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EFFECT OF STAINING ON THE ROUGHNESS OF BEECH FURNITURE SURFACES

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ABSTRACT

Staining is a process of transparent wood surface colouring. Stains are liquid systems that wet and penetrate treated surfaces, changing their properties, including their roughness. The article presents research on the surface roughness change of beech, beech plywood, and beech veneered wood-fibre boards after treatment with waterborne and solvent-based stains and waterborne stains with PVA resin additive. Before staining, the surfaces were sanded with P150-grain sandpaper. A contact roughness tester model SJ-210 and a standard Gaussian filter were used to evaluate the roughness. The influence of the substrate structure, the stain dilution and the type of thinner on the surface roughness were determined. The parameters *Ra, Rpk*, *Rk*, *Rvk* and the composite parameter *Rpk+Rk+Rv*k were analysed. The results are presented graphically and also in tables.

Key words: waterborne stain, solvent-based stain, roughness, beech, beech plywood.

INTRODUCTION

Staining is a process of transparent surface colouring of wood details and elements (Kavalov and Angelski 2014). It refers to the operations preceding coating formation.

Stains are low-viscosity liquid systems that wet-treated surfaces and penetrate them, changing their properties, including their roughness. In recent days, the use of solvent-based stains has decreased because of the poisonous volatile organic compounds (VOC) included in their formulation. Their replacement with waterborne stains, when treating wood surfaces, leads to longer drying times and wood grain raising. Grain raising depends on several factors, including wood species, surface preparation, substrate type, stain formulation, solids contents and surface tension of the applying products, amount of stain applied, drying speed, application method, and ambient humidity and temperature (Landry *et al*. 2013, Onegin 2015, Yakovlev 2020, Atanasova and Angelski 2023). Wood grain raising is an unwanted effect resulting from the treatment of wood surfaces with liquid systems. To negate it, additional intermediate sanding of the surface is required before applying the next coating layer.

The main approaches to limiting wood grain raising are the rationalisation of the process conditions of the surface preparation for coating (Evans, 2009), and the inclusion of special additives in the coating system formulation (Landry *et al*. 2013).

Traditionally, changes in surface roughness are measured using a group of roughness parameters. A rational approach to assess the wettability of wood surfaces is to measure parameter values before and after treatment (Magoss et al. 2019, Atanasova et al. 2023).

The arithmetic mean deviation of the assessed profile *Ra*, in combination with the surface profiles, gives an accurate overall assessment of the change of the profile as a result of wetting. A detailed assessment of the influence of the substrate structure is given by the material ratio curve parameters: core roughness depth *Rk*, reduced peak height *Rpk*, and reduced valley depths *Rvk* (Magoss *et al*. 2019, Atanasova and Angelski 2023).

The aim of the present study is to establish the change in surface roughness of beech, beech plywood, and beech veneered wood-fibre boards after treatment with solvent-based stain, waterborne stain, and waterborne stain with PVA resin additive.

METHODOLOGY

Stains were applied with a brush to beech wood, beech plywood and beech veneered wood-fibre boards. In the case of the waterborne stain, the excess amount was wiped off with a porous material.

The beech wood (*Fagus sylvatica* L.) density was measured to be 763 kg/m^3. The specimens with dimensions of 140 x 70 x 20 mm (L x B x δ) were plane-milled.

The plywood was manufactured by S.C. Cildro Plywood, Romania. According to the manufacturer, it has a symmetrical structure and density of 760 kg/m^3, according to CEN EN 323:1993. The plywood surfaces were sanded with sandpaper P80 and P120 and met quality II/III according to CEN EN 635-2:1995. The plywood face layers were made of peeled beech veneer. The specimens had dimensions of 140 x 70 x 15 mm (L x B x δ).

The veneered detail was made from a wood-fibre board and veneered with radial beech veneer with a thickness of 0.55 mm and a moisture content of 12±1%. The veneer was manufactured by Danzer, Germany. Its average density was measured to be 596 kg/m^3. PVA glue was used for veneering. The pressing temperature was 75℃. After pressing, the surfaces were not sanded. The specimens had dimensions of 140 x 70 x 17 mm (L x B x δ).

All materials were conditioned for 5 months at 20 ± 2°C and 50 ±5% R.H.

Before staining, the specimens were sanded with *P150*-grain sandpaper.

The surfaces were treated once with a waterborne stain, a waterborne stain with a PVA additive or a solvent-based stain. Stains were produced by N.K.N, Bulgaria.

The waterborne stain CWT 4 (concentrate) contains 15% C.I. Acid orange and up to 130 g/l VOC (https://lakove.bg/).

According to the manufacturer, to limit the wood grain raising of the treated surfaces, it is recommended to add a minimum of 30-40% PVA resin to the waterborne stain. For the experiment, 40% PVA resin was added to the waterborne stain.

The formulation of the solvent-based stain TM-T22 (concentrate) includes Methoxypropanol and pigments. The product contains up to 700 g/l VOC (https://lakove.bg/).

Three series of specimens were prepared for each of the three surface types: stain-concentrate treatment (100%), thinner-only treatment (0%), and treatment with a 50% stain-thinner mixture. The measurements were carried out 24 hours after staining.

A weighting method was used to determine the density of the investigated materials and the amount of stain applied.

The measurements of roughness parameters were made with a contact roughness tester Mitutoyo SJ-210 with a V-shaped stylus tip of radius R = 5 μm and evaluation length ln =15 mm. A standard Gaussian filter with limits λc = 2.5 mm and λs = 8 μm was applied. The measurements were taken perpendicular to the wood grain, at the same evaluation lengths, before and after staining.

The arithmetic mean deviation of the evaluated profile *Ra*, according to ISO 4287:1997, was chosen as the main parameter studied. Additional parameters were selected from the material ratio curve parameters: core roughness depth *Rk*, reduced peak height *Rpk*, and reduced valley depths *Rvk*, according to ISO 13565-2:2002. The composite parameter *Rpk+Rk+Rvk* was also calculated.

The Excel program was used for the data statistical processing and their graphical presentation.

RESULTS AND DISCUSSION

The results of the experiment to determine the influence of the stain dilution and the type of thinner on the roughness parameters of the three types of treated surfaces are presented in Tables 1–3.

A comparative graph of beech surface profiles, before and after staining with concentrated (100%) waterborne stain, concentrated waterborne stain with PVA additive, and concentrated soluble-based stain are presented in Figures 1–3.

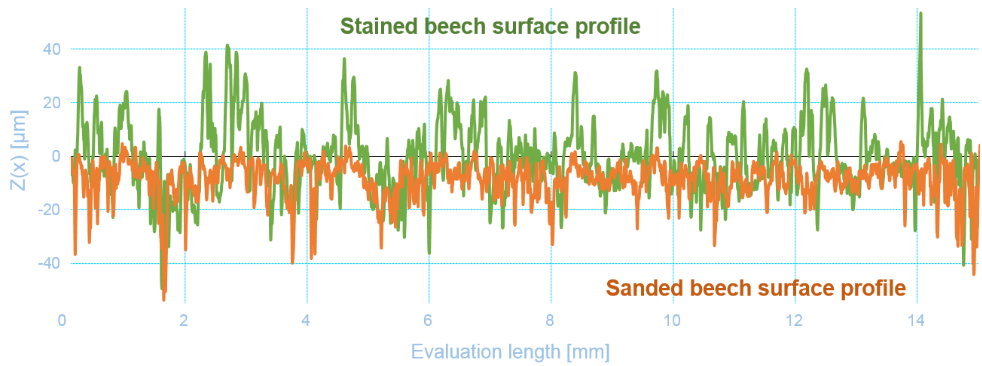


Figure 1: Beech surface profile change as a result of treatment with a waterborne stain

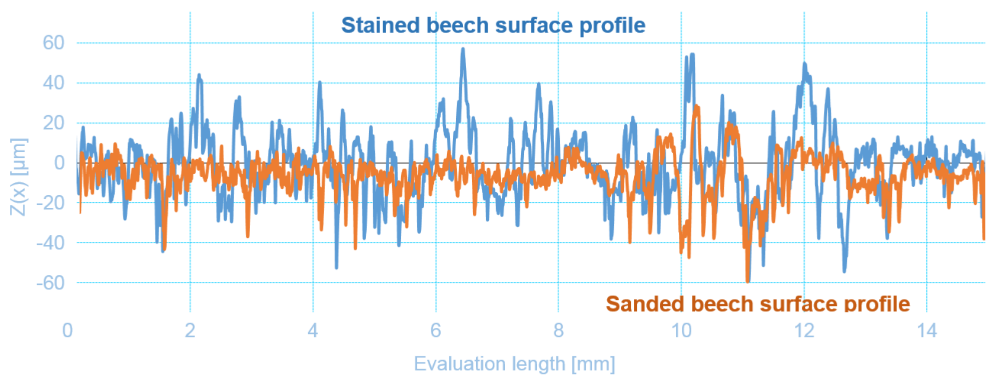


Figure 2: Beech surface profile change as a result of treatment with a waterborne stain with a PVA additive

Table 1: Average values of the roughness parameters of the beech surfaces treated with waterborne stain, waterborne stain with PVA additive, and solvent-based stain. Change in the roughness parameter values *ΔR* [%] and accuracy index *p* [%] for sanded and stained surfaces

Type of stain		Waterborne stain					Waterborne stain with PVA additive					Solvent-based stains				
Stain concentration [%]	Roughness parameter	Average values		*ΔR* [%]	Accuracy index *p* [%]		Average values [µm]		*ΔR* [%]	Accuracy index *p* [%]		Average values [µm]		*ΔR* [%]	Accuracy index *p* [%]	
		Sanded surface	Stained surface		Sanded surface	Stained surface	Sanded surface	Stained surface		Sanded surface	Stained surface	Sanded surface	Stained surface		Sanded surface	Stained surface
0	*Ra* [µm]	5,93	10,35	75	3,17	2,85	4,95	7,17	45	3,26	3,33	3,98	6,75	71	5,62	6,82
	Rk [%]	14,22	30,95	118	3,31	4,91	14,00	20,07	43	4,31	3,00	11,00	18,84	71	4,81	7,56
	Rpk [%]	5,10	12,21	139	5,23	8,79	4,84	13,48	179	5,30	8,08	4,09	14,13	245	8,41	6,81
	Rvk [%]	18,51	19,22	4	3,33	6,80	13,52	14,26	5	9,15	7,85	11,33	11,83	4	10,22	10,86
	Rpk+Rk+Rvk [%]	37,83	62,38	65	3.24	3.19	32,37	47,81	48	2.9	4.10	26,43	44,80	70	7.42	7.6
50	*Ra* [µm]	5,61	13,50	140	5,43	6,13	4,79	10,87	127	4,32	4,16	5,46	5,97	9	7,60	8,59
	Rk [%]	15,11	41,02	171	6,24	7,45	13,00	31,46	142	3,95	3,93	15,71	16,71	6	8,50	9,25
	Rpk [%]	5,34	21,41	300	11,13	5,10	5,17	15,76	205	7,91	4,22	4,96	6,43	30	6,42	18,33
	Rvk [%]	14,99	19,81	32	6,27	7,86	14,27	18,06	27	9,69	9,45	14,05	16,52	18	5,99	14,96
	Rpk+Rk+Rvk [%]	35,43	82,23	132	5.51	5.76	32,45	65,28	101	6.17	3.59	34,73	39,67	14	5.93	10.46
100	*Ra* [µm]	3,88	7,16	84	3,01	2,33	6,63	13,00	96	3,88	3,39	4,27	5,50	29	3,70	3,89
	Rk [%]	11,34	21,41	89	2,76	3,21	17,89	39,27	120	5,13	3,46	12,13	16,40	35	3,65	4,53
	Rpk [%]	3,60	13,04	262	4,75	2,69	8,85	21,05	138	9,36	5,79	4,13	7,97	93	7,88	6,01
	Rvk [%]	9,47	10,32	9	4,24	5,07	18,25	19,71	8	4,65	5,15	11,28	12,92	15	7,30	9,35
	Rpk+Rk+Rvk [%]	24,41	44,76	83	3.21	1.71	44,99	80,03	78	4,43	2,70	27,54	37,29	35	4.80	5.32

From the presented results, it can be concluded that after staining, the values of all investigated roughness parameters increased. The greatest change was found for surfaces treated with waterborne stain, while the smallest was for surfaces treated with solvent-based stain. The most significant change was in the values of the parameter *Rpk*. A similar trend of parameter change was established when beech surfaces were treated with a single-layer low-viscosity waterborne varnish system (Atanasova and Angelski 2023), but *Ra*, *Rk*, and *Rpk+Rk+Rvk* were less affected.

The stain dilution affected the roughness parameter values. The change in the values of the stained surface parameters was influenced by the presence of a PVA additive in the waterborne stain. The values of the parameter *Rvk* were the least affected.

When the surfaces were treated with thinner alone, the variation in parameter values was much greater than when treated with stain (concentrate or diluted). An exception was the *Rvk* parameter.

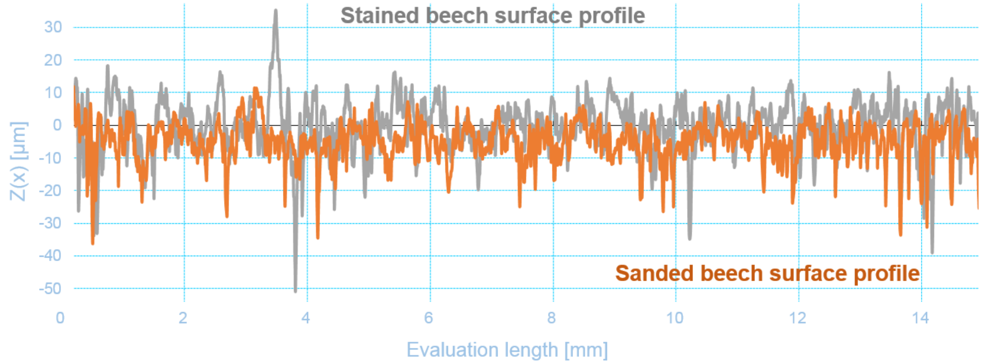


Figure 3: Beech surface profile change as a result of treatment with a solvent-based stain

Table 2: Average values of the roughness parameters of the veneered surfaces treated with waterborne stain, waterborne stain with PVA additive, and solvent-based stain. Change in the roughness parameter values *ΔR* [%] and accuracy index *p* [%] for sanded and stained surfaces

Type of stain		Waterborne stain					Waterborne stain with PVA additive					Solvent-based stains				
		Average values			Accuracy index *p* [%]		Average values [µm]			Accuracy index *p* [%]		Average values [µm]			Accuracy index *p* [%]	
Stain concentration [%]	Roughness parameter	Sanded surface	Stained surface	*ΔR* [%]	Sanded surface	Stained surface	Sanded surface	Stained surface	*ΔR* [%]	Sanded surface	Stained surface	Sanded surface	Stained surface	*ΔR* [%]	Sanded surface	Stained surface
0	*Ra* [µm]	6,96	8,45	21	4,00	3,08	6,19	9,92	60	5,69	4,82	6,16	6,51	6	0,53	2,49
	Rk [%]	16,82	22,56	34	2,57	3,65	15,79	27,89	77	4,67	4,73	16,02	16,10	0	2,24	1,96
	Rpk [%]	6,20	10,35	67	9,20	10,25	5,90	13,57	130	5,76	5,52	5,75	5,75	0	7,31	6,77
	Rvk [%]	20,55	21,61	5	4,18	5,40	16,88	20,05	19	8,25	10,05	15,85	17,89	13	3,36	3,11
	Rpk+Rk+Rvk [%]	43,57	54,52	25	2.73	5.05	38,58	61,51	59	5.35	4.87	37,62	39,74	6	2.66	2.16
50	*Ra* [%]	8,14	10,24	26	3,25	3,47	6,26	7,34	17	6,16	2,70	7,29	6,81	-7	4,15	4,14
	Rk [%]	19,55	27,48	41	5,95	4,73	14,59	19,68	35	5,73	4,67	17,72	17,24	-3	3,99	4,80
	Rpk [%]	6,12	11,20	83	9,43	15,89	4,35	8,35	92	8,88	6,81	5,92	5,06	-15	9,84	6,62
	Rvk [%]	21,64	23,03	6	4,01	3,96	18,65	19,59	5	5,43	5,40	21,10	19,86	-6	4,22	2,09
	Rpk+Rk+Rvk [%]	47,31	61,71	30	4.20	5.05	37,58	47,62	27	5.60	2.84	44,74	42,17	-6	4.19	3.28
100	*Ra* [µm]	7,71	9,16	19	4,84	2,58	5,15	6,91	34	2,39	2,66	5,93	5,56	-6	2,24	2,75
	Rk [%]	18,43	24,36	32	4,64	3,02	12,51	19,04	52	1,76	1,78	15,57	14,77	-5	2,58	2,76
	Rpk [%]	6,09	10,12	66	7,22	6,69	4,05	10,01	147	9,08	8,66	5,04	5,02	0	5,37	5,16
	Rvk [%]	21,09	22,06	5	4,20	3,40	15,16	15,96	5	4,61	5,95	15,31	15,44	1	3,50	4,26
	Rpk+Rk+Rvk [%]	45,60	56,54	24	4.09	2.27	31,71	45,01	42	1,91	2,01	35,92	35,23	-2	2.83	2.68

From the results presented in Table 2, it can be concluded that after treatment with a waterborne stain, the roughness parameter values increased. The greatest change was in the parameter *Rpk*. The *Rvk* parameter was the least affected. The stain dilution affected the roughness parameter values.

As a result of treatment with a solvent-based stain, the values of the roughness parameters decreased or increased slightly. Dilution affected the change of the parameters *Rpk* and *Rvk* to the greatest extent.

The PVA additive presence affected the roughness parameter values. In the case of water presence in the stain composition, the PVA additive limited the surface profile change.

A comparative graph of veneered surface profiles, before and after staining with concentrated (100%) waterborne stain, concentrated waterborne stain with PVA additive, and concentrated soluble-based stain are presented in Figures 4–6.

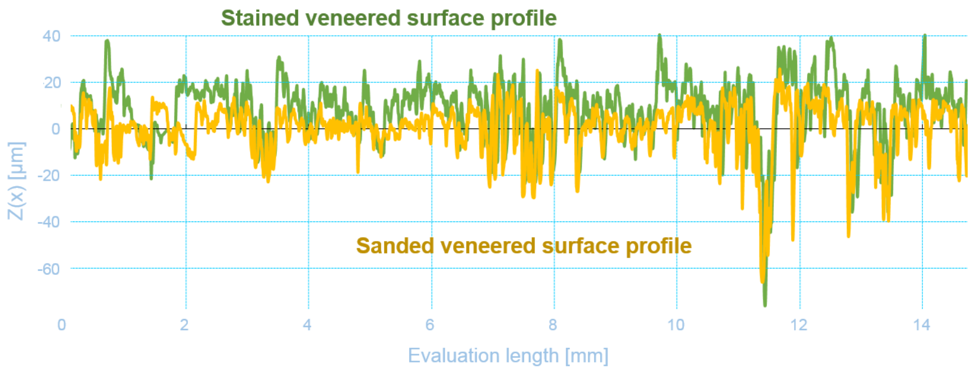


Figure 4: Veneered surface profile change as a result of treatment with a waterborne stain

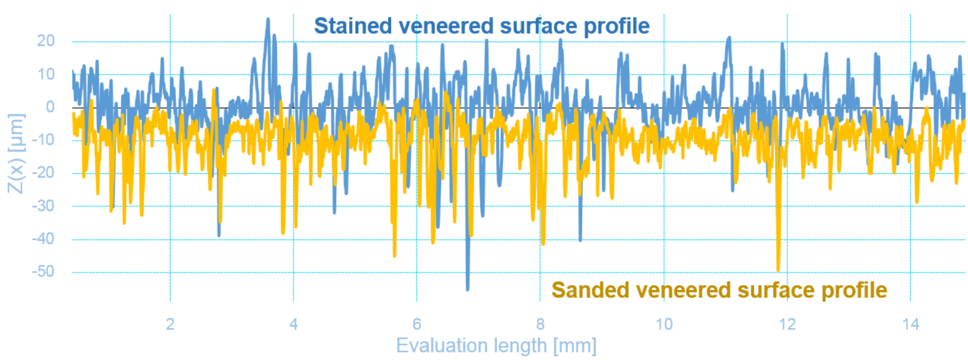
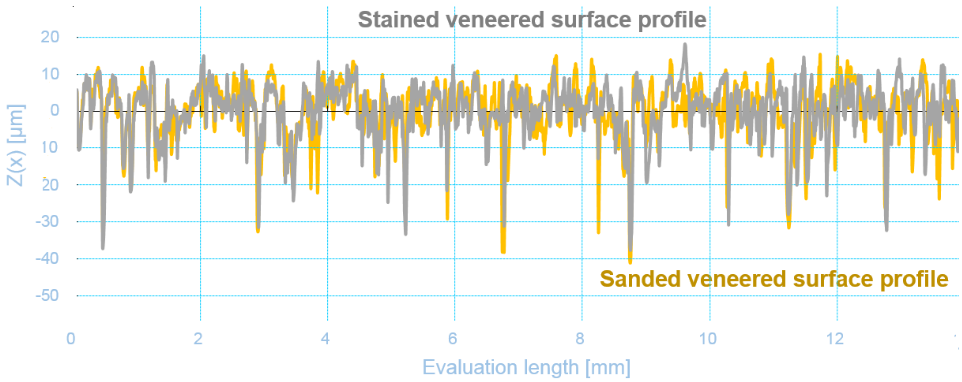


Figure 5: Veneered surface profile change as a result of treatment with a waterborne stain with a PVA additive



Figur 6: Veneered surface profile change as a result of treatment with a solvent-based stain

Table 3: Average values of the roughness parameters of the plywood surfaces treated with waterborne stain, waterborne stain with PVA additive, and solvent-based stain. Change in the roughness parameter values *ΔR* [%] and accuracy index *p* [%] for sanded and stained surfaces

Type of stain		**Waterborne stain**					**Waterborne stain with PVA additive**					**Solvent-based stains**				
Stain concentration [%]	**Roughness parameter**	**Average values**		**ΔR [%]**	**Accuracy index *p* [%]**		**Average values [µm]**		**ΔR [%]**	**Accuracy index *p* [%]**		**Average values [µm]**		**ΔR [%]**	**Accuracy index *p* [%]**	
		Sanded surface	**Stained surface**		**Sanded surface**	**Stained surface**	**Sanded surface**	**Stained surface**		**Sanded surface**	**Stained surface**	**Sanded surface**	**Stained surface**		**Sanded surface**	**Stained surface**
0	*Ra* [µm]	12,38	13,85	12	2,84	2,66	11,57	15,16	31	2,03	3,44	11,79	12,09	3	5,31	4,71
	Rk [%]	32,65	39,66	21	5,49	3,29	30,53	44,10	44	3,98	3,83	31,80	33,34	5	5,57	5,18
	Rpk [%]	6,29	17,40	177	7,07	8,18	8,16	22,86	180	5,70	7,95	8,73	7,93	-9	5,64	6,95
	Rvk [%]	28,75	26,21	-9	5,60	5,62	25,63	26,03	2	3,48	4,47	26,28	27,15	3	6,15	5,23
	Rpk+Rk+Rvk [%]	67,69	83,27	23	2,66	3,56	64,32	92,99	45	1,47	4,17	66,81	68,42	2	4,29	4,40
50	*Ra* [µm]	11,11	14,55	31	3,31	1,86	11,78	16,21	38	2,77	2,79	10,89	11,26	3	4,20	4,47
	Rk [%]	27,74	42,96	55	3,60	1,91	33,08	48,62	47	5,33	3,24	26,83	27,71	3	3,56	2,74
	Rpk [%]	7,30	18,65	155	7,62	7,85	7,37	21,28	189	7,62	7,79	7,48	6,63	-11	9,58	7,48
	Rvk [%]	27,17	26,61	-2	6,27	8,23	24,23	27,09	12	4,70	6,47	27,19	28,02	3	6,47	6,95
	Rpk+Rk+Rvk [%]	62,22	88,22	42	3,67	2,89	64,69	96,99	50	2,74	3,49	61,50	62,36	1	4,90	4,27
100	*Ra* [µm]	11,89	14,97	26	1,99	2,23	12,07	14,84	23	3,03	2,53	12,10	12,28	1	4,39	4,04
	Rk [%]	33,13	47,25	43	2,81	2,61	30,20	44,68	48	6,12	3,34	30,52	31,33	3	5,75	5,14
	Rpk [%]	9,10	17,95	97	15,32	7,83	7,34	20,21	175	8,83	7,37	7,92	9,85	24	7,06	5,37
	Rvk [%]	23,67	24,23	2	4,62	2,78	27,98	27,86	0	4,18	4,69	27,81	27,25	-2	5,04	5,18
	Rpk+Rk+Rvk [%]	65,90	89,43	36	2,61	2,35	65,52	92,75	42	3,53	3,22	66,24	68,42	3	4,46	4,38

The results presented in Table 3 show an increase in the values of the investigated roughness parameters for the surfaces treated with waterborne stains. The change in *Rvk* is insignificant. A similar trend of parameter change was established when beech plywood was treated with a single-layer low-viscosity waterborne varnish system (Atanasova and Angelski 2023), but the changes in *Ra*, *Rk*, and *Rpk*+*Rk*+*Rvk* values exceeded 100%.

The stain dilution affected the parameter values.

The change in the parameter values is insignificant for the surfaces treated with a solvent-based stain. In some cases, the values decrease.

For all surfaces, the *Rpk* parameter values changed the most.

The change in the parameter values of the stained surfaces was influenced by the presence of PVA additives in the waterborne stain. The parameter *Rvk* values were the least affected.

A comparative graph of plywood surface profiles, before and after staining with concentrated (100%) waterborne stain, concentrated waterborne stain with PVA additive, and concentrated soluble-based stain, are presented in Figures 7–9.

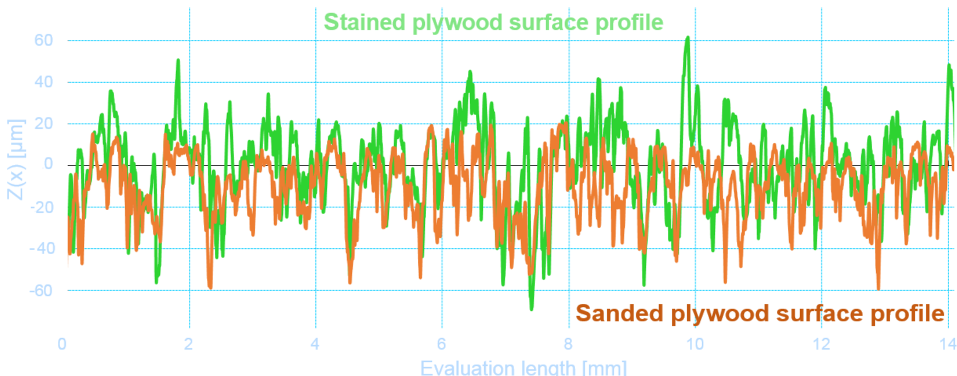


Figure 7: Beech plywood surface profile change as a result of treatment with a waterborne stain

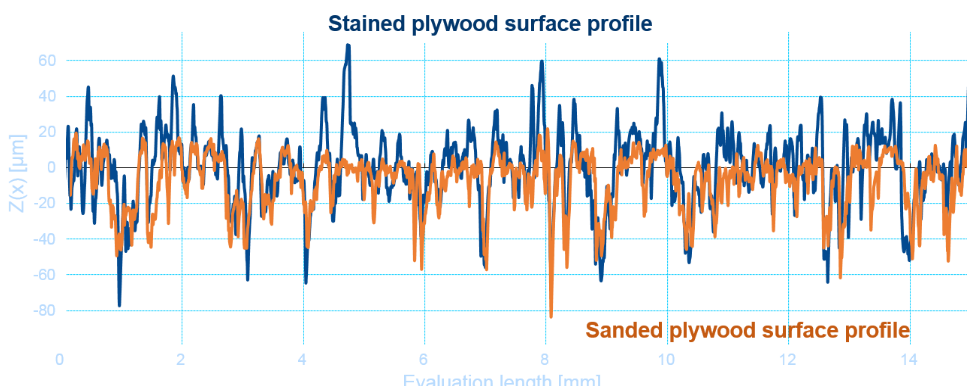


Figure 8: Beech plywood surface profile change as a result of treatment with a waterborne stain with a PVA additive

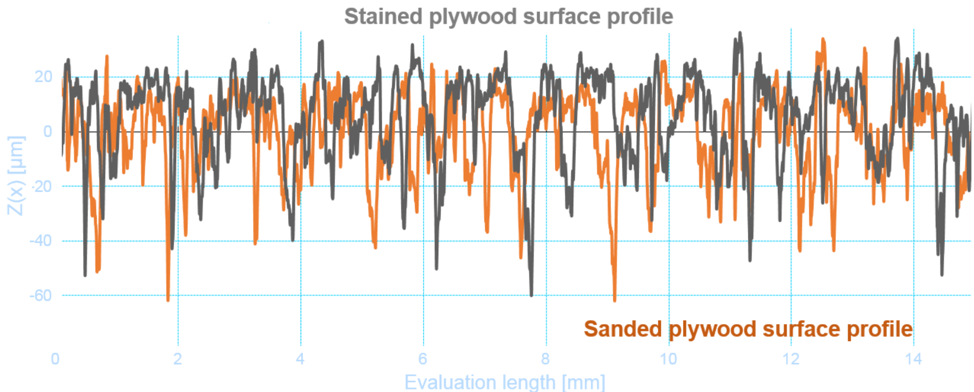


Figure 9: Beech plywood surface profile change as a result of treatment with a solvent-based stain

CONCLUSION

The presented research investigates the change in roughness of surfaces of beech wood, beech plywood, and beech veneered wood-fibre boards after treatment with waterborne stain, waterborne stain with PVA additive, or solvent-based stain. Surface changes after treatment with concentrated stain, with thinner only, or with a 50% stain-thinner mixture are presented. The arithmetic mean deviation of the assessed profile *Ra* and material ratio curve parameters, core roughness depth *Rk*, reduced peak height *Rpk*, and reduced valley depths *Rv*k were investigated. The measurements were carried out with a contact roughness tester Mitutoyo SJ-210 with a standard Gaussian filter and an evaluation length *ln* =15 mm. The results showed that the roughness of the surfaces after staining is mainly influenced by their structure, the stain formulation, and the type of thinner.

Significant wood grain raising was found when the surfaces were treated with waterborne stains. Profiles were last modified in the area of the *Rvk* parameter. When stained with a solvent-based stain, wood grain raising was negligible for the veneered and plywood surfaces. For the beech surfaces, the grain raising was less pronounced compared to the surfaces treated with waterborne stains.

For all investigated surfaces, the parameter *Rpk* changes to the greatest extent.

For all surfaces, the dilution of the waterborne stains affects the roughness parameter values.

When treating beech and veneered surfaces with thinner alone, the change in parameter values was much more significant than when treated with stain (concentrate or diluted). An exception was the *Rvk* parameter.

Adding PVA resin when beech surfaces and surfaces veneered with beech veneer are treated with waterborne stains is recommended.

The present study can serve to rationalise the staining processes and increase the quality of stained beech furniture surfaces.

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