Analysis of the possibility of using polylactide in production of building materials

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Abstract. The article analyzes the features of the production, use and utilization of biodegradable biopolymers. The results of studies are presented, the purpose of which is to assess the combination of properties of polylactide for use in construction. The fundamental possibility of using a thermoplastic biopolymer based on lactide (lactic acid) for the production of building materials is considered. Comparative data on the results of studies of the physical and mechanical properties of materials based on polylactide are presented.

1 Introduction

The global use of natural resources and the accumulation of man-made and household waste associated with the increasing human production activities have a detrimental effect on the environment. Therefore, in the modern world, the tasks of the rational use of natural resources, the protection of the environment and the recycling of waste are put forward.

Despite the accumulated experience in the production and use of materials from industrial waste and undoubted achievements in the use of some of their types, the total percentage of waste utilization is unacceptably small.

During the industrial production of plastics, over 8 billion tons were produced. In terms of its share in world production, polyethylene is in first place - 29%, polypropylene is in the second - 19%, polyvinyl chloride is 11%, and the share of polystyrene, polyethylene terephthalate and polyurethane is about 21%.

Approximately 9% of plastic waste is recycled, 12% is destroyed, and the remaining 79% accumulates in landfills or ends up in the environment. In terms of the level of polymer processing, the Russian Federation lags significantly behind developed countries. In 2016, per capita consumption of plastics in Russia amounted to 48 kg/person, while in the USA - 177 kg/person, in Germany - 151 kg/person, in Italy - 123 kg/person, in France - 92 kg/person, in the UK - 79 kg/person, respectively.

The largest amount of plastics is used in the production of packaging, therefore the table 1 [1] provides comparative data on the volume of plastics consumption in other sectors of the economy. Thus, construction consumes about 2 times less plastic, the textile industry - three times, and the transport industry uses about 20% of the volume of packaging materials. At the same time, when using packaging materials, more than 96% goes to waste,

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about 90% in the production of consumer goods, 80% in the textile industry, and only 20% of plastics in construction.

Table 1. Plastics production in various industries.

Economical sector	**Amount of consumed plastic, t/% of packaging**	**Percentage of plastic consumed**	**Generated plastic waste, t/%**	**Used polymers**
Packaging	146/100	35.9	141/96.5	Polyethylene
Construction	65/45	16	13/20	Polycarbonate, nylon, polyethylene
Textile industry	47/32	14.5	38/81	Polyester
Consumer goods	42/29	10.3	37/88	Polyethylene
Transport	27/19	6.6	17/63	Acetate group

Thus, there is an urgent need to address the global accumulation of plastic waste. One of the ways to solve this problem is the use of biodegradable polymers, which do not harm either human health or the environment [1-3].

Previously, materials could be classified as biodegradable only on the basis of the fact that over time they disintegrated into smaller fragments. Today, when working with bioplastics, terms such as “biodestruction” and “biodegradation” are used. Biodestruction is the loss of physical and mechanical properties, while biodegradation is a microbiological process that results in the mineralization of organic components. Biodegradable polymer is completely mineralized in the soil layer during a certain period of time, after which there should be no polymer itself or other toxic residues.

It should be understood that the material under the influence of water and carbon dioxide decomposes by microorganisms in whole or in part, that is, it can be biodegraded in the natural environment. Such materials can be produced on the basis of natural and synthetic polymers, as well as their mixtures.

Considering that 40% of polymer consumption falls on packaging, it was for packaging materials that the standards for determining biodegradability were developed. In accordance with GOST R 54530-2011, the biodegradability of plastic packaging materials is determined by tests for aerobic and anaerobic biodegradation. Duration of tests is no longer than 6 months. When tested for aerobic biodegradation, by this time, the degree of biodegradation must be at least 90% of the maximum degradation of the standard (reference) substance. At anaerobic biodegradation, the degree of biodegradation is determined based on biogas production (at least 50% of dry weight of theoretical values for the test material). Plastics decompose under aerobic or anaerobic conditions to carbon dioxide, water, methane, biomass and inorganic compoundsc [4-6].

There are several organizations in the world that issue an official certificate for the biodegradability of plastic materials. In Europe, this is done by the European Committee for Standardization (CEN) and the European DIN certification, and in the United States it is done by the American Society for Testing Materials (ASTM).

Most plastics produced from oil and gas does not biodegrade in the soil, but they can be made biodegradable by adding special additives. Recently, there has been a growing trend in the production of polymers based on plant materials, which are called bioplastics, but this does not mean that they are safe for the environment.

In the middle of the twentieth century, polymers began to be produced from plants rich in sugary substances, for example, from corn, sugar cane and potatoes. Thus, conventional polymers (ethylene, etc.) and biodegradable plastics can be produced from plants. For example, castor oil is isolated from castor-oil plant, Polyamide can be produced from castor oil, and the so-called “green” polyethylene can be produced by hydrolysis and fermentation of sugar from sugar cane. But polyamide or polyethylene produced from biomass still needs to be processed, that is, the problem of disposal remains a live issue [7-8].

The current trend is not just the production of polymers from plant materials, but the production of biodegradable polymers, which account for about 75% of the total production. There are three main groups of biodegradable plastics: starch-based materials, polyhydroxyalcanoates (PHAs) and polylactides (PLA).

Agricultural crops such as potatoes, rice, wheat, and corn are used for the industrial starch production. Starch is a polysaccharide that is synthesized in tubers, seeds, stems and leaves of plants, is present in plants in the form of granules ranging in size from 5 to 100 microns and degrades under environmental conditions.

Starch exists in three crystalline modifications and consists of amylose and amylopectin. In the development of biodegradable starch-based materials, either mixtures of starch with synthetic or natural polymers or thermoplastic starch produced by changing the initial structure are used. To produce thermoplastic starch, it is necessary to destroy its crystal structure.

Thermoplastic starch is produced by heating above the glass transition temperature and melting in the presence of a high-boiling plasticizer (glycerine, ethylene glycol) and a destructive agent (urea, sodium oxide). It leads to the destruction of its crystal structure. The resulting thermoplastic is the basis for other composition production.

Despite the fact that starch is not a true thermoplastic, in the presence of a plasticizer (for example, glycerine) at high temperatures (90-180°C) it melts and liquefies, which makes it possible to use standard extrusion and moulding equipment used in the production of synthetic plastic products.

The disadvantages of thermoplastic starch include hydrophilicity and low mechanical properties compared to conventional polymers [9-11].

Polyhydroxyalcanoates (PHAs) are products of vegetable sugars processing by microorganisms based on acyclic hydroxycarboxylic acids. The disadvantages of the product include thermal instability and high cost. The main and most studied product based on polyhydroxyalcanoates is polyhydroxybutyrate (PHB), which is a stereoregular isotactic homopolymer of (R)-3-hydroxy-butanoic acid ($C_4H_8O_2$). In addition to polyhydroxybutyrate, microorganisms are able to synthesize heteropolymeric PHA - copolymers of hydroxybutyrate and hydroxyvalerate. On an industrial scale, polyhydroxybutyrate valerate (PHBV), a copolymer of 3-hydroxybutyrate and 3-hydroxyvalerate, is mainly produced.

The synthesis of polyhydroxyalcanoates is possible using various raw materials: sugars, alcohols, acetate, as well as hydrogen and carbon dioxide. The choice of technology is determined primarily by economic factors [8].

Polylactide is a thermoplastic polymer that can be used to produce durable and water-resistant biodegradable materials, the properties of which correspond to the traditional polymers such as polyethylene, polypropylene (PP) and polystyrene.

To produce polylactide, which is aliphatic polyester, two types of monomers are used: lactic acid and its dimer (lactide). Thus, polylactide is produced either by polycondensation of lactic acid (polylactic acid) or by polymerization of a dimer of lactic acid (lactide). Lactic acid is produced by enzymatic decomposition of carbohydrate raw materials (corn, sugar beets, etc.).

The mechanism of polylactide biodegradation is a two-stage hydrolysis: first, the ether bonds between the structural units of the polymer are cleaved to form low molecular weight products, and then these resulting products are decomposed into carbon dioxide and water under the influence of microorganisms [12].

Biodegradable polymers can be used in combination with other polymers and additives, and most standard plastics technologies can be used for recycling - moulding, extrusion, casting and blow melting [13-17].

Despite this fact, biodegradable polymers are practically not used in construction industry. This, in our opinion, is due to the availability and relatively low cost of traditional polymers produced from oil and gas processing, and with the high cost of biodegradable polymers. For example, the price of one kilogram of polylactide is 1.5 times higher, and of thermoplastic starch is 3 times higher than that of polypropylene. Therefore, in the production of building materials, it is advisable to use polymers with filler, the so-called polymer biocomposites [18-22].

The availability of raw materials, the consistent growth in the polylactide production in the world, high physical and chemical properties, biodegradability, as well as the possibility of using standard equipment, allows polylactide to be considered as a real alternative to traditional polymers in the production of building materials.

All the aforementioned help to formulate main idea of the research – it could be possible to obtain effective wooden-polymer composite for application in decking with usage of polylactide components as binder. First stage of the research contains analysis of properties of materials and preliminary composition based on them.

2 Materials and methods

Materials are evaluated in accordance with GOST R 57224-2016 (ISO 14855-1: 2012) “Plastics. Determination of the capacity for complete aerobic biodegradation and degradability under controlled composting conditions. Carbon Dioxide Evolved Analysis” and ASTM D 5338 Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions.

In addition, the requirements of the DIN 54900 standard are taken into account. The standard establishes a method for determining the presence of organic and inorganic hazardous products that are not biodegradable during composting, the sequence for determining the complete biodegradation of components in laboratory conditions, as well as the procedure for conducting tests for biodegradability.

When choosing materials for research, the properties of polylactide were analysed (Table 2).

Table 2. Properties of different types of polylactide.

Properties	Polylactide type		
	Poly-L-lactide	**Poly-D, L-lactide**	**Poly-D-lactide**
Density, g/cm^3	1.29	1.25	1.248
Glass transition temperature / melting temperature, °C	55-80 / 173-178	43-53 / 120-170	40-50 / 120-150
Breaking tension, MPa	48-110	48-110	48-110
Percentage elongation, %	2.5-100	2.5-100	2.5-100

To produce a wood-polymer composite, a mixture of polymer and pine sawdust was used in a 2:1 ratio. The samples were prepared at a temperature of 240°C and a pressing pressure of 10 MPa. For the experiments, we chose poly-L-lactide, the physical and mechanical properties of which are shown in Table 3.

Table 3. Physical and mechanical properties of used polylactide.

Properties	Index
Density, g/cm^3	1.25
Melting temperature, °C	175-179
Glass transition temperature, °C	60-62
Breaking tension, MPa	64
Percentage elongation, %	5.8
Transverse strength, MPa	94
Resilience, kJ/m^2	3.8

All the properties were determined on the samples according to ASTM and GOST standards. The study works were done by the equipment of MSUCE.

3 Results and discussion

The studies carried out have shown the fundamental possibility of biocomposite production based on a biodegradable polymer polylactide, the properties of which allows one to use it for the production of building materials (table 4).

Table 4. Physical and mechanical properties of polylactide and traditional polymers.

Properties	Polypropylene	Polystyrene	PET	Polylactide
Density, g/cm^3	0.9	1.05	1.37	1.25
Melting temperature, ^{o}C	163	-	250	120 - 178
Glass transition temperature, ^{o}C	-	95	75	40 - 80
Breaking tension, MPa	21-37	34-46	47	64
Modulus of elasticity in tension, GPa	1.1 - 1.5	2.9 - 3.5	3.1	3.5 – 3.8
Elongation percentage, %	20-800	3-4	79	5.8

Physical and mechanical properties of polylactide are higher than these of traditionally used polymeric binders. When using polylactide as main component of the matrix, it is possible to obtain wooden composites with higher properties. As shown at table 5, produced wood-polymer composite based on polylactide filled with sawdust, has the following properties: average density 1.035 g/cm^3, water absorption within 24 hours - 4.6%, breaking tension - 0.9 MPa, softening coefficient - 0, 85.

Table 5. Physical and mechanical properties of wood-polymer composite based on polylactide.

Properties	Measure
Average density, g/cm^3	1.035
Water absorption within 24 hours, %	4.6
Breaking tension, MPa	0.9
Softening coefficient	0.85

Wood-polymer composites are produced from a homogenized mixture of wood raw materials, such as sawdust, and polymer. As usual, only solid wood or waste from mechanical processing of wood (for example, sawing waste) and polymers such as polyethylene, polypropylene and polyvinyl chloride with the necessary processing additives are used as raw materials. The use of the extrusion method makes it possible to obtain products in the form of a profile of various sections. Thus, various types of siding, decking, door trims, window profiles, skirting boards, etc. can be obtained.

To assess the quality of chipboard and fiberboard, such indicators as humidity, water absorption and swelling in thickness, density, ultimate strength in bending, modulus of elasticity in bending, tensile strength are determined.

To assess the quality of decking, not only the main parameters are determined - density, ultimate strength in bending, ultimate strength in bending, but also such characteristics as water absorption and swelling when kept in boiling water, hardness, coefficient of friction, wear resistance, etc. Table 6 shows the approximate values of some indicators according to the data of the material manufacturers.

Table 6. Comparison of properties of developed decking material and traditional wood.

№	Characteristics		Decking	Chipboard	Fiberboard	OSB
1	Density, g/cm^3		Less than 1300	-	Less than 1100	-
2	Humidity, %			Up to 5	3-10	-
3	Flexural strength, MPa		25	5.5-13	15-47	8-20
4	Flexural modulus, MPa			1050-1800		1200-2500
5	Tensile strength (perpendicular to the plane of the plate), MPa			0.14-0.45	0.30-0.32	0.26-0.30
6	Water absorption, %		5,0		7-13	
7	Swelling, %		Up to 1,5		13-23	25
8	Ball indentation hardness, N/mm^2		90			
9	Resistance to impact of a falling ball	Cracks, no more than, mm	10			
		Deepening, no more than, mm	1			
10	Friction coefficient, not less than		0,43			
11	Resistance to bending under temperature load (deflection value under load 85 kg), mm		10			
12	Coefficient of linear thermal expansion (in the temperature range + 30 ... + 80°C), $°C^{-1}$		7×10^{-5}			

Thus, it is most expedient to obtain products on the basis of polylactides with a developed polymer matrix, which perceives high mechanical influence. Decking based on polylactide binder could meet the requirements of the regulations for such a material. The use of polylactide for the production of traditional fiberboard, chipboard or OSB boards could improve their performance as well. Nevertheless, additional studies of the properties of wood-polymer composites are required to determine the optimal ratio of polylactide binder and develop a technology for producing such composites for industrial use.

4 Conclusions

The conducted studies of the properties of polylactide and wood-polymer composite based on it show that the use of polylactide can make it possible to obtain efficient and environmentally friendly building materials. The most preferred type of material may be decking, since the characteristics of the wood-polymer composite meet the requirements for decking. The consumption of polylactide in this case is quite high, but the products differ in quality and, after the end of their service life, can be processed by thermal biodegradation.

However, it is also possible to obtain more conventional polylactide based materials. The use of polylactide as a binder makes it possible to obtain chipboard, fiberboard and OSB products with improved performance properties. Such products can be used for all construction tasks, but the most effective seems to be their use as auxiliary materials (formwork panels, box walls, pallets, etc.). Such materials are subject to higher mechanical and chemical stresses, and their wear and tear gives rise to the need for efficient processing.

As a direction for further research, further study of the properties of wood-polymer composite based on polylactide, optimization of its composition and development of more efficient products based on it were chosen.

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