**Polyhydroxybutyrate Composites Reinforced with Lignocellulose: Compositional Analysis**

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**Abstract.** The recycling of wood and farm waste and its use is an important issue today for environmental and economic reasons. This study aims to make polyhydroxybutyrate (PHB) biocomposite materials mixed with fillers based on cellulose and lignin taken from wood waste and look at their physical and mechanical properties. During the study, composite materials made of PHB and wood flour, cellolignin, and their mixture were made on PLAsti-Corder Lab-Station equipment. The samples were tested for density, hardness (by Shore D scale), tensile strength, and modulus of elasticity. The results showed that adding filler raises the density and hardness of the composite materials. But the strength increases to a 40% filler level, and then it starts to drop. This study grows the chances of making environmentally safe and mechanically stable biocomposites using wood waste. It also serves as a base for introducing them on an industrial scale.

**Keywords:** Polyhydroxybutyrate (PHB), lignocellulose, biodegradable composites, natural filler, ecological materials, water absorption, natural polymers

**INTRODUCTION**

The yearly increase in wood and farm waste poses a major problem for people [1]. Incorrect disposal of this waste hurts the environment. Burning plant waste releases toxic substances like nitrogen oxides, sulfur dioxide (SO₂), and airborne particles. It also creates carcinogens such as dioxins, furans, and polycyclic aromatic hydrocarbons, as well as greenhouse gases like CH₄ and N₂O. This damages human and animal health and worsens global warming. It is crucial to process waste from the wood industry and farms [2].

Plant and wood waste varies in origin and potential as raw stuff. The waste is mostly cellulose, hemicellulose, and lignin. The structure of these parts, plus the stability of lignin, makes them hard to break down biologically. Currently, farm leftovers, aquaculture waste, and other organic wastes are the most usual sources [3]. There are two types of waste: plant waste and farming-related waste. Big amounts of these are made daily in factories and by people.

In Russia, the forest business is important to their money flow. Managing wood waste from this business is a main concern. The wood-making process makes different wastes like wood chips, sawdust, twigs, bark, and wood pieces [4].

One main plus of using wood in composites is that it can be made to have the qualities you want. By using natural stuff like wood waste, these things can be made in different thicknesses, grades, sizes, and strengths. Processing wood stuff more can help it be used in more ways [5]. For example, using acid to break down cellolignin can help it be used as a filler in composite stuff [6]. The making of polyhydroxybutyrate (PHB), a biopolymer often used by itself in factories, was looked at. But, because the made thing is pricey, the biopolymer is used to hold the composite material together instead.

This research explores making composite material from polyhydroxybutyrate (PHB) and fillers like wood flour, cellolignin and a mix of wood flour and cellolignin. The physical, mechanical, and performance attributes of the produced composites were assessed to see if they might be used in factories [7].

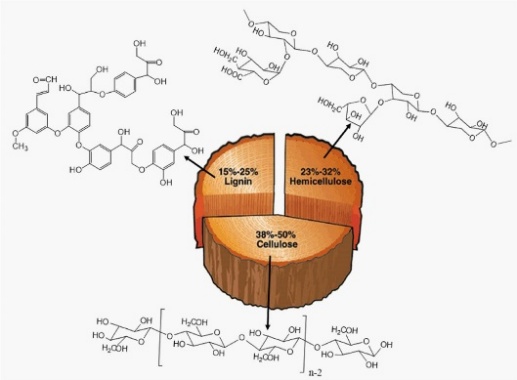
**MATERIALS AND METHODS**

Polyhydroxybutyrate from processed wood flour, with features listed in Table 1, was the polymer used to make the composite material [8].

**TABLE 1.** Key Features of the Polyhydroxybutyrate Biopolymer Used

|  |  |  |
| --- | --- | --- |
| **№** | **Indicator** | **Value** |
| 1 | Density, g/m3 | 1.30 |
| 2 | MFI, g/10 min | 34.12 |
| 3 | Impact Strength, kJ/m | 43.17 |
| 4 | Softening temperature, °C | 135 |
| 5 | Tensile strength, MPa | 14.71 |
| 6 | Tensile Modulus, MPa | 200 |
| 7 | Hardness, Shore D | 48 |

In composite materials, fillers made from pine wood sawdust waste (fraction size 1-2 mm) are used. Lignocellulose solid waste is also used after hydrolysis, along with a pine wood flour and cellolignin mix in a 50/50 weight ratio [9].



**FIGURE 1.** Lignin from poplar wood

Initially, the wood flours went through hydrolysis. After this process, the lignocellulose raw material was dried in a “Memmert VO400” vacuum drying oven at 100±5 °C until a constant mass was achieved [10]. Then, the raw material was ground into powder. Figure 1 shows images of the filler samples that were created.



**FIGURE 2.** Examples of fillers: (1) wood flour from poplar wood; (2) lignocellulose obtained from hydrolysis;   
(3) a mixture of wood flour and lignocellulose.

**RESULTS AND DISCUSSION**

*Composite material preparation.* The mixing of composite material filled with wood was done with a Measuring Mixer 350 E mixing chamber joined to a Brabender PLAsti-Corder® Lab-Station. The process happened at 175 °C, with the rotors spinning at 40 rpm for 7 minutes. The physical and mechanical qualities of the composite material were studied using standard blade and bar samples made by pressure casting. To get the sample’s, pre-crushed material was put into a casting machine. The casting was done at 160 °C and 8 bar pressures. Then, samples with smooth surfaces and without flaws were picked. During the test, 10 samples were cast, and their physical and mechanical qualities were found in order. The ratios of the composite material are in Table 2.

**TABLE 2.** Composition and Ratios of Composite Material

|  |  |  |  |
| --- | --- | --- | --- |
| **Samples** | **Polyhydroxybutyrate (PHB), %** | **Filler, %** | |
| **Poplar wood flour** | **Cellolignin obtained from the hydrolysis process.** |
| 1 | 100 | 0 | |
| 2 | 80 | 20 | |
| 3 | 70 | 30 | |
| 4 | 60 | 40 | |
| 5 | 50 | 50 | |
| 6 | 40 | 60 | |
| 7 | 30 | 70 | |
| 8 | 20 | 80 | |
| 9 | 10 | 90 | |
| 10 | 0 | 100 | |

Ten composite material samples with varying percentages of filler were made, as shown in Table 2. The study found that composites with high filler content (70%) could not be produced because the composite became fragile due to a clear lack of binder. Because of this, samples with up to 60% filler were tested. The research went on to study the composite material's physical and mechanical properties. Several tests were done to find these properties: material density, hardness, tensile strength, and impact resistance. The test results were analyzed as follows.

*Composite Material Density Determination*. Composite material samples shaped like bars were tested to find density. The tests were done by GOST R 57713-2017, using a method where samples were weighed in air and water using a BM-22 microanalytical balance.

**FIGURE 3.** Density of the composite material relies on filler composition and type

Figure 3 shows the density results based on lignin content. The charts show that as the amount of filler in the composite rises, so does the density of the samples. This is because processed wood filler has a greater density than the polymer binder (PGB).

It is very important to determine a composite material's hardness since this measurement tells us how well the material resists penetration by other objects. Experimental tests were done using a Test Stand OS-300-2-OO diameter based on GOST 24621-2015 standard. Measurements were taken right away and 15 seconds after a load was applied at three spots on the test samples. Then, the average of these values was worked out.

To find out how hard the material was, readings were taken right after the load was applied and again after 15 seconds. Figure 3 shows the results of studying the hardness of the samples on the Shore D scale after a load was applied for 15 seconds.

According to Figure 4, the hardness of the composite material goes up as the filler amount goes up.

**FIGURE 4.** The impact of wood filler composition on Shore D hardness

This suggests the stiffness of the treated filler is greater than the polymer binder (PGB). Also, stiffness increases by 30% when the composite material contains 20 to 40% wood-based filler by weight. But when the filler amount reaches 50 to 60% by weight, the changes aren't as big.

To measure the tensile strength of the composite material, we used a universal testing machine according to GOST 11262-2017 to find the tensile strength of composite material samples. Figures 5 and 6 show how the concentration of the treated wood filler affects tensile strength and elastic modulus in tension. The tests showed that as the filler amount rises, strength increases up to a wood filler concentration of 40%, then drops sharply. This is likely because the amount of binder matrix goes down. if filler is at 50%, the composite material's strength is about equal to that of the pure polymer binder (PGB).

**FIGURE 5.** Impact of Recycled Wood Filler Content on Tensile Strength

**FIGURE 6.** The Impact of Filler Composition on Voltage Module

To learn about how well composite materials resist impact, tests were done to find the Izod impact strength. These tests followed GOST 19109-2017. In this approach, samples were broken by the hit of a pendulum with a 2.75 J hammer, set at a distance from where they were held. The results of the Izod impact strength tests are in Figure 7.

**FIGURE 7.** Shows how the impact strength of the composite material changes with different wood filler content

Based on the graph in Figure 7, as the amount of wood filler increases, the impact viscosity (resistance to impact) decreases linearly.

To study the performance characteristics of composite materials, square samples measuring 30x30 mm with a thickness of 1 mm were cut from pre-made sheets before a series of performance tests. These samples were then dried in a Memmert VO400 vacuum oven at a steady temperature of 100±5 °C for 12 hours until they reached the necessary moisture level.

To determine how much water the composite material absorbed, the water resistance of the composites was determined by soaking samples in distilled water as per GOST 4650–2014. For this, pre-dried composite material samples were put in a container filled with distilled water for 1, 4, 8, 12, 16, 20, and 24 days. During these periods, the material was taken out of the water, weighed on an electronic scale, and assessed. The graph shows the mass percentage of water absorbed by the composite material sample depending on how long it was kept in water. The result of the analysis showed that as the filler concentration increased, the material absorbed more water.

*(a)*

*(b)*

*(c)*

**FIGURE 8.** Water absorption rate of composite material with different filler content:   
(a) PGB/ poplar wood flour; (b) PGB/cellolignin; (c) PGB/ poplar wood flour + cellolignin.

**CONCLUSION**

Current research on obtaining plant-based biopolymers from wood and agricultural waste was analyzed, as well as methods for processing plant materials and the state of hydrolysis in the processes of obtaining biopolymers from these materials. It was determined that agricultural products are the primary source for biopolymer production. They can be used in animal husbandry as a feed source and have a seasonal characteristic. Therefore, it is appropriate to develop technologies for obtaining biopolymers using wood waste. In particular, this process can be carried out by creating a nutrient medium from wood hydrolysis products for the cultivation of biopolymer-accumulating bacterial microorganisms. This reduces the cost of biopolymers and products made from them. The physical-mechanical and operational properties of a PHB (polyhydroxybutyrate) and cellulolignin-based composite material were studied. The results showed that the most suitable composition is a ratio of 60/40%. This composition ensures that the tensile strength is 1.15 times higher than that of the unfilled biopolymer, and the impact absorption capacity is almost 3-4 times higher than that of other fillers, and is characterized by good biodegradation and stability to UV radiation.

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