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The effect of the densification process on dowel tensile performance with different types of glues

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Abstract

This study was performed to determine the effects of the densification process and glue type in wood material on dowel tensile performance. For this purpose, 8 mm and 10 mm diameter dowels were obtained from black poplar (*Populus nigra*) and Eastern spruce (*Picea orientalis L.*), which were densified at 50% and 75% ratios. The dowels were bonded with PVAc and D-VTKA glue separately after drilling 18 mm deep holes in the edge of the melamine-coated particleboard. The tensile performance test was determined with the Universal test device according to TS 2475 and ASTM-D 1035 principles. As a result, Eastern spruce wood had the highest tensile performance (kg/cm2), and poplar wood had the lowest (173.66). For the dowel diameter parameter, the highest value (195.11) was found at 8 mm in diameter and the lowest value (161.05) was found at 10 mm in diameter. In terms of glue type, the highest value (185.92) was seen at PVAc while the lowest value (170.24) was seen at D-VTKA. And for the densification ratios, the highest value (191.4) was determined at 75%, while the lowest value was found in control samples at (167.4). According to the wood species, densification ratio, dowel diameter and glue type interaction, the highest value was determined at Es + d75% + 10mm + PVAc as (303.5) and the lowest value was found at P + d50% + 10mm + Dv as (110).

As a result, where the dowel's high tensile performance is sought, using a 10 mm diameter dowel made from 75% densified spruce wood with PVAc glue may be advantageous.

Key words

dowel tensile performance, densification, wood material, glue, particle boards

Introduction

In particular, the fast-growing softwood species create highly hollow textures, and therefore, their density is low (Parham et al. 1984). High demand for quality material in the wood industry makes it important to expand the usage area of forest assets by improving their properties (densification modification) due to rising prices and increasing environmental awareness (Pelit 2014).

In scientific studies related to furniture, data on mechanical, for example, joint performance, is used. The mechanical properties of furniture products depend on the materials from which the elements are produced, and the joining techniques applied to assemble these elements. For jointing furniture elements, several types of fitting systems are used. One of these is using wood dowels. Dowel joints have been used with glue for many years. This technique is widely preferred in se-

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rial production factories and small workshop furniture enterprises due to its low cost and high-performance features.

A dowel is a wooden material that is used to connect two furniture elements. It can be applied with or without glue and can be prepared in different diameters (Kasal et al. 2020).

Dowel joining is the most preferred, easy, and economical method of joining in furniture production. For this purpose, multiple dowel drilling machines are used in serial production (Imirzi et al. 2014).

Research has been carried out to determine the effects of joining methods in determining the resistance at the joints of furniture elements. The dowel tensile performance values of wooden length joints prepared using dowels produced from ash (*Fraxinus excelsior* Lipsky), chestnut (*Castanea sativa* Mill) and sessile oak (*Quercus petraea* Lieble) wood were investigated. According to the test results, the highest dowel tensile strength value (N/mm^2) was obtained in the test samples as 7.70, prepared using sessile oak using polyvinyl acetate (PVAc-D4) glue, and the lowest dowel tensile strength value (N/mm^2) was obtained in a chestnut dowel using polyurethane (PU-D4) glue (Karaman 2019).

Some physical, mechanical, and technological properties of wood materials, thermo-mechanically compressed and heat-treated have been investigated. Scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) woods were densified at 110 C and 150 C by compressing 20% to 40% radially. It has been found that resistance properties have increased from 4% to 81% (Pelit 2014).

Compressive strains of 12%, 16%, 24%, and 32% were applied to white spruce woods at temperatures of (20°C , 100°C, 150°C, and 200°C). At 150°C and 200°C, modulus of rupture (MOR) and modulus of elasticity (MOE) values showed minor differences between 150°C and 200°C (Tabarsa and Chui 1997).

After bleaching the colors of Scotch pine (*Pinus sylvestris* L.), eastern beech (*Fagus orientalis* L.), ash (*Fraxinus excelsior* L.*)* and sessile oak (*Quercus petraea spp.*) wood in which PVAc glue was used, the adhesion resistance was determined. As a result of the bonding resistance tests, it has been determined that there is a decrease in the adhesion performance of all tree species whose color is lighter compared to natural materials (Atar and Özçiftçi 1999).

Wood samples prepared from wild cherry (*Cerasus avium* (L.) Monench) were heat treated by the Thermo Wood method at 190°C and 212°C for 1 and 2 hours. It has been determined that the average surface roughness decreases with heat treatment (Aytin 2013).

Different wood species are statically densified in a quietus press up to 140 MPa pressure. The performance potential index at bending varied between 0.65 and 1.03, the highest for oak (*Fagaceae*) and the lowest for alder *Alnus* (Blomberg 2006).

Beech (*Fagus silvatica*), Norway spruce (*Picea abies*) and coast pine (*Pinus pinaster*) trees are densified in the radial direction at 150°C temperature with 13 MPa pressure. After densification, the density of beech (0.67 g/cm^3), Norway spruce (0.42 g/cm^3), and beach pine (0.50 g/cm^3) increased to 1.27 g/m^3, 1.30 g/cm^3, and 1.32 g/cm^3, respectively. As a result of mechanical tests, the modulus of elasticity, Brinell hardness, and shear resistance are found to be much higher than the control samples (Navi and Girardet 2000).

Wooden materials prepared in different thicknesses have been subjected to the densification process with the thermo-mechanical method at 175°C press temperature and 13% and 22% compression level. It has been reported that hardness values increased by 23% and 31%, respectively, compared to the control samples (Adlam 2005).

In the study investigating the effect of high press temperatures on beech wood, it has been reported that with increasing pressing temperatures and pressing time, there has been a significant improvement in the dimensional stability of the beech wood samples. The most suitable press temperature value is 200°C and the most suitable pressing time is 6 minutes (Kudela and Resetka 2011).

Experimental samples obtained from *Pinus Caribaea var. Hondurensis* wood were subjected to the thermomechanical condensation process with 25% and 50% compression ratios for 50 minutes. As a result of the research, it was determined that a moderate improvement occurred in surface roughness and an improvement was observed in mechanical properties (Santos et al. 2012).

Samples prepared from Scotch pine (*Pinus sylvestris* L.*)* wood were subjected to surface densification at 150°C and in three different levels. A 90% increase was observed in Brinell hardness values with a 3.8% mass loss in the samples (Rautkari et al. 2009).

Polyvinyl acetate (PVA) glue was used as an adhesive in the study investigating the adhesion strength of yellow pine (*Pinus silvestris* L.), beech (*Fagus orientalis* L.), and oak (*Quercus rubra*) wood.

In terms of wood species, the highest adhesion resistance was found in beech, then in oak and pine, respectively (Altnok 1998).

Eckelman (1979) has found a strong relationship between tensile performance and shearing resistance that is parallel to the fibers of the wood used in construction. As a result of the regression analysis, the dowel tensile performance of the wood material from the edge he proposed.

$$F = 0.834\ DL\ .89\ (0.95\ S1 - S2)\ ab \quad (1.1)$$

where:

F – dowel tensile performance (pound),
D – dowel diameter (inches),
L – dowel effective length (inches),
S1 – shearing resistance of wood material which dowel fixed (psi),
S2 – shearing resistance of wood material which dowel made (psi),
a – glue coefficient,
b – dowel hole space coefficient (Eckelman 1979).

Samples from poplar (*Populus tremula*) and birch (*Betula pubescens*) woods have been subjected to the condensation process at a temperature of 200°C and pressures between 1.5 MPa and 7.3 MPa. Defects occurring in the condensation process are found in 75% of poplar wood and 25% of birch wood. Some physical and mechanical properties of Scots pine (*Pinus sylvestris* L.) are investigated after densification processes. It was found that the most suitable temperature level was 120°C while an increase in densification temperature decreased strength properties (Ülker et al. 2014).

However, it has been determined that these defects can be minimized by increasing the steaming time (Ahmed et al. 2013). The optimal condensation parameters for fir *Abies* wood densified by the thermo-hydromechanical (THM) method were determined to be a compression ratio of 60%, a temperature of 230°C, and a time of 20 minutes. At the end of the condensation process, hardness was found to be 30 MPa while adhesion strength was 8 MPa. (Li et al. 2012).

The properties of Eastern redcedar (*Juniperus virginiana*), southern pine (*Pinus echinata*), and yellow poplar (*Liriodendron tulipifera*) samples that had undergone heat treatment were assessed. For the testing, a total of 80 samples-20 for each temperature level-were used. The results suggest that, when compared to two other species of wood, eastern redcedar specimens exhibited the lowest levels of discolouration. Hardness values of the samples consistently demonstrated a negative impact of heat exposure (Ulker et al. 2018).

Viscoelastic thermal compression (VTC) was used to densify low-density hybrid poplar (*Populus deltoides* x *Populus trichocarpa*) to three distinct densification levels (63, 98, and 132%). The findings demonstrated that the increased density had a considerable positive impact on the bending characteristics of the VTC wood (MOR and MOE) (Kutnar et al.2018).

Surface quality, adhesive bondline shear strength, hardness, and color changes were studied for materials compressed at temperatures ranging from 100°C to 180°C. According to these findings, compressed specimens' surface roughness decreased with rising temperature (Ulker et al. 2017).

Material and methods

Materials

Wood material

Eastern spruce (*Picea orientalis)* and poplar (*Populus nigra),* which have low densities, were used in the experiments. In the selection of woods, factors such as not being damaged by insects and fungi, lack of fiber curls, being dry and naturally colored, and fibers parallel to each other were taken into consideration. In the selection of wood material, TS ISO 3129 principles have been followed.

The materials intended for physical and mechanical tests were selected considering the purpose of the test, as well as the requirements to ensure that the properties obtained from the test pieces represent the sample population.

So, samples were selected to represent the population. For each species to be tested, at least five logs representative of that species or species group were selected. The heart plank was cut in the direction of two mutually perpendicular diameters (Fig. 1).

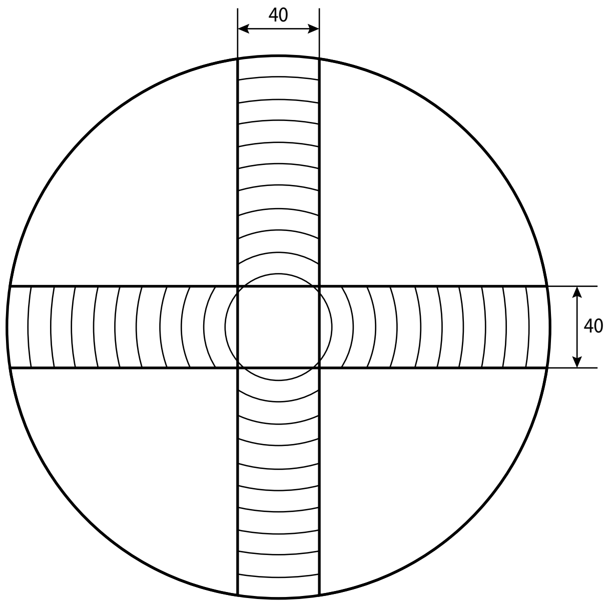

Figure 1. Cutting pattern of heart planks from a log

The number of the samples were determined to represent whole log. In this scope wood properties and structure such as percentage of late wood and early wood, were considered to minimize its effects on the test results.

Glue

Desmodur-VTKA and polyvinyl acetate (PVAc) glues are the most used glues in the wood industry. Desmodur-VTKA is polyurethane based with one component, solvent free adhesive. It is mostly preferred in assembly work in the wood industry. On the other hand, PVAC glue is a water-based adhesive. It is formed from vinyl acetate monomer under the action of a polymerization initiator and is commonly known as white adhesive.

Both glues were applied to the dowel surfaces and holes at an average of 10 g/m^2. PVAc glue is widely used in the furniture industry due to its cold application, quick hardening, odorless, and fireproof properties. It does not dye wood or wear down tools during processing. The properties of the PVAc glue used in the trials were determined by the glue manufacturer as its density of 1.1 g/cm^3, viscosity 160–200 cps, PH = 5.00 and ash content of 3% (Polisan 1996). PU glue is a solvent-free, single-component polyurethane-based glue that is resistant to water and moisture, and it is used for bonding wood, metal, polyester, stone, ceramic, PVC, and other plastic surfaces. As specified by the glue manufacturer, the density of the PU glue is 0.02 g/cm^2 at 20°C, and its viscosity is 3300–4000 cps at 25°C, and it hardens in 30 minutes at 20°C and 65% relative humidity (Polisan 2019).

Dowel

In the study, dowels made of Eastern spruce and poplar with a diameter of 8 mm and 10 mm and a height of 70 mm, the body surface of which is flat and smooth grooved, were used in accordance with the principles of TS 4539.

Melamine coated particleboard

Melamine coated chipboard, most used material in dowel joints in the furniture industry, has dimensions 5×5 cm with 18 mm thickness was used.

Method

Densification processes

Wooden samples used for the dowel have been dried up to the amount of an average humidity of 12% in the automatic drying oven. The samples were kept at a temperature of 20°C and a relative humidity of 65%. Samples were kept in the air conditioning cabinet until they reached a constant weight before densification processes. To obtain the target compression thickness (10 mm) with the compression ratios (50% and 75%), the test specimens were brought to two different draft thicknesses (15 mm and 20 mm). Compression ratios and the dimensions of draft test samples are indicated in Table 1.

Table 1. Pre-compression dimensions of draft test samples

Compression ratio	Dimensions (mm)		
	length (longitudinal direction)	width (tangent direction)	thickness (radial direction)
50%	800	10	20
75%	800	10	40

Draft examples of poplar and Eastern spruce woods were densified by using the thermomechanical (TM) compression method. For this process, a specially designed hydraulic press with a 60×60 cm table size is used under temperature and pressure control (100 tons to 250 atm) (Fig. 2).

Figure 2. Hydraulic press used in densification processes

The technical properties of the hydraulic press are given in Table 2.

Table 2. Technical properties of the hydraulic press

Press temperature	Compression ratio
Pressure capacity	100 ton – 250 Bar
Temperature range	0–250°C
Pressure piston stroke	500 mm
Table size	60 × 60 cm
Motion	auto/manual, 8–11 mm/sec.

The densification process was applied to the wood material at 140 ± 5°C in two different compression ratios of 50% and 75%.

Table 3. Densification process

Densification		
Press temperature	Compression ratio	Time
140°C	50%	press heating + 15 minutes
	75%	press heating + 15 minutes

The test specimens were placed on the press table as both surfaces touched the press table. The internal temperature of the press was controlled by a digital heat meter. Samples are kept under light pressure until the internal temperature of the samples reaches the desired temperature (140°C) value for the press tables. A 10 mm thick metal stopper profiler was used for targeted compression ratios. The samples were compressed in the radial direction using an automatic control of the loading speed of 60 mm/min. Compressed samples have been kept under pressure for 15 minutes. At the end of this period, samples are taken from the press and, to minimize its spring-back effect, samples are allowed to cool up to room temperature under an average pressure of 5 kg/cm^2.

Preparation of experiment samples

Dowels made from poplar and spruce wood have been made ready after pulling them at 8 and 10 mm in the dowel machine. For dowel joints, 18 mm thick melamine coated particleboard was brought to a 50 × 50 mm net dimension and 18 mm deep holes were drilled into the boards. Samples are divided into control and densification groups before the tensile performance test. Test parameters are given in Table 4.

Table 4. Test parameters

Poplar	800 × 10 × 8	PVAc	Control	6	Eastern spruce	800 × 10 × 8	PVAc	Control	6
			50%	6				50%	6
			75%	6				75%	6
		D-VTKA	Control	6			D-VTKA	Control	6
			50%	6				50%	6
			75%	6				75%	6
	800 × 10 × 10	PVAc	Control	6		800 × 10 × 10	PVAc	Control	6
			50%	6				50%	6
			75%	6				75%	6
		D-VTKA	Control	6			D-VTKA	Control	6
			50%	6				50%	6
			75%	6				75%	6

Dowels and melamine coated particleboards were adhered with polyvinyl acetate (PVAc) and Polyurethane (D-VTKA) adhesives and then left to dry for 1 day.

According to this, a total of 144 dowels were prepared, including 2 wood species (poplar and Eastern

Figure 3. Experiment samples

Figure 4. Dowel tensile test

spruce), 3 different densification ratios (control, 50%, and 75%), 2 dowel diameter varieties (8 and 10 mm), 2 glue types (PVAc and D-VTKA), and 6 samples needed for each (Fig. 3).

Conducting the experiment

The tensile values of the dowel were determined according to the principles specified in TS 2475 and ASTM-D 1035 standards. Method for determining the ultimate tensile stress of wood parallel to grain on small clear specimens is performed by measuring the breaking load applied statically along the longitudinal axis of a test piece. The maximum dowel tensile performance is recorded in kilogram force (kg/cm^2). The experiments were carried out on a 5-ton universal test machine with a loading speed of 2 mm/min under static load (Fig. 4). Testing machine is capable of ensuring a constant rate of loading and movement of the loading head and allowing measurement of the load to an accuracy of 1%.

Data analysis

The MSTAT-C package program was used for statistical evaluations. A one-level analysis of variance (ANOVA) was conducted to determine the effect of the type of wood material on the physical and mechanical properties of wood materials. The interactions of tree species, densification values, diameter varieties, and glue types were determined by multiple variance analysis and if the differences were statistically found significant according to p, the smallest significant difference (LSD: least significant difference) test was used for the significance of these differences between the groups. The success sequences of the factors included in the experiment were determined by dividing them into homogeneity groups.

Table 5. Compression ratios in air dry moisture after densification processes

Wood	Densification conditions	Thickness before compression	Thickness after compression	Press thickness	Compression ratio	Std.
Poplar	140°C 50%	20 mm	10.14 mm	10 mm	47.80%	0.16
	140°C 75%	40 mm	10.57 mm	10 mm	73.57%	0.58
Eastern spruce	140°C 50%	20 mm	10.22 mm	10 mm	48.90%	0.31
	140°C 75%	40 mm	10.86 mm	10 mm	72.85%	0.51

Results

Physical properties

This section presents the densities and spring-back rates of poplar and Eastern spruce woods compressed at 50% and 75% at 140°C temperature using the thermo-mechanical (TM) method.

Spring-back rates

Average values of the compression ratios are given in Table 5.

Density and moisture content

Density values and moisture content of the samples are given in Table 6.

Table 6. Density values and moisture content of dowels

Densification ratio	Density values (g/cm^3)		Moisture content (%)	
	poplar	eastern spruce	poplar	eastern spruce
Control	0.390	0.401	8.218	8.925
50%	0.508	0.540	4.558	6.485
75%	0.622	0.629	4.381	5.187

The highest density (g/cm^3) was found in Eastern spruce (0.629), with the highest densification ratio of 75%. The lowest density (g/cm^3) was found in the control samples (0.390) in poplar wood. The moisture content (%) was higher in the control samples (without densification) because the pores on the wood surface were closed and water was ejected with the compression process.

Mechanical properties

Tensile performance test

Average values of dowel tensile performance test according to wood species, densification ratios, dowel diameter varieties and glue types are given in Table 7.

The tensile performance of dowels varies depending on the wood species, dowel diameter, densification ratio, and glue type. The highest tensile performance (kg/cm^2) value was determined as 303.547 in 10 mm of Eastern spruce glued with PVAc glue and 75% densified. The lowest value was found in 10 mm spruce as 110.105 glued with D-VTKA and 50% densified. A variance analysis

Table 7. Descriptive Statics

Parameters			Tensile performance (kg/cm^2)*	
densification	dowel diameter (mm)	glue type	poplar	eastern spruce
control	8	PVAc	177.302	139.665
	8	D-VTKA	176.582	206.168
	10	PVAc	171.640	134.923
	10	D-VTKA	154.833	178.178
50%	8	PVAc	227.615	183.760
	8	D-VTKA	226.072	192.995
	10	PVAc	160.153	187.593
	10	D-VTKA	110.105	115.582
75%	8	PVAc	177.780	189.280
	8	D-VTKA	203.208	222.127
	10	PVAc	159.003	303.547
	10	D-VTKA	120.853	136.205

* Arithmetic average.

was performed to determine the effects of independent variables such as wood species, dowel diameter, densification ratio, and glue type on tensile performance.

The effects of wood species (A), densification ratio (B), diameter variety (C), glue type (D) and their interactions with each other (binary, triple, and quadruple) on the results of the tensile performance test were found significant (0.05). It is seen that dowel diameter showed the most effect on tensile performance test results, with an f value of 109.9050. The other variables that had the greatest impact were glue type, densification ratio and wood species, with f values of 23.29, 18.73, and 7.39, respectively. In the results, the Duncan test was applied to determine in which groups the difference was important. The homogeneity test regarding wood species, densification ratio, and dowel diameter is given in Table 9.

The highest tensile performance (kg/cm^2) was found to be 191.4 in dowels, which were exposed to 75% densification. It was determined that there existed a direct proportion between densification ratio and tensile force. When densification ratios are increased, the tensile force also increases. Besides, the diameter of the dowel (mm) contributes negatively to the tensile force. An increase of 21% has been detected in tensile tests of 8 mm dowels compared to 10 mm dowels. According to the wood species, the tensile forces were found close to

Table 8. Variance analysis of tensile performance test

Source	Degree of freedom	Sum of square	Mean of square	F	α < 0.05
Wood species (A)	1	2,811.562	2,811.562	7.3974	0.0075*
Densification (B)	2	14,244.143	7,122.071	18.7386	0.0000*
AB	2	21,040.921	10,520.461	27.6799	0.0000*
Diameter (C)	1	41,772.206	41,772.206	109.9050	0.0000*
AC	1	15,980.963	15,980.963	42.0468	0.0000*
BC	2	16,775.502	8,387.751	22.0686	0.0000*
ABC	2	9,586.050	4,793.025	12.6107	0.0000*
Glue (D)	1	8,853.084	8,853.084	23.2930	0.0000*
AD	1	43.263	43.263	0.1138	0.0000*
BD	2	28,015.219	14,007.609	36.8548	0.0000*
ABD	2	20,149.924	10,074.962	26.5078	0.0000*
CD	1	42,854.177	42,854.177	112.7517	0.0000*
ACD	1	9,539.593	9,539.593	25.0992	0.0000*
BCD	2	15,928.969	7,964.484	20.9550	0.0000*
ABCD	2	9,423.694	4,711.847	12.3971	0.0000*
Error	120	45,609.062	380.076		
Total	143	302,628.332			

* Statistically significant.

Table 9. Tensile performance test results according to wood species

Wood species*	Tensile performance (kg/cm^{2}) X – HG
Eastern spruce	182.50^{a}
Poplar	173.66^{b}
Densification ratio**	
75%	191.4^{a}
50%	175.5^{b}
Control	167.4^{c}
Dovel diameter***	
8 mm diameter dowel	195.11^{a}
10 mm diameter dowel	161.05^{b}
Types Glue****	
PVAc glue	185.92^{a}
D-VTKA glue	170.24^{b}

HG: * LSD – ±6.423, ** LSD – ±7.866, *** LSD – ±16.129, **** LSD – ±6.423. LSD– Least small significant difference, HG: Homogeneity Groups.

each other, while the highest tensile performance (kg/cm^{2}) was found in Eastern spruce with a value of 182.5. Tensile performance according to wood species, densification ratio, dowel diameter and glue type is given in Figure 5.

Table 10. Tensile performance test results according to binary interactions

Wood + Densification	X-HG	Densification + Diameter	X-HG	Densification + Glue	X-HG
Es + $d^{75\%}$	212.8^{a}	$d^{50\%}$ + 8^{mm}	207.6^{a}	$d^{75\%}$ + PVAc	212.1^{a}
P + $d^{50\%}$	181.0^{b}	$d^{75\%}$ + 8^{mm}	202.8^{a}	$d^{50\%}$ + PVAc	189.8^{b}
P	170.1^{bc}	$d^{75\%}$ + 10^{mm}	179.9^{b}	C + Dv	178.9^{bc}
Es + $d^{50\%}$	170^{bc}	C + 8^{mm}	174.9^{b}	$d^{75\%}$ + Dv	170.6^{cd}
P + $d^{75\%}$	169.9^{bc}	C + 10^{mm}	159.9^{c}	$d^{50\%}$ + Dv	161.2^{de}
Es	164.7^{c}	$d^{50\%}$ + 10^{mm}	143.4^{d}	C + PVAc	155.9^{e}
LSD = ±11.09		LSD = ±11.12		LSD = ±19.21	
Wood + diameter	X-HG	Wood + Glue	X-HG	Diameter + Glue	X-HG
P + 8^{mm}	201.2^{a}	Es + PVAc	189.8^{a}	8^{mm} + Dv	204.5^{a}
Es + 8^{mm}	189.0^{b}	P + PVAc	182.1^{b}	10^{mm} + Dv	186.1^{b}
Es + 10^{mm}	176.0^{c}	Es + Dv	175.2^{c}	8^{mm} + PVAc	185.7^{b}
P + 10^{mm}	146.1^{d}	P + Dv	165.3^{d}	10^{mm} + PVAc	136.0^{c}
LSD = ±15.68		LSD = ±11.12		LSD = ±9.083	

Es – eastern spruce; P – poplar; $d^{50\%}$ – 50% densification ratio; $d^{75\%}$ – 75% densification ratio; C – Control; PVAc – polyvinyl acetate glue; Dv – desmodur-VTKA glue; HG – homogeneity groups.

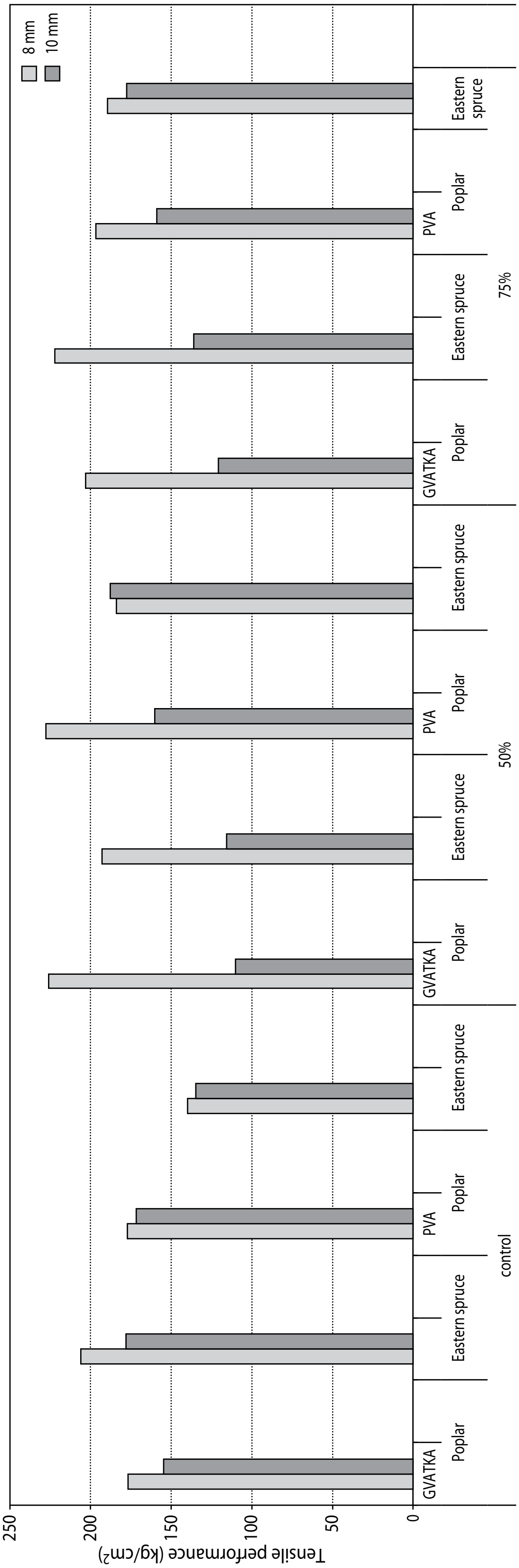

Figure 5. Tensile performance according to wood species, densification ratio, dowel diameter and glue type

Binary interactions of AB (wood species×densification ratio), AC (wood species×diameter), BC (densification ratio×diameter), AD (wood species×glue type), BD (densification ratio×glue type) and CD (diameter×glue type) are given in Table 10.

According to the bilateral interactions, the maximum tensile performance (kg/cm^2) was determined at Es+d$^{75\%}$ as 212.8 and found least at 10 ^{mm} + PVAc as 136. The interactions of all parameters with each other are given in the Table 11.

Table 11. Tensile performance (kg/cm^2) test results according to quadruple (Duncan Test) interactions

Wood species + Densification ratio + + Diameter of dowel + Glue type	X-HG (kg/cm^2)
P + d$^{50\%}$ + 8^{mm} + PVAc	227.6^{a}
P + d$^{50\%}$ + 8^{mm} + Dv	226.1^{a}
Es + d$^{75\%}$ + 8^{mm} + Dv	222.1^{a}
Es + C+8^{mm} + Dv	206.2^{b}
P + d$^{75\%}$ + 8^{mm} + Dv	203.2^{bc}
P + d$^{75\%}$ + 8^{mm} + PVAc	196.6^{bcd}
Es + d$^{50\%}$ + 8^{mm} + Dv	193.0^{cde}
Es + d$^{75\%}$ + 8^{mm} + PVAc	189.3^{cde}
Es + d$^{50\%}$ + 10^{mm} + PVAc	187.6^{cde}
Es + d$^{50\%}$ + 8^{mm} + PVAc	183.8^{cdef}
Es + d75% + 10mm + PVAc	177.8^{def}
Es + C+10^{mm} + Dv	178.2^{defg}
P + C + 8^{mm} + PVAc	177.3^{defg}
P + C + 8^{mm} + Dv	176.6^{efg}
Es + C + 10^{mm} + PVAc	171.6^{efg}
P + d$^{50\%}$ + 10^{mm} + PVAc	160.2^{fgh}
P + d$^{75\%}$ + 10^{mm} + PVAc	159.0^{fghi}
P + C + 10^{mm} + Dv	154.8^{ghi}
Es + C + 8^{mm} + PVAc	139.7^{hij}
Es + d$^{75\%}$ + 10^{mm} + Dv	136.2^{hij}
Es + C + 10^{mm} + PVAc	134.9^{ij}
P + d$^{75\%}$ + 10^{mm} + Dv	120.9^{jk}
Es + d$^{50\%}$ + 10^{mm} + Dv	115.6^{jk}
P + d$^{50\%}$ + 10^{mm} + Dv	110.1^{k}

LSD value – ±15.73.

According to quadruple interactions the highest tensile performance (kg/cm^2) was found in P + d$^{50\%}$ + + 8^{mm} + PVAc as 227.6 while the least value was found

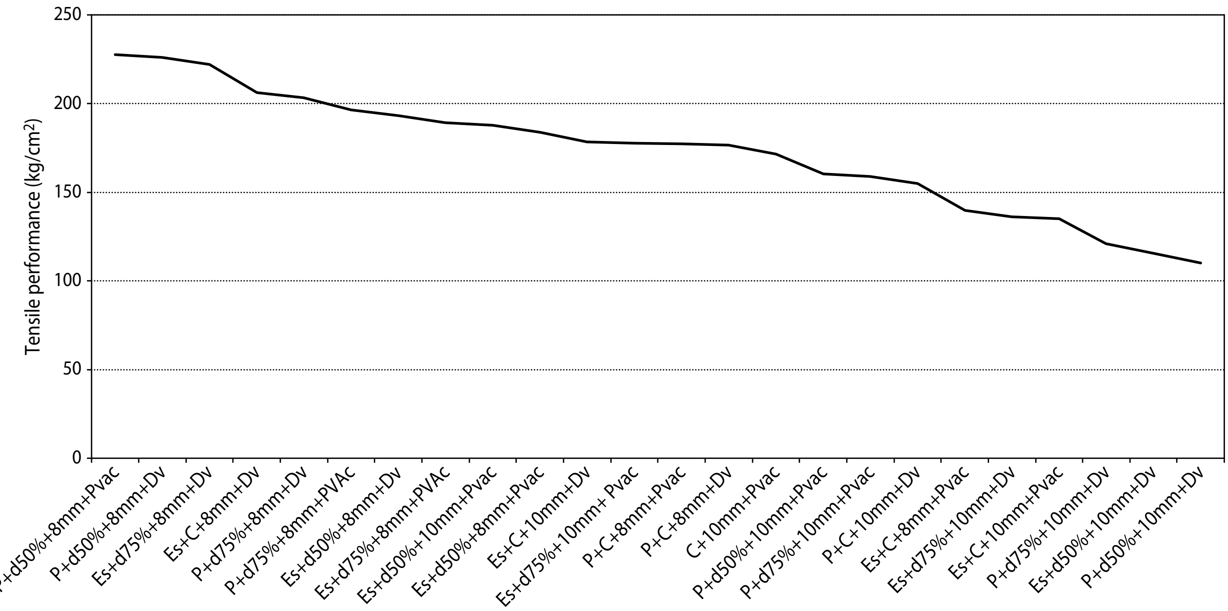

Figure 6. Interaction of all parameters

in P + d$^{50\%}$ + 10^{mm} + Dv as 110.1 Graph of quadruple interactions are given.

Conclusion

In this study, dowel tensile performance values on melamine-coated chipboard were investigated. As a result of the experiments, the test samples prepared using different glues, densification ratios, and wood species in different diameters showed different performance properties against tensile forces. The effects of wood species, densification, diameter, and glue type on dowel tensile performance were found to be significant.

The densification process had a positive effect on wood material tensile performance values. The highest tensile performance (kg/cm^2) was determined in samples with a 75% densification ratio of 303.547. The lowest tensile performance (kg/cm^2) was obtained with the test sample as 110.105, to which a 50% densification ratio was applied. According to the control samples, the 50% densification process increased the tensile performance by 4.79%. This increase was by 14.37% in the test samples with 75% densification.

Scots pine solid wood was densified at 40, 50, and 60% of the thickness. The hardness of densified samples with a ratio of 40, 50, and 60% was found to be 19.0, 29.3, and 23.9 N/mm2, respectively, while control samples had a hardness of 15.5 N/mm2 (Laine, 2016).

One of the aims of this study is to find out whether the type of glue is effective in dowel tensile performance. For this purpose, the two most used glues in joining operations in the wood industry were preferred, and the results were interpreted according to these glue types. It has been clearly observed that PVAC glue has superior adhesion properties to D-VTKA glue. According to the glue type, the highest tensile performance was obtained in PVAc glue (303.547 kg/cm^2) while the lowest value was in D-VTKA glue (110.105 kg/cm^2). PVAc is thought to penetrate deep into the wood material by adjusting the viscosity of the adhesive molecules with water, which is used as a thinner for PVAc glue.

The effects of Vacsol Azure (VA) on the bonding power of PVAc and D-VTKA adhesives on some impregnated wood materials were determined. The highest bonding performance was obtained in PVAc treated samples at 9.707 N/mm^2 (Keskin et al. 2009).

According to the dowel diameter, the highest tensile performance was obtained with a 10 mm dowel diameter (303.547 kg/cm^2). The lowest tensile performance was obtained on an 8 mm dowel (176.582 kg/cm^2).

Edge dowel holding performance at 10 mm dowels was found to be 11% higher than that at a diameter of 8 mm (Kasal, 2007). Wood material density values, elasticity properties, late wood ratios, resin presence, and glue type can all influence dowel tensile performance.

Eastern redcedar (*Juniperus virginiana*), southern pine (*Pinus echinata*), and yellow poplar (*Liriodendron tulipifera*) samples that had undergone heat treatment had their properties assessed. Hardness values of the samples consistently demonstrated a negative impact of heat exposure. The surface quality of the samples from all three species appears to have improved with rising temperatures (Ulker et al. 2018).

As a result, considering its widespread use, the properties of wood materials, dowel diameter, densification amount, glue type, and engineering design approach are important to make dowel joints in accordance with the purpose.

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