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GRAPHICAL REPRESENTATION AND ANALYSIS OF THE DISTRIBUTION OF TEMPERATURE FIELDS IN ELEMENTS OF BUILDING STRUCTURES WHEN EXPOSED TO STABLE NEGATIVE TEMPERATURE

***Abstract**: Exposure of building materials to low temperatures causes a decrease in their mechanical and operational properties and a change in their microstructure. By considering the main building materials, such as concrete, baked clay with additives (brick), wood (pine), and glass, the depth of cooling of these materials was analyzed under the influence of a stable negative temperature for 90 seconds.*

***Key words**: temperature, cooling depth and rate, frost resistance, time.*

***Language**: English*

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1. Introduction

Temperature plays a crucial role in the performance and durability of building materials [1]. Exposure to high temperatures can cause deformation, cracking, aging, loss of strength, and reduced service life in some building materials [2]. At negative temperatures (below zero degrees), materials contract, which can cause significant stress and lead to cracking. For example, metal materials become brittle, and wood undergoes significant shrinkage [3-6]. The combination of high and low temperatures at the boundary of seasonal changes and their impact on the structure and durability of building materials is an important research issue in the field of residential and industrial building safety in Europe and North America [7-10].

The purpose of this article is to analyze the cooling depth of the most common building materials when exposed to negative temperature. The simulated process dynamics allow us to draw conclusions about the calculated cooling rate and depth of concrete, baked clay with additives, wood, and glass.

2. Materials and methods

An experiment was conducted to determine the cooling depth of building materials when exposed to negative temperature using the Comsol Multiphysics software package. The object of the study was a two-dimensional rectangular model with a length of 250 mm and a height of 65 mm, which simulated the dimensions of a brick. The effect of a constant temperature of -30°C on one broad surface of the constructed model was simulated for 90 seconds. The initial temperature of the material model was set to 20°C. The experimental models were assigned the properties of concrete, baked clay with additives (brick), wood (pine), and glass (the Table 1).

Table 1. Properties of materials for research.

Parameter	Concrete	Baked clay with additives (brick)	Wood (pine)	Glass
Density, kg/m^3	2300	2000	520	2500
Thermal conductivity, W/(m×K)	1.8	900	0.14	1
Heat capacity at constant pressure, J/(kg×K)	880	0.5	1550	840
Coefficient of thermal expansion, 1/K	10×10^{-6}	6×10^{-6}	4.8×10^{-6}	8×10^{-6}
Young's modulus, Pa	25×10^{9}	17×10^{9}	1.1×10^{7}	3×10^{10}
Poisson's ratio	0.33	0.3	0.45	0.25

A finite element mesh of 492 elements was generated for numerical modeling of the physical process in the material model domains. At the same time, the mesh quality is characterized by the uniform distribution of elements over more than 88% of the mesh area.

3. Results and discussion

The Figure 1 shows the results of finite element modeling of the thermal conductivity problem for the materials under consideration. The model's calculation domain generates color contours of temperature when exposed to low temperature on the sample's outer surface. The figures on the left show the temperature fields in the longitudinal section of the test materials at 90 seconds of exposure to -30°C. The graphs on the right show the dependencies of temperature changes in the range from 10 to 90 seconds with an increment of 10 seconds in cross-sectional samples of material models.

Let's choose a criterion for evaluating this research: the frost resistance of building materials, where the temperature of the samples is 20°C. When exposed to negative temperature, the samples show different degrees of cooling intensity. For example, the concrete sample demonstrates the greatest cooling depth of 41 mm, relative to the initial temperature of the material. Compared to materials such as baked clay with additives and wood, the cooling depth of both samples was about 19 mm. The glass sample was cooled to a depth of 31 mm.

The maximum negative temperature of -30°C applies only to the outer surface of all sample models. At the tenth second of exposure to negative temperature, the internal layers of samples of baked clay with additives and wood are heated to 2.5°C above the initial temperature (at a depth of 6-8 mm from the side of the temperature load). The concrete also heats up to 0.2°C above the initial temperature at a depth of 14 mm. This effect occurs due to the release of latent heat during the crystallization of materials. For glass, heating of the inner layers does not occur.

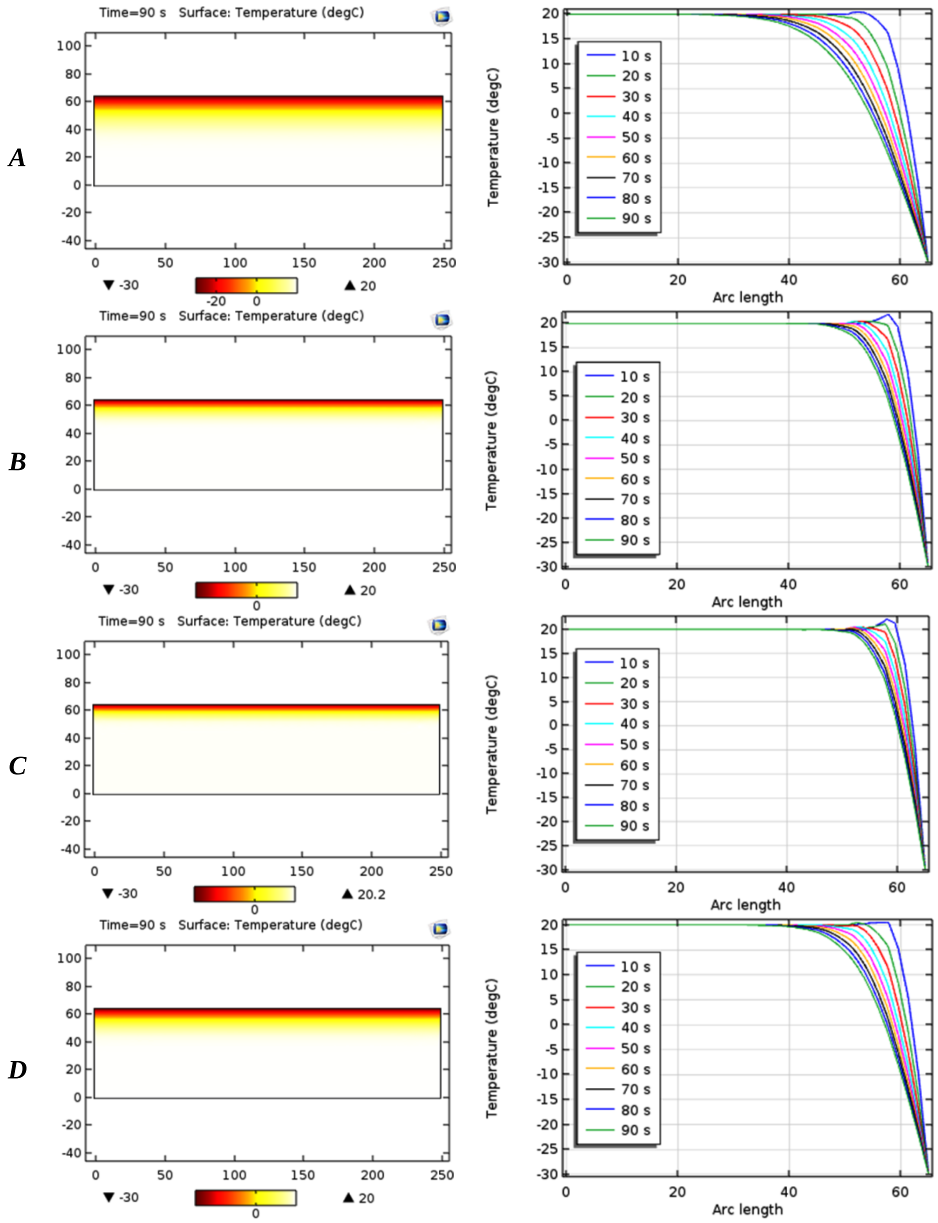

Figure 1. Simulation results: *A* – temperature distribution in the longitudinal section of the concrete sample at 90 seconds of temperature exposure (left) and temperature change dependencies in the cross-section of the concrete sample in the time range of 10-90 seconds (right); *B* – temperature distribution in the longitudinal section of the sample of baked clay with additives (brick) at 90 seconds of temperature exposure (left) and temperature change dependencies in the cross-section of the sample of baked clay with additives (brick) in the time range of 10-90 seconds (right); *C* – temperature distribution in the longitudinal section of the wood sample (pine) at 90 seconds of temperature exposure (left) and temperature change dependencies in the cross-section of the wood sample (pine) in the time range of 10-90 seconds (right); *D* – temperature distribution in the longitudinal section of the glass sample at 90 seconds of temperature exposure (left) and temperature change dependencies in the cross-section of the glass sample in the time range of 10-90 seconds (right).

The samples are fully cooled to -30°C at different rates (v_{10} is the cooling rate at the 10th second of the process, v_{90} is the cooling rate at the 90th second of the process, and $v_{avg.}$ is the average cooling rate): concrete – v_{10} = 1 mm/s, v_{90} = 0.26 mm/s, $v_{avg.}$ = 0.63 mm/s; baked clay with additives – v_{10} = 0.7 mm/s, v_{90} = 0.5 mm/s, $v_{avg.}$ = 0.6 mm/s; wood – v_{10} = 0.5 mm/s, v_{90} = 0.51 mm/s, $v_{avg.}$ = 0.5 mm/s; glass – v_{10} = 0.8 mm/s, v_{90} = 0.4 mm/s, $v_{avg.}$ = 0.6 mm/s.

4. Conclusion

In conclusion, it is important to consider the frost resistance of building materials when choosing them. This study showed that baked clay with additives and wood have the highest frost resistance, while concrete has the lowest frost resistance. The glass takes on intermediate values without undergoing interfacial transformations within the accepted temperature range.

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