Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 92, 2015: 373-382
(Ann. WULS - SGGW, For. and Wood Technol. 92, 2015)

Study of Chosen Physical Surface Properties of Antique Parquet Panel Elements

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Abstract: *Study of Chosen Physical Surface Properties of Antique Parquet Panel Elements*. The paper describes the research of properties of antique parquet panel elements taken from Tarnowiec, Przewrotne and Falejówka manor houses. The panels under research were made of oak, pine, ash and elm wood. We tested the density profile, the contact angle and calculated the surface energy of panel elements. The values of density of antique wood do not diverge from the values provided in contemporary reference tables. The increase of density for the maximum positions from the frontal side suggests the presence of non-structural substances.The front surface of antique wood before processing has lower surface energy than after processing, which means that non-structural, hydrophobic substances are present on the frontal surface. We have not found significant differences concerning surface energy between antique and contemporary wood.

Keywords: surface energy, contact angle, density, antique parquet

INTRODUCTION

Wood is a specific natural material, whose properties depend on the habitat conditions and may vary in accordance with the manner of processing. All that results in a non-uniform wood durability even within one species. Wood durability is defined as its resistance to destructive factors and is expressed as the period during which timber preserves the properties that make it suitable for use. Some factors that have significant influence on wood durability are: water content, density, age, species and the part of the trunk (sapwood or heartwood) [Krajewski, Witomski, 2005], as well as the conditions in the place where it is stored or installed.

The manor houses from which the research materials were taken were built in 1823 (Falejówka) and 1830 (Tarnowiec) [Różańska et al. 2011a]. Parquet wood had to endure changes in humidity, high and low temperatures, UV radiation, static and dynamic loads and microbiological corrosion [Kozakiewicz, Matejak 2006, Różańska et al. 2011b]. In the 19th century, manor houses were heated with stoves, floors did not have good thermal and anti-humidity insulation, windows and doors were not tight and some rooms were probably not used during winter at all. Even in the rooms that were heated, the temperature was about 10°C lower than nowadays [Kozakiewicz, Matejak 2006]. Additionally, parquets got wet due to water leaking through the roofs, improperly working or nonexistent gutter system, as well as water condensing on the building envelope as a result of the dew point. Wet wood was infested by fungi and insects. Tests of relative air humidity in the Tarnowiec Manor House at the end of October and at the beginning of November gave results of 75-95%. In the 1st half of the 19th century, manor houses did not have kitchens nor water and sewage systems. Water used for washing or cooking was brought in buckets, which caused an abrupt increase of local relative air humidity [Różańska et al. 2011b]. When temperatures dropped below zero, the water present in wooden parquets froze. On the other hand, in close proximity to the stoves, wood was locally overheated, and that heating system (especially if the rooms were only temporarily inhabited) caused rapid changes of temperature and relative air humidity. Moreover, sun rays that got in through large windows caused local overheating of parquets, and as a result of that thermal effect, the temperatures in the rooms were temporarily increased and UV radiation caused accelerated ageing.

Those conditions affected the properties of wooden parquets.

AIM AND SCOPE OF STUDY

The aim of the research consists in specifying selected usage-related properties of antique parquet panels from Tarnowiec, Przewrotne and Falejówka manor houses. We conducted tests of the density profile, contact angle and calculated surface energy. The test results for selected physical properties were analysed in view of differences between antique and contemporary wood. The tests of the density profile show density distribution in the cross section of floor panels and permit a comparison with contemporary wood. The tests of the contact angle and surface energy permit us to analyse the surface properties of antique parquets in comparison with contemporary wood.

RESEARCH MATERIAL

The tests were carried out on antique and contemporary wood samples for the species of common pine (*Pinus sylvestris* L.), elm *(Ulmus sp.)*, ash *(Fraxinus exelsior* L.*), and* oak *(Quercus* sp.*)*. Samples were cut out of parquet panels to obtain dimensions of 50mm±1mm in height and width. Sample characteristics are presented in tables 1 and 2.

Tab.1. Characteristics of contemporary wood samples used in the tests of density profile, contact angle and surface energy (the angle α calculated in line with [Staniszewska, Zakrzewski 2002])

Name	Species	Type of cross-section	Angle α[°]	Number of growth rings
S1	Pine *(Pinus silvestris* L.)	Tangential-radial	20	12
S5	Pine *(Pinus silvestris* L.)	Tangential-radial	8	10
S6	Pine *(Pinus silvestris* L.)	Tangential-radial	12	5
J4	Ash *(Fraximus excelsior L.)*	Tangential-radial	16	5
J5	Ash *(Fraximus excelsior L.)*	Tangential-radial	18	5
J6	Ash *(Fraximus excelsior L.)*	Tangential-radial	24	3
D3	Oak *(Quercus sp.)*	Tangential-radial	34	2
D4	Oak *(Quercus sp.)*	Tangential (flat-sawn)	0	5
D6	Oak *(Quercus sp.)*	Tangential-radial	15	3
W3	Elm *(Ulmus sp.)*	Tangential-radial	28	2
W4	Elm *(Ulmus sp.)*	Tangential-radial	28	2
W6	Elm *(Ulmus sp.)*	Tangential (flat-sawn)	0	3

METHODOLOGY

Density profile. Density profile tests were carried out with the GreCon device with the use of a DA-X analyser. Radiation passes through the sample at the angle of 45° and is measured in two positions. The measurements were made along the cross section from the frontal (usage) side of the parquet panel towards its bottom side.

Tests of the contact angle and surface energy. Tests of the contact angle and surface energy were carried out with the use of the PHOENIX 300 device. Surface wettability can be measured thanks to the "sessile drop method". Phoenix is equipped with a camera and a stepper motor. The camera permits to photograph the drop precisely, while the stepper motor permits to dose small drops. The contact angle was measured for chosen samples (3 samples for each parquet), with the help of a profilemeter and a goniometer. The tests were repeated for the same antique wood samples after processing. A layer of about 2 mm was polished off from the usage (frontal) surface of the sample. Additionally, we tested the bottom sides of the parquet panels and surfaces of contemporary wood samples. The Fowkes method (also called the Owens-Wendt method) was used in the tests. The goniometer is equipped with software that permits to calculate surface energy as the sum of the dispersive and polar components on the basis of measurements of the contact angle for water and diiodomethane.

Tab.2. Characteristics of antique wood samples used in the tests of density profile, contact angle and surface energy (the angle of the direction of annual growth ringsα calculated in line with [Staniszewska, Zakrzewski 2002])

Sample number	Origin	Wood species	Density [kg/m³]	Type of cross-section	Angle α[°]	Number of growth rings
F1	Falejówka	Oak *(Quercus sp.)*	610.91	Tangential-radial	18	5
F2	Falejówka	Oak *(Quercus sp.)*	631.65	Tangential-radial	16	3
F3	Falejówka	Oak *(Quercus sp.)*	621.02	Tangential-radial	32	4
F4	Falejówka	Oak *(Quercus sp.)*	794.53	Tangential-radial	16	3
F5	Falejówka	Oak *(Quercus sp.)*	616.72	Tangential (flat-sawn)	0	5
F6	Falejówka	Oak *(Quercus sp.)*	797	Tangential-radial	18	3
P_2_5	Przewrotne	Ash *(Fraximus excelsior* L.)	682.23	Tangential-radial	28	3
P_2_6	Przewrotne	Ash *(Fraximus excelsior* L.)	761.71	Tangential-radial	18	2
P_2_7	Przewrotne	Ash *(Fraximus excelsior* L.)	719.43	Tangential-radial	47	2
P_2_1	Przewrotne	Pine *(Pinus silvestris* L.)	430.44	Tangential-radial	60	3
P_2_2	Przewrotne	Pine *(Pinus silvestris* L.)	512.81	Tangential (flat-sawn)	0	2
P_2_3	Przewrotne	Pine *(Pinus silvestris* L.)	439.51	Tangential (flat-sawn)	0	3
T1_2_1	Tarnowiec Room 1	Oak *(Quercus sp.)*	663.81	Tangential-radial	34	3
T1_2_2	Tarnowiec Room 1	Oak *(Quercus sp.)*	759.53	Tangential-radial	50	3
T1_2_3	Tarnowiec Room 1	Oak *(Quercus sp.)*	670.72	Tangential-radial	48	4
T4_1	Tarnowiec Room 4	Oak *(Quercus sp.)*	736.3	Tangential-radial	50	2
T4_2	Tarnowiec Room 4	Oak *(Quercus sp.)*	775.59	Tangential-radial	75	3
T4_3	Tarnowiec Room 4	Oak *(Quercus sp.)*	708.12	Tangential-radial	77	3
T5_1_1	Tarnowiec Room 5	Elm *(Ulmus sp.)*	649.9	Radial	90	3
T5_1_2	Tarnowiec Room 5	Elm *(Ulmus sp.)*	638.91	Radial	90	3
T5_1_3	Tarnowiec Room 5	Elm *(Ulmus sp.)*	662.6	Radial	90	3
T5_2_1	Tarnowiec Room 5	Elm *(Ulmus sp.)*	549.9	Tangential-radial	65	4
T5_2_2	Tarnowiec Room 5	Elm *(Ulmus sp.)*	522.95	Tangential-radial	55	4
T5_2_3	Tarnowiec Room 5	Elm *(Ulmus sp.)*	547.18	Tangential-radial	65	5

TEST RESULTS

Density profile. The density values obtained for the entire profile and the mass (weighed on the order of 0,001g) of the samples are presented in Table 3, while the standard deviation and the coefficient of variation are presented in Table 4.

Table 3. Results obtained for the density profile analysis

Sample name	Sample thickness	Sample mass	Max. density on the frontal side	Max. density on the bottom side	Max. density position from the frontal side	Max. density position distance	Average sample density	Minimum density in comparison with the average
	[mm]	[g]	[kg/m³]	[kg/m³]	[mm]	[mm]	[kg/m³]	in %
Pine								
P_2_1	15.32	16.59	966	475	0.3	14.88	430	89
P_2_2	17.82	22.58	1082	580	0.22	13.7	513	87
P_2_3	17.76	19.34	1079	477	0.28	17.38	440	92
Average	16.97	19.5	1042	510	0.27	15.32	461	89
Ash								
P_2_5	17.72	29.99	1153	693	0.34	9.16	682	100
P_2_6	17.86	33.08	1372	827	0.2	9.7	762	88
P_2_7	17.72	31.4	1103	762	0.36	8.84	719	104
Average	17.77	31.49	1209	761	0.3	9.23	721	97
Oak I								
F1	19.38	30.3	1110	629	0.16	10.08	611	99
F2	21.66	32.66	919	689	0.32	20.74	632	93
F3	21.72	33.11	1046	773	0.16	21.28	621	93
F4	20.82	41.1	988	817	0.32	20.12	795	97
F5	23.28	35.04	805	624	0.72	17.72	617	92
F6	21.06	42.09	1050	820	0.26	13.56	797	98
Average	21.32	35.72	986	725	0.32	17.25	679	95
Oak II								
P_1_1	20.76	31.89	825	624	0.5	10.04	618	98
P_1_2	24.34	44.04	973	730	0.24	23.98	702	94
P_1_3	26.6	42.51	1028	630	0.2	13.34	628	98
P_1_4	26.98	45.31	812	711	0.58	13.92	687	101
P_1_5	26.76	46.93	1014	725	0.18	13.64	705	99
P_1_6	21.86	33.12	751	614	0.66	14.1	604	98
Average	24.55	40.6	852	721	0.39	14.84	657	98
Oak III								
T1_2_1	20.4	33.24	1043	682	0.56	18.78	664	97
T1_2_2	16.36	34.29	1244	749	0.16	8.14	760	97
T1_2_3	16.26	31.25	1328	698	0.18	15.38	671	97
T1_2_4	18.64	33.95	1120	755	0.34	17.8	736	97
Average	17.92	33.18	1184	721	0.31	15.03	708	97

Sample name	Sample thickness	Sample mass	Max. density on the frontal side	Max. density on the bottom side	Max. density position from the frontal side	Max. density position distance	Average sample density	Minimum density in comparison with the average
	[mm]	[g]	[kg/m³]	[kg/m³]	[mm]	[mm]	[kg/m³]	in %
Oak IV								
T4_3	36.7	63.74	1199	726	7.12	2.32	708	98
T4_2	31.7	62.28	1340	776	0.1	16.3	776	98
Average	34.2	63.01	1270	751	3.61	22.81	742	98
Elm								
T5_1_1	31.12	50.05	1100	689	0.28	17.72	650	97
T5_1_2	30.92	50.17	1091	685	0.14	15.8	639	98
T5_1_3	30	51.17	1024	703	0.22	18.3	663	97
T5_2_1	29.68	41.56	1027	560	0.18	14.72	550	101
T5_2_2	29.74	38.61	752	543	0.32	14.66	523	103
T5_2_3	30.32	42.01	1103	549	0.22	16.36	547	99
Average	30.3	45.59	1016	622	0.23	16.26	595	99

Table 4. Standard deviation results for density profile tests.

Sample name	(x-xavr)² [(kg/m³)²]	σ-standard deviation [kg/m³]	v - coefficient of variation [%]
Pine	1348	37	8
Ash	1042	32	4
Oak I	6903	83	12
Oak II	1733	42	6
Oak III	1698	41	6
Oak IV	1122	34	5
Elm	3183	56	9

The lowest average density value out of all the tested species was observed for antique pine samples. In case of all the tested antique wood species, the highest density values were observed on the frontal side.

A consistent increase of density up to the depth of ca. 2-3 mm, and then its slow decrease suggests the presence of non-structural substances.

The comparison of average density values of the tested samples with reference table density values for contemporary wood has been presented in Table 5.

Table 5. Comparison of average density values of the tested wood and the table values [Kozakiewicz 2005].

Species	Origin	Average density of antique wood [kg/m³]	density of contemporary wood [kg/m³]
Oak	Falejówka	679	430-690-940
	Przewrotne	657	430-690-940
	Tarnowiec Room 1	707	430-690-940
	Tarnowiec Room 4	741	430-690-940
Ash	Przewrotne	721	480-720-960
Pine	Przewrotne	461	330-520-890
Elm	Tarnowiec	595	480-680-860

Contact angle analysis

Tables 6-7 present the test results of contact angle for frontal surfaces before polishing, frontal surfaces after processing and bottom side of antique wood in comparison with contemporary wood.

Table 6. Water and diiodomethane (DM) contact angle values for antique wood

Name of the sample	Antique wood - front		Bottom surface		Antique wood - after processing	
	Water [º]	DM [º]	Water [º]	DM [º]	Water [º]	DM [º]
Pine						
P_2_1	75	19	65	25	45	15
P_2_2	71	25	61	15	47	22
P_2_3	36	21	69	21	47	23
Average	61	22	65	20	46	20
σ	17.58	28.93	3.49	5.38	1.26	2.75
V[%]	3	12	4	19	4	19
Ash						
P_2_5	41	44	79	38	38	27
P_2_6	68	24	52	28	35	27
P_2_7	42	26	73	36	39	28
Average	50	31	68	34	37	28
σ	12.71	25.28	11.68	17.18	1.59	4.25
V[%]	9	29	4	12	0	2
Oak I						
F3	54	27	105	-	54	23
F4	53	39	63	-	51	29
F6	51	30	91	-	50	30
Average	53	34	86	-	52	27
σ	1.56	2.96	17.55	20.41	1.54	2.94
V[%]	5	15	-	-	3	11
Oak II						
P_1_1	61	16	62	33	50	29
P_1_2	66	26	54	26	45	32
P_1_6	64	17	88	45	52	33
Average	64	22	68	35	49	32
σ	1.98	3.1	14.59	21.57	2.87	5.88
V[%]	5	23	8	23	2	6
Oak III						
T1_2_2	76	18	83	-	64	16
T1_2_3	73	17	77	-	62	13
T1_2_4	75	20	66	10	68	14
Average	75	18	75	10	65	14
σ	1.41	1.88	7.38	9.8	2.27	3.51
V[%]	1	6	-	-	1	9

Name of the sample	Antique wood - front		Bottom surface		Antique wood - after processing	
	Water [º]	DM [º]	Water [º]	DM [º]	Water [º]	DM [º]
Oak IV						
T_4_2	90	11	67	26	48	42
T_4_3	82	15	79	-	51	35
Average	86	13	73	26	50	39
σ	4.14	4.82	5.88	8.05	1.46	2.97
V[%]	14	6	-	-	4	9
Elm						
T5_1_1	82	29	78	-	58	17
T5_1_2	77	16	80	-	61	11
T5_1_3	83	30	74	22	56	16
Average	80	25	77	22	58	14
σ	4.69	5.83	2.56	3.32	1.76	3.03
V[%]	6	25	-	-	2	16

In case of pine , the average e of wettability with water on the frontal and bottom sides are close to one another (within 60º). Antique wood on the frontal surface after processing has the smallest water contact angle. The highest value of water contact angle is observed for the bottom surface of antique wood. In comparison with other species, pine has the lowest contact angles (except for contemporary elm wood).

Similarly, in case of antique ash, the lowest water contact angle was observed for wood after polishing, higher - for frontal side before processing and the highest for the bottom surface. The highest contact angle was observed for contemporary ash wood.

Similarly, the contact angle of antique oak wood is, in general, lower than that of contemporary oak.

Oak I has the highest value of water contact angle at the bottom surface. The angle values for the frontal surface before and after processing are similar.

Table 7. Contact angle values for contemporary wood

Pine		Ash		Oak		Elm	
Water [º]	DM [º]	Water [º]	DM [º]	Water [º]	DM [º]	Water [º]	DM [º]
80	16	86	28	88	36	36	63
74	32	83	21	72	35	41	31
42	19	97	27	84	27	54	27
Average-65	Average-22	Average-91	Average-25	Average-79	Average-33	Average-43	Average-40
σ -16.41	**σ** -6.96	**σ** -6.01	**σ** -3.02	**σ** -6.82	**σ** -3.65	**σ** -7.65	**σ** -16.32
v[%]-25	**v[%]**-31	**v[%]**-7	**v[%]**-12	**v[%]**-8	**v[%]**-11	**v[%]**-18	**v[%]**-40

Oak II has the biggest water wettability angles on the bottom surface and frontal surface before processing. The smallest water contact angle was observed at the frontal surface after polishing. The angle values are similar to the results observed for pine.

Similarly, oak III shows the smallest water contact angle for wood after processing. It is the highest value among all the antique wood samples after polishing.

In case of non-processed frontal side, the highest water contact angle out of all the antique samples was observed in Oak IV (angle of growth ring direction 50º,75º,77º).

Elm has a high water wettability angle in antique wood: for front side before processing, front side after processing and bottom side (sample with growth rings angle 90º). Contemporary elm wood has the lowest wettability out of all the tested samples.

The following relations have been noticed:

1) The contact angle of antique wood is consistently larger before processing. This is due to the non-structural substances (like finish) present on the frontal surface.
2) For individual samples of antique pine, oak II and IV, ash and elm on the bottom side, we noticed that water contact angle is reduced when density grows.
3) This relation is also true for the frontal side of antique pine, oak I and III and elm wood before polishing.
4) In case of the frontal surface of antique ash, oak II and oak IV (before polishing), the water contact angle grows together with the growth of mean density.
5) For antique wood after polishing, together with the growth of density, the water contact angle gets smaller in case of ash, oak II, III and IV, and grows in case of pine and elm.
6) All the tested antique oaks, pine and ash have the biggest contact angle on their bottom side, just like it is the case with contemporary wood, and the smallest contact angle was observed for antique wood after processing.
7) Samples with the biggest angle of growth ring direction (elm, oak IV) have the biggest values of water contact angle.
8) Out of contemporary wood, the biggest water contact angles were observed for ash, then for oak and then pine. Elm showed the smallest values.

Surface energy analysis

After calculating the mean contact angles, we measured the surface energy of tested samples. The values have been presented in Fig 1.

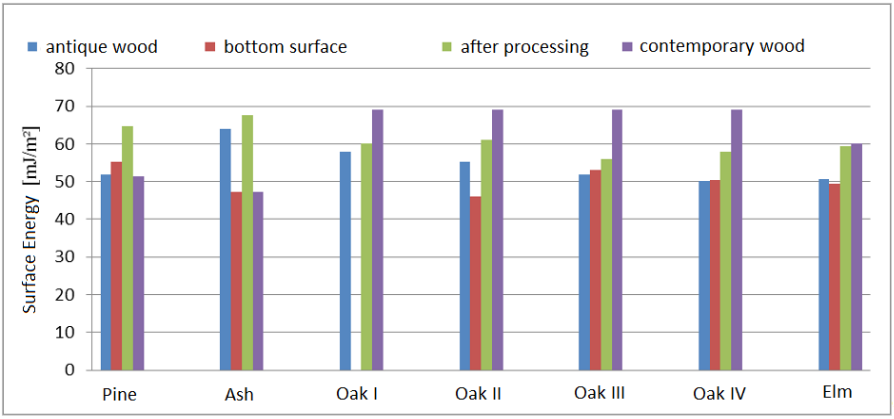

Fig. 1. Surface energy chart

The highest value of surface energy out of antique woods has been observed in case of ash - both before and after processing. The lowest value among antique wood samples was observed for oak IV.

The surface energy of the bottom side of antique pine has the highest value (density value and growth ring direction angle value lower than average). The lowest value has been observed for ash that has the smallest growth ring direction angle but high density; and for oak II.

In case of oaks, their surface energy values have been similar in all the manor houses.

When density grows, surface energy is reduced.

The values of surface energy are lower before processing than after.

The surface energy values on the bottom side of parquet elements are comparable or smaller than on the frontal side, and are always smaller than the surface energy on frontal side after processing.

Antique wood has higher surface energy values than contemporary wood in case of pine and ash (growth ring direction angles differ between samples). Oak and elm have smaller values (large and similar values of α angle between samples).

CONCLUSION

The average density values of antique wood for the species of oak, pine, ash and elm are in line with the reference tables for contemporary wood.

The increase of density for the maximum positions from the frontal side suggests the presence of non-structural substances.

Together with the growth of density, contact angle grows and surface energy drops.

Antique oak wood has lower surface energy than contemporary wood.

The front surface of antique wood before processing has lower surface energy than after processing, which means that non-structural, hydrophobic substances are present on the frontal surface.

We have not found significant differences concerning surface energy between antique and contemporary wood.

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Streszczenie: *Badanie wybranych właściwości fizycznych powierzchni elementów zabytkowych tafli posadzkowych.* Tematem pracy jest badanie właściwości elementów zabytkowych tafli posadzkowych pozyskanych z dworów w Tarnowcu, Przewrotnym i Falejówce. Badane tafle wykonane były z drewna dębowego, sosnowego, jesionowego i wiązowego. Na elementach zbadano profil gęstości, kąt zwilżania oraz obliczono energię powierzchniową. Wartości gęstości drewna zabytkowego nie odbiegają od obecnych wartości tablicowych. Wzrost wartości gęstości dla maksymalnych pozycji od strony licowej sugeruje obecność substancji niestrukturalnych. Powierzchnia licowa drewna zabytkowego przed obróbką wykazuje mniejszą energię powierzchniową niż po przeszlifowaniu, co świadczy o obecności hydrofobowych substancji niestrukturalnych na licu powierzchni. Nie wykazano znacznych różnic dla energii powierzchniowej między drewnem współczesnym, a zabytkowym.

Słowa kluczowe: energia powierzchniowa, kąt zwilżania, gęstość, posadzka zabytkowa

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