The Effects of Water-based Insulation Paint Applied to Laminate Flooring Panels on the Thermal Conductivity Coefficient and Adhesion Resistance

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In an effort to reduce negative feedback resulting from temperature fluctuations, house floors are commonly laid with laminate flooring. The aim of this study was to study the thermal insulation properties and adhesion strength of the water-based insulation paint mixed with hollow glass spheres and applied onto the laminate flooring. The objective was to determine whether a prepared insulation paint mixture can be used instead of backing paper. For this purpose, two different laminate flooring samples were used. In the first case, the upper surface of the sample was coated with decorative paper and the lining surface was coated with backing paper. The upper surface of the second sample was coated with decorative paper and the lining surface was not coated with backing paper. Then, insulation paint mixture was applied 2, 4, or 6 times to the lining surfaces of both groups, and experimental results were obtained. As the number of layers was increased, the insulation mixture applied to the lining surfaces of the test samples was found to contribute positively to thermal insulation and adhesion resistance of specimens.

Keywords: Format; Laminate flooring; Water-based insulation paint; Hollow glass microspheres; Thermal conductivity coefficient; Adhesion resistance

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INTRODUCTION

People express their lifestyles by covering the ceilings, walls, and floors in places where they live, and the consumers expect the heat insulation to be sufficient. Notably, the cold conductivity from the ground has made the floor coverings indispensable with regard to thermal insulation. In many countries of the world, as in Turkey, coatings and finishes are produced from different materials (Döngel *et al*. 2008; Kaymakcı *et al.* 2014). The high cost of solid wood, dimensional change at different ratios in three directions (radial, tangent, and longitudinal), and some other disadvantages of wood, such as the difficulty of providing different colors and patterns, has provided motivation to consider composite wood flooring (laminate flooring) (As 1998). The use of composite floors has brought along some advantages such as not requiring varnish and paint on the upper surface, good abrasion resistance, easy installation, and thermal insulation. However, the contribution of this application to thermal insulation is not at the desired level yet. In order to improve the thermal insulation properties of laminate floorings, which are lower cost than in solid wood materials (Sahin Kol *et al.* 2010; Uysal *et al.* 2011), low density and interstitial materials are reinforced into the middle layer and lining layers of laminate flooring.

There are many studies on the thermal insulation properties of composite materials, wood panels, and protective layers supported by different nano materials. Composite materials treated with different coatings (paper, PVC, *etc.*) and preservatives (paint, varnish, *etc.*) have thermal conductivity values that vary depending on the concentration of chemicals used in them (Acik and Tutus 2012; Ustaomer and Usta 2017; Sahin and Dongel 2018). Another material developed for isolation is water-based isolation paint, which contains additives such as micro-sized hollow glass spheres. Currently, these kinds of applications are used for interior and exterior facades of buildings for thermal, acoustic, and moisture isolation (Wang *et al.* 2014; Posmyk 2016; Kimetsan 2018). The use of water-based paints that are reinforced by micro-sized hollow glass spheres in floor coverings and the investigation of their heat insulation properties can contribute to the flooring industry.

It is important to know the thermal conductivity coefficient in the evaluation of the performance of thermal insulation materials (Zhou *et al.* 2013), and a low conductivity coefficient is one of the desirable features (Nemli and Kalaycioglu 2002; Lan *et al.* 2014). Further enhancement of the porous structure positively influenced the thermal performance of water-based paints reinforced by micro-sized hollow glass spheres (Dzyazko and Konstantinovsky 2014; Wang *et al.* 2014). The thermal conductivity values of the paints based on thicknesses of 0.10 to 0.18 W/mK have been reported (Chukhlanov *et al.* 2017). The thermal conductivity coefficient values of WBNTP-D45 at the dry film thickness are 0.017 to 0.022 W/mK (Tech. Rep.1 2010) and demonstrate that 72 °C on one surface of the test device is measured at 36 °C on the other surface (Oztin 2014). In some studies, the thermal conductivity values of hollow water-based paints are quite different from each other and it has been reported that academic circles cannot reach a consensus on the quality of thermal insulation (Bozsaky 2017, 2018).

If the material to be used for heat insulation purposes is in paint, then the adhesion of the paint with material is the most important criteria. The adhesion resistance values of protective layers may vary depending on weather conditions, the properties of the resin used, and its molecular dimensions. The number of layers in the applications, the varnish, and the modification of the paints are also important. In addition, it has been reported that the adhesion resistance of the protective layers may vary depending on their material density and surface hardness (Budakci and Sonmez 2010; Dilik *et al.* 2015). Especially in recent years, by means of the production of protective layers with nano technological products, new developments have been encountered. There is a higher surface area and a higher increase in molecule ratios per head in these developments (Dongguang *et al.* 2002). This may contribute positively to the adhesion resistance of nano-technological protective layers. As a matter of fact, it has been reported that the adhesion resistance may decrease with mixing some additives (Panchenko *et al.* 2018). Various protective layers with different adhesion resistance values have been applied to different wood material surfaces: on cellulosic based (1.86 to 3.62 MPa), on synthetic based (3.72 to 5.43 MPa), on water-based (1.44 to 3.73 MPa), on polyurethane based (2.37 to 4.05 MPa), and on acrylic based (3.66 to 3.80 MPa). Adhesion resistance values differ in the literature (Ozcifci and Ozpak 2008; Atar and Peker 2010; Dilik *et al.* 2015; Ozdemir *et al.* 2015; Sogutlu *et al.* 2016; Kesik *et al.* 2017; Oncel *et al*. 2019).

The aim of this study was to determine the effects of applying water-based insulation paint to laminate floorings with different numbers of layers (2, 4, and 6) in order to determine their thermal conductivity and adhesion resistance. In addition, this research aimed to determine whether insulation paint mixture can be used instead of backing paper.

EXPERIMENTAL

Materials

High-density fiberboard (HDF)

In this study, laminate flooring based on HDF, which is widely used in flooring, was preferred as a test material because of its direct primability and coating and polishing ability. Two different laminate floorings used in the experiments were manufactured by SFC Plant, Kastamonu, Turkey. According to the relevant standards, the laminate flooring was coated with backing paper on one of the plates to be laminated, and the other surface was specially produced with 350 N/cm^2 press pressure in dimensions of 2070 × 2610 mm without covering the surface with backing paper. The backing paper used was 150 g/m^2, and overlay paper was 140 g/m^2. After pressing, the average density value was determined to be 0.96 g/cm^3 in coated laminate flooring with backing paper, and 0.95 g/cm^3 in the uncoated laminate floorings (TS EN 323 1999). The pre-press backing paper (a) and the laminate without backing paper (b) within the parquet elements are shown in Fig. 1. In Fig. 2, it is possible to observe the elements of laminate flooring with (a), without (b) the backing paper and a test sample, and (c) following paint application.

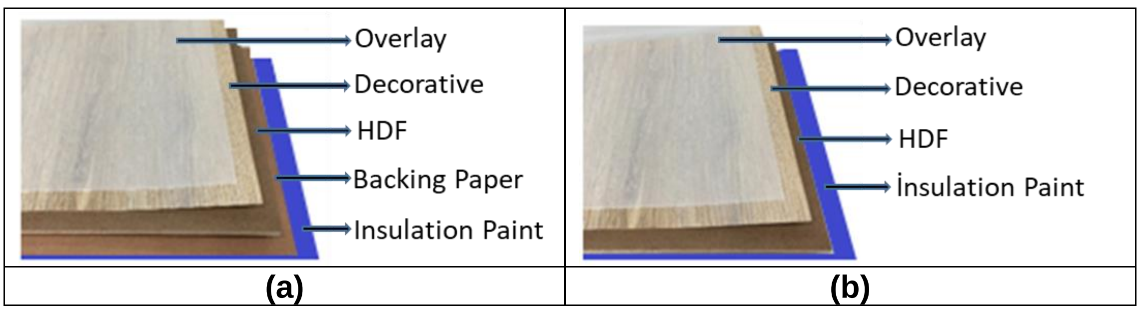

Fig. 1. Before pressing the laminate flooring elements with (a) and without (b) backing paper

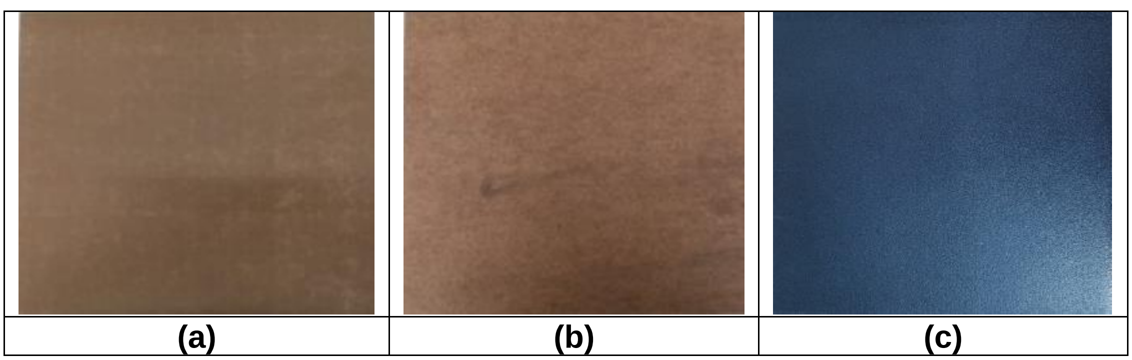

Fig. 2. After pressing the laminate flooring with (a), without (b) backing paper, and painted test sample (c)

Water-based covering agents

Water-based filler varnish (WBF-D45), water-based topcoat varnish (WBV-D45), and water-based heat-insulating paint mixed with hollow glass spheres (WBTP-D45) are the materials that were used in the experiments. The sourcing company (Kimetsan Co., Ltd., Ankara, Turkey) had defined the paint as water-based nano and micro technological insulating paint (WBNTP-D45) with the property to make micro-acrylic modified polyurethane insulation that was heat and water proof. The paint was prepared by mixing acrylic modified polyurethane nano-size resin (70%) with micro-size hollow glass spheres (30%). The technical specifications of the paints, varnishes and applications used in the study are given in Table 1 (Technical Bulletin. 2018).

Table 1. Technical Specifications Used Agents and their Applications Parameters

Protective Layer Type	pH	Density (g/cm³)	Viscosity (s/DINCup/4 mm)	Nozzle Gap (mm)	Working Pressure (Bar)
WBF-D45	9.17	1.014	18	1	2
WBV-D45	9.10	1.015	18	1	2
WBTP-D45	8.20	0.82	30	2	2

The SEM image of the large and small microscale hollow glass spheres in the paint is shown in Fig. 3, and the SEM (Quanta FEG 250; FEI Company, Brno, Czech Republic) at) image of the WBTP-D45 applied to the test sample is given in Fig. 4. All SEM images were captured at Kastamonu University Central Research Laboratory with the test specimens.

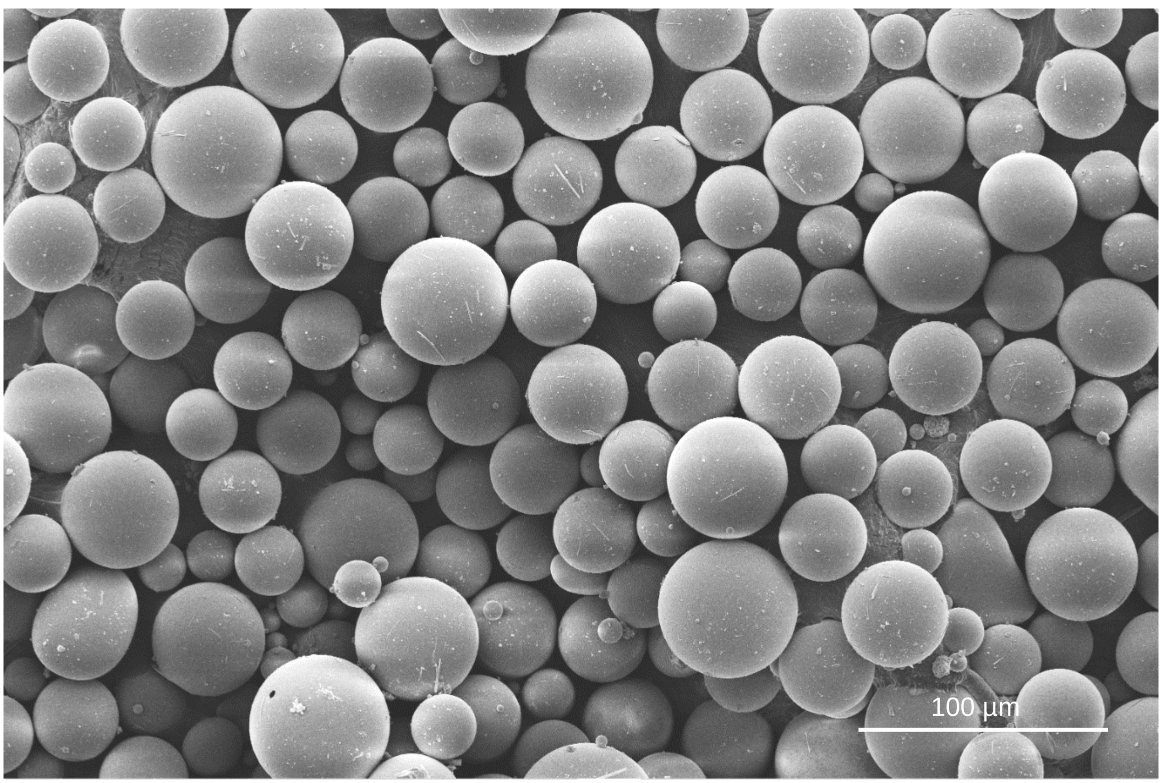

Fig. 3. SEM image of hollow glass spheres

Preparation of experiments

Test specimens prepared in the dimensions of 310 × 310 mm had been kept in an air conditioning cabinet at a temperature of 20 ± 2 °C with a relative humidity of 65 ± 5% until they reached a constant weight (TS 2471 2005). The test specimens to be used in surface adhesion were prepared as 100 × 100 × 8 mm tests and 80 were prepared at 300 ×

300 × 8 mm for thermal conductivity tests. According to the company recommendations, WBTP-D45 laminate was first applied as a layer, and WBF-D45 was used for filling to provide good bonding with parquet lining surfaces. For the second application, WBTP-D45 was applied 2, 4, and 6 times separately for both coated and uncoated groups of samples. For the final application, WBV-D45 was applied as a coat to the upper surface of each sample to prevent surface abrasion and contamination. The samples were coated with paints and varnishes according to company specifications and ASTM-D 3023-98 (2011) values.

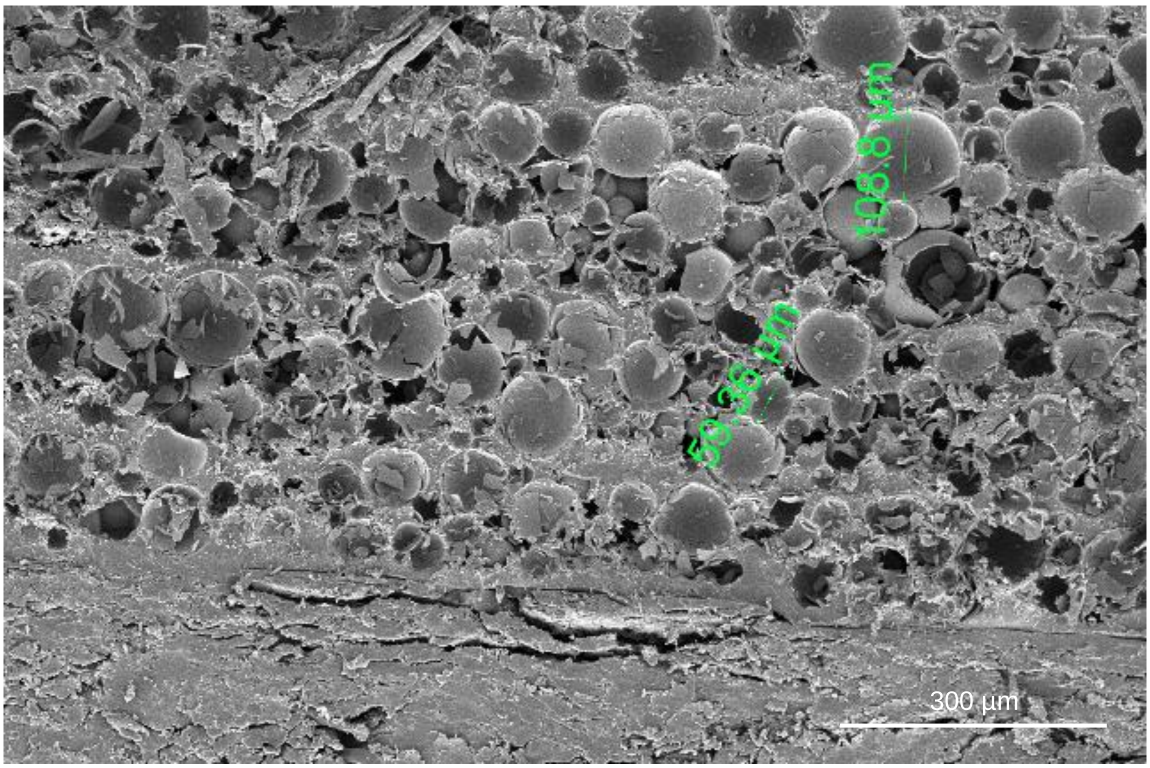

Fig. 4. SEM image of the WBTP-D45 applied to the test sample

The WBTP-D45 application was made in layers with 15 min between each layer application. The hollow glass spheres were added to the paint surface and mixed well before each application. Oven dried WBTP-D45 film thicknesses were measured as nearly 60 µm. Paint applications were made with a spray gun (Fig. 5) with a Fuji brand bag type compressor (Fuji Q4 Gold Tribune; Fuji Industrial Spray Equipment Ltd., Toronto, ON, Canada) and high volume low pressure (HVLP).

Thermal conductivity tests were conducted according to TS EN 12627 (2003) in the testing laboratory of the Department of Woodworking Industrial Engineering of Gazi University Faculty of Technology with a Linseis HFM 300 tester (Linseis Messgerate GmbH, Selb, Germany). The top plate temperature of the device calibrated to 30 °C and the bottom was set to 20 °C, and the painted surfaces of the test specimens were placed between the plates and thermal conductivity coefficient values were determined by means of computer software.

Fig. 5. Bag type compressor and spray gun with HVLP feature

For surface adhesion tests, steel cylinders with a diameter of 20 mm were glued to the painted surfaces of the test specimens with 150 ± 10 g/m^2 double component epoxy in 20 ± 2 °C media and left to dry for 24 h. Then, the steel rollers adhered to the paint layer were cut to the surface of the sample with a circular knife and tests were performed. Surface adhesion tests were conducted according to ASTM D4541-02 (2009) by a Shimadzu universal test instrument (AG-IC 20KN/50KN; Shimadzu Suzhou Instruments Wfg. Co., Ltd., Suzhou, Jiangsu, China) in the laboratory of the Department of Forest Industry Engineering of Faculty of Forestry of Kastamonu University (Kastamonu, Turkey).

Evaluation of data

Statistical evaluations and analysis of thermal conductivity and dye adhesion resistance data obtained from laminated flooring of heat-insulating paint were performed using IBM SPSS 20 package (IBM Corp., Armonk, NY, USA). While this data was taken into consideration separately, analysis of variance (ANOVA) was carried out to determine the effects of the factors of backing paper usage and the number of dye layers on laminate parquet lining surfaces; the Duncan test was applied to determine homogeneous groups according to the results of bilateral interaction.

RESULTS AND DISCUSSION

Thermal Conductivity Coefficient (λ)

The results of ANOVA based on the effect of availability of backing paper (ABP) and number of dye layers (PLN) on the thermal conductivity coefficient of laminate parquet lining surfaces are given in Table 2.

Table 2. Results of Variance Analysis on the Effect of ABP and PLN on Thermal Conductivity and Permeability Coefficient

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance
ABP	1	0.002	0.002	218.231	0.000*
PLN	3	0.002	0.001	108.011	0.000*
ABP × PLN	3	0.0000781	0.000026	3.768	0.014*
Error	72	0.000	0.00000691		
Total	80	1.023			
* Important to p < 0.05					

According to Table 2, adhesion resistance values of ABP, PLN, and the double interaction of the main variables were found to be statistically significant ($p < 0.05$). Duncan test results, mean values and homogenous groups of the effects of ABP and PLN interactions are given in Table 3.

Table 3. Duncan Test Results Regarding the Effect of the Thermal Conductivity Coefficient of the ABP and PLN Binary Interaction

ABP	PLN	N	Thermal conductivity coefficient (λ) W/mK		LSD
			Mean (± Std. Dev.)	HG	
With backing paper	Control	10	0.115 (± 0.003)	c	± 0.003
	2	10	0.111 (± 0.001)	d	
	4	10	0.105 (± 0.003)	e	
	6	10	0.104 (± 0.003)	e	
Without backing paper	Control	10	0.126 (± 0.004)	a	
	2	10	0.120 (± 0.001)	b	
	4	10	0.114 (± 0.002)	c	
	6	10	0.110 (± 0.002)	d	
HG: Homogenous groups, LSD: Least significant difference					

According to Table 3, the highest coefficient of thermal conductivity was obtained at the control samples. The lowest thermal conductivity values were obtained in the samples covered with backing layer with the 6 layer applications. In the study conducted with QTM-500 Kyoto device by Acik and Tutus (2012), the thermal conductivity coefficient (0.246 W/mK) in the 8-mm-thick HDF samples coated with only one surface melamine resin decor paper is approximately two times (0.126 W/mK) higher than the findings of this study. This difference can be caused by measurement with different devices (QTM-500 Kyoto). In a study conducted by Chukhlanov *et al.* (2017), with hollow glass micro-spherical filler thermal insulation dyes has given the conductivity coefficient range between 0.10 to 0.18 W/mK. Also Chukhlanov *et al.* (2017) suggested at least 5 mm thickness dye thickness for adequate heat insulation. In this study, the thickness of WBTP-D45 was 360 µm (for 6 layers), in which the thermal conductivity coefficient ranged from 0.104 to 0.110 W/mK. This is important in terms of the reliability of the WBTP-D45, so that it is not necessary to apply excess thicknesses. In addition, when the hollow glass spheres ratio is increased in the WBTP-D45 (30% micro size hollow glass spheres and 70% nano size acrylic modified polyurethane resin), the thermal conductivity coefficient is reduced. This view is supported by Dzyazko and Konstantinovsky (2014) and Wang *et al.* (2014). They indicated that when the porosity is increased in the paint, thermal performance is increased. The change in the thermal conductivity coefficient according to ABP and PLN is given in Fig. 6.

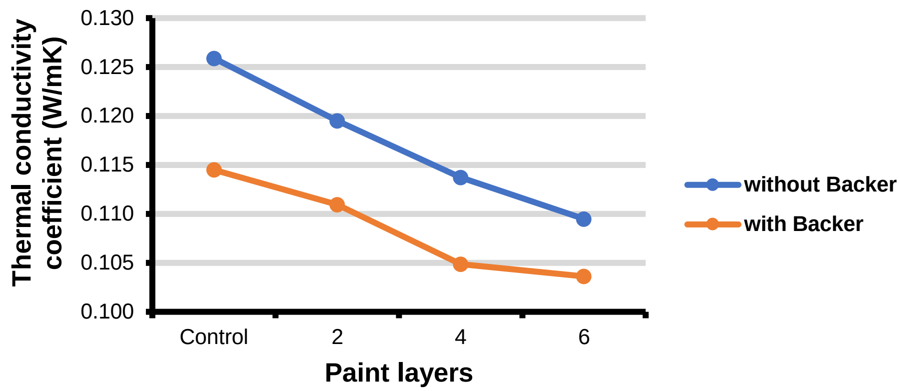

Fig. 6. Change of thermal conductivity coefficient in flooring specimens w/ and w/out backing paper

In general, the mean value of thermal conductivity coefficient of the test specimens covered with backing paper was significantly higher than those without backing paper (Fig. 6). In particular, the results indicated that the application of backing paper significantly affects the thermal conductivity coefficient of laminated floorings. Results showed that thermal conductivity was drastically improved with the application of backing paper. Therefore, this result indicates how important it is to use the backing paper even if the insulating paint mixture is utilized. In the literature, it is claimed that thermal conductivity coefficient values of composite materials treated with different coatings and preservatives have been changed positively (Acik and Tutus 2012; Ustaomer and Usta 2017; Sahin and Dongel 2018). This study proved to be compatible with the literature.

Surface Adhesion Resistance

The results of ANOVA based on the effect of availability of backing paper (ABP) and number of paint layers (PLN) on the adhesion resistance of laminate parquet lining surfaces are given in Table 4.

Table 4. Results of Variance Analysis on the Effect of Adhesion Resistance of ABP and PLN

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance
ABP	1	10.061	10.061	152.846	0.000*
PLN	2	8.214	4.107	62.389	0.000*
ABP × PLN	2	122	0.061	0.927	0.402
Error	54	3.555	0.066		
Total	60	562.732			
* Important to $p < 0.05$					

According to Table 4, the adhesion resistance values of the main variables ABP and PLN were statistically significant and the pair interaction was statistically insignificant ($p < 0.05$). Duncan test results of adhesion resistance of ABP and PLN are given in Table 5.

Table 5. Duncan Test Results on the Adhesion Resistance of ABP and PLN

Operations		N	Bonding Strength (MPa)		LSD
			Mean (± Std. Dev.)	HG	
ABP	with backing paper	30	3.41 (± 0.46)	a	*± 0.23*
	without backing paper	30	2.59 (± 0.45)	b	
PLN	2	20	2.59 (± 0.47)	c	*± 0.32*
	4	20	2.93 (± 0.51)	b	
	6	20	3.49 (± 0.61)	a	
HG: Homogeneous groups, LSD: Least significant difference					

According to Table 5, the adhesion resistance value was determined to be high in the laminate flooring coated with balancing paper on the primer surfaces, and low in the uncoated laminate flooring for the lining surfaces. The high adhesion resistance of WBTP-D45 applied to the laminate flooring coated with balancing paper on the primer surfaces may be due to the surface quality, density, hardness of the surface of the primer, and its strong bonding with the backing paper. The adhesion resistance of WBTP-D45 was determined to be the highest in the 6 layer applications (3.49 MPa) and the lowest in the 2 layer applications (2.59 MPa). In the literature, the adhesion resistance values of the different protective layers such as paint and varnish were reported to be between 2.97 MPa and 3.73 MPa (Ozcifci and Ozpak 2008; Atar and Peker 2010; Dilik *et al.* 2015; Ozdemir *et al.* 2015; Sogutlu. *et al.* 2016; Kesik *et al.* 2017). As seen, these results support this statement as well. This compatibility can be due to the fact that the concentration of 30% hollow glass spheres in the WBTP-D45 is strongly bonded with the resin and penetrates into the depths of the wood. In particular, the ratio of glass spheres with resin to good adhesion resistance is good. This result shows that the adhesion resistance will not change with the addition of 1/3 hollow glass spheres (Aznar *et al.* 2006), depending on the increase in filler concentration (Panchenko *et al.* 2018). The change of the adhesion resistance according to ABP and PLN is given in Fig. 7.

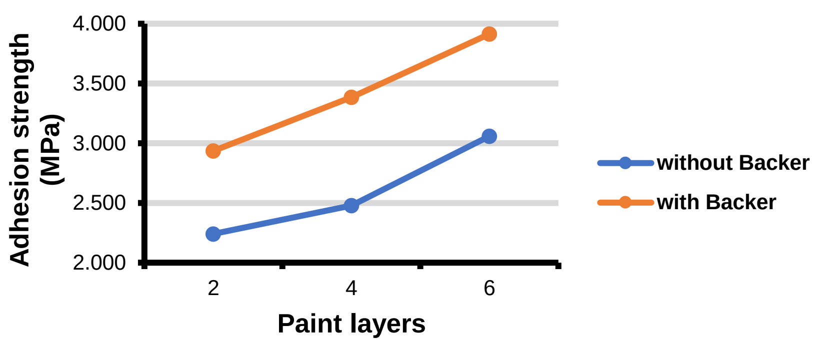

Fig. 7. Change of adhesion resistance to ABP and PLN

In general, the test samples without backing paper on the primer surfaces resulted in lower adhesion strength compared to the test samples covered with the backing paper within each paint layer (Fig. 7). It is possible to claim that the effect of backing paper on adhesion resistance is important. The test samples without backing paper applied to the 6 layer paint of WBTP-45 and the test samples covered with the backing paper applied to the 2 layer paint gave values close to each other. The adhesion strength values in the samples with backing paper on the 2-layer painted laminated parquet were close to the one without backing paper on the 6-layer painted laminated parquet. Therefore, it could be deduced that there is no need to use paint layers on the laminated parquet because the backing paper with two layers is enough to cover the rest.

CONCLUSIONS

1. Water-based insulation paint applied to the primer surfaces of laminate flooring produced with backing paper demonstrated a positive difference and it will increase the thermal insulation properties.
2. WBTP-D45 showed positive effects on the thermal conductivity coefficients of the laminate floorings. Depending on the insulation requirements, the extra glass bead addition and up to 750 micron thickness in WBNTP-D45 applications could be tried in new studies. It is understood from this study that WBNTP-D45 applications contribute to the thermal insulation of primer surfaces of laminated flooring in the sector with different methods.
3. Water-based insulation paint adhesion values were higher in the samples covered with the backing paper on the primer surfaces of laminate flooring. The application of WBTP-D45 at least 6 times (average 360 micrometer) on the primers of laminated flooring may be beneficial.
4. WBTP-D45 applications has not been seen effective against warping of the samples when used instead of backing paper.
5. If it is desired to have higher adhesion values on laminate floorings, it may be beneficial to perform transparent varnish applications on a WBTP-D45 at each layer.
6. Depending on the insulation and adhesion requirements, different WBTP-D45 dosages and different ratios of the hollow glass spheres in the covering agents should be recommended for further studies.

ACKNOWLEDGMENTS

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