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Determining Moisture Content of Laminated Veneer Lumber (LVL)

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Abstract

Wooden load-bearing structures are becoming more common as an eco-friendly alternative to steel and concrete in large buildings. In these buildings, laminated veneer lumber (LVL) is increasingly used in structural building elements, particularly in the flanges of wooden I-beams. However, as for all products made from wood, proper moisture control is important to ensure the long-term integrity of the elements. The purpose of this study is to investigate the moisture properties of LVL and the correlation between moisture sensor readings and the actual moisture content determined from accurate weighing of the samples. Laboratory measurements were made of two different wooden materials using 20 identical sensors. The test was conducted on samples of LVL flanges delivered by the Norwegian wood production company Hunton, and on samples of pine lumber. The moisture sensors were delivered by Omnisense. For the LVL samples, the test results show that the resistance values given by the resistance method were too high compared to the more accurate gravimetric method. Conversely, the measured values were too low for the pine samples. LVL also had a faster moisture sorption than pine under the same moisture conditions. The glue between the veneer layers affects the electric conductivity of the wood in LVL and interrupts the readings. The glue might also affect the moisture sorption.

Keywords: laminated veneer lumber; moisture content; moisture sensor; pine; hysteresis.

Introduction

The annual average global temperature has increased by 0.8°C since the late 1880s. According to a 2018 report from the Intergovernmental Panel on Climate Change, the temperature will continue to increase (IPCC, 2018). In Norway and the Nordic countries, climate change is expected to bring a milder and more humid climate (Hanssen-Bauer et al., 2015). A more humid and milder climate can increase the risk of rot and mould in buildings, which is negative for sustainability, health and finances. It is therefore important to build houses and buildings that can withstand a more humid climate in the future (KLD, 2013).

Buildings with a load-bearing structure made of wood are emerging as an increasingly popular technology, being an eco-friendly alternative to steel and concrete. The properties of wood are strongly linked to its moisture content, meaning that knowledge of the wood's moisture properties is required in order to use wood materials effectively. New construction techniques enable the use of wooden

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load-bearing structures in compact roofs, reducing building height and material use. However, this solution is vulnerable to moisture and requires firm moisture control to be sustainable.

There are several methods to investigate the moisture content of a wood sample. In this paper, the moisture content was measured by two different methods: the resistance method and the gravimetric method. The resistance method uses an electric current between two electrodes placed inside the material sample, whereby the measured resistance to this current is used to calculate the moisture content of the sample. The gravimetric method is based on weighing the sample before and after oven drying, the moisture content being calculated from the weight difference. The gravimetric method is known as the most precise, because the quantities used for defining moisture content are measured directly (James, 1963). However, the method has the disadvantage of being time consuming and requires partial destruction of the specimen. The resistance method, on the other hand, is simpler and faster, but less accurate (James, 1963).

The resistance method has been used for a long time, but the additional chemicals (e.g. glue) used in new wood types may influence conductivity and hence the moisture sensor readings. Studies have found that the measurements of plywood gave a different result to the gravimetric method and the resistance method (Glass & Carll, 2009; Geving & Holme 2009). Some types of glue used in plywood are electrical conductors and can therefore affect the readings of electric moisture meters (Bell & Krueger, 1949).

This leads to speculation as to whether the sensors using the resistance method might also give wrong results when using other types of structural composite lumber (SCL). This article examines the differences between measuring moisture content by the gravimetric method and the resistance method, respectively, and possible causes of these differences. It also investigates the difference between the moisture content of mixed spruce/pine LVL and pine lumber (*pinus sylvestris*) according to the resistance method, and whether the glue between the veneer layers in LVL can affect the conductivity of the material.

There are two assumptions made in the gravimetric method: that the water is completely removed by oven drying and that only water is removed, and that no other parts of the material are affected during the measurement period. If the weighing is performed precisely, the method is only limited by the two basic assumptions mentioned (James, 1963).

This paper examines the following research questions:

1. What are the differences between the measured moisture absorption in LVL and pine?
2. To what extent do the resistance method and the gravimetric method give different results for the two materials?
3. What causes electric resistance measurements of LVL to give different moisture content readings to wood?

The tests were limited to investigating moisture absorption properties, as desorption studies were deemed infeasible, given the practical constraints of the study. Scots pine (*pinus sylvestris*) lumber was used as a reference source, which may cause results to deviate slightly from studies conducted of southern yellow pine (SYP) or spruce lumber. Only one type of electric resistance sensor was used in the research. The main motivation for the research was to establish correlation curves in order to evaluate the moisture performance of the compact wooden roofs with smart vapour barrier pilot projects *Sveabakken* (Bunkholt et al., 2020) and *ZEB Laboratory* (Bunkholt et al., 2021). The roofs of both pilot projects were constructed with LVL beams.

Theoretical framework

The wood fibre-based product, laminated veneer lumber (LVL), is a veneer-based material that consists of thin layers of veneer from pine or spruce, usually 3 mm thick, glued tightly together. The detrimental effects of knots and imperfections decrease by distributing them throughout LVL members. To ensure that the finished product will have the required engineered properties, the veneers are often sorted using ultrasonic testing (Ross, 2010). The veneers are oriented in one direction, which improves the mechanical properties of the product. LVL is produced using a phenol formaldehyde adhesive that glues each layer together under high pressure. Today, it is commonly used in composite I-joints, in the flanges (Ross, 2010).

Most of the important properties of wood will depend substantially on the moisture content. This can vary widely, depending on the history of the wood and its environment (James, 1963). Among the processes that cause deterioration of building materials, moisture is an important factor and plays a dominant role in accelerating the degradation process. The damage can have many forms, such as swelling of materials, decay of wood and cracking, which can reduce the wood strength capacity (Geving & Thue, 2002).

Bell and Krueger (1949) tested the effect of ten different glues on moisture meter readings for plywood. They found that for phenolic-bonded plywood, the conductance meter readings were, without exception, higher compared to the gravimetric moisture content when testing with needle electrodes penetrating the glue lines. They connected the effect of the increase in conductivity from the electrolytes within the glues in the plywood (Bell & Krueger, 1949). Another report (James, 1965) concludes that salts from wood preservatives may influence resistance measurements.

A similar experiment was performed by Boardman, Glass and Carll (2012), who tested untreated dimensioned lumber, untreated plywood and ACQ-treated plywood in an environment maintained at relative humidity (RH) values between 35% and 85%. They found that the gravimetric method and the resistance method did not give the same values. In 2009, they performed a similar test and got the same outcome; the SYP (south yellow pine) plywood needs a correction curve. Their data indicated that the conductance of plywood was reduced considerably if it had been previously exposed to considerable wetting, such as soaking of the samples. Their theory is that the electrolytes in the glue layers provide high conductance pathways (Glass & Carll, 2009).

The conductivity of the wood varies in a definite and predictable way with the changing moisture content. However, the correlations are not perfect. Using electrical methods to determine moisture content is therefore always subject to some uncertainty. The results can be imprecise because the electrical current patterns between electrodes can change, depending on many chemical and physical factors, such as wood grain direction, defects in the samples, amount of glue between veneer layers and temperature. The results of conductivity measurements must usually be corrected according to temperature and wood species (Casieri et al., 2004).

Methods

General

The paper is based on a laboratory experiment and a literature search concerning moisture in wood. Laboratory measurements were made of 20 pieces of wood. The LVL flanges were taken from a project at Sveabakken outside Trondheim in Norway (Kvande & Gullbrekken, 2018), where I-profiles delivered by Hunton were used. The material is described in closer detail in Section 3.4.

The test was conducted mainly on the LVL flanges, but also on six pinewood samples, to compare the results. The laboratory measurements took place in the lab of SINTEF and NTNU in Trondheim. By placing the test samples in different climates, between 20% to 98% relative humidity (RH), data from the sensors and from weighing each sample could be used to determine the connection between the measuring methods. To create the ideal climate, in one test the samples were placed in a climate chamber (described in Section 3.3), where the RH was changed between 23%, 75% and 98%, with a constant temperature of 23°C. Testing at the 50% RH level was conducted in a moisture laboratory at SINTEF, where the room holds RH at 50% and also a temperature of 23°C. The last part of the experiment was conducted by laying the wood samples in liquid water to find the absolute moisture content. To gain the hysteresis effect, the same test samples were moved from one climate to another, to examine the moisture values at different humidity with different moisture history.

Experimental set-up

The flanges were cut from the web with 1 mm left as clearance. The flanges were cut up into fourteen equal sizes, with dimensions of 70*38*59 mm^3. Six pinewood samples were cut to equal size for comparison. After the samples were cut up, holes with a diameter of 10 mm were drilled into the samples at a distance of 32 mm from the centre, into which the sensors could be inserted. The samples were labelled according to their origin. L1 (*Limtre/gluelam*) for the top flanges, L2 for the bottom flanges and H (*Heltre/wood*) for the pine samples.

Each sample was then weighed on a METTLER PM400 scale, with an accuracy of 0.001g (METTLER, 1999). The samples were weighed again after the sensors were mounted in them. The testing started at climate 23% RH. Over a time span of two weeks, the test samples were weighed regularly, and the sensors logged the data to a gateway. At a given relative humidity, the sample was considered stable when the weight difference was less than 0.1% over a 72-hour period, and the sensors showed constant moisture content (MC) values. It was assumed that the test samples had reached an equilibrium, and they were then moved to the next climate 50% RH, 75% RH and 98% RH in that order. Then the wood samples were stored in liquid water to find the absolute moisture content, followed by storage at 98% RH, 75% RH, 50% RH and finally back to 23% RH to gain the hysteresis effect. The system's operating temperature of 23°C was maintained within a tolerance of ± 1°C during the whole testing.

Fig. 1

Omnisense sensor placed in an LVL sample, with the electrodes perpendicular to the grain direction. Also parallel to the grain direction was tested. The nails are not insulated

A resistance moisture meter uses an electric approach to measure the moisture content of the samples. In this experiment, a resistance meter manufactured by Omnisense (Hygrotrack S-160-0) was used to measure the moisture present in the samples. The method is based on the theory that between the oven-dry condition to the fibre saturation point, there is a nearly linear relationship between the moisture content and the logarithm of the electrical resistance (Kollmann & Cote, 1968). The meter measures display readings as percentage moisture content. The set-up with a sensor mounted in an LVL sample is shown in **Fig. 1**.

The moisture sensors correct the moisture reading, depending on the registered temperature. Their calibration is based on US Douglas Fir, an American pine species with a density of 530 kg/m^3.

To establish the exact moisture content of the wood samples, the gravimetric method is used as a reference method. To calculate the moisture content u, **Eq. 1** is used.

$$u = \frac{m_v - m_0}{m_0} \times 100\% \quad (1)$$

where m_0 is the dry weight of the sample, m_v is the whole mass when the sample is humid, and u is the moisture content as a percentage of the dry weight (NS 3524:2014). The samples were weighed regularly throughout the experiment, and m_0 was found at the end by drying the samples.

The drying process was performed according to the NS-EN 13183-1:2002 *Moisture content of a piece of sawn timber - Part 1: Determination by oven dry method* standard. The sensors were removed from the samples and placed in a heating cabinet with a temperature of (103±2)°C for four weeks. When the mass between two weighings was less than 0.1% for an interval of two hours, the samples were considered fully dried.

After oven-drying of the samples, they were cut into half, where the screw electrodes were inserted. This was to see exactly where the screws had penetrated, and whether there were any open holes or disturbance inside the samples that could affect the measurements. All the samples were weighed on a METTLER PM400 scale, which was used during all the weighings of the samples.

Climate

The climate test chamber used for this study was of the ClimeEvent brand (Weisstechnik 2017) for the climate 23% RH, 75% RH and 98% RH. The chamber simulates an environment of between RH 20%-95%, with a constant temperature of 23°C ± 1°C. During the study, it was noted that the climate test chamber could only maintain the chosen temperature and humidity for 2-3 days. As a result, the settings were set to run a program every second day, at 40°C for 30 minutes without any humidity and then back to the chosen humidity and 23°C. To verify the exact temperature and humidity, a handheld monitor from HygroPalm was placed in the chamber and the values were read for each weighing of the samples.

The measurements were conducted in a small laboratory with constant relative humidity of 50% ± 1% and a temperature of 23°C ±1°C. This climate was not changed during the entire study.

Materials

Laminated Veneer Lumber (LVL)

The timber flanges consist of laminated veneer bonded with phenol-formaldehyde adhesive, which is laid with the grains in parallel. The LVL used in this paper is taken from flanges of a Hunton I-profile beam (SJ60/250), with a width of 60 mm and a flange height of 39 mm (TG 20381:2013). Its layers consist of a mix between pine and spruce. The flange and the web are glued together with construction glue into a groove in the centre of the wide face of the flange, around 15 mm into the flanges. Although veneers are often sorted using ultrasonic testing to ensure that the product has the required engineering properties, it was noted that some of the samples contained knots. The product is intended to be used for load-bearing building structures, for instance roofs, floors, walls, facades and trusses. The flanges have a density of 500 kg/m^3.

Pine

In the experiment, Scots pine (*pinus sylvestris*) was used as a reference material. It has a density of 510 kg/m^3. The samples were all taken from the same piece of construction lumber.

Boundary and initial conditions

The experiments only used one type of LVL and pine, with the LVL samples all cut from the same I-beam from one supplier. The results may also differ based on the growth conditions for the pine (climate, solar conditions, age, etc.). The hysteresis effect was tested for 23% RH and 50% RH, but due to time limitations desorption was not tested for 75% RH and 98% RH.

Results

General

Using the gravimetric method, the data of the sorption curve from the laboratory practice was plotted into a graph from earlier research conducted on spruce lumber (Time 1998), shown in Fig. 2. The results obtained using the gravimetric method fit with earlier research results. Fig. 3 shows the difference between gravimetric method and resistance method. Fig. 4 shows the sorption curve obtained from the research in this article, plotted against results from earlier research. Fig. 5 shows the sorption curve for LVL, with comparison of gravimetric and resistance methods. At 65% RH the difference between resistance method and gravimetric method increases. No significant difference was seen between measurement by the resistance method perpendicular and parallel to the grain direction.

Fig. 2

Data from this experiment plotted into a figure from Time (1998), collecting earlier work on absorption and desorption of moisture in pinewood. The red dotted line is the best fit curve of the data from the current set of measurements

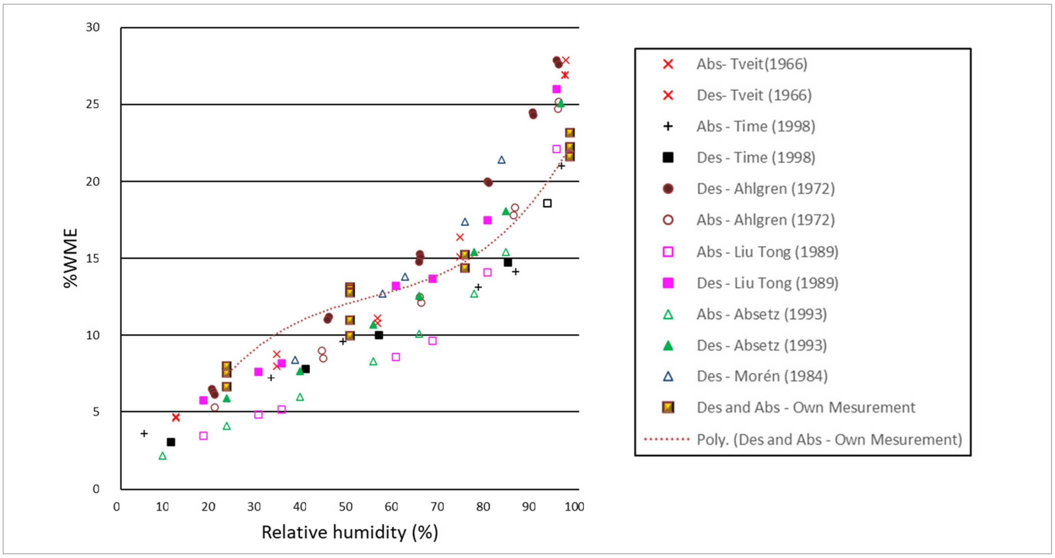


Fig. 3

Sorption and desorption curves for the pine samples, using both the resistance and gravimetric methods. Note that the resistance method gives lower values than the gravimetric method

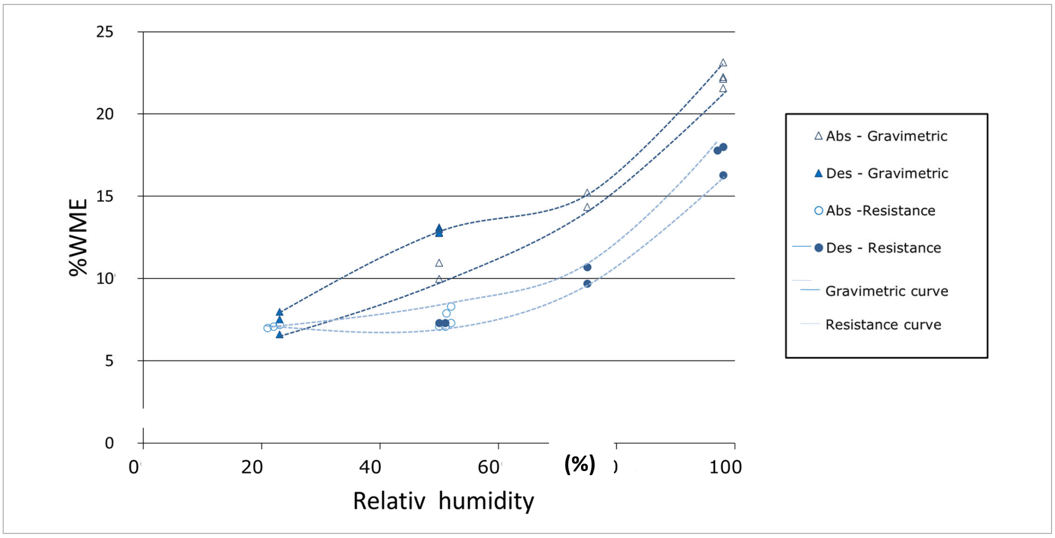
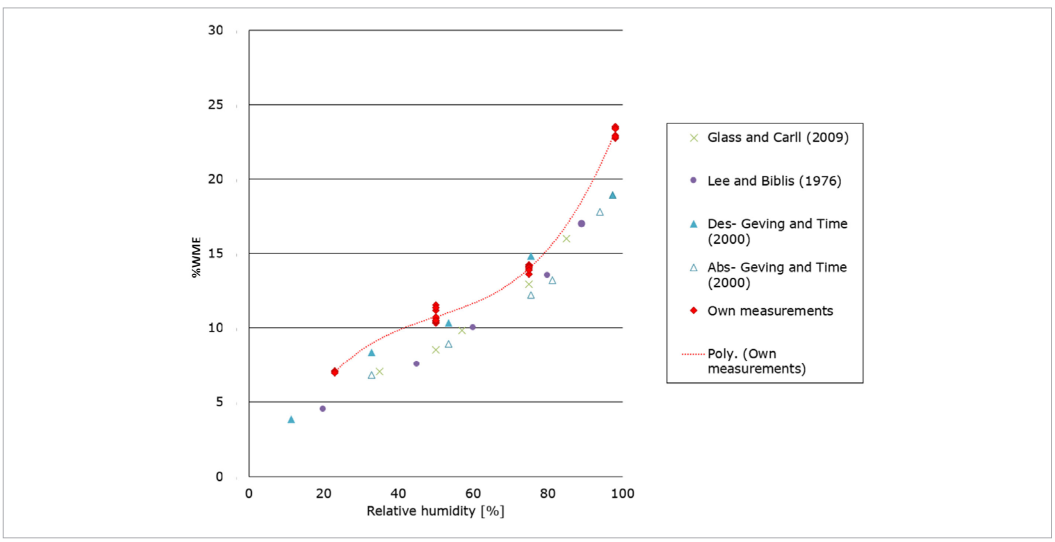


Fig. 4

Sorption curve for LVL based on gravimetric studies in this paper and earlier research



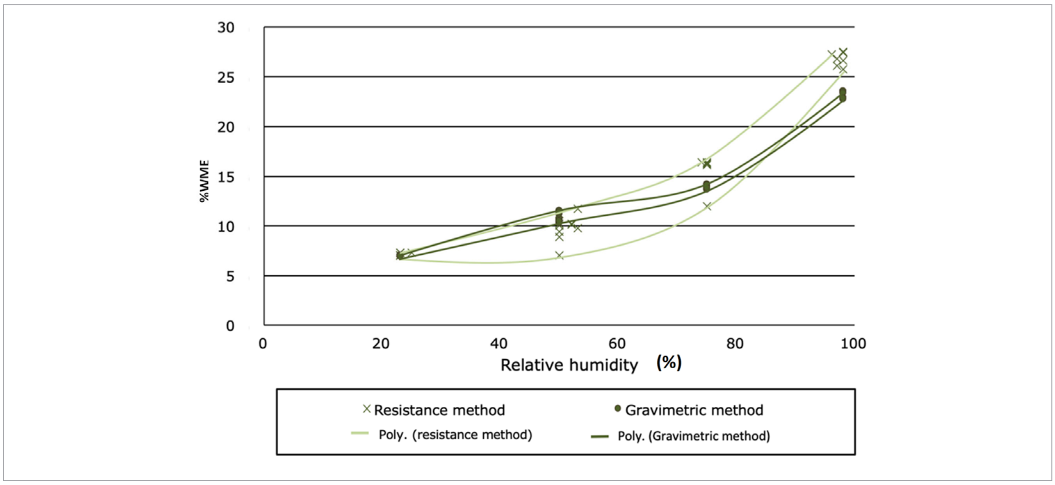


Fig. 5

Scanning curves (Polyline) for moisture content in LVL based on resistance and gravimetric methods

In **Fig. 6**, the difference between the two measurement methods is shown. The resistance method is shown to produce higher readings of moisture content than the gravimetric method in LVL, and lower readings than the gravimetric method in pine. At low humidity percentages, the two methods provide almost the same results in LVL. The discrepancy of the readings in LVL increases with higher moisture content, while it is fairly constant in pine. A correction curve provided by the manufacturer is also shown; however, it has not been used to correct any data in this paper.

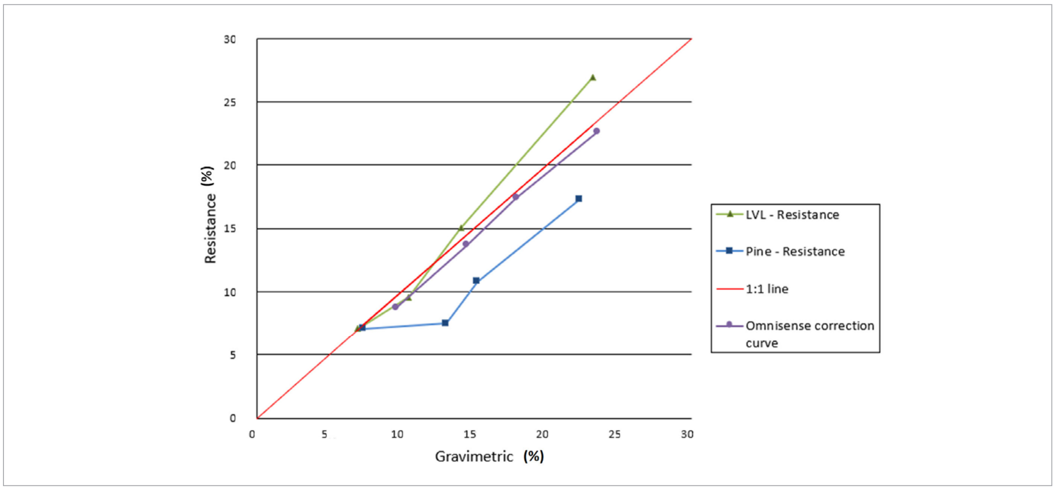


Fig. 6

Difference between resistance and gravimetric measurements of moisture content in LVL and pine. An ideally calibrated sensor would have shown no difference, as illustrated by the red line

Correction tables

The results suggest that **Table 1** and **Table 2** may be used to determine the equilibrium moisture content in pine and LVL after exposure to air at various levels of humidity. Note that the results only include moisture absorption.

Table 1

Correction table for moisture content in pine measured by the resistance method

Relative humidity [% RH]	Resistance method [weight-%]	Gravimetric method [weight-%]	Correction number [weight-%]
23	7.0	7.0	0
50	7.3	11.5	+4.2
74	10.0	13.8	+3.8
80	11.5	15.0	+3.5
86	13.0	17.0	+4.0
92	15.0	19.0	+4.0
96	16.5	21.0	+4.5
98	17.5	22.0	+4.5

Table 2

Correction table for moisture content in LVL measured by the resistance method

Relative humidity [% RH]	Resistance method [weight-%]	Gravimetric method [weight-%]	Correction number [weight-%]
23	7.0	7.0	0
43	9.0	10.0	+1.0
50	9.5	11.0	+1.5
60	11.5	11.0	+0.5
65	12.5	12.5	0
75	15.5	14.0	-1.5
79	17.5	15.0	-2.5
85	20.0	17.0	-3.0
90	22.5	19.0	-3.5
98	27.0	23.0	-4.0

Possible error sources

The following deviations from the measurement setup were noted that may have influenced the measurements: It was discovered that two of the LVL samples (L1.1. and L1.5) gave deviating results from the other samples. Even in a stable climate, L.1.1 showed variations in its moisture content. The deviations were noted early in the research period, and data from L1.1 was not included in the final calculations or figures. The inspection of the samples by sawing them in half at the end of the research period revealed that the sensor had been placed in a knothole in one of the LVL samples. Another sample had its sensor come loose from the hole in which it was fastened.

Discussion

The following research questions were examined in this article: Whether there are differences between the measured moisture absorption in LVL and pine, to what degree the resistance method and the gravimetric method give different results for the two materials, and what causes resistance measurements on LVL to give different moisture content readings to wood.

LVL appears to absorb moisture faster and to a greater degree than pine. According to measurements, the resistance method will yield too high moisture readings from around 65% RH upwards. It seems evident that the two measurement methods give different results for both the materials examined. At low moisture levels, the two methods were accurate for both materials, but at higher moisture levels the resistance method reported too high RH in pine and too low RH in LVL. In cases where sensors use the resistance method to monitor the moisture conditions in buildings, accurate readings are important, as the measured moisture levels may guide costly decisions. For instance, retrofitting a roof because the sensor readings show unacceptable moisture levels and risk of rot, where the roof in reality is within tolerated moisture ranges. A wrongly calibrated sensor may lead to a waste of resources on unnecessary work or cause moisture damage because they report too low values.

Conclusions

This study aims to undertake the development of a calibration curve to predict the “correct” moisture content from using a resistance moisture meter for laminated veneer lumber. The resistance method shows a higher moisture content compared to pine. Results show that LVL takes up more moisture than pine and that some factors affect the resistance in LVL when the RH goes above 65%. The resistance method then yields a too high moisture content above 65% RH, a deviation that increases on higher RH. Conversely, for pine the resistance method gives a wood moisture equivalent that is around 3% too low. To achieve a good result on measuring the moisture content of LVL, it is important that there are no holes (knotholes or other imperfections) in the material where the sensors are placed and that the screws are tight. However, this may not always be possible to assess from the surface of the sample, but it is possible to judge from the resistance in screwing the electrodes into the LVL. If in doubt about the electrode contact, the sensor must be replaced.

The literature search shows that the measurements of moisture in LVL are affected by the glue, although precise investigations into the physical mechanisms have not been conducted in this paper. It is theorised that capillary suction in the interface between the glue and veneer layers causes the material to absorb moisture more easily.

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