Prognosis method of wooden structure durability

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Abstract. The relevance of the studied topic is due to the fact that, despite the longtime wood use as a building material, the issue of durability predicting keeps underexplored. Wood offers a wide range of positive properties, but still has a number of disadvantages, one of which is a tendency to biodeterioration. The main way to control wood biodeterioration is its antiseptic treatment. However, during the operation or storage of treated wooden structures, there is a process of washing out antiseptic agents from them (depreservation) and, as a result, a decrease of biostability. The paper proposes the methodology for accelerated prediction of the wood treated durability with an antiseptic, taking into account the real conditions of its operation. The optimal conditions and the temperature effect on the rate of diffusion antiseptic transfer to external environment are established, depending on the actual operating conditions of wooden structures.

Keywords: wood, durability prediction, antiseptic, concentration, biostability.

1 Introduction

Wood is perhaps one of the first materials people used in construction, but even today wood products are widely used in wide variety of construction industries [1-4]. However, despite the very long history of its use, the issue of prediction and durability keeps underexplored and relevant [5].

Predicting the service life of a wooden structure, it is necessary to highlight the most significant parameters by which the ultimate state will be estimated, taking into account power and atmospheric factors [6].

The most significant factors affecting the wooden structures durability, in addition to fire, are: temperature, UV radiation, humidity and, the most importantly, biodeterioration.

The temperature increase causes a decrease of strength and other physical and mechanical wood properties. With a sufficiently long exposure to elevated temperature (more than 50 °C), irreversible, residual variation occur in the wood, which depend not only on temperature level, but also on humidity [7, 8, 9]. Low temperatures have an opposite effect on the wood strength: the strength of frozen wood increases markedly.

Ionizing radiation reduces the strength characteristics of wood. This is explained by radiolysis (decomposition) of its organic components [10].

The most dangerous for wood are biological factors and among them fungi [11]. There are three main groups of fungi that affect wood: wood-destroying [12], mold and wood-staining [13]. When fungi spores get into favorable conditions, they begin to develop actively and spoil the wood [14-16]. Favorable conditions for the fungi growth and development are high humidity (over 50 %) [14, 17] and the temperature in range of 24-30° C. At temperatures above 80° C and below -10° C, fungi which are in vegetative stage of development die. [18, 19]. The main way to control wood biodeterioration is antiseptic treatment [20].
In 2016, the observation results of 48 Corsican pine pillars treated by antiseptic agent of the CCA group, installed in 1960, were published [21]. Throughout observation period, the most serious injuries were noted in 1997 on 3 pillars affected by brown rot [22], with the depth of not more than 3 mm. In 2016 appraisal showed that the 2 pillars with the highest amount of rot also had deep pockets with rot. This means that there could be internal rot that was not previously detected. Observation data showed that the antiseptic of the CCA group is washed out rather slowly and the service life of structures treated by this antiseptic can exceed 70 years.

Nevertheless, any fabricated parts, products, and structures during long-term operation and under the influence of external environmental factors lose on one degree or another the protection level obtained by special treatment [17, 23, 24].

There is the degreasing, characterized in most cases by a decrease in protective agent content in material.

The service conditions of wooden structures are diverse, but can be reduced to 3 types according to characteristics of operating environment: soil, water and air (with and without washing out) [20].

For all conditions the most important factors affecting the wood preservation process are humidity and temperature of materials. It should be taken into account that antiseptics are different in terms of leachability from wood, volatility and chemical activity; destroyers have different rates of adaptation to antiseptics, and materials have different density and humidity, affecting the antiseptics stability in them.

The most washing out is observed during the wood service in water and soil. The washing out rate of protective agent from wood depends on its solubility and the rate of diffusion into external environment [25-27].

2 Methods

The accelerated climate test method has been developed to evaluation of the durability of wooden structures treated by antiseptic and taking into account the service life, operation in conducive conditions to biodegradants growth and development.

Summary of the test method is to conduct accelerated tests of wood treated by antiseptic for ageing resistance when exposed to temperature and humidity, to establish the nature of kinetic dependence of the indicator change during aging and to build a prognosis curve.

The determination and prediction of durability was carried out according to several characteristic ageing indicators. The statistical characteristics of climatic factors necessary for establishing test modes were determined according to climatological handbooks and other regulatory documents.

The calculation of the conditional year of laboratory tests was carried out using the temperature-time analogy principles. In research practice, the Arrhenius equation [28] finds the greatest application in the form:

$$\tau_s = \tau_s \exp \left( \frac{E_i}{R} \left( \frac{1}{T_s} - \frac{1}{T_j} \right) \right)$$  

(1)

here $T_s$ – wood operating temperature (°K), calculated by the formula

$$T_s = \frac{-E}{R} \left\{ \ln \left[ \frac{1}{\tau_0} \sum_j \Delta \tau_j \exp \left( -\frac{E}{R T_j} \right) \right] \right\}$$  

(2)

Samples, in the amount necessary for each mode, were previously dried at a temperature of 105° C. Then they were placed in a desiccator under the insert, covered with distilled water and closed with a lid.

The desicator with the samples was placed in an oven and thermostatically controlled according to the selected modes. Thermal aging was carried out at temperatures $T_1 > T_2 > T_3$. When thermo stating occurs, the antiseptic is washed out of the samples and, accordingly, its concentration in water increases. When a certain concentration level is reached, diffusion processes slow down. The tests at $T_1$ provide for 3 reading, after the first and second water was changed. To maintain the same experimental conditions for other temperature conditions, it was decided to change water twice as well.
At set time intervals, 5 samples were taken from the batch, for each mode, dried for 3 days at a temperature of 105 °C, and then weighed to an accuracy of 0.01 g. Before weighing, the samples were cooled to room temperature in a desiccator with a hygroscopic substance.

After each reading, an evaluation of aging index change was made. The value of key indicators was taken equal to an arithmetic mean value, after eliminating gross errors. The kinetic dependences of samples mass change during the tests are shown in figure 1.

![Sample mass change during the test](image)

**Figure 1.** Samples mass change during the test.

### 3 Results and Discussions

The tests were carried out in three temperature conditions on the samples with 3 different levels of antiseptic concentration $C_{\text{max}} > C_{\text{mid}} > C_{\text{min}}$. After each reading, the residual antiseptic content in the samples was determined. The data are given in the table 1. Then it was necessary to determine the samples toxicity level in relation to fungi. Figures 2-4 show that, despite the varying levels of antiseptic concentration in the samples, the washing out kinetics are of a similar nature.

**Table 1.** Antiseptic concentration after testing.

| Sample Level | Time, days | Cu, mg/kg | Cr, mg/kg | As, mg/kg |
|--------------|------------|-----------|-----------|-----------|
| $C_{\text{max}}$ T₂ | 12 | 6964 | 14330 | 15040 |
|              | 24 | 5577 | 9855 | 9364 |
|              | 36 | 4674 | 7262 | 6395 |
|              | 48 | 3156 | 6235 | 6097 |
| $C_{\text{mid}}$ T₂ | 12 | 3413 | 6259 | 5621 |
|              | 24 | 3672 | 5647 | 4743 |
|              | 36 | 3342 | 4827 | 3775 |
|              | 48 | 2797 | 4213 | 2800 |
| $C_{\text{min}}$ T₂ | 12 | 3099 | 6811 | 5723 |
|              | 24 | 3329 | 6072 | 5819 |
|              | 36 | 2723 | 4456 | 4637 |
|              | 48 | 2263 | 3048 | 2629 |
| $C_{\text{max}}$ T₃ | 35 | 5877 | 11680 | 11890 |
|              | 70 | 4458 | 8443 | 7513 |
|              | 105 | 4023 | 8663 | 7331 |
|              | 140 | 2782 | 4770 | 2929 |
Figure 2. Mass changes and antiseptic concentration level changes of the samples at $C_{\text{max}}$ and $T_2$.

Figure 3. Mass changes and antiseptic concentration level changes of the samples at $C_{\text{mid}}$ and $T_2$.

Figure 4. Mass changes and antiseptic concentration level changes of the samples at $C_{\text{min}}$ and $T_2$. 
By the 48th day of the test, the residual antiseptic concentration level in the samples reached $C_{\text{max}} = 41.61\%$, $C_{\text{mid}} = 41.86\%$, $C_{\text{min}} = 44.76\%$ of the initial one. In quantitative terms, the mass of the antiseptic washed out the samples was $C_{\text{max}} = 0.10\,\text{g}$, $C_{\text{mid}} = 0.071\,\text{g}$, $C_{\text{min}} = 0.058\,\text{g}$. The data are shown in figures 5-7.

**Figure 5.** Loss of samples mass and the antiseptic contained at $C_{\text{max}}$ and $T_2$.

**Figure 6.** Loss of samples mass and the antiseptic contained at $C_{\text{mid}}$ and $T_2$.

During the tests it was found that a too high level of antiseptic concentration is not advisable, since it leads to its washing out in a larger volume.
Figure 7. Loss of samples mass and the antiseptic contained at $C_{\text{min}}$ and $T_2$.

It was also found that at a temperature of 80° C and 70° C in the sample, destructive processes in wood were found that do not correspond to real atmospheric and operational influences. Conducting accelerated climate tests at temperatures above 60°C are not recommended. The samples mass change and the antiseptics concentration during the tests at 60°C are shown in figures 8 and 9. Here, a noticeable decrease in residual dependence level occurs, both in percentage and in quantitative value, in relation to the samples tested at higher temperatures.

Figure 8. Mass changes and changes in the antiseptic concentration level of the samples at $C_{\text{max}}$ and $T_3$. 
Further, in the samples with different residual concentrations, biostability is evaluated, by germination of fungi family Chaetomiaceae, class Ascomycota, species Chaetomium globosum. Due to this, it is possible to determine the minimum acceptable level of residual CCA concentration, at which there is no fungi growth and subsequent material rotting.

Due to the developed methodology, it is possible to give a prediction after what time the concentration level would fall up to a threshold value and wood would become attacked by fungi.

4 Conclusion
1. As the tests result, it was concluded that CCA antiseptics have high fungicidal properties and a fungi growth is possible only as a result of antiseptic washing out treated wood below a threshold value.
2. The most washing out is observed during the wood service in water and soil. The main factors affecting the antiseptic washing out are humidity and positive ambient temperature.
3. The test mode should not exceed 60°C in order to avoid destructive processes in the samples. The unnecessarily high concentration level is also not advisable.
4. The developed methodology for accelerated climate testing allows predicting the decrease rate in the concentration of antiseptics CCA group. Using a spectral analysis and biostability test, a threshold level of antiseptic concentration is determined at which fungi growth does not occur. The totality of these data allows us to predict the wooden structures durability.

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