International Biodeterioration & Biodegradation 82 (2013) 87–95

Contents lists available at SciVerse ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Review

The decay resistance of modified wood influenced by moisture exclusion and swelling reduction

Emil Engelund Thybring*

Wood Technology, Danish Technological Institute, Gregersensvej 4, DK-2630 Taastrup, Denmark

A R T I C L E I N F O

Article history:
Received 5 September 2012
Received in revised form
15 January 2013
Accepted 12 February 2013
Available online 9 April 2013

Keywords:
Wood modification
Decay resistance
Moisture exclusion
Swelling reduction

A B S T R A C T

The relation between modification intensity and decay resistance of modified wood is investigated based on a compilation of experimental data from literature for six different modification techniques. The purpose is to expand our knowledge on the mechanism of wood modification, in particular how decay resistance is achieved. Decay resistance of modified wood appears to be related to reduction in maximum moisture capacity of the cell wall. The analysis indicates that decay cannot progress below 25% moisture content. The moisture exclusion efficiency (MEE) and anti-swelling efficiency (ASE) are both discussed as means of quantifying modification efficacy. Both MEE and ASE have advantages and disadvantages, but MEE seems to provide a threshold for decay resistance unaffected by type of modification. However, MEE cannot be determined at water saturation and the use of it as a measure for modification efficacy therefore relies on the assumption that MEE is more or less similar at saturation and below.

Contents

1. Introduction

Wood modification covers techniques that enhance the properties of wood by chemical, biological or physical means (Hill, 2006). Modification typically targets dimensional stabilisation, i.e. reduced moisture induced movement, and increased durability, i.e. resistance to decay. Traditionally, the susceptibility of wood to decay has been circumvented by use of toxic chemicals. Wood modification on the other hand provides decay resistance through non-biocidal modes of action (Hill, 2006). In order to achieve this, adequate modification intensity is required. Modification intensity is typically described by the relative amount of modification agent added, i.e. agent-to-wood mass ratio m_{agent}/m_{wood} given as weight percent gain (WPG), see Fig. 1. Alternatively, in the case of thermal modification the intensity is described by weight loss (WL).

A range of different modification techniques have been tested and their modification intensities tuned to yield the desired durability. Despite variety in the nature of different modification techniques, their efficacy in improving decay resistance has often been linked with reduced amounts of moisture in the modified wood (Ibach and Rowell, 2000; Hill, 2002). So far, however, no common criterion has been established for the reduction needed for decay resistance.

* Tel.: +45 72 20 23 55; fax: +45 72 20 20 19.
E-mail addresses: ete@teknologisk.dk, emil.engelund@gmail.com.

0964-8305/$ – see front matter
http://dx.doi.org/10.1016/j.ibiod.2013.02.004

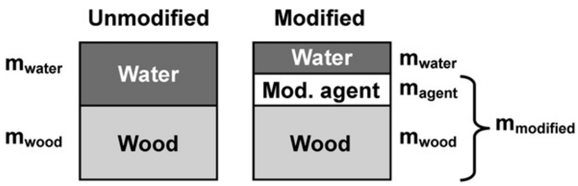

Fig. 1. Illustration of different masses of moist unmodified and modified wood. A lesser amount of water is shown in the modified wood.

In this study, the relation between modification intensity and decay resistance of modified wood is investigated based on a compilation of experimental data from literature. Six different modification techniques are reviewed in an attempt to find parameters that can be correlated with decay resistance. These modifications include two bulking modifications (acetylation and furfurylation), three crosslinking modifications (DMDHEU, glutaraldehyde, and glyoxal treatments), and thermal modification. The goal is to establish a common criterion for decay resistance of modified wood based on parameters which are valid for all modification techniques. This allows screening of the efficacy of new wood modifications along with optimisation of modification intensity before moving on to more elaborate laboratory and field test of durability. Furthermore, if such a criterion can be established, it may also hint at conditions required for fungal attack to occur in wooden products in general.

2. Characterising the performance of modified wood

Moisture is a critical parameter for nearly all properties of wood, and one which wood modification targets in order to provide better dimensional stability and decay resistance. Therefore, modified wood has traditionally been characterised by reduction in moisture content or swelling, i.e. moisture induced movement. The measures of each of these are the moisture exclusion efficiency (MEE) and the anti-swelling efficiency (ASE). MEE is based on the equilibrium moisture content (EMC) of modified wood (EMC_m) compared with that of unmodified wood (EMC_u) as seen in (1)

$$MEE = \frac{EMC_u - EMC_m}{EMC_u} \tag{1}$$

EMC for modified and unmodified wood is commonly expressed as the mass ratio of moisture to dry substance. For modified wood, this approach can, however, be misleading when determining whether a particular modification technique reduces the amount of moisture due to the added mass of modification agent, Fig. 1. Even for similar amounts of water in unmodified and modified wood, EMC calculated in the traditional way would yield a lower value for the latter. A more appropriate way of calculating EMC in modified wood is the reduced EMC, EMC_R (Hill, 2008) which is the mass ratio of moisture to dry wood substance, i.e. where the mass of modification agent is deducted from the dry mass.

If the EMC_R is not used to calculate MEE, the comparison of MEE as a measure of efficacies between different modification techniques is problematic, since heavy modification agents in themselves are favoured. This can be illustrated by filling the void structure of wood with substances that do not enter or affect the cell walls. For instance, Stamm and Hansen (1935) impregnated wood with various oils and waxes, and found WPGs of 142% for paraffin wax, 179% for stearin, and 204% for linseed oil. None of these substances did, however, influence amount of moisture in the cell wall or swelling; they only delayed the sorption processes (Stamm and Hansen, 1935). For the case of 20% moisture content (MC) of the cell walls of both unmodified and these modified (impregnated) woods, EMC of the latter is 6–8% if calculated the traditional way, yielding an MEE of 59–67%. EMC_R, on the other hand, is 20% yielding 0% MEE, since the amount of moisture in the cell wall is unaffected by modification. In the following, MEE is always reported on the basis of EMC_R. The conversion from EMC to EMC_R can be done as in (2) if WPG is given

$$\begin{aligned} EMC_R &= \frac{m_{water}}{m_{wood}} = \frac{m_{water}}{m_{modified} - m_{agent}} \\ &= \frac{m_{water}}{m_{modified}\left(1 - \frac{WPG}{1+WPG}\right)} = EMC(1+WPG) \end{aligned} \tag{2}$$

where the masses are defined in Fig. 1. In this study only EMC_R measured above 50% relative humidity (RH) is included in order to minimize the effect of measurement uncertainty on MEE at low levels of relative humidity.

The swelling of wood is well correlated with the amount of moisture (Hartley and Avramidis, 1996; Derome et al., 2011). Therefore, comparison of the swelling of modified and unmodified wood via ASE has been used to characterise the efficacy of modification. ASE is typically calculated as

$$ASE = \frac{S_u - S_m}{S_u} \tag{3}$$

where S_m and S_u is the swelling of modified and unmodified wood, respectively. Most modifications tend to increase the dimensions of the wood. This effect can be described by the bulking coefficient (BC) which is the volume increase from modification relative to the original dry wood volume. The use of ASE as a direct measure of efficacy to compare different modification techniques is problematic, since modifications that pre-swell wood the most, i.e. with high BC are favoured. This is illustrated in Fig. 2, based on the assumption that adsorption of moisture increases the volume of wood substance to a similar degree. If so, ASE of the bulking modification would be greater than ASE for the crosslinking modification, despite having similar volume increases. Instead, different modification techniques can better be compared using ASE^* which measures volume increase due to swelling of modified wood in proportion to the volume increase of untreated wood, i.e. where the volume increase from modification is deducted from the dry volume, see (4).

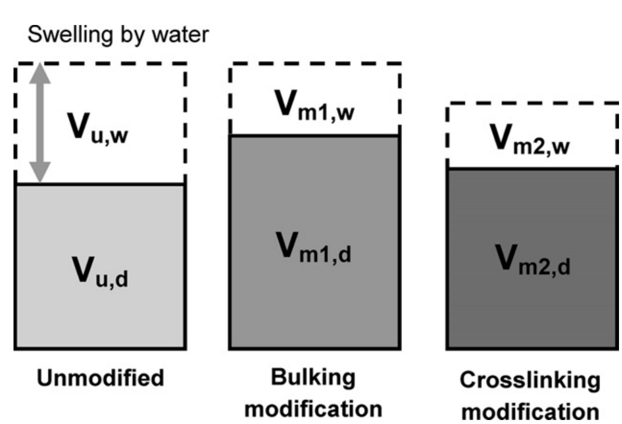

Fig. 2. Illustration of dry (index d) and water-swollen (index w) volumes of unmodified and modified wood.