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INFLUENCE OF SURFACE DAMAGE ON MOISTURE BEHAVIOR AND DECAY SUSCEPTIBILITY OF FILM FACED PLYWOOD

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Abstract

The protection phenolic film of water resistant birch plywood was mechanically damaged (scratched and scraped) in order to assess its influence on the rate of moisture content uptake and the natural durability of this wood-based material to white-rot fungus Trametes versicolor. Damaged and undamaged samples were exposed to liquid water and water vapor and their change of moisture content was observed. Trametes versicolor degraded these three groups of samples for 14 weeks and its activity was evaluated as the mass loss after exposure and change in bending properties – modulus of rupture (MOR) and modulus of elasticity (MOE).

The rate of the moisture content change was influenced by the mechanical damage to the surface phenolic film only when plywood was exposed to liquid water. The critical limit - 20% of moisture content - for fungi activity was reached after 10 or 40 days when plywood was exposed to liquid water or vapor, respectively. The mass loss of plywood caused by Trametes versicolor was low (around 2%) and the observed decrease in MOE of decayed samples compared to the reference ones was caused rather by wetting during the fungi exposure and the subsequent redrying of samples than by fungus degradation.

Key words: *moisture content; wood-rotting fungi; absorptivity; hygroscopicity; bending properties.*

INTRODUCTION

Among the engineered wood products, plywood is a wood-based panel showing the best physical and mechanical properties for application in use class 3, i.e., exterior exposure without ground contact (Van De Bulcke et al. 2011). Biological degradation, delamination, decrease in strength and stiffness of plywood are usually related to high moisture content, moisture dynamics and complex ageing processes (Brischke and Rapp 2008, Van den Bulcke et al. 2009). In particular for biobased building materials such as wood, biological agents should be considered in order to predict service life. Their occurrence and the risk of infestation depend on the exposure conditions and the geographical position (Brischke and Thelandersson 2014). Wood-rotting fungi are not a critical degradation factor in plywood if it is never exposed to high moisture levels (Reinprecht et al. 2012). It is widely known that for effective growth and wood degradation by wood-rotting fungi the moisture content must be above 25%, or better above the fibre saturation point (Zabel and Morrel 1992, Viitanen 1997). The lower limit of 20% moisture content is commonly considered as a safety margin against fungal decay (Wood Handbook 1999).

A possible way of wood protection against decay is holding its moisture content at a sufficiently low level. In exterior, the surface protection by coatings is the prevailing method. A very important property of wood coatings is the ability to protect against unacceptable absorption and desorption of moisture in wooden constructions. The use of surface coatings is based on the formation of a surface film of polymeric materials, such as varnish, lacquer, or paint (Hyvönen et al. 2005). As long as the coating film is perfect without cracks or other defects, water is not able to penetrate into the wood or at least penetration is very slow (Borgin 1961).

It needs to be realized that the use of a non-durable wood species is not suitable in the highest hazard classes. There are, however, many wood-based materials, like plywoods, produced from these species and used in the outdoor exposition. Birch is commonly used for plywood and blockboard manufacture not only in Finland and Russia. The uniform texture and the density of birch make it well suited for plywood. Besides that, birch complies with desirable characteristics for plywood veneers like straight-grain and the presence of few knots (Cameron 1996). The birch plywood, with adequate surface protection and composition is regularly used in the transport and buildings sectors and most other exterior applications (Zanuttini et al. 2003). Van den Bulcke et al. (2011) stated that the phenolic coating reduces the moisture content of the plywood samples and keeps it well below the critical 25% limit most of the time of outdoor exposure. Zanuttini et al. (2003) tested the effect of surface treatment and edge painting of poplar plywood on its durability against fungi. Nonsignificant or low improvement of protection were found in the case of the phenolic resin film. An increase in plywood decay resistance using more durable species as the top layer was proved by Reinprecht et al. (2012). A positive effect of durable outer veneers or coating application on the plywood durability was observed by Van den Bulcke et al. (2011) as well. As stated by Foliente et al. (2002), data on biological durability and a related test method are not still available for different wood-based products in comparison with solid wood from which they are produced.

OBJECTIVE

The aim of this study was to determine the effect of surface damage of film faced water resistant plywood on its moisture uptake and decay susceptibility. The rate of fungi-caused damage was evaluated according to the mass loss and bending properties of the plywood.

MATERIAL, METHOD, EQUIPMENT

Water resistant film faced plywood (DYAS.EU) was evaluated in this experiment. It is made from rotary-cut birch veneers (11 layers, 15mm in thickness) glued by phenol-formaldehyde resin and both-sided covered by a phenolic film (150g/m^2). The surface layer was mechanically damaged in two different ways to simulate usual defects during use of this material – scratched by a sharp object and areal scraped by a grinder (see Fig. 1). The damage was created uniformly along the whole length of the sample.

Samples used to determine the moisture uptake with dimensions 50×50×15mm were protected on the edges by two-component epoxy resin to ensure that moisture was only taken through the damaged surface. The samples were dried in the drying chamber (103°C) to determine the dry weight and subsequently conditioned (t=20°C, φ=65%) to the equilibrium moisture content. Ten samples for each set (scratch, scrape and undamaged – control samples) were exposed to fully saturated air (exsiccator with distilled water) to measure hygroscopicity. The absorptivity was measured in an equal number of samples, which were in contact with distilled water only by the damaged surface. The weight was recorded regularly. After 30 days of experiment, the samples were relocated to the conditioning chamber (t=20°C, φ=65%) and desorption was measured for the next 30 days.

Fig. 1.
Mechanical damage of film faced plywood – from left: control, scratch, scrape

The edges of decay susceptibility samples with dimensions 300×50×15mm were sealed with water based acrylic paint which is applied by producer for edge coating. The samples were dried in the drying chamber (103°C) as well, followed by conditioning (t=20°C, φ=65%). Beech samples (15 x 25 x 50mm) were used as the virulence control samples in accordance with EN 113 on the basis of mass losses. A series of 10 samples was prepared for each damage level (scrape, scratch and control), totaling to 30 samples.

After steam sterilization the samples were placed in vessels which contained the sterilized culture medium (agar) inoculated with the mycelium of white rot fungus *Trametes versicolor*. In each vessel two plywood samples and one virulence sample were placed on top of stainless steel grids. The samples were exposed to fungi for 14 weeks after inoculation in the culture chamber (22°C, 70% RH). After fungal attack, decayed specimens were cleaned by removing the mycelia and weighed before and after gradual drying with a final phase at 103°C to avoid cracks or deformations.

The static bending test was performed by the three-point loading method by the universal testing machine Zwick Z050 (loading capacity of 50kN); the experiment procedure and evaluation of results were derived from EN 310. The sample length and span of supports were chosen shorter than is recommended by standard due to vessel dimensions. The samples were tested in the position with the damaged surface on the tension side and they were loaded until destruction occurred to determine both the modulus of rupture (MOR) and the modulus of elasticity (MOE). The span of supports was 280mm, the radius of supports and the forcing head was 15mm. The value of MOR was calculated from the maximum loading force as is given in equation:

$$MOR = \frac{3F_{\max} l}{2bh^2} \tag{1}$$

where:
F_{max} is the maximum force (N), l is the distance between the supports (mm), b is the width (mm) and h is the thickness of the plywood (mm).
The calculation of MOE was based on the forces measured at 10% and 40% of the maximum loading force (force of destruction) and the corresponding deflections of the bent beam were measured by the extensometer. The MOE was calculated using equation:

$$MOE = \frac{l^3 (F_{40\%} - F_{10\%})}{4bh^3 (u_{40\%} - u_{10\%})} \tag{2}$$

where:
l is the distance between the supports (mm), $F_{40\%}$ and $F_{10\%}$ are the forces at the 40% and 10% level of the maximum force F_{max}, b is the width (mm) and h is the thickness of the plywood, $u_{40\%}$ and $u_{10\%}$ are deflections at forces $F_{40\%}$ and $F_{10\%}$. The results were compared with reference samples (samples not exposed to fungus activity).

RESULTS AND DISCUSSION

Hygroscopicity

The moisture content of the conditioned plywood samples increased almost regularly during 62 days (see Fig. 2). On the 30th day of exposure to fully saturated air all the three conditioned sets reached moisture content of about 18% (see Table 1). Moisture content changes can be retarded, but not prevented, by protective coatings such as varnish, lacquer, or paint (Glass and Zelinka 2010). The level (20%) necessary for fungi activity was overstepped after 40 days. There are no observable differences between control samples and samples with mechanically damaged surface. The film on the surface is only one of several protective layers against moisture movement because the glue line itself might acts as a barrier for water vapor. The phenol-formaldehyde adhesive was categorized as slow absorbing adhesive with low diffusion coefficients (Wimmer et al. 2012). The desorption process was again similar for all three groups but slower in comparison with water uptake. The greater the vapor pressure differential, the greater the tendency for water vapor to migrate from the high-pressure side to the low-pressure side. The fully saturated air (absorption) caused more intensive movement of water vapor than standard condition (65% RH) during desorption.

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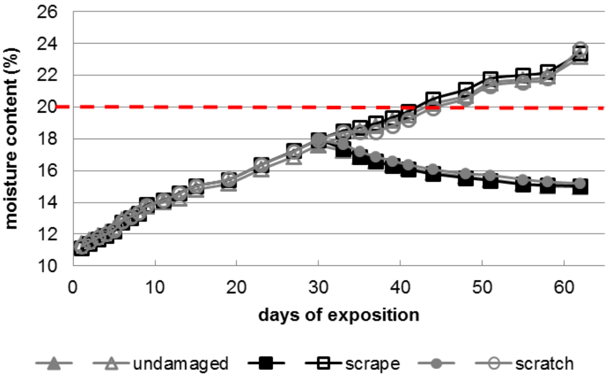

Fig. 2.
Plywood moisture content change during the exposition to fully saturated air (increasing line) and during conditioning (20°C, 65% RH; decreasing line); red line - safety margin against fungi

Absorptivity

The mechanical damage was more important in surface contact with liquid water. While undamaged water resistant film can protect plywood against wetting to the critical moisture content (20%) for more than 30 days, the damaged samples reached this value after a distinctively shorter time – 11 days for scratch and 8 days for scrape (see Fig. 3). The mechanism of water absorption is called capillary action and it is the most efficient mechanism for moisture exchange. The interaction with wood cell wall combined with the water–air surface tension creates a pressure or force which tends to pull the liquid into the empty spaces, e.g. microcracks in the glue line. Contact with liquid water can induce rapid changes in the moisture content of wood, in contrast to the slow changes that occur due to water vapor sorption (Glass and Zelinka 2010). It is important to consider that the distibution of moisture is not homogenous, therefore the surface veneer (exposed to fungi attack preferentially) reached the critical limit in a shorter period. Analogously, the following decrease in moisture content was faster in the surface damaged samples. The moisture content of all samples ranged between 16 to 17% after 30 days of exposure to standard conditions (20°C, 65% RH).

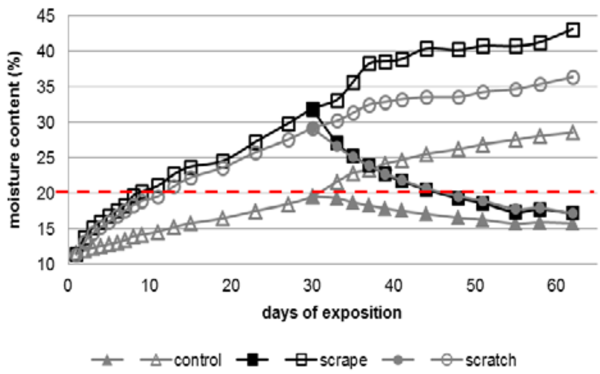

Fig. 3.
Plywood moisture content change during the exposition to distilled water (increasing line) and during conditioning (20°C, 65% RH; decreasing line); red line - safety margin against fungi

Table 1
Moisture content of plywood with different mechanical damage of surface (coefficient of variation in brackets - %)

	water			air humidity		
	control	scratch	scrape	control	scratch	scrape
30 days sorption	20.4 (5.5)	30.2 (14.8)	33.1 (9.6)	18.1 (2.0)	18.4 (3.1)	18.5 (1.3)
60 days sorption	27.2 (2.1)	37.7 (9.2)	45.0 (6.7)	23.8 (1.1)	23.8 (1.4)	24.1 (0.2)
30 days desorption	15.8 (2.0)	17.2 (3.5)	17.2 (1.0)	15.0 (1.1)	15.8 (3.7)	15.0 (1.1)

Decay susceptibility

The average mass loss of the samples of the three different levels of mechanical damage (control, scratch and scrape) as a result of the exposure to white rot fungi *Trametes versicolor* is given in Table 2. It is considerably low considering that the plywood was produced from non-durable birch wood (Farmer 1972). Moisture content is one of the limiting factors required for the fungi growth. It has been found that the moisture content of 30% or more is necessary for fungi growth (Highley 1999) and the optimum moisture content for *Trametes versicolor* ranges between 50 and 60% (Liao 1990). In the first phase of fungi degradation, the moisture content of samples must be increased. Due to the low absorption of the water resistant plywood, the fungus mainly moistened the substrate to the required level most of the experiment time. Both damaged samples showed slightly higher mass loss in comparison with control samples (see Table 2). The first veneer was susceptible to direct degradation by fungi but the spread of hyphae was slowed down due to the physical effect of the glue line. The observed mass loss of the control samples could be caused by the slow degradation of the edges, which were protected by acrylic resin. Cappitelli et al. (2005) showed high resistance of acrylic resins to microbial attack by several *Ascomycetes* fungi, on the other hand, polyacrylates are not able to increase the wood resistance against the brown-rot fungi. These fungi were able to penetrate the polyacrylate film on the inner surface of wood cell walls and to decay the wood (Tiralová and Reinprecht 2004).

The presence of phenol formaldehyde resin in the glue line can influence the activity of fungus. As stated by Schmidt et al. (1978), phenol formaldehyde resin provided a greater resistance to fungal deterioration than e.g. urea formaldehyde resin due to its higher pH and content of noncondensed phenols. Zanuttini et al. (2003) also showed a possible toxicity effect of not only free formaldehyde but free phenol as well in the case of higher durability of plywood connected by phenol-melamine-urea-formaldehyde. The protective effect of phenol formaldehyde resin against biological factors was proved in other investigations (Lee and Ashaari 2015, Loh et al. 2011, Ryu et al. 1991).

Table 2

Flexural modulus of rupture (MOR), modulus of elasticity (MOE), density and mass loss of plywood with different mechanical damage of surface after fungus degradation (coefficient of variation in brackets - %) compared to non-decayed reference samples

	density ($kg \cdot m^{-3}$)	MOR (MPa)	MOE (MPa)	mass loss (%)
control	659 (1.1)^a	58.6 (15.9)^a	7216 (8.3)^a	1.9 (53.6)
scratch	643 (1.2)^b	56.1 (8.1)^a	6806 (6.9)^a	2.5 (20.2)
scrape	642 (1.3)^b	56.6 (9.3)^a	6992 (7.7)^a	2.5 (31.5)
reference	673 (2.7)^a	53.8 (10.1)^a	7890 (8.6)^b	–

Flexural strength and modulus of elasticity

The density of plywood slightly decreased during the fungus degradation, which is shown in Table 2. The decrease was higher (statistically significant) in mechanically damaged samples (4.5%) than in control samples (2.1%), which corresponds to mass losses during fungus exposure.

The effect of fungal decay on the mechanical properties of water resistant birch plywood is shown in Table 2 as well. The mechanical damage of surface foil did not accelerate the decay of plywood. The differences were statistically significant neither for MOR nor MOE (Table 2). The effect of fungus activity itself on flexural properties was not statistically proved for MOR either. On the other hand, MOE was influenced during degradation. Despite low mass loss, the modulus of elasticity decreased more distinctively by about 8.5%, 13.7%, 11.4% for control, scratch and scrape, respectively, in comparison with reference samples. As fungi grow inside the wood, they alter the chemical structure and remove the mass, thereby altering the mechanical properties of wood (Zabel and Morrell 1992). Many authors stated that during the early stages of fungal degradation some mechanical properties often dramatically decreased, but with only modest mass losses and minimal appearance changes (Wilcox 1978, Green et al. 1991, Clausen and Kartal 2003). The usually mentioned rapid decrease in strength is connected with brown-rot fungi because the mass loss is related to carbohydrates degradation (Curling et al. 2002, Winandy and Morrell 1993). The strength effect associated with white-rot fungi is less significant at the beginning of decay - mass loss lower than 5% (Zabel and Morrell 1992). In addition, the degradation was concentrated mainly in the surface veneer or sample edges, so it was not distributed in the whole volume of samples. The decrease in

MOE in comparison with reference samples could not be caused by decay but by wetting during exposure and following redrying. The moisture content of plywood samples increased during the exposure to 65%. Wei-hong et al. (2005) showed that the decrease in mechanical properties of hem-fir plywood was only attributed to the wet condition exposure without fungi activity, when the MOE declined from 6.25 to 5.06 GPa. The presence of water promotes hydrolysis in wood at temperatures exceeding 100 °C and these temperatures can interact with the excess moisture in wetted wood to accelerate thermal degradation (Winandy et al. 1988).

CONCLUSIONS

The moisture uptake was not influenced by the mechanical damage of surface phenolic film in conditions of fully saturated air, while in contact with liquid water the mechanical damage significantly increased the absorptivity of plywood. The minimal limit of moisture content for fungi activity (20%) was reached after 40 days when plywood was exposed to water vapor, without differences between groups. The same moisture content level was reached after 30 days in the case of control (undamaged) plywood exposed to water, whereas mechanical damage of surface layer shortened this time approximately three times. The mass loss caused by *Trametes versicolor* was low (around 2%) considering the low durability of birch wood. Slow increase in moisture content and presence of toxic phenol-formaldehyde resin could influence the degradation activity of the fungus. The significant decrease in density and MOE was observed in the samples with damaged surface layer. The wetting during fungi exposure and subsequent redrying of samples could lead to MOE change rather than fungus activity itself.

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