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Surface retention of polyurethane and acrylic coatings on impregnated spruce wood (*Picea abies* Karst.) and comparison with some wood preservatives

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Abstract

The natural spruce wood has low resistance against biological degradation and weather effects, so further protection is required, up to meeting the durability requirements for wood used in exterior classes. According to the wood preservatives standards, coatings as water repellents belong to the group OS (organic solvent) preservatives. The coatings have a water-repellent function, and they are not toxic, so these advantages make them usable like impregnation material. The objective of this work is impregnation of the spruce wood (*Picea abies* Karst.) using the “Double vacuum process” with coating material based on polyurethane and acrylic isocyanate resins and determinate the coatings quantity in wood. The impregnation efficiency is expressed through the retention. The coatings retention is compared with the minimal standard prescribed retention of the preservatives, most frequently used, namely creosote, copper chrome arsenate (CCA) and waterborne copper-rich systems like copper azole (CBA-A, Thanalite E), to show the efficiency of the applied double vacuum process. The coating retention is not significantly different from the minimum prescribed retention of creosote and amounts 118–149 kg/m^3 or 32 to 38 times higher than the recommended retention of CCA or CBA-A for wood protection in the exterior use. The polyurethane and acrylic wood coatings can be successfully applied for wood impregnation purposes.

Keywords: impregnation, retention, spruce wood, polyurethane coatings, acrylic isocyanate coatings

Introduction

Protection of wood is primarily focused on protection against biological degradation, atmospheric influences, and fire. The protection level depends on the type of the applied impregnation material, its penetration and fixation in the wood (Archer and Lebow 2006). At the same time, three groups of changes may occur: lumen filling, filling of cavities in the cell wall (bulking) and chemical bond formation, i.e. chemical modification (Homan 2004).

Spruce (*Picea abies* Karst.) wood has large application, as a material applied in the interior and exterior areas, constructing facades and floorings (Wagenführ 2007). The natural spruce wood has low resistance to fungi and, according to its resistance, is classified as class 4 (EN 350-2). Further protection is required, up to meeting the requirements of class 3 (EN 460, EN 335-2). Tests have shown that during the process of spruce wood drying, closed pores are formed in the structure which results in low lumen permeability (Gindl et al. 2006). That is the reason for the low penetration of impregnation material into the spruce wood.

By the end of the last century, wood protection was mainly performed by impregnation of oil and salt-based preservatives. The most frequently used salt preservative was CCA (Copper Chrome Arsenate) developed in the USA in the ‘30s of the last century, as a substitute of creosote oil protection. The CCA and the creosote oil preservatives were used to impregnate millions of cubic metres of wood for external applications, telecommunication poles, ships, bridges, facade construction joinery and other wood products. At present, these means are considered as unacceptable in terms of environmental protection due to the late emission of toxic materials containing in treated wood (Williams 1994). The second-generation preservative systems include the waterborne copper-rich systems like copper azole (CBA-A, Thanalite E). Those systems are arsenic and chromium free, but they have some disadvantages as: high level of copper that causes hazardous effect of copper leaching into aquatic systems, relatively high formulation cost, causing corrosion of metals, growth of different moulds on the surface and long-term disposal issue of the treated wood (Schultz et al. 2008). The standard prescribed quantities of CBA-A are almost equal to those of CCA. Therefore, a need has occurred for their replacement with environmentally accepted materials. One of the potential solutions is impregnation with coatings based on artificial resins used for surface wood treatment (Kumar et al. 2015, Kumar et al. 2016, Xi et al. 2018, Raphael et al. 2018).

According to BS 1282 standard (1999) wood preservatives are divided into three groups: type TO (tar-oil) distillates of coal-tar including creosote, type WB (water-borne) and type OS (organic solvent). Coatings as water repellents belong to the third group. Preservatives of the first two groups are toxic and repellent to biological destructors. Apart from this function, the coatings also have a water-repellent function; they keep the wood moisture below 20 %, which reduces the possibility of the insect and fungal attack. The idea of this research is to determine the coatings retention and to compare it with the most used preservatives by other groups according to the standard. Most often the protection of wood by these preservatives is done by impregnation.

Wood impregnation with resins means an importing of viscous materials through the cell lumens in the surface area of the wood. It is a method of modification. The resins are polymerising and are fixated in the lumens and the inter-cell cavities, thus reducing porosity and increasing the wood density. Such modified wood, besides of the protection function, has altered physical and mechanical properties.

The double vacuum impregnation is applied to impermeable and impervious wood species, such as the spruce wood. The pressure value has no significant impact on the penetration depth and the retention of the impregnation material in the wood. Only the increase of active pressure duration has a positive impact over the impregnation (Richardson 2003). The double vacuum process is especially suitable for protection of spruce wood products, where a complete filling of wood pores is required.

The objective of this work is to impregnate the spruce wood with coating material based on polyurethane and acrylic isocyanate resins, instead of their standard coating use. In the process, the quantity of these two types of coatings in the wood should be determined. That is a pre-requisite for achieving surface modification of the wood with lumen filling. The impregnation efficiency expressed through the retention, compared with the minimal standard prescribed quantities of the preservatives, most frequently used like creosote and CCA or CBA-A, shall show the efficiency of the applied double vacuum process.

Materials and methods

Preparation of test pieces

Test pieces were made of spruce wood (*Picea abies* Karst.) with dimensions 20 × 20 × 30 mm. The selected wood pieces were without visible defects, average growth in radial direction to eight annual rings of 10 mm (Figure 1s.). The test pieces were conditioned up to equilibrium moisture content of the wood in accordance with ISO 554.

The moisture content and wood density were measured according to ISO 13061-1 and ISO 13061-2 standards (2014). The average value of moisture content was $W = 12$ %, the average value of density in absolutely dry matter was $\rho_o = 0.45$ g/cm^3. Two impregnated groups of 32 test pieces were treated for each type of coating, as well as a control group of untreated pieces.

Coating properties

The coatings were based on polyurethane and acrylic resins, standard products from the range of reputable manufacturer (ICA LP152P and ICA LAC367). The preparation of the coatings was carried out according to the instructions given by the manufacturer, they were not additionally diluted. The viscosity was determined according to ISO 2431 standard (2011), and the dry content percentage according to ISO 3251 standard (1993). The polyurethane coating viscosity was $v_{pu} = 15$ “ F4/20°C and the acrylic coating viscosity was $v_{ak} = 27$ “ F4/20°C. During the process the viscosity was not changed. The dry content of polyurethane coating was $N.V._{pu} = 49.3$ (%), and that of acrylic coating was $N.V._{ak} = 54$ (%). Although the acrylic coating has got a slightly higher amount of dry content, but the difference of 4.7 % was statistically negligible.

Impregnation procedure

The impregnation of the wood was performed according to “Double vacuum process” procedure (Videlov 1980, Richardson 2003). This treatment is applied to impermeable wood species, where the impregnation pressure has a minor impact over the penetration and the retention of the materials in the wood, only the increased time of action has impact (Richard-

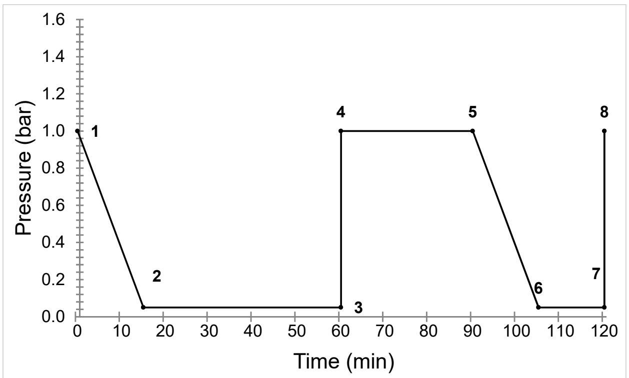

Figure 1. Mode treatment of a wood samples

son 2003). The wooden test pieces were completely sunk into the coating solution (Figure 2s.). The end of vacuum procedure (Figure 1, point 6 or 7) was done after removing the impregnating solution from the autoclave (Figure 3s.), made in order to prevent the formation of film on the wood surface. The pressure to time ratio of the operation is shown in Figure 1.

After the treatment (Figure 4s.), the poly-addition process was followed up by the achievement of constant weight, under conditions prescribed in ISO 554 standard.

Fixation of materials

The resin retention in the wood is calculated according to EN 113 standard (1996):

$$F = \frac{m_2 - m_1}{V} \text{ [kg/m}^3\text{], where}$$

m_1 is the test piece pre-treatment mass (kg);
m_2 is the mass (kg) of test piece after treatment;
V is the test piece volume (m^3).

The obtained database (set of data) was processed and statistical analyses were performed using a Microsoft Excel software package (2013).

Statistical data processing – checking the differences between two related values, significance for statistical data sets with over 30 measurements is determined by:

$$T = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

The level of the test significance $\alpha = 0.01$, a degree of reliability of 99 %, whereby the critic values are outside the threshold ± 2.58.

Results

The average value of the polyurethane coating in the wood was 153.13 kg/m^3, with a standard deviation of 79.4 kg/m^3, and the acrylic coating was 128.3 kg/m^3, with a standard deviation 67 kg/m^3. The value of retention of impregnated test pieces and prescribed values for the creosote and the CCA and CBA-A are shown in Figure 2.

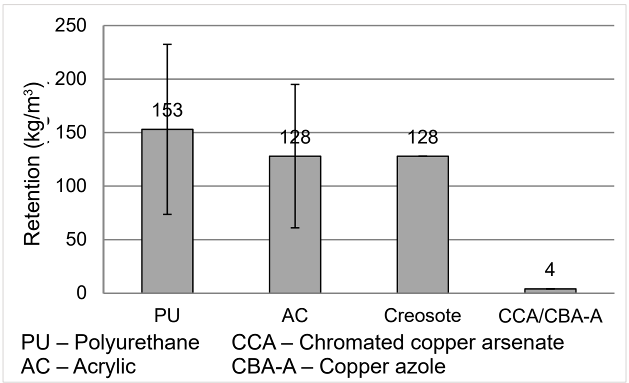

Figure 2. Retention from coatings and prescribed values for the creosote and the CCA or CBA-A, according to class 3, EN 335-2 (2006)

Discussion and conclusions

The difference between the average retention values of polyurethane and acrylic coating is 24.83 kg/m^3 and is not significant with a factor $T = 1.02$. The obtained differences of values with high variation coefficients are confirming that the spruce wood is not permeable, and it's difficult to process it with impregnation (Militz 1993, Mamonova 2000). The amount of coating applied as a film in polyurethane coating is 30 kg/m^3, in acrylic film is 34 kg/m^3, compared to the fixed impregnation amount in the same coatings, impregnation fixes 4 to 5 times more quantity than film coating (Bahchevandziev and Mihajlovski 2014).

The comparison of the modified wood was made within the standard for wood classification according to its use and the protection level (AWPA 2008), class UC3A, which corresponds to class 3, EN 335-2. The wood of this class is recommended for external conditions: joinery, floor and wall coverings, mouldings which are not in contact with soil, exposed to cyclic moisture, which can afterwards be surface treated. The comparisons with the creosote and the CCA or CBA-A are in prescribed minimal values for wood protection in the prescribed class 3. The fixation values of the coatings and the minimal values prescribed for wood protection are shown on Figure 2.

The retention achieved with the polyurethane coating is 25 kg/m^3 higher than the lowest prescribed retention of creosote and 149 kg/m^3 higher than the CCA or CBA-A prescribed retention. The retention of the acrylic coating is equal with the prescribed creosote value but is 118 kg/m^3 higher than the CCA prescribed value. From the statistical analysis of the values, it is concluded that the fixation of the polyurethane and acrylic coating has no significant difference. Also, there is no significant difference in relation of the retention of polyurethane and acrylic coatings to the prescribed retention of creosote. The retention of coatings in relation to CCA or CBA-A is significantly higher, polyurethane more than 38 times, and acrylic about 32 times.

Based on the results of spruce (*Picea abies* Karst.) wood impregnation using polyurethane and acrylic isocyanate coatings as impregnating material and the comparison with retentions of the standard applied wood preservatives, creosote oil and CCA or CBA-A, the following conclusions were reached:

- Retention of polyurethane coating and acrylic coating in the spruce wood has no significant statistical difference. The fixation of the polyurethane is 153.13 kg/m^3 and the acrylic is 128.3 kg/m^3.
- The coating retention is not significantly different from the minimum prescribed retention of creosote and is 118–149 kg/m^3 or 32 to 38 times higher than the recommended retention of CCA or CBA-A for wood protection in the exterior applications with above-ground use.
- The double vacuum process can be an efficient method for impregnation with polyurethane and acrylic isocyanate coatings of spruce wood.

The polyurethane and acrylic wood coatings can be successfully applied for wood impregnation purposes. Further research should be directed towards determining the properties of the impregnated wood, as well as the level of wood protection against biological degradations under conditions of external use.

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Supplement

Figure 1s. Selected test pieces before treatment

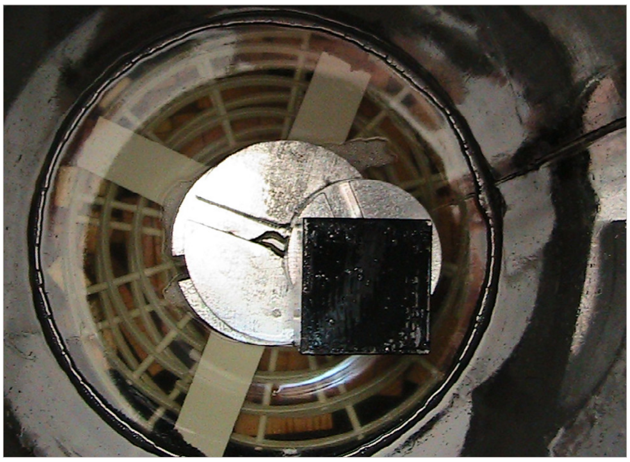

Figure 2s. Test pieces completely sunk into the coating solution

Figure 3s. Autoclave for wood impregnation

Figure 4s. Test pieces after treatment