ON PROCESSING WOOD IN THE CENTRIFUGAL FORCE FIELD

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Abstract: Dehydration and impregnation with subsequent dehydration of wood are integral operations in manufacturing engineering and construction timber. Searching for energy-efficient methods of performance of these operations is a task of great current interest. The objective of this work is to study the potential of impregnation and dehydration of engineering and construction sawn wood in the centrifugal field. The experiment conducted has shown the efficiency of processing small-section timber in one and the same centrifugal plant, first for the purpose of impregnation, and next – dehydration up to the 30% humidity. The obtained data have allowed establishing dependencies between the duration of processing, humidity, and weight change of the samples under study.

Keywords: dehydration, impregnation, wood, timber, centrifugal method.

1 Introduction

Impregnation of wood is one of the important stages in the added-value conversion of wood raw material. Owing to impregnation, one can modify the physical and mechanical characteristics and properties of wood, thus expanding the application range of items made of it.

According to GOST 20022.6-93 (1994), the quality of impregnation is characterized by general absorption of the protective agent and the depth of impregnation. For impregnation to be effective, saturation of the internal pore space of the wood with special chemical elements has to be ensured. The elements are introduced into the interporous space of the wood by dissolving them in the impregnating compound body (water, oil, alkyd, acryl, and so on), with the latter to be subsequently removed from the interporous space of the wood.

For deeper penetration of the impregnating compound and a faster impregnation process, forces ensuring this effect have to be created artificially. There are numerous wood impregnation technologies differing in the method of putting the pressure to ensure penetration of the impregnating compound into the interporous space of the wood, for example, high pressure steam impregnation, static impregnation, etc.

During impregnation of wood, its humidity is increased; in particular, the relative humidity turns out to be much higher than that of green wood and even higher than the humidity which engineering wood must have. For example, the required humidity of sawn wood amounts to 12 ±3% for the timber used in indoor construction (boards and bars for the floor, rafters, siding, framework, etc.) and 15 ±3% – for the outdoor construction timber (GOST 8242-88, 2008). For the timber used in making containers, the humidity is around 22% (GOST 10131-93, 2008), and it ranges within 8±2% for the wood designed for manufacturing furniture (GOST 16371-93, 2008).

The sawn timber impregnation and dehydration operations are performed using different specialized equipment: as a rule, impregnation is carried out in pressure chambers or by steeping while dehydration is achieved in drying chambers. With the known impregnation methods, the timber humidity must not exceed 30% to achieve quality impregnation (Grigoriev et al., 2015). Meanwhile, green wood has the humidity of 50% and more (Vesnina et al., 2020), therefore, it needs pre-dehydration. Given the above, after impregnation of wood, the question of its subsequent dehydration becomes essential.

The efficiency of impregnation and dehydration depends in a substantial way on the physical phenomena involved in this process, first of all, and second – on the way the production process is organized. One of the least power-consuming processes of dehydration and impregnation of wood is processing of wood in the centrifugal field. There is a number of studies confirming the efficiency of each of these processes considered individually when processing sawn timber of various sizes and sections. Meanwhile, this wood processing method has not won extensive use, which is associated with imperfection of the existing equipment and technologies of its performance. With regard to this, the lack of studies can be traced concerning the combination of the said operations by carrying them out in one and the same plant without repositioning the blanks, which is a task of great current interest. If the additional transport operation is excluded, coupled with the fact that two operations are performed with one piece of equipment, and the rational processing time is selected for each production stage, this will allow ensuring the high efficiency of the impregnation process with the subsequent dehydration. It will also contribute to creation of the equipment and energy-efficient technologies for implementing the centrifugal method into the operating procedure of sawn wood processing. The relevance of this work is associated with all the above.

2 Literature Review

When studying the scientific technical literature on impregnation of wood by the centrifugal method, the authors have selected the following works to be noted. In their paper the scientists O. A. Kunitskaya, I. V. Kostin, and S. S. Burmistrova (2012) point out that impregnation of wood in the centrifugal field is distinguished by the relatively low power consumption, and it allows achieving the high extent of wood saturation with liquid within a short time span. The works by G. V. Grigoriev (2013) and by S. V. Kucher, G. V. Grigoriev, and V. A. Ivanov (2018) substantiate rational modes of the process of centrifugal impregnation for timber of the soft-wooded broadleaf species (birch, asp), with the non-linear impregnating liquid filtration law considered. The scientists give the mathematical model to represent wood saturation kinetics for the impregnating liquid as influenced by the non-linear filtration law and to take into account the microstructure of wood when calculating the speed of centrifugal impregnation. V. A. Katsadze and D. V. Vinogradov (2007) cite results of experimental studies of impregnation of wood by the centrifugal method in their paper. They have shown that the drier the wood is, the less impregnated it can be; nevertheless, volumetric impregnation by the centrifugal method can be conducted with any initial humidity of the wood.

Information on the physical bases of hydrothermal processing of wood, with the characteristics of wood which are important for dehydration specified, and properties of various drying agents and heat media described, are presented by E. S. Bogdanov, V. A. Kozlov, V. B. Kuntysh, and V. I. Melekhov (1990) in their book. The paper by the scientists O. A. Kizina, A. L. Adamovich, and Yu. G. Grozberg (2011) discusses the most widespread wood dehydration methods describing the operating principle for each of them, particularities of practical performance, with advantages and disadvantages of each of them noted. The opinion about the current situation associated with drying of broadleaf wood in Europe is given by G. Milić (2019) in work; the scientist also suggests potential lines of research from the viewpoint of improving the energy efficiency of this process. In his paper, Jarl-Gunnar Salin (2010) outlines the history of modeling the wood drying process for the latest 30 years and discusses some questions associated with modeling the behavior of free moisture in the capillary system of wood during dehydration.

When studying the scientific published works concerning the process of dehydration based on the use of centrifugal forces, the authors have selected the following works to be noted. In his thesis, Oti Moto Paul Maxime (2008) suggests theoretical models of removal of the free moisture from the capillary-porous structure of wood. He also describes regularities of moisture distribution along the length of timber pieces being dehydrated and the effect of moisture accumulation in the butt end of samples dehydrated by the centrifugal method on the quality of wood during storage. V. V. Orlov's thesis (2016) discusses questions associated with dehydration of wood chips under the effect of centrifugal forces for enhancing its operational capacities, namely, the calorific capacity. In this work, the mathematical model of dehydration of wood chips placed as a layer on the internal surface of the centrifuge is presented which allows calculating the dehydration process parameters, with the specific structure of the wood pore space taken into account. With regard to this, the scientist considers both hardwood and coniferous species. In his paper, D. M. Bogdanov (2014) demonstrates the prospects of using the centrifugal method of dehydration for sawn timber in terms of enhancing its energy efficiency. Kostin I. V. (2011) presents the mathematical model of dehydration and impregnation of small-diameter timber of soft-wooded broadleaf species (asp, alder, birch, poplar, willow, lime tree) in his work; the model allows forecasting the principal indicators of the said processes. He has also studied regularities of moisture distribution along the length of samples being dehydrated, taking into account specific effects the impregnating liquid has on the blanks.

As the review of known impregnation and dehydration methods has shown, centrifugal forces can be used efficiently in both cases. In particular, both operations can be carried out using one and the same piece of equipment – a centrifugal plant representing a rotating rotor, with timber to be treated placed on its surface. During the impregnation operation, the rotating rotor together with timber pieces placed on it is dipped into the impregnating compound, and it runs in such a submerged condition. For the dehydration operation, the rotor is taken out of the impregnating compound to further run freely.

3 Research Methodological Framework

The objective of the paper consists in studying the potential of impregnation and dehydration of engineering and construction sawn timber in the centrifugal force field.

Achievement of the set objective required completing a number of tasks:

- developing the design of the plant for performing the impregnation and dehydration operations in the centrifugal field in one and the same plant without repositioning the test pieces of wood;
- conducting experimental studies of the impregnation process in the centrifugal field;
- conducting experimental studies of the dehydration process in the centrifugal field;
- elaborating the recommendations on organizing a more profound research of the potential of combining the impregnation and dehydration operations in one plant.

For achieving the set objective, the authors used the method of functional, structural, and technological analysis which implies selecting the research object, considering its particularities in terms of design, technology, and functions, and carrying out the statistical processing of the experimental data.

4 Results and Discussion

The use of centrifugal method involves rotation of the sawn timber, which requires placing the blanks into a rotary drum. To ensure the possibility of dipping the sawn timber into the impregnating compound, the rotary drum with the timber attached to it has to be placed into a sealed shell provided with a pipeline. The latter serves for supplying the impregnating compound, removing it later, as well as removing any moisture separated during dehydration. Such a design of the plant implies the simplicity of its structural embodiment and saving of the impregnating compound used in the process.

Thus, in the study, the timber to be impregnated was placed on the internal surface of the drum located in the sealed shell. After that, the impregnating compound was supplied into the shell and the drum, accordingly. Next, the drum was set to rotation at the speed of 1950 RPM^{-1}. During rotation, the impregnating compound was pushed back to the drum periphery and distributed over its internal surface under the action of centrifugal forces while interacting with the timber attached to this surface. With such a design, the internal volume of the shell has to be filled up only partially and not completely, for the impregnating compound to cover the sawn timber distributed along the periphery of the drum, which results in lowering the used volume of the impregnating compound. Meanwhile, reduction of the duration of saturation of the timber with the impregnating compound was observed owing to centrifugal forces intensifying this process. The impregnating compound was then drained from the drum and shell. This operation can be performed without stopping the drum rotation. Under the effect of centrifugal forces and due to the absence of any external moisture sources, the reverse process was observed – dehydration, during which the moisture remaining in the porous space of the timber was brought out.

When studying the process of impregnation with test pieces sized 253*102*28 cm, it has been found that in 35 min. after the start of rotation of the centrifuge loaded with wood samples and impregnating liquid, the weight of the samples went 12% up. However, rotation of the centrifuge at the same parameters for 15 min. more did not lead to any essential change in the weight of the test pieces under study. Control of the studied samples has shown that in 15 min. after the rotation start, they achieved the 60% humidity on their surface, and in 25 min. after the rotation start, humidity was 64%, remaining at the same level during rotation for 25 min. more.

When studying the test pieces sized 250*51*52 mm, it has been noted that in 50 min. of rotation, their weight went 8,5% down. Humidity control has shown that the surface humidity reached the value of 45% in 35 min. At rotation of the samples in the centrifuge with the impregnating compound for further 15 min., the value of the humidity indicator remained at almost the same level but the increase of weight of the test pieces was observed. Higher weight of the blanks is indicative of their saturation with the impregnating compound.

Control of the impregnation depth has also shown that with the course of time, the depth at which the impregnating compound penetrates into the studied wood samples increases. In particular, it is mainly into the sap portion of the wood that the impregnating liquid penetrates, as this portion has big curvature radii of annual rings, and it does not matter at which side of the board face sap is located – closer to the centrifuge rotation axis or further from it, closer to the internal surface of the centrifuge. So, after 50 min. of rotation, in the test pieces sized 250*51*52 mm, the impregnating compound penetration depth amounted to 10 mm on the board face side having large curvature radii of annual rings, measured at the distance of 5 cm from the end. Meanwhile, in the samples sized 253*102*28 mm, the impregnating compound penetration depth measured at the distance of 5 cm from the end was 6 mm after 50 min. of rotation.

The study of wood samples in terms of their dehydration has shown the following results. During research, it has been found that the test pieces sized 250*60*20 mm and having the average initial humidity of 80% were dehydrated up to the 30,2% average humidity in 90 min., i. e., the moisture loss was 49,8%. The average initial weight of the samples amounted to 174,5 g while their average weight as of the end of the experiment was 146 g. Thus, there was the weight loss of 28,5 g, which corresponds to 16% of the initial weight. In this case, the dehydration speed was 0,32 g/min.

When studying the test pieces sized 250*40*30 mm and having the average initial humidity of 54,5%, the following findings have been obtained. Within 75 min. of the drum rotation, the samples were dehydrated up to the average humidity of 30%, i. e., the loss of moisture made 24,5%. Initially, the average weight of the samples amounted to 174 g while it was 163 g as of the experiment end. Thus, the weight loss equaled 11 g, which amounts to 6% of the initial weight. In this case, the dehydration speed was 0,15 g/min.

When studying the test pieces sized 250*40*15 mm and having the 53,5% average initial humidity, the findings have been as follows. According to the results of the experiment, the humidity of 30% was achieved in 55 min. Further rotation of the samples in the drum did not yield any significant change of humidity. Within this time span, weight of the samples being dehydrated changed from 92 g to 83 g. Thus, there was the 9 g weight loss, which amounts to 9,7% of the initial weight. Meanwhile, it was noted that in the last 20 min. of rotation of the test pieces in the centrifuge, their humidity kept close to the 30% value but reduction of their weight was observed. By minute 55 of the experiment, the average weight of the samples reached 83 g, and it was 82 g at minute 75 of the experiment. In this case, the dehydration speed was 0,17 g/min. The authors have also noted that in all test pieces, the humidity of the external board face was slightly higher than of the one closer toward the rotation center. All the above is indicative of the fact that moisture is extracted from timber under the effect of centrifugal forces; it moves in the radial direction to the rotation axis and is removed through the board face located at the maximum distance away from the rotation center. Hence, the board face which is external in relation to the rotation center remains more moisturized.

When studying the test pieces sized 250*40*10 mm and having the average initial humidity of 65%, the following data have been obtained. According to the experiment results, the 30% humidity was achieved in 70 min. Further rotation of the samples in the drum did not lead to any essential change in humidity. During this time span, the weight of the test pieces being dehydrated changed from 65 g to 53 g. Thus, the weight loss was 12 g, which amounts to 18% of the initial weight. In this case, the dehydration speed was 0,17 g/min.

According to the preliminary experiment findings, the conclusion has been made that humidity indicators have to be controlled not as soon as the centrifuge rotation is stopped but after a while. During rotation under the action of centrifugal forces, moisture moves through the wood porous space toward the external board face, as a result of which it remains constantly moisturized. So, for leveling out moisture within the volume of the sample under study, a waiting time span has to be allowed.

The research has shown that more intensive dehydration occurs in samples with a larger board face area and smaller thickness than in narrower samples having a greater thickness. As for the test pieces with equal face width, dehydration occurs at a slightly more intensive rate in samples having a smaller thickness in the radial direction in relation to the rotation center.

The experimental study conducted has shown the centrifugal method to be promising both for impregnation of wood by special modifying compounds and for dehydration of timber up to 30%. If required, further dehydration up to lower humidity values can be performed by the conventional method, for example, in a drying chamber.

First of all, the suggested method allows reducing consumption of the impregnating compound because the impregnating compound which has not penetrated into the wood porous space and the one to be extracted from the wood during dehydration is scavenged completely and can be re-used. Secondly, impregnation and dehydration are performed in one and the same plant, and no further operations to reposition the timber being treated are required in the process. Thirdly, this method is energy-efficient because considerably less power is needed for rotating the drum as compared to the conventional thermal dehydration method in which the drying chamber is heated by a heat medium.

5 Conclusion

Research shows that at present, in spite of numerous and many-year studies and developments, the operations of wood drying and impregnation remain quite power-consuming, and both the equipment and technologies used in the operations need improving.

Wood is known to contain two kinds of moisture: the first one, the free moisture, is that found in spaces between cells and their cavities; the second kind is the bound moisture, the one sitting in the cell walls.

When dehydrating up to the humidity of 12 ±3%, both free and bound moisture have to be taken out from the sawn wood. Removal of the bound moisture is significantly more challenging; using the centrifugal dehydration method to remove the bound moisture is not expedient due to the long duration of this process.

As for the free moisture removal, the centrifugal method has demonstrated its high efficiency, and it is expedient to use for dehydrating the hyper-humid timber, e. g., green or saturated with the impregnating compound. Meanwhile, the energy-efficient method of impregnation of wood is impregnation in centrifugal plants with the subsequent dehydration to the humidity of 30% in the centrifugal force field.

The conducted study of the impregnation and dehydration processes using the described design plant which allows carrying out the said two processes without repositioning the blanks has shown the promising outlook of the use of centrifugal method for these two operations in processing the construction and engineering sawn timber of small cross-sections.

Impregnating and subsequently dehydrating wood in centrifugal plants without repositioning the blanks allows enhancing the impregnation process efficiency by reducing the labor consumption of the process, as well as the equipment idle time associated with repositioning operations.

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