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Integrated utilization of secondary wood resources: a case study of sawmill waste

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Abstract. This paper assesses the relevance of the problem of waste generation and use at sawmills. An analysis of the process of formation of wood waste in the form of sawdust was carried out depending on the equipment and technology used at the enterprise. The feasibility of adding sawdust to wood concrete blocks, which are widely used in the construction of both residential and non-residential buildings and structures, is substantiated. As a result, the purpose of this research was to scientifically substantiate the effectiveness of the production of wood concrete blocks with the addition of sawdust waste in the form of sawdust. During the work, methods of statistical and analytical analysis were used. The results of laboratory studies of the production of wood concrete blocks with the addition of sawdust from softwood and hardwood are presented. The results of laboratory studies were processed, regression dependencies were developed and graphical dependencies were constructed. The results of this research can be widely used in the timber industry, as well as in the production of building materials.

1 Introduction

The dynamic development of logging and wood processing technologies and equipment caused by the demand for wood materials contributes to the development of environmental problems due to the irrational use of natural resources. In the context of the current shortage of wood raw materials and the continuous increase in its cost, the issues of integrated use of wood reserves become of great importance in the economics of wood processing enterprises [1, 2].

Problems of increasing the efficiency of wood use in sawmilling can be achieved through resource-saving technologies and modes that provide for the reduction of waste generated and their maximum involvement in production. Today, for wood processing enterprises, this problem is becoming relevant due to the reduction in reserves of industrial wood located relatively close to wood processing plants [3, 4].

The relevance of this problem increases every year for enterprises that, in the process of wood processing, generate a large amount of waste in the form of sawdust, bark, slats and slabs, which, having not found their use, are burned or buried. Production sites and adjacent areas of wood processing enterprises are beginning to pose fire and environmental hazards

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due to the accumulation of wood waste. An analysis of the practical experience of wood processing industries has shown that no matter what sawmill equipment and technology is used at enterprises in the process of sawing wood, a significant amount of waste in the form of sawdust is inevitably generated. It has been revealed that solving the issue of using wood processing waste in the form of sawdust as an additional raw material is relevant and contributes to the rational use of wood raw materials. In our opinion, one of the promising areas for using wood waste in the form of sawdust is their addition to the mass in the production of wood concrete blocks, which have found wide application in the production of both residential and non-residential buildings [5, 6].

2 Materials and methods

The purpose of this research is to scientifically substantiate the efficiency of the production of wood concrete blocks with the addition of sawdust waste.

The initial data for the research was the analysis of scientific works of domestic and foreign authors, as well as the results of production activities of wood processing enterprises. Methods of statistical and analytical analysis were used in the work process.

3 Results and discussion

Based on the analysis of literary sources and the results of search experiments, the following factors were identified: controllable (species composition of sawdust (P_o, g), rock composition of crushed wood (P_d, g), sawdust content in the total volume of mass (C_o, %)); controlled (humidity (W, %), strength of the finished block (Pr, MPa), density of the finished block (P, kg/m^3)).

Functional dependencies were built:

$$\text{Pr, P, W} = f\,(C_o, P_o, P_d), \quad (1)$$

At the first stage of the research, a series of one-factor experiments was planned and carried out to determine the dependence of the density (P) of arbolite blocks from crushed hardwood on the percentage of sawdust of coniferous, deciduous and mixed species $C_{o.x.}, C_{o.l.}, C_{o.c}$. Regression dependencies were obtained:

$$P_{l.d.} = 655.07 + 7.44C_{o.cm.} - 0.08\,C_{o.cm.}{}^2, \quad (2)$$

$$P_{l.d.} = 671.79 + 2.60C_{o.l.}\ 0.04C_{o.l.}{}^2, \quad (3)$$

$$P_{l.d} = 692.5 - 1.07C_{o.x.} - 0.01C_{o.x.}{}^2, \quad (4)$$

A visual representation of the presented dependencies is given by the graphs constructed using the obtained equations presented below.

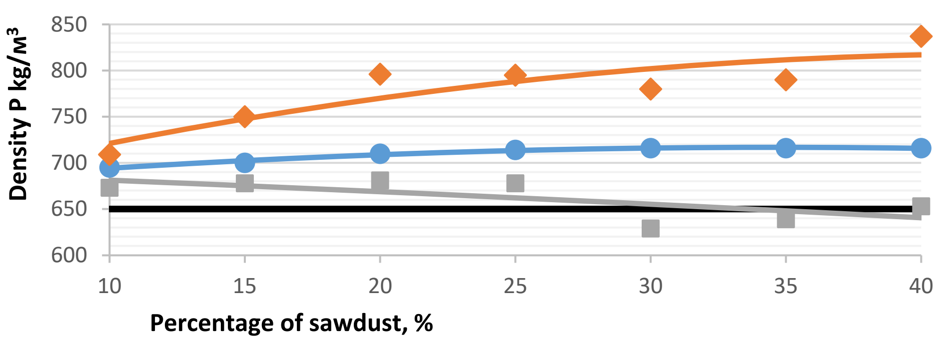

Fig. 1. Dependence of the density of wood concrete blocks from crushed hardwood on the percentage of sawdust of different species.

Next, the dependences of the density (P) of wood concrete blocks from crushed coniferous wood on the percentage of sawdust of coniferous, deciduous and mixed species $C_{o.x.}$, $C_{o.l}$, $C_{o.cm}$ were determined. Regression dependencies were obtained:

$$P_{l.x.} = 721.07 - 6.30C_{o.l.} + 0.18C_{o.l.}{}^{2}, \quad (5)$$

$$P_{d.x.} = 655.93 + 3.36C_{o.cm.} - 0.05C_{o.cm.}{}^{2}, \quad (6)$$

$$P_{d.x.} = 555.07 + 7.42C_{o.x.} - 0.14C_{o.x.}{}^{2}, \quad (7)$$

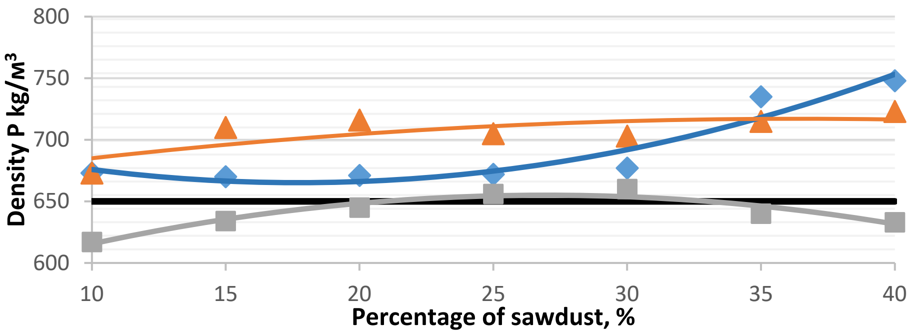

Fig. 2. Dependence of the density of arbolite blocks from crushed pine on the percentage of sawdust of different species.

It is seen from the presented graphs, with an increase in the volume fraction of hardwood and mixed sawdust, the density parameters increase, and with the use of coniferous sawdust, they decrease. For example, with a value of $C_{o.x.}$ = 10%, the density of wood concrete blocks is 670 kg/m^3, and with $C_{o.x}$ = 30% density will be 630 kg/m^3, while the grade of the wood concrete block is reduced. The increase in the density of wood concrete blocks with deciduous and mixed sawdust can be explained by the different moisture content of the initial wood raw materials.

Then the dependences of the humidity (W) of wood concrete blocks from crushed hardwood on the percentage of sawdust of coniferous, deciduous and mixed species $C_{o.x.}$, $C_{o.l}$, $C_{o.cm}$ were obtained. Regression dependencies were obtained:

$$W_{d.l.} = 5.29 + 0.42C_{o.cm.} - 0.005C_{o.cm.}{}^{2}, \quad (8)$$

$$W_{d.l.} = 7.14 + 0.07C_{o.l.} - 0.001C_{o.l.}{}^{2}, \quad (9)$$

$$W_{d.l.} = 7.22 + 0.06C_{o.x.} - 0.003C_{o.x.}{}^{2}, \quad (10)$$

The graphs constructed from regression dependencies are presented below.

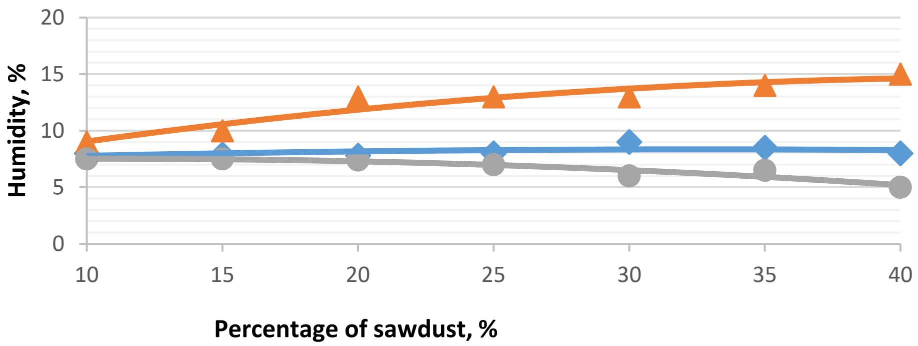

Fig. 3. Dependence of the humidity of arbolite blocks from crushed hardwood on the percentage of sawdust of coniferous, deciduous and mixed species.

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The following regression dependencies were obtained:

$$W_{d.x.} = 15.28 - 0.88C_{o.l.} + 0.022C_{o.l.}{}^{2} , \quad (11)$$

$$W_{d.x.} = 4.14 + 0.65C_{o.cm.} - 0.014C_{o.cm.}{}^{2} , \quad (12)$$

$$W_{d.x.} = 4.04 + 0.41C_{o.x.} - 0.009C_{o.x.}{}^{2}, \quad (13)$$

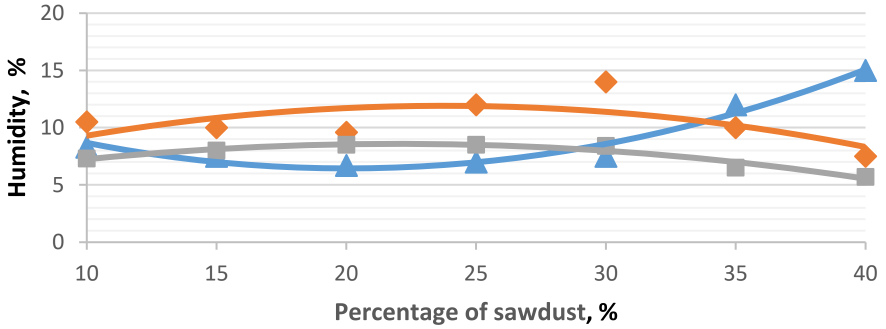

Fig. 4. Dependence of the moisture content of wood concrete blocks from crushed softwood on the percentage of sawdust of softwood, hardwood and mixed species.

As can be seen from the presented graphs, with an increase in the volume fraction of mixed sawdust, the humidity parameters increase, and with the use of coniferous sawdust, it decreases. With an increase in the volume fraction of hardwood sawdust, the humidity parameters increase, and with the use of coniferous and mixed sawdust, it decreases. For example, with a value of $C_{o.x.}$ = 10%, the moisture content of arbolite blocks is 7.3%, and with $C_{o.x.}$ = 40% humidity will be 5.7%. The increase in the humidity of wood concrete blocks with deciduous sawdust can be explained by the different humidity of the original wood raw materials. According to GOST 19222-84, the release humidity should not exceed 25%; based on the graphical dependencies, the humidity indicators are within the GOST limits.

Then the dependences of the strength (*Pr*) of wood concrete blocks from crushed hardwood on the percentage of sawdust of coniferous, deciduous and mixed species $C_{o.x.}$, $C_{o.l}$, $C_{o.cm}$ were obtained.

Regression dependencies were obtained:

$$Pr_{d.l.} = 1.46 + 0.07C_{o.cm.} - 0.001C_{o.cm.}{}^{2} , \quad (14)$$

$$Pr_{d.l.} = 1.19 + 0.032C_{o.l.} - 0.001C_{o.l.}{}^{2} , \quad (15)$$

$$Pr_{d.l.} = 2.6 - 0.10C_{o.x.} + 0.002C_{o.x.}{}^{2} , \quad (16)$$

The graphs constructed using regression dependencies are presented below.

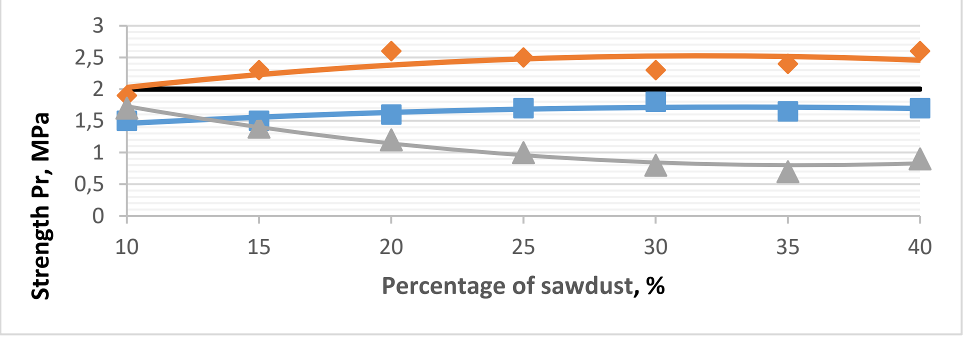

Fig. 5. Dependence of the strength of wood concrete blocks from crushed hardwood on the percentage of sawdust of coniferous, deciduous and mixed species.

The following regression dependencies were obtained:

$$Pr_{d.x.} = 1.8 + 0.04C_{o.cm.} - 0.001C_{o.cm.}{}^{2}, \quad (17)$$

$$Pr_{d.x.} = 2.13 - 0.001C_{o.l.} - 0.001C_{o.l.}{}^{2}, \quad (18)$$

$$Pr_{d.x.} = 3.30 - 0.15C_{o.x.} + 0.002C_{o.x.}{}^{2}, \quad (19)$$

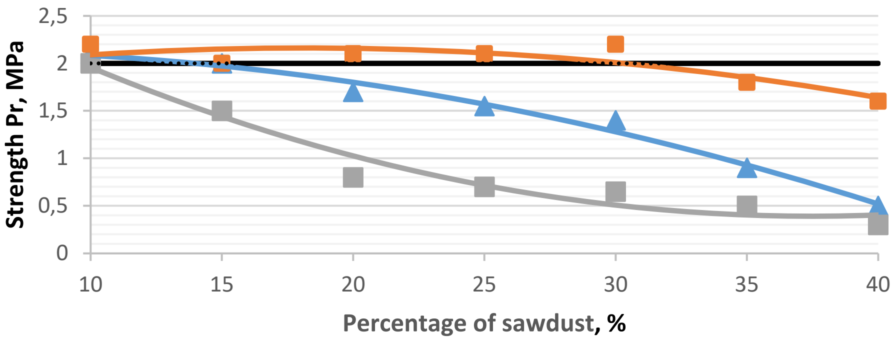

Fig. 6. Dependence of the strength of wood concrete blocks from crushed softwood on the percentage of sawdust of softwood, hardwood and mixed species.

Analysis of graphical dependencies showed that with an increase in sawdust content in the total mass, an increase in strength by 5-10% is observed. From the analysis of graphical dependencies it is clear that with an increase in the percentage of sawdust from coniferous, mixed and hardwood species, the value of the strength indicator decreases. This is due to the fact that the strength index of the wood concrete block depends on the moisture content of the wood raw material. For example, at a value of $C_{o.x.}$ = 10%, the compressive strength of arbolite blocks is 2 MPa, and at $C_{o.x.}$ = 30% strength will be 0.65 MPa. The same is true with the addition of deciduous sawdust.

4 Conclusion

It has been established that during structure formation, with fluctuations in wood moisture content, rigidity and plasticity change. This directly affects the structure of the armbolite block and the value of the density indicator. Wood material is characterized by relatively high rigidity. As humidity increases, the hardness of wood particles decreases significantly. As the value of wood density increases, it increases. In this case, elasticity has the maximum influence on the compaction and structure formation of the wood concrete block [7].

Many researchers [8, 9] note in their scientific works that the loosening of micellar rows and the destruction of hydrogen bonds between molecules occurs as a result of the penetration of water into wood fibers. Thus, the presence of sorbed liquid in wood not only changes its mechanical characteristics, but also determines the wood's conductivity of liquids. As a result, a change in the mechanical characteristics and conductivity of the wood liquid occurs due to the presence of sorbed liquid in the wood. The change in humidity of the wood concrete block is caused by the movement of water in the wood. The moisture in wood manifests itself differently depending on its location and degree of bonding. Free moisture is found in capillaries, cell cavities and intercellular space. It is easily moved and removed from the wood. Bound moisture is located on cellulose micelles and enters between the micelles as submicroscopic layers. Bound moisture is chemically a component of the woody substance of the cell membranes. When the moisture content of wood fluctuates, its linear dimensions and, accordingly, volume change. In an absolutely dry state and humidity equal to the fiber saturation point, the volume of wood remains constant. The change in linear dimensions occurs due to the separation of the intermicellar structure by the water layers.

As the sawdust content of softwood wood increases, the strength decreases. This is due to the fact that wood includes extractive and easily hydrolyzed substances. They help slow down the strength gain of arbolite blocks.

The equations obtained as a result of processing the experimental data adequately describe the process under study for the production of wood concrete blocks with the addition of sawdust. Based on the equations, response surfaces were constructed in the form of graphical dependencies. For them, the main requirement is that the experimental points lie as close as possible to the curve, which is the graph of the desired function. Therefore, these equations, in our opinion, allow us to predict the production of high-quality wood concrete blocks depending on the percentage of recycled materials. For given values of the technological and design parameters of the process under study, by changing the percentage of sawdust and the type of wood in the wood concrete mass, it is possible to predict the physical and mechanical properties and geometric dimensions of the finished commercial product. This allows you to customize the manufacturing technology of wood concrete blocks with the addition of sawdust, depending on the individual characteristics of the enterprise's raw material base.

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