

PAPER • OPEN ACCESS

The adhesive behavior of the polyethylene component in the “GP-ice” for studying the ice propulsion of the promising Arctic icebreakers

To cite this article: Valeri Zuev *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **678** 012024

View the [article online](#) for updates and enhancements.

You may also like

- [The New Areas of the Ice Cover Modeling Using the Composite Model Ice “GP-ice”](#)
A S Sebin and Yu A Dvoichenko
- [Water resistance forecasting of the icebreaking air cushion platform](#)
V A Zhev, E M Gramuzov, N M Semenova et al.
- [Towards automated identification of ice features for surface vessels using deep learning](#)
E Kim, N Panchi and G S Dahiya



245th ECS Meeting • May 26-30, 2024 • San Francisco, CA

Present your work at the leading electrochemistry & solid-state science conference.

Network with academic, government, and industry influencers!

Submit abstracts by December 1, 2023

[Learn more & submit!](#)



The adhesive behavior of the polyethylene component in the “GP-ice” for studying the ice propulsion of the promising Arctic icebreakers

Valeri Zuev, Yuri Dvoichenko, Andrei Sebin¹ and Natalia Semenova

Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Department of shipbuilding and aviation technology, 603950, Minin St., 24, Nizhny Novgorod, Russia

E-mail: ¹asebin@nntu.ru

Abstract. The maritime constituent is the crucial component of the Arctic transport and logistics system. In the modern period of the development of science and technology, the ice model experiment in the experimental model basin is the main instrument of the research engineer, who creates and develops the existing arctic vessels forms. The article is dealt with the one of the aspects of the composite model ice (“GP-ice”) consisting of the polyethylene granules frozen into natural ice. The crucial factor providing the modelling conditions is the model ice strength reduction due to lower adhesion forces on the granules. The aim of this investigation was to assess the reliability of the existing data and to obtain the one’s own results in terms of the adhesion strength value at the normal fracture. The experimentation procedure in the NNSTU small ice tank is presented. The adhesive compound strength of the high-pressure polyethylene and ice at the normal fracture was determined. The analysis of results, which has satisfactory statistical characteristics, is presented. As the experiments results, the dependence of the adhesion strength value on the temperature inside the heat chamber (-20, -10) was revealed. The influence of the frozen surface boundaries was also significant and had a negatively impact on the results of the samples separation of a smaller dimension-type. In further the obtained results will be used in the mathematical models of the “GP-ice” deformation and fracture, as well as for improving the ice cover composite model for testing the promising Arctic icebreakers forms in the experimental model ice basin.

1. Introduction

Water transport is the basis of the transport and logistics system of the Arctic region. The success of all projects for the Arctic socioeconomic development directly depends on the its state and the operational efficiency [1, 2].

The freight charge in the Arctic is significantly determined not only by the vessels tonnage, but also by the service fee of the icebreaker. The icebreaker operating costs are very significant and are primarily associated with significant energy costs for the ice cover failure. This is shown in the high capacity of the ship power installations of the modern icebreakers and negative influence on the cost of goods transported along the Northern Sea Route.

To increase the cost-effectiveness of the ice cover failure and the ship’s channel laying in the ice and to reduce the cost of the icebreaking services is the one of the main ways to overcome these restrictions. The solution to this problem is associated with the development of new promising forms of the icebreaker hulls, the development of the issues of the ice propulsion of the ships [3]. The ice



model experiment in the experimental model basin is the main instrument of the research engineer, dealt with the naval ice technology.

However, such researches are very expensive and severely limit the researchers' ability. This is due to the fundamental contradictions between the approaches built into the classical theory of the ice modelling and the real picture of the ice failure by the technical tools [4]. Consequently, the suitable for practice result can only be obtained by the experimenting on the large-scale models (geometrical scale $\lambda \leq 20$). Testing within the specified limits is possible only in the ice basin with very large bowl sizes, which affects the experiment cost and quality deeply. To use the smaller basin and smaller scales, the new ways to model the ice cover is required. One of the main requirements for the ice model is to reduce its strength under transverse forces. The main purpose of this work is to study methods of strength reduction and determine the physical characteristics of this reduction.

2. The composite ice model

To achieve this aim at the NNSTU n.a. R.E. Alekseev the new ice cover model [5] was proposed (figure 1). It consists in the adoption of the spherical granules of the high-pressure polyethylene (HPPE). It is assumed that such material due to the small quantity of the adhesion strength of its connection with ice will weaken the ice cover, reducing its strength characteristics. The density and the friction coefficient of the high-pressure polyethylene are the same as for natural ice, and the repeatability of the experiments is ensured by the lack of the reaction with water and the same growth limitation of the ice crystals.

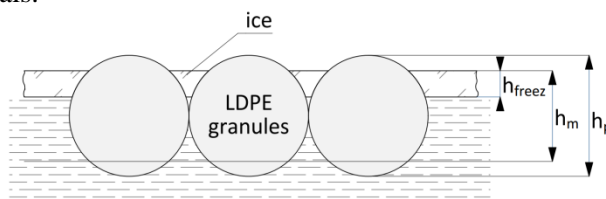


Figure 1. The composite model of the ice cover: h_{freez} – freezing thickness of the granules layer; h_m – the reduced thickness of the model ice; h_p – layer thickness of the polyethylene granules.

The positive qualities of the high-pressure polyethylene (density, friction coefficient) make it possible to create the model ice that meets the requirements of the classical modelling theory. At the same time, the varying possibility with the different parameters (granule diameter, layer number, freezing thickness) opens up wide possibilities to create the ice model that is adequate to the nature ice on the scale smaller than other models. As a result the conducting of the ice model experiment is greatly reduced the cost.

In the process of the deformation and the failure, the ice cover is covered with the radial and the circumferential cracks net [6, 7]. The polyethylene granules adoption into ice should replace the tensile strength in the ice wedge (figure 2) with the “ice-HPPE” adhesion strength (figure 3).

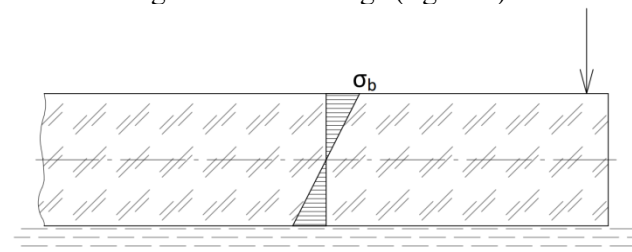


Figure 2. The ice wedge bending: σ_b – the bending stresses.

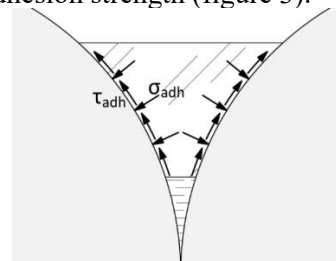


Figure 3. The adhesive bonding stresses on the granules surface: σ_{adh} , τ_{adh} – the normal and the shearing stress components of the adhesive bonding.

Obviously, the strength characteristics of the composite ice model significantly depend on the adhesion and the value of the adhesion bonding strength of the ice and polyethylene [8]. Adhesion is a rather complex phenomenon caused by the many factors [9, 10]. The experimental investigation of the ice adhesion to various hard materials is a very time-consuming and complex process, strongly depended on the experimental conditions [11, 12, 13]. Usually, the obtained data in the similar experiments from different authors significantly differ.

Therefore, it is believed that it is impossible to objectively experimentally measure the ice adhesion strength so that it exhaustively describes this phenomenon in all cases, and must be separately determined in each specific case.

To study the adhesion strength of ice and polyethylene as a part of the development of the composite ice model, the experiment to develop the adhesive strength at the normal fracture was chosen. In the literature, the sufficient number of the corroborated data on this quantity for polyethylene is not available. And the value of these studies not only in the applied, but also in the fundamental sense is confirmed.

3. The experimental procedure

To determine the adhesive strength of ice and high-pressure polyethylene in the NSTU n. a. R.E. Alekseev small basin [14], the experiments series was conducted. The basin has a bowl with the dimensions of 2.4x1.1x0.4m, placed in the cooled heat chamber with dimensions 3.16x1.96x2.2 m, the possible test range is not less than -25°C , the refrigerating unit capacity is 1.3kW.

At the initial stage, in the ice basin the ice field over 50 mm thick was frozen. The ice thickness was chosen to be sufficient for the ice base to be considered rigid and non-deformable. The triangular blocks with two dimension type of the frozen surfaces (125x19 mm and 75x10 mm) were used as polyethylene samples (figure 4). These surfaces were specially prepared for freezing, the edges bounded the surface were chamfered at the angle of 45° .

After obtaining the ice layer of the specified thickness in the basin, its surface was smoothed out and marked for the samples installation. To ensure the qualitative adhesive bond, the ice surface was watered (temperature about 1.5°C) taken from the basin before placing the samples. The polyethylene samples precooled to the air temperature in the heat chamber ($-10...-20^{\circ}\text{C}$) were arranged on ice according to the dimension type. After installing the plastic blocks, it was kept for some time (1.5-2.5 hours). It is necessary for the structure integration of the new ice layer formed between the ice base and polyethylene into ice base structure, as well as to form the high-quality adhesive compound. After predetermined time, the polyethylene samples were detached from the ice base using the laboratory setup, and the peak force was recorded.

The laboratory setup [14] is the rigid frame installed on the basin gunwale. A linear moving rod with the drive from electromotor is mounted on this frame. At the rod end, the specially strain gage made in the form of the bracket and connected with separated samples is fixed. The applied force was recorded in real time through the amplifier and the analog-to-digital converter to the computer. During the experiment, the air temperature in the heat chamber and the water temperature in the basin were regularly monitored with digital thermometer.

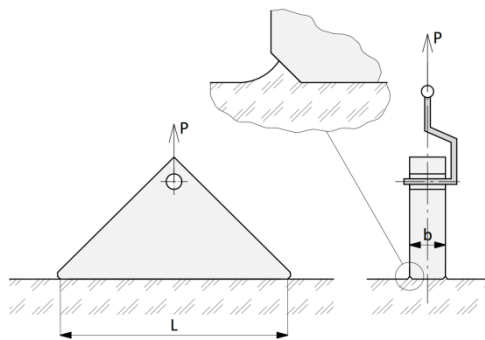


Figure 4. The scheme of the freezing blocks: L , b – length and width of the frozen surface; P – the tearing force.

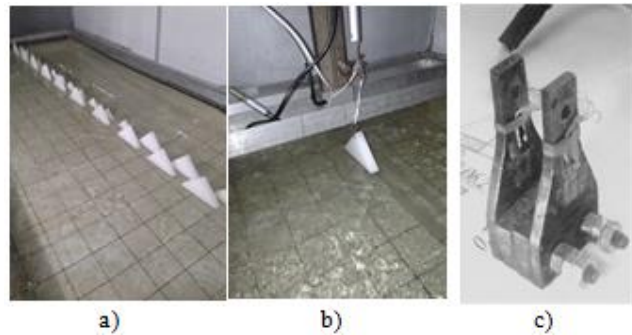


Figure 5. The experiments to determine the adhesive strength: a) ice field with the frozen blocks; b) tearing blocks from ice; c) strain gage that measures the tearing force.

The experiments were performed at two different air temperatures: -10°C and -20°C (figure 5). The results are shown in figures 6-9 (histogram and diagram of the probability density).

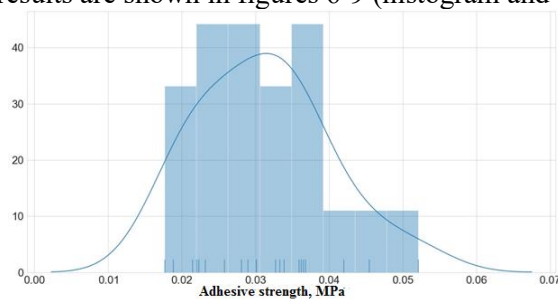


Figure 6. The value of the adhesive strength at the normal fracture of the large blocks at -20°C .

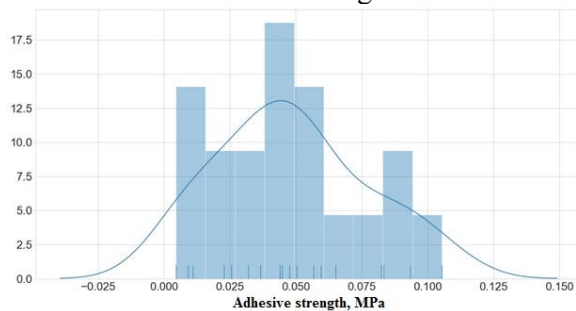


Figure 8. The value of the adhesive strength at the normal fracture of the small blocks at -20°C .

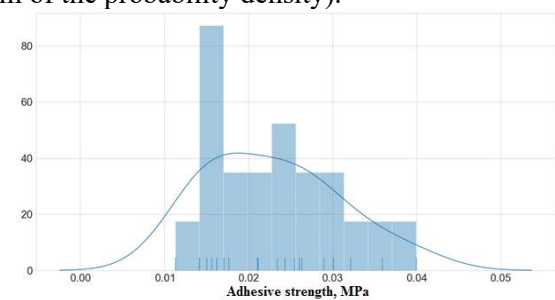


Figure 7. The value of the adhesive strength at the normal fracture of the large blocks at -10°C .

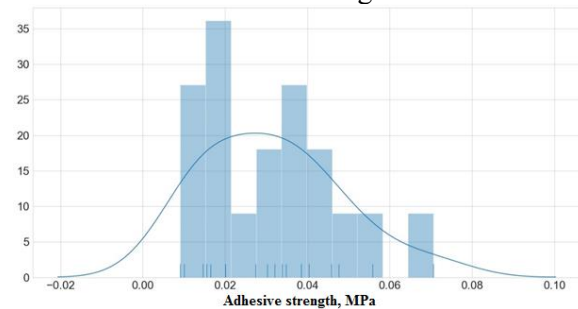


Figure 9. The value of the adhesive strength at the normal fracture of the small blocks at -10°C .

4. Result discussions

The data obtained on the small block have a wide spacing due to the fact that the ratio of the ice sides length along the blocks perimeter to the separation area is greater for small blocks than for large ones. Also on the small blocks, the large values of the adhesion strength average were obtained (≈ 0.05 MPa at -20°C and 0.03 MPa at -10°C), which is also explained by the sides influence. Therefore, the results obtained on the large blocks should be considered more reliable.

The experiments results with the large blocks at -20°C have a smaller scatter than at -10°C , which is explained by the greater stability of the blocks freezing conditions. At -10°C , the average value of the adhesion strength was about 0.02 MPa, and at -20°C was about 0.03 MPa.

Since the composite ice effect is to replace the ice tensile strength with the adhesive strength, the two strengths should be compared. From the data [4, 9, 15, 16] it follows that the tensile strength of freshwater ice is 1.2-4.5 MPa (from -10°C to -20°C). In this case, the exact comparison of the stresses determined the strength could not be entirely correct, since in the composite ice on the granules surface the tangential shear stresses can play a significant role. Finally, the issue can be resolved after conducting experiments to determine the adhesion strength of the “ice-HPPE” at “pure shear”, developing the mathematical model of the composite ice cover bending taking into account adhesion and experimentally confirming the model adequacy.

5. Conclusions

1. It can be reasonable considered the decrease in the composite ice strength consists in replacing the ultimate tensile strength of ice 1.2-4.5 MPa with the adhesion strength of 0.02-0.02 MPa of the “ice-HPPE” upon separation.
2. This fact will make it possible to ensure the fulfillment the one of the main modeling conditions, i. e. a decrease in the strength characteristics of the model ice cover.
3. The proposed method of the ice cover physical simulation is the main alternative to methods used the various chemical compounds solutions to reduce the model ice strength.

6. Acknowledgement

The reported study was funded by RFBR and NSFC according to the research project №19-08-00820.

7. References

- [1] Sazonov K E and Dobrodeev A A 2016 Arctic: history and modernity *Int Sc Conf The relationship of the shipbuilding development and Arctic exploration* pp 241–250
- [2] Dehtyruk Yu D, Dobrodeev A A and Sazonov K E 2013 Arct: ecol and econ *Res and Anal J* Some issues of creating sea transport systems for the hydrocarbons export from the Arctic no 2 vol 10
- [3] Sazonov K E 2018 Development of the ice propulsive quality of ship in the XXI century *Trans Kryl St Res Cen* vol 2 p 384
- [4] Ionov B P and Gramuzov E M 2014 *Ice propulsive quality of ship*
- [5] Zuev V A 1986 *Means of the Extending Navigation on the Inland Waterways*
- [6] Zuev V A, Gramuzov E M and Dvoychenko Yu A 1989 Ice cover failure vol 2
- [7] Dvoychenko Yu A 1978 To the issue of the ice cover ultimate strain *Theor and Str of Icebr* pp 47–49
- [8] Dvoychenko Yu A, Zuev V A and Sebin AS 2019 Trans of the Krylov St Res Cen To the issue of the ice cover modeling using the composite ice model *Sc J* (2019)
- [9] Bogorodckii V V and Gavrilov V P 1980 Ice: physical properties *Modern methods of glaciology*
- [10] Bogdanova Yu G *Adhesion and its role in ensuring the strength of the polymeric materials*
- [11] Goldshtein R V, Epifanov V P 2011 Measuring the ice adhesion to other materials *PNRPU Mech Bull* vol 2
- [12] Shadrinov N V 2015 Operability research of the polymer materials under conditions of the friction with ice and snow *Sc J of KubSAU* vol 107
- [13] Matsumoto K and Kobayashi T 2007 Fundamental study on adhesion of ice to cooling solid surface *Int J of Refr* vol 30 pp 851–860
- [14] Zuev V A, Dvouchenko Yu A and Sebin A S 2019 Technique and technology of the model ice research in the small ice pool of the NSTU na REAlekseev *Tr Syst J* vol 3 pp 39–47
- [15] Voytkovski K F 1960 *Ice mechanical properties*
- [16] Peschanski I S *Ice research and ice technology*