

PAPER • OPEN ACCESS

Features of technology for producing wood and polymer composites by extrusion method

To cite this article: S I Ponikarov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012090

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Features of technology for producing wood and polymer composites by extrusion method

S I Ponikarov¹, R F Sagitov², V D Bashirov³, V E Dudorov³, V G Korotkov³, Z R Akhmadiyeva⁴ and E A Tsyraeva⁴

¹Kazan National Research Technological University, 68 Karl Marx Street, Kazan, Republic of Tatarstan, 420015, Russian Federation

²LLC Research and Design Institute for Environmental Problems, 6a Karavannaya Street, Orenburg, 460037, Russian Federation

³Orenburg State University, 13 Victory Avenue, Orenburg, 460018, Russian Federation

⁴Kumertau branch of Orenburg State University, 3B 2nd Soviety Lane, Kumertau, 453300, Russian Federation

²E-mail: rsagitov@mail.ru

Abstract. Currently, in Russia, much attention is paid to the recycling and recycling of industrial and household waste. A huge amount of waste is accumulated and not processed in various industries. The bulk of food production waste (beer pellet, alcohol bard, husk) either simply merges, due to the inability of the enterprise to process it, or is used as fuel (husk). In the wood processing industry, there is also no proper processing of the waste (chips, shavings, sawdust). This also includes waste polymer materials, the amount of which increases every year. The relevance of the use of food waste, wood processing, polymer industries in building materials and products is associated primarily with the problems of preserving the environment (they are not subject to decay, corrosion) but also with the problem of resource conservation. At present, the use of polymer waste in the construction materials industry is widespread, and quite an acute problem is the disposal of waste from food and wood processing industries. A particularly promising direction of recycling is the production of high-filled plastics which can be used as construction composite materials. The paper discusses the technology of producing wood-polymer composites by extrusion. It is proposed to use wheat bran, pre-treated with chemical reagents, in the composite in addition to traditional components (plastics and sawdust) in the proposed technology.

1. Introduction

Many organizations and institutes have been engaged in the production of wood-polymer composites based on thermoplastic polymers (wood-plastic composites, WPCs) in our country since the 1970s. Since then, certain theoretical results have been obtained, but this has not been practically applied in production yet. In the 80-90s in many countries (Finland, Sweden, Germany, Italy, Holland, Japan, USA), research work was carried out, a lot of money was spent on the creation of appropriate composite materials, increasingly used in various industries [1].

Fillers play an important role in the polymer composition. Many properties of plastics can be significantly improved with the application of a variety of fillers. According to the modern



classification, WPCs include not only composites that are based on wood flour, but also other types of natural cellulose fibers, including agricultural waste (stalks, shells, grain husks) and waste paper. Fillers can be solid, liquid or gaseous substances of inorganic and organic nature, which are relatively evenly distributed in the volume of the resulting composition and have a clearly defined interface with a continuous polymer phase (matrix). When introducing fillers, plastics often become stronger, less deformed and shrink, or acquire other valuable performance properties, such as incombustibility, high friction coefficient, electrical conductivity, etc. In some cases, the fillers practically do not improve the operational characteristics of plastics, but, as they are a cheaper and more accessible part of plastics, the fillers reduce the cost of the product. Fillers that significantly improve the operational properties of plastics are called active fillers [2-4].

The content of the filler in plastics can vary widely, and is usually 15–50 % of the total weight of the composition. However, there are highly filled plastics where the concentration of the filler can be several times higher than the content of the polymeric itself [5].

The work that currently being conducted under the leadership of Academician N. S. Yenikolopov in the field of obtaining highly filled thermoplastics directly in the process of synthesis is interesting and promising. The idea is that the filler is used as a catalyst carrier, and as a result of the synthesis process, the filler is covered with a layer of the formed polymer (the filler particles are encapsulated in a polymer shell). Thus, the filled composition is obtained directly in the reactor, which not only simplifies, facilitates and makes the mixing process less energy-intensive, but also contributes to the creation of a stronger connection between the components. The materials of the new class are called “norplasts”.

The choice of the method of processing polymers into various products is determined by the physicomechanical and rheological properties of the material being processed. When heated, polymers behave differently and, depending on this, they are divided into two groups: thermoplastic and thermoreactive [1].

Thermoplastic polymers soften when heated, while their plastic properties improve with increasing temperature. After cooling the polymer to normal temperatures, it restores its original properties. From the softened thermoplastic polymer it is possible to form any products, to pull out very thin threads and tapes. In this state, the polymer mixes better with the filler and dye [1].

The experience of Western countries shows that a promising direction for the processing of secondary polymers is the creation on their basis of various compositions, in particular polymeric wood-filled composites (wood-filled plastics). In this case, there arises the possibility of partial or complete replacement of traditionally used formaldehyde-containing resins, which are the source of long-term migration of formaldehyde into the environment, which is classified as carcinogenic substances.

WPCs are made of a compound consisting of a mixture of wood particles, a thermoplastic polymer and a small amount of functional and technological additives. The compound for molding is prepared in advance or mixed directly in the course of the molding process [6].

In the production technology of products from composite materials compounding, as a rule, is of key importance. The purpose of this operation is to obtain a dense homogeneous structure of the composite. Due to some peculiarities of the chemical structure of WPCs, thorough compounding plays a crucial role in ensuring the strength and durability of the manufactured products. Wood particles are polar, and molecules of thermoplastic polymers are not always polar. In addition, each particle of wood should be covered with a thin tape of resin, and the necessary functional and technological additives should be evenly distributed in the polymer matrix [6].

By itself, wood does not enter into chemical interaction with thermoplastic PE and PET. This can be explained by the inertness of low-functional polymers, which can only physically envelop the wood particles without forming a chemical bond with it. Wood is an inert filler. The chemical interaction of wood and thermoplastic polymers can be achieved by activating the polymer or modifying the wood filler with bifunctional or polyfunctional compounds able to interact simultaneously with the components of wood and polymer [7-9].

The process of compounding occurs hot with stirring of heated wood particles, molten base resin and necessary additives. Compounding should be done as quickly and sensitively as possible in order to avoid mechanical ruptures of polymer chains and thermal-oxidative degradation of polymer and wood [6].

In the production of WPCs compounding can be implemented using a variety of mixers and compounders. Most often, twin screw extruders and thermo-kinetic mixers are used for this. The finished compound is usually supplied in the form of granules, convenient for storage, transportation and further processing [6].

Among production methods, the most common method is extrusion.

According to various sources, the volume of world production of wood-polymer composites based on thermoplastic resins, produced by extrusion, amounted to about 500-600 thousand tons in 2002, worth about 750 million US dollars (for comparison, this amount approximately corresponds to the annual production of domestic furniture). It was expected that sales of WPCs in the world in 2006 would exceed \$ 1.5 billion, i.e. rates of growth were around 20 percent per year [10].

Materials and semi-finished products, and fully finished products are obtained using extrusion methods. Extrusion plastics products, filled with polymers and composite materials, expand their presence in almost all areas of construction, engineering, consumer goods, especially where large volumes of production and intensive production methods are required [11].

The Department "Machines and Devices of Chemical and Food Production" of Orenburg State University has accumulated quite a wealth of experience in extruding vegetable and lignified raw materials and obtaining food and fodder products from it.

Both traditional vegetable raw materials (grain) and lignified raw materials, in which the content of cellulose (fibre) and lignin is high enough and can reach 50 % or more in terms of absolutely dry matter, have been extruded. In particular, extrusion treatment of barley, wheat bran and buckwheat husk (sunflower) was subjected to it [12].

Studies have shown that vegetable raw materials containing significant amounts of fiber and lignin are rather difficult to be extruded, and sometimes it is almost impossible to extrude.

Wood is made up of two fabrics: xylem and sclerenchyma. The walls of their cells consist of cellulose (fibre), hemicelluloses and lignin. Together they form a three-dimensional complex in which cellulose molecules are assembled into a skeleton, hemicelluloses fill the gaps between them, and hydrophobic lignin strengthens the cells of the walls and makes them impermeable to water. Cellulose and lignin, in large quantities are part of the wood, for example, coniferous trees contain from 23 to 38 % of lignin [13].

In the works of P.P. Erinsh and a number of other scientists, it has been shown that cellulose in lignified cell walls is in the form of elementary fibrils constructed from parallel macromolecules. The degree of their order varies depending on the type of raw material. Elementary fibrils include both the available amorphous regions and the more orderly crystalline regions that are less permeable to solvents and enzymes, which are the catalysts for their conversion reactions. Lignin and hemicellulose fill the space between the elementary cellulose fibrils. Consequently, the lignified substance is a polymer composition consisting of cellulose reinforcement and an amorphous matrix.

Lignin is highly reactive and interacts with many chemicals. It reacts with formaldehyde and other aldehydes. The resulting products are used in the production of plastics [14].

In an alkaline environment, lignin dissolves. This process is easier for grass and cereal lignins, harder for wood lignins. As a result, alcoholates, salts are formed, lignohydrocarbon bonds are destroyed. This process explains the ability of lignin to bind ammonia, metal cations, atoms and groups of atoms. With an increase of temperature in an alkaline medium, lignin is destroyed [15].

It has been established that during the delignification process, for example, treating lignified raw materials, for example, with calcined soda or sodium hydroxide, occurs during a series of physicochemical and chemical transformations of cell walls and their components. First of all, as a result of the partial dissolution of water-soluble compounds, mineral substances, hemicelluloses, lignin, the submicroscopic structure of the cell walls of the raw materials changes, turning into a

super-swollen state. The volume of submicroscopic capillaries increases, the surface area of the raw material rises [14].

Thus, the goal of our research was to obtain by extrusion products based on thermoplastic materials, in which the composite includes, besides traditional sawdust (flour), vegetable raw materials with a lower content of fiber and lignin than wood, which will make the process of obtaining such products more economical and expand the scope of such materials.

2. Experimental part

For this purpose, a number of exploratory experiments were conducted, during which the main research paths for the detailed development of this technology were outlined.

During the experiments, sawdust (pine with the initial moisture content of 6.3 %) in pure form, and as part of the mixture (wheat bran) was extruded. Also sawdust or mixture was pre-moistened: with tap water, 5 % solution of calcined soda Na_2CO_3 to a moisture content of 40 %. Humidification was carried out for 30 min, followed by sweeping for 18 h. Only after the preparatory procedures, sawdust or mixture was extruded. Thus prepared sawdust (mixture) was pressed. The pressing process was carried out on a PESH-30/4 single-screw press extruder with a 12 mm diameter spinner installed in it, and 54 mm long with screw rotation speed $\omega = 15 \text{ c}^{-1}$. [16]

3. The discussion of the results

As a result of extruding of clean sawdust, an extrudate with a fairly low degree of homogenization, which fits into the assumption that the process is influenced by the content of cellulose (cellulose) and lignin, is obtained.

Sawdust treated with a 5 % solution of calcined soda Na_2CO_3 to a moisture content of 40 % or as part of a binary mixture gave more satisfactory results, both in process of management and in the degree of homogenization of the resulting extrudate. In addition, the low dispersion of the obtained product can be explained by the low degree of homogeneity of the feedstock.

The results are preliminary, during which the degree of wetting of the feedstock, the percentage ratio in the mixture of both sawdust and bran, the use of a chemical reagent will be clarified.

The decision to extrude not only clean sawdust, but mixed with wheat bran, is due to the fact that the content of fibre and lignin in bran is much lower compared to sawdust, they are extruded quite well, and the process of delignification is more efficient, as confirmed by the analysis of the literature and our own research. In addition, the bran, due to the strongly pronounced capillary-porous structure of the shell particles, is very hygroscopic, therefore, at high humidity, they are quickly moistened, which is good enough to prepare the mixture for extrusion [16–18].

Table 1. Chemical composition of wheat bran [16–18].

The composition of wheat bran	
Protein, %	10-18
Starch, %	no more 15 %
Dietary fiber, %	not less 45-47
Cellulose, %	10-12
Hemicelluloses, %	22-26
Pectin, %	4-6
Lignin %	1-13

4. Findings

On the basis of the results obtained, an assumption was made about obtaining WPCs or other products based on thermoplastic materials, in which the composite consists of not wood sawdust (flour) in its pure form, but a binary mixture of wood sawdust with wheat bran. Instead of formaldehyde-containing resins, which are classified as carcinogenic substances, it is possible to use, for example, starch as a binder, which makes the resulting product more environmentally friendly.

In general, the proposed technology for producing products based on thermoplastic materials can consist of the following operations: superfine grinding of the main components (plastics, sawdust and wheat bran), pretreatment of sawdust and bran with aqueous solutions of chemical reagents, allowing the destruction of lignohydrocarbon bonds, the operation of mixing and molding the mixture in a press extruder. The need for a binding substance will be established during experimental studies. The proposed technology will make the process of obtaining such products by extrusion more economical, as well as expand the range and scope of such products.

References

- [1] Silenko S G 1973 *Mechanical Equipment of Enterprises of the Construction Industry* (Moscow: Stroizdat) p 348-349
- [2] *Encyclopedia of Polymers* 1974 *Plastics Recycling* vol 2 (Moscow: Soviet Encyclopedia)
- [3] Lipatov Yu S 1980 *Interphase Phenomena in Polymers* (Kiev: Naukova Dumka)
- [4] Solomko V P 1980 *Filled Crystallizable Polymers* (Kiev: Naukova Dumka)
- [5] Wolfson S A 1982 *Composite Polymeric Materials Today and Tomorrow Ser. "Chemistry"* (Moscow: Knowledge) **1**
- [6] *Tree.ru* Business magazine on wood processing, July-August 2008 **4** 88-94
- [7] Korotkov V G, Popov V P, Bashirov V D, Sagitov R F, Akhmadieva Z R and Tsirkaeva E A 2018 Modeling of processing technologies in food industry *IOP Conf. Ser.: Materials Science and Engineering* **327(11)** 022061
- [8] Sagitov R F, Fazlieva D Kh, Utyaganova Z Z and Sharipova S G 2016 The mathematical model of the process of extruding waste of different productions with receiving wood-filled compositional materials *News of the Orenburg State Agrarian University* **1(57)** 51-53
- [9] Sagitov R F, Fedorov E A, Antimonov S V and Kulyasov D N 2015 Experimental determination of rheological parameters of the equation of Ostwald de Ville for communication index and consistency coefficient with temperature of the process of extruding highly filled plastics with layered flow *News of the Orenburg State Agrarian University* **3(53)** 73-75
- [10] *Furniture maker* 2005 **2(26)**
- [11] *The world market WPCs*, available at: http://www.pi.com.ua/statji_07.html
- [12] *What is the extrusion: the basic concepts and definitions*, available at: <http://c-a-m.narod.ru/wpc/abWPC.html>
- [13] Dudkin M S 1986 *Chemical Methods to Improve the Quality of Feed and Animal Feed* (Moscow: Agropromizdat) pp 68-73
- [14] Lind R et al 2004 Increasing the feed value of bran *Feed Milling Industry* **6** 52-53
- [15] Litvinov M 2006 Taming of lignin *Chemistry and Life of the XXI Century* **2** 18-19
- [16] Antimonov S V, Sagitov R F and Solovykh S Yu 2008 Technology of extruding buckwheat (sunflower) husk mixed with bran *News of Universities. Food Technology* **2-3** 61-63
- [17] Borovikov A M 1989 *Wood Handbook: Textbook for Forestry Engineering Specialist Universities* (Moscow: Lesnaya promyshlennost)
- [18] ed E G Lyubeshkina 1985 *Recycling of Polymeric Materials* 1985 (Moscow: Chemistry)