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Research physic-mechanical properties of composite materials on the base of crushed wood

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Abstract. Influence of traditional thermoset (urea- and phenol-formaldehyde) and thermoplastic alternative (recycled high density polyethylene and recycled polypropylene) binders on the performance of slab composite materials using as a filler of the special pieces of wood chips are considered. Results studies of physic-mechanical properties of considered materials are presented. Rational conditions production of plate materials based on recycled thermoplastic matrices are revealed. Comparative analysis of wood-polymer composite materials based on two types of adhesives have allowed to establish the possibility of obtaining competitive materials based on recycled thermoplastics with higher water resistance (in terms of swelling in thickness meet the requirements of GOST (Interstate standard) 32399-2013 for plates of type P7) and strength characteristics compared with materials based on traditional thermosetting adhesives. Using of thermoplastic binders indicates the feasibility of their use in production of particle boards due to the positive effect on the environment.

Keywords: composite materials, thermoplastic polymers, thermosetting binders, environmental friendliness, physical and mechanical properties.

1. Introduction

Currently, in domestic production of particleboards (composite materials based on synthetic binders and special pieces of wood chips) are widely used synthetic thermosetting binders based on urea-formaldehyde (UFO), urea-melamine-formaldehyde (UMFO) and phenol formaldehyde (PFO) oligomers. The problem of such boards is that one of the condensation products in the synthesis of oligomers is formaldehyde, a toxic gas of the second class of danger [1], which is a carcinogen, and presumably, a mutagen and an allergen. In a free state (due to incomplete condensation) it will be present in the binder and in finished product based on it.

The current domestic standard for particleboards (GOST 10632-2014) provides maximum permissible levels of formaldehyde in the board at the emission class E0,5 – not more than 4 mg, at the emission class E1, respectively, from 4 to 8 mg of formaldehyde, inclusive. If the production of boards with class of emission E1 on the basis of traditional thermosetting binder is applied in practice, the production of plates E0,5 very problematic. In this case, it is possible to use formaldehyde acceptors [2], however, it will not be possible to reduce its content to almost zero.

From other side, there is now a widespread use of polymeric (primarily polyethylene and polypropylene) packaging materials, which creates the problem of their disposal. It is not efficient to
carry out the disposal of polymer waste, because the time of their decomposition is approximately from 50 to 100 years [3]. The burning causes harm to the environment (produce large quantities of toxic substances). An alternative would be sorting and recycling plastic wastes for use in various fields. In recent years, in Russia there are enterprises for processing of polymeric waste. In Kostroma, this set earned in 2016 (design capacity of 100 000 t/year).

Scope of primary and secondary polyolefins is quite wide. The polyolefins used for the production of wood-plastic composite materials [4, 5] mainly for construction purposes: decking, window and door profiles, window sills, siding, panels, stairs [6, 7]. The filler here is usually wood flour. Thermoplastics can be used to obtain slab composite materials, where the filler used the bark of the tree [8–10], agricultural wastes [11].

The work provides production of wood-polymer composite materials on the production technology of particleboards on hard metal pallets. As a binder, it is proposed to use secondary thermoplastic polyolefins, as a filler – a special cut wood chips used in the production of chipboards.

This study will differ from the traditional production of particleboards type of binder used, and from the production of wood-polymer composite materials – type of filler used and production technology.

The use of secondary polyolefins as binders will solve the problem of toxicity of particleboards and partly the problem of disposal of polymer waste.

The aim of the study is a comparative analysis of physical and mechanical properties of wood-polymer composite materials based on secondary thermoplastic polyolefins and traditional thermosetting binders.

2. Methods of research

Influence of the specific pressure of pressing (varied from 3.0 to 6.7 MPa) was investigated by active single-factor experiment) on physical and mechanical properties of plate composite materials. As a binder used traditional thermosetting adhesives based on urea- (UFO) and phenol-formaldehyde oligomers (PFO) and alternative thermoplastic – granular secondary high-density polyethylene (SHDPE) and secondary granular polypropylene (SPP). In the preparation of adhesives based on urea-formaldehyde oligomer was additionally introduced hardener – ammonium chloride in the amount of 1 % by weight of the oligomer, the remaining adhesives were one-component. Thermosetting binders (UFO and PFO) were taken from existing production NAO «SVEZA Kostroma», Kostroma, Russia (GOST 14231-88 and GOST 20907-75, respectively), thermoplastic – with OOO «EcoTechnologies», Kostroma, Russia. The filler used was a special cut birch shavings for particleboards production enterprise, the NAO «SVEZA Kostroma» (average particles length 10.6 mm, width 0.7 mm, thickness 0.4 mm). Manufacture and testing of plate composite materials was carried out according to the technology of pallet pressing particleboards in a laboratory hydraulic press P100-400 on the base of Kostroma state university at the following constant factors:

- nominal thickness of board – 10 mm;
- specific duration of pressing – 1.0 min/mm;
- ratio: thermoplastic binder / filler is 45/55 %;
- consumption of thermosetting binder – 11% by weight of absolutely dry wood filler;
- temperature of pressing + 230 ℃.

The levels of constant factors are determined on the basis of preliminary experiments, the results of which are partially presented in the already published works [12,13].

Physical and mechanical properties of particleboards were determined in accordance with the requirements of GOST 10633-78, GOST 10634-88 and GOST 10636-90. When conducting research on the determination of material properties the mean value of the indicator was calculated on the basis of data for the four duplicate experiments.
3. Results of research
After statistical processing, the following results of studies of the properties of the boards. For boards based on secondary thermoplastics values are presented in table 1, on the basis of traditional thermosetting binders – in table 2.

**Table 1.** Properties of particleboards on the basis of secondary thermoplastic binders.

| Type of the binder | Specific pressure of pressing, MPa | Limit of tensile strength perpendicular to the plate, MPa | Swelling in thickness, % | Volumetric swelling, % | Water absorption by weight, % |
|-------------------|----------------------------------|------------------------------------------------------|--------------------------|------------------------|-------------------------------|
| SHDPE             |                                  |                                                      |                          |                        |                               |
| 3.0               | 0.58a                            | 6.97                                                 | 8.87                     | 28.55                  |                               |
| 3.7               | 0.60a                            | 5.23                                                 | 7.84                     | 26.01                  |                               |
| 4.4               | 0.70a                            | 4.10                                                 | 5.60                     | 23.03                  |                               |
| 5.2               | 0.59a                            | 5.39                                                 | 6.04                     | 24.26                  |                               |
| 5.9               | 0.55a                            | 6.55                                                 | 7.91                     | 25.82                  |                               |
| 6.7               | 0.53a                            | 8.86                                                 | 10.12                    | 27.39                  |                               |
| SPP               |                                  |                                                      |                          |                        |                               |
| 3.0               | 0.52a                            | 3.64                                                 | 4.68                     | 17.96                  |                               |
| 3.7               | 0.56a                            | 3.27                                                 | 4.26                     | 14.17                  |                               |
| 4.4               | 0.55a                            | 3.08                                                 | 3.30                     | 11.82                  |                               |
| 5.2               | 0.53a                            | 3.03                                                 | 3.43                     | 11.94                  |                               |
| 5.9               | 0.51a                            | 3.24                                                 | 4.10                     | 12.89                  |                               |
| 6.7               | 0.50a                            | 6.21                                                 | 7.17                     | 15.43                  |                               |

*a rupture occurred on the adhesive layer

**Table 2.** Properties of particleboards on the basis of traditional thermosetting binders.

| Type of the binder | Specific pressure of pressing, MPa | Limit of tensile strength perpendicular to the plate, MPa | Swelling in thickness, % | Volumetric swelling, % | Water absorption by weight, % |
|-------------------|----------------------------------|------------------------------------------------------|--------------------------|------------------------|-------------------------------|
| UFO               |                                  |                                                      |                          |                        |                               |
| 3.0               | 0.22                             | 62.33                                                | 64.78                    | 88.60                  |                               |
| 3.7               | 0.24                             | 63.87                                                | 65.73                    | 89.33                  |                               |
| 4.4               | 0.26                             | 65.86                                                | 67.13                    | 91.58                  |                               |
| 5.2               | 0.27                             | 61.72                                                | 65.49                    | 89.52                  |                               |
| 5.9               | 0.28                             | 57.16                                                | 59.09                    | 87.71                  |                               |
| 6.7               | 0.30                             | 56.82                                                | 57.52                    | 86.65                  |                               |
| PFO               |                                  |                                                      |                          |                        |                               |
| 3.0               | 0.53                             | 21.81                                                | 24.59                    | 69.45                  |                               |
| 3.7               | 0.56                             | 16.69                                                | 19.03                    | 62.66                  |                               |
| 4.4               | 0.64                             | 21.77                                                | 24.00                    | 41.68                  |                               |
| 5.2               | 0.61                             | 22.89                                                | 25.21                    | 60.20                  |                               |
| 5.9               | 0.59                             | 24.08                                                | 27.22                    | 60.89                  |                               |
| 6.7               | 0.57                             | 24.58                                                | 27.48                    | 61.44                  |                               |

Influence of specific pressure of pressing on physical and mechanical properties of particle boards shown in figures 1–4.
Figure 1. Influence specific pressure of pressing to the limit of tensile strength perpendicular to the plate

Figure 2. Influence specific pressure of pressing on the swelling in thickness
Figure 3. Influence specific pressure of pressing on the volumetric swelling

Figure 4. Influence specific pressure of pressing on the water absorption by weight
4. Conclusion
The limit of the tensile strength of the boards perpendicular to the plate is the best value at a compression pressure of 3.7–5.2 MPa for plates on the basis of PFO, SHDPE and SPP, for boards based on the UFO values of the index increase with the increase of specific pressure of pressing. At the same time, the actual values of the index will be higher for the plates based on SHDPE and SPP (since the rupture of the sample during the test did not occur due to higher adhesion between the glue and the wood filler in the structure of the sample). At the same time, the materials based on the UFO compared to all the others, the values of the indicator are significantly lower and range from 0.22 to 0.30 MPa (figure 1). The plates on the rest of the binder the value of the indicator is much higher (0.5–0.7 MPa).

Swelling in thickness and volumetric swelling (figures 2–3) composite materials based on recycled thermoplastics (primarily SPP) have best value (not to exceed 10%) compared with the thermosetting binder (the boards is based on UFO – 56–67%, on the basis of the PFO – 16–28%). The best values of the index are observed in the boards based on secondary thermoplastics at a pressing pressure of 3.7–5.2 MPa.

Water absorption is minimal in SHDPE-based materials (no more than 29%) and SPP (no more than 18%). At the boards on the basis of UFO and PFO reaches 92 and 70% respectively (figure 4). Values of the index minimum at a compression pressure of 4.4 MPa for boards on the basis of PFO, SHDPE and SPP. The best value of the indicator was observed from plates on the basis of the SHDPE and SPP at a compression pressure of 4.4–5.9 MPa.

Comparative analysis of the results shows that the use of secondary thermoplastic binders values of the studied parameters is significantly higher than using traditional thermosetting. Boards on the basis of secondary polyolefins will be water-resistant (in terms of swelling in thickness meet the requirements of GOST 32399-2013 for boards of type P7). Thus, by replacing the binder, it is possible to obtain environmentally friendly water-resistant materials with a slight change in the current technology of production of particleboards.

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