Changing wood texture with combination of selective treatment and pressing

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Abstract. Structural and anatomical models of alder wood have been developed on the basis of technical and physical models of wood. The models enable to solve the problem of penetrating changes in wood texture by combining selective treatment (impregnation) with two wood colouring agents in different directions of anisotropy, followed by uneven pressing. Specimens with the texture of mahogany, rosewood, walnut, etc have been obtained. Alder wood is pressed at an angle of 45° to the radial direction to obtain the texture of mahogany, at an angle of 90° for a texture of rosewood. At the same time, physical and mechanical properties of modified wood correspond to similar indicators of wood of these species. The study of macro- and microstructure of pressed wood suggests that texture of the obtained material corresponds to the texture of rosewood and mahogany. It is possible to imitate any species of valuable wood using the obtained structural models and the developed techniques.

1. Introduction

The appearance of wood is characterized by colour and texture. All kinds of colour can be set with a large selection of colouring agents and bleaches. The situation with texture is more complicated. It is needed to analyse the description of the term "texture" to find a mechanism for improving it. Hardwoods with a complex structure are characterized by a presence of large vessels (ash, cork tree, oak, etc.) visible to the naked eye, core rays, usually coloured darker than the surrounding wood (beech, elm, plane tree, etc.), malposed fibres (Karelian birch, wood knob), etc. All these create richer texture [1, 2].

The choice of cut direction determines the nature of the texture. Talking about domestic hardwoods, maple, beech, sycamore, oak, elm, English elms have beautiful texture on the radial section, due to the presence of core rays. The last three ring-vascular species are valued for their texture on the tangential section.

The variety of forest species on the planet allows the use of wood in decorative products used by humans. However, forest trees of Russia, as a rule, do not have high aesthetic qualities and, in contrast to tropical hardwood, are very scarce. In this regard, the goal of improving the decorative wood properties of low-value soft hardwoods (aspen, alder, birch, poplar) is urgent. Therefore the purpose of this work was to improve the waste wood quality to create a full-fledged substitute for imported mahogany and rosewood. In addition to these species, ash, walnut, cork tree, chestnut, elm have beautiful texture, mainly formed by cut vessels on a tangential cut. The confused arrangement of fibres (cross grain) creates the texture of burled wood (burls) on tree trunks of deciduous trees differing in high decorative properties [3].
Wood of all species has various colours with numerous shades. For example, spruce, fir, linden, aspen wood is white; birch, maple, beech – white with a reddish hue; oak, chestnut, ash, larch – greyish-brown; boxwood, Osage orange – yellow elm, English elm, cork tree – reddish brown, etc. Three indicators are used to characterize the colour: colour hue $\lambda$, brightness $P$, and lightness $\rho$ [4, 5].

To produce wood which has a texture of valuable species, it is necessary to find out the reasons of the structural features of these species. Wood texture of rosewood and date plum gives the impression of “three-dimensional” pattern due to different colouring of libriform fibres and core rays in combination with golden colour and the presence of multi-coloured veins. Texture of mahogany and ash wood is formed by different colouration of early and late wood in the annual layer, giving strips on radial section and waves on the tangential cut. Wood texture of Karelian birch - with grain and white-pink colouring. Wood texture of beech, sycamore and maple – pattern explained by wide core rays; they have darker colour than surrounding wood. Acacia wood texture – wavy year rings. Thus, a beautiful wood texture is determined by different colouration of early and late zones of wood. In this case, there are stripes on the radial section, and waves on the tangential section. Oak, elm, ash, walnut, cork tree and maple have such a texture: wide, clearly visible core rays, tinted darker than the surrounding wood. Such core rays have the form of ribbons on radial cut, and they have the form of dashes on the tangential section. Beech, maple, oak, sycamore, elm have such a texture. Presence of anatomical elements, which are visually different in size is found in large vessels of oak, ash and other species. Deviation in the regularity of structure can be seen in cross grain of Karelian birch fibres, wavy growths of locust and hornbeam. Rosewood shows multi-coloured fibres.

Alder is the most suitable wood species, which can gain the first two characteristics. First, alder has clearly visible boundaries of annual layers, which have the form of strips and the form of waves - on a tangential section. Secondly, in all the cases, false-wide aggregate core rays are present besides single-row narrow core rays. If these rays are coloured, then you can get a pattern in the form of ribbons on a radial cut and in the form of dashes – on a tangential cut. Also, the wood is initially coloured and has a pleasant pink-orange hue. The most common way to increase strength and density of softwood wood is to compress it across the fibres [6-9].

Cross-sectional vessels are numerous. Towards the late zone of the annual layer, the number and size of cavities are slightly reduced. Segments of vessels have a length of 800-1200 $\mu$m and a diameter of 30-80 $\mu$m. The wall thickness of the segments is 25 $\mu$m. Perforations are scalariform ones; number of crossbeams varies from 10 to 30. We have made structural and anatomical model of alder wood to study the influence of selective colouring and pressing on its texture. Rays are homogeneous, narrow, single-row ones. Their height is 3-5 rows of cells. There are also wide, high aggregate rays, including a group of narrow rays separated from each other by fibrous elements [1, 2].

The purpose of this work was to obtain a full-fledged substitute for valuable wood species, for example, mahogany and rosewood, using aspen and alder weed wood and to develop structural and analytical models that enable to reproduce the texture of almost all valuable wood species.

2. Experimental part
A technical model of alder wood had been created to describe the impregnation process and determine the impregnation time in [10, 11]. To describe the impregnation process and determine the impregnation time, we used a method for obtaining the modified wood, described in [11] and developed a technological wood model [12-14]. The technical model (table 1) was developed taking into account the experimental data published in [12, 13].

| Indicator                        | Average value |
|---------------------------------|---------------|
| Vessel segment length, mm       | 1.0 ± 0.2     |
| Diameter of the vessel cavity, mm| 0.05 ± 0.025  |
| Pore diameter, mm               | 0.004 ± 0.001 |
| Vessel wall thickness, mm       | 0.003 ± 0.001 |
2.1. Selection of colouring agent

All colouring agents (Ajanta Chemical Industries, India) used for wood were divided into three groups according to their chemical composition: coloured chemical compounds that colour wood without interacting with any of its components; chemical reagents those dye into wood when interacting with some of its components; and chemical reagents that form a coloured compound when interacting with each other, but not interacting with wood.

The first group is the so-called ready-made colouring agents. These include natural and synthetic colouring agents. Wood colouring solutions of such agents enable to display texture and give the desired colour. However, the molecules of these agents penetrate only into the cavity of vessels.

Chemical dyes (metal salts) and solutions of aromatic amines belong to the second group of colouring agents. The disadvantage of wood chemical dyes is dependence of their effect on the properties of wood; they do not give clean, bright hues; the colour obtained with their use changes with time.

A coloured compound is formed during chemical interaction of colourless aromatic amines with lignin forms. That is, their action is similar to chemical dyes, and the colour also depends on the properties of wood. It is impossible to say exactly what colour the wood will have (the same situation is in colouring with chemical dyes - amine solutions). The third group includes the following chemical reagents: complex compounds of iron and inorganic metal salts (copper, chromium, cobalt, nickel). The coloured compounds formed during their interaction are beautiful and resistant, durable to water and wood pattern is seen well.

Vessel cavities and cavities of core rays cells must be impregnated with a brown colouring agent to obtain wood with rosewood texture. For this purpose, dyes of the third group were used. If potassium ferricyanide and blue copperas are taken as reagents, brown colouring agent can be produced.

\[
\text{CuSO}_4 + K_4[\text{Fe(CN)}_6] \rightarrow \text{FeSO}_4 + K_2[\text{Cu(CN)}_4]_2 + \text{KCN} \quad (1)
\]

To obtain wood with mahogany texture, the cavity of core rays cells must be impregnated with brown colouring agent, and the cavity of vessels – with red one. Potassium ferricyanide and copper sulfate were also used to dye the cavities of core rays cells. Agents of the first group (we choose fuchsine) can be used for vessel cavities dyeing, since they do not penetrate into the cavities of core rays.

2.2. Impregnation technique, micro slice and decorative properties studies

Alder (Alnus glutinosa L.) wood harvested in the vicinity of the city of Voronezh in the Russian Federation was used for impregnation. Bars with a cross section of 55×55 mm and a length of 1 m were cut from alder timber which was 80 years old. Then these bars were subjected to atmospheric drying. Upon reaching a moisture content of 30%, the bars were sawn into the specimens with the dimensions of 55×55×55 mm.

Impregnation was carried out in three stages when producing wood with mahogany texture. At the first stage, the specimens were impregnated along the fibres with a 0.5-1.5% solution of potassium ferricyanide (K₄[Fe(CN)₆]). The required volume of solution for the impregnation of one specimen, including the cavity of vessels and core rays is 200 ml. At the second stage, the specimens were impregnated along the fibres with 1-3% solution of copper sulphate (CuSO₄). The required volume of solution for the impregnation of one specimen, including the cavity of vessels and core rays is 200 ml. At the same time solid brown colouring agent precipitates in the cavities of vessels and core rays cells. Mass fraction of colouring agents in wood is 1-3%. At the third stage, the specimens were impregnated along the fibres with an alcohol fuchsin solution with a concentration of 1.5%. The required volume of solution for the impregnation is 150 ml. In this case solid brown colouring agent, contained in the cavities of vessels, is washed out, and the cavities of vessels are filled with fuchsine. Then, the dyed specimens were dried at a temperature of 90°C to a moisture content of 20%.

After that, the specimens were pressed in one direction to a density of 800-1000 kg/m³ in molds on a hydraulic press, dried in ovens to a moisture content of 4-6%. Radial pressing corresponded to φ = 0°, tangential to φ = 90°, radial – tangential to φ = 45°.
The photograph was taken with a Canon EOS 350 D digital camera with a resolution of 8 Mpix (3280×2460 pixels). The distance between the photographed surface and the camera lens is 20 cm in macro photography. The photographs were taken with a double magnification. Microscopic measurements were made using an MBI-6 microscope with a non-standard adapter. Lenses with magnification of 20 and 40 were used to zoom the photographed image.

3. Results and discussion

Structural and anatomical model of alder wood shown in figure 1 (with various options for filling voids with colouring agents) is constructed according to the description of the wood structure and technical model (table 1). Taking into account the previous developments [3, 4], the influence of vessels and core rays dyeing on the texture of alder wood using the obtained model has been studied. Vessels and medullary rays are groups of cells located in the same line. Thus, dyeing of a vessel or core ray is reduced to colouring each cell of these anatomical elements or most of the cells.

The following parts of cells can be dyed: cell wall, inner surface of cell cavity, and the content of a living cell. If there is an air bubble in the cell cavity during dyeing, and the colouring agent has a large surface tension, then the air bubble remains under the colouring agent film after evaporation of the solvent. Thus, a dye film covering the entire cavity or part of it is visible on the cut in the cell cavity [4, 5]. Also, the cell cavity can be filled with a coloured substance. Such a substance may be an insoluble dye introduced into the cell cavity as a suspension. Typically, such an insoluble dye is a suspension of pigment in water. It can also be obtained by reacting two or more soluble chemicals (usually in the form of salts).

If we consider these methods of cell dyeing in relation to the selective colouring of vessels and core rays, then it can be seen that all the anatomical elements are dyed during colouring of cell walls. That is, there is no selective colouring of vessels or core rays. In the remaining methods, selective colouring of vessels or core rays takes place.

The simplest method of selective colouring is the use of an insoluble dye in the form of a suspension, but the molecules of such a dye will not pass through the pores between the vessels and core rays. This is due to the fact that the size of the dye molecules is larger than the pore size. However, if two reagents are used, which, when combined, give such a dye, and are easily soluble themselves, then (at sequential impregnation with these reagents) the dye will be formed not only in the cavities of the vessels, but also in the cavities of core rays cells. This will colour the inner surface of the cell cavity. In this way, only vessels (figure 1b) or only core rays (figure 1c), as well as vessels and core rays (figure 1c) can be selectively coloured. This option produces the best texture, which has the decorative properties of the two previous methods.

For dyeing vessels, impregnation should be carried out from the end-grain, which is quite possible in practice. Impregnation should be carried out along the core rays for core rays dyeing, but this is difficult to be achieved in practice. For dyeing vessels and core rays, impregnation should be carried out with the end-grain with soluble reagents.

Figure 1. Structural and anatomical model of alder wood (a) with colouring agent in vessels (b), core rays (c): V – vessel, CR – core ray; L - libriform; B – boundary of the annual layer; SV – dyed vessel; CCR – coloured core ray.
If after dyeing vessels and core rays with one colouring agent the same wood is impregnated from the end-grain with an agent with relatively large molecules (as in the first method), then the vessels will have a colour different from the hue of the core rays.

Using the last two dyeing options, one-colour or two-colour hue can be obtained. This enables you to get a variety of texture, including texture, similar to the fine wood [10, 11]. Initially, there is a filling of the vessel cavities, and then solution penetrates into the cavities in the process of wood impregnation. Thus, the nature and degree of impregnation are mainly influenced by the vessels and the size of the molecules of the used colouring agent. When pressing wood in radial direction, cell cavities decrease in the radial direction. The dimensions of cell cavities in tangential direction do not change (figure 2).

![Figure 2](image)

**Figure 2.** Model of alder wood pressing in tangential (a) and radial (b) direction, and in radial and tangential directions (c).

When pressed in the semi-radial direction, the cell cavities are compressed in both directions by an amount less than in the first two cases. The shape of libriform fibres and core ray cells does not change (figure 2c).

The following formula is used to determine the final height of the bar during pressing:

\[ h_f = h_0(1 - \Sigma) \]

where, \( h_0 \) – initial height of a specimen, mm; \( \Sigma \) – pressing ratio.

The models constructed in figure 2 (a, b, c) enable theoretical justification for obtaining wood texture similar to the texture of such valuable species as rosewood and mahogany. Let us make a description of the wood structure of these species [1, 12, 15].

Rosewood is an all-heart diffuse-porous species. Sapwood is narrow, light yellow in colour. The core is brown in colour. The boundaries of annual rings are clearly visible. The vessels are large, isolated or arranged in radial chains of 2-4 pieces each. The cavities of all the core vessels are filled with dark brown phenolic compounds. Core rays are homogeneous, two-ranked. The height of a ray is 10-16 cells.

Mahogany is an all-heart diffuse-porous species. Sapwood is narrow, white in colour. The core is red-brown in colour. The boundaries of annual rings are clearly visible. The vessels are large, isolated or arranged in radial chains of 2-4 pieces each. The cavities of all the core vessels are filled with red phenolic compounds. The core rays are heterogeneous, multi-row (3-6 rows) with one row of covering cells. The height of the ray is 10-16 cells. The most suitable wood for obtaining texture, similar to the texture of rosewood or mahogany, is alder. It also belongs to diffuse-porous species and has an ink-orange colour. Also, annual rings are clearly visible in this wood. Alder vessels are also isolated or located in radial chains in 2-4 pieces each. In addition, alder is characterized by the presence of both narrow core rays, similar to the narrow rays of rosewood, and false broad rays, similar to the wide rays of mahogany.

Alder wood is well impregnated both in vessels and core rays. Consequently, if vessel cavities and core rays of alder are filled with a coloured substance of the required colour, then the resulting texture will be similar to the texture of rosewood or mahogany. In particular, to obtain a texture similar to the texture of rosewood, dyed alder wood must be pressed in the radial-tangential direction. The shape of vessels and cells of core rays practically does not change. Dyed alder wood must be pressed in the radial
direction to obtain a texture similar to the texture of mahogany. The boundary of the annual ring becomes more visible, and the width of core rays does not change.

The wood must be processed by ultraviolet radiation to improve the texture depth. When processing dyed wood with ultraviolet radiation, the colouring agent decomposes. The depth of the decomposition front corresponds to the size of cavities of the anatomical elements located near the surface. Thus, processing of wood by ultraviolet radiation gives bulking power to the wood texture. The above operations enable to produce wood with a texture similar to rosewood or mahogany.

Table 2 presents the optimal values of the technological parameters for producing modified wood with rosewood and mahogany textures. To obtain the optimal parameters presented in table 2, a number of experiments were conducted that prove the repeatability of the data taking into account deviations.

Figure 3 shows the structure of modified alder wood in a radial section with rosewood (figure 3a) and mahogany (figure 3b) textures compared to natural rosewood (figure 3c) and mahogany (figure 3d). In the figure, we see that there is practically no difference between natural wood and modified wood. This is due to the high efficiency of this modification technology.

Table 2. Optimizing the process for producing rosewood texture.

| Parameter                     | Optimal value |
|-------------------------------|---------------|
| Colouring agent concentration | 3 ± 0.2       |
| Degree of pressing            | 40 ± 1        |
| Pressing angle, degree        | 45            |
| Density, kg/m³                | 800 ± 100     |
| Wave length, nm               | 676 ± 50      |
| Reflection coefficient, %     | 51 ± 2        |
| Brightness, %                 | 61 ± 10       |

In order to save valuable wood resources, it can be replaced with modified wood without losing the quality of finished products. As can be seen from table 2, no expensive technology is needed to apply this modification method, but it is necessary to observe the main parameters reflected in this table fairly accurately.

![Figure 3](image-url)

**Figure 3.** The external appearance of modified alder wood on a radial section with the texture of rosewood (a) and mahogany (b) and natural wood of rosewood (c) and mahogany (d).
4. Conclusion
Optimization of wood production with improved texture has made it possible to obtain modes for production of wood with rosewood (dye concentration – 3%, pressing degree – 40%, angle between pressing direction and the boundary of the annual layer – 45°) and mahogany (colouring agent concentration – 3%, pressing degree – 40%, the angle between the pressing direction and the boundary of the annual layer is 90°) texture.

Wood with mahogany texture is characterized by the following indicators: texture wavelengths 690 nm, reflection coefficient 49.1 %, brightness 50.91 %. The study of macro- and microstructure of pressed wood suggests that texture of the obtained material corresponds to the texture of rosewood and mahogany.

It is possible to imitate any species of valuable wood using the obtained structural models and the developed techniques. This technology for producing modified wood will dramatically reduce the import of valuable wood from Asia, Africa and South America.

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