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# COMPOSITES BASED ON SECONDARY POLYVINYL CHLORIDE RAW AND WOOD WASTE

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**Abstract.** A solution to the problem of rational use of secondary polymeric raw materials and wood waste is presented by creating composite materials for structural and decorative purposes on their basis.

Wood-polymer composites (WPC) are modern materials made from a mixture of an organic thermoplastic polymer and a plant-based filler. To obtain WPC, various fillers and thermoplastic binders are used. Work in this direction is being actively carried out and the production of WPC (molded, sheet, complex profile) is widely mastered in the world.

In order to significantly reduce the cost of composites while maintaining their physical, mechanical and operational characteristics, studies were carried out on the use of secondary raw materials as the main raw material. The object of the study was the most large-tonnage types of waste polymeric thermoplastic materials, in particular, polyvinyl chloride, which is formed both in the process of its industrial production, and in the field of industrial and domestic consumption, as well as soft waste from sawmilling and woodworking (sawdust, shavings).

In the studies, the direct extrusion method was used.

Based on the results of a complex of studies, the optimal technological parameters of the extrusion processing mode of the developed press compositions were determined, which have sufficient manufacturability and ensure high physical, mechanical and operational performance of the created composites at their minimum cost.

The optimal content of the modified polymer component in the press composition should be in the range of 40–50% wt., depending on the purpose of products from this composite. From a wide range of additives, only the most, in our opinion, significant and affordable additives were used: calcium stearate (stabilizer and lubricant), dioctyl phthalate (plasticizer). These additives provide the necessary thermal stability and fluidity of the press composition during extrusion, as well as a certain light and thermal stability during product operation.

The best performance is for a composite based on wood particles of medium fraction ($l$ = 2.0…8.0 mm), which is characterized by an optimal structure of reinforcing particles and uniform distribution of the binder.

Comprehensive evaluation tests (physical-mechanical, technological, operational, sanitary and hygienic) of WPC based on polyvinyl chloride waste and soft wood waste showed the practical possibility and expediency of creating and mastering the production of structural and decorative and finishing profile elements that are not inferior in basic properties to coniferous wood products rocks or polymers. On an industrial scale, on the basis of domestic equipment, in particular, the WP 90×25 extruder with modified working bodies, a wide range of products has been launched (for example: flooring profiles for civil and industrial construction, finishing boards, platbands, plinths, etc.).

**Keywords**: wood-polymer composites, press composition, polyvinyl chloride waste, wood waste, direct extrusion method.

**Introduction.** One of the promising ways of rational use of secondary polymer raw materials (production waste, depreciated products, etc.) and wood waste is the creation of wood-polymer composite materials and products (WPC) for structural and decorative and finishing purposes on their basis. The promise and competitiveness of the created composites is due to the fact that in terms of their basic physical, mechanical and operational properties they are not inferior to most traditional materials (from the same polymers and wood) and at the same time surpass them in terms of efficiency [1–4].

**Analysis of recent research and publications.** The term "wood-polymer composites (wood-plastic composites)" in modern foreign and domestic literature is applied to materials obtained from a mixture of an organic thermoplastic polymer and a filler of plant origin. To obtain wood-polymer composites (WPC), a variety of fillers and thermoplastic binders are used. Works in this direction are actively carried out and the production of WPC (molded, sheet, complex profile) is widely mastered by a number of manufacturers in the world [5–8].

From the available information, it follows that the well-known composite formulations use specially prepared fine wood (wood flour, needle-shaped shavings, wood fibers, etc.), primary polymer raw materials, and various additives. The high cost of all these components is a significant brake on the wide development of the industrial production of the developed composites.

**Purpose and tasks.** In order to significantly reduce the cost of composites while maintaining their physical, mechanical and operational characteristics, studies were carried out on the use of secondary raw materials as the main raw material. The object of the study was the most large-tonnage types of waste polymeric thermoplastic materials, in particular, polyvinyl chloride [9], which is formed both in the process of its industrial production, and in the field of industrial and domestic consumption, as well as soft waste from sawmilling and woodworking (sawdust, shavings).

The screw extrusion method for processing wood-polymer mixtures (press compositions) into WPC was chosen after a detailed analysis of its advantages over other methods.

**Materials and methods of research.** At the stage of the exploratory experiment, the primary raw materials of polyvinyl chloride suspension (PVCS) and polyvinyl chloride emulsion (PVCE) powder were used as a polymer matrix material. At the next stage of research, the results of which are presented in this article, primary raw materials were replaced by secondary ones. The production wastes of suspension polyvinyl chloride (WPVCS) and emulsion polyvinyl chloride (WPVCE) were used, as well as the mass of finely dispersed shock-absorbing plastic products made of polyvinyl chloride (WPVC).

The reinforcing filler in the press compositions was soft wood waste (sawdust, machine shavings, small chips, mainly coniferous species), cleaned of foreign impurities and large inclusions, dried to a moisture content of not more than 2 ... 3% wt.

From a wide range of additives, only the most, in our opinion, significant and affordable were used:

- stabilizer and lubricant – calcium stearate (non-toxic, relatively inexpensive, quite effective);
- plasticizer – dioctyl phthalate (highly effective plasticizer of domestic production, relatively inexpensive).

These additives provide the necessary thermal stability and fluidity of the press composition during extrusion, as well as a certain light and thermal stability during product operation.

The preparation of the press composition, the refinement of the recipe and the technology for manufacturing prototypes of composites were carried out using a paddle mixer of thermoplastics (non-standard equipment, heated, temperature 70 ± 2 °C, rotation speed 28 ± 2 rpm), and a single-screw worm press brand "Reifenheiser" (screw diameter 63 mm, screw length to diameter ratio 20:1, screw for PVC processing), equipped with a die head (die), in the following sequence:

- dosage of prepared initial components by weight method;
- thermal plasticization of the polymer component by successive mixing of WPVC with a stabilizer (3…5 min.) and a plasticizer (irrigation of the continuously stirred mixture for 5…7 min.);
- mixing of the prepared polymeric component with wood raw material for 7…10 min.

In the studies, the direct extrusion method was used. The freshly prepared press composition was fed directly into the feed hopper of the worm press for molded product extrusion. At this stage of research, a die was used to form a square bar 20×20 mm, directly intended for evaluation tests.

The product waste generated during extrusion was crushed and the mass was returned for recycling at the stage of mixing the components.

**Research results.** Based on the results of experiments on the development of extrusion technology, the optimal parameters of the extrusion mode were determined (Table 1).

Table 1 – Extrusion parameters of WPVC – wood press composition

| Polymer component of the press composition | Temperature regime by worm press zones, °C | | | | | Speed of rotation of the screw, rpm | Productivity, m/min |
|---|---|---|---|---|---|---|---|
| | I | II | III | IV | die | | |
| WPVCE | 90 | 120 | 140 | 150 | 150 | 12…15 | 0.6…0.7 |
| WPVCS | 100 | 130 | 150 | 160 | 160 | 10…12 | 0.5…0.6 |
| WPVC blend (powdered/crushed=1:1) | 100 | 130 | 160 | 170 | 170…180 | to 10 | 0.4…0.5 |

The determination of the optimal prescription compositions of composites was carried out on the basis of the results of studies of the dependence of the properties of the composite on the following factors:

- concentration and composition of the polymer component (matrix material);
- nature and fractional composition of the wood component;
- concentrations of modifying additives, etc.

The following criteria were adopted as the main evaluation criteria: the strength limit in static bending and water absorption in one day of WPC samples made according to a certain recipe. Samples were tested according to standard methods.

The results obtained are presented in Table. 2-4.

Table 2 – Dependence of the physical and mechanical characteristics of WPC on the content of the polymer component (the content of additives is 5%)

| Polymer component | Meaning of indicators: flexural strength, MPa/water absorption, % wt. | | | | | | |
|---|---|---|---|---|---|---|---|
| | from the mass fraction of the polymer component in the compound, % wt. | | | | | | |
| | 25 | 30 | 40 | 50 | 60 | 70 | 80 |
| WPVCS | 2.8/– | 6.5/19.8 | 12.2/12.7 | 16.4/7.5 | 15.8/4.7 | 16.7/4.0 | 16.6/4.1 |
| WPVCE | – | 7.1/21.9 | 11.0/13.8 | 13.4/8.0 | 14.1/6.5 | 15.3/5.7 | 15.2/– |
| WPVC blend | – | – | 7.6/19.5 | 10.2/17 | 10.8/14 | 11.8/8.1 | 11.3/7.1 |

From the data in Table. 2 shows that the creation of composites with stable properties containing a polymer component in an amount of less than 25% wt. practically not feasible. Press compositions containing 30% wt. WPVCS or WPVCE are technologically advanced and allow obtaining WPC samples with reproducible performance. When using as a matrix material a mixture of WPVC powder with finely dispersed cushioned PVC products in a ratio of 1:1 (WPVC blend), the minimum content of the matrix material in the press composition should be at least 40% wt.

With an increase in the content of the polymer component (WPVCS or WPVCS) from 30 to 60% wt., and the WPVCS mixture up to 70-80% wt. the water absorption of composites sharply decreases to a certain minimum, which is explained by the formation of a continuous polymer film on the surface of wood filler particles, which prevents the penetration of water into the capillary-porous system of wood particles. In the case of using a polymer material in an initially more highly dispersed form, a greater effect of waterproofing filler particles is achieved, especially in the region of low polymer concentrations.

The dependence of the increase in the strength characteristics of composites on an increase in the content of the polymer component (or, which is the same, a decrease in the degree of filling of the composites) in the range from 30 to 60% wt. has the following character: for WPVCS – extreme, for WPVCS and WPVC blend – at first intense, turning into monotonous. With an increase in the proportion of polymer in the composite up to 80% wt. a monotonous increase in strength is observed. This is most likely due to the weak reinforcing effect of wood particles, which have approximately similar dimensions in length, width, and thickness. With a low content of the polymer phase in the composite, there is no solidity of the polymer interlayers between the wood particles, which leads to low strength. With an increase in the polymer content, its uniform distribution over the volume of the composite occurs and the formation of a continuous polymer skeleton (as a result, an intensive increase in strength), and then an increase in the thickness of the interlayers between wood particles (a monotonous increase in strength).

Based on the results obtained, considering the economic factor, it can be concluded that the optimal content of the modified polymer component in the press composition should be in the range of 40–50 wt.%, depending on the purpose of products from this composite.

Table 3 shows the physical and mechanical properties of WPC samples obtained on the basis of wood pulp of various nature and fractional composition. The ratio of components in the composite was constant: dispersed wood pulp – 50%, polymer component – 45%, modifying additives – 5%.

Table 3 – Dependence of the physical and mechanical properties of composites on the nature and fractional composition of the filler

| The name of indicators | The value of the indicator when used as a filler | | | | | |
|---|---|---|---|---|---|---|
| | wood pulp fraction, mm | | | crushed grapevine fr. 2.0-8.0 | wood pulp special preparation | wood /flax fire mixes |
| | less 2.0 | 2.0-8.0 | 8.0-20.0 | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Ultimate strength in static bending, MPa | 12.0 | 15.2 | 13.7 | 15.2 | 18.9 | 19.4 |
| Water absorption, % | 11.0 | 7.8 | 7.0 | 7.8 | 6.5 | 7.2 |

From the data in Table 3 it follows:

1. The nature of the wood filler (hardwood or coniferous wood, grapevine, etc.) does not significantly affect the properties of composites (columns 3, 5), if the particles of various fillers do not differ significantly in their strength, geometry, fractional composition, moisture content, etc. indicators.

2. With an increase in the fraction, the physical and mechanical characteristics of the samples improve (columns 2-4). This is due to the fact that with an increase in the linear dimensions of the particles, the ratio of the surface area of the particles to their volume decreases, i.e. at a given consumption of the binder, the thickness of the polymer interlayers between the particles increases to the optimum. In addition, there is a reinforcement effect, which significantly increases the strength properties of the composite. The best performance is for a composite based on wood particles of medium fraction ($l$ = 2.0…8.0 mm), which is characterized by an optimal structure of reinforcing particles and uniform distribution of the binder.

3. The influence of the reinforcing effect is clearly manifested if, instead of a filler based on wood waste, a specially prepared (chopped and sifted) wood pulp of a fraction of 5.0 ... 10.0 mm is used in the form of needle-shaped particles with a length-to-thickness ratio in the range of 5 ... 10 (column 6), and also if instead of 50% wt. wood filler with a fraction of 2.0 ... 8.0 mm, use chopped flax fire fibers up to 20 ... 25 mm long (column 7).

As shown by the results of experimental work, a significant factor affecting the technological and physical and mechanical properties of the composite is the presence and concentration of various modifying additives. For example, in the Chinese patent [10], it is proposed to use polyvinyl alcohol as a plasticizer in the production of WPC.

The absence of such additives makes the extrusion processing of rigid press compositions problematic; at the same time, an excess of one or another ingredient can play a negative role. Table 4 shows the data on the dependence of the physical and mechanical characteristics of the WPVC-wood composite on the content of the plasticizer used by us – dioctyl phthalate (DOP). It follows from the given data that the optimal ratio of the amount of DOP and WPVC is close to 1 to 10.

Table 4 – Dependence of the physical and mechanical properties of composites on the content of the plasticizer (DOP)

| The compound of the press composition, % wt. | | | | Tensile strength at static bending, MPa | Water absorption, % |
|---|---|---|---|---|---|
| woody filler | WPVC | DOP | stabilizer | | |
| 50 | 47 | 2.5 | 0.5 | 15.5 | 10.0 |
| 50 | 45 | 4.5 | 0.5 | 16.5 | 8.5 |
| 50 | 40 | 9.5 | 0.5 | 13.0 | 6.5 |

The complex of conducted studies made it possible to determine the optimal formulations of press compositions that have sufficient manufacturability and provide high physical and mechanical properties of composites at a minimum cost. In Table 5 shows some of them, and in Table 6 comparative estimated physical and mechanical parameters of WPVC-wood composite and pine.

**Conclusions.** Comprehensive evaluation tests (physical-mechanical, technological, operational, sanitary and hygienic) of WPC based on polyvinyl chloride waste and soft wood waste showed the practical possibility and expediency of creating and mastering the production of structural and decorative and finishing profile elements that are not inferior in basic properties to coniferous wood products rocks or polymers. On an industrial scale, on the basis of domestic equipment, in particular, the WP 90×25 extruder with modified working bodies, a wide range of products has been launched (for example: flooring profiles for civil and industrial construction, finishing boards, platbands, plinths, etc.).

Table 5 – Recipe composition of WPVC-wood press compositions

| Name of components | Content, % wt | | |
|---|---|---|---|
| | composition I | composition II | composition III |
| Fine wood waste (sawdust, shavings, industrial chips, etc.) with a moisture content of not more than 3%, preferably a fraction of 2.0-8.0 | 50.0 | 60.0 | 65.0 |
| Recycled polyvinyl chloride, for example, PVCS waste according to TU 6-01-II77 or PVCE waste according to TU 6-01-II79 or others (preferably a mixture of WPVCS: WPVCE = 2:1) | 45.0 | 36.0 | 31.5 |
| Dioctyl phthalate according to GOST 8728 | 4.5 | 3.6 | 3.2 |
| Calcium stearate or barium stearate according to TU 6-09-4803 or their waste | 0.5 | 0.4 | 0.3 |

* Note. In case of replacement of a part of fine-dispersed WPVC with crushed PVC products, composition III is not recommended for use.

Table 6 – Physical and mechanical (estimated) indicators of WPVC-wood composite (composition I from Table 5) in comparison with control samples of pine grade I according to GOST 8486

| № | Name of indicator | Evaluation tests were carried out according to the methodology | The value of the indicator for the sample from | |
|---|---|---|---|---|
| | | | composite | pines |
| 1 | Ultimate compressive strength, MPa | OST 5.9296 | 27.4 | 26.6 |
| 2 | Ultimate strength at stat. bending, MPa | GOST 4648 | 16.5 | 55.0 |
| 3 | Impact strength, kJ/m$^2$ | GOST 4647 | 2.94 | 5.43 |
| 4 | Stiffness coefficient, kN/mm<br>at +22 °C<br>at -20 °C | GOST 16483.2 | <br>8.6<br>18.7 | <br>8.0<br>8.0 |
| 5 | Abrasion, % | GOST 16483.39 | 0.09 | 0.4 |
| 6 | Splitting resistance<br>along the fibers<br>across the fibers | GOST 13537 | 18.7 | <br>9.8<br>35.7 |
| 7 | Volumetric weight abs. dry matter, kg/m$^3$ | OST 5.9296 | 1180.0 | 560.0 |
| 8 | Water absorption, %<br>for 1 day<br>for 7 days | OST 5.9296 | <br>6.0<br>14.8 | <br>47.9<br>86.1 |
| 9 | Thermal conductivity coefficient, W/m·K | GOST 7076 | 0.21 | 0.15 |

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# КОМПОЗИТИ НА ОСНОВІ ВТОРИННОЇ ПОЛІВІНІЛХЛОРИДНОЇ СИРОВИНИ ТА ВІДХОДІВ ДЕРЕВИНИ

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**Анотація.** Представлено вирішення проблеми раціонального використання вторинної полімерної сировини та відходів деревини шляхом створення на їх основі композиційних матеріалів конструкційного та декоративно-оздоблювального призначення.

Дерев'яно-полімерні композити (ДПК) це сучасні матеріалам, що виготовляються із суміші органічного термопластичного полімеру та наповнювача рослинного походження. Для отримання ДПК застосовують різноманітні наповнювачі та термопластичні в'яжучі. Роботи у цьому напрямі активно ведуться і випуск ДПК (погонажних, листових, складнопрофільних) широко освоюється у світі.

З метою суттєвого зниження собівартості композитів при одночасному збереженні їх фізико-механічних та експлуатаційних характеристик було проведено дослідження щодо застосування як основної сировини – вторинної. Об'єктом дослідження було обрано найбільш великотоннажні види відходів полімерних термопластичних матеріалів, зокрема, полівінілхлориду, що утворюється як у процесі його промислового виробництва, так і у сфері виробничого та побутового споживання, а також м'які відходи лісопиляння та деревообробки (тирса, стружка).

У дослідженнях застосовували метод прямої екструзії.

На підставі результатів комплексу проведених досліджень визначено оптимальні технологічні параметри режиму екструзійної переробки розроблених прес-композицій, що мають достатню технологічність і забезпечують високі фізико-механічні та експлуатаційні показники створених композитів за їх мінімальної собівартості.

Оптимальний вміст модифікованого полімерного компоненту у прес-композиції складає 40-50% мас., залежно від призначення виробів з даного композиту. З широкого асортименту адитивів були застосовані лише найбільш, на нашу думку, суттєві та доступні: кальцію стеарат (стабілізатор та мастило), діоктилфталат (пластифікатор). Ці додатки забезпечують необхідну термостабільність та плинність прес-композиції при екструдуванні, а також певну світло- та термостабільність при експлуатації виробів.

Найкращі показники композиту на основі дерев'яних частинок середньої фракції ($l$ = 2,0...8,0 мм), для якого характерна оптимальна структура укладання армуючих частинок і рівномірність розподілу в'яжучого.

Всебічні оціночні випробування (фізико-механічні, технологічні, експлуатаційні, санітарно-гігієнічні) ДПК на основі відходів полівінілхлориду та м'яких відходів деревини показали практичну можливість і доцільність створення та освоєння випуску конструкційних та декоративно-оздоблювальних профільних елементів, що не поступаються по основним властивостям виробам із деревини хвойних порід або полімерів.

У промисловому масштабі на базі вітчизняного обладнання, зокрема, екструдера ЧП 90×25 з модифікованими робочими органами, налагоджено випуск широкої номенклатури виробів (наприклад: дошка та брус настилів підлоги для цивільного та промислового будівництва, оздоблювальна фасадна дошка, наличники, плінтуси тощо).

**Ключові слова**: дерев'яно-полімерні композити, прес-композиція, відходи полівінілхлориду, відходи деревини, метод прямої екструзії.

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