Justification of impregnation modes for wood

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Abstract. One of the most significant disadvantages of wood materials is increased combustibility. Therefore, the problem of reducing the combustibility of wood materials is relevant. The article describes an experimental study of impregnation of wood using biopiren MIG-09, which is a hybrid composition on a salt basis with the addition of functional substances of non-salt nature, at different temperature regimes. Two stages of the study were chosen for the experiment. The optimum temperature regimes for different methods of applying the composition to increase the fire resistance of wood were established experimentally. Also fire tests were carried out to analyze the degree of penetration of the solution.

1. Introduction

The use of traditional methods of fire protection of wooden structures is due to the availability of the used compositions, the ability to provide almost any fire resistance limit, as well as a relatively low cost [1]. The disadvantage of these methods is the shallow penetration of flame retardant and, therefore, low consumption rates of compositions [2-4].

Impregnation is one of the effective methods of applying protective agents. It is believed that the deeper the wood is impregnated with a fire retardant composition, the more reliably it is protected. This is the method by which the fire retardant solution penetrates most deeply into the wood and works best [5-7].

The mechanism of fixing in wood "MIG-09" is a hybrid composition, on a salt basis with addition of functional substances of non-salt nature.

The most promising areas of research are: reducing the number of components in the compositions, reducing the density of the coating, using industrial wastes as components, improving such performance characteristics as water resistance, adhesion [8-12].

2. Materials and methods

To study the impregnation of wood samples the MIG-09 flame retardant composition was used, at different temperature regimes (see table 1).

Samples for testing the fire resistance of impregnation composition are made in accordance with State Standard 2140, State Standard R 53292-2009.

The direction of arrangement of fibers in the wood slice along the fiber can be determined by figure 1. In order to minimize the effect of machining on the fire retardant efficiency of the samples surfaces of the working part were made smooth, without cracks and other defects [11].
The samples were made in the form of a cube with a cross section of 50x50 mm and a fiber length of 50 mm, with a moisture content of 25% and a density of 400-550 g/m$^3$.

The experiments were conducted in two stages:

At the first stage, wood samples were soaked in a solution of flame retardant at different temperatures: 46, 41, 36, 31 и 26 °C, that is, the interval between the compositions was ±5 °C (figure 2).

At the second stage, in order to deeply impregnate the samples, they were soaked in impregnation compositions twice at temperature ±26 °C, at intervals of 24 hours.

**Figure 1.** The appearance of the fibers in the section of the sample.

**Figure 2.** Sample soaking process.

| Characteristic                      | Modes |
|-------------------------------------|-------|
| Characteristics of the composition(°C) | 1    |
|                                     | 2    |
|                                     | 3    |
|                                     | 4    |
|                                     | 5    |
|                                     | 6    |
| Appearance                          | 46 °C|
| Dilution factor by mass, (kg)       | 41 °C|
| Dry concentrate (g)                 | 36 °C|
| Volume of prepared solution (g/m$^2$) | 31 °C|
| Processing temperature (°C)         | 26 °C|

Table 1. Impregnation modes.
3. The results of the tests

The result of the first phase of research is shown in table 2.

Table 2. Results of the first phase of the experiment.

| Sample number | Mass before impregnation (g) | Mass after impregnation (g) | Time processing | Drying time at temperature (23±5)°C |
|---------------|------------------------------|-----------------------------|-----------------|-------------------------------------|
| 1a            | 43.135                       | 43.311                      |                 |                                     |
| 2a            | 46.996                       | 47.901                      |                 |                                     |
| 3a            | 45.883                       | 46.118                      |                 |                                     |
| 4b            | 42.729                       | 43.378                      | 2 mins.         | 24 hours                            |
| 5b            | 35.996                       | 36.952                      |                 |                                     |
| 6b            | 38.780                       | 39.744                      |                 |                                     |
| 7c            | 43.797                       | 44.286                      |                 |                                     |
| 8c            | 36.986                       | 37.770                      |                 |                                     |
| 9d            | 37.876                       | 38.239                      |                 |                                     |
| 10d           | 44.332                       | 44.646                      |                 |                                     |
| 11d           | 36.992                       | 37.508                      |                 |                                     |
| 12d           | 35.938                       | 36.697                      |                 |                                     |
| 13e           | 44.192                       | 44.795                      |                 |                                     |
| 14e           | 39.017                       | 39.410                      |                 |                                     |
| 15e           | 38.907                       | 39.255                      |                 |                                     |

*a* wood impregnated at 46°С; *b* wood - at 41°С; *c* wood - at 36°С; *d* wood - at 31°С; *e* wood at -26°С.

The total impregnation (absorption) rate was determined by measuring the mass of the sample before and after impregnation with fire retardant. The results are shown in table 3.

Table 3. Total absorption of the flame retardant.

| Sample number | Mass of the absorbed composition (flame retardant) (g) | Total absorption R, (kg/m³) |
|---------------|--------------------------------------------------------|-----------------------------|
| 1a            | 0.176                                                  | 1.408                       |
| 2a            | 0.905                                                  | 7.240                       |
| 3a            | 0.235                                                  | 1.880                       |
| 4b            | 0.649                                                  | 5.192                       |
| 5b            | 0.956                                                  | 7.648                       |
| 6b            | 0.964                                                  | 7.712                       |
| 7c            | 0.489                                                  | 3.912                       |
| 8c            | 0.784                                                  | 6.272                       |
| 9c            | 0.363                                                  | 2.904                       |
| 10d           | 0.314                                                  | 2.512                       |
| 11d           | 0.516                                                  | 4.128                       |
| 12d           | 0.759                                                  | 6.072                       |
| 13e           | 0.603                                                  | 4.824                       |
| 14e           | 0.393                                                  | 3.144                       |
| 15e           | 0.348                                                  | 2.784                       |

As it can be seen from the results of stage 1 of the experiment, the absorption coefficient was:
- low - 1.408-1.88;
- middle - 2.512-5.192;
- high - 6.072-7.712.

Samples 1 and 3 at temperature 46°С showed a low absorption coefficient, and sample 2 showed a high absorption coefficient. Thus, at temperature 46°С the desired result is not detected, at a temperature of 41 °С samples 5, 6 have the best absorption coefficient, and sample 4 - the average. At temperatures of 36°C, 31°C, 26 °C all samples have an average absorption coefficient.
At the second stage of the experiment, the samples were impregnated two times each at temperature 26 °C. The results of the experiment are shown in table 4.

**Table 4. Results of the second phase of the experiment.**

| Sample number | Mass before impregnation (g) | Mass after impregnation (g) | Time Processing | Drying time at temperature (23±5)°C |
|---------------|------------------------------|-----------------------------|-----------------|------------------------------------|
| 1             | 42.915                       | 43.556                      |                 |                                    |
| 2             | 36.962                       | 37.551                      |                 |                                    |
| 3             | 44.350                       | 44.471                      |                 |                                    |
| 4             | 43.046                       | 43.975                      |                 |                                    |
| 5             | 39.996                       | 40.320                      |                 |                                    |
| 6             | 37.033                       | 37.845                      |                 |                                    |
| 7             | 44.590                       | 44.736                      |                 |                                    |
| 8             | 48.034                       | 48.703                      | 2 mins.         | 24 hours                           |
| 9             | 37.840                       | 38.288                      |                 |                                    |
| 10            | 43.480                       | 45.510                      |                 |                                    |
| 11            | 48.250                       | 49.864                      |                 |                                    |
| 12            | 43.036                       | 44.034                      |                 |                                    |
| 13            | 49.819                       | 51.288                      |                 |                                    |
| 14            | 46.250                       | 47.604                      |                 |                                    |
| 15            | 47.937                       | 49.729                      |                 |                                    |

The total absorption of the flame retardant for the second stage of the experiment is shown in table 5.

**Table 5. Total absorption of the flame retardant.**

| Sample number | Mass of the absorbed composition (flame retardant) (g) | Total absorption R, (kg/m³) |
|---------------|-------------------------------------------------------|----------------------------|
| 1             | 0.641                                                 | 4.912                      |
| 2             | 0.589                                                 | 4.712                      |
| 3             | 0.121                                                 | 9.68                       |
| 4             | 0.929                                                 | 7.432                      |
| 5             | 0.324                                                 | 2.592                      |
| 6             | 0.812                                                 | 6.496                      |
| 7             | 0.146                                                 | 1.168                      |
| 8             | 0.669                                                 | 5.352                      |
| 9             | 0.448                                                 | 3.584                      |
| 10            | 2.030                                                 | 16.240                     |
| 11            | 1.614                                                 | 12.912                     |
| 12            | 0.998                                                 | 7.984                      |
| 13            | 1.469                                                 | 11.752                     |
| 14            | 1.354                                                 | 10.832                     |
| 15            | 1.792                                                 | 14.336                     |

In the second stage of the experiment, the impregnation composition was applied to the samples in two layers at a temperature of 26 °C. As the experiment showed, nine out of fifteen samples have the highest absorption coefficient (table 5), and four samples - the average, which provides the first category of fire protection efficiency.

For clarity of the conducted experiments a diagram was built (figure 3). The results show that when impregnating in one layer, it is most effective to maintain the temperature regime around 41° C. When impregnating in 2 layers, an increase in temperature has a negative effect on absorption, therefore, it is necessary to carry out the impregnation process at a temperature closer to room temperature (26 °C).
Figure 3. Effect of impregnation temperature regime on the total amount of absorption of samples.

At high temperature impregnation, the absorption of the composition into the wood is deeper, which increases the smoldering of wood and does not lead to rapid burning of wood material. At the same time there is an increase in the fire protection group: one-stage impregnation up to the II group of fire protection efficiency, two-stage - up to the I group of fire protection efficiency.

The depth of penetration of the composition was assessed in accordance with State Standard 27014-86.

Upon completion of impregnation, wood samples were split along the fibers in two directions perpendicular to each other and to the sides (figure 4). The samples were 20 mm thick, 50 mm wide, and 50 mm long. The depth of penetration of the protective agent (impregnation solution) was determined on the split surfaces).

Figure 4. Sawing wood samples and measuring the impregnation depth.

Also to analyze the degree of penetration of the impregnating composition, fire tests were carried out. Preliminary test specimens were placed in an experimental cabinet (consisting of a ceramic box with outer dimensions of 120x120x300 mm and wall thickness of (16±2) mm), with a metal holder.

The results of studies of fire properties revealed that the use of flame retardant MIG-9 to improve the fire resistance of wooden structures also allows to improving its class of structural fire hazard to class K1, and hazard class of the materials on which it is applied to class KM2.
4. Conclusion
When impregnating in one layer the best temperature regime of impregnation with flame retardant MIG-9 is 41 °C. And when impregnating in 2 layers it is necessary to carry out the process at a temperature closer to room temperature (26 °C).

When treating wood with fire retardant composition at high temperature you can achieve deep absorption of the composition into the wood regardless of the wood species, the drier the wood, the deeper is the penetration and caking of wood pores, which does not allow the oxidant (oxygen) to penetrate the wood, and thus preventing the process of burning. If the product is impregnated in several layers, the protective layer increases not due to adhesion, but due to absorption and creation of an integral protective "wall" and the quality of the product does not change.

It has been shown that an increase in fire protection group is achieved: in one-stage impregnation up to Fire Protection Group II, in two-stage impregnation up to Fire Protection Group I.

5. References
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