Reinforcing of Composite Materials on the Basis of Fresh Ice and Natural Origin Additives

A S Syromyatnikova1,2,a, A M Bol’shakov1,b, A V Alekseeva3,c

1 FRC YaSC SB RAS, IPTPN SB RAS, Department of Mechanics and Safety of Designs, 1, Oktyabrskaya str., Yakutsk, Russia, 677980
2 Department of Physics of Metals and Technologies of Welding, Institute of Physics and Technologies, NEFU, 28, Kulakovsky str., Yakutsk, Russia, 677027
3 Middle School of General Education № 17, 6, Petrovsky str., Yakutsk, Russia, 677980

E-mail: a.s.syromyatnikova@mail.ru, a.m.bolshakov@mail.ru, alekseeva.kira@mail.ru

Abstract. Possibility of application fibrous additives of a natural origin in an ice matrix as the reinforcing additives is investigated. As a matrix, fresh ice water was used, reinforcing additives — hay fiber 10 mm long and 0.5–1 mm thick and basalt fiber produced by Plant of Basalt Materials LLC (Pokrovsk, Sakha Republic (Yakutia)) with a thickness of 9–12 µm and 40 mm long. The volume content of hay fibers was 10, 20, 30%. The density of chaotic styling of basalt fiber in a single layer was about 3 mm / mm². Magnitude of breaking load was determined experimentally when tested according to three-point bending pattern. It is shown, that introduction fibrous additives a natural origin leads two - to triple increase of ultimate bending strength of fresh ice. During the tests, unreinforced ice samples fractured brittle along the loading force, and reinforced samples showed viscous fracture and an increase in breaking load due to the mechanical adhesion of reinforcing fibers to ice matrix.

1. Introduction

Development of scientific foundations for creation of new materials and operational technologies that are effective when used in the Arctic, is an important task, which is important in both fundamental and applied aspects [1, 2]. In recent years, interest in ice and ice-ground composites has increased not only as objects of scientific research, but also as promising materials for solving applied problems: from the construction of temporary ice structures to permanent hydraulic structures. Climatic conditions of more than half of the Russian Federation territory make it possible to build and operate ice and ice-ground structures with natural cooling. An effective conventional method of hardening ice as a structural material is its reinforcement. The choice of reinforcement method is determined by feasibility study, which takes into account the costs of its creation and technical and economic effect obtained from its application: reduction of construction time, increase in terms and safety of operation, as well as environmental friendliness. From this point of view, the study of influence of dispersed, fibrous and mesh fillers from local natural raw materials: waste wood processing, mineral fibers, etc. - on physical and mechanical properties, thermal cracking and durability of composite materials based on fresh ice seems to be an urgent task of the Arctic materials science.
Experimental and theoretical aspects of ice study as a structural material have been studied since the middle of the XXth century [3-11]. Ice as a structural material is considered in the vast majority of studies as a paving material. To enhance the ice cover, the use of various materials of natural and artificial origin was proposed: grass, straw, wood pulp, brushwood, glass fibers, water-soluble high-molecular compounds, metal and polymer reinforcement. It is known that during World War II, Jeffrey Pike proposed the first composite material based on ice and cellulose for the manufacture of aircraft carriers, known as pikerite [12]. In the monograph of Sirotyuk V. V., Yakimenko O. V., Zakharenko A. A. the results of the study and implementation of geosynthetic materials use for reinforcement of winter roads and ice crossings are given [13]. The properties and technology of obtaining ice composites and possibility of its use as full-fledged substitutes for traditional building materials in the northern construction-climatic zone are considered in the works of N. K. Vasiliev and others [14-16]. Conducted in recent years, a group of researchers devoted to methods for producing ice composite materials (paintwork materials) with various types of reinforcing polymer fillers and chemical modifiers and the study of their influence on physical and mechanical properties of fresh ice [17-19].

It is obvious that in the conditions of the North and the Arctic, which are remote from industrial centers and vulnerable ecology, economically and technologically efficient and environmentally friendly types of reinforcing fillers are materials of natural origin from local raw materials. Despite a fairly significant amount of work on the reinforcement of ice, it is necessary to recognize that there have been no targeted and comprehensive experimental studies on management of physical and mechanical and operational properties of ice compositions by introducing environmentally friendly fillers of natural origin.

The aim of our research is to develop scientific foundations of creating new composite materials based on fresh ice strengthened with natural materials from local raw materials that are effective and environmentally friendly when used in the North and the Arctic. This paper describes a method for producing paintwork materials with fillers of natural origin and presents the results of initial stage of experiments to study the effect of natural fillers on the strength properties and durability of ice composites.

2. Material and Methods of Experiment

As a matrix, fresh ice water was used, reinforcing additives — hay fiber 10 mm long and 0.5–1 mm thick and basalt fiber produced by Plant of Basalt Materials LLC (Pokrovsk, Sakha Republic (Yakutia)) with a thickness of 9–12 µm and 40 mm long. The volume content of hay fibers was 10, 20, 30%. The density of chaotic styling of basalt fiber in a single layer was about 3 mm / mm². Ice composites were obtained by layer-by-layer churning with a quiet pouring of water in polypropylene molds with dimensions Lxbxh = 160x45x40 mm in full-scale conditions at an outside air temperature of 36 °C. In the manufacture of reinforced sample, the lower layer of ice of required thickness was first frozen in the form, then a layer of filler was placed on it, and layer-by-layer freezing continued. Water cooled to the containers was poured to 0°C to prevent thawing of lower layer of ice during its freezing. The reinforcing filler was placed in 1-3 layers, so the samples consisted of 2 to 4 layers of ice with 1 to 3 layers of filler arranged between them. After complete freezing, the sample was taken out of container and an edge cut with a width t = 2 mm and a depth c = 2 mm was applied to it with a soldering iron. The scheme of samples is shown in Fig. 1, a. Magnitude of breaking load was determined experimentally when tested according to three-point bending pattern Pf (Fig. 1, b). The result was taken as an average of three trials for each point. The distance between the supports was l = 140 mm. The obtained results were used to calculate the tensile strength at bending of samples with the cut Rb of reinforced and non-reinforced ice using the formula [20]:

\[
R_b = \frac{3P_f l}{2b(h-c)^2} \cdot 10^{-2},
\]  

(1)
where $P_F$ in H, $l$, $b$, $h$, $c$ in cm.
Also the time of complete thawing of ice samples at room temperature $T$ was determined.

![Diagram of strength limit](image.png)

**Figure 1.** The scheme of strength limit of the sample with a regional cut (a) on a tension at a bend (b).

### 3. Results and Conclusion

Results of the study are shown in the Table 1.

| Number of additives layers | Time of full thawing $T$ [minutes] | Breaking load $P_F$ [H] | Strength limit on a tension at a bend $R_b$ [MPa] |
|----------------------------|-----------------------------------|------------------------|---------------------------------------------|
| -                          | 150                               | 230 ± 20               | 0, 74 ± 0.07                                |
| 1                          | 130                               | 325 ± 30               | 1, 04 ± 0.1                                |
| 2                          | 120                               | 415 ± 40               | 1, 33 ± 0.1                                |
| 3                          | 90                                | 535 ± 50               | 1, 71 ± 0.1                                |

- Hay fibers
- Basalt fiber

Obtained experimental results show that introduction of fillers leads to an increase in tensile strength of ice composites by a factor of 2–3 and to a decrease in their durability with an increase in the content of filler.

During the tests, unreinforced ice samples fractured brittle along the loading force, and reinforced samples showed viscous fracture and an increase in breaking load due to the mechanical adhesion of reinforcing fibers to ice matrix (Fig. 2). Reducing the time of thawing with introduction of filler is expected and is due to reduced content of ice matrix in the composite, as well as structuring of ice with introduction of a filling agent.
Figure 2. Character of destruction of samples from fresh ice and reinforced by basalt fibres (a) and hay fibres (b).

So, introduction of fibrous fillers of natural origin leads to a two-, threefold increase in strength characteristics of fresh ice, which makes it possible to consider ice composite materials as promising environmentally friendly, economically and technologically effective materials for construction and construction purposes, as well as road paving materials in the arctic regions.

4. References
[1] Buznik V M, Burkovskaya N P, Zibareva I P, Cherepanin R N 2017 To a question of construction of a map of domestic materials technology Materialovedenie 4 22-28
[2] Buznik V M, Kablov E I 2017 Arctic materials technology: condition and perspectives Vestnik Rossiiskoi Akademii nauk 9 831-843
[3] Peschanskii I S 1975 Ice study and ice engineering (Gidrometeoizdat, Leningrad)
[4] Butyagin I P 1966 Strength of ice and ice cover (Nauka, Novosibirsk)
[5] Savel’ev B A 1963 Structure, composition and properties of an ice cover of sea and fresh reservoirs MGU Publishing House (Moscow)
[6] Ice and Construction Ed. by L Makkonen 1994 RILEM Technical Committee TC-118
[7] Kobble R L, Kingery U D 1966 Art hardening (reinforcing) of ice Ice and snow Mir (Moscow) 94–116
[8] Cederwall K 1981 Behaviour of a Reinforced Ice Cover with Regard to Creep Proc. of International Conference on Port and Ocean Engineering under Arctic Conditions (POAC) (Quebec, Canada) I 562–570
[9] Nixon W A, Smith R A 1987 The Fracture Toughness of Some Wood-Ice Composites Cold Reg. Sci. Technol. 14 139–145
[10] Fransson L, Elfgren L 1986 Field Investigation of Load-Curvature Characteristics of Reinforced Ice Proc. of POLARTECH 86 Conference (Helsinki) I 175–196
[11] Sazonov K E, Dobrodeev A A 2014 Research of durability of ice on a bend in a northeast part of Caspian sea Problems of Arctic and Antarctic 3 62-68
[12] Kravchuk A N, Lusenko V A 2015 The surprising composite – pikerit Composite world 61 68 – 70
[13] Yakimenko O V, Sirotuyuk V V 2015 Strengthening of ice crossings by geosynthetic materials SibADI Publishing House (Omsk)
[14] Vasil’ev N K, Pronk A D 2015 Ice and ice-ground composites as building materials in ice constructions Izvestiya VNIIG imeni B.E.Vedeneeva 277 35-45
[15] Vasil’ev N K, Ivanov A A, Shatalina I N 2013 Methods of hardening and reinforcing of ice for designs of hydraulic engineering constructions from ice and ice-ground composites Vestnik NGU. Series: Mathematics, mechanics, informatics 3 31-37

[16] Vasil’ev N K, Ivanov A A, Sokurov V V, Shatalina I N, Vasilyev K N 2013 Strength Properties of Ice-Soil Composites Created by Method of Cryotropic Gel Formation Cold Reg. Sci. Technol. 70 94–97

[17] Buznik V M, Landik D N, Erasov V S and others 2017 Physical and mechanical properties of composite materials on the basis of an ice matrix Materialovedenie 2 33-40

[18] Buznik V M, Goncharova G Yu, Nuzhnui G A, Cherepanin R N 2018 Influence vegetative reinforcing fillers on strength properties of composite materials with an ice matrix Materialovedenie 9 33-40

[19] Cherepanin R N, Nuzhnui G A, Razomasov N A, Goncharova G Yu, Buznik V M 2017 Physical and mechanical properties of ice composite materials reinforced by RUSAR-C fibres Materialovedenie 7 38-44

[20] GOST 10180-2012