Technology of Manufacturing Small Piece Construction Materials Using Ice and Snow

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Abstract. In the study, we present the technologies for manufacturing ice and snow blocks, the strength characteristics of which are sufficient for the construction of temporary low-rise structures (warehouses, garages, hangars, caponiers, and others). A technological feature of manufacturing blocks is the possibility to produce them without using specialized equipment. The technological modes of molding blocks and their thermal-physical and strength characteristics are determined. The blocks and a model of a single-story building with 3×4.2×2.3 m dimensions were tested on resistance to warming in the spring period. The results have revealed the possibility of a wide application of the proposed technologies in the North and the Arctic.

1. Introduction

Currently, in the northern and Arctic regions, due to the remoteness from the main industrial centers and the high cost of imported construction materials, there is a renewed interest in engineering structures made of ice and snow, which are almost the only materials that are available in unlimited quantities and can be procured with minimal costs. The northern and Arctic climatic conditions allow managing structures made of ice and snow for a sufficiently long period (up to 10 months). The facilities self-destruct after the expiration of useful life, and this can be an additional advantage.

The main features of ice as a building material are summarized in the works of K.F. Voitkovsky [1-3], I.S. Peschansky [4], B.A. Savelyev [5], and others. The problems of obtaining composites with an ice matrix and their use in construction have been investigated for more than a decade. The vast majority of works is focused on the development and study of reinforced composites for the construction of snow roads, ice crossings, dams and dykes [6-8]. According to the research results, it is acceptable to use all kinds of materials to reinforce ice and compacted snow: rice straw, twigs, fiberglass, cellulose, plastic rods, steel cables, newsprint pulp, parchment sheets, and others. Many publications on ice reinforcement emphasize the positive effect of increasing bearing capacity and durability.

Currently, the development and study of the physical-mechanical properties of composites with an ice matrix are conducted at the All-Russian Scientific Research Institute of Aviation Materials together with specialists from the National Research Tomsk State University, Bauman Moscow State Technical
University, Institute on Laser and Information Technologies, and others. However, the composites proposed by the organizations above are characterized by the complexity of the composition, which includes expensive fillers, polymer and chemical modifiers [9, 10]. There are known works on reinforcing fresh ice with fillers of natural origin [11]. Besides, the developed composites are intended for the construction of snow roads, ice crossings, buildings, and structures.

It should be noted that the technologies suggested by various authors for producing ice-based composites are considerably time-consuming, which significantly reduces the rate of manufacturing of construction materials. The analysis of scientific and technical literature and patent information revealed the lack of data on the application and the possibility of producing construction materials based on ice and snow mixtures. There is also no information on snow blocks in the outer reinforcing shells.

Thus, the present research aims to develop easily implemented technologies for producing wall materials based on ice and snow for the construction of temporary structures in the northern and Arctic climatic conditions.

2. Methodology of experimental research
For the laboratory research, samples were manufactured using tap water according to GOST R 51232, snow and sawdust of coniferous wood, as well as polypropylene bags for manufacturing exteriorly reinforced materials. Wooden molds with dimensions of 200x200x400 mm and 250x300x600 mm were prepared for each type of item. The curing time of the building blocks after freezing was 7 days at a temperature not exceeding minus 20°C. Compressive strength was investigated according to GOST 8462-85 “Wall materials. Methods for determining the compressive and bending strengths” on IT-1A-1000 compression-testing machine. Thermal conductivity was studied according to GOST 7076–87 “Construction materials and products. Method for determining thermal conductivity and thermal resistance under stationary thermal conditions ”on the ITP MG 4”100 "thermal conductivity meter.

3. Discussion of the results
Although ice blocks are the cheapest material for constructing temporary structures in the northern and Arctic conditions, their extraction from the ice cover of reservoirs is a particularly time-consuming process. It is also problematic to ensure the necessary dimensional accuracy. Freezing water in molds is complicated by the freezing duration, the difficulty of removing the block when it freezes to the surface of the mold, and the possibility of block destruction due to volume expansion during ice formation. Moreover, ice blocks have sufficiently high thermal conductivity. It can be reduced by introducing heat-insulating fillers, which can stand as reinforcing components.

However, when freezing a mixture of water with reinforcing and heat-insulating elements, it is difficult to ensure a uniform distribution of reinforcing components in the ice volume due to the floating of substances with a low specific gravity up to the water surface and submersion of reinforcing ingredients with a density higher than the water density. The manufacturing technology of ice blocks is greatly simplified with the use of snow-water mixture as raw material [12]. Thus, the application of a snow-water mixture, which is characterized by high viscosity, as a matrix can ensure uniform distribution of reinforcing components in the volume.

Cubic-shaped samples were formed 100x100x100 mm in size for studying the strength properties of snow-water mixtures. Snow-water samples were prepared as follows. Water was poured into the mold. The snow was added afterwards and mixed with the water until a homogeneous mass was obtained. Then the mixture was slightly compacted, the surface was levelled. Later, the sample was removed from the mold and frozen in a free state at ambient temperature from minus 15°C to minus 25°C. The curing time under these conditions was seven days before testing. When snow is added to the water, its temperature drops to almost 0°C, which accelerates sample freezing.

Table 1 presents the compressive strength values of the samples obtained at a temperature of minus 20°C.
Table 1. Strength of samples from snow-water mixtures.

| No. | Mixture composition water/snow, % wt | Compressive strength, MPa | Persistence of block shape |
|-----|-------------------------------------|---------------------------|----------------------------|
| 1   | 90/10                               | 0.45                      | Shape is not preserved     |
| 2   | 80/20                               | 0.68                      | Shape is not preserved     |
| 3   | 60/40                               | 3.3                       | Sample preserves the shape |
| 4   | 55/45                               | 3.3                       | Sample preserves the shape |
| 5   | 50/50                               | 6.4                       | Sample preserves the shape |
| 6   | 45/55                               | 5.0                       | Sample preserves the shape |
| 7   | 40/60                               | 3.1                       | Sample preserves the shape |
| 8   | 30/70                               | -                         | Sample preserves the shape |

The geometric dimensions of the snow-water blocks with 40-60% of snow stay practically unchanged after removing from the mold. The sample can be removed from the mold without restraint and freeze in a free state. When the snow content is more than 60% or less than 40%, the blocks do not preserve the geometric dimensions after removal from the mold, and freezing in the free state is practically impossible.

Measurements of the geometric dimensions of the obtained block samples showed sufficient stability after freezing. The range of the geometric dimensions of the samples does not exceed 1.5%, which meets the requirements for dimensional accuracy of bricks or concrete blocks and half blocks provided by GOST 503-2012 “Ceramic brick and stone. General specifications” and GOST 21520-89 “Small wall blocks of cellular concrete. Specifications”.

The compressive strength of samples containing 40 wt.% to 60 wt.% snow ranges from 3.1 MPa to 6.4 MPa, which is sufficient for the construction of low-rise structures.

The samples were prepared 100x100 mm in size and 10 mm thick for determining the coefficient of thermal conductivity of snow-water materials according to the technology described above.

The results of the experiment have revealed that the thermal conductivity of snow-water material is slightly lower than that of freshwater ice and ranges from 1.38 W/(m·°C) with the same water and snow contents.

As stated above, reinforcing and heat-insulating additives can be introduced into the composition of a snow-water mixture of ice blocks to increase their strength and thermal properties. However, this operation is difficult for ice materials. When snow is added to the water, the viscosity of the mixture significantly increases. The additional introduction of ingredients ensures uniform distribution after mixing.

The possibility of using this approach is proved by the example of manufacturing snow-water mixture with the addition of sawdust in an amount of from one to five weight parts. The fractographic analysis of the sample sections showed a sufficiently uniform distribution of the sawdust in the snow-water mixture.

Table 2 presents the results of studies of the strength properties and thermal conductivity of frozen snow-water samples after seven days of curing.

The composition of the snow-water mixture contained five weight parts of water and snow. Sawdust of coniferous wood was added in the amount of one to four weight parts, and the dispersion of the particles was 2.5 mm. When the amount of sawdust prevails 4 weight parts, the sample does not preserve the shape after removing from the mold.

According to the measurements of the thermal conductivity, the introduction of sawdust significantly increases the thermal properties of composite material. If the minimum thermal conductivity of snow-water mixtures with the same weight ratio of water and snow is set at 1.38 W/(m·°C), then with the introduction of four weight parts of wood sawdust with thermal conductivity of 0.07 W/(m·°C) coefficient of thermal conductivity decreases to 0.526 W/(m·°C).
Table 2. Compressive strength and thermal conductivity of snow-water samples filled with wood sawdust.

| No. | Mixture composition water/snow/sawdust, weight part | Thermal conductivity, W / (m · °C) | Compressive strength, MPa |
|-----|--------------------------------------------------|-----------------------------------|--------------------------|
| 1   | 5/5/1                                            | 1.5076                            | 7.99                     |
| 2   | 5/5/1.5                                          | 1.1505                            | 5.97                     |
| 3   | 5/5/2                                            | 1.5182                            | 6.43                     |
| 4   | 5/5/2.5                                          | 0.7906                            | 5.57                     |
| 5   | 5/5/3                                            | 0.7859                            | 4.41                     |
| 6   | 5/5/4                                            | 0.5259                            | 3.67                     |

It should be noted that when the amount of sawdust in the snow-water mixture increases, the strength of the composite material monotonously decreases, i.e. hardening effect is not observed. Probably, this is due to a decrease in the strength of individual particles of wood after being treated by a cutting tool. However, with sawdust less than four weight parts, the strength of a snow-water material reaches 3.67 MPa, which is sufficient for the construction of low-rise structures.

For conducting field tests and determining the resistance to spring warming, blocks were prepared from ice and snow-water mixtures with sawdust. Dimensions and other characteristics are presented in Table 3. In total, three types of materials were manufactured: blocks from frozen tap water, blocks from a snow-water mixture with a content of 50% water and 50% snow, and snow-water blocks containing 5 weight parts of water, 5 weight parts of snow and 1 weight part of wood (pine) sawdust.

Table 3. Characteristics of ice and snow-water blocks.

| Composition of a block | Outline dimensions, mm | Weight, kg | Volume, d³ | Density, g/cm³ |
|------------------------|------------------------|------------|------------|---------------|
| Ice                    | 180x200x400            | 13.66      | 14.4       | 0.975         |
| Snow-water mixture     | 200x200x400            | 11.46      | 16         | 0.716         |
| Snow-water mixture with sawdust | 200x200x400 | 11.94 | 16 | 0.746 |

Three models of wall enclosures 1 m long, 1 m high, 0.2 m thick were built from the manufactured blocks. The long sides of the models were facing south. Photos are presented in Figure 1.

Figure 1. Models of wall structures made of snow-water blocks (on the right) and blocks from snow-water with the addition of sawdust.
Testing of the models began in March 2018 and continued almost until the structures completely melted. Structures made of snow-water blocks containing sawdust demonstrated the least durability. We assume that despite their lower thermal conductivity, the intensity of their melting depends on the degree of darkness of the composite material.

The production technology of small piece construction blocks is completely identical to the technology for manufacturing pilot samples. It is possible to use wood for manufacturing molds, the volume of which should not exceed 30 l since the permissible limit for lifting and carrying weights is not more than 30 kg according to the current rules and standards of labor protection. It is recommended to apply polyethylene film coating to its inner surface to avoid freezing and adhesion of the snow-water mass to the walls of the mold. Compared with blocks obtained after freezing the water in molds, snow-water blocks almost completely lack warpage during ice formation, and the blocks are rectangular with flat surfaces. It is easy to remove them by turning the mold and shaking it lightly.

Despite the simplicity and affordability of the production technology of snow-water blocks, there are two disadvantages, which are a freezing duration and the need to use water. Moreover, it is desirable to reduce labor intensity, increase production rates and improve thermal characteristics.

As known, the North American Indians used to build their temporary housing from snow blocks obtained from naturally compacted snow cover. However, the strength of such blocks is very low and amounts to 0.5-0.8 MPa [1-3]. A significant increase in the strength of snow blocks can be achieved by coating even with a soft cover. It is performed as follows. A soft cover, such as sack, is placed in a wooden rectangular mold and periodically rammed with snow. Then it is tightly sealed and removed from the mold. Thus, a construction block is ready for immediate use in the wall construction. The block joints can be sealed with an unfrozen snow-water mixture. At the end of the winter season, the rest of the snow affected by a thaw and meltwater is removed from the cover. The envelope can be reused in the next season after drying.

The thermal properties of such enclosures are determined by the thermal conductivity of compacted snow, which is about 0.4 W/(m·°C). It is significantly lower than that of ice and snow-water materials.

For testing, a model of a one-story building with an area of 4.2x3 m, a height of 2.3 m, and an internal volume of 7.2 m³ was built with externally reinforced snow blocks [13] with 250x300x600 mm dimensions (Figure 2). Wall thickness is 0.6 m, ceiling thickness is 0.25 m, ceiling overlap is made of pine boards 40 mm thick. The construction was built on a soil foundation, the thermal protection of which was not provided. The model of a building was heated by GII-3.65 Sibirychka heater with a rated thermal power of 3650 W.

![Figure 2. General view of the one-story building model.](image)

The conducted tests showed the following. At ambient temperature and an onset indoor temperature of minus 40°C, when the heater is turned on for 6 hours, the temperature in the structure stabilizes and...
reaches 9-10°C under the ceiling, 7°C in a meter from the floor, and minus 8°C on the floor surface. According to the test results, it is further recommended to strengthen the thermal insulation of the ceiling or increase the power of the heating equipment.

The strength of externally reinforced snow blocks is sufficient for the construction of one-story structures. During the tests from the beginning of December to April, not a single defective block was detected with a violation of the external reinforcement. Over time, under the influence of a constant load, gradual subsidence and a slight decrease in the height of the structure are observed due to compaction of snow in the blocks.

Additional experiments on the deformability of snow blocks under constant load have revealed the following. At loads of 91.2 kg and 190 kg on the surface of a block with an area of 1800 cm², a decrease in the height of the block is observed during one week and then stops. Height lowering values are 2 mm and 4 mm. With an average weight of 16 kg of one block, these loads are suitable for walls 1.4 m and 2.9 m high.

The actual value of the height settlement of the construction is 25 mm during five months of testing, which is consistent with the experiment results, taking into account the decrease in load in the blocks located above. According to the test results in the range of Yakutsk, the operation of the structure from externally reinforced snow blocks is possible until mid-April. To the north, at higher latitudes, the operation can be extended until May.

4. Conclusions
1. Technology has been developed for the production of small-piece snow-water construction materials, including the preparation of a mixture of water and snow in molds, the removal of molded blocks and freezing in a free state. Introduction of additional ingredients to the snow-water mixture can reduce thermal conductivity and improve thermal properties.
2. Technology has been developed for the production of compacted snow blocks. The snow is compacted in a soft cover placed in the mold, which creates its external reinforcement.
3. Laboratory and field tests of the construction materials and models of structures, which were made using the developed technologies, have shown the possibility of their widespread use for the construction of low-rise temporary buildings and structures in the northern and Arctic regions.

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