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The effect of relative humidity and moisture to the durability of spruce and laminated timber

Mustafa Erkan KARAGÜLER[1], Gülfem KAYA[2]
[1] karagulerm@itu.edu.tr • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey
[2] gulfemkaya@gmail.com • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey

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Abstract

Wood is a hygroscopic material. Material properties are affected by the hygroscopicity of wood; for example, the strength value decreases with increasing moisture content of wood. Wood in the living tree generally has a moisture content (MC) of 30% or greater. The cell wall is fully saturated. After the tree is felled, the green wood is exposed to atmospheric conditions. It loses water until it comes to an adequately low moisture content to be at equilibrium with the surrounding atmosphere. This is called equilibrium moisture content (EMC) which is approximately proportional to the relative atmospheric humidity (RH). Also, EMC varies with the kind and distribution of cell-wall constituents, different wood species, affected by temperature, between heartwood and sapwood, extractives, previous exposure history and mechanical stress. The EMC decreases with decreasing relative humidity, also, increases with the increasing relative humidity of the surrounding air at a constant temperature. The important point that the EMC at a given relative humidity is not constant. It is increased or decreased to reach equilibrium depends on the level of moisture in the timber. The paper presents experimentally and theoretically approach to the effect of relative humidity and moisture to the durability of massive spruce and spruce laminated timber during to drying and wetting exposure.

Keywords
Moisture, Laminated timber, Durability, Massive spruce, Strength, Compression, Bending.

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1. Introduction

The most important factor affecting the equilibrium moisture content of wood is the relative humidity or relative vapor pressure (h) to which the wood is exposed.

The strength of timber depends on its moisture content and the duration of load. Moisture gradients lead to cause local swelling or shrinkage, that changes the stress distribution and has an impact on load bearing capacity.

Moisture presents in wood with adsorbed by the cell walls or fills within the cell cavities after the cell walls are saturated. The first type is called bound water and the second free water. Adsorbed water softens the cellulose/lignin material of the cell water. Therefore, it reduces all strength and stiffness properties; that weakens the wood (Stalnaker and Harris, 1989).

In practical, it can be said that all strength properties decrease as MC increases, but the fiber saturation point (FSP) in increased. FSP is the moisture content at which the cell wall material is completely saturated, but the cell cavities are mostly empty. If wood dried at the manufactory to the usual moisture content, then it tends to use in a very dry location, such as the interior of a heated building. The material gives up moisture to the atmosphere, and then maybe it will shrinking and perhaps warping. On the other hand, if the wood is used in a very moist place, such as in a bathroom or over a swimming pool, it will absorb moisture from the atmosphere, swelling and perhaps again warping. This moisture movement is a slow process, so that if atmospheric conditions fluctuate, the moisture content tend to reach average value. An important point that the timber elements be dried to a moisture content approximately equal to the EMC of its surroundings, intended use.

If green wood is thoroughly dried, swelling and shrinkage are slight in the longitudinal direction, varying from 0.1% to 0.2%. However, they are considerably more in the radial direction 4%to 4,5% and highest of all tangentially 7,5%-8,5%. The position of the annual rings is usually not known in advance. Thus, in estimating the dimension change, the designer should assume the rings to be nearly parallel to the dimension in question; that is, the larger dimension change (tangential) should be anticipated.

Vanya (2012) summarize the reasons for cracking in glulam beams; change in air humidity, hindered shrinking and bulking mainly at connections, cycling changing in climatic conditions, incorrect gluing, low-quality adhesive, end grain lamellas without surface protection, outrunning grain, different moisture content in lamellas, different thickness of the lamellas, perpendicular normal stresses, other kinds of technological problems.

According to Vanya (2012), small cracks are not rare in glulam beams. These cracks are the result of the changes in humidity. Absorption of water depends on the grain direction like its other physical properties because of its orthogonal anisotropic structure. In the grain direction, the absorbed volume of water is higher than transverse direction. Swelling occurs by the absorbed water that builds between the fibers, loss of water causes shrinking for the same reason. When air humidity changes too quickly, swelling and shrinking cannot follow this process, and that time internal stress occur, the developing internal stresses cause deformations and cracking in the wood. Cyclic climatic changes decrease the strength of the wood.

If the moisture content of the glulam beam is homogeneous, there are no inner stresses. This appearance is extraordinary in the value of the moisture content. There is no homogeneity in the moisture content of the lamellas in new built glued laminated timber construction, at least not at a particular time. Lamellas' moisture content will be equal to humidity, but this takes time, and during this equalization process, the superposition of the inner and external stresses can cause damage.

Angst and Malo (2012) emphasized that climate variations affected timber structures by causing moisture induced stresses. These stresses may lead to injury in wood members. In their experimental study, moisture induced stresses that arise perpendicular to the grain of glulam specimens during exposure to one-dimensional drying and wetting. Timber structures are affected by climate variants of the environment, as moisture gradients are induced, and, therefore, internal stresses arise.

According to Angst and Malo's (2012) experimental study, the difference between local stress and average stress depends on the geometrical configuration of the glulam laminates. The varying relative humidity (RH) induced stresses perpendicular to grain in timber members.

Another experimental study from Gereke and Niemz (2009) show that the change of the wood moisture content is accompanied by a volume change of the material. The swelling and shrinkage change considerably between the directions perpendicular and parallel to the grain. A change in humidity causes an irregular moisture distribution that anticipates to spatial variation of the swelling/shrinkage.

The results showed that the important of local stresses. Local stresses are seriously larger than average stresses. The results showed that moisture induced stress leads to small cracks in the cross section even without external load. These cracks could reduce the load bearing capacity of the member. The cracks will start in the central part of the timber in the case of wetting exposure, and this is not visible from the outside of the element.

Based on compression tests in Frese, and others (2012) study numerically reproduced, the influence of the density, the moisture content and the knot area ratio on the compressive strength was investigated. The knot area ratio of the used sawn timber reduces marginally to the strength value.

Fragiacomo and others (2011) focused on a study of internal stresses perpendicular to grain induced in timber by variations of moisture content that are caused by exposure to different climates. The fact that, tension perpendicular to the grain is the most common failure mode.

2. Materials and methods

Tension perpendicular to grain is the most common and critical failure mode in timber construction. RH gradients in climatic conditions, affect timber structures with causing internal stresses. An experimental approach has been conducted in order to examine the effect of the relative humidity and the wetting and drying exposure to the timber samples at a constant temperature. The scope of the present work is to submit enough experimental study for releasing characteristic strength values for laminated timber and structural timber in the mechanical properties.

2.1. Specimens

Laminated sample which is made of spruce with nine lamellas, four lamellas, and massive spruce samples were prepared. The specimens were between 12±2% moisture content, and they were conditioned to equilibrium at 23C° and 60% relative humidity. All specimens have been weighed and measured. In glulam specimens, annual rings orientation has been disregarded. The type of glue is Melamine Urea Formaldehyde (MUF) in laminated timber. The samples have been grouped into three types as shown in figure1.

- Type A: 40mmx40mmx160mm:18 specimens each with 9 lamellas: Each spruce lamellas were approximately 18mm thickness, 12±2% moisture content.
- Type B: 40mmx40mmx160mm: 18 specimens each with 4 lamellas: Each spruce lamellas were approximately 40mm thickness, 12±2% moisture content.
- Type L: 40mmx40mmx160mm:18 specimens of spruce: massive, 12±2% moisture content.

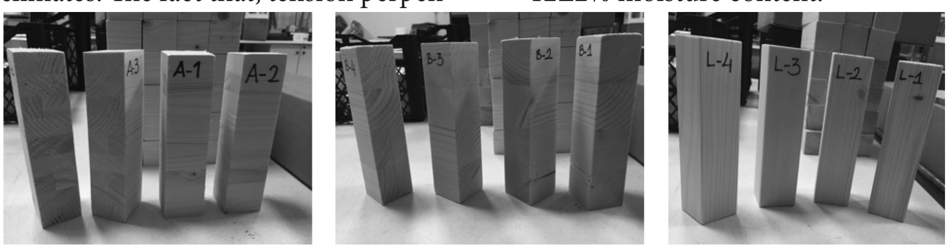

Figure 1. *A series with 9 spruce lamellas - B series 4 spruce lamellas - L series massive spruce.*

2.2. Methods

Nine lamellas laminated timber, four lamellas laminated timber and massive spruce samples, each with the size of 40x40x160mm, has been prepared and marked. According to figure 2, total 54 specimens have been put in the climatic chamber with an RH of 90% and 23ºC temperature in wetting exposure. The same amount of specimens with the same specifications have put in the climatic chamber with an RH of 40% and 23 ºC temperature in drying exposure. The samples located in climatic chamber properly that shown in figure 3.

Figure 2. *Climatic chamber.*

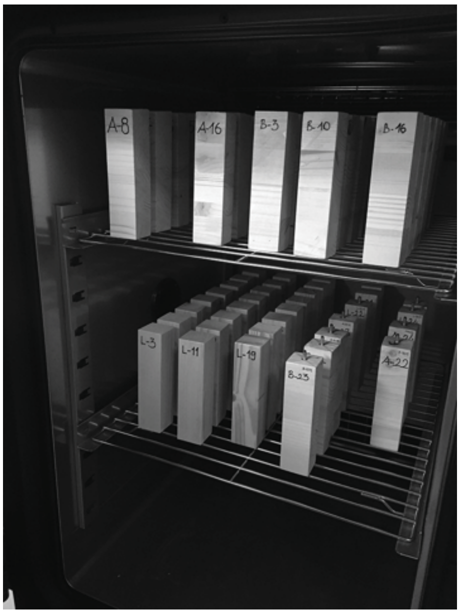

Figure 3. *The samples were put in the climatic chamber.*

2.3. Tests

According to table 1 bending tests perpendicular to grain and compression tests which were perpendicular to grain and parallel to grain have been performed to the trial group of specimens after 7,14,28,35 and 42 days of wetting and drying respectively.

As seen in figure 5, because of the tension perpendicular to grain failure, the cracks occurred and run distinctly in the direction of the applied force.

According to EN 1193, compression strength perpendicular to grain (σc,90) defines for experimental study. The specimens often show tension perpendicular to grain failure before the compression strength value is reached.

Force applied perpendicular to grain as shown in figure 6. While the wood became more dense as it was compressed, that action caused slight displacement of the supported member. Thus, limits were placed on allowable loading in bearing perpendicular to the grain.

3. Results

In this study glulam and massive spruce specimens were exposed to wetting and drying climate changes. All test results have been recorded and strength–time graphics have been drawn for each set of specimens in each climate conditions. No serious failures have been observed in the specimen with a moisture content 12 ±2%. On the other hand, brittle failure has been observed in the specimens with knots under the axial loads, mild grained specimens and laminated timber specimens with improperly glued lamellas.

Strength in static bending is an important mechanical property because in most structures wood is subjected to loads which cause it to bend. The strength of timber in bending is usually expressed by the modulus of rupture. According to the strength values both for compression and bending tests, some of the samples gave so high or so small strength values. At that time, it can be said that most important factor for the structural glulam elements was

Test series	Seasoned in RH	Wetting samples (RH 90%)	Drying samples (RH 40%)	Total number of test samples	Test Days
Bending tests	60%	54	54	108	7,14,21,28,35,42
Compression parallel to the grain	60%	54	54	108	7,14,21,28,35,42
Compression perpendicular to the grain	60%	54	54	108	7,14,21,28,35,42

Figure 4. *Test program.*

Figure 5. *Bending tests.*

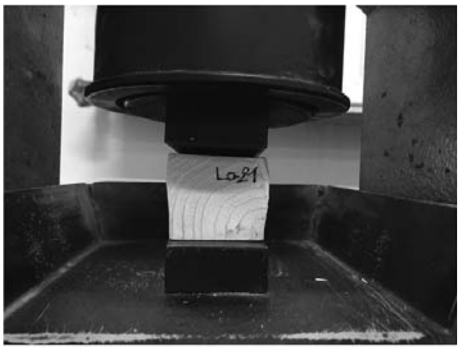

Figure 6. *Compression perpendicular to grain.*

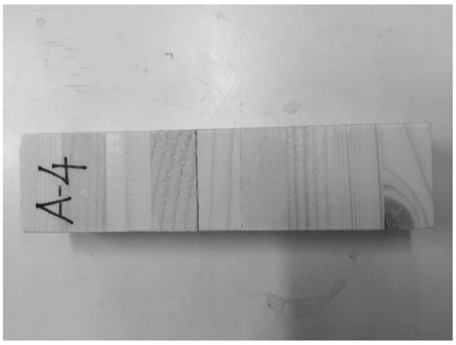

Figure 7. *Improperly glued lamella.*

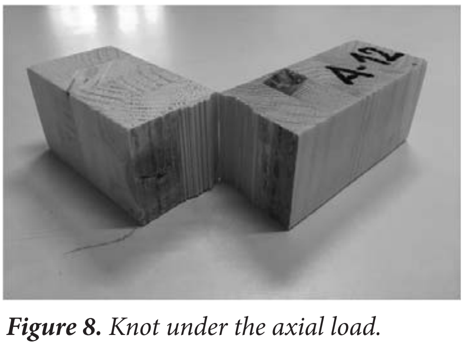

Figure 8. *Knot under the axial load.*

identified to be the annual ring pattern or the geometrical pith location of the lamellas within a cross section.

On the other hand, as seen in figure 7, the cracks have been observed easily from the improperly glued lamella in perpendicular to grain bending test.

The strength of wood may be considerably reduced by knots, depending on their kind, size, and location and on the type of loading. The following table 1 presents a comparison of bending strength in laminated timber with nine lamellas which include knot and without a knot. Sample A-12 includes knot and decreases the bending value approximately 50%. Knot often causes damage and reduces the strength value of the material.

The different values were recorded for the samples in the same properties. There are so many probabilities for these results. It has been observed, that in softwoods like spruce, tangential compression strength is higher than radial, whereas the situation is opposite in hardwoods. The annual ring orientation in a laminated timber samples has a significant influence on the strength value of the elements. Constitute positions of the piths in the walls reduces strength of the laminated timber.

Wetting exposure didn't affect the strength value of the specimens significantly which are approximately in the same moisture content 12±2% that shown in Table 2.

But it can be easily said that the sample with 4 lamellas had higher strength values than 9 lamellas samples, but the spruce massive samples had the highest value for section of the same size.

According to table 3, the strength values of compression perpendicular to grain in wetting exposure, was similar for both test groups. On the other hand, compression tests parallel to grain the results showed that the glulam samples were similar, but massive spruce samples had higher strength values that were relevant to the section size of the samples as seen in table 4. In structural applications, the height of the laminated timber beam element is increased depending on the opening to be used according to calculations.

In table 5, in drying exposure, the results showed that massive spruce samples had the highest strength values according to specific cross section. For the glulam samples, the specimens with 4 lamellas had a higher bending strength value than the specimens with 9 lamellas.

There was no serious difference between the glulam specimens in compression perpendicular to grain values as seen in table 6. But in contrast, 4 lamellas glulam test specimens had slightly higher strength value in compression tests parallel to grain in table 7.

Before the compression strength value is reached, tension perpendicular to grain failure often occurs in glulam but for structural massive timber such failure mode is not seen.

A strength test of wood in compression perpendicular to grain showed that the massive spruce sample with more summer woods had a higher compression value as shown in figure 9 and in table 8.

4. Conclusions

- The bending strength of the 4 lamellas specimens is higher than those of the 9 lamellas specimens with the same section. In this particular section, the massive spruce samples have the highest values. This is pointed out that the cross section size of the lamellas is necessary for the glulam elements.
- As Angst (2012) stated perpendicular to grain is the weakest point of the timber and tension perpendicular to the grain is the most common failure mode as seen in the test results.
- Based on the results, it has been observed that the samples with more summer woods have a higher strength value. Summer wood is stronger than spring wood because it contains more cellulose.
- As a result of the tests for wetting and drying exposure, it can be asserted that the effect of moisture gives vulnerability to the samples.
- Before the compression strength value is reached, tension perpendicular to grain failure often occurs in glulam but for structural massive timber such failure mode is not

Table 1. *The effect of knot on the strength value of the sample under the axial load.*

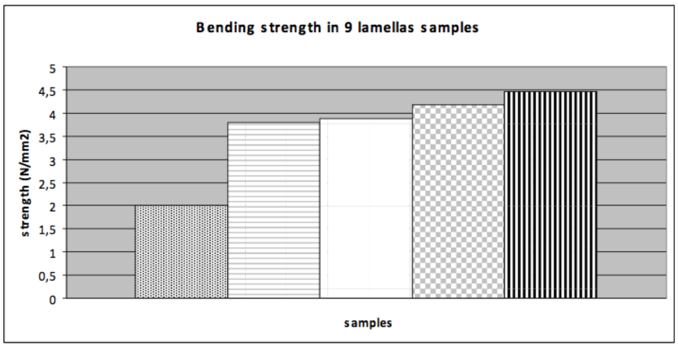

Table 2. *Bending tests results in wetting exposure.*

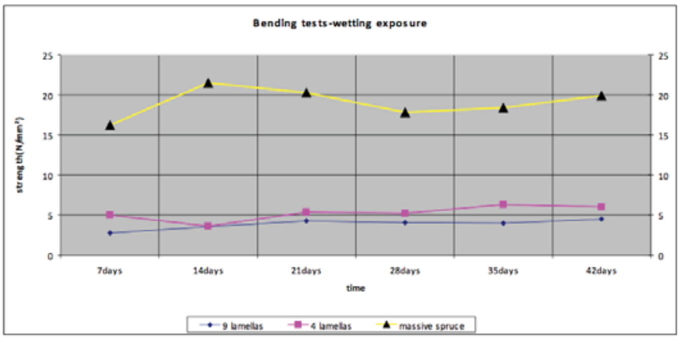

Table 3. *Compression perpendicular to the grain tests results in wetting exposure.*

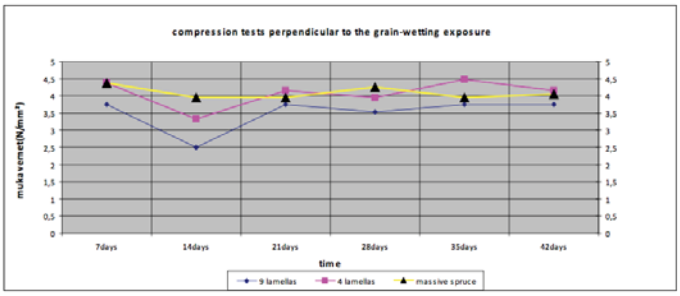

Table 4. *Compression tests parallel to the grain in wetting exposure.*

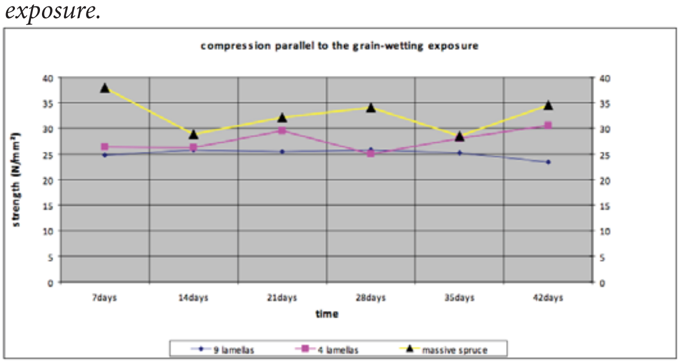

Table 5. *Bending tests in drying exposure.*

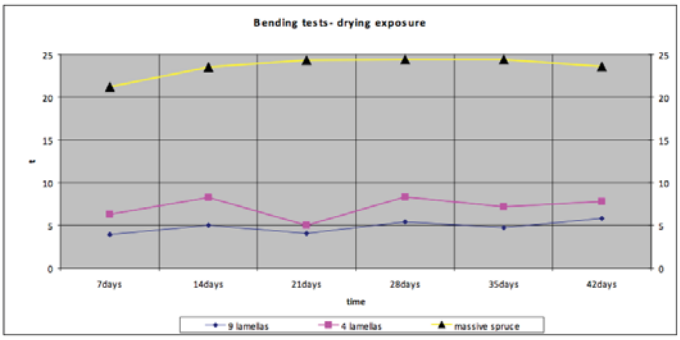

Table 6. *Compression tests perpendicular to grain in drying exposure.*

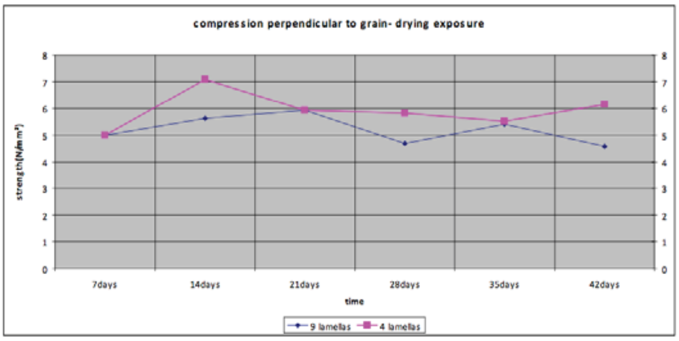

Table 7. *Compression tests parallel to grain in drying exposure.*

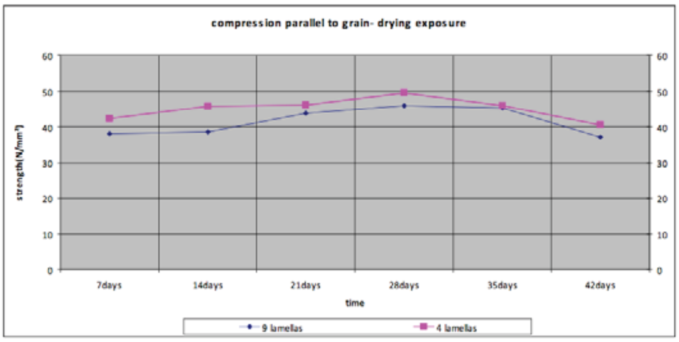

Table 8. *Comparison strength value with the fewer summer woods sample (La-22) with, the more summer woods sample (La-23).*

Massive Spruce Samples	La-22	La-23
Compression strength (N/mm²)	24,37	37,5

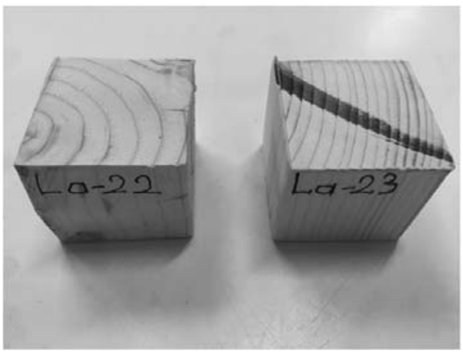

Figure 9. *The spruce sample which has more summer woods has a higher compression value.*

seen.

- The existence of the knots decreases the strength value of the timber. Knots also affects the machining, drying and gluing properties of the wood. This means knots cause weakness in timber. Especially knots on the load axis cause a remarkable decrease in the strength value of the timber. Maybe it is impossible to avoid from the knots in the samples, but it is necessary to start as early as possible in order to reduce the diameter of the central knot core.
- As a consequence of wetting and drying exposure effect, the dissociation becomes more visible where the glue could not be applied properly. It can be said that the gluing line in glulams is an important part of the structural glulam elements.

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