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DEVELOPMENT OF NEW COMPOSITE MATERIAL WITH SPECIFIED PROPERTIES

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Keywords: wood, waste, composite, properties, use.
Abstract. The article discusses the problem of efficient use of industrial and consumer wastes in special-purpose products. The task of developing modern advanced materials remains very urgent: replacement of currently widely used wooden and reinforced concrete sleepers with sleepers made of water-resistant wood-glass composite material (DSWCM), which will ensure preservation of the line forest (conventional raw materials for the manufacture of wooden sleepers), significant reduction of the weight of sleepers (due to almost complete elimination of metal) and their rigidity, saving of electricity and increase of the service life of sleepers.

РАЗРАБОТКА НОВОГО КОМПОЗИЦИОННОГО МАТЕРИАЛА С ЗАДАННЫМИ СВОЙСТВАМИ

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Ключевые слова: древесина, отходы, композиционный материал, свойства, использование.
Аннотация. В статье рассмотрена проблема эффективного использования промышленных и потребительских отходов в изделиях специального назначения. Задача разработки современных передовых материалов остается весьма актуальной: замена широко используемых в настоящее время деревянных и железобетонных шпал на шпалы из водостойкого древесностекловолокнистого композиционного материала (ДСВКМ), что обеспечит сохранение строевого леса (обычное сырье для изготовления деревянных шпал), значительное уменьшение массы шпал (за счет практически полного исключения металла) и их жесткости, экономию электроэнергии и повышение срока службы шпал.

The given article acquires special actuality in view of anticipated global changes in our planet’s atmosphere, when the warming and possible floods result in the woods destruction and reduction of oxygen amount. Therefore, already today it is necessary to preserve the woods, utilizing solid wood for constructing articles only when it is not possible to substitute it by other materials. Moreover the modern tendencies in the development of wood products market demonstrate the utilization of this material in more profitable directions [1].

The problem of both industrial and consumer wastes application acquires special actuality in the conditions of ecology deterioration and growing deficit of raw materials. Only in Russia about 60 million tans of wastes are produced annually, those of polyethylene and plastic bottles constituting 8% of total amount. At the moment the wastes of woodworking enterprises constitute 20…50% of the total amount of processed wood (wooden chips and saw-dust) [2]. Consequently, their modernization should be aimed at the more efficient utilization of raw and energy resources alongside with the technology improvement.

Reinforced concrete as a substitute is practically equal to the wood in its initial value and durability, therefore it can be widely utilized on the railroads (for ex. sleepers, plates, supports). At the same time, this material has a number of physical-technical and mechanical limitations (fragility, rigidity and extra mass of finished products) negatively affecting the foundation bolts in the under-rail zone and breaking down the chassis of the rolling stock. These factors inevitably bring about big economic losses.

Thus, the task of developing modern advanced materials both deprived of the above mentioned shortcomings and guaranteeing maintenance reliability remains very actual.

The properties analysis carried out for the materials applied for special purpose products both in Russian Federation and abroad revealed their serious limitations. It also made possible utilizing the experience of creating composite materials on the basis of furfural resin existing in Voronezh State Forestry University. Taking natural composite – wood as a standard, the following concept of making composite materials with improved qualities was offered: furfural resin 2–3 times cheaper than other thermosetting resins was applied as one of the basic components; wooden lump wastes of wood-processing industry were used as the large aggregate [3].

The resulting wooden fiber-glass composite material (WFGCM) was supposed to possess assigned set of physical-mechanical qualities: improved strength, high chemical resistance and durability. To solve this task we have developed a mathematical model of WFGCM composition designing.

The explored material WFGCM presents a system including nine components:

1) furfural resin;
2) polymerization catalyst;
3) glycerin – crystallization inhibitor
4) sifted sand;
5) threshed sand or andesite;
6) graphite flour;
7) plumbum chloride;
8) wooden chips;
9) fiberglass (in the form of net).

Correlation of mass parts of these composites, as well as the wooden chips sizes are supposed to define the modification phenomenon of physic-mechanical characteristics WFGCM, such as ultimate tensile strength Under pure bending σ_u, elastic modules under pure bending E_u, ultimate tensile strength under compression $\sigma_{сж}$, elastic modules under compression $E_{сж}$, ultimate elongation ε_p, durability coefficient K_{cm}.

Mathematical model of WFGCM composition projection includes formation of six linear regression equations for above – mentioned physical-mechanical composite characteristics as well as the following definition of adequate ingredients supporting on the given level the pre-defined characteristics of the final material.

The regression equations are developed on the bases of experiment plan matrix $\{X_{ij}\}$ (i=1,…,62, j=1,…,11, X_{ij}=1) (with different meanings of input parameters; sixty-two experiments). The corresponding measurement vector $\vec{\eta_i} = \{\vec{\sigma_u}, \vec{E_u}, \vec{\sigma_{co}}, \vec{E_{co}}, \vec{\varepsilon_p}, \vec{K_{cт}}\}, (i = 1 \ldots 6)$ are the result of statistics processing in every set of tests [4].

The dependence between the input and output parameters is supposed to be of linear nature and has a form of

$$\eta_i(x) = \theta_{i_1} x_1 + \theta_{i_2} x_2 + \ldots + \theta_{i_n} x_n, \quad (1)$$

where θ_{ij} (i=1,...,6, j=1,...,11) – are the coefficients of linear regression.

The coefficients of linear models (1) can be found by the method of the least squares [3]. The definition algorithm of θ_{ij} is realized with the help of Excel set of electronic tables. We choose the given programmes because they allow visibly present the data, as well as efficiently support numeric applied for data processing. All calculations are given for the encoded variables:

$$\overline{x_i} = (x - x_{cp})/(x_{\max} - x_{\min}), \overline{\eta_i} = (\eta - \eta_{cp})/(\eta_{\max} - \eta_{\min}). \quad (2)$$

Here the index (average) is applied for the average meaning value.

In the result of the above mentioned calculations the linear regression models are received for six WFGCM quality criterions. Their coefficients are presented in the table 1.

Tab. 1. Coefficients of WFGCM quality criteria

θ_{ij}	1	2	3	4	5	6	7	8	9	10
1	0,7134	1,1261	–0,31	–0,202	–0,663	–0,585	0,5749	0,1796	0,842	0,6462
2	0,3902	1,5815	–0,336	–0,523	–0,855	–0,847	0,8145	0,7025	0,0581	0,7944
3	0,2064	1,193	0,225	–0,704	–0,403	–0,615	0,261	0,9339	–0,191	0,1099
4	–0,113	–0,324	–0,366	–0,714	1,1403	1,153	0,0459	–0,181	0,1991	–0,049
5	0,8849	0,7342	0,4206	–0,194	–0,553	–0,381	0,4579	0,2187	0,5823	0,5231
6	1,269	–0,679	–0,293	–0,032	0,9349	1,2276	0,2268	0,8868	–0,267	–0,134

In the result of calculations of equations coefficients (1) it became possible to pass to the problem of material structure definition, which was supposed to answer the desired meanings of efficiency parameters $\tilde{\sigma}_u, \tilde{E}_u, \tilde{\sigma}_{сж}, \tilde{E}_{сж}, \tilde{\varepsilon}_p, \tilde{K}_{cm}$. The mathematical formulation of this task includes six linear equations with already known coefficients:

$$\theta_{ij}\bar{x}_j = \tilde{\eta}_i,\ \tilde{\eta}_i = \{\tilde{\sigma}_u, \tilde{E}_u, \tilde{\sigma}_{сж}, \tilde{E}_{сж}, \tilde{\varepsilon}_p, \tilde{K}_{cm}\},\ i=1...6,\ j=1...11, \quad (3)$$

the condition for percentage parts of composite ingredients of WFGCM:

$$x_1 + x_2 + \ldots + x_9 = 100, \quad (4)$$

and the system of inequalities:

$$-1 \le \bar{x}_i \le 1, i = 1...9, \quad (5)$$

$$0 \le x_6 \le 0,5, \quad (6)$$

$x_{10} \geq 10,$ (7)

$15 \leq \tilde{\sigma}_и \leq 24(МПа),$ (8)

$1{,}0 \cdot 10^4 \leq \tilde{E}_и \leq 1{,}2 \cdot 10^4 (МПа),$ (9)

$20 \leq \tilde{\sigma}_{сж} \leq 30(МПа),$ (10)

$1{,}0 \cdot 10^4 \leq \tilde{E}_{сж} \leq 1{,}2 \cdot 10^4 (МПа),$ (11)

$0{,}4 \leq \tilde{\varepsilon}_p \leq 0{,}5,$ (12)

$0{,}45 \leq \tilde{K}_{cm} \leq 0{,}62.$ (13)

The inequality (5) is connected by the definition of encoded variables (2). The limitations associated both with the glass-net content (6) and the sizes of wooden chips (7) are introduced because of the special requirements of railway ties production technology, developed in VSAFT [1, 3], while (8…13) – answering the recommendation of RRIRT (Russian Research Institute of Rail Transport).

The above formulated mathematical model is in fact the optimization task, which can be solved by the method of Newton supported by the Excel set of electronic tables. The accuracy of approximation meanings of the objective functions to the optimal values $\tilde{\eta}_i$ and the maximal iteration number varied in the frameworks of solvation definition algorithm offered by the given set.

Table 2 presents the data of WFGCM composition satisfying the above-mentioned demands. The meanings of corresponding objective functions are given in table 3.

To receive the statistically reliably WFGCM physical-mechanical characteristics the most adequate composition option 6 was selected.

The comparison of received statistically reliable physical-mechanical basic characteristics of the selected composition with the given RRIRT and theoretic (table 4) ones proved the validity of the developed model.

Tab. 2. Theoretic material compositions received by the method of mathematical modeling

Components	Possible compositions of WFGCM, % mass					
	1	2	3	4	5	6
Furfural resin	19,2	19,2	19,2	19,3	19,2	19,2
Benzenesulfonic acid	3,9	3,9	3,9	4,3	4,1	4,1
Glycerin	0,3	0,3	0,3	0,3	0,3	0,3
Sand	34,4	30,1	33,3	40,1	38,5	38,7
Andesite	14,9	18,8	16,0	12,1	12,1	12,1
Graphite	4,7	4,3	4,6	5,6	4,5	4,7
Plumbum chloride	0,1	0,1	–	–	0,1	0,1
Fiberglass	0,5	0,5	0,5	0,5	0,4	0,5
Wooden chips	22,0	22,8	22,2	17,8	20,8	20,3
Length of chips, sm	10,0	11,7	10,0	12,3	14,0	16,0
Total	100	100	100	100	100	100

Tab. 3. Experimental physical-mechanical composite characteristics

Physical-mechanical characteristics	Characteristics for selected composition (table 2)					
	1	2	3	4	5	6
Ultimate tensile strength Under pure bending, MPa	22,0	22,3	22,0	18,3	18,5	19,1
Ultimate tensile strength under compression, MPa	20,0	18,9	20,0	20,0	19,8	20,0
Elastic modules under pure bending $\cdot 10^4$ MPa	1,2	1,2	1,2	1,0	1,0	1,0
Elastic modules under compression $\cdot 10^4$, MPa	0,9	0,9	0,9	1,0	0,9	1,0
Ultimate elongation, %	0,40	0,43	0,45	0,42	0,37	0,39
Average density, g/m^3	0,6	0,56	0,6	0,61	0,5	0,6

Tab. 4. Experimental, theoretic and offered RRIRT physical-mechanical composite characteristics

Physical-mechanical characteristics	Characteristic Values		
	RRIRT	theoretical	experimental
Ultimate tensile strength Under pure bending, MPa	15…20	19,1	21,5
Ultimate tensile strength under compression, MPa	6,0	20,0	17,4
Elastic modules under pure bending 10^4 MPa	0,8…1,0	1,0	1,0
Elastic modules under compression 10^4 MPa	1,0…1,2	1,0	0,99
Ultimate elongation,%	–	0,39	0,48
Average density, g/m^3	0,9…1,2	–	1,2

The error between the values being 13…15%, we can speak about satisfactory results for the parameters of ultimate elongation. The elastic modules are practically equal [1, 3]. Consequently, the given model can be applied for the composite material designing.

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