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Influence of traditional wood surface modification methods on changes in aesthetic and resistance properties

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Abstract: For ages, furniture makers have been using various methods to accelerate the natural process of wood aging, in order to achieve a more sophisticated colour and to provide a uniform appearance for furniture parts replaced during restoration. Nowadays, wood aging is popular due to its aesthetic value associated with naturally aged wood, which can be enjoyed in conjunction with favourable mechanical properties of contemporary wood. Methods of wood surface modification used in wood aging can be divided into mechanical ones, consisting in changing the structure of wooden surfaces (eg. sanding, brushing, paint rubbing or structuring with chisel or other tools) and chemical ones, involving the use of chemical substances to change the colour of wood (eg. greying; application of lye, paint or wood stain; and ammonia fuming). The purpose of our study was to determine the influence of traditional wood modification techniques used in furniture-making − such as: structuring, whitewashing, rubbing, greying, dyeing with potassium permanganate solution and ammonia fuming − on the aesthetic and resistance properties of wooden surfaces (colour, gloss, roughness, abrasion resistance and resistance to scratches). Tests were performed on wood species most frequently used in Poland to produce artificially weathered wood: Scots pine (*Pinus sylvestris L.*) and common oak (*Quercus* Sp).

Key words: wood modification, weathering, aging, structuring, whitewashing, rubbing, sanding, greying, potassium permanganate, ammonia fuming

1. INTRODUCTION

In the recent years, the market of new, durable modified wood products has been developing very dynamically. Those products are used mostly for external applications, and the wood is prepared by means of chemical processing (acetylation, furfurylation, resin impregnation, etc.), thermo-hydro processing (thermal treatment); and thermo-hydro-mechanical processing (surface densification) [Sandberg et al. 2017]. In particular, this process takes place in Europe and is related, on the one hand, to limiting the need of restoration and conservation, while preserving durable aesthetic properties, and limiting the use of toxic preservatives to reduce environmental impact. A sustainable development goes hand in hand with awareness of the environmental impact of the products used, and also takes into account the life cycle assesment and embodied energy of the construction materials applied. Considering the above, wood turns out to be a perfect construction material. For this reason, nowadays, wood modification is being carried out both to improve the properties of wood as a construction material to broaden the range of its possible applications in construction, and to improve its aesthetic and functional properties.

Surface modification treatment performed to improve/change the aesthetical properties of wood is not a new idea and traditionally it is called wood weathering or aging. Contemporary Internet sources present many ideas on how to age wood, including precise intstructions, which indicates that there is a huge market for this kind of products. This refers both to loft-style modern interiors, as well as traditional interiors in the so-called "shabby chic" style. Modification processes are applied to new furniture made of recycled materials (old buildings or boats), as well as antique furniture in historical styles (such as the Neo-rococo), modern furniture from the 1960s, and even contemporary furniture (Ikea − sic!).

Processes accelerating the natural aging of wood have been used in furniture-making for ages [Rodel 1999], both to achieve a sophisticated colour, and to even out the colour after furniture conservation and achieve a uniform appearance of the replaced parts. Modification methods help to achieve a unique colour of wood, comparable with antique timber [Matsuo et al. 2011] or exclusive species [Weigl et al. 2009]. Nowadays, accelerated wood aging is fashionable due to its aesthetic properties resembling naturally aged wood, in combination with the favourable mechanical properties of new wood, and it has become a subject of many scientific studies [Weigl et al. 2012, Miklecic et al. 2012].

2. AIM OF RESEARCH

The methods of wood modification used to weather wood can be divided into mechanical ones that focus on the changes to the structure of wooden surfaces (eg. rubbing, brushing, structuring with chisel, or painting) and chemical ones involving the use of reagents that change the colour of wood (eg. dyeing, whitewashing, greying, leaching, and smoking with ammonia).

The purpose of our research is to study the methods of wood aging that are popular nowadays and to specify the influence of wood modification methods used traditionally in furniture-making, such as: structuring, whitewashing, rubbing, greying, dyeing with potassium permanganate and ammonia smoking on the aesthetic and resistance properties of wooden surfaces (colour, gloss, surface roughness and resistance to scratches).

In the study, we have used the wood species that are most frequently used in Poland together with wood aging techniques, and namely: Scots pine (*Pinus sylvestris L.*) and oak (*Quercus* Sp).

3. REVIEW OF TRADITIONAL METHODS OF WOOD SURFACE MODIFICATION

Among the mechanical methods of wood modification, we can mention the broadly understood wood structuring and painting.

Brushing − is a method of weathering classified among mechanical means. It consists of structuring wood by rubbing a brush against its surface along the growth rings. During this operation, the soft part of wood − earlywood − is removed. This allows for highlighting the natural wood pattern. Brushing works best with wood species that have clear growth rings and limits between the earlywood and latewood growth, as well as a clear difference in the hardness of those. Brushing can be performed manually, with the use of electric tools, and with the help of machines in the mass production of large batches [penny.pl… szczotkowanie; derva.blogspot.com].

Structuring helps to underline the natural wood pattern and is a process composed of several stages, whose exact number depends on factors such as the desired effect and the species of wood subjected to these methods. Heads with steel wires are used for the brushing of coniferous species, as well as deep processing or the opening of vessels in deciduous species. The bristle of the brushes can be single or woven. It is important to remember that deciduous wood requires bristle made of stainless steel or copper, because otherwise the tannins present in the wood will react with steel and cause undesired stains and discolorations that may appear even after a long time. To process softer species such as pine or spruce, or for final touches of the brushing process in hard species, we can use brush heads with tinex bristle that also have variants combined with steel wire, and moreover, have several grains and dimensions to choose from. The last stage of structuring is carried out with abrasive brush heads [polishstyl.com.pl].

Sand blasting, glass bead blasting or soda blasting − this is another group of processes within the mechanical methods of wood aging. Similar to brushing, it also consists of removing the soft part of wooden tissue. Several different materials can be used as the abrasive, blasting agent: sand, soda or ground glass. The abrasives have different grain sizes. The process is performed with the use of a special pistol and a compressor. The effects depend on the pressure and grain size of the abrasive agent. The advantages of this process over brushing are that the treatment does not leave longitudinal marks visible from close distance and the effect is more natural. The best material for sand blasting is quartz sand. Soda and glass bead blasting with very fine grain is used in conservation tasks, as it permits to clean the wood without damaging its structure, which is especially important in the conservation of ornaments, sculptures, etc. [soda-blaster.pl].

Making scratches and signs of damage − this method is also classified as mechanical treatment. It often consists in hitting wood repetitively with an axe, hammer or nails in a sock, or making scratches or grooves with the use of chisels and other tools, so the material seems heavily worn. Additionally, nice colouring can produce interesting effects. In many cases, even insect tunnels are imitated [vidaron.pl].

Rubbing − consists in applying two coats of paint in contracting colours and then rubbing the external coat in selected spots until the bottom coat becomes visible. The rubbing can be done in places that are the most prone to abrasion, such as edges and corners of furniture or areas near handles. Before the treatment, wax is applied in those places to facilitate the abrasion process. The paint can be scraped with the help of a blunt knife or sandpaper. Such rubbing causes the weathered object to look much older than it really is [vidaron.pl]

Shabby chic − this method consists in painting the object with dark wood stain, and then applying wax in certain areas. The next stage consists in painting the element with brighter paint and rubbing the waxed areas with fine grain sandpaper to make the dark wood stain visible. Another similar method consists of applying **cracking lacquer** on the previously painted element along the line of the paintbrush. An example of such lacquer can be varnish. It can be classified as single-ingredient or two-ingredient, and additionally requires the use of patina in the final stage, to hightlight the cracks [drewno.pl].

Cracked acrylic paint is achieved by applying a thick layer of polyvinyl acetate glue over the first coat of paint, in a way that the non-transparent glue layer completely covers the wood. Next, when the glue has initially dried and becomes sticky, the second layer of paint is applied on top. This layer cracks when it dries together with the glue [cowans.org].

In the Scandinavian style, it is popular to apply the so-called **whitewashing** of wood. For this purpose, it is enough to paint it with white, diluted acrylic paint. An additional effect is achieved by spreading the paint with a hard paintbrush along the growth rings and rubbing it in selected spots, to make the natural colour of wood slightly visible [vidaron.pl]. A similar result can be achieved by applying white wax [vidaron.pl].

Another method consists of making small indentations − e.g. with chisel − and covering the surface with a whitewashing paste that fills those indentations. A subsequent application of an additional layer of fast-drying lacquer increases the contrast between the colour of wood and the colour of the paste [penny.pl…postarzanie drewna].

Chemical methods of wood modification can be superficial or affect the entire structure of wood. In order to change colour and obtain attractive appearance, to highlight the natural wood pattern, and to hide certain wood defects such as blue rot, **dyeing** can be used. Wood stains form part of solvent dyes made of metal-organic compounds. The stains most frequently used in wood aging are chemical pre-stains made of solutions of metal salts that in reaction with tannins present in the wood allow for achieving different colours. The most popular are dyes based on salts of metals such as e.g.: copper, iron, chromium, nickel, manganese, cobalt, and zinc; and namely: **potassium dichromate**, **iron sulphide**, and **ferric chloride**. Ammonia can be added to those salts in order to increase their reactivity, although it cannot be used with iron salts, because it causes precipitate formation. Dyeing usually leads to a darker surface, but the range of colours is very broad. Irena Swaczyna, in her book "Meble − naprawa i odnawianie" (Furniture − Repair and Renovation) quotes a traditional formula for achieving the colour of old oak: apply a water solution of tannin (1:10) on the surface; next, a ca. 65% solution of potassium dichromate; and after drying, a hot solution of 10% catechin [Swaczyna 1995]. On the other hand, when using substances such as: 15% solution of hydrogen peroxide (optionally, with the addition of ammonia or 6-10% oxalic acid solution) wood can be weathered by **whitewashing.**

In case of wood species containing many tannins, like oak, one stage of staining is enough, while in case of species with less tannins, two stages of staining are performed. Two-stage staining consists in first saturating the surface with a pre-stain made of a solution of tannins, and later, after drying, applying the main stain (containing metal salts) [Proszyk 1999].

It is also popular to apply the process of **leaching** with the use of a special soap emulsion. Leaching consists in a chemical change of wood structure with the use of leach, an emulsion made of a water solution of sodium base. It penetrates deeply into the wood, whitewashes it and provides a "blurred" appearance, while at the same time highlighting the growth ring pattern. This method additionally protects the wood against turning yellow and against darkening with time. Leach is rubbed into the surface with the help of a paintbrush, and a ready surface should be polished and protected with oil or lacquer [vidaron.pl]. This method is transparent − it does not cover the natural growth ring pattern, at the same time granting a grey hue to the wood [drewno.pl 2014].

Greying − refers to dyeing the wood with a solution obtained after several days of soaking steel wool in apple vinegar, that reacts with tannins in the wood. The final colour of wood depends, to a large degree, on the time of soaking the wool (from one to 5-7 days) and on the preliminary application of a tea solution before the vinegar solution. A solution made of tea can be applied in the form of localized stains in certain areas, which will make those areas stand out as darker. If the wood naturally contains many tannins, like oak, dying results in a significantly darker colour. Kinds of wood that do not contain tannins can be dyed with the use of tannin, gallic acid, pyrocatechin or oak tannins [vidaron.pl].

"Smoking" with ammonia − it is an alternative to wood dyeing that provides a darker colour in the entire volume of wood, by exposing it to ammonia fumes. The ammonia absorbed by the wood reacts with the tannins, fats and resins contained within it. Oak wood can acquire a brown colour that resembles fossil oak, while black locust becomes golden-brown, which is an alternative for more expensive, exotic wood species. It is recommended to use ammonia as a gas, because in the form of water solution it can cause deformations. This method can be used to dye both raw wood and wood covered with French polish or lacquer, without affecting the gloss of the external layer. Wood exposed to ammonia acquires a very durable colour and becomes resistant to unfavourable weather conditions. Moreover, this method of modification also improves the resistance properties of the material: its bending strength, compressive strength and hardness, by 10-20%. Wood modified with ammonia can be coated only with solvent lacquers.

The properties of ammonia were discovered in medieval Europe when a carpenter noticed that it caused the darkening of oak wood used in stable carpentry at that time (which was caused by the presence of ammonia in manure).

Ammonia is a strongly corrosive, invisible gas a bit lighter than air [leevalley.com]. It is dangerous to work with due to its volatility and high toxicity, so it can only be used in airtight chambers and requires a lot of caution. Industrial ammonia smoking takes place in tightly closed chambers, where wood is exposed to ammonia fumes in high pressure, after setting the adequate temperature and time parameters. After the modification, the material must be ventilated, in order to remove unbound ammonia.

4. RESEARCH METHODOLOGY

4.1. Research Material

The study was carried out on cuboid samples with the dimensions of 100 x 100 mm, and about 20 mm thick. We used 10 samples of oak and 10 samples of pine wood. The samples were adequately polished with sandpaper (grit 150) and seasoned in laboratory conditions, i.e.: temperature ca. 20-23°C and air humidity of 50-60%.

4.2. Sequence of Tests

4.2.1. Zero samples

The first series of tests were conducted on zero samples (Fig. 1), which refers to materials that had not yet been subjected to any weathering treatment. After testing the gloss, colour, roughness, resistance to abrasion, and resistance to scratches, the samples were polished with the use of 150 grit sandpaper to remove any damage caused during the tests and to even their surface.

Figure 1. Zero samples of oak wood (row 1 and 2) and pine wood (row 3 and 4)

4.2.2. Samples whitewashed with acrylic paint

The first process of modification consisted in whitewashing with acrylic paint diluted in water in the ratio of 5:1 (Fig. 2). A hard paintbrush was used to apply two thin coats of paint. In several selected places, the paint was rubbed in a bit harder. After the surface dried, the samples underwent a series of tests except for colour and abrasion, because those tests were considered unnecessary in the comparison with other methods od modification. After carrying out the tests, the paint was completely removed with an oscillating grinder and 150-grit sandpaper.

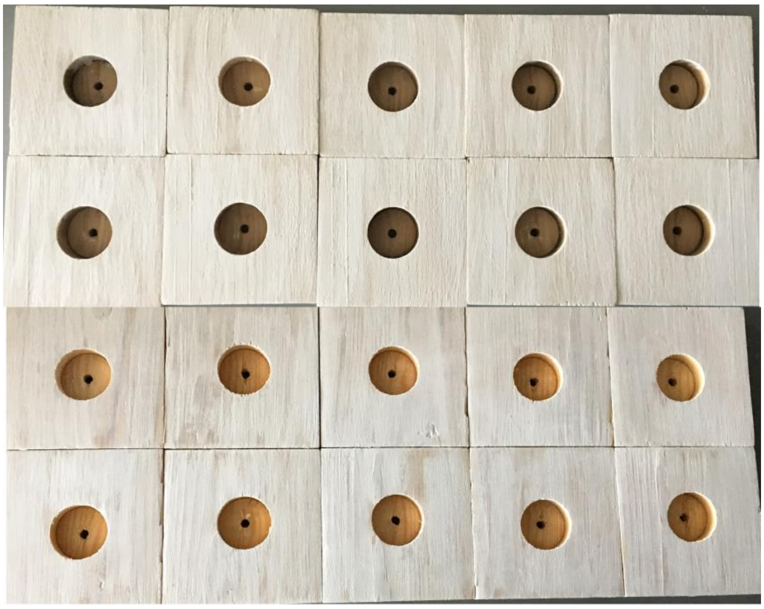

Figure 2. Whitewashed samples: oak wood (row 1 and 2) and pine wood (row 3 and 4)

4.2.3. Samples after rubbing

Another method of aging treatment consisted in applying two coats of paint in contrasting hues, one layer each (and the second one applied after the first one has dried), and later rubbing the dry coating with 240-grit sandpaper in selected spots. The tests of colour and abrasion were also omitted in this case, for the same reason as in the case of the previous method. After the tests, the samples were polished with oscillating grinder and sandpaper (grit 150).

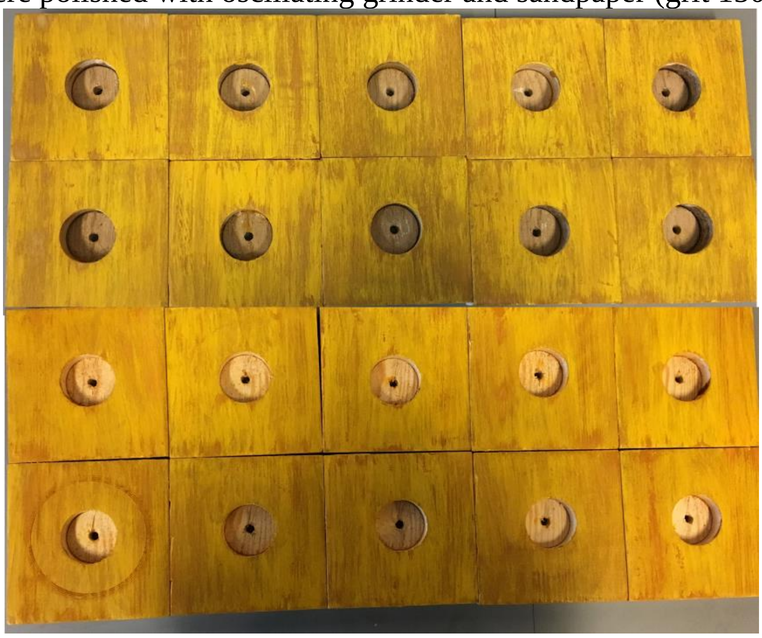

Figure 3. Samples treated with rubbing: oak wood (row 1 and 2) and pine wood (row 3 and 4)

4.2.4. Greyed samples

Another weathering method tested by us was the change of colour with the help of a solution made by soaking steel wool, for a week, in 200 ml apple vinegar, in a tightly closed jar. The surface of each sample was rubbed with a fragment of steel wool, which also slightly structured its surface. A complete series of tests, except for abrasion, was conducted, and afterwards the samples were polished with oscillating grinder and sandpaper (grit 150).

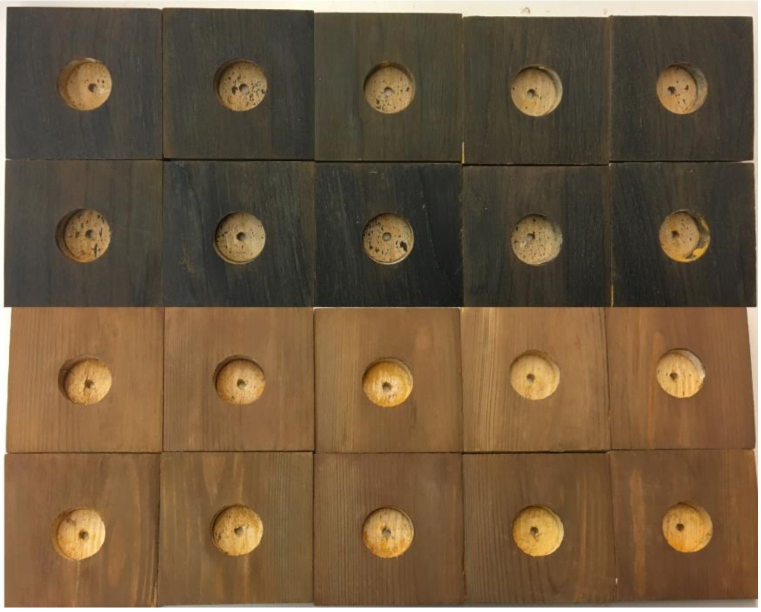

Figure 4. Greyed samples: oak wood (row 1 and 2) and pine wood (row 3 and 4)

4.2.5. Brushed samples

Another aging method consisted in structuring the samples (Fig. 5). This process was carried out with the help of two abrasive heads mounted on a polishing machine (one head made of copper-clad steel wire with single strand, and later a head of tynex wire in order to "lay down" the standing fibers on the surface of wood). Afterwards, the samples underwent a series of tests except for roughness, because comparison with other methods in case of a structured surface would be unreliable. After performing the tests, the surface of samples was smoothened with format saw and polished with 150-grit sandpaper.

Figure 5. Samples after brushing: oak wood (row 1 and 2) and pine wood (row 3 and 4)

4.2.6. Samples dyed with potassium permanganate solution

Subsequently, we prepared a solution of potassium permanganate (60 tablets, 100 mg each, dissolved in 200 ml of water). The final concentration was 3%. Because the visual effect achieved in the process of modification was satisfactory, we decided not to increase the content of permanganate (Fig. 6). Potassium permanganate solution was applied with the help of a cotton ball twice, at the interval of 30 min. After the tests, the samples were polished with sandpaper, grit 150.

Figure 6. Samples dyed with potassium permanganate: oak wood (row 1 and 2) and pine wood (row 3 and 4)

4.2.7. Samples dyed with ammonia fumes

The last kind of modification was "smoking" in ammonia. For this purpose, we prepared a smaller container for ammonia water and a bigger, tight container that was going to hold both the samples and the small container with ammonia water. We used ammonia water with the concentration of 25%. After 24h, ammonia water was replaced, and samples were left for the next 24 hours. The two wood species were treated separately (Fig. 7). After the fuming stage was completed, the samples were ventilated for a week, to remove any free ammonia, and later the tests were conducted on them.

Figure 7. Oak wood samples dyed with ammonia fumes

4.3. Gloss tests

The tests of gloss were performed in accordance with the PN-EN ISO 2813 standard, with the use of the reflectometer Picogloss Model 503 by Erichsen (Fig. 5). Four measurements were conducted on each sample: 2 parallel to the grain and 2 perpendicular to the grain, each at the angle of 60˚.

4.4. Tests of colour

The tests of colour were carried out in accordance with the PN-EN ISO 7724-1:2003 and PN-EN ISO 7724-2:2003 standards. The spherical spectrophotometer X-Rite SP60 was used to conduct the tests. Photometrical parameters were measured in the L a b colorimetric system. After calibration, each sample was tested four times: 2 measurements parallel to the grain and 2 perpendicular to the grain. To determine colour change, we used the CIE-L*a*b method. The difference in colour was calculated from the formula: $\Delta E = \sqrt{L^2 + a^2 + b^2}$. Results were compared to the constants:

ΔE ϵ (0; 1) – no difference can be noticed

ΔE ϵ (1; 2) – difference can be noticed only by an experienced observer

ΔE ϵ (2; 3.5) – difference can be noticed also by unexperienced observers

ΔE ϵ (3.5; 5) – visible colour change

ΔE > 5 – impression of two different colours

4.5. Roughness tests

Roughness tests were performed with the contact method, using a profilometric system, according to the PN-84/D-01005 standard. We used the roughness meter Mitutoyo SJ-210. Four measurements were carried out: 2 in parallel and 2 in perpendicular to the grain. The measurement sections had 4 mm. The parameters taken into account were: Ra, Rq, Rz and Rz1max.

Ra parameter − this is the arithmetic average of the profile coordinates in relation to the deviation of the profile from the average line, measured along the tested section,

Rq parameter − square average of roughness surface deviation in μm,

Rz parameter − the highest point of the profile,

Rz1max parameter − the maximum height of the roughness.

4.6. Tests of resistance to scratches

The tests of resistance to scratches were carried out on the basis of the PN-EN 438-2:2005 standard, using the Taber-Shear / Scratch Tester 550, making 5 scratches with the force of 1-5 N. The analysis was based on the scratch width, measured with a stereoscopic microscope Nikon SMZ 1500 with the use of a digital camera and the computer software NIS-Elements, with the accuracy of 0.01 μm. Each sample was measured four times, at a diagonal grain direction.

5. TEST RESULTS

The results of individual tests in numerical form have been presented in the engineering dissertations of Agnieszka Sokołek and Adam Barski [Sokołek 2019, Barski 2018]. Figures 8 and 9 present the percentual influence of the modification methods on selected properties of oak wood surface (Figure 8) and pine wood surface (Figure 9).

Table 1 presents the total colour change values.

All the modification methods caused changes in the tested properties of wood surface. The biggest percentual change comparing to non-modified wood, in case of oak, occurred after greying for the colour parameter (up to 77%), and the smallest for scratch width with 5N force for whitewashing (0%).

When comparing the percentual influence on the changes of individual properties of oak wood, we can notice that the biggest change in colour was caused by greying, which darkened the colour (by 52%), increased the share of the green colour (by 77%) and blue colour (by 74%), providing a colder hue. The second most significative change in colour occurred after modification with potassium permanganate, which darkens the colour by 50% and makes it more purple, increasing the share of red by 31% and blue by 48%. Smoking with ammonia darkens the colour by 38%, and makes the colour a little colder by increasing the share of green by 19% and blue by 37%, comparing to non-modified wood. All those three modifications cause an impression of a totally different colour. The smallest colour change was caused by brushing, which darkened the wood by 5% and made the colour warmer, increasing the share of red by 8% and yellow by 5%. The value of total colour change caused by brushing is at the limit between noticeable and clear difference - ΔE equal to 3.6.

Colour change for whitewashing and rubbing were not tested, because they depend on the paints applied.

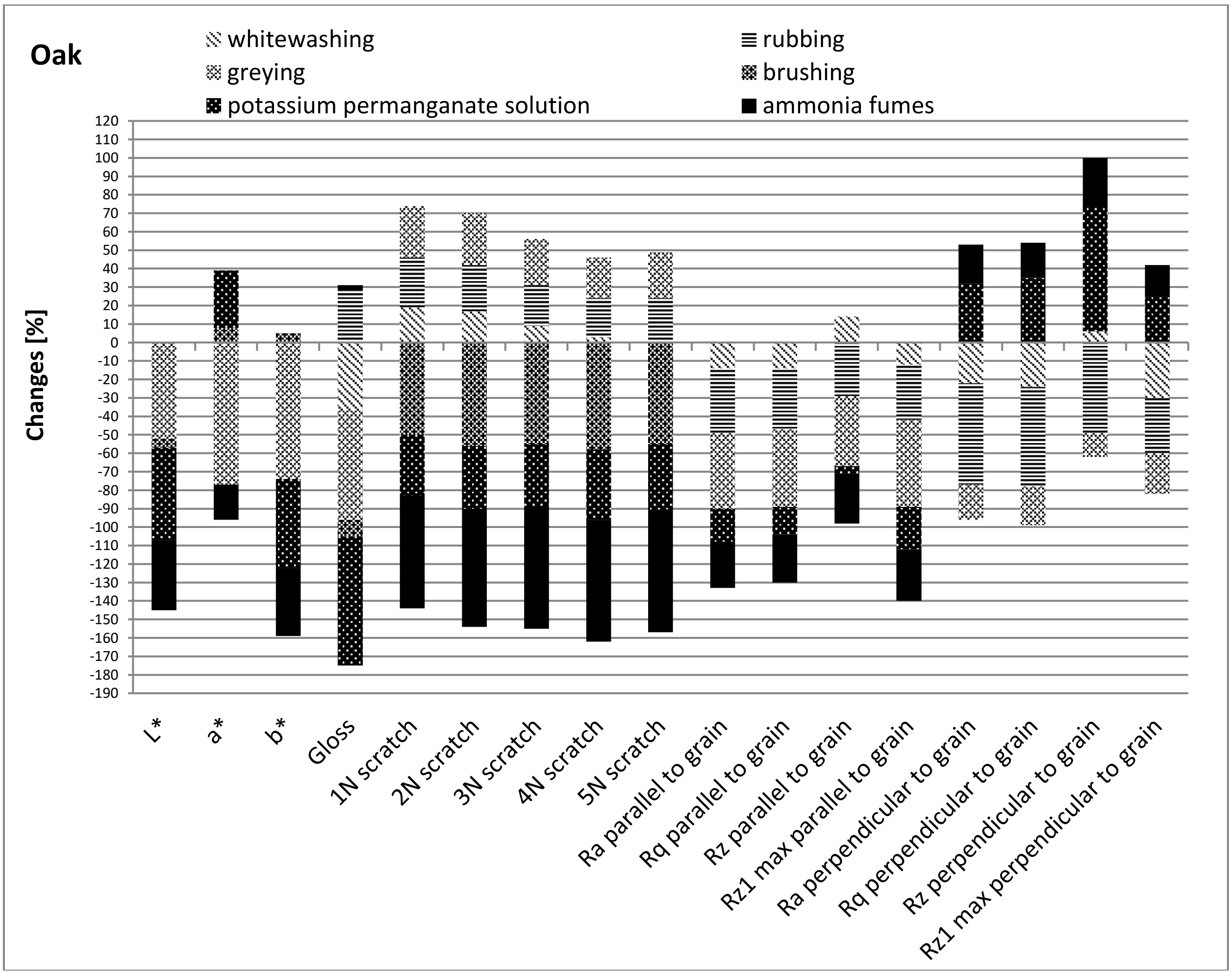

Figure 8. Percentual influence of modification on the properties of oak wood, comparing to non-modified wood (colour change for whitewashing and rubbing were not tested, just like the changes in roughness for brushing)

Potassium permanganate and greying significantly decreased the gloss of oak wood, by 70% and 59%, correspondingly. Whitewashing also decreased gloss (by 37%), while rubbing increased it (by 28%), although in both cases the gloss values depend on the paints applied. It can be noticed that gloss is not affected by modification with ammonia (a 3% increase) and brushing (9% decrease).

Table 1. Total colour change values

ΔE	Oak samples	Pine samples
Greyed wood	56	15,5
Brushed wood	3.6	3.1
Wood dyed with potassium permanganate solution	37	49.5
Wood modified with ammonia fumes	27.8	4.1

Some of the modification techniques increase the resistance to scratches - scratch width becomes much smaller (by over 60%) in case of ammonia, in case of brushing (by 50%), potassium permanganate (by over 30%) and becomes by over 20% larger in case of greying and rubbing. The smallest improvement of resistance to scratches appeared in case of whitewashing (the width of scratches grew by 0% for 5N force and up to 19% for 1N force).

We did not test roughness in case of structuring through brushing. All the tested modifications reduced wood roughness tested parallel to the grain. In case of the Ra parameter, the change amounted to: 41% in case of greying, 35% for rubbing, 25% for ammonia smoking, 18% for potassium permanganate and 14% for whitewashing. In case of the Rq parameter, the change amounted to 42% in case of greying, 33% for rubbing, 26% for ammonia smoking, up to 15% for potassium permanganate and 14% for whitewashing. Rz measured parallel to the grain was reduced by 38% in case of greying, 29% in case of rubbing, 27% for ammonia smoking, and up to 4% in case of potassium permanganate modification. In the process of whitewashing, Rz grew by 14%. The Rz1 max parameter was reduced by 47% in case of greying, 30% for rubbing, 28% in case of ammonia smoking, 23% for potassium permanganate, 30% for rubbing, and 12% for whitewashing.

When measuring roughness perpendicular to the grain, whitewashing, rubbing and greying reduced this parameter. Chemical modifications with potassium permanganate and ammonia fumes increased surface roughness. The values of the Ra parameter were decreased by 55% in case of rubbing, 22% for whitewashing and by 19% during greying, and were increased by 32% in case of modification with potassium permanganate and 21% in case of ammonia fumes. The Rq parameter decreased by 54% for rubbing, 24% for whitewashing and 21% for greying, and increased for potassium permanganate (by 35%) and ammonia (by 19%). The Rz parameter measured perpendicular to the grain decreased by 49% for rubbing and by 13% for greying, and increased by 67% for potassium permanganate and by 27% for ammonia. It also slightly increased for whitewashing, by 6%. The Rz1 max parameter measured perpendicular to the grain decreased by 30% for whitewashing and rubbing and by 22% for greying. It increased by 25% for potassium permanganate modification and for ammonia fumes by 17%.

In case of pine wood, the biggest percentual influence was observed in case of gloss reduction by 83% after potassium permanganate, and the smallest for structuring through brushing for the b* parameter (the share of yellow and blue) and scratches made with the force of 5N (in both cases, 0% change). Ammonia fumes caused the colour to become colder, in the direction of green and blue, while potassium permanganate increased the share of red and blue.

When comparing the percentual influence on the changes in the individual properties of pine wood, we can notice that the change in colour was influenced in the largest degree by potassium permanganate, which darkened the colour by 61%, increased the share of red by 55% and blue by 41%. Greying changed colour by darkening it by 19%, and increasing the share of green (by 29%) and blue (by 32%), which led to a colder hue. The third modification that caused most colour changes was modification with ammonia, which only slightly darkened the colour by 3%, made it colder and increased the share of green by 41% and blue by 9%. When pine was dyed with potassium permanganate and greyed, these modification methods caused the impression of a totally different colour (refer to Table 1). The smallest colour change was caused by brushing, which darkened wood by 4% and made the colour warmer, increasing the share of red by 13%. The value of total colour change caused by brushing is at the limit of change noticeable for unexperienced observer − ΔE equal to 3.1. In case of pine wood, ammonia modification led to a significantly smaller change in colour than in case of oak wood, because for pine wood ΔE amounted to 4.1 (oak 27,8).

Potassium permanganate and greying significantly decreased the gloss of pine wood, by 83% and 57%, correspondingly. Gloss was also decreased by whitewashing (by 33%), brushing (by 35%) and ammonia modification (by 33%), and it was increased by rubbing (by 37%), although in case of coatings application, the values of gloss depend on the paints.

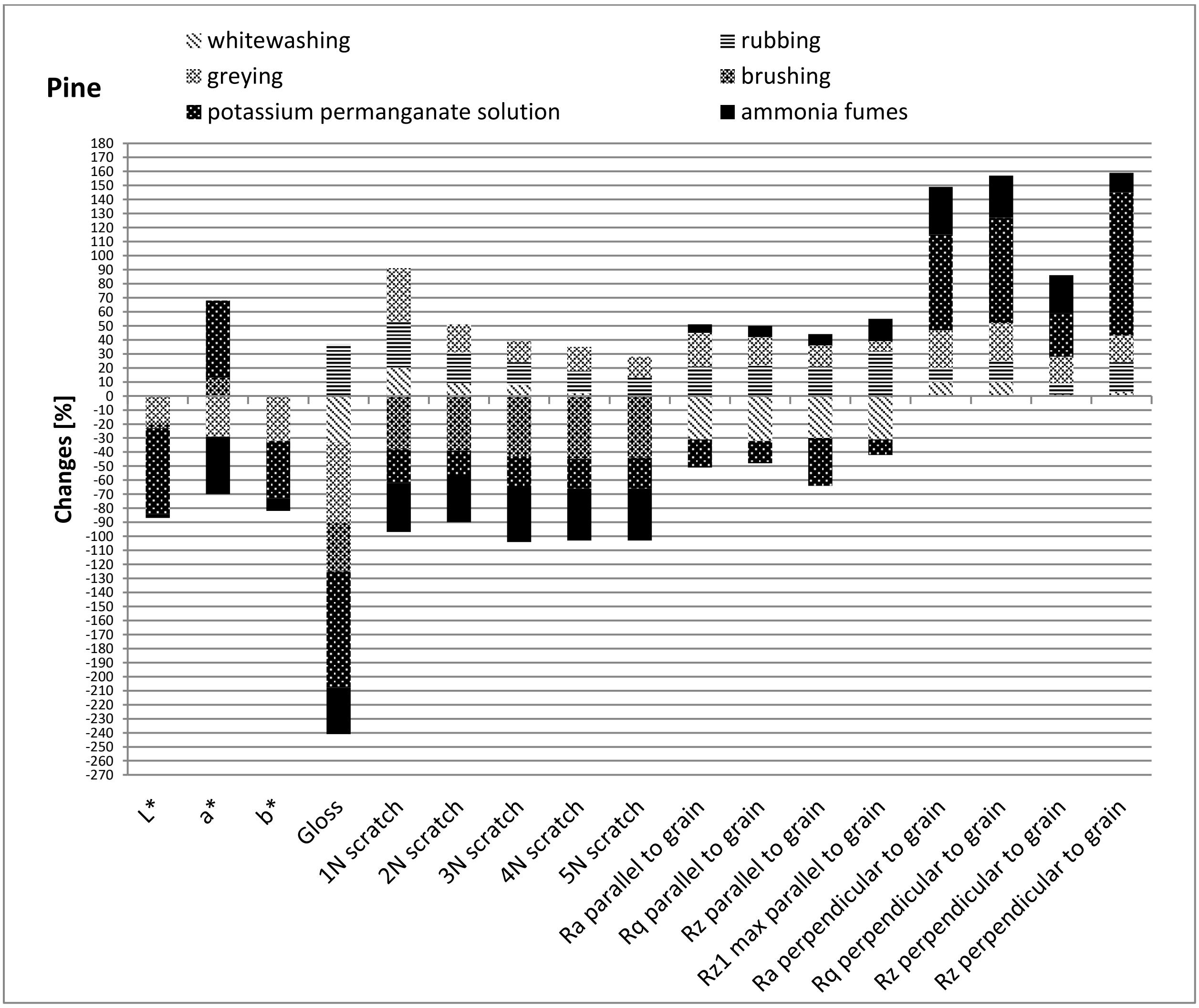

Figure 9. Percentual influence of modification on the properties of pine wood, comparing to non-modified wood (colour change for whitewashing and rubbing were not tested, just like the changes in roughness for brushing)

Some of the modification techniques increase the resistance to scratches − scratch width is most significantly reduced − by over 40% − in case of brushing (because the softest, summer growth part was removed mechanically), by over 30% for ammonia modification, by over 20% for potassium permanganate, while it grows by over 20% for greying and rubbing. The smallest influence on improving the resistance to scratches appeared in case of whitewashing (the width of scratches grew by 0% for 5N force and up to 20% for 1N force).

We did not test roughness in case of structuring through brushing.

Roughness measured parallel to the grain becomes smaller for potassium permanganate and whitewashing modification methods, while it grows for ammonia smoking, greying and rubbing. Values of the Ra parameter become lower: by 31% for whitewashing and by 20% for potassium permanganate; and become higher: for greying, by 24%, rubbing − 21%, and by 6% for ammonia smoking. In case of the Rq parameter, the values become smaller for whitewashing (by 32%) and potassium permanganate (by 16%) and become higher for rubbing (22%), greying (20%) and ammonia smoking (8%). The values of the Rz parameter measured parallel to the grain become reduced from 34% for potassium permanganate to 30% for whitewashing; and grow by 21% for rubbing, 15% for greying and 8% for ammonia. The Rz1 max parameter was reduced by 31% in case of whitewashing, by 11% for potassium permanganate modification, and it grew by 32% in case of rubbing, 16% for ammonia and 7% in case of greying.

When measuring roughness perpendicular to the grain, all the modification methods under research increased the value of roughness. The values of the Ra parameter were increased by 68% in case of potassium permanganate modification, by 34% for ammonia smoking, by 27% for greying, and 10% for rubbing and whitewashing. The Rq parameter increased by 75% for potassium permanganate modification, by 30% in case of ammonia smoking, by 27% for greying, by 15% for rubbing and 10% for whitewashing. The Rz parameter measured perpendicular to the grain increased by 31% for potassium permanganate, by 27% for ammonia, by 19% for greying, 8% for rubbing, and 1% for whitewashing. The Rz1 max parameter measured perpendicular to the grain grew by 102% for potassium permanganate modification, by 21% for rubbing, 19% for greying, 14% for ammonia smoking and 3% for whitewashing.

In case of roughness tests, pine wood reacts differently than oak to rubbing and greying (by increasing, and not decreasing roughness measured parallel and perpendicular to the grain) and to ammonia smoking (by increasing, and not decreasing roughness measured parallel to the grain). In case of pine wood, all the modification methods under research increased roughness measured parallel and perpendicular to the grain, except for potassium permanganate that reduced roughness measured parallel to the grain. In case of oak wood, whitewashing, rubbing and greying reduced roughness measured parallel and perpendicular to the grain, and only modification with potassium permanganate and ammonia increased roughness perpendicular to the grain.

Modification of oak wood with ammonia fumes has a much stronger influence on colour change and resistance to scratches (over 60% for oak and only 30% for pine).

6. CONCLUSIONS

The test results permit to draw the following conclusions:

- The whitewashing of wood leads to a gloss decreased by 33-37%, slightly reduces surface roughness, and it also causes a small reduction of resistance to scratches, but these changes are not statistically significant. A statistically significant change took place only in case of the Rz1 max parameter for oak wood, measured perpendicular to the grain [Sokołek 2019].
- Rubbing led to a decrease in surface roughness of oak wood by over 40% and increased the roughness of pine wood by ca. 20%, it also allows for the biggest gloss increase (37% for pine). In case of roughness tests, a statistically significant change was observed only for the Rz1 max parameter of oak wood perpendicular to the grain [Sokołek 2019]. Rubbing caused a decrease of resistance to scratches.
- Wood greying completely changed its colour (especially in case of oak wood), because the results depend on the presence of tannins in the wood. This method also leads to the surface becoming more matte by reducing gloss (ca. 58%), increasing the roughness of pine wood surface, decreasing the roughness of oak wood, and reducing the resistance to scratches for both species. The changes in roughness, gloss and resistance to scratches are not statistically significant [Sokołek 2019].
- Brushing improves the resistance to scratches of wood (by ca. 40% in case of pine and over 50% in case of oak wood). Has no statistically significant impact on colour for both species, and gloss of oak wood [Barski 2018]. Brushing causes a reduction of gloss especially in case of pine. Structuring impacts roughness to a very large extent.
- Dyeing with potassium permanganate allows to change the colour of wood completely, making it much darker and more purple, increasing the share of red by and blue. Reduces the glow to a large degree (by 83%-70%), making the surface matte, increases resistance to scratches, and slightly − by ca. 17% − increases the average roughness value.

- The technique of "smoking" of oak wood with ammonia fumes changes colour to a large extent (significant changes of brightness by 38%) and makes the colour a little colder by increasing the share of green and blue, permits to preserve its natural gloss, and in certain cases even to increase it, and it is the most efficient modification method when it comes to improving the resistance to scratches (over 60%). In case of oak wood, this kind of modification reduces roughness measured parallel to the grain, and proportionally increases roughness tested perpendicular to the grain, so on average it does not significantly affect roughness (ca. 3.5%) [Barski 2018]. In case of pine wood, roughness becomes, on average, by 18% higher, and colour changes to a lesser extent than in case of oak (no significant changes of brightness), while gloss becomes reduced by 33%.

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Streszczenie: *Wpływ tradycyjnych metod powierzchniowej modyfikacji drewna na zmiany właściwości estetycznych i wytrzymałościowych.* Przyśpieszenie naturalnie zachodzącego procesu starzenia się drewna stosowane jest w meblarstwie od wieków zarówno dla nadania drewnu wyszukanej barwy, jak i w celu scalenia kolorystycznego uzupełnień powstałych w procesie konserwacji mebla. Współcześnie postarzanie jest popularne ze względu na walory estetyczne utożsamiane z naturalnie starym drewnem, połączone z korzystnymi właściwościami mechanicznymi jakie posiada drewno nowe. Metody powierzchniowej modyfikacji drewna podczas zabiegów postarzających dzielimy na mechaniczne polegające na zmianie struktury powierzchni drewna (np. przecieranie, szczotkowanie, bielenie czy strukturyzacja dłutem) i chemiczne czyli działanie odczynnikami, które zmieniają barwę (np. szarzenie, ługowanie, „wędzenie” drewna amoniakiem). Celem badań jest określenie wpływu tradycyjnie stosowanych w meblarstwie zabiegów modyfikacji drewna takich jak: strukturyzacja, bielenie, przecieranie, szarzenie, barwienie roztworem nadmanganianu potasu oraz wędzenie amoniakiem na estetyczne i wytrzymałościowe właściwość powierzchni drewna (barwa, połysk, chropowatość powierzchni, ścieralność i odporność na zarysowania). Do badań wykorzystano gatunki drewna najczęściej użytkowane w Polsce w celu sztucznego postarzania drewna: sosnę zwyczajną (*Pinus sylvestris L.*) oraz dąb (*Quercus* Sp).

Słowa kluczowe: modyfikacja drewna, postarzanie, strukturyzacja, bielenie, przecieranie, szarzenie, barwienie roztworem nadmanganianu potasu, wędzenie amoniakiem

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