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Promising areas for the use of industrial hemp for the manufacture of sheet building materials

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Abstract. The relevance of the study is to identify the potential for creating innovative building materials that can improve the quality and efficiency of construction and furniture production. The purpose of the study is to analyse the market of sheet building materials, explore the possibilities of using plant materials in construction and furniture industry, and compare the properties of the latest building materials with the existing ones. The analysis of literature sources included a search and evaluation of new developments in the construction industry, as well as an analysis of statistical data on the production of architectural materials in Ukraine, using information resources and Internet search services. To evaluate the consumer properties of innovative building materials, the author used quality assessment methods using visual perception and special tools, in accordance with the established regulatory documentation. Important issues aimed at using resource-saving technologies in construction and developing the latest (environmentally-friendly) building materials are considered. The current state of the Ukrainian market of building sheet materials and the properties of industrial hemp are investigated in order to determine the most cost-effective use of hemp raw materials as an effective basis for the creation of building materials for various purposes. The suitability of the raw materials was determined and assessed, experimental samples of chipboards with different fillers were obtained, and the physical, mechanical and aesthetic characteristics of the finished products were investigated. The research will contribute to the development of the hemp processing industry, as well as enterprises that produce goods for various functional purposes from hemp, which will provide conditions for combining the agricultural sector and the construction industry, i.e. building a closed production cycle

Keywords: chipboards; wood fibre boards; density; thermal conductivity; hemp fire; hemp stem; insulation materials

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Introduction

Since the beginning of 2012, the demand for wood and wood waste products from the population, construction and furniture industries has been accompanied by a significant decrease in wood resources. In addition, growing consumer demands for the quality of materials used in home furnishings are driving demand for safer products, forcing manufacturers to introduce the latest technologies to produce environmentally-friendly products.

T. Jami *et al.* (2022) noted that construction is considered one of the most dangerous sectors for the planet – it accounts for 28% of carbon dioxide emissions annually, and in general, buildings generate 40% of the total amount of harmful substances in the course of their existence. That is why considerable attention has been paid to the search for and use of environmentally-friendly building materials since the 1990s and as of 2024. There are two main areas that can reduce the negative impact on the environment and help preserve wood resources. These studies are aimed at optimising existing technologies and developing new resource-saving technologies for the production of innovative building materials. Therefore, research into the possibilities of using industrial hemp as an alternative raw material for the production of building materials is quite important and relevant.

The study by E.M. Tudor *et al.* (2020) focuses on the development of materials that can meet consumer requirements for heat, noise and other types of insulation and can also be considered environmentally-friendly. Hemp-based composite materials are an important alternative for the construction sector. These materials are considered environmentally-friendly, they contribute to the energy efficiency of buildings, absorb carbon dioxide and reduce pollutant emissions during the production process, while generating limited waste (Liu *et al.*, 2023).

Among all industrial crops, hemp attracts special attention due to its agro-technological and technical properties, as it is one of the most stable and fastest-growing agricultural plants. R. Grigorov *et al.* (2022) argue that it can be harvested twice a year, so it is twice as effective in reducing the greenhouse effect. During its growth, industrial hemp absorbs 8 to 15 tonnes of CO_2 per hectare of crop. In comparison, forests typically absorb between 2 and 6 tonnes of CO_2 per hectare per year, depending on the number of years of growth, climate region and tree type.

The search for resource-saving building technologies has become an important area of innovation in the construction sector. Natural building materials, such as wood, industrial hemp and clay, have proven their quality and durability in buildings that meet modern requirements for a healthy indoor environment (Barbhuiya & Das, 2022).

Modern research by scientists confirms that hemp is an excellent filler in composite materials for thermal insulation and the manufacture of chipboards. The source UBC students build near-zero carbon hempcrete building on vancouver campus (2023) confirms that the use of hemp aggregate for concrete mixtures began in France in the 1980s to replace adobe (mixed clay, sand and straw) for wall cladding. The introduction of the latest construction technologies in Europe through the use of plant materials has expanded the possibilities of using industrial hemp.

Studies conducted by P. Bouloc *et al.* (2023) show that almost the entire hemp stem can be used to produce a variety of building materials. Hemp fibre is an alternative substitute for synthetic fibres for the manufacture of insulation materials, and hemp is used to produce lightweight concrete and plastering solutions. Insulation materials, which are widely used in construction, improve the energy efficiency of a building and provide comfortable indoor conditions.

In the works of S.M.Q. Bokhari *et al.* (2021), J. Liao *et al.* (2022) noted that hemp has quite good acoustic and insulating properties, but the issue of maintaining these properties, as well as chemical resistance and compatibility with various adhesives during the production process, is crucial. In addition, the mechanical properties of hemp raw materials, such as particle size, density, thickness and shape, depend on the morphological structure of the stem. Therefore, these material parameters are important characteristics that are taken into account in the production of construction products and determine their performance properties.

The purpose of the article was to study the existing technologies for the manufacture of facing, insulation and composite materials based on plant-based raw materials, analyse the market for harvesting wood raw materials and producing chipboards in Ukraine, and determine the suitability of hemp raw materials for the production of sheet building materials.

Materials and methods

The study to assess the quality of raw materials to obtain experimental samples of chipboards and their physical and mechanical properties was conducted in the laboratory at the Kyiv National University of Construction and Architecture during 2019-2023. Different types of raw materials were used to make the samples: straw (unprocessed stem) and hemp bark, as well as wood chips. The raw materials were prepared by grinding, sorting into fractions, and drying to a moisture content of 6-8%. The suitability of the raw materials can be determined by their properties (homogeneity and moisture content) using organoleptic methods and instrumental evaluation. Uniformity was determined by visual and touch assessment using DSTU ISO 6658:2005. Sensory testing. Methodology. General guidelines (2006), DSTU 4922:2008. Timber and sawn timber products. Methods for determining moisture content (2009).

In order to substantiate the feasibility and possibility of replacing wood with plant-based raw materials, namely industrial hemp, a comparative analysis of the mechanical properties of prototype samples of boards made on the basis of wood chips, hemp stalk and bark was carried out. The prototypes of wood chip and hemp boards were manufactured using the hot pressing technology, the essence of which is to keep the prepared samples at high temperatures (120°C-180°C) under a pressure of 3.5-5 MPa and subsequent holding in chambers for 8-1 hours to reduce shrinkage and level the moisture level. In Germany, almost 95% of all chipboards are produced using this method and it is called "flat pressing" (Baraboi *et al*., 2019).

To make the 200x200 mm specimens, 285 g of chopped hemp bark, stem or wood shavings were used, pre-dried to a moisture content of no more than 8%. The prepared raw materials were mixed with the adhesive solution, after which the samples were moulded and compacted using a hand press and finally baked in a hot press.

The research included a search and analysis of relevant scientific sources on innovations in the construction sector. Statistical data on the production of sheet materials in Ukraine were researched using various information resources and Internet search services. To study the consumer properties of innovative building materials, such as thickness, density, bending strength, water absorption and aesthetic indicators (surface condition and colour), organoleptic and instrumental evaluation methods were used, using the regulatory documentation DSTU EN 309-2003. Particleboard. Definition and classification (EN 309:1992, IDT) (2005), DSTU EN 311:2003. Particleboards. Surface strength of particleboards. Test methods (2005), DSTU B EN 12087:2016. Thermal insulation products for construction purposes. Determination of water absorption during prolonged immersion (EN 12087:2013, IDT) (2016), DSTU EN 312:2018. Particleboard. Technical requirements (EN 312:2010, IDT) (2018).

The research complied with all the standards set out in the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

Results and discussion

Economic growth, changes in consumer values, a greater awareness of social welfare and environmental issues, and evolving tastes are the main factors driving demand for woodworking and construction products. Awareness of environmental issues and consumer expectations regarding the quality and safety of goods are becoming more pronounced, prompting the development of specific requirements for the construction and furniture market.

An important factor driving the revision of technologies and the use of raw materials is the growing role of efficient use of renewable resources and waste. Increasing resource productivity and reducing waste are two key strategies for businesses to manage limited resources in the current and future.

The production of sheet wood materials in the world is constantly growing. This production is characterised by large volumes and a high position in the wood products markets. In the group of European countries, the largest share of wood panel production is accounted for by particleboard, with levels ranging from 83.3% in the UK to 57% in Italy (Kirilovs *et al*., 2012; Mirski *et al*., 2017; Hemp blocks for naturally efficient masonry, 2021). Particleboard is the most widely used material in furniture production and construction. The first production of this material began in Bremen (Germany) in 1941 (Nishimura, 2015). The main advantages of chipboard include ease of processing, cost-effectiveness, reliability and high practicality. According to the classification of the State Statistics Service of Ukraine, particleboard construction materials are used for partitioning and are classified under the code "Wood chipboards, unprocessed" (State Statistics Service of Ukraine, 2024).

Modern production technologies ensure high quality and safety of products. Particleboard is made by hot pressing wood chips, which are obtained from industrial wood of various species and waste from woodworking enterprises. During this process, bonding, water-repellent, antiseptic and other substances are added to give the board its special strength and durability.

Among the chipboard producers in Ukraine, there are Ukrainian companies that produce their own product and companies that work on behalf of well-known global brands such as Egger, Swisspan, Kronospan, whose products are supplied to most countries. The quality of board materials produced on high-tech lines (mainly Finnish and German automated conveyor systems) meets stringent European standards in terms of size, technical characteristics, performance, environmental and sanitary and hygienic indicators. The markey analysis and dynamics of chipboard production in Ukraine have undergone significant changes to both internal factors (raw materials, technology, availability of modern equipment) and external factors (COVID-19 and military situation in Ukraine). The dynamics of wood-based production in Ukraine is shown in Figure 1.

As can be seen from the data presented, since 2018, Ukraine has been experiencing a decline in the production of wood-based panels, which is due to the saturation of the market with imported goods and a decrease in the volume of wood harvesting. Thus, according to the State Statistics Service of Ukraine (2024), the volume of wood harvesting for various functional purposes has been gradually decreasing since 2018 (Table 1).

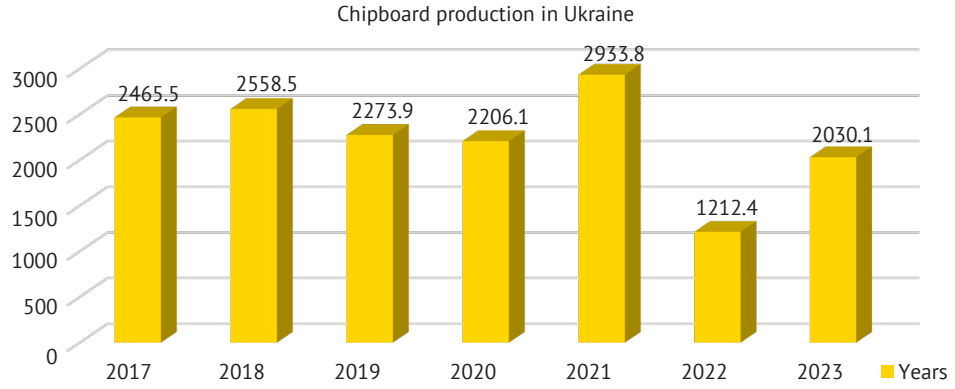

Figure 1. *Dynamics of chipboard production in Ukraine in 2017-2023, thousand m³*
Source: *developed by the authors based on data from the State Statistics Service of Ukraine (2024)*

Table 1. *Timber harvesting volumes in 2016-2023, thousand m³*

Years	2016	2017	2018	2019	2020	2021	2022	2023
The volume of workpiece	22612.8	21923.0	22529.7	20869.6	17826.2	17649.4	15934.3	12396.3

Source: *developed by the authors based on data from the State Statistics Service of Ukraine (2024)*

The data presented in Table 1 confirms the fact that the amount of own wood raw materials in Ukraine is significantly decreasing, while the demand for wood-based products is not decreasing. Therefore, an important issue is the search for alternative local raw materials that can be successfully used for the production of furniture and construction products.

The martial law and hostilities in the south and east of Ukraine have resulted in the suspension or destruction of many construction, processing and furniture companies. A large number of housing units have been destroyed, especially in the frontline areas, and various types of sheet construction materials, such as chipboard, fibreboard and OSB, are most often used to rebuild damaged housing. In order to solve the issue of providing the population with the necessary building materials and preserving our own wood, it is necessary to use plant-based raw materials that are not inferior in their properties to the wood used to make chipboard.

The properties of hemp allow it to be effectively used for the production of sound, vapour and heat insulation materials, which helps to create a special indoor microclimate, suppresses pathogens, fungi and bacteria, while its low cost and the possibility of complete recycling without harming the environment provide additional benefits to new building materials. Industrial hemp is a bast-fibre crop that has high strength and flexibility, which is a very important criterion for use in the production of various types of construction and furniture products. Therefore, the study was aimed at determining the suitability of plant-based raw materials for the manufacture of sheet building materials (SBM) and further evaluation of their consumer properties.

According to the results of the study of the quality of the input raw materials (wood chips, chopped hemp stem and bark), it was found that the presented samples differed significantly in terms of homogeneity, which is explained by the peculiarities of the morphological structure of wood and hemp, as well as the fractional composition. Thus, wood shavings and hemp pellets did not visually differ in homogeneity, although there was a difference in the surface condition of the crushed particles: the pellets, unlike the shavings, had a smoother surface. The raw material, which consisted of chopped hemp stem, was heterogeneous due to the high content of the fibrous part of the stem. The moisture content of the raw material samples was almost the same. The results of the raw material suitability assessment are presented in Table 2.

Table 2. *Raw material quality indicators*

Indicators	Types of input raw materials		
	wood chips	cannabis bonfire	chopped hemp stalk
Homogeneity	chopped wood particles – 25-30 mm thick, 10-50 mm long, golden to brown in colour	all the firewood particles are almost the same size: thickness – 15-20 mm, length – 20-25 mm, colour – light yellow with grey tint	the mixture is heterogeneous, contains wood and fibrous particles that vary in length and thickness, the colour is light yellow with a green tint
Moisture content, %	12	15	15

Source: *developed by the authors*

The results of the quality assessment of the prepared raw materials show (Table 2) that the hemp bark and stem do not differ significantly in fractional composition from wood chips, the differences in colour are not significant, and the humidity will be brought to the normalised level (6-8%) by further drying, which confirms the possibility of using hemp raw materials for the production of particleboards.

The technical characteristics of chipboard depend on the properties of the chips and impurities used in its manufacture, as well as on the thickness and dimensions of the board (Baraboi *et al.*, 2019). The main ones are:

- density;
- strength;
- rigidity;
- water absorption;
- fire resistance;
- environmental friendliness;
- size.

The results of the analysis of the mechanical properties of the experimental samples of slabs obtained from three types of raw materials by hot pressing are presented in Table 3.

Table 3. *Mechanical properties of the prototypes of wood chipboard and hemp chipboard*

No.	Indicators	Chipboard	Hemp chipboard obtained from a fire	Hemp chipboard made from the stem
1	Thickness, mm	15.0	15.0	15.0
2	Density, kg/m^3	670.2	658.6	598.3
3	Bending strength, MPa	6.2	7.1	7.5
4	Water absorption, %	120	135	395
5	Aesthetic indicators, points	5	5	3.5

Source: *developed by the authors*

The results of the studies of the mechanical properties of the experimental samples show that the hemp chipboard made from bark has better bending strength (7.1 MPa) and lower density (658.6 kg/m^3) compared to wood chipboard and bark chipboard, but is better than both samples in terms of strength (7.5 MPa). This is due to the presence of fibrous impurities in the raw material mixture.

The water absorption (after full immersion for 28 days) of the boards differs significantly. For example, the best value is achieved by the chipboard – 120%, which is 15% better than that of the board made from bark (135%), which is explained by the more porous structure of bark and the lower density of the board. As for the sample obtained from the hemp stem, a rather high percentage of water absorption (395%) is observed due to the heterogeneous structure of the prepared mixture and the presence of the fibrous part of the stem.

The aesthetic characteristics of the samples, namely the surface condition (smoothness, roughness, structure) and colour, which were assessed by visual inspection, have the same score for chipboard and bark board. The stem board received a lower score due to its heterogeneous structure and atypical colour (yellow with a greenish tint), but this feature can be corrected in the process of further processing of the board (painting, applying a protective film, etc.).

Theoretical and experimental studies aimed at assessing the suitability of various hemp raw materials for the production of sheet building materials and determining their consumer properties confirm the possibility of using industrial hemp. This paper presents the results of producing plates using only one method – the hot pressing method. Studies conducted by H. Kallakas *et al.* (2018), in which different raw material compositions (hemp trust, hemp bark, and a mixture of wood chips and bark) are used to produce particleboards, proved the possibility of producing different sheet materials – wood chip and fibreboard – by dry and wet pressing, as well as by applying a special type of paper to the surface to improve strength and aesthetics. The authors note that the best bending strength (7 MPa) is achieved by boards made from hemp bark, followed by boards made from wood chips (6.26 MPa). Wood-fibre boards made from hemp resin are significantly inferior in terms of flexural strength, which is 0.31-1 MPa. The water absorption of the board samples also differed. It is noted that the water absorption of wood-based panels from hemp bark is 18% higher than that of wood chips. Wood-fibre boards from hemp residue obtained by dry pressing did not pass the test for water absorption at all – as a result, they dissolved.

B. Abu-Jdayil *et al.* (2022) argue that due to the rapid growth of hemp and the accumulation of large biomass, the possibilities of using this plant are endless. In their work, the authors examined various ways to use composite panels made of hemp bark for insulation and sealing of buildings. The results of the study showed that energy consumption for heating the house decreased by 42%, and the airtightness of the room insulated with hemp panels increased by almost 70%, with heat loss overnight in winter being less than 1°C compared to 9ºC when using typical insulation materials.

B. Martínez *et al.* (2023) studied the influence of various factors on the formation of acoustic and thermal insulation properties of hemp-based materials. The authors note that reducing the particle size of the stem helps to improve the acoustic properties of finished

building products, the optimal particle length is 4-6 mm, and their density of 0.3 g/cm^3 improves thermal insulation performance.

In the production of particleboards and other sheet building materials, phenol-formaldehyde resins are used as an adhesive mixture, which were recognised as carcinogenic by the World Health Organisation in 2004 (World Health Organisation, 2010). Therefore, many manufacturers are facing the issue of replacing them with environmentally-friendly and human-friendly components in the production of chipboard. P. Alao *et al.* (2020) in their work manufactured particleboards from hemp bark using different adhesives: urea-formaldehyde, formaldehyde-free, acrylic and soybean resin on a biological basis. The samples were obtained by hot pressing and their properties were investigated. The results of the study show that hemp boards based on soy resin have the best strength and water absorption characteristics, which can be an alternative to hazardous formaldehyde aggregates.

A.T.M.F. Ahmed *et al.* (2022) note the wide potential of industrial hemp in various industries. The authors paid special attention to the study of methods for the production of composite materials as substitutes for plastic or polystyrene foam. The paper describes several methods of producing and processing composites and compares the mechanical properties of hemp fibre with other plants. The researchers noted that the tensile strength of hemp is 1100 MPa, which exceeds that of the following plants: jute – 800 MPa, ramie – 938 MPa, sisal – 855 MPa, which confirms the possibility of using hemp raw materials in construction, automotive industry, and for roadway reinforcement. In the production of composite materials for the woodworking and construction industries, important criteria for raw materials include not only basic properties, mechanical strength, and possible applications, but also additional characteristics such as microbiological resistance and thermal conductivity (Constantine *et al.*, 2018).

S.L. Lee *et al.* (2022) investigate the chemical composition and physical and mechanical properties of various types of plant material and agricultural waste to produce particleboards. The authors point out that non-wood biomass (leaves, seeds, fruits, stems, straw, husks) should be used for the production of sheet building materials. To this end, it is necessary to study their chemical composition, namely the content of cellulose and lignin, which are valued in wood, as they contribute to the strength and durability of finished products. The results of the study showed that the cellulose and lignin content of different plant species differs and is as follows: pine wood – 49.5% and 27.5%, wheat straw – 39.3% and 20.7%, hemp raw materials – 67.5% and 8.0%, respectively. Experimental samples of chipboard based on the presented types of raw materials did not differ significantly in terms of strength and density, but water absorption was higher in those boards with a lower lignin content.

As noted by S. Sair *et al.* (2018), the physical and mechanical properties of hemp-based insulation materials, namely thermal conductivity, flexural strength and water absorption, vary depending on the percentage of hemp fibre. In their research, the scientists produced polyurethane insulation materials by adding different amounts of fibres from 5 to 30%. When assessing thermal conductivity, it was noted that with an increase in the content of hemp fibres, the thermal conductivity of products increases. This is due to an increase in the density of the sample and the morphological characteristics of the raw material. Water absorption also increased with the percentage of hemp impurities. An inverse proportional relationship was observed in the bending strength study: with an increase in fibre content, the strength of the boards increased.

C. Lühr *et al.* (2018) studied the effect of hemp variety, growing conditions and primary processing on the quality of the resulting particleboards. The authors used varieties that differed significantly in their properties: the content of fibrous and woody parts, the amount of cellulose and lignin, as well as different methods of grinding raw materials. As a result, it is noted that the density of the boards depends on the particle size and the number of grinding stages. Thus, the studies conducted confirm the possibility of using hemp bark for the production of sheet building materials. However, it is necessary to take into account the functional purpose of innovative hemp boards (for what purpose and under what conditions such material will be used) for further development of manufacturing technology and adhesive solution components.

Conclusions

The research has confirmed that hemp-based chipboards are a suitable substitute for wood-based chipboards. In addition, the production method of hemp-based panels has a significant impact on their mechanical and technical characteristics. An analysis of the Ukrainian particleboard market and wood harvesting volumes confirms a gradual decline in chipboard production and wood harvesting.

Thus, in 2023, chipboard production in Ukraine decreased by 18% compared to 2017, while timber harvesting almost halved. Given the high demand for sheet construction materials and the need to preserve forests, it is proposed to use a rapidly renewable raw material, industrial hemp.

The study assessed the mechanical and esthetic properties of the experimental samples, which confirmed the feasibility of replacing wood raw materials with hemp in the manufacture of wooden boards. The results obtained in determining the suitability of hemp for the production of sheet materials showed that the bark has a good homogeneous structure and does not contain fibrous impurities, which is important when

mixed with adhesives. The strength of a board made from hemp bark is 7.1 MPa, which is 13% better than that of wood chipboard, and the water absorption is 15% higher. The board made from chopped stalks has the best bending strength of 7.5 MPa, but is significantly inferior in terms of water absorption, which is explained by its lower density (598.3 kg/m^3) and the presence of fibre.

Further research will focus on optimising hemp processing to produce the highest quality and most efficient building materials. New technologies and methods for the production of sheet building materials using industrial hemp will be developed, which can increase their productivity and reduce costs. The environmental performance of the production and use of such materials will be studied in detail to ensure their sustainability and compliance with environmental standards.

Conflict of interest

None.

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Перспективні напрямки використання технічних конопель для виготовлення листових будівельних матеріалів

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Анотація. Актуальність дослідження полягає у виявленні потенціалу створення інноваційних будівельних матеріалів, які можуть покращити якість та ефективність будівництва та меблевого виробництва. Метою роботи є аналіз ринку листових будівельних матеріалів, дослідження можливостей використання рослинної сировини у будівництві та меблевій промисловості, а також порівняння властивостей новітніх будівельних матеріалів із вже наявними. Під час аналізу літературних джерел проходив пошук та оцінка нових розробок у галузі будівництва, а також було проаналізовано статистичні дані щодо виробництва архітектурних матеріалів в Україні, з використанням інформаційних ресурсів та сервісів пошуку в мережі Інтернет. Для оцінювання споживчих властивостей інноваційних будівельних матеріалів було використано методи оцінки якості за допомогою зорового сприйняття та спеціальних інструментів, згідно з встановленою нормативною документацією. Розглянуто важливі питання, які спрямовані на використання ресурсозберігаючих технологій в будівництві та розробку новітніх (екологічних) будівельних матеріалів. Досліджено сучасний стан ринку будівельних листових матеріалів України та властивості технічних конопель з метою визначення максимально рентабельного напрямку використання конопляної сировини в ролі ефективної основи для створення будівельних матеріалів різного призначення. Визначено і обґрунтовано проведено оцінювання придатності сировини, одержано експериментальні зразки деревостружкових плит з різними наповнювачами, а також досліджено фізико-механічні на естетичні характеристики готових виробів. Проведені дослідження будуть сприяти розвитку коноплепереробної галузі, а також підприємств, які виготовляють товари різного функціонального призначення з конопель, що забезпечить умови для об'єднання аграрної сфери та будівельної галузі, тобто побудову замкненого циклу виробництва

Ключові слова: деревостружкові плити; деревоволокнисті плити; щільність; теплопровідність; конопляна костра; конопляне стебло; ізоляційні матеріали