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Investigation of bonding performance of polyurethane (pur) based athesives to different climate conditions

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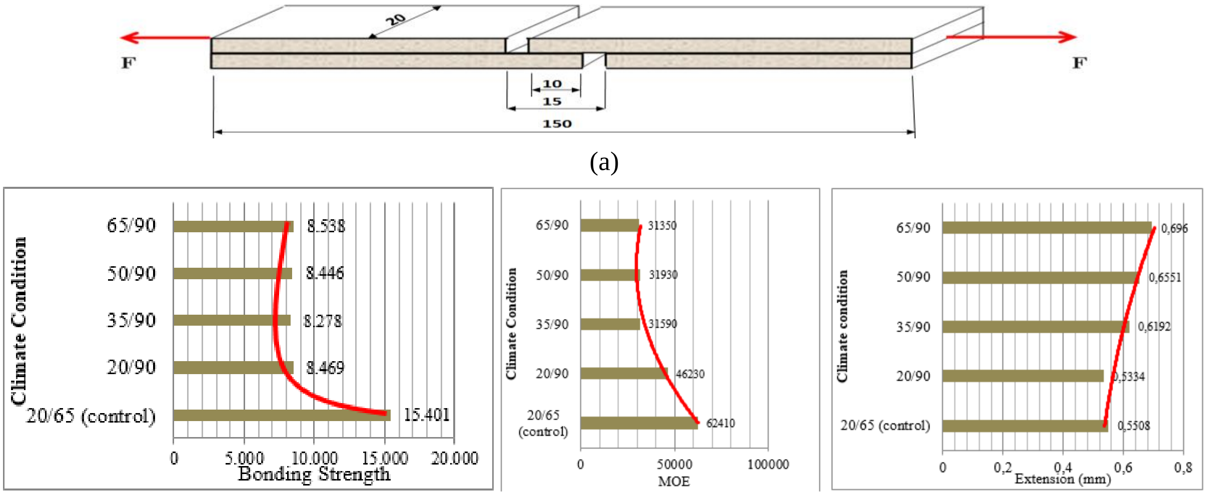
Investigation of Bonding Performance of Polyurethane (Pur) Based Adhesives in Different Climate Conditions

Highlights

- *Contrary to many studies,it was found that Scotch pine has a higher adhesion resistance than oak.*
- *PA 301 glue is better than PA 300 glue in all performances, namely (bonding strength, Modulus of Elasticity (MOE), and extension at break.*
- *Oak performs better than Scotch pine in the Modulus of Elasticity.*
- *In extension at break, Scotch pine has better performance than oak*
- *The best climatic condition for extension at break is found as 65/90.*

Graphical Abstract

The adhesion resistance, MOE and extension amounts of PA 300 and PA 301 glued Scotch pine and oak samples were determined in different climatic conditions.



(b) (c) (d)

Figure. Sample (a), graphics of bonding strength (b), MOE (c), and extension (d)

Aim

Determination of adhesion performance of polyurethane (PUR) based adhesives in different climatic conditions.

Design & Methodology

The experimental samples were first tested in 20/65 climatic condition and then in other climatic conditions (20/90-35/90-50/90-65/90).

Originality

It has been determined that it would be better to use Scotch pine and PA 301 glue in different climatic conditions.

Findings

The highest adhesion resistance was found to be 10.59 N/mm^2 in Scotch pine and 9.064 N/mm^2 in oak.

Conclusion

There is a loss of around 50% in the adhesion resistance and MOE against temperature and humidity increase.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Investigation of Bonding Performance of Polyurethane (Pur) Based Adhesives in Different Climate Conditions

Araştırma Makalesi / Research Article

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ABSTRACT

This study was carried out to determine suitable wood type and glue to be used in humid and warm enrivonments (in the construction of saunas, baths and various marine vehicles), to determine the changes in adhesion performance at variable temperatures and sequential and individual processes by keeping the relative humidity constant in these areas. For this purpose, as wood material, Scotch pine (*Pinus sylvestris* Lipsky) and stemless oak (*Quercus petrea spp*.), glue as polyurethane based PA300 and PA301 adhesives were preferred. Wood material was supplied by random method.

Test results in terms of bonding strength; sequential process adversely affected and decreased by 7 percent compared to the individual process. As wood type, 14 percent higher resistance was obtained in pine than oak.

In terms of modulus of elasticity(MOE); sequential process negatively affected and decreased by 1.4 percent compared to the individual process. As wood type, it was 10.5 percent with respect to oak, and 32.6 percent with higher elasticity than PA300 glue as glue type. In terms of elongation deformation in glue line; the sequential process adversely affected and reduced by about 19 percent compared to the individual process.

Keywords: Wood, oak, scotch pine, adhesion, climatic conditions, PUR-based adhesives.

1. INTRODUCTION

Most of the research in the field of wood adhesives has been in the form of adhesion performance and resistance to various climatic environments (especially wet climatic environment) and the development of new adhesives. It is known that the performance and behavior of wood adhesives, the smoothness and humidity of the adhesion surfaces, the extracts it contains, the pH of the glue and the viscosity of the glue [1]. Wood glue is a substance that crosses the surface of two wood materials in a liquid state and establishes cross bonds between them and can hold them together rigidly after hardening. The bonding of the adhesive to the wood substrate includes weaker forces or mechanical coupling, such as covalent bonding, van der Waals forces and hydrogen bonding [2, 3].

Wood structural elements are used for structural shaping of indoor and outdoor. In this embodiment, the formed and processed wood pieces are combined with various methods. It is supported with glue to ensure that the mechanical connection methods used in some parts become more reliable and to establish the stiffness. At this point, wood adhesives have increased in character and new adhesives continue to be developed. The areas where wood adhesives will be used are designated as dry, moist, high humidity and completely wet areas and glues are classified accordingly [4].

In this study, it has been determined whether there is any change in the adhesion performance of Scotch pine and oak from the native wood material adhered with polyurethane based PUR Marine Glue (PA300) and Express PU Adhesive (PA301) glues under different climatic conditions.

Synthetic-based urea, phenol, melamine-formaldehyde and resorcinol glue, which are developed for internal and external climatic environments and have good results, have long been used in the production of wooden components [5, 6, 7]. However, some of them are sensitive to water [8, 9] and some of them need to be hot pressed [10] and this increases the cost.

Thus, research scientists continue to develop new adhesives to eliminate these constraints [11, 12].

These are polyurethane based wood adhesives (PU). The base material of the adhesive is a polyurethane flexible polymer class [13]. It was found that PU adhesives exhibit reliability and high performance especially in the use of wood marine vehicles and in outdoor use [14].

The development of the cross-bond strength between the adhesive and the wood has been tried to be determined by means of tests.

Desmodur-VTKA glue, Scotch pine (*Pinus sylvestris* Lipsky) and T-CBC impregnation solution in the research used, impregnated material Desmodur-VTKA adhesive has been reported to reduce the bond bonding resistance [15]

Uzun et al. (2016), Beech (*Carpinus betulus* L.) lamella glued with melamine formaldehyde (MF), polyurethane (PUR) and polyvinyl acetate (PVAc-D4) adhesives of three hours of heat treatment. In their research on adhesion strength, they determined that the adhesion strength of the heat treated samples decreased with the

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temperature of the heat treatment and that the adhesive strength of the PUR adhesive was higher than MF and PVAc-D4 [16].

It was observed that the adhesion (slip) resistances of the glue joints were changed in different climatic atmospheres in the Scotsch pine (*Pinus sylvestris* Lipsky) and oak (*Quercus petrea spp.*) wood material affixed with Desmodur-VTKA glue.

2. MATERIAL AND METHODS

2.1- Wood materials:

The woods of Scotch pine with 0.52 g/cm^3 density, and oak 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, no deficient, proper, knotless, normally grown (without zone line, reaction wood, decay, insect and fungal infections) wood materials were selected.

2.2- Adhesives:

PUR Marine Glue (PA300) - Express PU adhesive (PA301); both glues have the same technical properties, PA300 with honey color and PA301 is transparent. Technical specifications of the both glues are given below.

Description: PUR Marin/Express PU adhesive is single component polyurethane based wood glue and solvent free. It cures and bonds with the humid in the air and materials. It has low viscosity and easy to apply. It cures fast and resistant against water and chemical corrosion. According to DIN EN 204 standards, the adhesive is D4 water resistant [17]. It also can be used on humid surfaces as a gap filling material. It is resistant to high temperature and does not lose its bonding strength. It is applicable bonding the rigid materials such as processed lumber, ceramic and wooden panel products to metal, stone, concrete, some synthetic materials and laminated surfaces.

The application surface shall be cleaned from all sorts of dust, oil and dirt. The surface and environment temperature shall be over +5^{0}C during bonding. It is most important that one of surfaces must be rigid for a good bonding. The adhesive must be applied for one or both surfaces evenly as a thin layer. Materials to be bonded shall sticked together within 10 minutes and be pressed at least 15-20 minutes. Final curing is completed in 24 hours. It was supplied from the manufacturer.

PUR Marin/Express Adhesive was applied under cold conditions. Its density was 1.1 g/cm^3, pH was 7, and viscosity was 3300–4000 cP at 25°C. At 20°C and 65 percent relative humidity, it solidifies in 30 min. It was recommended that PA300 adhesive should be applied to both surfaces at 150 g/m^2 [18].

2.3- Preparation of Test Samples:

The thickness of the sample draft pieces made of Scotch pine and sessile oak were cut to the dimensions specified in BS EN 205 standard, glue was applied between two wooden components on a 150 g/m^2 basis and pressed under 2 N/mm^2 pressure and 20^{0}C temperature. Standard size samples were cut from the draft pieces that were kept in the press for 24 hours and glued and marked according to the wood type and test procedures.

2.4- Test Method:

Both types of wood and varieties of glue in different climatic conditions, performance changes were examined in two processes.

The first of these: 20^{0}C ±2^{0}C temperature and 65±5 percent relative humidity for each variable prepared in each of the experimental samples (50 pieces) in each climatic condition, 10 pieces of tested, one week sequentially waiting, constant relative humidity and determining performance values such as bonding strength, modulus of elasticity and extension in increasing temperature environments (20/90, 35/90, 50/90, 65/90).

Table 1. Sequential performance determination process

	DETERMINATION OF SEQUENTIAL PROCESS PERFORMANCE				
	CLIMATIC CONDITION				
	20/65 (control)	**20/90**	**35/90**	**50/90**	**65/90**
Hold in climate condition.	bonding strength (50 pieces)	bonding strength (40 pieces)	bonding strength (30 pieces)	bonding strength (20 pieces)	bonding strength (10 pieces)
Determination /testing	10 pieces	10 pieces	10 pieces	10 pieces	10 pieces
Hold in climate condition.	MOE (50 pieces)	MOE (40 pieces)	MOE (30 pieces)	MOE (20 pieces)	MOE (10 pieces)
Determination /testing	10 pieces	10 pieces	10 pieces	10 pieces	10 pieces
Hold in climate condition.	Extension (50 pieces)	Extension (40 pieces)	Extension (30 pieces)	Extension (20 pieces)	Extension (10 pieces)
Determination /testing	10 pieces	10 pieces	10 pieces	10 pieces	10 pieces
Note: Samples of each type of wood and glue were kept in the climatic conditions above 1 week (Kägi, A.; ·Niemz, P, 2006) [19] in sequentially and technical characteristics were determined					

Second: 20^0C $\pm 2^0$C temperature and 65±5 percent relative humidity of the experimental samples prepared individually, the constant relative humidity and increasing temperature environments (20/90, 35/90, 50/90, 65/90) density. Determination of performance values such as bonding strength, modulus of elasticity and extension.

These environments represent wet and hot bath and sauna environments. The processes of holding and testing in both methods are given in Table 1 and Table 2.

Table 2. Individual performance determination process

	DETERMINATION OF INDIVIDUAL PROCESS PERFORMANCE				
	CLIMATIC CONDITION				
	20/65 (control)	**20/90**	**35/90**	**50/90**	**65/90**
Hold in climate condition.	bonding strength (10 pieces)	bonding strength (10 pieces)	bonding strength (10 pieces)	bonding strength (10 pieces)	bonding strength (10 pieces)
Determination / testing	10 pieces	10 pieces	10 pieces	10 pieces	10 pieces
Hold in climate condition.	MOE (10 pieces)	MOE (10 pieces)	MOE (10 pieces)	MOE (10 pieces)	MOE (10 pieces)
Determination / testing	10 pieces	10 pieces	10 pieces	10 pieces	10 pieces
Hold in climate condition.	Extension (10 pieces)	Extension (10 pieces)	Extension (10 pieces)	Extension (10 pieces)	Extension (10 pieces)
Determination / testing	10 pieces	10 pieces	10 pieces	10 pieces	10 pieces
Note: Each of the experimental samples from each variation in individual climatic condition for one week after waiting for the technical characteristics was determined.					

Each technical specification is determined according to the relevant standards. Bonding strength test sample is given in Figure 1.

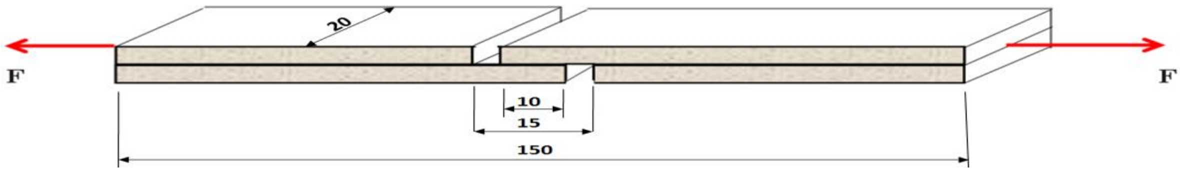

Figure 1. Test sample of bonding strength (mm)

Gazi University - Faculty of Technology - Wood Technology Laboratory with a Universal test device in accordance with the BS EN 205 standard tensile test is applied to determine the Bonding Strength [20]. The loading speed was 50 mm/min.

2.5-Data analysis

By using five different Climatic condition 20/65 (control), 20/90, 35/90, 50/90, 65/90 and two different kinds of wood, two different kinds of adhesive, two process (Sequential-Individual) species as parameters, a total of 240 samples were prepared, using 10 samples for each parameter. Multiple variance analysis has been performed. To determine the differences between density, bonding strength, modulus of elasticity and extension of the prepared samples. Should there be a significant difference between the groups, then, Duncan test was applied.

3. RESULTS AND DISCUSSION

In this study, it was examined whether the Bonding Strength, elasticity modulus and extension values changed with the effect of four different variables (process, wood type, glue type and climate condition).

Bonding Strength Change:

In adhesion performance change; the highest adhesion resistance was found to be 10.200 N/mm^2 in the individual process and 9.454 N/mm^2 in the sequential process. It has been found that the sequential process reduces the adhesion performance. The reason for this can be said that the change of the climatic environment at four different temperatures successive results from the weakening of the glue bonds. The highest adhesion resistance was found to be 10.59 N/mm^2 in Scotch pine and 9.064 N/mm^2 in oak. The reason for this can be said that Scotch pine is more permeable to hot moisture than oak. Contrary to many studies, it was found that a higher adhesion resistance occurred in Scotch pine than oak.

Table 3. Bonding Strength.

Process (A)	Average	HG
Sequential	9.454	B
Individual	10.20	A
LSD:0.1608		
Wood (B)	Average	HG
Scotch pine	10.59	A
Oak	9.064	B
LSD: 0.1608		
Climatic Condition (D)	Average	HG
20/65 (control)	15.40	A
20/90	8.469	BC
35/90	8.278	C
50/90	8.446	BC
65/90	8.538	B
LSD: 0.2542		

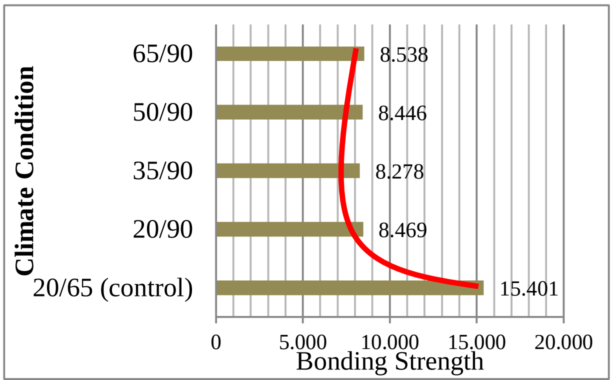

Figure 2. Bonding Strength graph

Adhesion resistance was found to be 15.401 N/mm^2 in the control samples at the highest 20/65 climatic conditions and very low in the samples under the other climatic conditions (20/90-35/90-50/90-65/90). It can be said that this is due to the weakening of the glue bond with increasing temperature and humidity (Table 3, Figure 2).

Modulus of Elasticity (MOE) Change:

In adhesion MOE change; the highest MOE was found to be 40980 N/mm^2 in the individual process and 40420 N/mm^2 in the sequential process. It has been found that the sequential process reduces the adhesion performance. This may be because the samples are kept in four different climatic conditions (all in succession) in the sequential process, reducing the elasticity of the glue joint. In adhesion MOE change, the highest MOE value was found to be 42950 N/mm^2 in the oak and 38450 N/mm^2 in the Scotch pine. This may be because the oak is less permeable than the pine, the negative effect of climate change is less transmitted, and that the oak has more force absorbing ability.

Table 4. Modulus of Elasticity (MOE)

Process (A)	Average	HG
Sequential	40420	B
Individual	40980	A
LSD:430.3		
Wood (B)	Average	HG
Scotch pine	38450	B
Oak	42950	A
LSD: 430.3		
Glue (C)	Average	HG
PA300	32780	B
PA301	48620	A
LSD:430.3		
Climate condition (D)	Average	HG
20/65 (control)	62410	A
20/90	46230	B
35/90	31590	C
50/90	31930	C
65/90	31350	C
LSD:680.4		

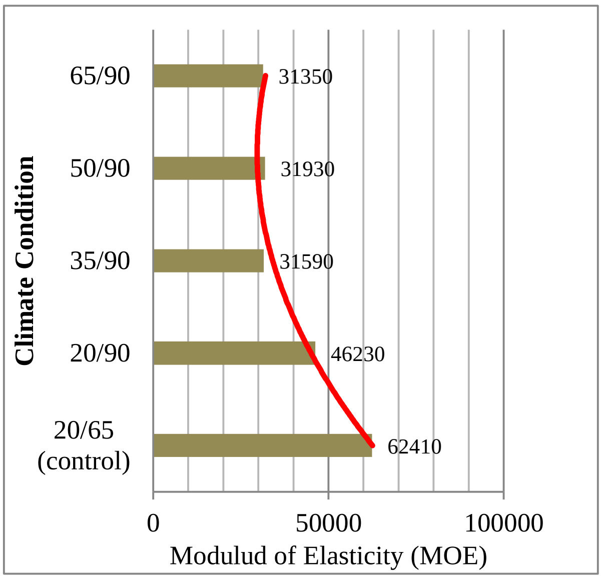

Figure 3. Elasticity Modulus graph

In terms of the effect of glue type; the highest elasticity modulus was obtained from PA301 glue samples at 48620 N/mm^2 with the lowest PA300 glue samples at 32780 N/mm^2. This is because PA301 glue is a more effective adhesive against high temperatures.
In terms of the effect of climatic condition; when the result of the control samples is set aside, the highest elastic modulus is determined in the condition of 20/90 under the condition of the lowest 65/90. It is seen that increasing the temperature of climatic condition negatively affects modulus of elasticity (Table 4 and Figure 3).

Extension at break:
The highest extension was observed in the samples kept in the individual process (0.6457 mm) and the smallest in the samples kept in the sequential process (0.5761 mm). In terms of the effect of the wood type variable; the highest extension was observed in the Scotch pine samples (0.7139 mm) and the smallest in the oak samples (0.5080 mm). In terms of the effect of the glue variable; the maximum extension amount was determined as 0.7131 mm in PA301 glue samples and 0.5087 mm in the glue samples with PA300 glue (Table 5).
Table 5. Extension at the breaking.

Table 5. Extension at break

Process A	Average	HG
Sequential	0.5761	B
Individual	0.6457	A
LSD: 0. 01243		
Wood type B	Average	HG
Scotch pine	0.7139	A
Oak	0.5080	B
LSD: 0.01243		
Glue type C	Average	HG
PA300	0.5087	B
PA301	0.7131	A
LSD:0.01243		
Climate condition D	Average	HG
20/65 (control)	0.5508	D
20/90	0.5334	D
35/90	0.6192	C
50/90	0.6551	B
65/90	0.6960	A
LSD: 0. 01966		

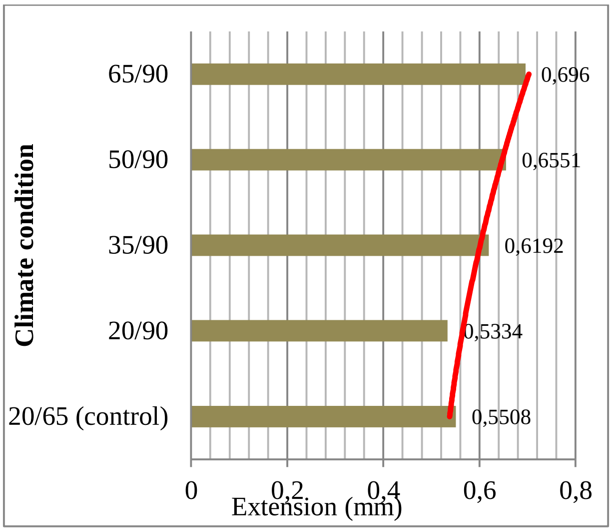

Figure 4. Extension at breeak graph

In terms of the climate condition; when the values of the control samples were left aside, the highest extension was obtained as 0.6960 mm in the samples kept under the 65/90 climate condition and 0.5334 mm in the samples kept under the climate condition of the minimum of 20/90. The samples kept in the remaining climatic conditions changed parabolically gradually (Figure 4).

Moisture Change:
Moisture levels in climatic environments; it was determined as 10.78% in 20/65, 21.82% in 20/90, 23.42% in 35/90, 18.23% in 50/90 and 17.52% in 65/90 temperature and relative humidity.

4. CONCLUSIONS

In this study, the adhesion performance (strength) of the four variable factors (glue type, wood type, process and climatic condition), MOE in adhesion and extension in adhesion were briefly affected as follows:

1) Process variable; The sequential process decreased the adhesion strength by 7.31 percent, the MOE by 1.37 percent and the adhesion elongation by 10.78 percent according to the individual process. It is recommended that these reduction amounts must be considered in the system (product) design stage required for successively variable wet-hot spaces such as bathrooms and saunas.

2) Wood type variable; according to the oak, the pine wood adhesion strength was increased by 16.84 percent, decreased MOE by 10.48 percent and the extension at break was increased by 40.53 percent. The reason for the increase in adhesion strength and extension at break. It can be said that the pine wood is due to its smooth surface and good adhesion and consequently it has more elastic glue joint.

3) Glue type; there was no difference in the adhesion strength of both glue types. It was found that PA300 glue increased MOE by 48.32 percent and PA301 glue increased extension at break rate by 40.18 percent. This is because both glues have elastic glue joint.

4) Climate condition variable; leaving the 20/65 ambient air conditioner where the samples were developed, the relative humidity remained constant at 90 percent in all four climatic conditions and the temperature of the environment was increased by 15^0C compared to the previous one. In this case, compared to the control environment, all four climatic condition decreased the average adhesion strength by 50 percent and MOE by 43.4 percent and the extension at break was increased by 13.64 percent. The reason for this can be said that the high relative humidity and temperature increase and weakening of the glue bond are due to the increase of ductility in the glue joint.

As a result, PA300 and PA301 adhesives are reported to be developed for use in humid and hot environments. However, as a result of this research, it has been found that there is a loss of adhesion resistance and MOE around 50 percent against the increase of temperature and humidity. Based on these results, it can be said that it is beneficial for designers to take this loss amount into consideration when using adhesive.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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