Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 9 (58) No.2 - 2016

FACTORS AFFECTING THE QUALITY OF WOOD-CEMENT COMPOSITES

Victor G. SANAEV[1] Vjacheslav I. ZAPRUDNOV[1]
Galina A. GORBACHEVA[1] Aleksandr N. OBLIVIN[1]

Abstract: *The aims of this research are the creation of wood-cement composites with predetermined properties and the prediction of the physical-mechanical characteristics of composites. The main factors that determine the quality of wood-cement composites are the properties of the original components (quality of organic filler, kind of mineraliser, type and activity of cement), composition of initial components, technological factors (conditions for preparing the wood-cement mixture, moulding method, method of densification and hardening), design features and type of finish. In order to manufacture the highest-quality wood-cement composites, it is recommended to use fillers, obtained from waste wood with the least amount of water-soluble substances such as spruce, fir, pine. The water-cement ratio and wood-cement ratio in the mixture have a significant impact on the quality of wood-cement composites. Reducing the water-cement ratio or increasing the strength of cement can improve the strength of the wood-cement composite. The fractional composition of the organic filler has a significant influence on the properties of the wood-cement composite. The average value of the shape factor of particles (ratio of the largest dimension to smallest) should not be over 8. The surface treatment of the wood filler gel composed of liquid silica and calcium chloride, increases the adhesive bond strength for the filler of aspen by 8.4 times, of birch by 4.3 times, of pine by 2.3 times. Gel is particularly effective in the production of wood-cement composites from green wood.*

Key words: *wood-cement composites, wood filler, composite structure, strength.*

1. Introduction

The most complete and genuine reflection of the term "quality" is provided in the wording of the international standard ISO 8402:1994, according to which the quality of the wood-cement composite is a set of characteristics relating to its ability to meet stated and implied requirements, in accordance with the purpose.

The existing standards for wood-cement composites (GOST 26816-86, 54854-2011) provide a very limited number of indicators of the physical-mechanical

[1] Faculty of Forestry, Forest Engineering Technologies and Landscape Architecture, Mytischi Branch, Bauman Moscow State Technical University, 1st Institutskaya street, 1, Mytischi, Moscow region, 141005, Russia.
Correspondence: Galina A. Gorbacheva; email: gorbacheva-g@yandex.ru.

properties, which mainly focus on the quality control over the technological process of manufacturing wood-cement composites, and which reflect only the average wood-cement composites, as achieved at the current technical level of production, not the limit values for special-purpose materials.

The key factors determining the quality of wood-cement composites, are: properties of the original components (i.e. organic filler, type of mineraliser, type and activity of cement); composition of original components; technological factors (preparation conditions for wood-cement mixtures, method of fabrication and method of densification and hardening); designed features and type of finish.

2. Properties of Original Components

The organic matter (wood) and the inorganic binder (cement) are antagonistic in nature. Wood consists mainly of organic chemical compounds (cellulose, hemicelluloses and lignin) which account for at least 99% of the total mass. The elemental chemical composition (carbon, hydrogen, oxygen and nitrogen) of wood of all species is almost identical [10]. In a solution of wood-cement mixtures, there are the specific quantities of hemicelluloses and extractives, entering into a chemical interaction, when mixed with wood filler and cement, which determine the quality of the overall wood-cement composite.

The issues related to the physical-chemical interaction in the wood-cement system, are currently adequately investigated by other researchers [3-5,7]. When assessing the suitability of a particular type of wood for manufacturing wood-cement composites, the mechanical and physical properties of wood are often left in the background. First of all, the harmful effects of the water-soluble substances in the wood, on cement, are taken into account.

In order to manufacture wood-cement composites of the highest quality, it is recommended to use fillers obtained from the waste wood with the lowest amount of water-soluble substances, such as spruce, fir, pine. Such species as aspen, birch, poplar, beech, and other hardwoods, are richer in water-soluble substances. Different contents of water-soluble substances lead to large differences in the setting time of wood-cement mixture, and affect the strength of adhesive joints. As a result, wood-cement composites derived from various wood species have different physical and mechanical properties.

The suitability indicator of chipped wood for the production of wood-cement composite is determined by the testing according to GOST 54854-2011. The coefficient of suitability of wood results from the expression:

$$k_s = CA_c /(10R_{sc}R_{cr}) \qquad (1)$$

where:

C is the consumption of cement [kg/m^3];

R_{sc} – the strength of wood-cement composite under compression [MPa];

A_c – the activity of cement [MPa];

R_{cr} – the strength of the reference cement equal to 40 MPa.

The fractional composition of the organic filler has a significant influence on the properties specific to the wood-cement composite. The average value of the shape factor of particles (the ratio between the largest and smallest dimension) should not be higher than 8. The number of particles with a shape factor over 8 should not exceed 2 % residue on a sieve with holes sized of 20 mm, and 10 % on the sieves of 10 and 5 mm. The dimensions of the chipped-wood particles should not exceed 40 in length, 10 in width, 5 mm in thickness. The bark content in powdered wood must not be over 10%, and pine needles and leaves over 5% in terms of weight, in a dry mixture of fillers. The content of water-soluble reducing substances should not exceed 2 %.

Special chips (wood wool) are used for the manufacture of fibreboards. Wood wool is produced in wood-carding machines. Their required sizes should not be less than 350 mm in length, 5 ... 10 mm in width, 0.2 ... 1.0 mm in thickness.

In the sawmill- and woodworking-wastes used as filler for the manufacture of wood-cement composite, it is always possible to find a mixture of different wood species. The selection of wastes and the attentive control of their composition by the kind of raw materials cannot be always made carefully enough. So as to investigate the effect of the mixtures of different softwood and hardwood fillers, on the strength of the wood-cement composite, we have conducted a research. The results of the experiments, shown in Figure 1, indicate that, when introducing to the filler of conifers, 20 % and 40 % birch-fractured particles, the strength of wood-cement composite diminished, respectively by 17 % and 21 %.

Bazhenov [1] suggested to characterize the quality of concrete by the ratio of its strength R_b to the strength of the weakest element R_1:

$$A = R_b / R_1 \qquad (2)$$

The analysis shows that because the actual structure of the wood-cement composite is complex (Figure 2), the coefficient of the structure A can vary within these limits (3):

$$A_{\min} \le A \le A_{\max} = f(R_b / R_1; k) \qquad (3)$$

where k is the coefficient taking into account the stress concentration and other factors.

At $A_{\min}$ or $A_{\max}$ the strength of concrete slightly depends on the properties of the filler and is determined primarily by the strength of the solution.

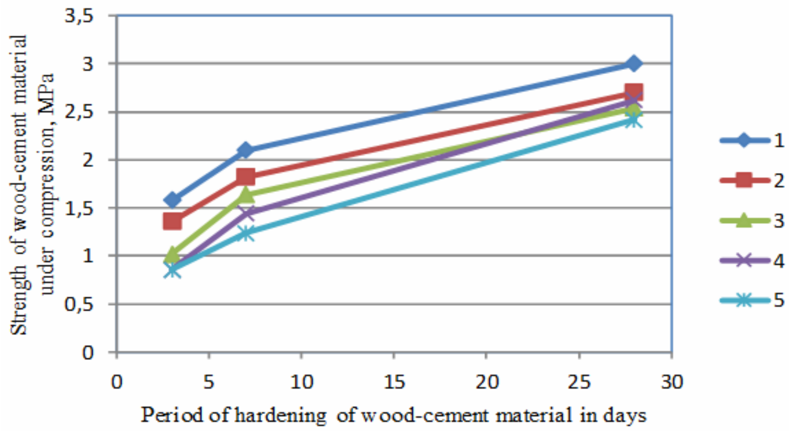

Fig. 1. *The dependence of the strength of wood-cement composite at various stages of hardening of the composition of wood fractured particles:*
1 are fractured particles of softwood 100%; 2 are fractured particles of softwood 80% and aspen 20%; 3 are fractured particles of softwood 60% and aspen 40%; 4 are fractured particles of softwood 80% and birch 20%; 5 are fractured particles of softwood 60% and birch 40%.

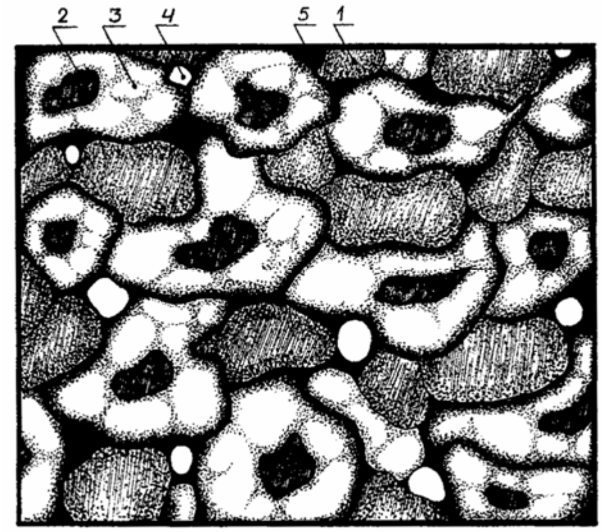

Fig. 2. *The scheme of the microstructure of system: wood filler - cement binder – water: 1 is wood filler; 2 are cement particles; 3 is shell of gel, formed from dissolved cement particles; 4 are air pores; 5 is free water.*

The quality of wood-cement composites depends not only on the strength of structural components, but also on the strength of the bonds between them. The research on the adhesion phenomena in wood-cement compositions has found a weak adhesion of cement to wood, and has established the aforementioned to be one of the main reasons for the low strength and high deformability of wood-cement composites. Furthermore, it is necessary to take into account the cohesive properties of bonded bodies and adhesives, since the phenomena of adhesion and cohesion are interrelated.

A deep insight into the nature of adhesion phenomena requires taking into account the achievements of modern science: physics and chemistry of surfaces, physics and chemistry of solids, physics and chemistry of polymers and surface phenomena. Despite the high number of works, adhesion continues to be a problem of modern science, and much remains to be done in this regard.

In the production of wood-cement composites, the chemical additives (such as liquid silica, calcium chloride, calcium nitrate, sulphate of alumina, etc.) are widely used. They are added to the wood-cement mixture, so as to increase grade strength, to accelerate the process of hardening, to improve the technological and deformation properties of wood-cement mixtures. Chemical additives localize and slow down the effects of water-soluble substances, or they coat filler particles with a waterproof film which prevents the contact of harmful substances within the filler, with the cement paste. The choice of chemical additives depends on the type, and quality of filler, as well as on the sugar content in water-soluble substances of the wood filler.

Our research has shown that the surface treatment of the wood filler gel composed of liquid silica and calcium chloride, increases the adhesive bond strength for the filler of aspen – 8.4 times, of birch – 4.3 times, of pine – 2.3 times. Gel is particularly effective in the production of wood-cement composites from green wood.

Many chemical additives, including sulphate of alumina, calcium chloride, are corrosive to steel reinforcement; therefore, their addition in an amount of more than 2 % of the overall mass of cement is not recommended. Currently, the solutions of calcium chloride and liquid silica as mineraliser for wood filler are most widely used in the manufacture of wood-cement composites.

In the production of wood-cement compositions, the best quality indicators of wood-cement composites, are achieved by rapid-hardening and by setting Portland cement above 400 in terms of grade, a fact which allows reducing the interaction time between the water-soluble substances of wood, and the cement, in the early stages of hardening of the wood-cement composite. At the same time, it should be noted that the use and selection of mineral binding agents for making wood-cement composites, have not been sufficiently explored.

3. The Composition of the Primary Components

The composition of the wood-cement mixture has a crucial impact on numerous properties of the wood-cement composite [3,4,6]. We have found that once with the increase in class (grade) of the wood-cement composite, its modulus of elasticity (MOE), modulus of rupture (MOR) for bending and tensile strength increase, whereas creep, shrinkage, and Poisson's ratio decrease.

According to the theory [8] the best properties of the materials with the conglomerate structure, which include wood-cement composites, are achieved in their optimal structure. The optimal structure is characterized by the uniform distribution of the solid phase in dispersion medium, the maximum possible packing density of particles, respectively, in the conglomerate and in its portion binder, the presence of a continuous layer of a binder to form a strong structural framework of the hardened binder.

When selecting the composition of wood-cement composites, in a factory laboratory, the basic requirement is to achieve the predetermined average density and the compressive strength at the minimum possible consumption of cement. Sometimes there are new challenges associated to imparting wood-cement composites with additional properties (increased frost resistance etc.). The consumption of components for the production of 1 m^3 of wood-cement composite depends on the type of filler and its class.

There are several ways to determine the composition of wood-cement composites. Building regulations recommend a calculation-experimental method. In this case, it is necessary to produce control samples (cubes) and their subsequent testing.

As regards the composition of the wood-cement composite, the method of selection, using nomograms developed at MSFU [7], gives the possibility to choose the composition of the wood-cement composite within a short timeframe. The method of selection of the composition of wood-cement composites is based on triangular diagrams "composition – property", for the creation of which, a simplex coordinate system is used.

These diagrams are easily displayed graphically and allow visualising and assessing the properties of a three-component system, due to which the wood-cement composite is in the area of optimum, and in the whole studied area. The simplex coordinate system has the constancy property of the sum of independent variables, and it has the aspect shown below, for the wood-cement composite:

$$x_1 + x_2 + x_3 = \sum k = const \qquad (4)$$

where:

$\sum k$ is the total mass of all components in 1 m^3 of wood-cement composite;

x_1, x_2, x_3 – the masses of binder, filler and water in 1 m^3 of wood-cement composite.

The water-cement ratio W/C and the wood-cement ratio D/C in the mixture have a significant impact on the quality of the wood-cement composite [13]. Reducing the water-cement ratio or increasing the strength of cement can improve the strength of the wood-cement composite. This dependence can be expressed by the formula (1):

$$R_b = R_c / [A(W/C)^{1/2}] \qquad (5)$$

where:

R_b is the strength of concrete after 28 days of normal hardening;

R_c – the activity of the cement;

A – a coefficient taking into account the influence of other factors;

W/C – the water-cement ratio.

In order to determine the composition of the concrete, it is more convenient to use the correlation of strength of the cement-water ratio instead of using the dependency of cement strength in the water-cement ratio. This dependency is linear when cement-water ratios changes from 1.3 to 2.5 and can be expressed by equation (5).

4. Technological Factors

The technological factors have a significant impact on improving the quality and on changing the properties of wood-cement composites [11]. Thus, the properties of wood-cement composites are significantly influenced by the compression method of the wood-cement mixture when these products are moulded [12]. The properties of wood-cement composites largely depend on the moulding method, and especially on the degree of compaction of the wood-cement mixture in the manufacture of products (Figures 3 and 4). Once with the increase in the specific pressure of pressing, the strength of wood-cement composite rises dramatically [9].

Studies of the effect of the compacting pressure for obtaining compositions of wood-cement composites of high quality have shown that the moulding pressure depends on the amount of cement in the mixture. With the increase in cement consumption in the range of 200...450 kg/m^3, the moulding pressure should increase from the values of 0.3…0.4 MPa up to the value of 1.1 ... 1.6 MPa.

The data on the modes of hardening of wood-cement composites relate mainly to thermo-moistening treatment of the products and in the paper [9] the hardening of the product is recommended at a relative humidity of 60 – 80 %.

5. Constructive Features and Type of Finishing

The constructive features and type of finish of wood-cement composites significantly affect their quality. Wood-cement composites have a high insulating ability, but a relatively low strength and large deformations. The properties of wood-cement composites such as shrinkage and swelling, creep and limit of compressibility are characterized as disadvantages of this composite. Full-scale surveys of various buildings, carried out by us in various climatic zones of the Russian Federation, have shown that strains of construction from wood-cement composites under the influence of long-term permanent loads are increasing.

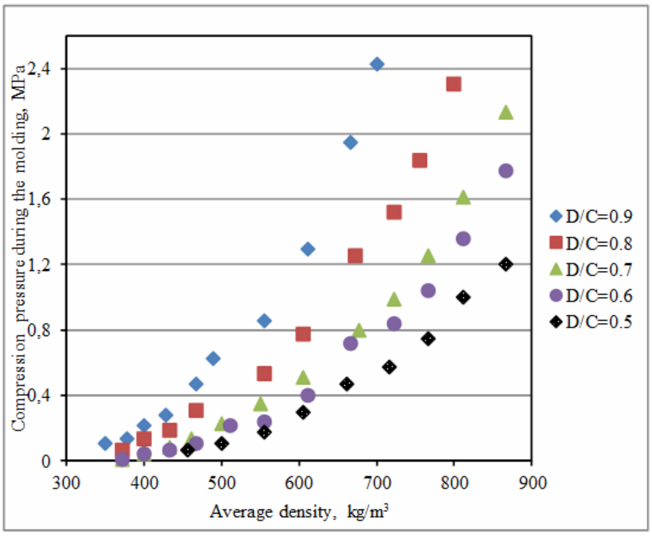

Fig. 3. *The influence of compression pressure during the moulding of wood-cement mixture on the average density of the material at various ratios D/C*

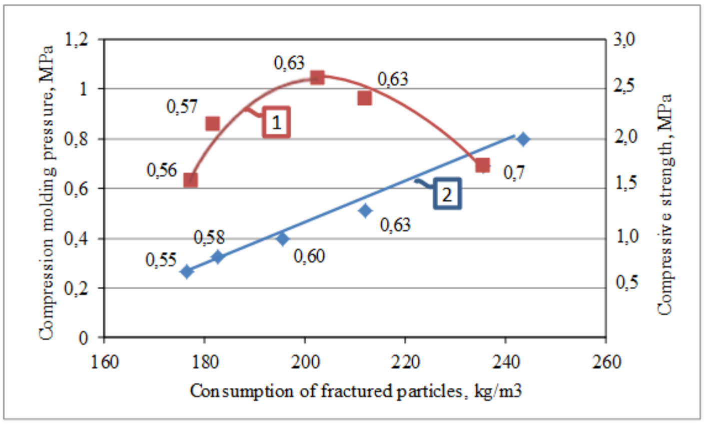

Fig. 4. *The influence of the compression moulding pressure, consumption of fractured particles and the value D/ C (the value of D/C is indicated by numbers) on the strength of arbolite at cement consumption at 330 kg/m^3 [9]:1 – compressive strength; 2 – compression moulding pressure*

Deformations lead to the formation of cracks both in the vertical and horizontal joints, and in the corners of the buildings, and in the planes of the walls. Textured layers of cement-sand mortar coated after moulding of products usually exfoliate. As a result, the constructions of wood-cement composite are moistened, are attacked by fungi in summer, as well as destroyed during winter.

In many buildings, several deflections of the wall panels can be observed. The high strains and low bearing capacity of the structures made of wood-cement composite, in particular their deflectability, are due to the fact that the adhesion of the wood-cement composite to the reinforcement is very low (0.1 – 0.2 MPa). In addition, the anchoring of the reinforcement in the wood-cement composite by conventional methods does not fulfil its role because of the low-resistance of wood-cement composite to local compression. A large discrepancy in the moduli of elasticity of the metal and wood-cement composite eliminates the possibility of economical use of steel reinforcing in flexible elements. It should be noted that the reinforcement in wood-cement composite is subject to corrosion [2].

6. Conclusions

Based on the aforementioned reasons, we can conclude that it would be most expedient to engineer bearing and enclosing structures of wood-cement composites, by working on the compression and bending. An example thereof is the complex three-layer sandwich, which displays a good combination of thermophysical, strength-related and stress-strain properties.

Acknowledgements

The research for this paper was financially supported by the Ministry of Education and Science of the Russian Federation, in the framework of realization of the basic part of the Government Contract № 2014/118, No. 1165 «Theoretical bases of creation of new nano-, bio - and composite materials on the basis of integrated and sustainable use of forest resources».

References

1. Bazhenov Yu. M., 1987. Technology of Concrete (in Russian). Higher School, Moscow.
2. Egorova E.M., 1985. Protection of steel rebar in the arbolit (in Russian). In: Calculation, designing and technology of manufacturing of concrete products. NIIZHB, Moscow.
3. Frybort S., Mauritz R., Teischinger A., Muller U., 2008. Cement bonded composites – a mechanical review. In: BioResources, vol. 3(2), pp. 602-626.
4. Jorge F.C., Pereira C., Ferreira J.M.F., 2004. Wood-cement composites: a review. In: Holz als Roh- und Werkstoff, vol. 62(5), pp. 370-377.
5. Miller D.P., Moslemi A.A., 1991. Wood-cement composites: effect of model compounds on hydration characteristics and tensile strength. In: Wood and Fiber Science, vol. 23(4), pp. 472-482.
6. Papadopoulos A.N., Ntalos G.A., Kakaras I., 2006. Mechanical and physical properties of cement-bonded OSB. In: Holz als Roh- und Werkstoff, vol. 64(6), pp. 517-518.
7. Podchufarov V.S., Chemleva T.A., Shcherbakov A.S., 1976. On the optimal composition of arbolit of high quality (in Russian). In: Proceedings of Moscow Forest Technical Institute, vol. 93, pp. 68-88.
8. Ryb'ev I.A., 1965. Two most important regularities of the properties of materials with a conglomerate type structure (in Russian). In: Building Materials, no. 1, pp. 17-20.
9. Shcherbakov A.S., Khoroshun L.P., Podchufarov V.S., 1979. Arbolit. Improving of the quality and durability (in Russian). Forest industry, Moscow.
10. Ugolev B.N., 2007. Wood Science and Forest Products (in Russian). Moscow State Forest University, Moscow.
11. Zaprudnov V.I., 1996. Investigation of the influence of technological factors on properties of wood-cement insulation (in Russian). In: Proceedings of Moscow State Forest University, vol. 285, pp. 12-17.
12. Zaprudnov V.I., Podchufarov V.S., 1988. Deformability of the carpet from the fibre-cement mass at the manufacture of three-layer wall panels for low-rise housing (in Russian). In: Proceedings of Moscow Forest Technical Institute, vol. 203, pp. 167-171.
13. Zhou Y., Kamdem D.P., 2002. Effect of cement/wood ratio on the properties of cement-bonded particleboard using CCA-treated wood. In: Forest Products Journal, vol. 52 (2), pp. 73-81.