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*Full Length Research Paper*

# The effect of air dried conditions on mechanical and physical properties of laminated and impregnated wood

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**In this study, laminated Scotch pine samples bonded with polyurethane adhesive were impregnated with water repellent (protim WR230) and preservative (tanalith-C). Non-impregnated and impregnated Scotch pine samples were air-dried by placing them uncovered in a concrete above ground for one year. Bending strength, compression strength, bonding strength and physical properties were determined. Bending strength was reduced by 20% for non-impregnated samples, 12% for tanalith impregnated samples, and 11.3% for protimWR230. Compression strength was increased by 5.5% for non-impregnated samples, 10.1% for tanalith treated and 10.4% for ProtimWR230. Bonding strength was reduced by 8.3% for untreated samples, but increased by 36.05 and 35.7% for tanalith and ProtimWR230, respectively. Impregnated samples were colonized by fungi during the one year outdoor conditioning; both dimensional and insect damages were not observed. Treated samples were well protected but non-impregnated samples were covered by white rot, insects, color changes and considerable odour. In impregnating test samples, water and relative humidity affected the bonding properties positively for one year, and this increased the bonding and compression strength. But bending strengths were reduced. In determining the bonding and compression strengths, the applied force parallel to adhesive layer; while in determining bending strength the applied force is vertical to adhesive layer.**

**Key words:** Weathering, bending strength, compression strength, bonding strength, Scotch pine.

## INTRODUCTION

Using solid wood curve and in big dimensions is neither economical nor proper from the point of strength. Producing carrier elements in big dimensions from solid wood is not very practical, because it is not possible to overcome most of the defects such as knot, rottenness, rift crack, spiral grain, worm powder in wood. This makes it necessary to use high quality wood material. This also causes increase in cost and price of wood. Besides, cutting for curved form of diagonal timber of the wood causes strength loss (Topal, 2001).

It is possible to produce wood in high quality and in desired form through laminating technique. This method has many advantages for solid wood. With this method, it is possible to produce long wood products from narrow width and short wood. Besides, its quality increases as it becomes possible to use this product by removing the faults of wooden material. The waste ratio decreases, as small dimension wooden material is used and this affects the cost of production (Altinok, 2005).

The first serious application of laminating technique was used for the production of chair in Istanbul, Turkey in 1987 by a private firm. Later in Ankara, a private firm made a study on laminated wood for framing, but this was not approved by the public. West-epoxy laminating technique was first used in 1990 by the Department of Wood Workings Industry Engineering for Wood in Hacettepe University for the production of 18 m two mast wood yacht (Tascı, 1993).

In the US, laminating techniques are used in plywood sports material and furniture production. The first sample of carrier laminate was tried in constructing sector by Forest Product Laboratory. Later in Europe it was used

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for church, gym, saloons, swimming pools, factory buildings, stock hangar, farms and stables constructions (Anon, 1987). During World War II, lamination techniques were applied in bridge construction requiring high resistance with help of synthetic adhesives. And this has improved rapidly with the use of polimer adhesion; high resistant lamine elements to air dried condition were easy to produce.

Application of inadequate glue to the surface of wooden material will lead to weak joint and when high pressure is applied on the specimen, mechanic adhesion decreases, resulting in a weak joint (Mc Namara and Waters, 1970). Woods of diffuse porosity show different sticking characteristics than ring-pored. The resistance of glue line of ring-pored increases in relation to its density (Marra, 1992).

In order to determine the characteristics of early growth and autumn wood, Chung (1968) has done an experiment, tension-shearing test on the plywood from the southern pine. At the end of research, early growth-early growth was the strongest; early growth-autumn wood, the medium; and autumn wood-autumn wood, the weakest resistance of glue line obtained (Chung, 1968).

The humidity of glued wooden material usually changes from 6-18% according to the usage conditions: in air dried constructions, 18 ± 6%; in semi open-air constructions, 15 ± 3%; in constructions without central-heating, 9 ± 3% humidity containing wooden materials should be used (Bozkurt and Kurtoglu, 1979).

In this study, laminated Scotch pine samples obtained by polyurethane adhesive and polyvinyl acetate were impregnated with water repellent and preservative. Non-impregnated and impregnated laminated woods were left in air dried conditions, side and top uncovered for one year on concrete ground. After this time period, changes of bending strength, compression strength, bonding strength and physical properties were determined.

## MATERIALS AND METHODS

### Test methods

All tests in this study were carried out in Department of Furniture and Decoration Education Laboratory on universal testing device. Technical specifications of universal testing machine are given in Table 1. Bending strength tests were carried out according to TS 2474 standards (Anon, 1976). The samples, having 2 x 2 x 30 cm dimensions, with 3 layers were used for bending strength. Thickness of layers is 6.5 mm. 10 samples have been used for each experiment. The samples prepared are conditioned to reach 12% moisture at 20°C and 65% relative humidity conditions. Test specimens are determined through measurement from the middle parts by ± 1% mm sensitivity micrometer. Span to thickness ratio for bending is 24 cm. Bending strength test mechanism is given in Figure 1.

The following equations were used in the calculation of bending strength ($\sigma_e$):

**Table 1.** Technical specifications of universal testing machine.

| Specification | | UTM 3000 |
|---|---|---|
| Capacity<br>Load measurement accuracy<br>Displacement measurement accuracy | | 400 kN<br>± %1<br>0,01 mm |
| Columns diameter | Lower<br>Upper | 60 mm<br>70 mm |
| Vertical test distance | Min<br>Max | 80 mm<br>400 mm |
| Distance between columns<br>Piston stroke | | 420 mm<br>200 mm |
| Max pressure | Grips<br>Load | 300 bar<br>130 bar |
| Test space<br>Height | | 680 x 540<br>2500 mm |

$$[\ \sigma_e = \frac{3.\ P.\ Ls}{b.\ h^2}\ ] \quad (1)$$

Where $\sigma_e$ = bending strength (N/ mm$^2$), P = max. force at the moment of breaking (N), L s = distance between points of support (mm), b = width of sample piece (mm), and h = thickness of sample piece (mm).

Compression strength tests were carried out according to TS 2595 standards (Anon, 1976). The samples having 2 x 2 x 3 cm dimensions with 3 layers were used for bending strength. Thickness of layers is 6.5 mm. 10 samples have been used for each experiment. The samples prepared are acclimatized to reach 12% moisture at 20°C and 65% relative humidity conditions. Test specimens are determined through measurement from the middle parts by ± 1% mm sensitivity micrometer. Compression strength test mechanism is given in Figure 2.

The following equations were used in the calculation of compression strength ($\sigma_b$):

$$[\ \sigma_b = \frac{F_{max}}{a.b}\ ] \quad (2)$$

Where $\sigma_b$ = compression strength (N/mm$^2$), $F_{max}$ = max. force at the moment of breaking (N), a = width of sample breadth cross-section (mm), and b = length of sample breadth cross-section (mm).

The specimens were prepared according to TS 53 (Anon, 1976) and TS 2470 (Anon, 1976). Bonding strength tests were done according to DIN 53255 standards (Anon, 1964). The samples having 15 x 20 x 150 mm dimensions with 2 layers were used for bending strength. Thickness of layers is 7, 5 mm. 10 samples have been used for each experiment. The samples prepared were conditioned to reach 12% moisture at 20°C and 65% relative humidity conditions. Test specimens are determined through measurement from the middle parts by ± 1% mm sensitivity micro-

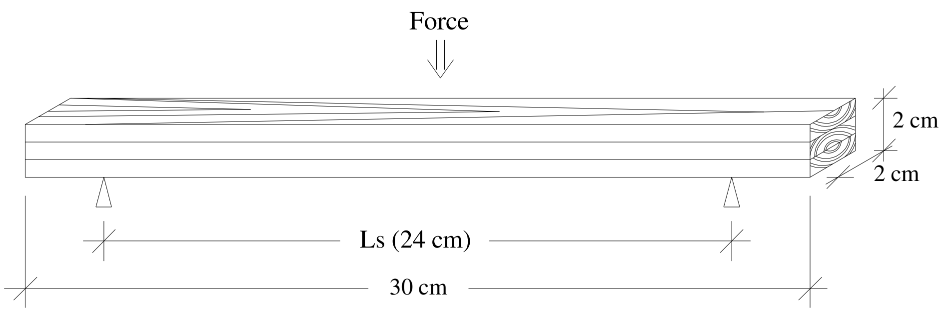


**Figure 1.** The dimensions of bending strength test specimens.

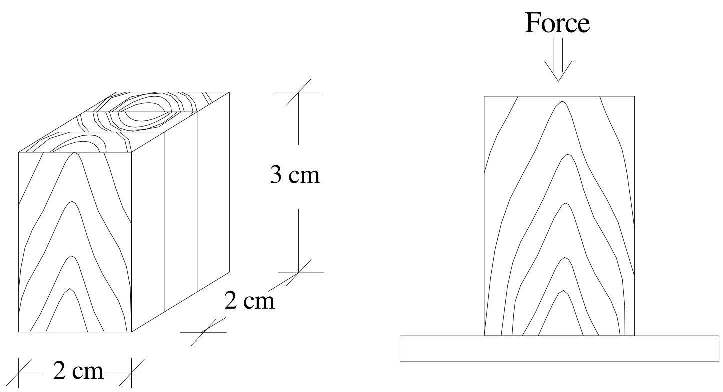


**Figure 2.** The dimensions of compression strength test specimens.

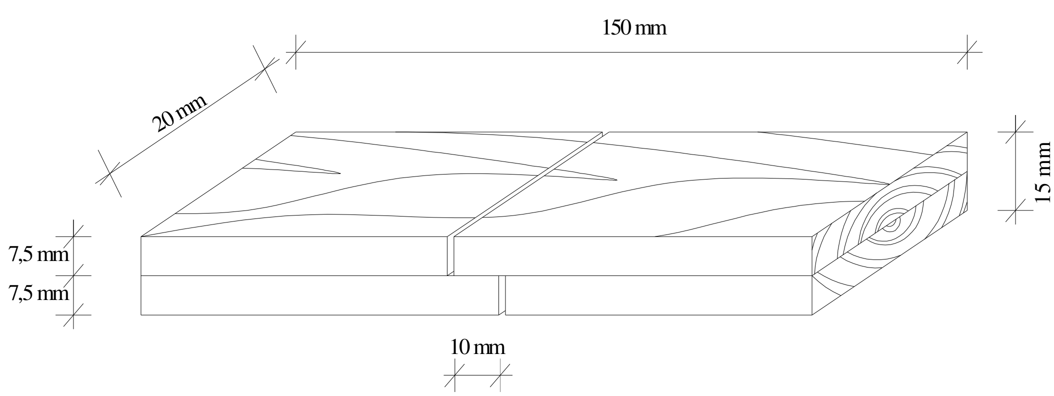


**Figure 3.** The dimensions of bonding strength test specimens.

meter. Bonding strength test scheme is given in Figure 3.

The following equations were used in the calculation of bonding strength (σ):

$$[\acute{o} = \frac{F_{max}}{b.l}] \qquad (3)$$

Where σ = bonding strength ($N/mm^2$), $F_{max}$ = max. force at the moment of breaking (N), b = width of bonding surface (mm), and l = length of bonding surface (mm)

#### Wood material

Scotch pine was used in all sample experimental studies. The Scotch pine was taken from the area of Murat Mountain in Gediz-Kutahya Province of Turkey. Samples are prepared from whole sapwood trunk. Density of wood dry is 0.490 $g/cm^3$.

#### Impregnating compounds

In this study, two types of impregnating compounds were used. One

**Table 2.** The concentration of tanalith-C impregnating compound.

| Compound | % | g/l |
|---|---|---|
| Chromium trioxide | 30.2 | 52.8 |
| Copper oxide | 11.2 | 196 |
| Arsenic pentoxide | 17.3 | 303 |

**Table 3.** General properties of polyurethane adhesive.

| General properties | Polyurethane adhesive (PU) |
|---|---|
| Commercial type | Liquid-solid |
| Storing period (month) | 6–9 |
| Colour | Bold brown |
| Effect on health | Harmful above 60 ˚C |
| Wood humidity (%) | Max. 15 |
| Dry material (%) | 20–90 |
| Amount of using (g/m$^2$ ) | 200–250 |
| Fitting time (hour) | 0.5–1 |
| Pressure (N/mm$^2$) | 0.3-0.8 |
| Temperature (°C) | 10–60 |
| Resistance to water | Resistance to boiled water |
| Resistance to microorganism | Extra |

was preservative tanalith-C (CCA: chromated copper arsenate) and the other was organic solvent water repellent protim WR230. Samples used in this study were impregnated in Semitas Company.

#### Protim WR230

Samples impregnated in Protim WR230 were dipped and soaked for 45 min. After impregnating solvent material is evaporated from wood material and main active, material stays and is preserved. Hydrocarbons are used as solvent. Protim WR230 is highly effective on insect and fungi, so it should not be used for the earth touching places. Density is O.8 gr/cm$^3$ and flammable over 36ºC. It contains tributyltin naphthenate (14.4 g/l) and permethrin (0.8 g/l) (Nicholas, 1973).

#### Tanalith-C; CCA (Tanalith-C 3310)

This is obtained from Hemel company at 4% concentrate. The impregnating of samples is carried out with bethell process. After, samples in cylinder vacuuming process are applied for 30 min to 760 mm Hg level. When the drum is totally filled with the chemical substance, vacuuming process is stopped and pressure process commences. 10-15 bars pressure is applied for one hour. After impregnating process, the retention ratio is calculated to be 18.89 (kg/m$^3$) for the samples. The rates of tanalith-C impregnating compound are given in Table 2.

#### Adhesive

In this study, polyurethane adhesives are used for preparing all samples. The rate of the adhesive applied to the surface of the samples is 235.4 g/m$^2$ on average. Polyurethane adhesive is chosen as it is resistant to water, heat, cold and impregnating compound's solvents. General properties of used polyurethane adhesive are given in Table 3.

#### Press pressure and pressure period

All samples were pressed and prepared at 20˚C temperature, with 65% relative humidity and under 0.4 N/mm$^2$ pressure with 3 h time period.

#### Climate conditions

Climate conditions in which the samples are exposed to in different months during one year are given in Table 4.

#### Statistics analysis

The experimental results were statistically analyzed using analysis of variance (ANOVA), and significant differences between the control and the treated samples were determined using Duncan's Multiple Range Test (Anon, 1988).

## RESULTS

### Visual observations

Treated samples exposed outdoor for air-dried did not show any sign of fungal colonization, or insect attacks and dimensional instability, suggesting that chemicals of formulations used for treatment by impregnation offered adequate protection against fungi and insects. However for untreated samples, odour, color changes and presence of white rot on surface were observed. No dimensional deformation was observed on any sample.

### Results for mechanical properties

The values of average bending strength for laminated Scotch pine sapwood (3 layers) are given in Table 5. Bending strength variance analysis results are given in Table 6. According to Duncan multi range test results leaving impregnating and non-impregnating samples in air dried conditions for one year on bending strength, 95% reliable statistical differences were found to be significant. The values of average compression strength for laminated Scotch pine sapwood (3 layers) are given in Table 7. Compression strength variance analysis results are given in Table 8.

According to Duncan multi range test results leaving impregnating and non-impregnating samples in air dried conditions for one year on compression strength, 95%

**Table 4.** Climate conditions under which specimens are exposed per months.

| Months | Mean Temperature (˚C) | Max. Temperature (˚C) | Min. Temperature (˚C) | Average relative humidity (%) | Average total rain (mm) | Rain day number | Covered snow day number |
|---|---|---|---|---|---|---|---|
| January | 4.1 | 16.0 | -6.4 | 67 | 138.7 | 20 | 3 |
| February | 2.6 | 14.3 | -10.0 | 64 | 157.7 | 23 | 5 |
| March | 6.4 | 19.9 | -8.0 | 59 | 141.9 | 19 | 2 |
| April | 10.8 | 27.6 | -3.1 | 53 | 61.4 | 14 | - |
| May | 15.8 | 30.0 | 2.7 | 52 | 59.9 | 15 | - |
| June | 19.0 | 30.2 | 7.7 | 48 | 39.3 | 5 | - |
| July | 23.2 | 34.8 | 9.6 | 48 | 30.6 | 7 | - |
| August | 23.4 | 37.8 | 12.6 | 47 | 18.7 | 2 | - |
| September | 18.0 | 32.9 | 4.8 | 52 | 7.1 | 4 | - |
| October | 11.0 | 24.2 | -1.9 | 58 | 40.7 | 8 | - |
| November | 6.8 | 19.2 | -5.4 | 60 | 149.3 | 18 | 1 |
| December | 5.3 | 21.7 | -13.0 | 62 | 154.6 | 16 | 8 |
| Annual | 12.2 | 37.8 | -13.0 | 55 | 999.6 | 152 | 19 |

**Table 5.** The values of average bending strength.

| Duration in air dried conditions | Impregnating compound | Bending strength (N/mm$^2$) | | | | |
|---|---|---|---|---|---|---|
| | | n | Average | Max. | Min. | Standard deviation |
| Starting | Non-impregnated | 10 | 34.27 | 36.48 | 32.23 | 1.36 |
| | Tanalith-C | 10 | 35.46 | 37.75 | 33.35 | 1.46 |
| | Protim WR230 | 10 | 35.09 | 37.35 | 33.00 | 1.21 |
| 1 year | Nonimpregnated | 10 | 27.43 | 28.44 | 26.61 | 0.66 |
| | Tanalith-C | 10 | 30.17 | 34.34 | 27.47 | 1.67 |
| | Protim WR230 | 10 | 30.41 | 33.91 | 27.28 | 1.79 |

**Table 6.** Bending strength variance analysis results.

| Variance source | SD | Squares total | Average squares | Calculated F | P (Probability) (% ) |
|---|---|---|---|---|---|
| Repetition | 9 | 28.559 | 3.73 | 1.562 ns | 0.177 |
| Factor (Duration) | 3 | 237.342 | 79.114 | 38.953** | 0.000 |
| Error | 27 | 54.837 | 2.031 | | |
| General | 39 | 320.738 | | | |

**Table 7.** The values of average compression strength.

| Duration in air dried conditions | Impregnating compound | Compression strength (N/mm$^2$) | | | | |
|---|---|---|---|---|---|---|
| | | n | Average | Max. | Min. | Standard deviation |
| Starting | Nonimpregnated | 10 | 13.42 | 13.91 | 12.71 | 0.34 |
| | Tanalith-C | 10 | 13.95 | 14.46 | 13.21 | 0,39 |
| | Protim WR230 | 10 | 13.84 | 14.24 | 13.01 | 0,41 |
| 1 year | Nonimpregnated | 10 | 12.68 | 13.07 | 12.29 | 0.36 |
| | Tanalith-C | 10 | 14.78 | 15.05 | 13.91 | 0.46 |
| | Protim WR230 | 10 | 14.82 | 15.72 | 14.04 | 0.58 |

**Table 8.** Compression strength variance analysis results.

| Variance Source | SD | Squares Total | Average Squares | Calculated F | P (Probability) (% ) |
|---|---|---|---|---|---|
| Repetition | 9 | 1.625 | 0.181 | 0.752 ns | 0.661 |
| Factor (Duration) | 3 | 33.478 | 11.159 | 46.494** | 0.000 |
| Error | 27 | 6.480 | 0.240 | | |
| General | 39 | 41.583 | | | |

**Table 9.** The values of average bonding strength.

| Duration in air dried conditions | Impregnating compound | Bonding strength (N/mm$^2$) | | | | |
|---|---|---|---|---|---|---|
| | | n | Average | Max. | Min. | Standard deviation |
| Starting | Nonimpregnated | 10 | 4.42 | 5.01 | 4.13 | 0.28 |
| | Tanalith-C | 10 | 4.53 | 5.13 | 4.23 | 0.33 |
| | Protim WR230 | 10 | 4.48 | 5.08 | 4.18 | 0.29 |
| 1 year | Nonimpregnated | 10 | 4.05 | 4.59 | 3.77 | 0.26 |
| | Tanalith-C | 10 | 6.02 | 6.42 | 5.71 | 0.31 |
| | Protim WR230 | 10 | 6.06 | 6.51 | 5.61 | 0.35 |

**Table 10.** Bonding strength variance analysis results.

| Variance Source | SD | Squares total | Average squares | Calculated F | P (Probability) (% ) |
|---|---|---|---|---|---|
| Repetition | 9 | 1.217 | 0.135 | 1.428 ns | 0.225 |
| Factor (Duration) | 3 | 32.072 | 10.691 | 112.892** | 0.000 |
| Error | 27 | 2.257 | 0.095 | | |
| General | 39 | 35.846 | | | |

reliable statistical differences were found to be significant. The values of average bonding strength for Scotch pine sapwood are given in Table 9. Bonding strength variance analysis results are given in Table 10.

According to Duncan multi range test results leaving impregnating and non-impregnating samples in air dried conditions for one year on bonding strength, 95% reliable statistical differences were found to be significant.

## DISCUSSION

After this study, in all experimental studies, protim WR230 supplied enough preservation as tanalith-C in both physical and mechanical experiments. This is the reason protim WR230 impregnating compound can be preferred to tanalith-C for the furniture outside frames left in air dried conditions, because it was known before that protim WR230 does not have the natural colour of wood and not harmful to human health. Through this study it has been provided that protim WR230 has at least enough preservation (in all experiments) against fungi and insect as tanalith-C.

In all samples prepared with polyurethane adhesive, no dimensional deformation was observed in any sample left in air dried conditions for one year. Besides, air dried conditions affected the bonding properties positively. For these reasons polyurethane adhesive can be primarily preferred for laminating of the wooden material left in air dried conditions.

Black pine samples laminated with epoxy and polyurethane glues were treated with various wood preservative chemicals and made subject to seawater for one year (Percin, 2007). The samples were made subject to bending tests perpendicular to the fibers, compression tests parallel to the fibers and adhesion tests. Significant changes were observed as a result of mechanical tests. It was determined that sea insects nested on the said samples and began to live there; sea worms destroyed the wooden surfaces by drilling into them. The said surfaces were covered with seaweed, and became extremely soft and there were white decays on some regions. In case of impregnated samples, very small changes occurred in odour and colour and moreover, decay was not seen.

The impregnation materials of Tanalith- C (CCA) and Protim 230WR were used as preservative and water repellant in another experiment (Ordu, 2007). Wooden materials were taken from beech and black pine. The samples were subject to weathering conditions for one year. At the end of this period, changes in the samples' bending strength, compression strength and physical properties were examined. As a result of this study, it was observed that no significant variations occurred in mechanical values of the impregnated samples; however, severe losses occurred in case of the non-impregnated samples. It was seen that impregnation type provides different protection according to the type of the wooden material. It was also observed that discoloration is more significant in the non-impregnated samples compared with those impregnated.

Winandy (1994) performed static bending strength tests on the samples from *Pinus caribaea* in his study. As a result of tests performed, impregnation with CCA causes significant loses in strength and hardness. Also, it was observed that breaking modulus of the samples impregnated with CCA decreased due to drying at high temperatures.

Feist and Ross (1995) left their samples from south pines and coastal firs treated with CCA and non-treated in Wisconsin and Mississippi toward south with an angle of 45° for 2 years under atmospheric conditions. At the end of this period, variations were observed between samples treated with CCA and non-treated samples and it was reported that performance of the samples treated with CCA is higher than that of non-treated. It was also concluded that, notwithstanding CCA amount, wooden materials from first treated with CCA yield better results compared with those from pine.

Winandy (1989) treated *Pinus taeda* timbers with CCA wood preservative, made them dry by air and then at 116°C in an oven. Drying process under atmospheric conditions done after impregnation process affected bending strength at a rate of 20-40% depending on the impregnation degree. Drying in furnace affected all bending strength distribution.

## Conclusions

After exposure of Scots pine specimens (impregnated and non-impregnated) to air dry conditions for a year, the following observations were made:

- In bending strength, reductions took place in non-impregnated samples by 19.95%, in tanalith-C impregnated samples by 11.97% and protim WR230 impregnated samples by 11.26%,
- In compression strength, reduction took place in non-impregnated samples by 5.51%, increases took place in tanalith-C impregnated samples by10.13% and in protim WR230 impregnated samples by 10.43%,
- In bonding strength, reduction occurred in non-impregnated samples by 8.31%, increases took place in tanalith-C impregnated samples by 36.05% and in protim WR230 impregnated samples by 35.69%,
- In physical properties, at the physical experiments of the impregnating test samples left in air dried conditions for one year, infection by fungi, dimensional deformation and damage by insect were not seen. Impregnating compounds obtained the needed preservation against fungi and insects. But, in non-impregnated samples, smell, colour change and medium white rot were observed.
- In impregnating test samples, water and relative humidity affected the bonding properties positively for one year, and this increased the bonding and compression strength. But bending strength was reduced. In determining the bonding and compression strengths, the applied force parallel to adhesive layer; while in determining bending strength the applied force is vertical to adhesive layer. In the bonding strength in non-impregnated samples the breaking is seen on the wooden material itself, not on the adhesive layer due to decaying wooden material.

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