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Classification of uncoated plywood based on moisture dynamics

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HIGHLIGHTS

- Glue, wood and top veneer significantly influenced the moisture dynamics of plywood.
- A good correlation between laboratory test and field test was found.
- Recommendations for uncoated plywood regarding end use and service life were drafted.

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ABSTRACT

Moisture has a significant influence on the mechanical and physical properties and on the biological durability of wood and wood based materials. As plywood is commonly used as a building material for outdoor applications knowledge regarding its moisture behaviour is of utmost importance. The aim of this research is to model water accumulation in plywood panels in terms of their basic characteristics and in-service moisture conditions. Therefore, moisture dynamics of 29 uncoated plywood types consisting of different wood species, adhesives and layering were evaluated using a simple laboratory water floating test and an outdoor continuous moisture measurement set-up. A significant correlation was found between laboratory and field test results. By means of regression analysis the material characteristics affecting the moisture dynamics of plywood were evaluated. The most influential parameters were wood species, glue type and thickness of the top veneer. Limit values for the water left in the plywood specimen after 72 h absorption and subsequent 72 h desorption, the residual moisture content (rm_{72}), were calculated as to develop a classification tool for plywood. Based on such a classification tool some recommendations for uncoated plywood regarding end use and service life were drafted. Enhanced performance should be obtained by means of wood preservation or by reducing its residual moisture by applying a coating or by an optimal selection of adhesive, wood species and top veneer thickness.

1. Introduction

Wood based products such as plywood are increasingly used in building construction due to their advantage of low energy consumption and CO_2-emission [20,9,35]. However, they are mainly produced from non-durable timber (e.g. birch, poplar, beech, spruce) which as such renders such panels unsuitable for outdoor application according to European standards like EN 460 [16]. Nevertheless, these plywood types prove an excellent in service performance despite the limited natural durability of the corresponding solid wood [39]. Mainly two mechanisms of the glued layered structure of plywood influence its durability. The adhesive itself might act as a toxicant to invading fungi [11,14,24,23] and the adhesive can function as a physical barrier and thus, effectively prevents water uptake [25]. However, the glue line can also cause water entrapment resulting a decrease in mechanical properties, initiating fungal growth and physical deformation of plywood [10,12].

Therefore, reliable input for service life prediction of plywood requires an integrated approach combining data obtained from durability testing and moisture related properties. The former is well described in the ENV 12038 [18]. The test procedure and its drawbacks are extensively discussed by Van Acker and De Smet [36]. Knowledge on water entrapment is, however, also essential for an optimized use of plywood. Moisture dynamics or moisture behaviour can contribute significantly to this understanding through concepts such as time of wetness (ToW). ToW can be defined as the number of days during which a specimen has a wood moisture content of minimally 20% or 25%, which can be considered as threshold for fungal decay [29,33]. In order to

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monitor the moisture content (MC) of plywood specimens in exterior applications different methods exist. Van den Bulcke and co-workers [38] report on the Continuous Moisture Measurement (CMM) method whereas Brischke et al. [7] have used an electrical resistance method to monitor the moisture content of wood based products in practical exterior applications. Other techniques, for instance magnetic resonance imaging, X-ray scanning and neutron imaging, are also applied to monitor water in several wood based materials [40,27,25]. Although very well suited for in-depth research, these methods are time consuming or expensive thus difficult to be used as a routine assessment technique. Hence, an efficient laboratory method is required to calculate and predict the risk of water entrapment in plywood.

The aim of this research was to develop an approach that assesses water entrapment (residual moisture, rm) in plywood in terms of the basic panel characteristics. Therefore 29 uncoated plywood types consisting of different wood species, adhesives and layering were monitored during liquid water uptake and subsequent air drying. Replicates were also monitored outdoors by means of CMM in order to evaluate the correlation between the laboratory test (rm) and the field test results (ToW). Based on the moisture dynamics of uncoated plywood recommendations were given in terms of plywood composition to establish lower ToW and thus obtaining longer service life related to specific end uses.

2. Materials and methods

2.1. Test materials

A total of 29 different uncoated plywood panels, all produced by European plywood companies, were tested. The selection of plywood material was based on what can be regarded as typically available on the European market. Temperate hardwood species such as beech (*Fagus sylvatica*), birch (*Betula* spp.) and poplar (*Populus* spp.), as well as softwood species e.g., maritime pine (*Pinus pinaster*), radiate pine (*Pinus radiata*) spruce (*Picea abies*) and white spruce (*Picea glauca*) were used. Some tropical hardwood species such as okoumé (*Aucoumea klaineana*) and ilomba (*Pycnanthus angolensis*) were also included. An overview of the material is given in Table 1.

2.2. Floating test

Test specimens of 50 × 50 mm^2 were prepared from the test materials listed in Table 1. Four replicates were cut from three different panels, resulting in 12 test specimens per plywood type. Three layers of a two component polyurethane finish were applied as edge sealant.

The test specimens were put on the water surface to float freely in plastic containers in a conditioning room (20 ± 2 °C, 65 ± 5% RH). At regular intervals (1 h, 4 h, 24 h, 48 h and 72 h) water uptake was determined gravimetrically. Each time, the excess moisture was removed from the plywood with a tissue.

This absorption phase was followed by desorption during which the specimens were taken out of the containers and placed on one side to recondition until constant mass was reached. The specimens were positioned at minimally 10 mm of each other to allow free air circulation. Desorption was performed under the same climatic conditions as absorption. Again, the specimens were weighed after 1 h, 4 h, 24 h, 48 h and 72 h during desorption. After the desorption test the specimens were oven dried at 103 ± 2 °C till constant mass.

The floating test method is based on an absorption/desorption method for solid wood as proposed by Rapp et al. [31] and is to some extent also related to EN927-5 [17] which is developed for testing liquid water permeability of a coating for exterior wood. The test method is currently under review as part of a CEN/TS method 'Moisture dynamics of wood and wood-based products' [30].

2.3. Continuous moisture measurements (CMM)

The CMM set-up aims at monitoring the water absorption and desorption and thus the moisture dynamics of the specimens while subjected to outdoor exposure. The test set up consists of a frame upon which two parallel series of single load cells are fixed (Fig. 1). The precision of the load cells is 1 g. All specimens were inclined 45° with top veneers facing south west direction.

Weather data were recorded by means of a weather station consisting of a pyranometer, a pluviometer, a relative humidity probe, a thermometer, an anemometer and a windvane adjacent the test set-up. All data were collected by a delta-T logging unit every 5 min.

The test set up included a selection of plywood types (Table 1) with dimensions 150 × 150 mm^2, edge sealed with three layers of a two component polyurethane finish. Three replicates of each plywood type were mounted on the CMM. More details concerning CMM set-up and panel preparation can be found in Van Acker and De Smet [36] and in Van den Bulcke et al. [38]. The panels were exposed from October 2010 till March 2011.

All data were converted to hourly data by averaging and missing data were omitted from the analysis.

2.4. Statistical analysis

To examine the moisture dynamics of uncoated plywood in laboratory conditions and during outdoor exposure statistics based on Functional Data Analysis (FDA) and Principal Component Analysis (PCA) were performed with the statistical package R. FDA is a statistical technique enabling multivariate data analysis of the overall absorption/desorption pattern of each plywood specimen.

Regression analysis (General Linear Models) was used to study the residual moisture (rm) in more detail as this was a limit value to determine the time of wetness (ToW) and therefore the risk of performance failure. The residual moisture rm_{72} or the amount of water left in the plywood specimen after 72 h desorption, was calculated as given in Eq. (1).

$$rm_{72} = mc_{d72} - mc_i \tag{1}$$

With mc_i = the initial moisture content, mc_{d72} = the moisture content after 72 h desorption.

The moisture content at time t (mc_t) of each test specimen was calculated by expressing the mass of water at time t ($m_t - m_0$) as a percentage of the oven dry mass (m_0) (Eq. (2)).

$$mc_t = \left(\frac{m_t - m_0}{m_0}\right) \times 100 \tag{2}$$

Square root transformation of residual moisture data was necessary to meet the requirements of linear regression.

Pearson correlation analysis between residual moisture, calculated using the floating test data, and the total time of wetness (tToW), calculated using the CMM data, was performed. The tToW is an overall term defined as the number of periods with at least two (d2) or three (d3) consecutive days during which a specimen reached a minimal wood moisture content of 20% (mc20) or 25% (mc25).