

# Influence of Pretreatment on Shear Strength of Various Wood Species

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Received 18 April 2005; accepted 2 June 2005

DOI 10.1002/app.23030

Published online in Wiley InterScience (www.interscience.wiley.com).

**ABSTRACT:** A study was conducted to determine the effects of wood pretreatment on the bonding strength of wood materials. The woods used for the test samples (based on BS EN 204) were oriental beech (*Fagus orientalis* Lipsky), Scotch pine (*Pinus sylvestris* L.), oak (*Quercus petraea* Liebl.), and chestnut (*Castanea sativa* Mill.). They were impregnated with Tanalith-C, creosote, and Protim 230 WR-paraffin by full-cell methods according to ASTM D 1413-76 standards and the directions of the manufacturers. After impregnation, shear strength tests (based on BS EN 205) were applied on the samples bonded with poly(vinyl acetate) (PVAc), Desmodur-VTKA, and Pattex fast. The highest shear strength

was obtained in nonimpregnated (control) and PVAc-D<sub>1</sub> glued oak (5.328 N/mm<sup>2</sup>), and the lowest shear strength was obtained in Protim 230 WR-paraffin and Pattex fast glued chestnut (0.169 N/mm<sup>2</sup>). Accordingly, the impregnation process negatively affected the adhesive bonding strength. Impregnation chemicals, especially containing oily or similar substances, could not be proposed for wood elements exposed to shear strength. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 100: 245–252, 2006

**Key words:** adhesives; wood; mechanical properties; impregnation chemicals

## INTRODUCTION

Wood and lumber products are degraded by many organisms, principally fungus and insects. Consequently, lumber should be treated with biocides when it will be wetted frequently or placed in ground contact. In addition, before its economic life ends, the wood material may need to be repaired and renewed.<sup>1</sup> That is why wood materials must be impregnated with protective chemical substances before use.<sup>2</sup> Gluing is much more than an art; it is a science and is becoming more and more so daily.

In wood materials from the lowest to the highest quality, the selection and use of the right glue in the right way is of extreme importance and the right glue used properly is always the least expensive.<sup>3</sup>

The performance and behavior of adhesive systems for wood depend on a wide range of variables, such as the smoothness of the substrate surfaces, pH, presence of extractives, and amount of debris.<sup>4</sup> The bonding mechanism of the adhesive to the wood substrate can include covalent bonding, weaker forces such as van der Waals forces and hydrogen bonding, or mechanical interlocking.<sup>5,6</sup>

Although biological deterioration of wooden members has always occurred, it was not until the late

1970s that the American Institute of Timber Construction developed recommendations requiring that all exterior use laminated members be treated with preservatives.<sup>7</sup> Wood as a traditional construction material has been widely used in the transportation infrastructure. Glued laminated wood (glulam) materials have been used in bridge beams or stringers for approximately 30 years.<sup>8</sup>

Pressure treatment with wood preservatives has been known to interfere with the bond integrity of solid wood glued specimens. The preservative type, preservative retention, and interaction with the surface were reported as highly significant factors affecting the shear strength of glue bonds in solid wood samples.<sup>9–12</sup>

The demand for engineered wood products [such as oriented strand board, glulam, and laminated veneer lumber (LVL)] has increased because of a constant increase in the global population. The grain of each layer of veneer assembled into LVL runs parallel with each adjacent ply.<sup>13</sup> It is a homogeneous and dimensionally stable building material, so it can be used where strength and stability are required.<sup>14</sup>

Vick and collaborators<sup>10,11,15</sup> laminated preservative treated wood and reported that the lumen surfaces of chromated copper arsenate (CCA, a waterborne wood preservative) treated southern Scotch pine (*Pinus sylvestris* L.) were completely covered by hemispherically shaped deposits ranging in diameter from around 1.0 μm to essentially invisible at a magnification of 5000×.

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Poor bonding of creosote treated wood was attributed to a combination of improper wetting of the wood surfaces as well as inhibition of moisture absorption from the glue-line by the creosote, thus delaying or preventing proper cure.<sup>16</sup> Truax et al.<sup>17</sup> discussed the effects of preservatives and treatment on the strength of glue-lines and interference of the glue-line with the penetration of preservatives into the wood.

Ors et al.<sup>18</sup> reported that the highest shear strength (11.84 N/mm<sup>2</sup>) was obtained for wood materials of oriental beech (*Fagus orientalis* Lipsky) treated by Tanalith-CBC with Klebit 303 using the dipping method and the lowest shear strength (3.1 N/mm<sup>2</sup>) was obtained for Scotch pine treated by Tanalith-CBC with Kleiberit 305.0 using the vacuum method.

Another investigation by Sönmez et al. reported that, when Scotch pine wood is bonded with Desmodur-VTKA adhesive and impregnated with Tanalith-CBC by using full-cell methods, the hold resistance decreases.<sup>19</sup>

The aim of this experimental study is to determine the shear strength of wood materials of oriental beech, Scotch pine, oak (*Quercus petraea* Liebl.), and chestnut (*Castanea sativa* Mill.) that were impregnated with Tanalith-C, creosote, and Protim 230 WR-paraffin mixture by full-cell methods according to ASTM D 1413-76 standards and bonded with poly(vinyl acetate) (PVAc), Desmodur-VTKA, and Pattex fast.

## EXPERIMENTAL

### Wood materials

The wood species chosen randomly from the timber merchants of Karabük, Turkey, were chestnut, oak, Scotch pine, and oriental beech. Special emphasis was placed on the selection of the wood materials. Accordingly, nondeficient, knotless, proper, normally grown (without zone lines and reaction woods and without decay, insect, and fungus damage) wood materials were selected.

### Adhesives

Three different adhesives (each containing one component and solvent free) were used. These adhesives are usually preferable for the assembly process in the woodworking industry.

The adhesives used in this experiment were PVAc, Desmodur-VTKA, and Pattex. PVAc is an odorless, nonflammable adhesive. It can be used at low temperatures and solidifies quickly. The application of this adhesive is very easy and it does not damage tools during the cutting process. However, the mechanical resistance of PVAc adhesive is poor at elevated temperatures. It loses its bonding resistance capacity over

70°C. When using 150–200 g/m<sup>2</sup>, the adhesive seems to be suitable provided that it is applied to only one surface.

The TS 3891 standard procedure was used for applying the PVAc adhesive. The density of the PVAc should be 1.1 g/cm<sup>3</sup>, the viscosity should be 16.000 ± 3.000 mPa s, the pH should be 5, and the ash ratio should be 3%. A pressing time of 20 min for the cold process and 2 min and 80°C are recommended with 6–15% humidity for the jointing process. After a hot-pressing process, the materials should be clamped until their normal temperature is reached.<sup>20</sup> The PVAc adhesive was manufactured and supplied by Polisan (İzmit, Turkey).

The manufacturer<sup>21</sup> describes Desmodur-VTKA as a polyurethane-based component. A solvent-free adhesive is widely preferred for the assembly process in the woodworking industry. It is used for gluing wood, metal, polyester, stone, glass, ceramic, poly(vinyl carbonate), and other plastic materials. Its application is especially recommended in locations subject to high-level humidity. The gluing process was carried out at 20°C and 65% relative humidity. According to the manufacturer's advice, the adhesive was applied to the surfaces at 180–190 g/m<sup>2</sup>. Its viscosity was –14,000 ± 3000 mPa s at 25°C, and its density was 1.11 ± 0.02 g/cc at 20°C.

Pattex fast adhesive has two components according to the manufacturer.<sup>22</sup> The raw materials of Pattex fast are heptan and acetone. It is used for gluing wood, medium density fibreboard (mdf), rubber, chipboard, poly(vinyl carbonate), and other plastic materials and for repair of wood pieces. Its application is especially recommended in locations subject to dryness and purified from dust. Its viscosity and density are 1200–1700 cP and 0.684 g/cm<sup>3</sup>, respectively, at 25°C. It can be used in climates between –50 and +80°C. Its resistance against break-off is 20 N/mm<sup>2</sup>.

### Impregnation materials

Creosote, a mixture of different distillation fractions of hard coal tar, consists of many polyaromatic and heterocyclic compounds. The main components are naphthalene, quinoline, acenaphthene, dibenzofurane, fluorene, phenanthrene, anthracene, fluoranthene, and pyrene.<sup>23</sup> The creosote was produced and supplied by Kardemir (Karabük, Turkey). The analytical values of creosote given by KARDEMİR are 64% phenol, a density of 1.120 g/cm<sup>3</sup>, 0.8% H<sub>2</sub>O, and sediment absent at 32°C.

A Tanalith-C 1% concentration was used in this study. It was supplied by Hemel (Istanbul, Turkey). The contents of Tanalith-C were 30.2% and 52.8 g/L chromium trioxide, 11.2% and 196 g/L copper oxide, and 17.3% and 303 g/L arsenic pentoxide.

Pressure impregnation of timber using waterborne preservatives, such as Tanalith-C, of CCA by the full-cell process is an important method to increase the natural durability of wood against deteriorating organisms, and hence increase its service life. Efficient penetration and uniform distribution of the preservative salt is achieved by pressure impregnation as the preservative is driven via the wood capillary system. Factors of prime consideration governing the flow are the amount of pressure, fluid viscosity, solvent contact angle, wood pore radius, and wood capillary length.<sup>24</sup>

CCA is a wood preservative formulation containing copper, chromium, and arsenic. The copper acts as the main fungicide and provides some protection against termites. Arsenic provides protection against termites and copper-tolerant decay fungus. Chromium helps to bond and fix the chemical components to the wood.<sup>25</sup>

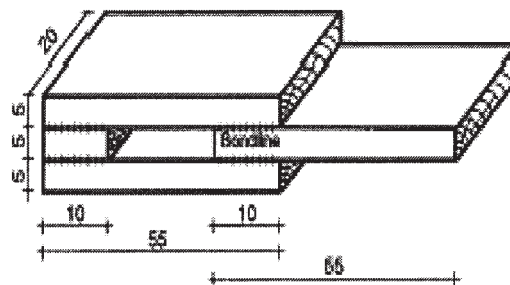
In addition, a 50/50 concentration ratio mixture of Protim 230 WR–paraffin was used.

Protim 230 WR is a pretreatment material based on an organic solvent. It is easily applied to the wood material by the dipping method and when necessary it is applied in factories. It has high resistance against fungus, insects that cause damage, and termites. Because it is water free, it does not cause any swelling or any changes in the dimensions. It contains water repellent additives that decrease the changes in the dimensions of the wood materials. It does not cause corrosion on metal connection elements. Protim 230 WR was supplied by Senkron A.Ş. (Istanbul). According to the manufacturer, its active components are Tributyl stannum naphthanat and permethrin, it is straw colored, its flash point is at least at 36°C, its density is 0.8 g/cm<sup>3</sup>, and it is ready for instant use and must not be diluted. The usage amount of this material changes between 15 and 40 L/m<sup>3</sup>, depending on the wood species and type of impregnation.

Paraffin was supplied by Cepni A.Ş., a distributor in Karabük, Turkey. They describe paraffin as a waxy crystalline substance that in the pure form is white, odorless, and translucent and has the approximate chemical formula of C<sub>20</sub>H<sub>42</sub> (and above). It is obtained from petroleum by distillation and is then purified by sweating or solvent refining. Paraffin, which is not a true wax, consists mainly of a mixture of saturated straight-chain solid hydrocarbons. Its melting points range from 50 to 57°C. It is used in the manufacture of certain types of paper, in leather dressings, in marbling, in producing paraffin prints, and so forth.

### Determination of density

The dry densities of the wood materials used for the preparation of treatment samples were determined according to TS 2472. Accordingly, air-dried samples were oven dried up to 103 ± 2°C until they reached constant weights. Then, the samples were cooled in a



**Figure 1** The test sample with the sizes given in millimeters.

desiccator containing calcium chloride and weighed in an analytic balance with ±0.01 g sensitivity. Afterward, the dimensions of the wood materials were measured by a compass with ±0.001 mm sensitivity and the volumes were determined by the stereometric method. The perfect dry density ( $\delta_0$ ) was calculated with the following equation:

$$\delta_0 = M_0/V_0 \quad (\text{g/cm}^3) \quad (1)$$

where  $M_0$  is the perfect dry weight (g) and  $V_0$  is the dry volume (g/cm<sup>3</sup>) of the wood material.

### Preparation of experimental samples

The wood samples cut from sap wood were conditioned at 20 ± 2°C and 65 ± 3% relative humidity until they reached constant weight by holding them for 3 months in a climatization room. There were 480 test samples with 12% average moisture with dimensions of 55 × 20 × 10 mm according to the procedure of BS EN 204 for each wood species.

The impregnation process was carried out according to the principles of ASTM D 1413-76. A vacuum, which was equal to 60 cmHg, was applied to the samples. They were then dipped for 60 min in a solution subject to open air pressure.

Before the impregnation process all samples were weighed and then kiln dried at 103 ± 2°C until they reached constant weight. Then, the samples were weighed in an analytic balance with 0.01-g sensitivity. After impregnation, all impregnated samples were held for 15 days in circulating air for evaporation of the solvent.

After this period the impregnated samples (except paraffin) were kiln dried at 103 ± 2°C until they reached constant weight. The samples that had paraffin were kiln dried at 55°C till they reach constant weight, because paraffin melts at 50°C or above.

After cooling, all dried samples in the desiccator were weighed on the scale. The dry weights of the samples were determined and recorded. The amount

**TABLE I**  
Perfect Dry Densities (g/cm<sup>3</sup>) of Wood Materials

| Wood species   | Before impreg. | Tanalith-C |     | After impreg. creosote |      | Protim 230 WR-paraffin |     |
|----------------|----------------|------------|-----|------------------------|------|------------------------|-----|
|                | Mean           | Mean       | %   | Mean                   | %    | Mean                   | %   |
| Scotch pine    | 0.508          | 0.550      | 8.3 | 0.536                  | 5.5  | 0.525                  | 3.3 |
| Oak            | 0.653          | 0.732      | 12  | 0.704                  | 7.8  | 0.661                  | 1.2 |
| Oriental beech | 0.669          | 0.765      | 14  | 0.740                  | 10.6 | 0.702                  | 4.9 |
| Chestnut       | 0.593          | 0.632      | 6.5 | 0.615                  | 3.7  | 0.610                  | 2.8 |

The percentages are fractional increases over control densities.

of retention ( $R$ , kg/m<sup>3</sup>) and ratio of retention ( $R$ , %) were calculated as follows:

$$R = \frac{G \times C}{V} 10^3 \quad (\text{kg/m}^3) \quad (2)$$

$$R(\%) = \frac{M_{di} - M_d}{M_d} 100 \quad (3)$$

where  $G$  is the mass of the sample after impregnation ( $T_2$ , kg) minus the mass of the sample before impregnation ( $T_1$ , kg),  $M_{di}$  is the dry mass after impregnation (kg),  $M_d$  is the dry mass before impregnation (kg),  $V$  is the volume of the sample (m<sup>3</sup>), and  $C$  is the concentration of the solution (%).

The characteristic features of the impregnation chemicals were determined before and after impregnation processes. All processes were carried out at  $20 \pm 2^\circ\text{C}$ . Impregnated test samples were kept at  $20 \pm 2^\circ\text{C}$  and  $65 \pm 3\%$  relative humidity until they reached constant weight. Afterward, approximately 150–200 g/m<sup>2</sup> adhesive was applied to the bonding surfaces of samples, based on TS 5430. Bonding was obtained with 0.5 N/mm<sup>2</sup> press pressure and 24-h pressing time. The perspective of the test specimen is shown in Figure 1.

### Application of experiment

The shear strength test was carried out according to the procedure of BS EN 205 standards. The loading was continued until a break or separation occurred on the surface of the test samples. The observing load

( $F_{\max}$ ), bonding surface of the sample ( $A$ , mm<sup>2</sup>), and shear strength ( $\sigma_k$ ) were calculated as follows:

$$\sigma_k = F_{\max}/2A = F_{\max}/2(ab) \quad (\text{N/mm}^2) \quad (4)$$

where  $a$  is the width of the glued face (10 mm) and  $b$  is the length of the glued face (20 mm).

### Data analyses

By using three different types of glue, three impregnation chemicals and one control sample, one kind of process, and four wood types as parameters, a total of 480 samples ( $3 \times 4 \times 4 \times 10$ ) were prepared using 10 samples for each parameter. Multiple analyses of variance were used to determine the differences between the bonding strengths of the jointing surfaces of the prepared samples. The Duncan test was used to determine whether there was a significant difference between the groups.

## RESULTS AND DISCUSSION

### Density

The dry densities of the wood materials used for the preparation of the test samples are indicated in Table I. The densities of the wood pieces were increased after the impregnation process. The highest increase of 14% was determined for oriental beech with 0.765 g/cm<sup>3</sup> Tanalith-C.

**TABLE II**  
Variation in pH and Density

| Impregnation type      | pH             |               | Density        |               |
|------------------------|----------------|---------------|----------------|---------------|
|                        | Before impreg. | After impreg. | Before impreg. | After impreg. |
| Tanalith-C             | 2.36           | 2.58          | 1.62           | 1.68          |
| Protim 230 WR-paraffin | 5              | 5.2           | 1.27           | 1.32          |
| Creosote               | 5.88           | 5.78          | 1.12           | 1.15          |

**TABLE III**  
**Retention Amount of Wood Species for Impregnation Type (kg/m<sup>3</sup>)**

| Impreg. type              | Wood sp.       | Minimum | Maximum | Mean  | SD      | Variance |
|---------------------------|----------------|---------|---------|-------|---------|----------|
| Tanalith-C                | Scotch pine    | 8.60    | 9.00    | 8.80  | 0.10801 | 0.012    |
|                           | Oak            | 12.29   | 12.45   | 12.37 | 0.52068 | 0.003    |
|                           | Oriental beech | 12.82   | 12.95   | 12.91 | 0.35901 | 0.001    |
|                           | Chestnut       | 6.00    | 6.10    | 6.051 | 0.02750 | 0.001    |
| Creosote                  | Scotch pine    | 408.0   | 416.0   | 412.0 | 2.309   | 5.333    |
|                           | Oak            | 680.0   | 694.0   | 687.0 | 4.447   | 19.778   |
|                           | Oriental beech | 755.0   | 785.0   | 770.0 | 8.831   | 78.000   |
|                           | Chestnut       | 379.0   | 391.0   | 385.0 | 3.829   | 14.667   |
| Protim 230<br>WR-paraffin | Scotch pine    | 540.0   | 560.0   | 550.0 | 5.374   | 28.889   |
|                           | Oak            | 621.0   | 643.0   | 632.0 | 7.071   | 50.000   |
|                           | Oriental beech | 705.0   | 725.0   | 715.0 | 5.477   | 30.000   |
|                           | Chestnut       | 270.0   | 280.0   | 275.0 | 2.581   | 6.667    |

**Peculiarities of impregnation solutions**

The variations in the pH and density of the impregnation type before and after the impregnation are indicated in Table II. As a result of using fresh solution in every impregnation process, there was no important change in the acidity and density of the solutions before and after impregnation. The pH value of the Tanalith-C solution was 2.36. This means that it is in the acidic zone and it may be effectual on the polysaccharide of the wood.

**Retention quantities**

The quantities of retention due to wood species and impregnation type are provided in Table III. The highest retention amount was 770 kg/m<sup>3</sup> in oriental beech impregnated with creosote and the lowest retention amount was 6.051 kg/m<sup>3</sup> in chestnut impregnated with Tanalith-C. Because of the impact of the perme-

ability of oriental beech, the highest retention was obtained in oriental beech of all impregnation types. In addition, the resin in pine, side compounds in chestnut, and thyll in oak could affect this result.

**Shear strength**

The average shear strength values obtained for different species of wood materials are given in Table IV. The average shear strength is calculated in Table IV according to the species of wood material, impregnation chemicals, and types of adhesives.

The shear strength values of oak and beech samples, which have higher density than Scotch pine and chestnut, are higher than those for Scotch pine and chestnut.

The highest shear strength was obtained in the control samples. The results indicate that the impregnation materials decrease the bonding strength values. Compared

**TABLE IV**  
**Average Shear Strength According to Types of Material**

|                        | Mean<br>(N/mm <sup>2</sup> ) | Hg | SE    | 95% Confidence interval |             |
|------------------------|------------------------------|----|-------|-------------------------|-------------|
|                        |                              |    |       | Lower bound             | Upper bound |
| Wood material          |                              |    |       |                         |             |
| Pine                   | 2.025                        | A  | 0.059 | 1.908                   | 2.141       |
| Oak                    | 2.183                        | AB | 0.059 | 2.066                   | 2.300       |
| Oriental beech         | 2.216                        | B  | 0.059 | 2.099                   | 2.333       |
| Chestnut               | 2.030                        | A  | 0.059 | 1.913                   | 2.147       |
| Impregnation chemicals |                              |    |       |                         |             |
| Tanalith-C             | 1.733                        | B  | 0.059 | 1.616                   | 1.849       |
| Creosote               | 1.512                        | A  | 0.059 | 1.395                   | 1.629       |
| Protim 230 WR-paraffin | 1.410                        | A  | 0.059 | 1.293                   | 1.527       |
| Control samples        | 3.799                        | C  | 0.059 | 3.682                   | 3.916       |
| Adhesives              |                              |    |       |                         |             |
| PVAc-D1                | 2.503                        | B  | 0.051 | 2.402                   | 2.604       |
| Polimarin              | 2.585                        | B  | 0.051 | 2.484                   | 2.686       |
| Pattex fast            | 1.252                        | A  | 0.051 | 1.151                   | 1.353       |

Hg, homogeneity.

**TABLE V**  
Results of Duncan Test ( $\sigma_k$ (N/mm<sup>2</sup>))

| Wood mater., impreg. type, & adhes. | x     | Hg    | Wood mater., impreg. type, & adhes. | x     | Hg     |
|-------------------------------------|-------|-------|-------------------------------------|-------|--------|
| IV-P-3                              | 0.169 | A     | I-T-1                               | 2.004 | GHIJK  |
| IV-T-3                              | 0.281 | A     | III-T-1                             | 2.023 | GHIJKL |
| III-P-3                             | 0.316 | AB    | II-K-3                              | 2.148 | HJKLM  |
| II-P-3                              | 0.333 | AB    | IV-C-2                              | 2.187 | IJKL   |
| III-T-3                             | 0.377 | AB    | III-T-2                             | 2.246 | JKLM   |
| II-C-3                              | 0.384 | AB    | IV-P-1                              | 2.317 | JKLMN  |
| I-P-3                               | 0.499 | ABC   | IV-T-2                              | 2.361 | JKLMN  |
| III-C-1                             | 0.690 | ABCD  | I-C-2                               | 2.398 | JKLMN  |
| I-C-3                               | 0.720 | ABCD  | I-T-2                               | 2.476 | JKLMN  |
| II-C-1                              | 0.967 | BCDE  | IV-K-3                              | 2.518 | KLMN   |
| I-T-3                               | 0.984 | BCDE  | IV-P-2                              | 2.697 | LMNO   |
| IV-C-1                              | 0.987 | BCDE  | III-C-2                             | 2.871 | MNO    |
| III-P-2                             | 1.065 | CDE   | II-C-2                              | 2.954 | NO     |
| III-C-3                             | 1.070 | CDE   | I-K-3                               | 3.214 | OP     |
| IV-C-3                              | 1.085 | CDE   | IV-K-2                              | 3.265 | OP     |
| I-P-2                               | 1.100 | CDE   | I-K-2                               | 3.626 | PR     |
| I-P-1                               | 1.114 | CDE   | II-T-1                              | 4.076 | RS     |
| II-T-3                              | 1.129 | CDE   | I-K-1                               | 4.329 | ST     |
| II-T-2                              | 1.256 | DEF   | II-P-2                              | 4.358 | ST     |
| II-P-1                              | 1.452 | EFG   | III-K-2                             | 4.686 | ST     |
| III-P-1                             | 1.492 | EFGH  | III-K-3                             | 4.799 | TU     |
| IV-T-1                              | 1.570 | EFGHI | IV-K-1                              | 4.917 | TU     |
| II-K-2                              | 1.803 | FGHIJ | III-K-1                             | 4.953 | TU     |
| I-C-1                               | 1.825 | FGHIJ | II-K-1                              | 5.328 | U      |

I, Pine; II, oak; III, oriental beech; IV, chestnut; T, Tanalith-C; C, creosote; P, Protim 230 WR-paraffin; K, control samples; 1, PVAc-D<sub>1</sub> poly(vinyl acetate); 2, Polimarín (Desmodur-VTKA); 3, Pattex fast.

to the types of adhesives, the highest shear strength was obtained in Polimarín and PVAc-D<sub>1</sub> adhesives and the lowest shear strength was obtained in Pattex fast.

The difference between groups in regard to the effect of variance sources on the shear strength was

significant (5%). The Duncan test results used to determine the importance of the differences between the groups are given in Table V.

According to the mean comparisons, the highest shear strength was obtained in oak control samples

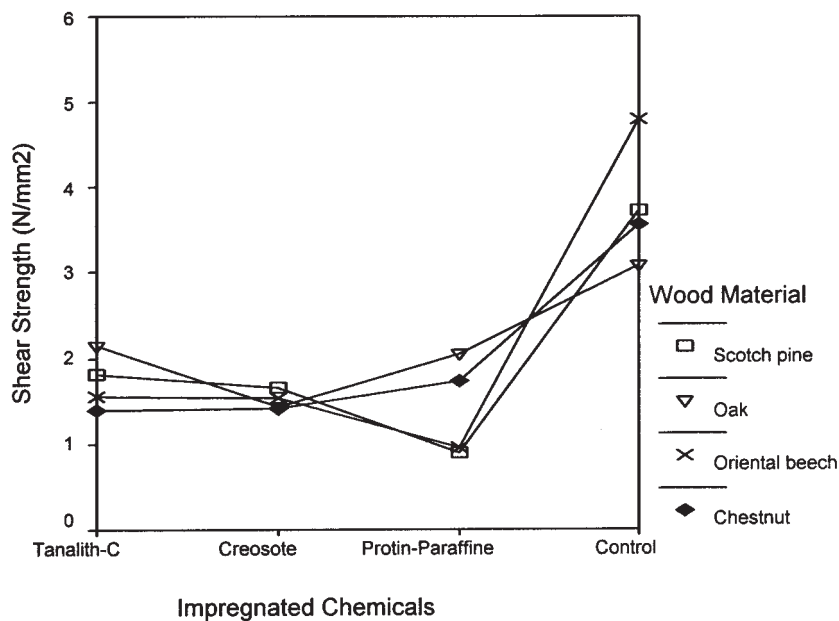


Figure 2 The shear strength according to the impregnation chemicals and wood materials.

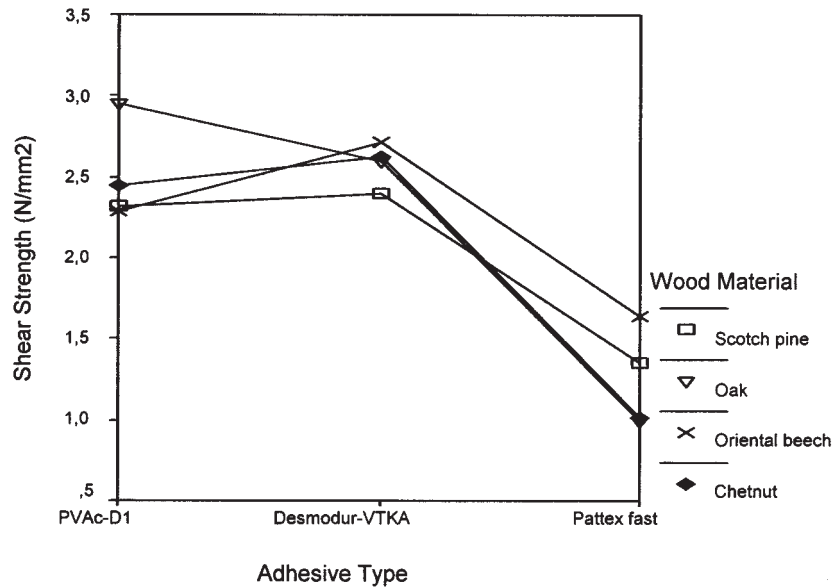


Figure 3 The shear strength according to the adhesive type and wood materials.

(5.328 N/mm<sup>2</sup>) bonded with PVAc-D<sub>1</sub> and the lowest shear strength was obtained in chestnut (0.169 N/mm<sup>2</sup>) impregnated with Protim 230 WR–paraffin and bonded with Pattex fast.

The shear strengths according to the impregnation type and wood species are shown in Figure 2. As seen from the figure, the bonding strength was lower in impregnated samples. The lowest shear strength was obtained in Scotch pine and oriental beech samples impregnated with Protim 230 WR–paraffin.

The shear strength according to the adhesive types and wood species are provided in Figure 3. The lowest shear strength was obtained in chestnut and oak samples bonded with Pattex fast.

## CONCLUSION

The densities of the wood pieces were increased after the impregnation process. The highest density increase was observed in oriental beech of all impregnation chemicals. The highest increase with 14% was determined as 0.765 g/cm<sup>3</sup> for oriental beech impregnated with Tanalith-C. On the contrary, the lowest density increase with 1.2% was obtained in oak impregnated with Protim 230 WR–paraffin.

When observing the rates of retention, except for Tanalith-C 1%, creosote had a higher value than the value of the mixture of Protim 230 WR–paraffin. The amounts of retention in the wood species are as follows: according to the impregnation process peculiarities, beech and oak in the permeable group had the highest value, Scotch pine in the semipermeable group had a lower value, and chestnut in the least permeable group had the lowest value.

In impregnated samples, the highest shear strength among wood species was obtained in oak, among adhesive types in PVAc-D<sub>1</sub> adhesive, and among impregnation chemicals in Tanalith-C. In this respect, the ranges from higher to lower shear strength were oak, oriental beech, chestnut, and pine among wood species; PVAc-D<sub>1</sub>, Desmodur VTKA, and Pattex fast among adhesive types; and control samples, Tanalith-C, creosote, and Protim 230 WR–paraffin among the impregnation chemicals. If the wood materials impregnated with impregnation chemicals contain oily or similar substances, there was a decrease in the shear strength.

Higher shear strength values were obtained in wood materials that were not impregnated. A similar study established that the longer the dipping period is during the impregnation process of Imersol-Aqua of wood species, the higher the retention quantities are, causing a decrease in shear strength. Consequently, an evaluation of the shear strength indicated that oak, PVAc-D<sub>1</sub>, and Tanalith-C gave better shear strength in the test samples. Thus, beech wood, PVAc-D<sub>1</sub>, and Tanalith-C could be proposed for wood elements exposed to shear strength.

## References

- Richardson, B. A. Wood Preservation; Construction Press: Lancaster, UK, 1987.
- Arsenault, R. D. In Preservatives and Preservatives Systems; Nicholoss, D. D., Ed.; Syracuse University Press: Syracuse, NY, 1978; Vol. II, p 121.
- Franklin International. Gluing and Furniture Design; Franklin International: Columbus, OH, 1998.

4. Pizzi, A. *Wood Adhesives Chemistry and Technology*, 1st ed.; New York: Marcel Dekker, 1983; Vol. 12.
5. Skeist, I. *Handbook of Adhesives*, 1st ed.; Van Nostrand Reinhold: New York, 1962; Vol. 669.
6. Packham, D. E. *Handbook of Adhesives*, 1st ed.; London: Longman, 1992; Vol. 407.
7. American Institute of Timber Construction. AITC109-98—Standard for Preservative Treatment of Structural Glued Laminated Timber; American Institute of Timber Construction: Englewood, CO, 1998; p 1.
8. Wipf, T. J.; Klaiber, F. W.; Funke, R. W. *J Struct Eng* 1990, 116, 1121.
9. Vick, C. B. In *Proceedings of the Wood Adhesive Symposium*; Forest Products Society: Madison, WI, 1998; p 47.
10. Vick, C. B.; Groot, R. C. D.; Youngquist, J. *Forest Products J* 1990, 40, 16.
11. Vick, C. B.; Christiansen, A. W. *Wood Fiber Sci* 1993, 25, 77.
12. Vick, C. B. *Forest Products J* 1981, 31, 34.
13. Badwin, R. F. *Plywood and Veneer-Based Products: Manufacturing Practices*; Miller Freeman: San Francisco, CA, 1995.
14. Colak, S.; Aydın, I.; Demirkır, C.; Colakođlu, G. *Turk J Agric* 2004, 28, 109.
15. Vick, C. B.; Kuster, T. A. *Wood Fiber Sci* 1992, 24, 36.
16. Kilmer, R. W.; Blankenhorn, P. R.; Labosky, P.; Janowiak, J. J. *Wood Fiber Sci* 1998, 30, 175.
17. Truax, T. R.; Blew, J. O.; Selbo, M. L. In *Proceedings of the American Wood Preservers' Association*; American Wood Preservers' Association: New York, 1953; p 113.
18. Ors, Y.; Atar, M.; Özçifçi, A. *J Appl Polym Sci* 2000, 76, 1472.
19. Sönmez, A. The Effects of Impregnation Chemicals of Scotch Pine Impregnated with Tanalith-CBC on Bonding Strength of Adhesive; *The Turkish Building Sci Tech and News Journal*: Ankara, 1996.
20. Turkish Standards Institution. *Adhesives-Polyvinylacetate Emulsion*; TS3891, Ankara, 1983.
21. Polisan Dilovası-Gebze. *Instruction Manual*; Polisan Dilovası-Gebze: Kocaeli, Turkey, 1999.
22. Henkel-Gebze, Çayırova. *Instruction Manual*; Henkel-Gebze, Çayırova: Kocaeli, Turkey, 2002.
23. Becker, L. Ph.D. Dissertation, Technische Universität München, 1997.
24. Siau, J. F. *Flow in Wood*; Syracuse University Press: Syracuse, NY, 1971.
25. <http://www.treatedwood.com/performance/faq.html>.