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Impact of internal structure on water-resistance of plywood studied using neutron radiography and X-ray tomography

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Abstract

To improve water resistance of plywood, a detailed understanding of the moisture dynamics of plywood and related solid wood is essential. Neutron radiography and X-ray CT were used to monitor water transport and the internal micro-structure respectively. Compared with solid wood, water uptake and release of plywood is, apart from wood species, also influenced by veneer checks and gaps between veneers. Type of adhesive and grain direction of veneers also play a crucial role. According to the findings of this paper and practical requirements, more water resistant plywood can be produced when taking into account abovementioned factors.

Keywords: Neutron radiography; X-ray tomography; Water resistance; Wood structure; Plywood.

1. Introduction

Wood is an important construction material with the advantage of being ecological sustainable and flexible in usage [1]. However, as a bio-material, moisture can decrease its physical, mechanical and biological durability. It is thus crucial to understand moisture dynamics in wood products to optimize their usage. The movement of water through wood is complicated by the fact that the coarse capillary system is interconnected via smaller openings. For softwood, tracheids dominate water transport and inter-tracheid pits play an important role on water movement along radial and tangential directions [2, 3]. Compared with softwood, hardwood has a more complex structure. Water conducting conduits in hardwood are composed of joined vessel elements end to end. Water transport in three dimensions, longitudinal, tangential and radial, of three different softwood species has been investigated by means of neutron radiography before [4]. Engineered wood materials, however, can have a different moisture dynamics behaviour, obviously still related to the properties of solid wood. Plywood is an important engineered wood material, which is manufactured by gluing solid wood veneers and pressing them together at high temperature. Its mechanical and physical properties are moisture dependent as well [5]. Although the water transport theory in solid wood has been well investigated [6], it has been rarely studied in plywood. A thorough understanding of water transport behaviour in plywood is valuable to optimize its production and application. The cross layered structure and presence of glue line between layers alters the water movement compared to solid wood. The main water movement directions of plywood are faces and side edges. Hence, it is interesting to investigate the water transport behaviour of plywood along these directions and compare it with related solid wood in dynamic water conditions.

To monitor the water distribution in wood products, several approaches have been used. The average moisture content (MC) of plywood exposed outdoors was continuously monitored by weighing [7]. To further continuously monitor the moisture distribution among layers of plywood, the electrical MC measurement method was introduced by Li et al. [8]. Other state-of-the-art techniques have also been used to monitor water movement in wood and wood-based products, e.g. magnetic resonance imaging, X-ray CT scanning and neutron imaging. Magnetic resonance imaging allows monitoring the free water movement in wood materials [9]. Research with X-ray CT scanning revealed the internal structure and density distribution of wood materials [10, 11]. Compared with the above two approaches, neutron imaging is more suitable to determine moisture distribution due to the high attenuation of the neutron beam by hydrogen nuclei [12, 13].

The objective of this paper is to investigate the water distribution in plywood and related solid wood during water uptake and air drying in climatized conditions. Several specimens of plywood and solid wood

were prepared and scanned with X-ray CT in order to obtain a 3D view of their internal structure. Water uptake and air drying was then periodically monitored by neutron radiography. For solid wood, liquid water uptake in longitudinal, radial and tangential direction of three different hardwood species was monitored. For five different plywood panels glued with PF and UMF, liquid water uptake / air drying from the faces and the side edges was monitored and quantified. To better investigate the difference in moisture dynamics between plywood and solid wood, all plywood panels are uncoated. The relationship between water distribution and the microstructure of the specimens was analysed by combining the data from neutron radiography and X-ray CT scanning. The classical uptake / air drying test was performed on three replicates of the five plywood panels under study to evaluate the results obtained by neutron radiography and X-ray CT scanning.

2. Materials and methods

2.1. Preparation of the specimens

Solid wood specimens were prepared from three different hardwood species: poplar (*Populus* spp.), birch (*Betula* spp.) and okoumé (*Aucoumea klaineana* Pierre). For each species, three 25×10×10 mm³ specimens were sawn in longitudinal, tangential and radial direction and 25 mm along the water uptake direction. Plywood panels were produced by European plywood companies. Two specimens from each plywood panels (Table 1), were cut to the size of 10×30×panel thickness mm³ and 10×10×panel thickness mm³ (Fig.1) respectively. For laboratory water dynamics test, three replicates of each plywood panels measuring 50×50×panel thickness mm³ were prepared. All specimens were without knots, decay or any obvious defects. The four sides of each specimen, parallel to the water uptake direction, were sealed with a two component polyurethane sealant to ensure that water uptake was only possible in a single direction.

Table 1

Structure of the plywood panels.

Code	Wood species	Glue	# of plies	Veneers(mm)	Thickness(mm)	Coating
P1	poplar	UMF	7	1.3/2.6/2.6	14.9	no
P2	poplar	PF	7	1.0/2.5/2.8	14.6	no
B1	birch	PF	11	1.4/1.4/1.4	15.0	no
B2	birch	PF	11	1.9/1.4/1.45	15.7	no
O1	okoumé	PF	7	1.3/3.0/2.0	15.2	no

PF: phenol formaldehyde glue; UMF: urea melamine formaldehyde glue.

Veneer thickness: top veneer/inner cross/ inner parallel.

Fig.1. X-ray CT cross-section of birch plywood for water uptake testing through side edge (left) and face (right).

Plywood is manufactured by cross-gluing veneers together. The veneers are cut (peeled) perpendicular to the grain with the knife parallel to the grain [14]. As such, the water ingress direction of the veneers is longitudinal and tangential when water penetrates from a side edge of plywood. If water is absorbed from the face, the radial direction in veneer is the water ingress direction (Fig.2).

Fig.2. Schematic overview of directions in solid wood and plywood. L = longitudinal direction, T = tangential direction, R = radial direction.

2.2. Neutron radiography and experimental procedures

For this experiment, the Neutron Transmission Radiography (NEUTRA) beam-line of the Paul Scherrer Institute (PSI) in Villigen, Switzerland was used. The same beam-line was utilized as described in Sedighi-Gilani et al. [4]. Fig.3 shows an overview of the experimental setup, in which 4 specimens were mounted in a custom-made aluminium sample holder. The detector consisted of a scintillator CCD camera system and a field of view of $70.5 \times 70.5 \text{ mm}^2$ was applied in this experiment. The distance between specimens and detector needs to be as short as possible to minimise the effect of geometrical unsharpness [15]. Therefore the specimens were positioned in front of the detector at a distance of approximately 10mm. The water container underneath the specimens was filled with demineralised water and positioned on a z-translation stage. The height of the water container could be adjusted by remotely controlling the height of this stage. The exposure time was 30s per radiography with an approximate resolution of $68 \mu\text{m}/\text{pixel}$.

Fig.3. Overview of the experimental setup for neutron radiography.

Before uptake water, a neutron radiograph of the specimens was acquired. Next, the water container was lifted such that the bottom of the specimens was in contact with the water surface. Water uptake was monitored for a period of 20 min taking a radiograph every 40 s. The specimens were then removed from the beam line and uptake water continued in a similar setup in an acclimatised room for several hours. During these periods neutron radiographies were taken periodically. Plywood specimens were monitored after approximately 2, 3, 7 hours of water uptake for the side edge experiment and after approximately 1.5, 4.5, 16.5, 25 hours for the face water uptake. For solid wood, specimens were scanned after approximately 1, 3, 5.5, 10 hours of water uptake. After water uptake, all specimens were removed from the water and air drying started. The plywood specimens were scanned after approximately 2, 5, 13.5 hours of air drying for the side edge experiment and 1, 2, 3 hours of air drying for the face experiment respectively.

2.3. X-ray scanning and image processing

Before water uptake, all specimens were scanned with HECTOR, the latest system developed by the Ghent University Centre for X-ray Tomography (www.ugct.ugent.be) in collaboration with X-Ray Engineering (XRE bvba, Ghent, Belgium) [16]. The voxel pitch of the reconstructed grid is approximately 30µm. To acquire further detailed data on the microstructure of a selection of specimens and explain some of the observed phenomena, the Nanowood CT scanner [17], also built at the Ghent University Centre for X-ray Tomography, was used to scan regions of interest of specimens during a second water uptake experiment, after the neutron experiments. The specimens were in contact with demineralised water in the same direction as in the neutron experiments. They were removed from the water after 0, 10, 20, 60 and 120 minutes and scanned. To avoid drying, the scan time was optimized to 8 minutes per specimen. Only the region close to water uptake face was scanned, with a resolution of approximately 20µm. In order to obtain vessel size of solid wood specimens, the Nanowood CT scanner was also used to scan them with a resolution of approximately 7µm. Reconstruction of all samples was performed using the construction software Octopus [18].

2.4. Water content quantification with neutron radiography

Neutron radiography is based on measuring the intensity of the neutron beam after transmittance through an object. Hence, water content could be calculated using the similar method described in Sedihgi-Gilani et al. [4].

In this experiment, to calibrate and evaluate the accuracy of neutron radiography for measuring water thickness, an aluminium water step wedge was always positioned in the field of view during the experiment. The step wedge is composed of aluminium and contains five different water steps, i.e. 0.5mm, 1mm, 1.5mm, 1.75mm, and 2mm (Fig.4).

Fig.4 Neutron radiography image of step wedge filled with water (left) and illustrated cross-section of step wedge (right).

The raw neutron images need to be corrected before analysing due to the artifacts induced by the experimental configuration. The Quantitative Neutron Imaging (QNI) software package was used to correct the images and quantify the water content [19]. To optimize the result, following steps were applied:

1. Image correction by using QNI to decrease artifacts e.g. dark current and flat field correction, background scattering and sample scattering correction.
2. Image spot filtering using ImageJ.
3. In order to decrease the error caused by wood swelling and shrinkage, image registration was performed using ImageJ's plugin UnwarpJ [20]. The initial image was applied as the target image.
4. Dividing registered image by initial image using ImageJ.
5. Water visualization and quantification using QNI.

To decrease the influence of noise attributed to the background of the camera and a hit on the detector by a γ -particle, the minimum water content is set to 0.02 kg/m³ in this research.

2.5. Laboratory water dynamics test with precision balance

A set of specimens was used to simulate the in-service water uptake and release as well as to compare these data with the calculation of neutron imaging. The specimens were conditioned at standard climate

conditions (65% RH and 20°C) until mass constancy was reached. Next, one face of specimens was immersed for 144 hours in a container filled with demineralised water. During this period, the specimens were weighed after 0, 1, 4, 8, 24, 48, 72, 144 hours of immersion. After immersion, the specimens were taken out of water and placed in conditioning room for 168 hours. The specimens were weighed after 0, 1, 4, 8, 24, 48, 72, 144, 168 hours.

3. Results and discussion

3.1. Evaluating the water thickness determined with neutron radiography

The water thickness of the step wedge based on neutron radiography was calculated according to neutron radiography images. Fig.5 shows a strong linear relationship ($R^2 = 0.991$) between the actual and calculated water thickness, which proves neutron radiography can accurately calculate water thickness. This result has also been proven by weighing the specimens before and after a water uptake test by Sedighi-Gilani et al. [4]. In this experiment, we did not weigh specimens because the specimens needed to be fixed in the sample holders. Such fixed position design is helpful for switching the specimens during neutron scanning and processing neutron images afterwards, as well as avoiding change of specimens in the sample holder during long-term recording of water movement. The differences at lower water thickness are more pronounced, probably induced by an imperfect step wedge design due to manufacturing difficulties, which can be enlarged as lower water thickness. A smaller quantity of water could also increase the error caused by a fluctuating beam line, noise correction, etc.

Fig.5. Relationship between actual and calculated water thickness of a step wedge.

The water content in the specimens was calculated using the registered radiography image. The registration, however, might induce small errors in the calculated total water content in specimens because the grey scale value of the pixels is not corrected accordingly. The approximate swelling of specimens was calculated according to their width variation in neutron images (Eq.1). The swelling in both solid wood and plywood specimens is less than 5.5% (Table 2). The influence of registration on water content calculation is thus minimal allowing interpretation of water distribution during uptake and release.

$$N = (W_m - W_i) / W_i \quad (1)$$

with N: swelling of the specimen after water uptake (%); W_m : the maximum width of the specimen after water uptake (mm); W_i : the initial width of the specimen before water uptake (mm).

Table 2
Swelling of specimens.

Specimens	Poplar	Birch	Okoumé	P1	P2	B1	B2	O1
Swelling (%)	2.9	3.5	1.5	1.9	3.8	5	5.5	2.2

3.2 Comparing water transport in solid wood and related plywood

In order to study water transport behaviour in plywood, investigating water transport behaviour in solid wood is essential. The water uptake in three wood species under study is discussed here first. Fig.6 shows that the water front moves approximately 2.5 mm into the solid poplar wood specimen after 5.5 hours of water uptake. This result is consistent with the results obtained by using X-ray CT scanning [8]. Water

uptake in birch is much faster than in poplar and okoumé, which could be caused by its higher density. Density and moisture uptake are closely interrelated [8, 21]. The high density, low porosity latewood becomes moisture saturated earlier than earlywood in water absorption test [22]. Hardwood species with high density have a high probability to have small cell lumens possibly acting as the preferential pathways for water transport in the longitudinal direction.

Fig.6. Water distribution in three solid wood species along three different directions after several hours of water uptake.

According to the theory of capillary action, the basic equation is given below (2), there is a negative relationship between water uptake height and vessel size.

$$H = \frac{2\gamma \cos\theta}{\rho g r} \quad (2)$$

with H: the height of liquid; γ : the liquid-air surface tension (N/m); θ : the contact angle; ρ : the density of liquid (kg/m³); g: the local acceleration due to gravity (m/s²); and r is radius of tube (m).

In order to test a possible contribution of capillary action, high resolution X-ray CT scanning was used to acquire detailed cross section images of solid wood specimens (Fig.7). Twenty vessels from each wood species were randomly chosen to calculate average vessel size listed in Table 3. Because birch has the smallest vessel, water uptake height in birch is higher than poplar and okoumé in the longitudinal direction. As the above analysis shows, water uptake height in hardwood negatively relates with the vessel size. Due to the complex structure of wood, many factors can also influence water uptake rate. Capillary action describes the flow of water through the vessel structure in response to the pressure gradient. Water, however, can also migrate across cell walls by diffusion through pits and ray cells [14]. The number of vessels of the three wood species was also determined on the X-ray CT scanning (Table 3). Poplar has more vessels and larger vessel size than birch, which means more lumen space for free water presence. Hence, for poplar, water content near the water uptake face is higher. For all three wood species, however, little water can move in radial and tangential direction (Fig.6).

Fig.7. High resolution X-ray CT cross section of three different wood species.

Table 3
Vessel features of the three wood species analysed (average values).

Wood species	Birch	Poplar	Okoumé
Vessel radius (µm)	56.7	66.8	121.4
Number of vessels	1640	1720	360

Note: number of vessels means the amount of vessels per cm².

The knowledge of water movement in solid samples can help in explaining differences between plywood specimens under investigation. First, it should be noticed that, as shown in Fig.8, an artefact is seen in the location of the glue lines, caused by an imperfect registration. When performing registration of two images, small positional inaccuracies are pronounced especially at glue layers. The amount of hydrogen nuclei between adhesive and wood substance is different, as such the neutron attenuation coefficient is also different. Hence, a small shift of the glue line could induce an error in comparing the target image to the registered image. This error is then, incorrectly, perceived as water (Fig.8).

Wood species, naturally, plays an important role in water resistance of plywood. Compared with poplar and birch plywood, water uptake in okoumé plywood is minimal (Fig.8). It is obvious that water resistance could be improved by using wood species with good water resistance to produce plywood.

Due to the layered structure, water can easily move along the even layers in this set up and is rarely absorbed by the odd layers of plywood during water uptake alongside edges (Fig.8). Water can penetrate the entire longitudinal layer within approximately two and half hours (Fig.8 P1) while the water front only moves 2.5 millimetres into the solid wood within 5.5 hours (Fig.6 poplar). Several plausible reasons for this difference can be put forward. It is possible that the production process of plywood, i.e. pressing at high temperature, increases the permeability of plywood, partially explaining the increased water uptake. Thermal treatment (approximate 6 minutes at 130 °C), however, can increase crystallinity and hydrophobicity of wood thus decreasing the permeability [23, 24], which is the opposite of higher water uptake.

Fig.8. Water distribution of plywood during water uptake (a) and air drying (d) from the side edge.

The microstructure in plywood can differ from the solid wood microstructure due to the plywood manufacturing process, possibly inducing checks and cracks. Water, therefore, can easily penetrate the longitudinal layers of plywood along these checks. To prove this hypothesis, the microstructure of specimens were investigated using the Nanowood X-ray CT scanner. Compared with poplar solid wood, several distinct checks were found in poplar plywood, which could be induced during veneer peeling or plywood pressing (Fig.9). Since water is the only factor changing the X-ray absorption, the difference before and after water uptake can be seen as whitening of the images. In order to investigate the detailed water distribution, cross sections of entire specimens are shown as well as a magnification of the central region (Fig.9). Most of the water is found in checks or distributed near checks, as shown in Fig.9 for poplar plywood. In solid wood, however, only a small amount of water was found in and nearby vessels. Veneer checks are thus the main reason for an increased water uptake in plywood. Reducing the amount of checks in veneers would be a crucial step to increase water resistance of plywood.

Another phenomenon can be identified when looking O1 in Fig.8, where water seems to accumulate near the glue line of okoumé plywood. This could be the result of imperfect gluing between veneers. It is indeed hard to combine two separate veneers without any gaps between them. Small gaps near the glue line could induce water uptake. It is well known that the vessel size of okoumé is larger, which makes it difficult for the adhesive to fill them entirely. Gaps, therefore, are present between two veneers as shown in Fig.9 for okoumé plywood. By comparing the X-ray images obtained before and after water uptake, it was found that more water appeared in gaps and nearby vessels. This seems to stress the importance of gluing in order to minimize the gaps between veneers. Veneer checks are also an additional reason for water transport in okoumé plywood (Fig.9).

Fig.9. Microstructure of poplar solid wood, poplar plywood and okoumé plywood obtained by X-ray CT scanning before (top) and after (bottom) water uptake.

3.3 Plywood specific behaviour in dynamic moisture conditions

To investigate the plywood specific behaviour in dynamic moisture conditions, the water uptake from face and side edge of plywood was studied shown in Fig.10 and Fig.11 respectively. For water uptake from the face, the average water content of the first three layers from face onwards, was calculated based on the neutron radiography experiment. Results are shown in Fig.10. In order to avoid the influence of the glue line, the middle region of each layer was used to calculate the water content.

Fig.10. Water distribution among layers of plywood during water uptake and air drying from the face. $\blacklozenge$ = 1st layer uptake, $\diamond$ = 1st layer air drying, $\blacksquare$ = 2nd layer uptake, $\square$ = 2nd layer air drying, $\blacktriangle$ = 3rd layer uptake, $\triangle$ = 3rd layer air drying.

Fig.11. Water distribution after uptake from the side edge.

3.3.1 Influence of the top veneer

The grain direction of the top layer of B1 and B2, only differing in top veneer thickness, was investigated in detail and no clear difference was found. Fig.10B1 and 10B2 illustrate that water content in the layers just beneath the top layer is lower when the thickness of the top layer is higher. The thick top layer acts as a barrier so it takes more time for water to penetrate it and reach the glue line. As is shown in Fig.10, the water desorption rate of the top layer is fast so water can only reach the inner layers of plywood when long-term continuously water uptake occurs. The thick top layer, however, can induce glue rupture in cyclic moisture sorption-desorption, which could increase water uptake. As such, the thickness of the top layer needs to be carefully fit the purpose.

3.3.2 Influence of the adhesive

Compared with other wood-based products, plywood has clear and integral glue lines. The performance of these glue lines plays an important role in the performance of plywood. In this experiment, specimens were selected from panels glued with the two most widely used adhesives, i.e. PF and UMF. For the side edge water uptake test, most of the water is trapped in the layers with longitudinal direction (Fig.11P1). Water penetrates glue lines and moves to the nearby layers with lower water content (Fig.11P2). Although the PF glue line is a strong moisture barrier, it is more permeable for water than UMF. Consistent results have been acquired by continuous weighing plywood in outdoor conditions [7]. It is thus better, in practical outdoor applications, to use UMF as adhesive of face layers. Water uptake can then be hindered more efficiently at the first glue line, which would keep inner layers at a low moisture level.

Water desorption in the second and third layer is much slower than the top layer because of the presence of the glue line, acting as a barrier. Below fibre saturation point, the mechanical strength of wood decreases with increase in MC [5]. Water entrapment in these layers could thus decrease the mechanical properties of plywood. The risk of delamination of plywood could also increase in this condition. Layers just beneath the face layer, with moisture content at a high level for a considerable long time, can be subject to fungal decay.

3.3.3 Influence of the grain direction of veneers

Water has have to move along the radial direction when water uptake is from the face of plywood. As shown in Fig.10, water can cross the first layer of plywood, then reach the second layer and even the third layer. However, according to above results on solid wood, water cannot easily move along the radial direction for all three hardwood species. Veneer checks induced during plywood production could increase the permeability. Furthermore, an imperfect radial direction also could induce an increased water uptake, which is the case for the first layer of P1 and the second layer of B1 (Fig. 12). Water is thus transported along vessels and reaches the next layer. Therefore, a carefully selected veneer with parallel grain direction to face could increase the water resistance of plywood.

Fig.12. X-ray CT cross-sections of plywood and detailed microstructure of veneers.

In general, water can easily move in longitudinal direction, however, the speed of water movement is different (Fig.11). As shown in Fig.13, grain direction of these layers with less water is not parallel to the glue line. In these layers, therefore, water needs to move along the mixed longitudinal and radial direction, which could decrease the speed of water movement. According to this theory, the water uptake from side edges could be decreased by using veneers with non-parallel grain direction to the face.

It is generally recommended to seal the edges of large plywood panels when applying in challenging moisture conditions. The fact, however, is that plywood panels are not always sealed properly in practice. It is thus necessary to produce plywood with good water resistance performance on side edges by using veneers with non-parallel grain direction. Such orientation, however, also influences the mechanical strength of plywood. Generally speaking, the mechanical strength of plywood is mainly dominated by the outer layers [25]. Hence, it would be possible to produce plywood panels with qualified strength properties if the grain direction of the outer layers is parallel. The panels with qualified strength properties as well as better water resistance could be produced by applying parallel and non-parallel grain direction veneers as outer and inner layers of plywood respectively. In practice the veneers could be scanned in-line during peeling or transportation using an X-ray radiography scanner to classify the veneers according to grain direction.

Fig.13. X-ray CT cross-sections of plywood and detailed microstructure of veneers.

3.4 Laboratory water dynamics test

The results of laboratory water uptake and release test are presented as water content in function of time to keep this comparable with the results of neutron radiography (Fig.14). For the calculation, the specimens' volume is assumed to be constant. As shown in Fig.14, the speed of water uptake in P1 is much slower than the others, which indicates that the glue line plays the most crucial role on increasing water resistance of plywood. With the same PF glue line, O1 absorbs less water so the wood species also plays an important impact on water resistance of plywood (Fig.14). Compared with B2, both water uptake and release in B1 is slightly faster (Fig.14). This result concurs with the result from neutron radiography. For B1, the thin top layer and non-parallel grain direction of the second layer causes higher water uptake. Hence, the top layer thickness has an influence on the water resistance of plywood but not as large as glue line and wood species. In current plywood manufacturing, plywood panels may be surfaced with coating metals, plastics, or other materials, or their veneers may be impregnated to achieve resistance against water and microorganisms [26]. Compared with these methods, it is more environmentally friendly and economic to select a top veneer with parallel grain direction, suitable thickness and possibly of a wood species already performing well in dynamic moisture conditions.

Fig.14. Water content of plywood during water uptake and release of laboratory test. $\times$ = P1, $+$ = P2, $\bullet$ = B1, $\circ$ = B2, $\blacksquare$ = O1.

4. Conclusion

Combining neutron radiography and X-ray tomography is an efficient way to investigate water resistance of plywood. Compared with solid wood, the checks in veneers and gaps between veneers could increase water uptake in plywood. Plywood specific factors such as adhesive and grain direction of veneers obviously impact the water resistance. UMF has a better water resistance profile than PF. Veneers with non-parallel grain direction to face can decrease the face water resistance but can increase side edge water resistance of plywood. In-line scanning by means of X-ray radiography could be a helpful means for classification of veneers according to grain direction. To improve the water resistance of plywood, it is helpful to produce plywood by using wood species with good water resistance. The grain direction of the top veneer should be

controlled to be as parallel as possible. Using an adhesive with effective water resistance to glue the top veneer to the plywood is important. The findings of this paper have to be combined with practicalities such as the price of the adhesive and wood material, as well as the application requirements.

In this research, plywood made from three different wood species and two different adhesives was investigated. In future research, more wood species and adhesives will be investigated. The relationship between veneer grain direction and the mechanical properties of plywood needs to be investigated especially considering inner veneers. This approach will be used to investigate water distribution in other laminated wood-based panels, e.g. MDF (medium density fibreboard) and OSB (oriented strand board). Based on the results of this paper, the first steps towards a moisture kinetics model of plywood will be taken.

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