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The effect of accelerated UV aging process on total color change after the varnishing process of 3D-printed wood composite material

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Keywords

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wood-plastic composite
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Abstract

This study investigated the effect of UV aging applied to the wood composite material produced by a 3D printer after varnish application on the total color change. For this purpose, water-based varnish and teak oil were applied to the wood composite material produced with wood-added filaments with 30% and 60% occupancy rates in a 3D printer, and on the same sizes of solid Oriental beech (*Fagus orientalis* Lipsky.) for comparison purposes. Then, the samples were subjected to rapid aging in a UV device for 24 hours, 48 hours, and 72 hours, and the color changes that occurred were analyzed. Obtained data were compared statistically with the MSTAT-C program. The type of material, UV exposure time, and type of surface protection material affect the total color change. While high occupancy rate and UV application time are effective in increasing total color change, teak oil is less effective in color change than water-based varnish.

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Introduction

The open-air effect is an important risk factor for tree material. This outdoor effect, called "Weathering" is a chemical and physical change in color on the wood material surface with the effect of light (UV, IR), humidity (rain, snow, humidity, dew), mechanical forces (wind, sand, dirt) and temperature causes some changes (Ekinci, 2011).

One of the main reasons why the color change in wood material is so important is that the color change determines the value of the material in the place of use. For this reason, protective surface treatments are applied to the wood material surface in order to reduce or completely eliminate color changes.

Before the surface treatments to be applied to the wood material, sanding is done to provide stability on the material surface finishing and this process is also effective on the color change. Thermal treatment can be applied to reduce the color change caused by the sanding process applied to the material surface. As a result of applying thermal processing instead of sandpaper, sensitivity in color differences decreases (Bekhta et al., 2022). Increasing the moisture content of the materials to be treated on the surface also helps to reduce the color change value. In a study, the humidity of the material to be varnished was determined as 8%, 10% and 12%, and water-based varnish was applied to the materials. Looking at the results of the study, it was determined that the least color change occurred in materials with 12% moisture content (Budakçı et al., 2012). Various methods are used to keep the amount of color change caused by finishing applied to the wood material surface. One of them is the addition of nanoparticles into the varnish. However, adding nanoparticles into the varnish to be used does not always give the desired results. Depending on the chemical structure of the nanoparticle used and the reactions that occur as a result of the interaction of this structure with the varnish, the color change may decrease or increase. While the increase in the color change was found to be high in the samples varnished with the varnishes to which the researchers added nano graphene, the increase in the color change was found to be low in another study using aluminum oxide and titanium dioxide (Aksu et al., 2022; Pelit and Korkmaz, 2019).

With proliferation the use of harmless products to nature, people and the environment in every field in recent years, studies are carried out to use natural and environmentally friendly alternatives instead of chemicals used in the woodworking industry. For this reason, the chemicals used especially in surface treatments have started to leave their place to natural alternatives. Alternatives such as tannin and valex are also used to eliminate this feature of the wood material, which has a structure affected by weather conditions like other polymers due to being an organic polymer. The use of tannin and valex, which are UV repellent, allows reductions in color change to compete with synthetic UV repellents (Tomak et al., 2018).

Varnish types have an effect on color change. When the effect of synthetic, cellulosic and water-based varnishes, which are widely used in the furniture industry, on the color change has been investigated, it was seen that the highest color change was in the materials varnished with synthetic varnish (Aykaç and Sofuoğlu, 2021).

With the development of the paint industry, it is seen that the color change in UV paint and varnish systems, which have been applied on wood materials in recent years, is directly proportional to the number of layers applied. As the number of layers increases, the total color change also increases (Gürleyen, 2021).

It is thought that the color change, which significantly affects the surface appearance of the wood material, is also an important factor for the wood-added filaments.

3D printers, one of the additive manufacturing methods that entered our lives with Industry 4.0, have also started to be used in the furniture industry. In the 3D printer technology, where filaments obtained from materials such as ABS and PLA are used extensively, wood-added PLA filaments are also used, which give the feeling of wood both in appearance and texture.

In the literature review, there was no study on the total color change that occurs as a result of varnishing the filaments. In this study, test samples printed with wood-added filaments with 2 different filling ratios and the total color change observed after 2 different varnish applications on beech wood were examined.

Methods and materials

Materials

Wood-added filaments to be printed from a 3D printer and teak oil and water-based varnish were used to make the top surface execution. The technical properties of the filament are given in table 1.

Table 1. Technical specifications of wood-added filament

Filament thickness	1.75 mm (0.01 mm precision)
Press temperature	190–220°C
Table temperature	0–80°C

Method

A total of 30 samples with the size of 100 × 100 × 8 mm were printed. The nozzle temperature and the printing speed of the samples were 200°C and 70 mm. While the fill rate of 15 samples was 30%, the fill rate of the other 15 samples was 60%. The material was printed with an open system 3D printer using wood-added PLA filament. The printing parameters of the 3D printer are given in Table 2.

The produced samples were kept in the air-conditioning cabinet adjusted to 20°C temperature and 65% relative humidity conditions until they reached a constant weight and became air-dry moisture content (12%). In order to compare the samples printed from the filament with the wood material, 15 test samples were prepared with a size of 100 × 100 ×8 mm, obtained from the beech (*Fagus orientalis* L.) wood, which is widely used in the woodworking industry.

Table 2. Printer parameters

Printer material	Wood added PLA
Layer height (mm)	0.3
Nozzle diameter (mm)	0.4
Filling ratio (%)	50
Printer nozzle temperature	200°C
Filament diameter (mm)	1.75
Fill pattern	linear

Each test sample was sanded with 180-grit sandpaper before varnishing and the amounts to be used in the surface treatment were prepared by taking into account the company's recommendations and applied to the sample surfaces.

The test samples were kept in a rapid aging (UV) device for 72 hours in accordance with TS EN ISO 4892-2 principles (TS EN ISO 4892-2, 2013). The irradiation intensity was selected as 340 mm under device operating conditions and the samples were positioned 100 mm away from the beam source. Each test sample was measured with a color-measuring device with a fixed reference point before being placed in the artificial aging device. The last measurement of the test samples, which were measured in 24-hour periods, was made at the 72nd hour and the aging process was terminated.

CIEL*a*b* color measurement system was used to measure the total color of the test samples. Color differences determined according to L* (color brightness), a* (red hue), b* (yellow hue) color coordinates and their locations form the basis of the CIEL*a*b* system (Söğütlü and Sönmez, 2006). The representation of the color areas in the CIEL color system is given in Fig. 1.

Fig. 1. CIELAB Color Space

The a, b and L values were used to calculate the total color change and the following equation was used.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{1}$$

A low total color change value indicates that the color has not changed or the amount of change is small.

The data obtained by the mathematical calculation of the total color change were analyzed by statistically.

Results and discussion

Some statistical values of the total color changes that occur depending on the type of protective material used on the upper surfaces of the test samples at the end of 72 hours are given in Table 3.

Table 3. Some statistical values of the color change in the material obtained from the three-dimensional printer and the wood material

	Printed biomaterial with 30% fill rate			Printed biomaterial with 60% fill rate			Beech		
	water-based varnish	teak oil	control group	water-based varnish	teak oil	control group	water-based varnish	teak oil	control group
Minimum	4.39	3.59	0.80	5.15	3.82	4.87	10.31	3.43	4.33
Maximum	6.71	4.55	14.66	6.27	4.91	9.91	11.87	6.96	7.45
Mean	5.45	4.16	6.40	5.75	4.47	6.44	11.36	5.75	5.56
Standard deviation	0.80	0.41	4.58	0.40	0.37	1.86	0.54	1.32	1.04
Coefficient of variation	14.66	9.83	71.45	6.90	8.22	28.94	4.78	22.92	18.65

Analysis of variance (ANOVA) was performed to determine whether there was a significant difference between the obtained data and the results are given in Table 4.

Table 4. Variance analysis results of total color change

K Value	Source	Degrees of freedom	Sum of squares	Mean square	F Value	Prob $*p \leq 0,05$
2	material (A)	2	78.52	39.26	142.14	0.00
4	time (B)	2	138.70	69.35	251.11	0.00
6	AB	4	8.81	2.20	7.98	0.00
8	varnish type (C)	2	110.92	55.46	200.80	0.00
10	AC	4	127.12	31.78	115.06	0.00
12	BC	4	2.40	0.60	2.17	0.08
14	ABC	8	3.12	0.39	1.41	0.20
–15	error	81	22.37	0.28		
	Total	107	491.96			

According to the ANOVA test results, it was determined that there was a significant difference between material, time, varnish type, material and varnish type, and material and time binary interactions ($p \leq 0.05$). In order to determine the order of the difference between the variables, the DUNCAN test was performed and the results are given in sequential tables.

Table 5. Leveling of total color change depending on material type

Material type	Total color change	
	mean	homogeneity group
Printed bio material with 30% fill rate	3.54	C
Printed bio material with 60% fill rate	4.06	B
Solid beech specimens	5.56	A

LSD = 0,25

As can be seen in Table 5, the maximum color change was observed in the solid beech (5.56) samples. This was followed by printed biomaterials with 60% and 30% fill rates, respectively.

The total color change increases with the increase of the waiting time in the UV device. Accordingly, the maximum color change was obtained at the end of 72 hours (5.95). Increasing the UV time, in other words, as a result of the prolongation of the exposure of the wood material to external factors, the total color change also increases. It is seen that the same result is obtained in different studies on wood material (Bekhta et al., 2022; Gürleyen, 2021).

Table 6. Leveling of total color change over time

Time	Total color change	
	mean	homogeneity group
24 hours	3.31	C
48 hours	3.90	B
72 hours	5.95	A

LSD = 0.25

In the study, when looking at whether the varnish type has an effect on the total color change resulting from the increase in UV time, no significant result was found in the UV time varnish type binary interaction.

As a result of the statistical analysis, when the effect of the varnish type on the total color change is examined, the most change is seen in the test samples varnished with water-based varnish (5.81), followed by unvarnished samples (3.86) and teak oil varnished samples (3.50) is doing.

As a result of the application of shellac paste, paraffin and teak oil to different tree species, it was determined that the highest total color change was in the samples varnished with teak oil (Söğütlü and Sönmez, 2006). The data obtained do not overlap

Table 7. Leveling of the total color change depending on the varnish type

Varnish type	Total color change	
	mean	homogeneity group
Water based varnish	5.81	A
Teak oil	3.50	C
Solid beech specimens	3.86	B

LSD = 0.25

with the results of the previous study. The reason for this may be that the chemical structure of the varnish used in the current study has a greater effect on color change than shellac paste and paraffin.

In the interaction of material and time (Table 8), the maximum total color change was obtained from the beech samples (7.68) that were kept in the UV device for 72 hours. The lowest total color change was observed in the biomaterials printed with 30% (2.70) and 60% (3.10) fill rate, which were kept in UV for 24 hours, and the printed biomaterials with 30% fill rate (3.11), which were kept in UV for 48 hours, although the differences between them were insignificant.

Table 8. Leveling of total color change due to material type and time binary interaction

Material type	Time	Total color change	
		mean	homogeneity group
Printed bio material with 30% fill rate	24 hours	2.70	E
	48 hours	3.11	E
	72 hours	4.81	C
Printed bio material with 60% fill rate	24 hours	3.10	E
	48 hours	3.73	D
	72 hours	5.37	B
Solid beech specimens	24 hours	4.13	D
	48 hours	4.85	C
	72 hours	7.68	A

LSD = 0,43

Considering the binary interaction of material type and varnish (Table 9), the highest total color change was seen in the beech samples varnished with water-based varnish (8.98), whereas the lowest total color change was observed in the samples without beech varnish (3.32) and varnished with teak oil, with 30% (2.97) and 60% (3.16) fill ratios, obtained from wood-added filaments.

Table 9. Leveling of the total color change due to the binary interaction of material type and varnish type

Material type	Varnish type	Total color change	
		mean	homogeneity group
Printed bio material with 30% fill rate	water based varnish	3.85	C
	teak oil	2.97	D
	solid beech specimens	3.82	C
Printed bio material with 60% fill rate	water based varnish	4.60	B
	teak oil	3.16	D
	solid beech specimens	4.43	B
Solid beech specimens	water based varnish	8.98	A
	teak oil	4.37	B
	solid beech specimens	3.32	D

LSD = 0.43

Conclusions

Compared to the color change in solid beech samples, the color change in wood-added biopolymer materials is lower. The regular and homogeneous void texture in the extractives and wood-added biopolymer materials in wood may have an effect on this result.

Increasing the UV rays interaction time increases the color change in solid beech wood and wood-added biopolymer material, with an increase in time-dependent surface structural degradation.

The least color change was observed in teak oil-applied samples, followed by unvarnished samples and water-based varnish-applied samples.

In solid beech, the least color change was seen in the unvarnished samples, while the color change in the water-based varnish-applied samples was higher compared to the teak oil-applied samples.

According to the fill rates, the color change is less in the teak oil applied samples at both 60% and 30% fill rates, and the difference between the color changes in the unvarnished samples and the water-based varnish applied samples is insignificant.

As a result, teak oil provides greater resistance to the color-changing effects of UV rays in both solid wood and wood-added polymeric materials compared to water-based varnishes. In order to ensure that teak oil is used on the surfaces of wooden products used in outdoor environments open to the atmosphere, natural resins used to increase resistance to sunlight, water and moisture, components such as linseed oil, tung oil and naphtha oil, and deeper penetration may be effective on this result. For this reason, it is recommended to use teak oil instead of water-based varnish on the surfaces of products made of both solid wood and wood-added polymeric materials, which are used in outdoor conditions where the interaction with sunlight is highest.

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