Role of fillers in the production of wood-polymer composites

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Abstract. During the examination and analysis of the physical and mechanical properties of wood polymer composites (WPC), researchers have consistently observed alterations in the strength and durability of the material. These changes have been found to correlate with variations in the wood content of the composite as well as its sensitivity to different climatic conditions. This dynamic relationship between composition, environmental factors, and material performance is a critical aspect of scientific research in this field. Moreover, the manufacturing processes and technologies employed in the production of WPC materials are intricately linked to these factors. Researchers carefully tailor production methods and select appropriate fillers based on the specific characteristics mentioned above. The inclusion of wood fillers in the composite composition is an important area of investigation, as it significantly impacts the resulting material properties. This systematic exploration of how different wood fillers influence the properties of the composite material is an integral part of the scientific research conducted in this domain. By comprehensively understanding these relationships, researchers can optimize the composition and production methods of WPC materials to enhance their strength, durability, and overall performance in varying climatic conditions.

1 Introduction

In the production of WPC materials, two main aspects must be taken into account: production conditions, i.e. place and climate, selection of wood fillers introduced into their composition, depending on their mechanical properties [1, 2]. Because there are two types of wood, softwood and hardwood, in which hardwoods have higher mechanical properties than softwoods, and in turn, the materials produced from them are relatively strong. In addition to the woodworking and furniture industries known to us, wooden materials in the construction industry in Uzbekistan are mainly imported [3, 4]. The deciduous tree species of Nina are quite difficult to grow in the climate of Uzbekistan, and this type of tree is of little industrial importance. Therefore, wood composite materials (chipboard, MDF, plywood, etc.), which are widely used in the woodworking industry and industries based on them, are imported [5, 6]. Based on these, in the conditions of Uzbekistan in the conditions of Uzbekistan, the creation and development of technologies for the production of composite materials is carried out on the basis of local wood species and their mechanical properties [7]. In our previous studies, the influence of wood fillers in wood-polymer composite materials on the composite mechanical properties of waste wood chipboard (chipboard) and fibreboard (MDF, HDF) boards, which are wood composite materials widely used in the furniture industry, was investigated [8].

At present, the annual volume of PVC demand at enterprises producing PVC-based composite materials in Uzbekistan is 8000-10000 tons, and 10-20% of it, that is, about 2000 tons, is used as secondary PVC. As for calcium carbonate ($CaCO_3$), the volume of supplies to industrial enterprises is sufficient to meet the needs. In our scientific study, there is a sufficient amount of wood waste from our sawmills and furniture and wood products factories. For example, the number of enterprises producing furniture and wood products in the city of Tashkent is about 3000, which means that these enterprises currently import about 1000 m^3 of wood chipboard (chipboard) and fibreboard (MDF, HDF) per month, 20 % of this amount, i.e. 200 m^3 is waste [9-14]. However, at present, enterprises for the production of chipboard operate in the Syrdarya, Surkhandaryn and Jizzakh regions [15-17].

In addition, there are many active advertising agencies in Uzbekistan that widely use composite materials obtained by extrusion based on PVC and calcium carbonate ($CaCO_3$) [18-20]. We also considered polymer composites in the form of PVC-based extruded board materials using the place of chipboard (chipboard) and fibreboard (MDF, HDF) in the

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furniture industry. However, the composition of these materials consists of 80% imported materials [21-24]. These materials in terms of physical and mechanical properties showed positive results compared to chipboard, MDF and HDF boards.
In this research study, we mainly aim to localize the production of materials based on wood and PVC, that is, to use local poplar wood waste. We are aimed at developing technologies for obtaining localized composite products using secondary PVC raw materials from existing enterprises in Uzbekistan and studying the effect of fillers on the properties of the composite.

2 Materials and methods

In our laboratory, we embarked on creating a novel variant of wood-polymer composite (WPC) material. For this purpose, we employed locally sourced poplar wood flour derived from the Tashkent region. Additionally, we utilized recycled polyvinyl chloride (PVC) obtained from the polyvinyl chloride suspension grade C-6346 manufactured at the NavoiAZOT chemical production complex situated in the Navoi region. To craft the composite material, we undertook an extrusion process using recycled polyvinyl chloride as the base material. This process was augmented with the inclusion of auxiliary chemical fillers procured from the WOODWIN enterprise based in Tashkent, which imports these fillers from China.
The development of this new WPC material involved the formulation of several distinct recipes. Each recipe encompassed specific proportions and combinations of the aforementioned components. This systematic approach aimed to optimize the composition and properties of the composite material, enhancing its potential applications and performance attributes.
This multifaceted effort in our laboratory underscores the innovative strides being made in the field of wood-polymer composite materials. By strategically combining locally sourced wood flour, recycled polyvinyl chloride, and specialized chemical fillers, we are working towards producing a versatile and resilient composite material with various potential benefits and applications.

3 Results and discussion

We have developed four different recipes where the mass fraction of wood filler (poplar flour) increases from bottom to top. We studied the physic-mechanical properties of the obtained samples. We know that according to GOST, the requirement for composite materials based on wood, depending on the area of use, must comply with the following properties: density, water and moisture resistance, bending and stretching strength. Therefore, we tested these parameters in the laboratory (Figure 1).

Fig. 1. Obtained samples of wood-polymer composite materials.

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From the first, we determined the density of the samples according to the guidelines and the requirement of GOST 15139-69. In this, to determine the density of the samples, we carried out the process by the hydrostatic method. To process the results, we calculated by this formula:

$$\rho = \frac{m(samples)}{m(in\ water) - m\ (with\ water)} * 100;$$

Once got these results (Table 1),

Table 1. Output of the hydrostatic method of density process.

#	Recipe 1	Recipe 2	Recipe 3	Recipe 4
μ	0.408	0.452	0.476	0.485
ρ	**0.45**	**0.48**	**0.52**	**0.63**

In the above table and graph, we see that the density of composites gives positive results, and if we compare the density of other composite materials like particle boards, then this is much better (Figure 2).

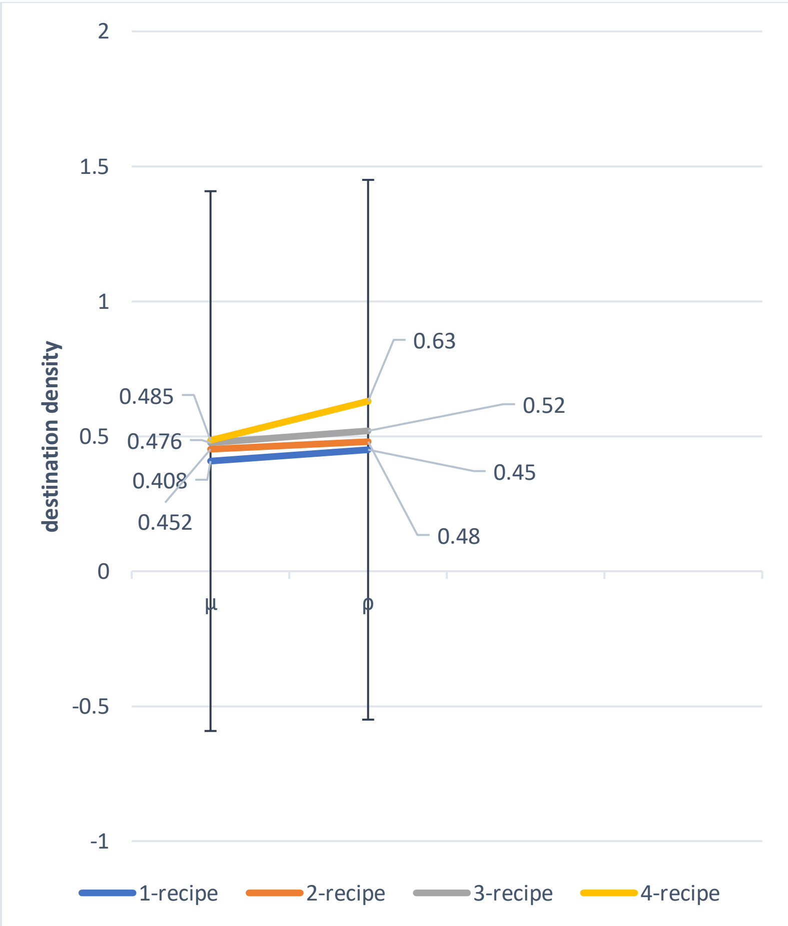

Fig. 2. Sample density plot.

The next test is to determine the swelling and water content of composite samples. The tests were carried out according to GOST 9590-76. Due to the properties of water absorption and boiling in water, the samples were preliminarily polished with sandpaper according to the procedure. Then, to achieve absolute drying, it was dried in a drying chamber at a temperature of 105°C for 1 hour and cooled in an extractor at a temperature of 20°C. Since water absorption is characterized by a change in the mass of the samples, and swelling is characterized by a change in the size of the samples, therefore, their mass and dimensions were first measured. Then the process began according to the method and to determine the swelling and water contention, we calculated according to these formulas:

$$X=\frac{h_2-h_1}{h_1}*100;$$

where h_2 is the thickness of the samples after boiling, mm; h_1 is the thickness of the samples before boiling, mm;

$$X=\frac{m_2-m_1}{m_1}*100;$$

where m_2 is the mass of samples after boiling, g; m_1 is the mass of samples before boiling, g;
We have compiled all the data obtained in Table 2 below.

Table 2. Parameters of the processing recipe of woods.

Parameters	Recipe 1	Recipe 2	Recipe 3	Recipe 4	Comment
Swelling	31x28x18	29x27x17	33x29x18	31x24x15	Initial dimensions of samples, mm
	30x27x17	29x26x15	32x25x16	29x23x14	Dimensions of samples after grinding, mm
	31x28x17	30x25x16	32x27x18	29x27x17	Dimensions of samples after boiling, mm
	5	**6.66**	**12.5**	**21.42**	**The amount of swelling %**
Water absorption	12.18	11.29	13.65	10.05	Initial mass of samples, g
	11.64	10.81	13.31	9.87	Mass of samples after grinding, gr
	12.97	12.08	15.09	12.28	Mass of samples after boiling, g
	11.64	**11.74**	**13.37**	**24.41**	**Amount of water agreement, %**

The results in the tables and diagrams above show that the parameters of water absorption and swelling of the obtained samples of compositions increase depending on the mass fraction of wood filler in the composition, this reason characterizes the physical properties of wood raw materials i.e. By its physical structure, wood is porous and tends to absorb moisture (Figure 3).

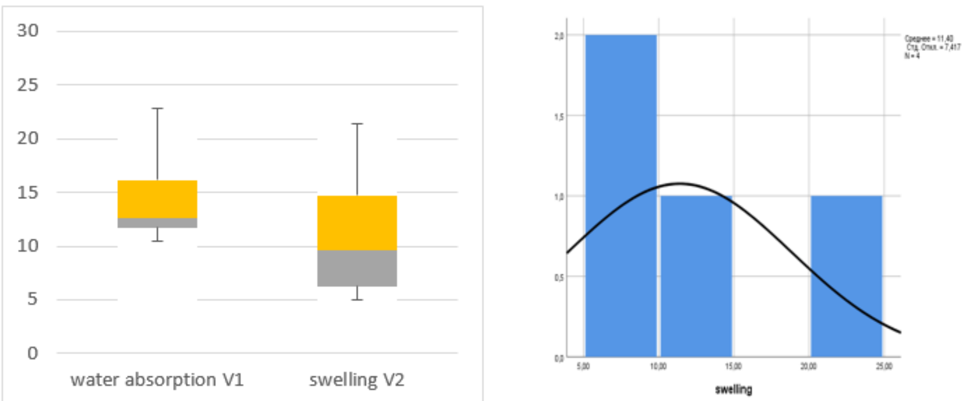

Fig. 3. Sample water absorption and swelling diagram.

Next, we tested the tensile strength and static bending of the specimens. The tensile strength of the obtained samples of wood-polymer composite materials was determined according to the method of GOST 11262-2017. For this, samples were prepared according to GOST 26277. That is, the dimensions are 120x4x15 mm. In addition, according to this GOST, the norm of the tension device was set equal to (0.5)%. When preparing samples for testing, they were kept in atmospheric conditions for 16 hours according to GOST 12423-66. Substituting the test results into the following formula:

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$$\sigma_{pm}=F_{pm}/A_0*1000 ;$$

where, F_{pm} is the maximum energy for stretching, N; A_0 – initial sample section surface.
With the above data in Table 3 and graphical curved stripes (Figure 4), we can see that the properties of the tensile strength of composites also overestimate the amount and type of wood filler.

Table 3. Properties of the tensile strength of composites.

#	Samples	Deformation point, N	Bending strength, MPa
1	Recipe 1	3.32	4.5
2	Recipe 2	3.58	6.29
3	Recipe 3	3.58	6.47
4	Recipe 4	4.18	7.12

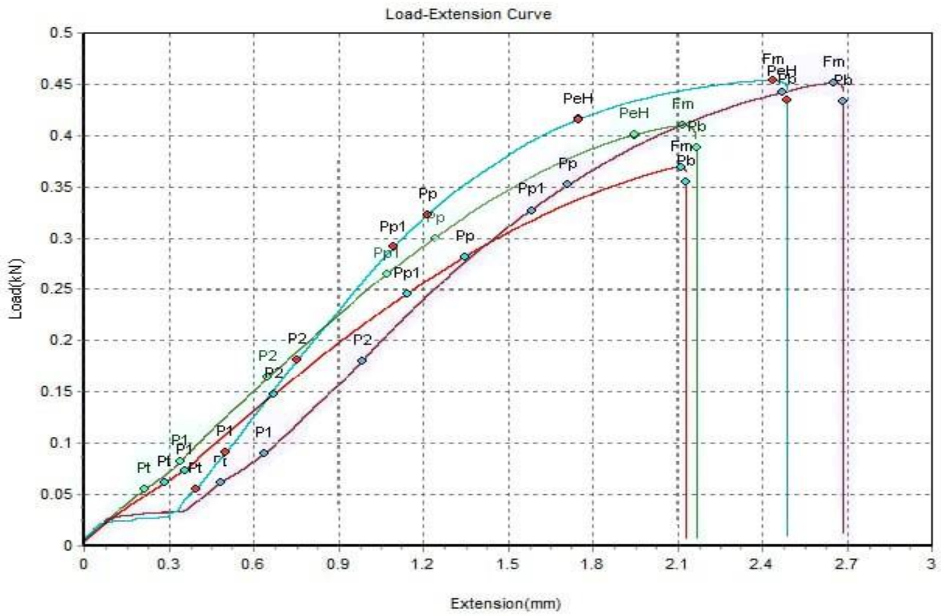

Fig. 4. Tensile strength chart of samples.

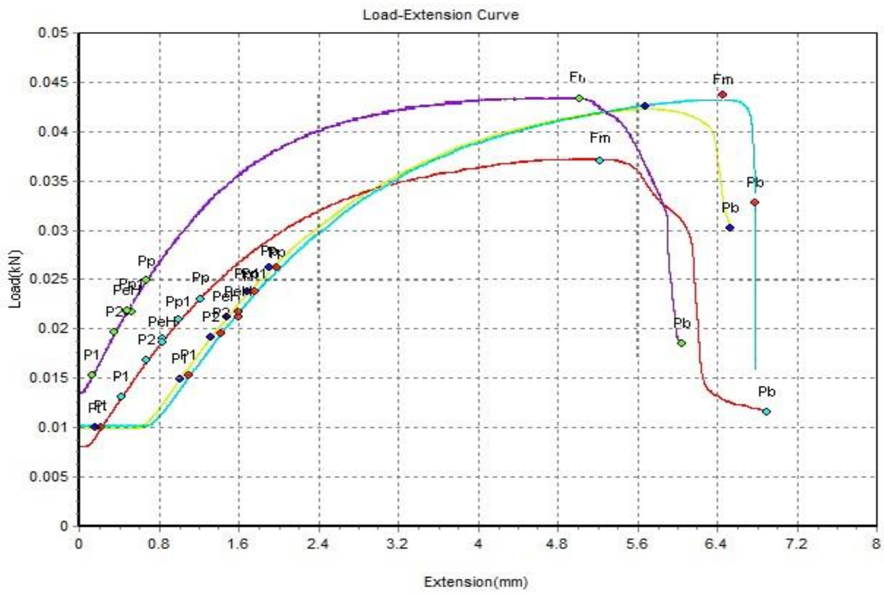

Fig. 5. Bending strength curve of specimens.

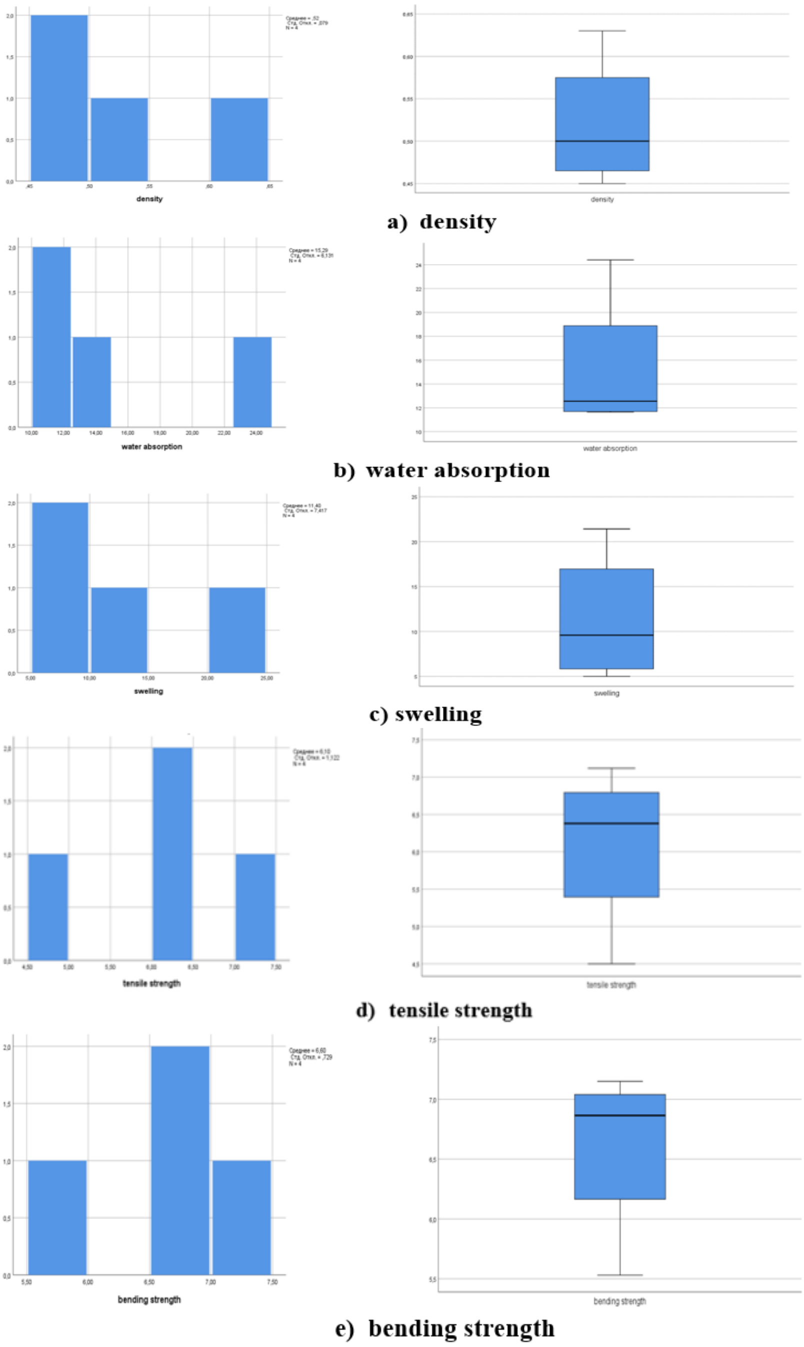

Fig. 6. Mechanical properties of the obtained samples: a) density, b) water absorption, c) swelling, d) tensile strength, e) bending strength

To test wood-polymer composite materials for bending strength, samples were made by cutting them into dimensions of 80x10x5 mm according to GOST 4648-71. When testing this parameter, the rate of applied force for deformation was set to (1.0±0.5)%. The samples were kept under atmospheric conditions for 16 hours according to GOST 12423-66. To process the results, the data obtained during the tests were calculated according to the following formula and summarized in Table 4 and Figure 5.

$$\sigma_1 = M/W*1000$$

where, M – bending moment, N; W is the initial cross-sectional surface of the samples.

Table 4. Testing wood-polymer composite materials for bending strength.

#	Samples	Deformation point, N	Bending strength, MPa
1	Recipe 1	6.82	5.53
2	Recipe 2	7.05	6.8
3	Recipe 3	9.8	6.93
4	Recipe 4	11.35	7.15

From the results obtained in the table and graph, the static bending strength of the composition is definitely dependent on the wood filler. It can be seen that if the amount increases in the composition, then the point of deformation during bending also requires a high pressure of the bending force (Figure 6).
We know from many literatures and articles by authors who have studied the properties of WPC materials, the main attention will be paid to fillers in the composition, especially wood fillers, because the nature and characteristics of wood and their waste vary depending on the climate of the region, because climatic conditions play a very important role in this production.

4 Conclusions

Particular attention is drawn to the fact that both primary polyvinyl chloride and secondary, in the entire range of the mass fraction of wood filler such as poplar in this study, the resulting physical and mechanical properties are much greater. Apparently, this is explained, firstly, the density of the WPC samples meets the requirements of the industry used. Secondly, the properties of water absorption and swelling gives the composition the possibility of using it in outdoor construction work. A study of the change in the mass fraction of wood filler in WPC products in the form of terrace boards produced in the laboratory was performed. The matrix polymer was polyvinyl chloride. Influence of wood components on chemical.
The structural-thermal and energy properties of various types of lignin, as well as hemicellulose, have been analyzed. It is established that WPC materials have a sufficiently high resistance to climatic influences. The intensity of changes in physical and mechanical properties depends not only on the humidity of the environment, but also on temperature, material composition and chemical composition of the components. All this is true for WPC products used for outdoor work, and can also be used in the construction industry.

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