increased durability against *Limnoria* if exposed in marine environment. Neither the treatment temperature nor the application of a higher vacuum affected the faecal pellet production significantly.

Keywords: durability, laboratory screening, *Limnoria quadripunctata*, marine borer, thermo-mechanical treatment, vacuum-heat treatment

1 Introduction

Thermal modification is a non-biocidal process to improve both, durability and dimensional stability of wood. At the same time, the strength properties of thermally modified wood are negatively affected by the process. This disadvantage can be compensated through the use of thermo-mechanically densified wood with increased initial strength for the process of thermal modification. A possible spring-back effect of the densified wood is minimised by applying the thermal modification subsequently to the densification (Wehsener et al. 2016). The increased density as well as the thermally modified chemical structure of the wood cell walls has the potential to improve the resistance against marine borers (Graham 2011).

It might furthermore be assumed that different vacuums applied during the process of thermal modification can have an impact on the durability of the modified wood since degradation products are being evacuated from the wood during the modification process. A higher vacuum and therefore the removal of degradation products such as organic acids could on the one hand lead to improved environmental compatibility of thermally modified wood, but may on the other hand negatively affect its durability.

The two-step process of thermo-mechanical densification and thermal modification allows applying high treatment temperatures and thus high modification levels to the timber while its strength properties remain at an acceptable level. Highly improved durability opens a large field of further applications for densified and thermally modified wood including the use in marine environment. The aim of this study was therefore to examine its resistance against the marine borer *Limnoria quadripunctata*.

2 Materials and methods

English oak (*Quercus robur*), European ash (*Fraxinus excelsior*), European beech (*Fagus sylvatica*), poplar (*Populus tremula*), and Norway spruce (*Picea abies*) were treated in a two-step process where they were first thermo-mechanically densified and afterwards thermally modified, using different temperatures and varying vacuums during the process (A: 230 °C / 20 % vacuum; B: 230 °C / 80 % vacuum; C: 240 °C / 20 % vacuum). The degree of densification varied between 43 % (English oak, European ash, European beech) and 50 % (Norway spruce, poplar). The thermal modification was performed by timura Holzmanufaktur GmbH, Rottleberode, Germany. For the thermo-mechanical densification, dehonit Deutsche Holzveredelung Schmeing GmbH & Co. KG, Kirchhundem, Germany, used a hot-press with heated press plates. More details about the densification and thermal modification process are given by Wehsener et al. (2016).

In total, 20 different parameter combinations were tested including untreated controls from each wood species. Each of twelve replicate samples of 20 x 2.5 x 4 mm^3 was manufactured from the middle part of the modified wooden boards which had a dimension of 2000 x 100 x 20mm^3.

Before exposure to the *L. quadripunctata*, the 240 wood specimens were vacuum impregnated with seawater for at least 24 h until they sank. Afterwards, the samples were leached in seawater for another 14 days with water exchange after 7 days to simulate a long-term exposure in the marine environment.

The *Limnoria* were picked from a heavily infested piece of wood, which was collected from the intertidal zone at Southsea, Portsmouth, UK and kept in running seawater at Portsmouth Institute of Marine Sciences. The limnoriid species of the animals was identified and the *L. quadripunctata* were checked for rapidly beating pleopods as well as the presence of folliculinids, which indicate a likely lower feeding rate (Delgery et al 2006). If folliculinids were found, these animals were not used for the laboratory screening.

Twelve-well cell culture trays with cylindrical wells, 20 mm in diameter, were used for the test set up. In each well 4 ml of unfiltered seawater were poured and the leached wood samples were placed individually into the wells. The prepared cell culture trays as well as the collected *L. quadripunctata* were conditioned at 20 ± 1 °C for 24 h before exposure to *L. quadripunctata* started.

L. quadripunctata were checked again visually for vital signs and then placed individually into each well. The trays were covered with a lid to avoid evaporation and kept at 20 ± 1 °C in a temperature-controlled chamber with a fluorescent light source in a 12 h on, 12 h off, day-night cycle.

The feeding rate of the *L. quadripunctata* on the wood samples was examined twice a week at 3-day and 4-day intervals over a 17-day period. Each time the feeding rate was measured, the *L. quadripunctata* and the corresponding wood samples were gently moved to identical cell culture trays, already filled with 4 ml of unfiltered seawater and kept at 20 ± 1 °C for 24 h. Again, all animals were examined visually for moulting and vitality. Any dead animals were replaced.

The feeding rates of the *L. quadripunctata* on the wood samples were measured indirectly. During the exposure time of three or four days, the *L. quadripunctata* used the wood samples as a food source and produced faecal pellets. The amount of faecal pellets was measured according to the process described by Graham (2011), used as an indicator for the activity of the animals and thus for the resistance of the material against *L. quadripunctata*.

After the *L. quadripunctata* and corresponding wood sticks were transferred to a new tray, each well, now containing only faecal pellets and seawater, was photographed individually. Data derived from animals that died or moulted during a counting period have been eliminated from calculations and adjustments to calculation of rate have been made to take account of such data gaps.

3 Results and discussion

The three different processes of thermo-mechanical densification and subsequent thermal modification resulted in significant reductions of the faecal pellet production rates of 64 % (Norway spruce), 55 % (poplar), 66 % (European beech), 48 % (European ash) and 28 % (English oak) compared to the untreated specimens (Fig. 1).

A positive effect of higher modification temperature on durability was observed only on Norway spruce. *L. quadripunctata* that fed on this wood species treated at 240 °C (20 % vacuum) produced 34 % less faecal pellets compared to those treated at 230 °C and at the same vacuum of 20 % (Fig. 1).

The higher vacuum within process B (80 % vacuum) did not lead to significantly different faecal pellet production rates compared to process A (20 % vacuum). Therefore, a potential effect of a higher vacuum on durability became either not evident or the wood degradation products such as formaldehyde, acids, furfural and other aldehydes had no significant influence on the feeding rates of *L. quadripunctata*.

Increased density of wood leads to reduced feeding rates as previously shown by Cragg et al (2007) and Graham (2011). The densification of the five wood species used in this laboratory screening was determined by measuring the weight and volume of the wood. *L. quadripunctata* fed on Norway spruce (460 kg/m^3) produced significantly more faecal pellets than those fed on other timbers and animals fed on poplar produced significantly more pellets than those fed on the more dense hardwoods English oak (630 kg/m^3), European ash (630 kg/m^3)

and European beech (710 kg/m^3) (Fig. 1). Therefore, the findings by Cragg et al. (2007) and Graham (2011) are generally consistent with the current results.

English oak, European ash and European beech with similarly high densities still showed differences in the feeding rates of *L. quadripunctata* on untreated specimens. In addition to wood density, wood extractives can have an impact on the feeding rates of *L. quadripunctata* (Borges et al. 2008). Among the tested wood species, in particular English oak, on which the lowest feeding rates were measured, has the potential for higher resistance against *L. quadripunctata* due to its tannic acid content.

In contrast to previous trials with wood treated with preservatives such as copper chromate and different anhydrides (Klüppel et al. 2015, Papadopoulos et al. 2008) the densified and thermally modified wood did not increase the mortality of *L. quadripunctata* compared to untreated controls.

The reduction of feeding rates by *L. quadripunctata* achieved through the combined effect of densification and thermal modification were in a similar range as previously determined for chemically modified wood such as wood modified with linear chain carboxylic acid anhydrides (Papadopoulos et al. 2008) and can therefore be considered as a substantial protection against *L. quadripunctata*. In addition, the achieved reduction of the faecal pellet production rates is comparable to those measured in a previous trial for purpleheart (*Peltogyne sp.*) compared to Scots pine (*Pinus sylvestris* L.) (Borges et al. 2008).

4 Conclusion

The process of thermo-mechanical densification and subsequent thermal modification was found to be applicable to the five tested wood species and increased their durability against the marine borer *L. quadripunctata* significantly. Therefore, the densified and modified wood has the potential to be used in sea water contact.

However, the suitability of building materials in the marine environment depends on numerous further properties such as mechanical strength, abrasion resistance, hardness, and its durability against fungi and other marine borers such as shipworms. Therefore, in addition to this laboratory screening under fixed conditions, some long-term seawater-trials had been installed in Kristineberg, Sweden, focussing on the resistance of the material against *Teredo navalis* and *Teredo norvegica*.

Besides these trials, the modified wood was tested for its static and dynamic hardness, bending strength, abrasion resistance and structural integrity, dimensional stability, wetting ability as well as its resistance against decay fungi and termites. Preliminary results are promising but need to be confirmed through long term field test results.

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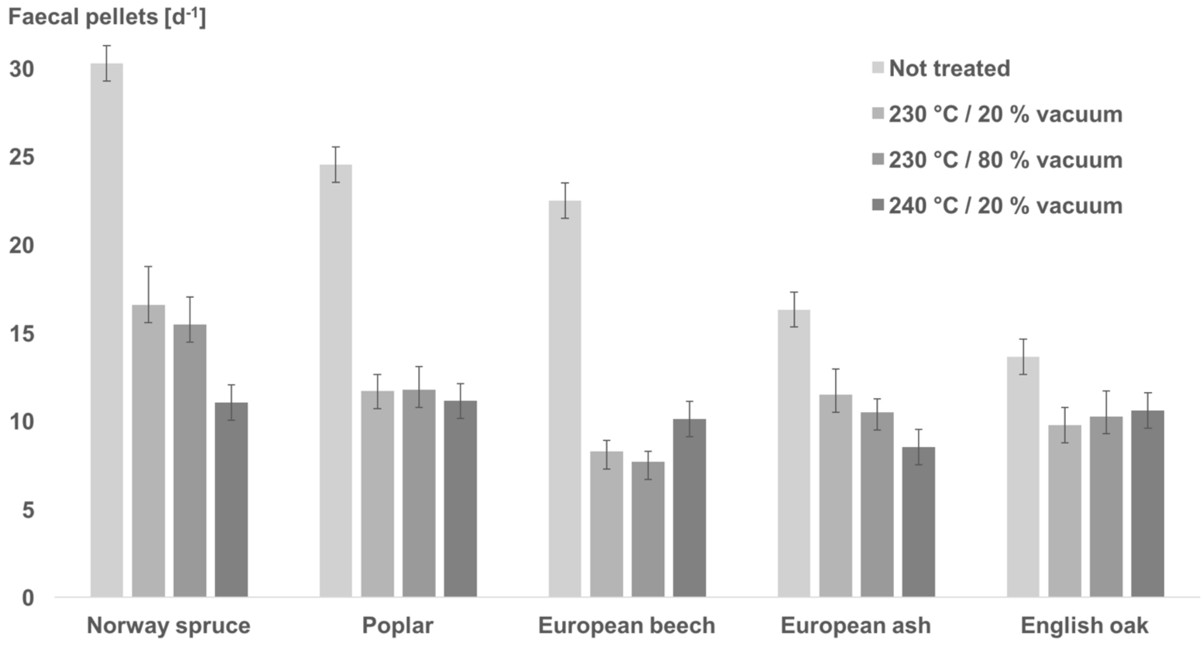

Fig. 1 Effect of densification treatment and timber substrate on faecal pellet production rate (mean ± SE, n=12) by *Limnoria quadripunctata* feeding over a period of 17 days. Data related to a period in which the animal died or moulted have been excluded from calculations.