

Plastics: physical-and-mechanical properties and biodegradable potential

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Abstract:

Introduction. Processing agricultural waste into plant biodegradable plastics is a promising way for its recycling. This work featured the main physical-and-mechanical properties of plant plastics without adhesive substances obtained from millet husk and wheat husk and wood plastic obtained from sawdust, as well as their biodegradation potential.

Study objects and methods. Objects of the study were plastics without adhesives based on wood sawdust, millet husk, and wheat husk.

Results and discussion. We analyzed of the physical-and-mechanical parameters of the plant plastic based on millet husk, wheat husk, as well as wood plastic based on sawdust. The analysis showed that, in general, the strength characteristics of the wood plastics were higher than those of the plastics based on millet husk, especially flexural strength. Thus, the average value of the density of the wood plastic exceeded that of the plant plastic from millet husk by 10%, hardness by 40%, compression elasticity modulus by 50%, and flexural modulus by 3.9 times. It was found that wood and plant plastics obtained from sawdust, millet husk, and wheat husk without adhesives had a high biodegradation potential.

Conclusion. The plastics obtained can be used as an insulating, building, and decorative material in the steppe regions experiencing a shortage of wood and wood powder.

Keywords: Plastic, agricultural waste, grain, husk, biodegradation

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INTRODUCTION

The concept of organic agriculture, which first appeared in European countries, has gained its popularity in Russia in the last few years. According to the concept, agricultural industry should ensure the environmental and biological safety of technologies, raw materials, and products [1–3]. In Russia, a new federal law on organic products comes into force in 2020 that regulates the activity of agricultural enterprises. It prohibits the use of packaging and transport package which damages to the environment and encourages the application of methods and technologies aimed at ensuring a favorable state of the environment, strengthening human health, as well as at maintaining soil fertility.

Besides, one of the problems is the utilization of agricultural wastes, which are currently mainly stored or disposed. Only a small part of them is used to produce coarse low-value feed and bedding for animals, fertilizers, or fuel [4]. These include straw, flax shive, coffee grounds, nutshells, plant waste from cereals and flour manufacture, as well as from fruit and berries processing. In Russia, efficient agricultural enterprises generate several million tons of such waste annually. In the Altai Territory, for example, the amount of grain husks obtained at elevators is on average 2–3 million tons per year [5].

One of the alternatives of plant waste recycling is the production of bioplastics and paper [6–9]. In the world practice, plant fillers from cereal husks

and agricultural plant fibers are widely used in the production of biocomposites and reinforced bioplastics. They can be produced both from plant materials only and with the addition of classical petrochemical products [10–12]. The improved technologies and performance characteristics of bioplastics as well as production cost reduction make it possible to fill new niches in the market [13]. Bioplastics without adhesive substances based on plant materials are environmentally friendly. Plant materials can be wood powder, sawdust, cereal husk, as well as flax and hemp fibers [6, 13]. Such plastics are biodegradable materials, and their degradation is due to microbial enzymes [14–16].

The use of plant biodegradable plastics, including plastics without adhesives, to produce containers with a short life cycle, building and packaging materials can be a promising way for agricultural waste recycling, which corresponds to the concept of organic agriculture [7, 17, 18].

Taking into consideration the obvious advantages of biodegradable plastics, the study of the main physical-and-mechanical properties of plant plastics without adhesives obtained from millet husk and wheat husk and analysis of their biodegradation potential are relevant.

STUDY OBJECTS AND METHODS

The objects of the study were plastic samples without an adhesive substance based on wood and plant materials. The samples were made at the Ural State Forestry University. Wood-based plastics made from industrial sawdust (State Standard 18320-78^I) were used as control samples. Experimental samples were plant plastics obtained from millet husk and wheat husk, cereal production wastes.

The plant fillers of 18.0 and 30.0 g in mass were subjected to pressing to obtain disks of 2.0 and 4.0 mm in thickness and 90 mm in diameter (moisture content of the molding material was 12%). The conditions of pressing were as follows: molding material mass, 10.0 g; pressing pressure, 124.0 MPa; pressing time, 10 min; and cooling time under pressure, 10 min. The physical-and-mechanical characteristics of the samples were analyzed both before and after biostability and biodegradation tests. We determined water absorption (State Standard 4650-80^{II}) and strength parameters such as density, flexural strength, hardness, elasticity number, compression elasticity modulus, elastic modulus in flexure, breaking stress, yield strength (State Standard 4648-71^{III}, State Standard 4670-77^{IV}, State Standard

10634-88^V).

To study biodegradation potential, the test samples were kept in soil for 21 days, then the main visual morphological characteristics of their biodegradation were evaluated. Soil was prepared in accordance with State Standard 9.060-75^{VI}. At the beginning of the test, pH of the soil extract was 7.0 and biological activity coefficient was 0.8. The soil microbiocenosis was formed by native field strains of microorganisms of the initial components of the soil.

We observed such biodegradation signs as splitting, swelling, loosening, macro- and microcavities formation, changes in the shape and size of the main plant component particles, fibrillation and fragmentation of particles, the local discoloration of the sample, the presence of colonies of microorganisms, hyphae, fungal fruit inside or on the sample surface, as well as its mucilagination. The samples that did not display biodegradation signs were tested for strength and water absorption.

In addition, the test with the germination of oat and clover seeds on a substrate containing the samples under study was carried out. For this, the substrate was prepared that included two layers of multi-purpose soil (60%) alternating with two layers of the samples (40%). Multi-purpose soil was used as control sample. Oat and clover seeds were sown in the substrate, germinated for 21 days, after that growth rate, as well as stem and leaves formation were evaluated in the experimental and control samples. The root system of the plants was determined in visible light and in ultraviolet light.

RESULTS AND DISCUSSION

We analyzed the physical-and-mechanical parameters of plant plastics based on husks of millet and wheat and wood plastic based on sawdust. The samples did not include adhesives. The analysis showed that the strength characteristics of the wood-based samples were higher than those of the plastics based on millet husk, especially flexural strength. Thus, the average density of wood plastics exceeded that of plant plastics from millet husk by 10%, hardness by 40%, compression elasticity modulus by 50%, and flexural modulus by 3.9 times (Figs. 1 and 2).

A comparative analysis of the physical-and-mechanical properties of the wood plastic samples with the samples of plant plastics from wheat husk showed similar results. Thus, the average value of the density of the wood-based plastics exceeded that of the plant samples from wheat husk by 15%, hardness by 10%, compression elasticity modulus by 10%, and flexural modulus by 2.6 times.

^I State Standard 18320-78. Technological wooden sawdust for hydrolysis. Specifications. Moscow: Izdatel'stvo standartov; 1986. 7 p.

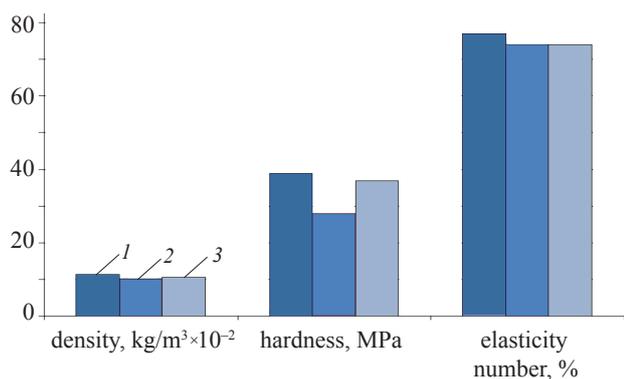
^{II} State Standard 4650-80. Plastics. Methods for the determination of water absorption. Moscow: Izdatel'stvo standartov; 2008. 7 p.

^{III} State Standard 4648-71. Plastics. Method of static bending test. Moscow: Izdatel'stvo standartov; 1992. 11 p.

^{IV} State Standard 4670-77. Plastics and ebonites. Method for determination of hardness by ball indentation under a given load. Moscow: Izdatel'stvo standartov; 1992. 6 p.

^V State Standard 10634-88. Wood particle boards. Methods for determination of physical properties. Moscow: Izdatel'stvo standartov; 1991. 10 p.

^{VI} State Standard 9.060-75. Unified system of corrosion and ageing protection. Fabrics. Method of laboratory tests for microbiological destruction stability. Moscow: Izdatel'stvo standartov; 1994. 9 p.



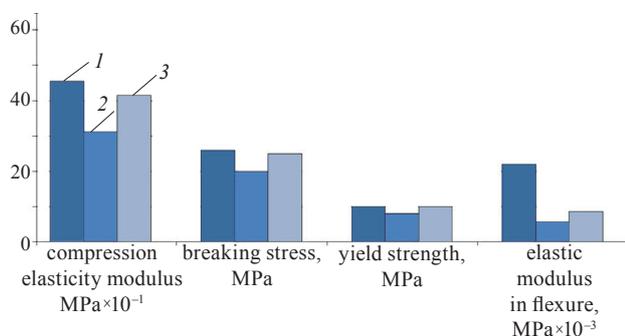
(1) wood plastic (2) plant plastics from millet husk (3) plant plastics without from wheat husk

Figure 1 Average values of density, hardness, and elasticity number of plastics without adhesives

According to the results of the comparative analysis of the physical-and-mechanical properties of the two plant plastic samples, the average values of hardness, compression elasticity modulus, and elastic modulus in flexure of the plastic from millet husk were higher than those of the samples based on wheat husk by 1.3, 1.3, and 1.5 times, respectively.

An increased pressing temperature (from 180 to 170°C) led to an improvement in the physical-and-mechanical properties of the plant plastics compared to the wood-based samples. Thus, the values of elasticity number, the elasticity moduli, breaking stress, and yield strength increased. Presumably, this is due to the difference in the dynamics of lignin polymerization reactions in wood and plant plastics. This factor should be taken into consideration when selecting pressing conditions.

The study of the biodegradation potential of plastics without an adhesive component based on wood sawdust, millet husk, and wheat husk showed that all the samples



(1) wood plastic (2) plant plastics from millet husk (3) plant plastics without from wheat husk

Figure 2 Average values of compression elasticity modulus, breaking stress, yield strength, and elastic modulus in flexure of plastics without adhesives



Figure 3 Plant plastic from millet husk, plant plastic from wheat husk, and wood plastic kept in active soil for 21 days (all plastics are made without adhesives)

studied had a relatively equal high biodegradation potential.

We analyzed the morphological signs of biodegradation of the materials kept in active soil for 21 days. The analysis showed that all the samples had surface mucilagination, edge swelling, and local discoloration of the surface (Fig. 3).

60% of the samples based on millet husk, 58% of the samples from wheat husk, and 47% of the wood plastics based on sawdust displayed longitudinal and transverse splitting, loosening, and macrocavities formation (Fig. 4). The splitting and loosening sites ranged from 1.5 to 5.5 mm in size.

Microscopy was used to assess signs of the sample destruction. The analysis revealed marginal fibrous structure; the fragmentation and destruction of individual particles of the plant component; focal darkening of particles; and microcavities formation between the particles of plant material. Moreover, all the samples under study showed bacterial contamination. 74% of the samples with millet husk, 85% of the samples from wheat husk, and 62% of the wood samples had



Figure 4 Wood plastic fragment with signs of splitting, swelling, marginal and longitudinal fragmentation



Figure 5 Fragment of plant plastics from wheat husk (without adhesives) with signs of mold growth

multiple large colonies of mold fungi of different growth phases (Fig. 5).

The plant plastics demonstrated a more pronounced biological destruction compared to the wood samples. Thus, they had changes throughout the sample, while the wood plastics were characterized by edge and surface changes.

Further, we evaluated the growth rate and organs formation of oat and clover grown on control and experimental substrates. Multi-purpose soil was used as the control substrate, while the experimental substrate contained multi-purpose soil and the samples under study. According to the results of the experiment, morphological signs of retardation and deviation in the oat and clover development were not detected. The root system of the plants did not also have significant differences. The roots penetrated into the plant and wood samples, fragmenting them. The soil – root conglomerate was analyzed in ultraviolet light. The result was typical of these plant species; no dependences

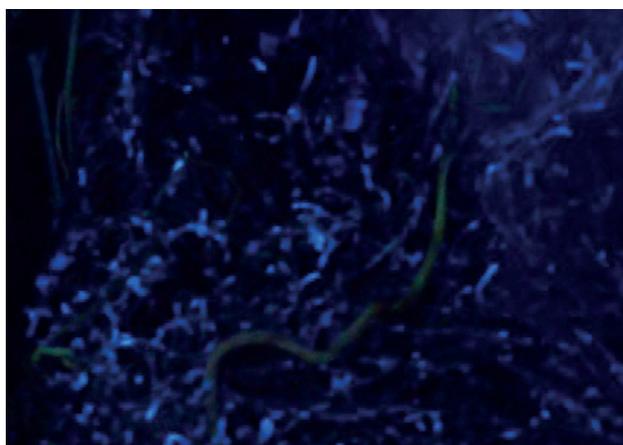


Figure 6 Root system of oat on a substrate with plant plastic from wheat husk without adhesives in ultraviolet light with luminescence foci

on the presence of the samples under study in the substrate were found (Fig. 6).

Based on the signs found, the plastics with wheat husk had the highest degree of biodegradation among all the samples under study.

The keeping of the plant and wood samples in active soil for three weeks led to their physical-and-mechanical properties deterioration. Then, hardness decreased by 66, 70, and 62%, elasticity number by 43, 47 and 46%, and compression elasticity modulus by 76, 80, and 73% for the wood plastics, plant plastics from millet husk, and plant plastics from wheat husk, respectively. Breaking stress and yield strength values decreased by 64% and 63% for the wood-based plastics and by 60% and 68% for the plant-based samples, respectively.

A comparative analysis of flexural strength values of the plastics under study without adhesives showed that the highest average value of this indicator was for the wood plastic samples (4 MPa), and the lowest for the plant plastic based on wheat husk (1 MPa). Water-absorbing capacity was 96, 85, and 94% for the samples with wheat husk, with wheat husk, and with sawdust, respectively.

CONCLUSION

According to the results of the study, plant plastic obtained under the same pressing conditions which are used for wood plastic production had lower strength characteristics. A decrease in the pressing temperature by 10°C improved such strength characteristics of the husk-based samples as elasticity number, moduli of elasticity in compression and flexure, as well as breaking stress. Also, the wood and plant plastics without adhesives based on sawdust, millet husk, and wheat husk were found to have a high biodegradation potential. Therefore, it makes it possible to utilize such materials naturally, i.e. without composting, in contrast with biodegradable wood-polymer composites.

On the other hand, a high biodegradation potential also indicates a low biostability of materials. Special conditions should be applied to use of products from plant plastics based on husk of millet and wheat, as well as from wood with sawdust. The conditions include a low humidity, no contact with water and soil, or with using antiseptics and waterproofing agents. The advantages of plant plastics without adhesives based on agricultural waste – millet husk and wheat husk – include their ecological safety, relative ease of production, low cost, raw materials availability, a high biodegradation potential, as well as performance characteristics comparable to those of wood plastics. Plant plastics without adhesives obtained from agricultural waste can be relevant in steppe regions as an insulating, building, and decorative material.

CONTRIBUTION

The authors were equally involved in developing the

research concept, obtaining and analyzing data, as well as in writing the manuscript.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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