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Regarding some mechanical properties of decking made of wood-polymer composites with different fillers

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Abstract. One of the areas of wood waste processing is their use in the production of wood-polymer composites (WPC). The relevance of wood-polymer products is due to the wide range of applications and qualities of this material. WPC does not rot, is not damaged by insects and fungi, and does not contain harmful binders. WPC products do not crack or warp and are water-resistant, which makes them a good material for manufacturing decking. Therewith, the decking board must have certain mechanical qualities, which will allow it to be used in fairly harsh conditions – under the influence of moisture, UV radiation, and with a certain load. The purpose of this study was to determine the main physical and mechanical characteristics (density, flexural strength, elastic modulus, water absorption, hardness, abrasion resistance, changes in linear dimensions when the atmospheric environment changes) of decking samples made of WPC with various fillers. For the study, samples were taken from hollow decking, in which polyethylene (PE) and polyvinyl chloride (PVC) were used as a filler.Based on the conducted experimental studies, it was identified that the density of both samples is quite high, close to the maximum; the difference is insubstantial, but when examining micro-cuts under a microscope in samples in which PE is used as a binder, a larger number of cavities are observed, which indicates the presence of excess moisture or a lack of mineral fillers. It can also be a sign of polymer destruction. It was determined that a number of other important indicators, such as flexural strength, elastic modulus, water absorption, and abrasion resistance, were the best in samples with polyvinyl chloride filler. The greatest difference was in the flexural strength index – 35%. It was also identified that both samples were equivalent in hardness. However, the elastic modulus of the sample with a PE filler exceeded the values of the sample with a PVC filler by almost 2.5 times. Thus, based on the conducted studies, it is possible to identify a number of clear dependencies that indicate that the use of polyvinyl chloride as a binder substantially improves the physical and mechanical performance of decking based on a wood-polymer composite. The results of the conducted research will allow solving the problems of improving the strength characteristics of wood-composite material to expand the range of goods based on wood waste

Keywords: density, hardness, modulus of elasticity, water absorption, abrasion resistance

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Introduction

One of the areas of wood waste processing is their use in the production of wood-polymer composites (WPC). The relevance of wood-polymer products is determined by a wide range of applications, ranging from interior decoration of houses, offices, construction of gazebos, and terraces, to details of automotive products. The disadvantages of existing similar products include the high cost associated with using only primary raw materials (Galiyev, 2015).

Given that the main share of WPC products falls on decking, the task of developing flooring in the form of boards based on wood waste and secondary polymers, produced by conventional methods of processing polymer composites, is relevant. Wood-polymer composite is a modern material containing wood filler (50-80%), polymers, and special chemical impurities (additives). The rapid development of WPC is due to a number of advantages noted in the papers (Klesov, 2010; Safin et al., 2014). The properties of WPC depend on the properties of the polymer matrix, wood particles, the nature of the bond, and the interaction between them. WPC does not rot, is not damaged by insects and fungi, and does not contain harmful binders. WPC products do not crack, do not warp, and are water-resistant. A number of authors note that moisture resistance is more affected by the type of binder, rather than the percentage of wood filler (Khasanshin et al., 2011). A functional relationship describing changes in water absorption and WPC density as a function of polymer content has also been established (Safin et al., 2014).

Since WPC is often used as a structural element, its physical and mechanical qualities become important. In the literature, there is very limited information about the dependence of the physical and mechanical properties of WPC on their composition. Some authors have noted that rigidity and strength are satisfactory only if an expensive binder is added to the material: this is necessary to increase the compatibility between wood flour and polymer, which would otherwise have no similarity in the course of the corresponding chemical reactions (Lu et al., 2005; Yang et al., 2012), and to create efficient load transfer between wood fibres and the surrounding polymer (Mazzanti et al., 2012).

Since WPC is brittle, it often contains impurities that increase impact strength (Mazzanti et al., 2019, 2019, 2020).

Matseyevich & Askadskiy (2017) noticed that WPC based on matrix polymer PVC has much better properties than WPC based on matrix polymers such as polyethylene and polypropylene. This applies to such important indicators as flexural strength and elastic modulus.

Based on the analysis of these literature sources, it was identified that wood-polymer composite is a modern material that is becoming increasingly popular due to its qualities. The main area of the study is the examination of the polymer component of the material and its impact on physical and mechanical parameters.

The purpose of the study is to determine the main physical and mechanical characteristics (density, flexural strength, elastic modulus, water absorption, hardness, abrasion resistance, changes in linear dimensions in the event of changes in the atmospheric environment) of WPC samples with different fillers.

Materials and Methods

For the study, samples of hollow decking made of wood-polymer composite with a cross-section of 23×128 mm of dark brown colour were selected, the layer on the back side is smooth, profiled on the front side with different fillers. In sample 1, the filler was polyethylene (PE), and in sample 2 – polyvinyl chloride (PVC) (Fig. 1, a, b).

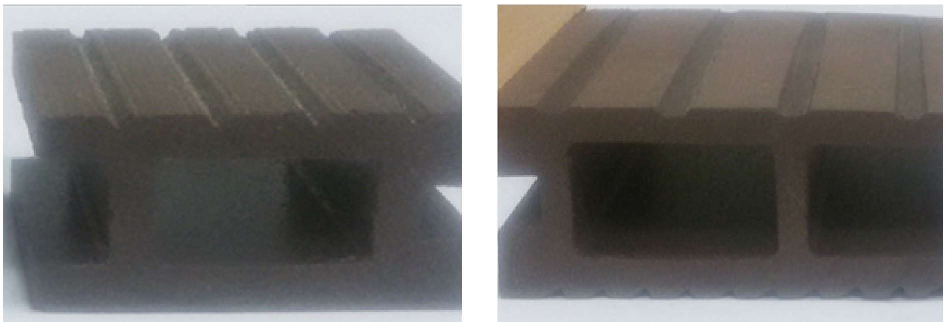

Figure 1. Prototypes of decking: a – with PE filler, b – with PVC filler

Since WPC is a fairly new material, there is no state regulatory framework for testing mechanical properties. The density was determined according to the international standard ISO 1183-1. Density for WPC is a reference indicator and gives an indirect assessment of strength indicators, characterises the presence of mineral fillers in the WPC, and depends on the type of polymer and the composite. Notably, the reduced density accelerates the process of WPC oxidation and is the result of increased porosity (the presence of cavities) of boards due to the presence of moisture in the initial components of WPC (primarily wood fibres) and the destruction of the polymer during processing (in case of overheating, excessive shear and/or lack of additives).

Excessive porosity allows oxygen to enter the WPC material from the inside, substantially increasing the available surface area along with the oxidation rate. Moisture is an effective catalyst for polymer oxidation.

A very important indicator for decking is hardness, which characterises the contact strength of the product, allows assessing the indentation resistance and scratch resistance. The value of the indicator depends on the type of polymer matrix, the amount of filler, and the density of the finished composite. Hardness was determined using a Shore hardness tester. The method described in GOST 24621-91 was applied. For the study, an indenter for a durometer of type D (from 20 to 90) was used in the form of a steel rod with a diameter of 1.10-1.40 mm.

Flexural strength is one of the main indicators of the mechanical properties of a material. It characterises the correctness of the selected composition and technological modes of production and the efficiency of the binder in the composition. The value of this indicator characterises the balance of the formula and the correctness of the technological process. The flexural strength was determined according to the methods given in EN 310 and GOST 10635.

The modulus of elasticity during bending is directly related to the deflection of the board placed on the supports under a certain load. In contrast to the flexural strength of composite boards, which usually substantially exceeds the requirements of building codes for the usually accepted step of laying logs (approximately 40 centimetres (16 inches) from the centre), the modulus of elasticity when bending composite boards on a polymer basis often imposes certain restrictions on their installation: the step of laying logs should not exceed 1/360 of the section. This indicator is not normalised, but at this density, it should be more than 1300 MPA.

Water absorption characterises the geometric stability and hygroscopicity of the WPC profile. Water is the main aggressive factor of atmospheric influences, as it causes swelling of the material and accumulation of defects, especially when the temperature changes from (-) to (+). The research method given in EN 1087-1 and GOST 32399 was used to determine water absorption.

The value of the water absorption index depends on the formulation and homogenisation of the composition, indicates the distribution and combination of the components of the wood filler.

Water absorption of WPC materials can lead to: the deformation of boards, swelling, and mould spread. In addition, the saturation of WPC boards with water sometimes reduces the modulus of elasticity when bending boards, therefore, causing greater deflection under load. Water absorption also leads to faster destruction of boards, oxidation (water is a catalyst for polymer oxidation), and other negative consequences. WPC materials absorb water due to their porosity (cavities).

WPC decking samples were first conditioned to a constant mass, then kept in water (pH 7±1) at a temperature of 20±1°C for 72 hours. In water, the samples were placed on the edge so that the distance to the walls and bottom of the container was at least 15 mm. After that, the samples were removed and wiped with filter paper. Dried samples were placed in a freezer with a temperature of minus 12°C for 24 hours. The samples were then removed and placed in a drying chamber for 70 hours at a temperature of 70°C. After drying and cooling the samples for 4 hours, the cycle was repeated. A total of three test cycles were performed.

Important indicators for decking are the rate of wear (abrasion) and the change in linear dimensions when the atmospheric environment changes (high humidity/low humidity), mm/100 mm in length. The study was conducted according to the method given in GOST 9590. Wear was determined on a Taber 5155 Rotary abrasimeter. The samples were pre-weighed with an accuracy of 0.001 g and fixed on the device. When reaching 500 rpm, the test was stopped and the samples were weighed again with an accuracy of 0.001 g. The wear rate was calculated by the formula.

Before determining the change in linear dimensions when the atmospheric environment changed, the length of the samples was measured with an accuracy of 0.02 mm. Three samples were placed in a drying cabinet and kept at a temperature of 70±2°C for 24 hours, and three samples were in a chamber with a relative humidity of 92±3% and a temperature of 40±2°C for 96 hours.

Results and Discussion

The density of both samples is quite high, close to the maximum; the difference is insubstantial, but when examining micro-sections under a microscope at 600x magnification, a larger number of cavities are observed in sample No. 1 (Fig. 2a), which indicates the presence of excess moisture in the board or a lack of mineral fillers, and the destruction of the polymer. In sample No. 2, which has a higher density of 1.91% and a lower porosity (Fig. 2b), the presence of metal is observed, which can accelerate the oxidation process of the board at high temperatures.

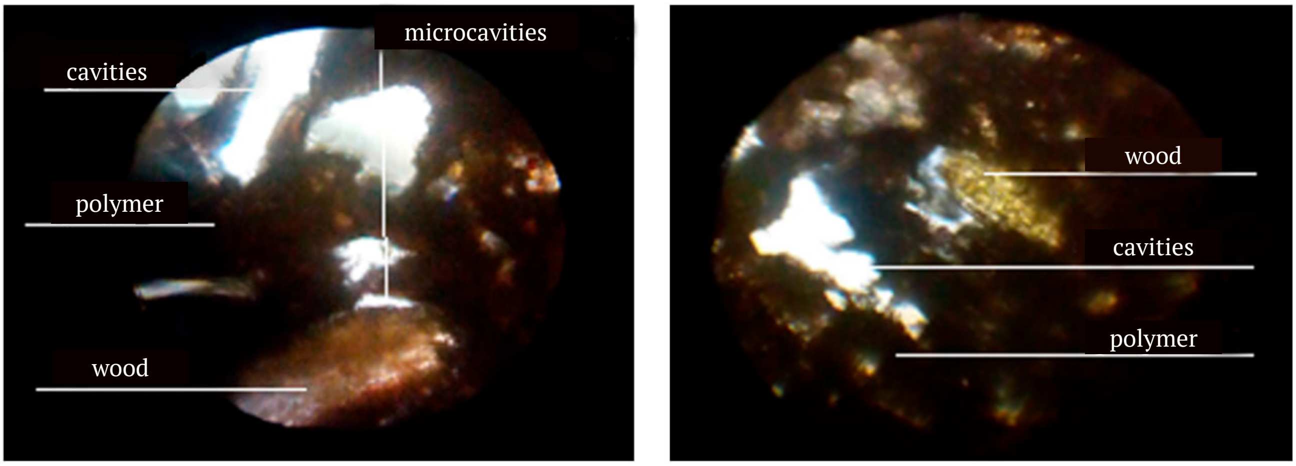

Figure 2. Images of WPC board sections under a microscope at 600x magnification:
a – sample No.1, board with larger cavities; b – sample No.2, board with smaller cavities

Table 1 shows the results of determining the physical and mechanical parameters of boards made of WPC. The hardness of sample No.1 slightly exceeds the hardness of sample No.2 – by 5.8%. Therefore, with this parameter in the complex, samples can be considered equally substantial.

Table 1. Results of experimental determination of physical and mechanical parameters of WPC decking

Indicator	**Parameter values**	
	Sample No.1 WPC (PE)	**Sample No.2 WPC (PVC)**
Density, $g*cm^{-3}$ ($kg*m^{-3}$)	1,258 (1258)	1,282 (1282)
Shore hardness (units of Shore by D durometer from 20 to 90)	62.1	58.5
Flexural strength, MPa ($kgf*cm^{-2}$)	17.1 (174.42)	26 (265.2)
Modulus of elasticity (hardness), MPa	2646	1053

Table 1. Continued

Indicator	Parameter values	
	Sample No.1 WPC (PE)	**Sample No.2 WPC (PVC)**
Water absorption, %	2.63	2.02
Abrasion resistance (wear rate, mg/100 rpm)	0.08	0.05
Change in linear dimensions when the atmospheric environment changes (high humidity/low humidity), mm/100 mm length	0.72/1.6	0.5/0.3

When examining the flexural strength, it was identified that sample No.2 substantially exceeds the strength of sample No.1, meets regulatory requirements (25 MPa) and has advantages in a substantial margin of flexural strength during board exploitation.

The study of the elastic modulus showed a substantial excess of this indicator in sample No.1 compared to sample No.2. The elastic modulus value of sample No.2 can be considered satisfactory, but insufficient for the available density.

During the experiment to determine water absorption, intense discolouration of board samples No.1 was observed, in contrast to the integrity of samples No.2. In addition, during an increase in humidity and temperature and during mechanical damage, a persistent unpleasant specific smell was observed from the samples of board No.1. According to this indicator, sample No.1 substantially exceeds sample No.2 (by 30.2%), which indicates that in conditions of high humidity and atmospheric influence, board No.2 will provide the best water absorption indicators.

Table 1 shows that the wear of sample No.1 substantially exceeds the wear of sample No.2, which indicates greater resistance to abrasion of board No.2. This is also due to reinforcement with metal elements.

The study of such an important indicator for decking as the change in linear dimensions under changing operating conditions showed that the elongation of 100 mm of WPC board No.1 was 0.72 mm and 1.6 mm, and sample No.2 – 0.5 mm and 0.3 mm. Consequently, sample No. 2 was more resistant to changes in linear dimensions under conditions of high humidity (92±3%) with the environment temperature of (40±2°C) and high temperatures (70±2°C) with low humidity. Notably, in general, this indicator of WPC boards is largely unpredictable. An increase in temperature for every 10°F (≈3.6°C) accelerates the oxidative degradation of WPC by about three times. On a hot sunny day, at an air temperature of 90°F (32°C), the surface of WPC flooring heats up to approximately 130-140°F (54-60°C). At 110°F (43°C), the flooring surface temperature reaches 160°F (70°C), and the thermal oxidation of the polymer in WPC is accelerated by a factor of 240. Two powerful stabilising factors contribute to extending the service life of composite decking boards – the density of WPC and the introduction of antioxidants.

Conclusions

The obtained results of experimental studies allow the evaluation of the physical and mechanical parameters of WPC decking with various fillers. According to the results of the study, it was identified that the quality indicators of decking made of wood-polymer composite have a fairly high level and generally meet the established standards. Therewith, it is noted that WPC decking with a PE-based binder has worse performance, which can be explained to some extent by the presence of a large number of cavities. The presence of cavities indicates excessive moisture in the board or a lack of mineral fillers, and the destruction of the polymer. Thus, based on the conducted studies, it is possible to identify a number of clear dependencies that indicate that the use of polyvinyl chloride as a binder substantially improves the physical and mechanical performance of decking based on a wood-polymer composite.

The results of the conducted study will help solve the problems of improving the strength characteristics of wood-composite material to expand the range of goods based on wood waste.

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Щодо деяких механічних властивостей терасної дошки з деревинно-полімерних композитів із різним наповнювачем

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Анотація. Одним із напрямів перероблення деревинних відходів є їх використання у виробництві деревинно-полімерних композитів (ДПК). Актуальність деревинно-полімерних виробів зумовлено широким спектром застосування та якостями цього матеріалу. ДКП не гниє, не ушкоджується комахами та грибами, не містить шкідливих в'яжучих. Вироби з ДПК не розтріскуються, не жолобляться, водостійкі, що робить їх гарним матеріалом для виготовлення терасної дошки. Разом з тим, у терасної дошки мають бути певні механічні якості, що дасть змогу використовувати її в досить жорстких умовах – під дією вологи, УФ-випромінювання та з певним навантаженням. Це дослідження мало на меті визначення основних фізико-механічних характеристик (щільності, міцності на згин, модуля пружності, водопоглинання, твердості, стійкості на стирання, зміни лінійних розмірів при зміні атмосферного середовища) зразків терасної дошки, виготовленої з ДПК з різними наповнювачами. Для дослідження було відібрано зразки з пустотілої терасної дошки, у яких як наповнювач застосовано поліетилен (ПЕ) та полівінілхлорид (ПВХ). На основі проведених експериментальних досліджень було встановлено, що щільність обох зразків є достатньо високою, близькою до максимальної; різниця є несуттєвою, однак при дослідженні мікрозрізів під мікроскопом у зразках, у яких як в'яжуче застосовано ПЕ, спостерігається більша кількість порожнин, що свідчить про наявність зайвої вологи або нестачу мінеральних наповнювачів. Також це може бути ознакою деструкції полімеру. Визначено, що низка інших важливих показників, як-от міцність на згин, модуль пружності, водопоглинання, стійкість до стирання, найкращими виявилися у зразках із наповнювачем із полівінілхлориду. Найбільша різниця була у показника міцності на згин – 35 %. Також встановлено, що за твердістю обидва зразки виявилися рівнозначними. Проте модуль пружності у зразка з наповнювачем з ПЕ перевищив показники зразка з наповнювачем із ПВХ майже у 2,5 разу. Отже, на основі проведених досліджень можливо виявити низку чітких залежностей, які свідчать, що застосування полівінілхлориду як в'яжучого значно покращує фізико-механічні показники терасної дошки на основі деревинно-полімерного композиту. Результати проведених досліджень дадуть змогу вирішувати проблеми покращення міцнісних характеристик деревинно-композиційного матеріалу для розширення асортименту на основі деревинних відходів

Ключові слова: щільність, твердість, модуль пружності, водопоглинання, стійкість до стирання