# Bond Strength and Durabilty Behavior of Polyurethane-Based Desmodur-VTKA Adhesives Used for Building Materials After Being Exposed to Water-Resistance Test

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**ABSTRACT:** Polyurethane adhesives are being used increasingly in the construction of furniture frames and buildings. Yet, there is little information available concerning the durability behavior of polyurethane adhesives on various wood species, after being exposed to water-resistance test. For this purpose, oriental beech (*Fagus orientalis L.*), oak (*Qercus petraea spp*.), and scotch pine (*Pinus sylvestris lipsky*) woods were chosen as test materials and bonded with Desmodur-VTKA polymarine, according to the procedure of BS EN 204 standards. The shear strength test was applied to the samples, according to the procedure of BS EN 205 standards, before and after immersion in cold water and in hot water, and afterward boiled and boiled recurrently. At the end of the shear test, it was found that Desmodur-VTKA polymarine had lost its durability. The highest shear strength (10.723 N/mm$^2$) was obtained in oak samples not exposed to water-resistance test. Owing to dissimilar swelling of Desmodur-VTKA polymarine and oak, resulting from moisture sorption, oak samples lost 85.6% of its strength after being boiled and boiled recurrently, and gave the lowest shear strength as 1.540 N/mm$^2$. As a result, if Desmodur-VTKA is used as an adhesive material in the long-term humidity condition, it cannot be recommended for bonding of wood materials with high density.  J Appl Polym Sci 100: 3943–3947, 2006

**Key words:** adhesives; mechanical properties; shear; strength and degradation

## INTRODUCTION

Much of the research that has been done over the years in the area of wood-based adhesives has mainly been in bond performance and durability and in the development of new adhesives from various resources. The performance and behavior of adhesives for wood are related to various variables, such as smoothness of substrate surfaces, pH, presence of extractives, and amount of debris.[1] An adhesive is a substance capable of holding materials together by surface attachment. An adherend is a substrate held to another substrate by an adhesive. The bonding process of the adhesive to the wood substrate has covalent bonding, weaker forces, such as vander Waals forces and hydrogen bonding, or mechanical interlocking.[2,3]

Wooden building materials are used indoor and outdoor and also at wet and dry surfaces. In this usage, parts of wood that are styled and processed with special methods should be joined. Since mechanical joint methods were not enough, they were not taken into consideration; the other method, which is based on glue connection parts, began to be used. Nowadays, the types of adhesives are increasing and gradually new glues are being introduced to markets. The places where these glues can be used have been determined or classified as dry, moist, high moisture, and wet places or environments.

Today, the synthetic resins are produced according to the wood materials used on dry and humid conditions. They are also convenient to be used in the workshop and mass production. To prevent materials scarps and to increase the quality, researchers have continued on the development of glue and its new application areas.[4]

Adhesives based on urea–formaldehyde and phenol–formaldehyde are commonly used for building materials,[5–7] but are very sensitive to hydrolysis[8,9] and stress scission.[10] To be able to solve such problems, scientists are trying to develop new polymeric adhesives.[11,12] Polyurethane (PU) is a class of polymer that is used in coatings, elastomeric items, foams, and adhesives.[13] PU adhesive has developed a reputation for reliability and high performance.[14]

Sandip and coworkers evaluated the adhesive performance of the PU adhesives on bonding of wood by lap-shear tests. The changes in lap-shear strength before and after exposure to cold water, hot water, acid, and alkali were evaluated. Development of bond

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**TABLE I**
**Test Procedure of Water-Resistance (EN 204 Anonym) [10,11]**

| Serial number of conditioning procedure | Procedures |
|---|---|
| I (control) | 1. Conditioned for 7 days in standard atmosphere (20 ± 2)°C and at relative humidity (65 ± 3)%. |
| II | 1. Conditioned for 7 days in standard atmosphere (as in I plus). |
| | 2. Immersed for 24 h in water at 20°C. |
| III | 1. Conditioned for 7 days in standard atmosphere (as in II plus). |
| | 2. Immersed for 24 h in water at 20°C (as in II plus). |
| | 3. First immersed for 3 h in water at 67°C (as in II plus) and then immersed for 6 h in water at 20°C. |
| IV | 1. Conditioned for 7 days in standard atmosphere(as in III plus). |
| | 2. Immersed for 24 h in water at 20°C (as in III plus). |
| | 3. Immersed for 3 h in water at 67°C and then immersed for 6 h in water at 20°C (as in III plus). |
| | 4. Boiled in water for 6 h and then immersed for 2 h in water at 20°C. |
| V | 1. Conditioned for 7 days in standard atmosphere (as in IV plus). |
| | 2. Immersed for 24 h in water at 20°C (as in IV plus). |
| | 3. Immersed for 3 h in water at 67°C and then immersed 6 h at 20°C water (as in IV plus). |
| | 4. Boiled in water for 6 h and then immersed for 2 h in water at 20°C (as in IV plus). |
| | 5. Boiled for 4 h in water then dried at 20°C in air and boiled for 4 h in water finally, immersed for 2 h in water at 20°C. |

strength to wood was determined by means of tests, at regular intervals. Also, curing time required for different adhesive formulations were determined, and they found that the PU adhesive derived from natural products was superior to the commercially available adhesive.[15]

It is reported that when scotch pine woods (*Pinus sylvestris lipsky*) are bonded with Desmodur-VTKA adhesive and T-CBC impregnation solution by using full-cell methods, the impregnation solutions have decreased the bonding resistance of Desmodur-VTKA adhesive.[16]

It is observed that the joints of oriental beech (*Fagus orientalis L.*), scotch pine (*Pinus sylvestris lipsky*), and oak (*Quercus petraea spp.*), which are bonded with Desmodur-VTKA, have changed their shear resistance after climatization process, being held in the cold, hot, and boiling water.[17]

Since there is little information available concerning the durability behavior of PU adhesives on various

## LIST OF FIGURES

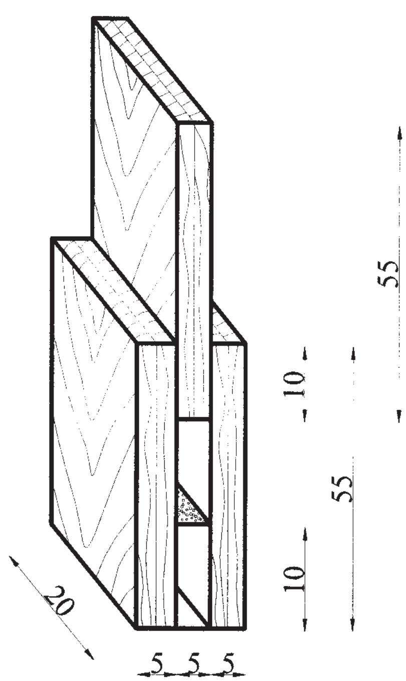


**Figure 1** The test sample (all dimensions are in millimeters).

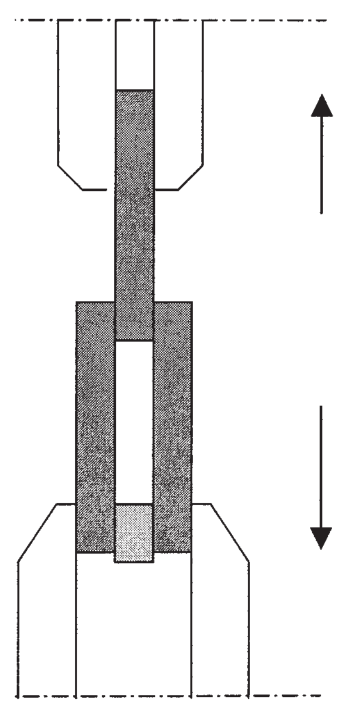

**Figure 2** Schematic of the tensile experiment fixture.

**TABLE II**
**Average Shear Strengths According to the Wood Species**

| Wood species | $\sigma_s$ (N/mm$^2$) | HG |
|---|---|---|
| Beech | 4.883 | A |
| Oak | 4.380 | B |
| Scotch pine | 3.957 | C |

wood species after being exposed to water-resistance test, we have tried to emphasize the bonding resistance and durability of the woods of oriental beech (*Fagus orientalis lipsky*.), scotch pine (*Pinus sylvestris lipsky*), and oak (*Quercus petraea spp*.) bonded with Desmodur-VTKA adhesive, before and after being exposed to standard atmosphere, cold and hot water, and boiling and recurrence boiling operations by applying shear-strength test.

## EXPERIMENTAL

### Wood materials

The woods of oriental beech (*Fagus orientalis l.*) with 0.66 g/cm$^3$ density, scotch pine (*Pinus sylvestris lipsky*) with 0.52 g/cm$^3$ density, and oak (*Quercus petraea spp.*) with 0.69 g/cm$^3$ density were chosen randomly from timber merchants of Ankara, Turkey. A special emphasis was put on the selection of the wood materials. Accordingly, nondeficient, proper, knotless, normally grown (without zone line, reaction wood, decay, insect and fungal infections) wood materials were selected.

### Adhesive

Desmodur-VTKA adhesive has been preferable for the assembly process in the furniture industry recently. It is a single component, solvent-free, and PU-based adhesive. It was used for gluing wood, metal, polyester, stone, glass, ceramic, PVC, and other plastic materials. It was specially recommended for the application in the location subjected to high-level humidity.

TS 3891 standard procedure was used for applying Desmodur-VTKA.[18] It was supplied from the manufacturer, Polisan in Gebze/Turkey.[19]

Desmodur-VTKA adhesive was applied under cold conditions. Its density was 1.1 g/cm$^3$, pH was ~7, and viscosity was 3300–4000 cps at 25°C. At 20°C and 65% relative humidity, it solidifies in 30 min. Owing to its foaming character, polymarine adhesive can also be successfully used as a sealant or as a flexible filling agent. Being resistant to cold, it can be applied by hand. It was recommended that Desmodur-VTKA adhesive should be applied to both surfaces at 180–200 g/m$^2$, and the adhesives should be pressed for about 30 min.[19]

### Preparation of experimental samples

The wood samples, which were cut from sapwood, were conditioned at (20 ± 2)°C and at (65 ± 3)% relative humidity, until their weights became stable, by holding them for 3 months in a conditional room; afterward, when the test samples reached 12% average moisture they were cut according to the procedure of TS 5430. For each wood species, 50 samples (totally 150 samples) were prepared.[20]

Prepared test samples were conditioned at (20 ± 2)°C and at (65 ± 3)% relative humidity, until their weights became stable. The test procedure is given in Table I.

After applying glue to the surface of the test samples (~180–200 g/m$^2$), they were pressed under 0.2 N/mm$^2$ pressure for 30 min. Bonded test samples are shown in Figure 1.

### Application of experiment

The shear strength test was carried out, according to the procedure of BS EN 205 standards.[21] The loading speed was 50 mm/min (Fig. 2).

The loading was carried out until breaking occurs or separations occur on the surface of the test samples. Meanwhile, the load observed (Fmax), bonding surface of the sample (A, in mm2), and shear strength ($\sigma$s) were calculated as follows;

$$\sigma_S = \frac{F_{\max}}{2A} = \frac{F_{\max}}{2(ab)} \quad (1)$$

**TABLE III**
**Average Shear Strength (N/mm$^2$) According to the Interaction of Wood Species and Procedure**

| Procedure | Scotch pine | Decrease (%) | Oriental beech | Decrease (%) | Oak | Decrease (%) |
|---|---|---|---|---|---|---|
| I (control) | 7.224 | – | 9.353 | – | 10.723 | – |
| II | 3.360 | 53.4 | 4.261 | 54.4 | 4.675 | 56.4 |
| III | 3.334 | 53.8 | 3.659 | 60.8 | 2.772 | 74.1 |
| IV | 3.020 | 58.1 | 3.608 | 61.4 | 2.191 | 79.5 |
| V | 2.847 | 60.5 | 3.534 | 62.2 | 1.540 | 85.6 |

**TABLE IV**
**The Results of Multiple Variance Analysis of Wood Species and Procedure**

| Sources | Degrees of freedom | Sum of squares | Means square | *F*-value | Probabilty of 5% |
|---|---|---|---|---|---|
| Int-A | 2 | 21.490 | 10.745 | 75.7028 | 0.0000 |
| Int-B | 4 | 861.618 | 215.415 | 1517.630 | 0.0000 |
| Error | 135 | 19.161 | 0.142 | 74.3400 | |
| Total | 149 | 986.680 | | | |

Int-A, Material (scotch pine, oriental beech, oak); Int-B, procedure I (control), procedure II, procedure III, procedure VI, and procedure V.

where $\sigma_s$ is the shear strength, a is the width of bonded face (10 mm), and *b* is the length of bonded face (20 mm).

### Data analyses

By using five different methods (procedure I (control), procedure II, procedure III, procedure IV, and procedure V) and three different kinds of wood species as parameters, a total of 150 samples with $5 \times 3 \times 10$ mm$^3$ dimensions were prepared, using 10 samples for each parameter. Multiple variance analysis has been performed to determine the differences between bonding strength and the joining surfaces of the prepared samples. Should there be a significant difference between the groups, then, Duncan test was applied.

## RESULTS

The average values of shear strength obtained from different species of wood materials are given in Table II. The average values of shear strength and interaction of wood species and procedure are also given in Table III. The results of multiple analyses with regard to the effects of wood species are given in Table IV.

When the wood species were evaluated among themselves, the highest value of shear strength was found for beech wood materials. This may be because the beech wood has a homogenous structure and smooth surface, and Desmodur-VTKA adhesive gives a stronger adhesion on the beech wood surface.

The highest shear strength values were found for control samples of all species, and the lowest values were found for procedure V. When the average values and the decreases of shear strength are evaluated, there is a linear relationship between the densities of wood samples and a decrease of shear strength. In parallel, with the swelling of wood, there occurs a failure in the bonding line.

The difference between the groups regarding the effect of variance sources on shear strength has been significant ($\alpha = 5\%$). Duncan test results, conducted to determine the importance of differences between the groups are given in Table V.

According to Duncan test results, it can be said that control oak wood with Desmodur-VTKA adhesive has given the highest shear strength values in three different woods species. It was determined that when bonded wood species were exposed to water-resistance test, their shear strength decreased. The shear strengths according to wood species and test methods are shown in Figure 3.

## CONCLUSIONS

After the application of water-resistance tests, the following results have been obtained:

Concerning the wood species, the highest value of shear strength was found for beech wood. Beech wood gave smoother surfaces, since it had a more homogeneous structure, and thus smoother surfaces increased the bonding strength.[22]

As given in Table III, the shear strength values from higher to lower were first, the control samples of oak wood was 10.723 N/mm$^2$, then, control samples of oriental beech was 9.353 N/mm$^2$, and finally, control samples of scotch pine was 7.224 N/mm$^2$, respectively. Owing to its higher density, the control samples of oak wood may have given the highest shear strength. In procedure II, the highest decrease of shear

**TABLE V**
**The Results of Duncan Test**

| Sources | $\bar{X}$ (N/mm$^2$) | HG |
|---|---|---|
| Oak +I | 10.723 | A |
| Beech + I | 9.353 | B |
| Pine + I | 7.224 | C |
| Oak + II | 4.675 | D |
| Beech + II | 4.261 | E |
| Beech +III | 3.659 | F |
| Beech IV | 3.608 | F |
| Beech + V | 3.534 | F |
| Pine + II | 3.360 | FG |
| Pine + III | 3.334 | FG |
| Pine + IV | 3.020 | GH |
| Pine + V | 2.847 | H |
| Oak + III | 2.772 | H |
| Oak + IV | 2.191 | I |
| Oak + V | 1.540 | J |

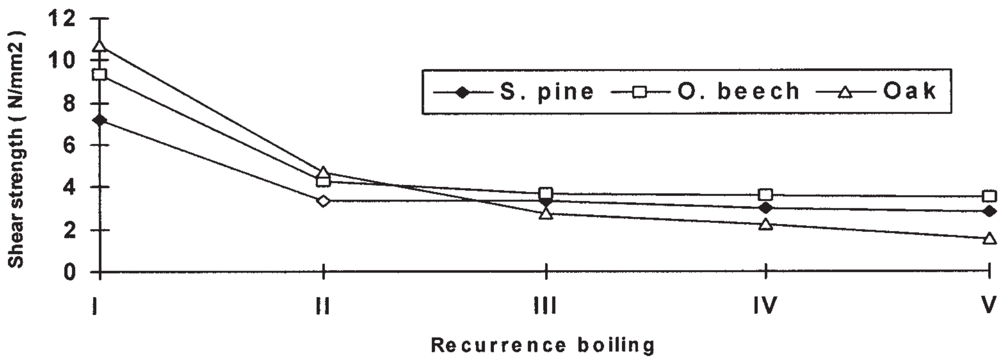


**Figure 3** Shear strength according to the wood species and test methods.

strength was found for oak as 56.4%, for oriental beech as 54.4%, and for Scotch pine as 53.4%. In procedure III, the highest decrease of shear strength was found for oak as 74.1%, for oriental beech as 60.8%, and for Scotch pine as 53.8%. In procedure IV, the highest decrease of shear strength was found for oak as 79.5%, for oriental beech as 61.4%, and for Scotch pine as 58.1%. In procedure V, the highest decrease of shear strength was found for oak as 85.6%, for oriental beech as 62.2%, and for Scotch pine as 60.5%. This can be a result of the ingredients (extractive chemicals) and higher density of oak wood. The higher the density more will be the swelling that will occur when moisture is added to the cell wall. Poor chemical and physical interfacial interactions between the wood surface and the resin and dissimilar swelling of resin and wood resulting from moisture sorption are two of the most important mechanisms of bond failure.[23]

Consequently, if Desmodur-VTKA is used as an adhesive material in the long-term humidity condition, it cannot be recommended for bonding of woods with high density.

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