

Determination of Abrasion Resistance and Adhesion of Varnishes with Various Ratios of Graphene Additive on Different Wood

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Graphene was mixed with varnishes at different ratios and applied by spraying method on different cross-sections of various wood materials, and their wear and adhesion performances were determined. Graphene (0.25%, 0.50%, 1%); varnishes (water-based and polyurethane varnish) and wood materials (beech (*Fagus orientalis* Lipsky), chestnut (*Castanea sativa* Miller), yellow pine (*Pinus sylvestris* L.), and spruce (*Picea orientalis* (L.) Link.)) were used. Adhesion and abrasion tests were performed. A total of 480 test specimens were prepared, 5 specimens for each wood type, cross-sectional direction, graphene ratio, and varnish type for adhesion and abrasion tests. The adhesion of the samples was determined by ASTM D 4541-09E1 pull-off test and abrasion resistance was determined in accordance with ASTM 4060-10. The data obtained were statistically analyzed and the significance values within and between groups were determined. As a result, abrasion resistance and adhesion increased in graphene 2 (0.50%) in both varnish types.

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INTRODUCTION

Graphene is a monolayer carbon macromolecule with high mechanical strength and large surface area. Due to these properties, it is currently being investigated in many fields (Novoselov *et al.* 2005; Lee *et al.* 2008; Blake *et al.* 2008; Geim 2009; Balandin 2011; Li *et al.* 2014; Zeng *et al.* 2016; Cui and Li 2020; Khan *et al.* 2022). Considering the literature information, it is thought that this study is important because graphene is a nano-sized material having positive technical properties. Since it is a nanoscale material, it is used in low concentrations (Pelit and Korkmaz 2019; Yu *et al.* 2019; Li *et al.* 2020; Araujo Sousa *et al.* 2022; Tamburrano *et al.* 2022; Bartczak *et al.* 2023). There are also very few studies in the literature on the use of graphene as an additive in varnish layers.

Wood is an organic material preferred from ancient times to the present day (Örs and Keskin 2003; Chen *et al.* 2021). However, although there are many methods to improve the stability and appearance of the disadvantages caused by the structure of the material, surface treatments are still considered the most popular method among others. Wood material type and varnish type affect the quality of surface treatments (Cheng and Sun 2006; Pocius 2021).

Abrasion resistance and adhesion are important for determining the performance of surface-treated wood materials, predicting their lifetime, quality control, and cost savings. Many varnishes (cellulosic, polyester varnish, lacquer, wax, paraffin, linseed oil, polyurethane varnish, parquet varnish, glass polish varnish, ultraviolet drying varnish, polymeric based varnish, synthetic, water based, acid hardening, acrylic varnish, acid curing varnish, *etc.*) have been used until now (Özdemir 2003; Keskin and Tekin 2011; Söğütlü *et al.* 2016, 2017). However, the use of these materials alone is not enough to improve the resistance values sufficiently. Their adhesion on the surface weakens and causes breaks in the varnish. Since it is very difficult and costly to re-varnish such materials, it is important to develop a mechanism to increase the bond resistance between varnish and wood material in the first application. It has been reported that varnishes mixed with nanomaterials have improved abrasion resistance and adhesion values (Sönmez and Budakçı 2004; Bauer and Mehnert 2005; Jalili *et al.* 2007).

In this study, it was aimed to increase the wear and adhesion of the material with graphene additive and to determine the varnish-additive volume concentration value. For this purpose, it was aimed to determine the prescription of the wood material, varnish, and additive ratio that provides the best wear resistance and adhesion. In this way, by determining the variation that provides the highest abrasion resistance and adhesion, many advantages have been obtained both economically and in terms of labor force.

EXPERIMENTAL

Materials

Wood materials studied

In this study, the woods of eastern beech (*Fagus orientalis* Lipsky), Anatolian chestnut (*Castanea sativa* Miller), eastern spruce (*Picea orientalis* L.(Link.)), and yellow pine (*Pinus sylvestris* L.), coniferous wood species, were used. The tree species were selected from the eastern Black Sea region, where they are naturally distributed. Trabzon, Gumushane, and Artvin regions with optimal growth were selected as sample areas. Homogeneous stands were taken into consideration and trees were selected according to simple random sampling method. Growing environment characteristics, such as age, aspect, diameter, and elevation, were taken into consideration in the selection of trees. In the selection of the experimental trees, care was taken to ensure that they were smooth and robust trees with perfect trunks.

Preparation of experimental samples

The test samples were kept for 4 weeks at 20 ± 2 °C temperature and $65 \pm 5\%$ relative humidity to reach equilibrium moisture content and their moisture content was stabilized at approximately 6% to 8%. Then, to bring the experimental materials to the size of $100 \times 100 \times 7$ mm³ and $100 \times 100 \times 10$ mm³, their thicknesses were measured in the side receiving machine, and then their widths and thicknesses were determined in the four processing machines. The two 2.5 mlong materials, whose widths and thicknesses were sized in the four processing machines, were calibrated with sandpaper 80 and 120 and then with 180 grit sandpaper in the calibrated sanding machine, in accordance with industrial applications as $100 \times 100 \times 7$ mm³ and $100 \times 100 \times 10$ mm in the circular saw machine, and the surfaces were made smooth. After the surface finishing processes were completed, the materials were kept in an air conditioning environment with an average temperature of

20 ± 2 °C and 65 ± 5% relative humidity according to TS 642 ISO 554 (1997), until they reached the equilibrium moisture content (6% to 8%) and then varnishing processes were started in accordance with industrial applications.

Varnishes used

Polyurethane varnish and water-based varnish were used.

Additives used

The additive used was graphene at 0.25%, 0.50%, and 1% concentrations.

Test standards

Surface adhesion ASTM D4060-10 (2010) and abrasion resistance ASTM D4541-09E1 (2009) standards were used.

Methods

Preparation of varnish and additive mixture

For water-based varnish samples, 60 g of water was added to 240 g of varnish as a thinner. The same process is valid for polyurethane varnish and 240 g of varnish 60 g of thinner was used. Each of the additives was mixed into the thinner at the specified percentages and mixed in an ultrasonic mixer for 10 min, then mixed with the varnish and then mixed again with an ultrasonic mixer for 10 min.

Application of varnishes

The varnishing of the sample parts was completed as 2 coats of filler varnish and 1 coat of final varnish according to industrial practices, 120 ± 5 g/m² per unit area. After both filler varnishing applications, the sample parts were dried and a vibrating hand sanding machine was used for sanding (aluminum oxide paper sanding belts). The prepared varnish + additive mixtures were applied using an overhead tank spray gun. For each sample, 120 m² of varnish was sprayed. The samples were first sanded with 180 grit sandpaper. Wood residues remaining on the samples were removed with compressed air. Then, the first coat of filler varnish was applied and left to dry for a day. After 220 grit sanding, the residues were removed again with compressed air and the second coat of filler varnish was applied. It was left to dry again for a day. For the last coat of varnish, it was sanded with 320 grit sandpaper and the third coat of topcoat varnish was applied.

Trial Methods

Determination of wear resistance values

For the determination of the abrasion resistance at the end of the aging test, 5 samples of each varnish type with dimensions of 100x100x7 mm were used and the experiments were carried out in accordance with ASTM D 4060-10 (2010). A 6 mm diameter drill hole was drilled in the center of the test samples and fixed on the horizontal tool disk with screws. Sanding strips, which were acclimatized and checked for suitability, were glued on the disks of the abrasive tool. The etching tool was then started and the sample surface was checked after every 5 cycles. When the destruction of the varnished material on the surface of each sample started and approximately 50% of it was exposed, the abrasion process was terminated and the number of abrasion cycles was obtained.

Determination of surface adhesion values (according to tensile method, pull-off)

For the determination of the adhesion at the end of the aging test, 5 samples of each varnish type with dimensions of $100 \times 100 \times 10 \text{ mm}^3$ will be used and the experiments will be conducted in accordance with ASTM D4541-09E1 (2009). For this purpose, 20 mm diameter steel cylinders will be glued to the center of the samples with epoxide glue and they will be kept for 1 day at $20 \pm 2 \text{ }^\circ\text{C}$ temperature and $65 \pm 5\%$ relative humidity conditions for the glue to dry completely. Then, the specimens will be placed under the tensile cylinder of the adhesion measuring instrument (Erichsen Adhesionmaster 525 MC), the steel cylinders will be connected and the experiments will be conducted at a speed of 0.5 N/s. The force value at break will be measured with a sensitivity of 0.01 N and the adhesion of the samples will be calculated using the equation: $P_a = F/A$, where P_a is adhesion (N/mm^2), F denotes the force at break (N), and A is application area (mm^2).

Data Analysis

Analyses were performed in International Business Machines Statistical Package for the Social Sciences (2022, New York, ABD) program. Statistical methods were used to calculate the arithmetic mean (X), standard deviation (S), and percentage coefficient of variation (V). Analysis of variance was used to determine whether there is a difference in the comparison of varnish + additives properties. In cases where there was a difference, homogeneity groups were determined by Duncan-test. In the analysis of variance, the values of the F-measure and F-table were determined, and if the F-measure values were greater than 5% (B.D), between 5% and 1% (*), between 1% and 0.1% (**), and less than 0.1% (***) will be explained with signs. Samples that did not fit the normal distribution were evaluated by t-test.

RESULTS AND DISCUSSION**Abrasion Resistance and Adhesion**

Table 1 shows the mean and standard deviation values of the abrasion resistance and adhesion of the samples. The highest abrasion resistance was found in chestnut (534.8 rpm) in graphene 2 (0.50%) mixed with polyurethane varnish; the lowest was in beech (254.4 rpm) in the control group. Graphene 2 (0.50%) mixed with water-based varnish was found in beech (268.4 rpm); the lowest graphene 3 (1%) was found in yellow pine (246.8 rpm). The highest adhesion was found in graphene 1 (0.25%) yellow pine (2.81 N/mm^2) mixed with polyurethane varnish; the lowest was found in spruce (0.52 N/mm^2) in the control group. Graphene 1 (0.25%) mixed with water-based varnish was found in spruce (1.95 N/mm^2); the lowest graphene 3 (1%) was found in chestnut (0.26 N/mm^2). It was observed that the abrasion and adhesion of graphene-added varnishes increased up to 0.50% graphene content; however, the resistance decreased when the graphene content was increased from 0.50% to 1%. The reasons for this are thought to be the decrease in the bonding of graphene with varnish after a certain concentration and the overlapping of the film layers formed on the surface. Polyurethane and water-based varnishes, which are among the varnishes used in wood materials, have many advantages and disadvantages in themselves. Polyurethane varnishes are known for their high abrasion resistance and adhesion. Their chemical structure creates a hard and durable surface.

Table 1. Mean and Standard Deviation Values of Abrasion Resistance and Adhesion of the Samples

Wear Resistance (rpm)																
	Polyurethane Varnish								Water-based Varnish							
	Tangent cross section				Radial section				Tangent cross section				Radial section			
	C	G1	G2	G3	C	G1	G2	G3	C	G1	G2	G3	C	G1	G2	G3
	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Beech	254.4 (3)*	400 (8.36)	483 (11.88)	292.6 (5.7)	257.2 (2.48)	290.6 (2.031)	294.4 (1.93)	253.8 (8.22)	256 (1.67)	256.2 (2.92)	268.4 (6.62)	256 (3.84)	256.4 (1.85)	255.6 (1.01)	260.8 (5.81)	260.8 (4.53)
Chestnut	261.2 (4)	340.8 (8.06)	534.8 (10.45)	402.8 (12.27)	256.6 (1.74)	203.8 (3.54)	274.2 (6.88)	234.8 (2.47)	253.8 (6.85)	256.4 (1.85)	253 (5.17)	255.6 (2.87)	262 (5.89)	256.4 (1.62)	263.4 (4.22)	259.4 (6.59)
Yellow pine	257.8 (5.97)	391.6 (9.56)	385 (7.28)	279 (2.76)	245.8 (23)	262.6 (5.7)	255.4 (2.8)	205.8 (5.23)	260.6 (3)	261.4 (5.95)	255.8 (1.72)	246.8 (2.1)	255.4 (2.05)	256 (1.67)	255 (2.75)	252.8 (2.13)
Spruce	258.6 (3.49)	316.4 (9.82)	404 (3.03)	382.8 (7.93)	257.4 (2.41)	274.2 (7.61)	273.8 (2.22)	253.2 (3.2)	256 (1.67)	256.4 (1.85)	254.4 (3)	256.6 (1.74)	256.4 (1.62)	257 (1.41)	258.4 (4.71)	251 (4.56)
Adhesion (N/mm ²)																
	Polyurethane Varnish								Water-based Varnish							
	Tangent cross section				Radial section				Tangent cross section				Radial section			
	C	G1	G2	G3	C	G1	G2	G3	C	G1	G2	G3	C	G1	G2	G3
	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Beech	2.11 (0.69)*	1.8 (0.24)	1.45 (0.18)	1.36 (0.26)	1.15 (0.3)	1.87 (0.34)	1.16 (0.27)	1.55 (0.17)	1.1 (0.34)	1.12 (0.51)	1.13 (0.49)	1.07 (0.35)	0.92 (0.12)	1.45 (0.23)	1.65 (0.68)	1.02 (0.43)
Chestnut	1.37 (0.37)	1.42 (0.45)	2.42 (0.22)	2.27 (0.3)	1.68 (0.21)	2.42 (0.25)	1.91 (0.33)	2.22 (0.2)	0.33 (0.01)	0.26 (0.01)	0.26 (0.02)	0.45 (0.25)	0.3 (0.01)	0.3 (0.01)	0.29 (0.06)	0.26 (0.05)
Yellow pine	2.26 (0.08)	1.81 (0.24)	1.61 (0.24)	1.35 (0.22)	1.32 (0.31)	2.81 (0.3)	2.6 (0.65)	1.67 (0.16)	0.57 (0.32)	0.84 (0.23)	0.64 (0.2)	0.68 (0.52)	0.51 (0.3)	0.32 (0.11)	0.34 (0.04)	0.38 (0.14)
Spruce	1.54 (0.3)	1.57 (0.12)	1.72 (0.29)	1.62 (0.23)	0.52 (0.14)	0.79 (0.2)	0.64 (0.09)	0.55 (0.16)	0.51 (0.12)	1.09 (0.2)	0.67 (0.29)	0.9 (0.37)	1.17 (0.17)	1.95 (0.72)	1.77 (0.33)	1.23 (0.63)
C: control, G1: graphene 1 (%0.25), G1: graphene 1 (%0.50), G1: graphene 3 (%1), X: arithmetic mean, *: standard deviation																

Although water-based varnishes are more environmentally friendly and have low VOC (Volatile Organic Compounds) content, their abrasion resistance may be lower than solvent-based varnishes. However, with the developing technology, abrasion resistance and adhesion of varnishes are increased. Methods of increasing abrasion resistance and adhesion include increasing the number of layers, sanding between layers, increasing the drying time, making the surface preparation properly, or making the varnish stronger by using additives. Graphene added to the varnish as an additive has a single-layer honeycomb-like lattice structure and carbon atoms. This corresponds to its high surface area and mechanical properties. When mixed with low amounts of varnishes, it improves wear resistance and adhesion by reducing the brittleness of the varnish (Zheng *et al.* 2016; Khan *et al.* 2022).

Table 2 shows a statistically significant difference ($P < 0.05$) (***) for additives mixed with polyurethane varnishes for abrasion resistance in terms of direction (radial, tangential), additive ratio, and wood species for additives at all ratios. Statistical evaluations were made for abrasion resistance and adhesion. An independent two-sample T-test was performed to determine whether there was a statistically significant difference between the abrasion resistance and adhesion of the control group and 3 variations in terms of direction (radial, tangential) of the additives mixed with polyurethane and water-based varnishes, and simple analysis of variance was performed to determine whether there was a statistically significant difference between them according to the additive ratio and wood species. These evaluations are given in Tables 2 and 3. Homogeneity groups were determined by Duncan test to determine the differences according to additive ratios. Control and graphene 3 (0,25%) formed a group, graphene 3 (0,25%), and graphene 1 (1%) formed a group, graphene 2 (0,50%) formed a separate group. For additives mixed with water-based varnishes, there was no significant difference ($P > 0.05$) (B.D) in terms of direction (radial, tangential), additive ratio and wood species.

Table 2. Statistical Analysis of Abrasion Resistance Test Results

Wear			Polyurethane Varnish				Water-based Varnish			
		N	Mean	Std. Deviation		HG	Mean	Std. Deviation		HG
Sf	R	80	255.85	46.10	0.000		257.3	4.96	0.572	
	T	80	352.80	111.24			256.46	7.82		
A.	C	40	256.12	9.92	0.000	(256.12) ^a	257.07	4.53	0.080	(257.07) ^{ab}
	G1	40	310	96.55		(310) ^b	256.92	3.26		(256.92) ^{ab}
	G2	40	363.07	120.99		(363.07) ^c	258.65	6.77		(258.65) ^b
	G3	40	288.10	93.40		(288.10) ^{ab}	254.87	9.49		(254.87) ^a
	All	160	304.32	97.82			256.88	6.54		
Tt	C	40	256.12	9.92	0.000	(256.12) ^a	257.5	6.02	0.081	(257.5) ^{ab}
	B	40	310	96.55		(310.00) ^b	258.77	5.85		(258.77) ^b
	Yp	40	363.07	120.99		(363.07) ^c	255.47	9.15		(255.47) ^a
	S	40	288.1	93.40		(288.10) ^{ab}	255.77	3.59		(255.77) ^{ab}
	All	160	304.32	97.82			256.88	6.54		

Number in parentheses are standard deviations; a, b, or c are homogeneity groups; Sf: Section form, A: Additive, Tt: Tree type, HG: Homogeneity Groups (Different letters indicate statistically significant difference between groups) R: Radial, T: Tangent, C: Chestnut, B: Beech, Yp: yellow pine, S: spruce, All: total

Mastouri Mansourabad *et al.* (2020) determined that using nano-cerium oxide nanomaterial as an additive in polyurethane varnish increased the abrasion resistance by 32%. Xu *et al.* (2022) reported that the abrasion resistance of water-based varnishes mixed with graphene increased by 14.8%. In the study, the abrasion resistance increased by 1.6% in water-based varnishes mixed with graphene and 142% in polyurethane varnishes. Abrasion resistance of surface treatment materials mixed with nanomaterials has been reported to improve (Sönmez and Budakçı 2004; Bauer and Mehnert 2005; Jalili *et al.* 2007). The fact that graphene used in the study increases the wear resistance is supported by other studies (Berman *et al.* 2013). Figure 1 shows the wear resistance values of the additives. The highest abrasion resistance was obtained in polyurethane varnish with graphene 2 (0.50%) and the lowest in the control group; the highest abrasion resistance was obtained in water-based varnish with graphene 2 (0.25%) and the lowest with graphene 3 (1%).

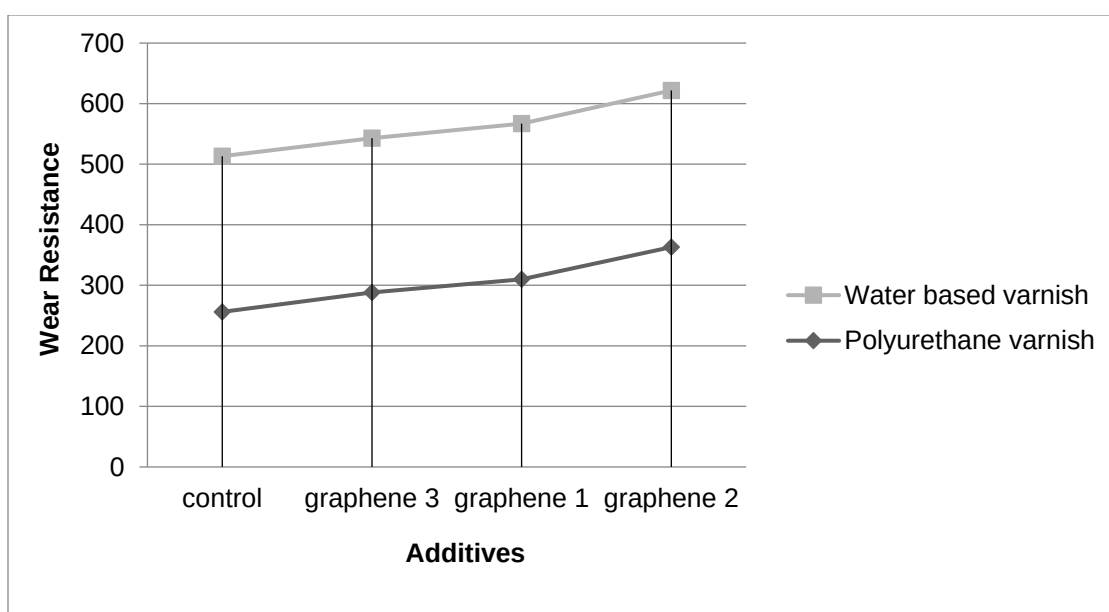


Fig. 1. Wear resistance values of additives

The hardness and specific gravity of the material are among the factors determining the abrasion resistance (Özdemir 2003). Among the wood species used in the study, pine, spruce, chestnut, and beech are listed in order of specific gravity from highest to lowest. Various wood species were varnished with various varnishes, and it was reported that the highest abrasion resistance was found in leafy trees and polyurethane varnish (Tekin 2009). Figure 2 shows the abrasion resistance values of wood species. The highest abrasion resistance was found in beech and the lowest in yellow pine in polyurethane varnish, while all wood species had similar abrasion resistance in water-based varnish. This is in harmony with the literature.

Table 3 shows a statistically significant difference ($P < 0.05$) (***) in terms of direction (radial, tangential) and wood species for additives mixed with polyurethane varnishes for adhesion, while there was no significant difference ($P > 0.05$) (B.D) in terms of additive ratio. To determine the differences according to tree species, homogeneity groups were determined by Duncan test. Spruce and beech formed a separate group, yellow pine and chestnut formed a group. In the case of additives mixed with water-based

varnishes, there was a statistically significant difference ($P < 0.05$) (***) in terms of direction (radial, tangential) and wood species, but not in terms of additive ratio ($P > 0.05$) (B.D). Homogeneity groups were determined by using Duncan test, one of the post-hoc tests, to determine the differences according to tree species. It was divided into 3 homogeneous groups. Chestnut and yellow pine formed a separate group, while spruce and beech formed a group. Adhesion is one of the most important factors in the adhesion of varnishes to wood materials. There are different theories about the interactions of the wood material with the varnish.

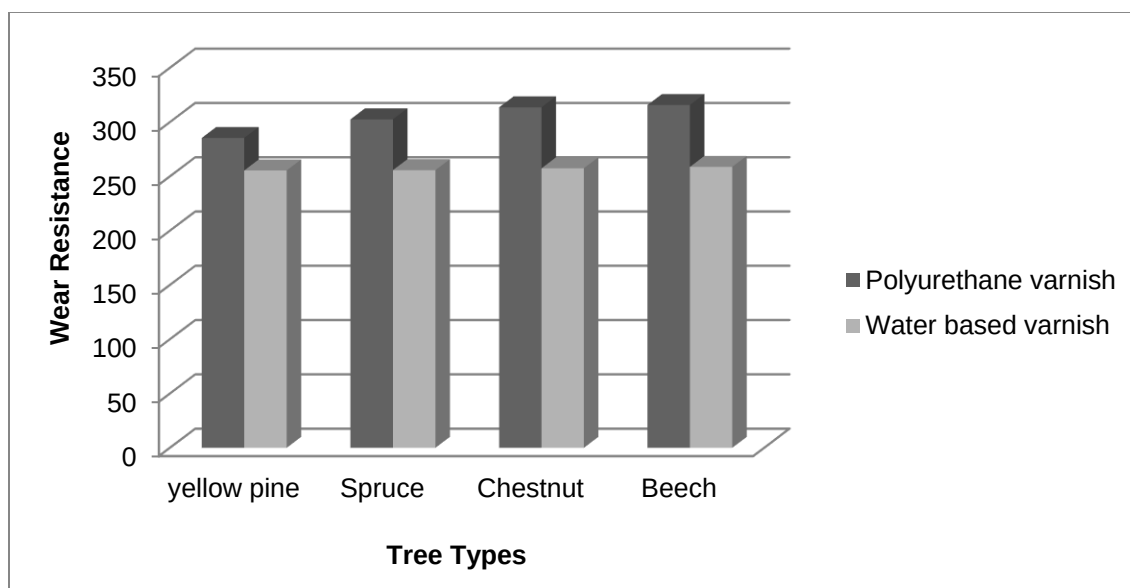


Fig. 2. Abrasion resistance values of wood species

Table 3. Statistical Analysis of Bond Strength Test Results

Adhesion		Polyurethane Varnish				Water-based Varnish			
		N	Mean	Std. Deviation	HG	Mean	Std. Deviation	HG	HG
Sf	R	80	1.51	0.77435	0.000	0.8710	0.68432	0.000	
	T	80	1.78	0.43341		0.7290	0.44254		
A.	C	40	1.49	0.63202	0.132	(1.49) ^a	0.6795	0.38979	(0.6795) ^a
	G1	40	1.81	0.64681		(1.81) ^b	0.9195	0.67480	(0.9195) ^a
	G2	40	1.69	0.68971		(1.69) ^{ab}	0.8483	0.67223	(0.8483) ^a
	G3	40	1.57	0.56314		(1.57) ^{ab}	0.7528	0.52208	(0.7528) ^a
	All	160	1.64	0.63993			0.8000	0.57884	
Tt	C	40	1.96	0.51964	0.000	(1.96) ^c	0.3118	0.11393	(0.3118) ^a
	B	40	1.55	0.48182		(1.55) ^b	1.18	0.49324	(1.18) ^c
	Yp	40	1.93	0.62428		(1.93) ^c	0.5375	0.32871	(0.5375) ^b
	S	40	1.12	0.54853		(1.12) ^a	1.16	0.63028	(1.16) ^c
	All	160	1.64	0.63993			0.8000	0.57884	

Number in parentheses are standard deviations. a, b, or c are homogeneity groups; Sf: Section form, A: Additive; Tt: Tree type; HG: Homogeneity groups (Different letters indicate statistically significant difference between groups) R: Radial; T: Tangent; C: Chestnut; B: Beech; Yp: yellow pine; S: spruce; All: Total

Özdemir and Hızıroğlu (2007) considered the adhesion properties of bleached, dyed, and preservative-treated wood species. Dyed samples reached an average adhesion

strength of 1585 N/mm², which is the highest among the other samples. Özdemir and Kocapınar (2015) applied cellulosic varnish with different processing properties on various wood species and found the highest adhesion of 2.42 (N/mm²). Pelit and Korkmaz (2019) reported an increase in adhesion from 12% to 25% in beech samples treated with water-based varnish with graphene added at different rates. In this study, adhesion increased by 136% in water-based varnishes mixed with graphene and by 122% in polyurethane varnishes. Increases in adhesion can be explained by the fact that graphene increases the bonding of the vein.

Nanomaterials reduce the initial adhesion of the varnish in film formation. This affects the adhesion to the surface (Miklečić *et al.* 2017). However, in this study, the use of nanomaterial-added varnish up to a certain ratio did not reduce adhesion. Figure 3 shows the adhesion values of the additives. The highest adhesion was obtained in polyurethane varnish with graphene 2 (0.50%) and the lowest in the control group; the highest adhesion was obtained in water-based varnish with graphene 2 (0.50%) and the lowest in the control group.

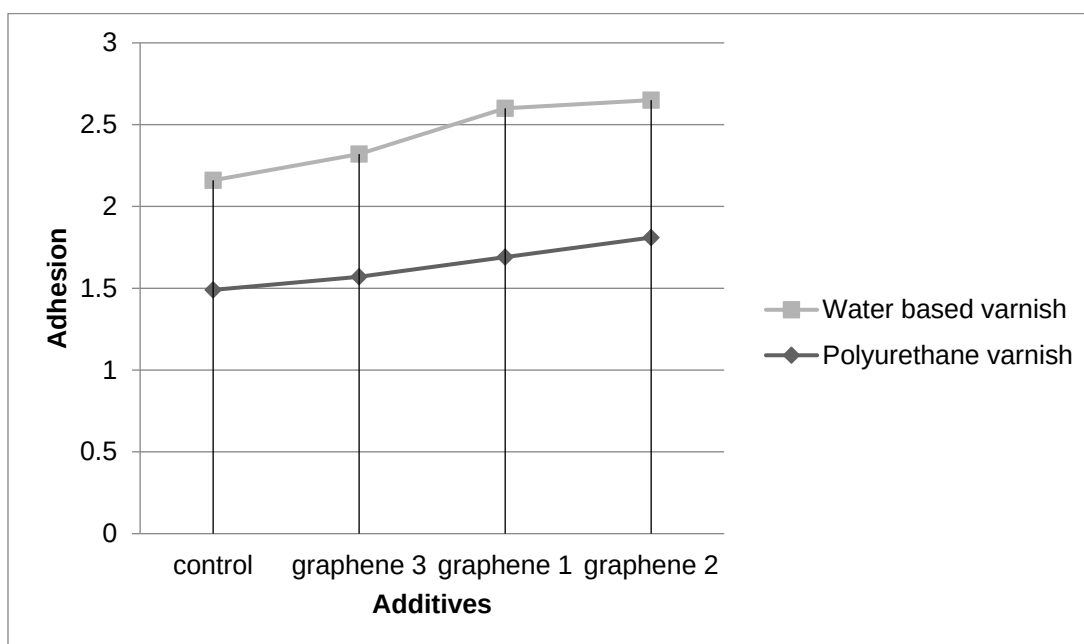


Fig. 3. Adhesion values of additives

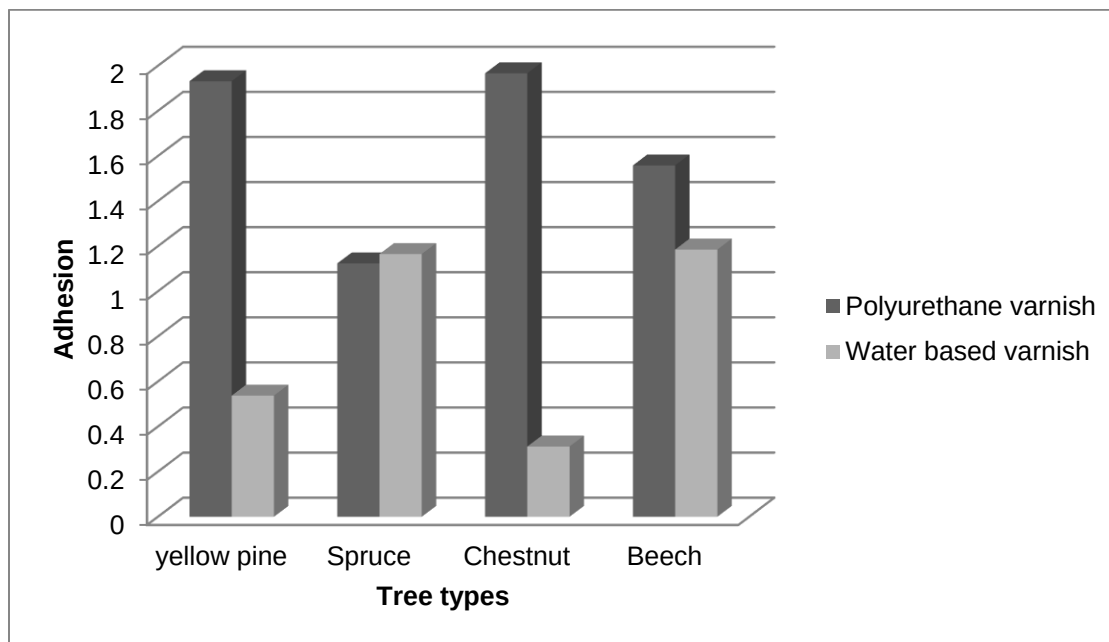


Fig. 4. Adhesion values of wood species

Wood species and varnish type had an effect on adhesion, while layer thickness had no effect. Leafy wood species exhibited higher adhesion in polyurethane and acrylic varnishes than coniferous wood species (Sönmez 1989; Shakri and Seman 1995; Nussbaum 1996; Özdemir 2003; Budakçı and Sönmez 2010). Differences in bonding arise due to different varnish compositions (Jaic and Zivanovic 1997). The adhesion strength of polyurethane varnishes is better than other varnishes (Budakçı and Sönmez 2010).

Figure 4 shows the adhesion values of wood species. The highest adhesion was found in chestnut, and the lowest in spruce for polyurethane varnish; the highest adhesion was found in beech and the lowest in chestnut for water-based varnish.

CONCLUSIONS

In this study, the abrasion resistance and adhesion of wood samples coated with graphene varnish were determined. Based on the findings, the following conclusions were reached.

1. Wear resistance was different for different graphene ratios. The abrasion performance of polyurethane varnish was higher than water-based varnish.
2. For the doped samples mixed with polyurethane varnish, there was a significant difference in each of the varnish + graphene 1 (1%), varnish + graphene 2 (0.50%), varnish + graphene 3 (0.25%) doped varnishes according to the crossing direction and doping ratio. However, no difference was found according to wood species.
3. There was no difference in the abrasion resistance of graphene doped samples mixed with water-based varnish according to the crossing direction, additive rate and wood species.

4. There was a significant difference in the adhesion of varnish+graphene 1 (1%), varnish+graphene 2 (0.50%), varnish+graphene 3 (0.25%) additive varnishes according to the cutting direction and wood species in the samples with additives mixed with polyurethane varnish and additives mixed with water-based varnish. However, no difference was found according to the additive ratio.
5. While the amount of graphene in the varnish increased up to 0.50%, the abrasion resistance and adhesion decreases as the amount increases towards 1%.
6. The use of graphene in water-based and polyurethane varnish can be recommended due to its high abrasion resistance and adhesion.

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