New materials for the "green building" of urban areas

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Abstract. In the modern world during the rapid development of urban agglomerates, mankind uses less and less natural building materials and mainly uses artificially created. New construction technologies and modern materials must comply with environmental safety requirements, technical regulations and legislation in the field of environmental protection, so that the erected buildings and structures in urban design do not harm either man or the biosphere. Composite materials based on polymers and industrial waste are gaining popularity. The environmental assessment of new mineral-polymer composite (MPC) materials confirmed their compliance with technical and sanitary-epidemiological requirements, as well as with the criteria of the STO NOSTROY 2.35.4-2011 standard "Green building" such as: "Comfort and ecology of the internal environment", "Energy saving and energy efficiency ", "Ecology of creation, operation and disposal ", which will reduce the load of construction on urban ecosystems and ensure the creation of a safe and comfortable living environment.

1. Introduction
Comfortable living in urban areas implies not only the use of "smart houses" with the use of technologies that reduce the consumption of energy and material resources, reduce waste generation, but also improve the quality of life of people with minimal damage to the environment. This is also achieved through the use of environmentally friendly materials that have high physical and mechanical characteristics, resistant to climatic changes, and also meet the "Uniform sanitary-epidemiological and hygienic requirements" for use in construction [1-2]. By giving preference to environmentally friendly building materials, we simultaneously care about our health and the health of future generations. With the growth of construction volumes, the need to provide the construction industry with highly efficient, environmentally friendly and relatively cheap building materials is growing [3]. Such mineral-polymer composite materials (MPC) were developed at the Federal State-Funded Educational Institution of Higher Education "Irkutsk National Research Technical University" (INRTU) [4-8].

In the modern world, there is a tendency to use artificially created building composite materials using industrial waste in the construction industry, therefore, strengthening environmental requirements for the construction industry becomes relevant and justified [9].

In recent decades, more and more attention has been paid to "green building", the main principle of which is the environmental safety of building technologies, building materials and structures while creating a safe and comfortable living environment. One of the key aspects of "green building" is energy-ecological, reflecting the desire of the modern generation to ensure for the next generations a fair right to use the Earth's resources [10].

In world practice, they successfully develop "green building" and have rating systems of assessment and certification. Leading standards that regulate the environmental friendliness of...
construction, which are accepted around the world, and on the basis of which their own certification systems are created, are BREEAM (Great Britain), LEED (USA) and DGNB (Germany) [11].

In Russia, the first "green" standard appeared in February 2010, then in April 2011 the second, improved version of this system was released STO NOSTROY 2.35.4-2011 "Green Construction". Since the spring of 2013, GOST R54964-2012 has been in effect in Russia, which determines the procedure for assessing construction objects for their compliance with environmental requirements. In particular, this GOST prescribes that artificial reservoirs, bicycle parking, charging stations for electric vehicles, etc. should be built next to residential buildings. In accordance with this GOST, materials that are environmentally friendly must be used during construction.

Thus, based on the principles of "green building", as well as international and Russian "green" standards, we can conclude that a prerequisite for all is the use of environmentally friendly materials, resource conservation and minimizing the negative impact on the ecosystem as a whole.

During the construction of urban areas, it has become a frequent occurrence when a person experiences environmental discomfort in an artificially created environment. Therefore, it is necessary that man-made conglomerates form the surrounding space as an integral part of the natural environment and combine with it without conflict. Hence, an important task set within the framework of the concept of "sustainable development" is the selection of building materials and environmental assessment of the degree of their danger to the environment and humans. Sustainability of materials is a guarantee of health and wellness [10, 12].

Mineral-polymer composite materials (MPC) developed at INR TU with a high, up to 40-60%, content of filler from industrial waste (fly ash, ash microspheres, marble flour (dust), waste of small-sized mica - vermiculite), are an analogue of wood polymer composite (WPC) [4-6]. The materials developed by the MPC have high physical and mechanical properties, are resistant to moderately cold climates, humid environments, as well as to UV radiation. The use of industrial waste as a raw material makes it possible to reduce the negative impact on the ecosystem of the region, as well as the costs of the production of MPC products, which is of no small importance [10, 14]. The production of these products is not accompanied by emissions of substances hazardous to the environment, including for humans. Durability and reliability are beyond doubt, and disposal of waste material fits into natural ecosystems [15].

2. Study purpose
The main purpose of the study was to substantiate the possibility of using in "green construction" mineral-polymer composite materials produced from waste of various industries, while creating a safe and comfortable living environment. Despite a significant amount of research, the issues of environmental assessment of new building materials based on waste in an integrated aspect remain insufficiently studied.

3. Materials and methods
The environmental assessment of the obtained new MPC materials is based on the use of modern techniques, control and measurement tools, collection and processing of initial and experimental data. Studies of the properties of new polymer-mineral composites were carried out, including studies on microstructure, X-ray phase and elemental analyzes, study of physical and mechanical properties. Climatic and sanitary-hygienic characteristics of materials have been determined for compliance with the STO NOSTROY 2.35.4-2011 standard, technical regulations and legislation in the field of environmental protection.

4. Results and discussion
The environmental assessment of mineral-polymer composite materials was carried out in accordance with the standard of the organization "Green Building" - the rating system for assessing the sustainability of the environment STO NOSTROY 2.35.4-2011. Materials used in "green building" must correspond to the categories:
- comfort and ecology of the internal environment;
- energy saving and energy efficiency;
- ecology of creation, operation and disposal of the facility.

Investigations of the microstructure of samples of MPC materials (Figure 1: a, b, c, d) on a JIB-4500 double-beam electron-ion scanning microscope showed a homogeneous structure, a uniform distribution of filler particles and a polymer matrix among themselves without the formation of agglomerates, which results in good strength characteristics products.

![Figure 1](a) (b) (c) (d)

**Figure 1.** Micrographs of samples filled with: (a) fly ash - 50%; (b) fly ash and fly ash microspheres - 55%; (c) marble flour - 50%; (d) vermiculite - 40%.

Based on the study of samples by X-ray diffraction (Figure 2), the present crystalline phases of minerals in the composition of the sample under study and in the original waste were determined.

Analysis of the research results revealed the similarity of the peaks related to the minerals identified in the waste composition - fly ash (quartz (SiO$_2$), mullite (2Al$_2$O$_3$ • SiO$_2$), fluorite (CaF$_2$), calcite (CaCO$_3$), dolomite (CaMg(CO$_3$)$_2$), ash entrainment with microspheres (quartz (SiO$_2$), mullite (2Al$_2$O$_3$ • SiO$_2$), microcline ((K, Na) AlSi$_3$O$_8$), calcite (CaCO$_3$), fluorite (CaF$_2$), hematite (Fe$_2$O$_3$), micromarble (calcite (CaCO$_3$), diopside (CaMg (SiO$_3$)$_2$), dolomite (CaMg (CO$_3$)$_2$), fluorite (CaF$_2$), vermiculite (dolomite (CaMg(CO$_3$)$_2$), vermiculite (Mg$_3$Si$_4$O$_{10}$(OH)$_$_2$)), quartz (SiO$_2$), calcite (CaCO$_3$)), and in the composition of samples of materials with the corresponding waste, but less intensity. Thus, in the samples, there is no chemical interaction between the components of the mixture during its processing, and, therefore, there is no release of volatile substances and gases, as well as the formation of hazardous compounds.

The study of the properties of MPC materials showed that the samples meet the requirements of the standards applied to building materials in terms of physical and mechanical properties, in terms of resistance to humid and aggressive environments, to UV radiation, and have improved climatic performance compared to wood-polymer composites (WPC) (table 1-2).

**Table 1.** Results of studying the physical and mechanical properties of samples.

| Indicator name                              | Control method | MPC with fly ash | WPC          | SIC WPC norm |
|---------------------------------------------|----------------|------------------|--------------|--------------|
| Density, kg / dm2                           | GOST 15139-69  | 1180-1600        | 1050-1800    | -            |
| Flexural strength, MPa                      | GOST 4648      | 35-52            | 25           | more than 25 |
| Tensile strength, MPa                       | GOST 11262     | 18.9             | 9            | more than 10 |
| Charpy impact strength, kJ / m2             | GOST 4647      | 10-17            | 3-4          | more than 3,5|
| Hardness (ball indentation), N / mm2        | GOST 467       | 200              | 65           | more than 90 |
| Specific resistance to pulling out screws, N / mm, not less | GOST 10637  | 330              | 120          | more than 120|
| Breaking load of the board, distance between supports 400 mm, kg | GOST 4648 | 5292 | 2000 | more than 2000 |
| Flammability                                | GOST 30244-94  | G2               | G3-G4        | -            |
| Color fastness - loss of color on UV exposure in 24 h | GOST 21903- 76 | C1               | C2           | -            |
MPC materials are stable in humid environments in terms of water absorption, in comparison with their analog WPC, almost 16 times and more than 2 times reliable in terms of geometric stability (swelling in width and thickness) (table 2).

Table 2. Results of studies on water absorption of samples.

| Indicators                               | Specifications       | MPC (average) | WPC      |
|------------------------------------------|----------------------|---------------|----------|
| Water resistance when soaked in water    | Water absorption,%   | 0.12          | < 2      |
| 24 hours at 20 ±1 °C                     | Swelling along length,% | 0.19          |          |
|                                          | Swelling in width,%  | 0.31          | < 1      |
|                                          | Swelling in thickness,% | 0.37          |          |
| Boiling water resistance 2 hours         | Water absorption,%   | 0.36          | < 5      |
|                                          | Shrinkage along the length,% | -1.1          |          |
|                                          | Swelling in width,%  | 0.62          | < 1.5    |
|                                          | Swelling in thickness,% | 0.62          |          |

To predict the service life and changes in the decorative properties of MPC materials in a moderately cold climate, accelerated climatic tests of samples were carried out in accordance with GOST 30973-2002 (table 3).

Table 3. Changes in the mass of samples during climatic tests.

| Filler                  | Initial weight, g | Weight after 11 cycles, g | Weight after 20 cycles, g | Weight after 30 cycles, g |
|-------------------------|-------------------|---------------------------|---------------------------|---------------------------|
| FA-50 %                 | 28,390            | 28,570                    | 28,180                    | 28,365                    |
| FA and MC-55 %          | 30,145            | 30,215                    | 30,055                    | 30,205                    |
| M-50 %                  | 23,455            | 23,545                    | 23,360                    | 23,535                    |
| B-40 %                  | 26,655            | 26,655                    | 26,420                    | 26,525                    |

According to the tests carried out, the guaranteed service life of MPC materials is 30 years with a slight loss of strength in static bending of 3.09% with an allowable value of 5%.

An important property of materials used for the arrangement of urban areas and exterior decoration of buildings and structures is resistance to UV radiation (loss of color, "weathering"). The studies were carried out in accordance with GOST 9.407-84 and GOST R 52490-2005 and showed only a slight color change after exposure in the Suntest XLS 'test light chamber for 500 hours. The investigated MPC materials retain their decorative properties well without significant changes in a moderately cold climate (UHL1), are resistant to UV radiation.

Tests to determine the resistance of products to aggressive chemical environments (gasoline, engine oil, sodium hydroxide 40% (alkali), sulfuric acid 75%, acetone) showed that the samples withstood tests in chemical environments: the destruction of the material is minimal, the extraction rate for samples in all media is less than 1% (from 0.02 to 0.53%), the weight change is insignificant and amounts to hundredths, except for tests in acetone.

The levels of migration of harmful substances into the model environments were established in accordance with GN 2.1.6.1338-03 "Maximum permissible concentrations ..." and GN 2.1.6.2309-07 "Tentative safe exposure levels ...", radiological studies were carried out using the method of measuring the activity of radionuclides and organoleptic studies (table 4), which showed that the concentrations of substances released into the atmospheric air do not exceed the maximum permissible concentrations.

Table 4. Isolation of harmful regulated substances from the MPC.

| Pollutant | Concentration, mg / m3 |
|-----------|------------------------|
| Name / Code of Regulated Substance | Measurement units | MPC with fly ash and microspheres | The value of MAC / RSIL | RD on research methods |
|-----------|------------------------|-----------------------------|------------------------|------------------------|------------------------|
Concentrations of substances emitted into the atmospheric air for dibutyl phthalate, dioctyl phthalate and methyl methacrylate according to different samples are 10-50 times lower than the permissible values; radiological indicators do not exceed the permissible 370 Bq / kg and are characterized as radiation safe; the smell of the MPC of materials does not exceed the permissible indicators according to GOST R ISO 16000-28-2015, which confirms the environmental safety of the materials under study.

An important indicator of the ecological assessment of the sustainability of the quality of the habitat is the indicators of fire safety of products used in urban construction. To be used in "green building", MPK products must comply with the requirements of Federal Law No. 123-FZ dated 22.07.2008 "Technical Regulations on Fire Safety Requirements". Studies have shown that MPC materials correspond to the group that does not spread flame (RP1), are moderately flammable (B2) with moderate smoke-generating ability (D2), and belongs to the class of moderately hazardous (T2) in terms of toxicity of combustion products.

In accordance with the obtained research results and on the basis of hygienic characteristics, expert opinions on compliance with the "Unified Sanitary-Epidemiological and Hygienic Requirements", certificates of conformity in the GOST R certification system, environmental certificates of conformity and permits for the use of the mark of conformity were obtained for the materials developed by the MPC. There are also patents, a certificate of state registration of the computer program "System for assessing the influence of used raw materials in the creation of building materials on their performance", technical conditions have been developed.

Thus, the environmental assessment of the MPC materials for the properties and release of harmful substances, confirmed their compliance with technical and sanitary and epidemiological requirements, which allows the use of these materials in "green construction", as they correspond to the categories: "Comfort and ecology of the internal environment", "Energy saving and energy efficiency ", "Ecology of creation, operation and utilization ". Consequently, the materials developed by the MPC can be used in "green construction", which will reduce the load of construction on urban ecosystems and ensure the creation of a safe and comfortable living environment.

5. Conclusion
The environmental assessment of the MPC of materials by their properties and the release of harmful substances has confirmed their compliance with the criteria of the STO NOSTROY 2.35.4-2011 standard, as well as their compliance with technical and sanitary-epidemiological requirements, which is confirmed by certificates and expert opinions. Based on the research carried out and using the knowledge gained about the properties of the materials developed by the MPC, it is possible to use them in low-rise construction, in the design of courtyards, patios, for the arrangement of sports.
grounds, in the creation of small architectural forms. Also from MPK it is possible to produce siding for "cladding" houses, garden furniture, external window and door frames, fences, roof tiles, it is suitable for decking on verandas or terraces, for sea piers, etc. In addition, using its absolute hydrophobicity, products from MPC can find their application in the construction of dams and water barriers (in the elimination of the consequences of flooding, etc.)

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