

*PERMAFROST ENGINEERING: STABILITY OF STRUCTURES AND FOUNDATIONS*

**A NOVEL HEAT-INSULATING MATERIAL FOR THERMAL STABILIZATION OF SOILS**

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The study has proven the feasibility of obtaining a novel heat-insulating material with an apparent density of 290–580 kg/m<sup>3</sup>, a compressive strength of 1.7–7.8 MPa, and a water absorption of 4 %. Heat treatment of a mixture of diatomite and alkali at 95 °C increases the leaching rate of amorphous SiO<sub>2</sub> while the resultant soluble sodium silicates promote foaming of the charge during sintering at 775 °C and decrease its apparent density. The new heat insulator is similar to the traditional foam glass in its structure and properties and thus can be used to protect the foundations of engineering structures.

The damaging frost action on the foundations of engineering structures built and operated in permafrost zones, such as thermokarst, thaw settlement and frost heaving of soils, require special preventive measures while constructing. The measures mitigating this frost action include, primarily, thermal stabilization of foundations which allows construction upon any soil, with only regard to its load-bearing capacity [Tsitovich, 1973]. In addition to making ventilated cellars, withdrawal of heat released by the building, and the use of special cooling (or heating) devices, etc., thermal stabilization of soils is achieved with heat-insulating materials. For instance, creating a sod layer reduces the freezing depth by a factor of 1.5 relative to open ground [Kiselev, 1985]. That is why any heat insulator laid on the ground surface will preclude heat flux and provide thermal stabilization of foundations.

Until recently the applicability of most heat-insulating materials to soil protection was limited by their ability of accumulating moisture (wetting). This is known, specifically, for expanded clay (keramzit) used as footing pads beneath paving, which loses its insulating capacity on saturation [Kiselev, 1985]. Therefore, a material with the minimum thermal conductivity and water uptake will be the best choice for heat insulation.

In the current practice, frost heaving effects and the thaw depth in permafrost are reduced using extrusion foam polystyrene plates. There is encouraging experience of employing this material as footing for buildings, highways, and railways [Alekseev and Bek-Bulatov, 2007]. However, foam polystyrene can lose its heat-proof properties and fail by natural destruction of the polymer, this making its endurance debatable.

Foam glass is an efficient insulator free from the above drawbacks. This is hardened glass foam with closed pores (its porosity reaches 97 %), which resists water uptake and loss of thermophysical properties. With its 140 kg/m<sup>3</sup> density, foam glass has a thermal conductivity of 0.045 W/(m·K) and an ultimate load of 50 t/m<sup>2</sup> (0.5 MPa) [Goryainov and Goryainova, 1982]. Its incombustibility, high chemical resistance, and unlimited lifetime make foam glass an exceptional material, but it is too expensive because of expensive starting materials and a complicated energy-consuming production technology.

Therefore, it is urgent to obtain heat-insulating materials similar to foam glass in their properties but based on cheap minerals. The author of this study has investigated the feasibility of obtaining foam silicate, an analog of foam glass, using widespread silicic rocks and alkali additions, within the limits of the project “Sintered Heat-Insulating Material on the basis of Mineral Resources of the Tyumen Region” supported by the Tyumen Region Governor.

The idea of obtaining foam silicate consists in alkaline leaching of amorphous silica from siliceous rocks. This well known method of making liquid glass has been of moderate use so far because of a refractory insoluble sludge which, in our case, is a useful component of the mixture with a significant amount of clay. Soluble alkaline silicates form low-melting eutectics and thus facilitate the transition of the batch into a melting state at temperatures below 700 °C [Iler, 1979] while crystallization water released from clay minerals in the insoluble precipitate acts as a foaming agent in the charge.

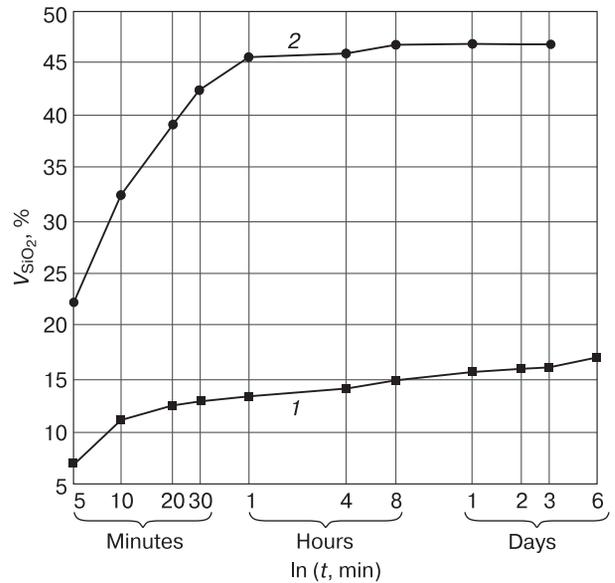
The study was performed using diatomite from the Kamyshlov deposit in the Sverdlovsk region, with 42.5 amorphous SiO<sub>2</sub>, 8.9 Al<sub>2</sub>O<sub>3</sub>, and 3.3 Fe<sub>2</sub>O<sub>3</sub>

(in wt.%). The charge with diatomite/40 % NaOH at a solution ratio 2.3:1.0 was mixed and filled with water until it became homogeneous, and then placed in a thermostat at 20 and 95 °C. The solution ratio was chosen proceeding from the fact that diatomite contains 40 % amorphous silica which yields a soluble silicate solution (SSS) with the mole ratio  $\text{SiO}_2/\text{Na}_2\text{O}$   $m = 3$ . The  $\text{SiO}_2$  yield (in percent of diatomite dry weight) and the  $m$  ratio in the charge after leaching were estimated following the technique reported in [Sokolovich, 1963].

After the leaching was over, cylindrical pellets, 3.4 cm in diameter and 1.6 cm thick, were fabricated from the charge by pressing at 2 MPa, as well as granules 5–8 mm in diameter made by rolling on a plate granulator. The pellets and granules dried at 100 °C to constant weight were then sintered and foamed in stainless steel moulds in air, with the treatment schedule of heating at 25 °C/min, 20 min exposure to 775 °C, and slow cooling together with the furnace at ~1 °C/min to room temperature. During heating, the granules became foamed and welded together into solid massive porous silicate, from which samples were cut in the form of 30 × 30 × 30 mm cubes.

Inasmuch as foaming of the diatomite-alkali charge largely depends on the  $\text{SiO}_2$  yield (YS), the first step consisted in investigating the kinetics of  $\text{SiO}_2$  extraction at different temperatures (Fig. 1). As a result, heating to 95 °C was found out to notably accelerate the process: already in 30 min of exposure at 95 °C, YS was 3.3 times that at 20 °C, for the same exposure time (42.5 % against 12.9 %), and almost did not grow further.

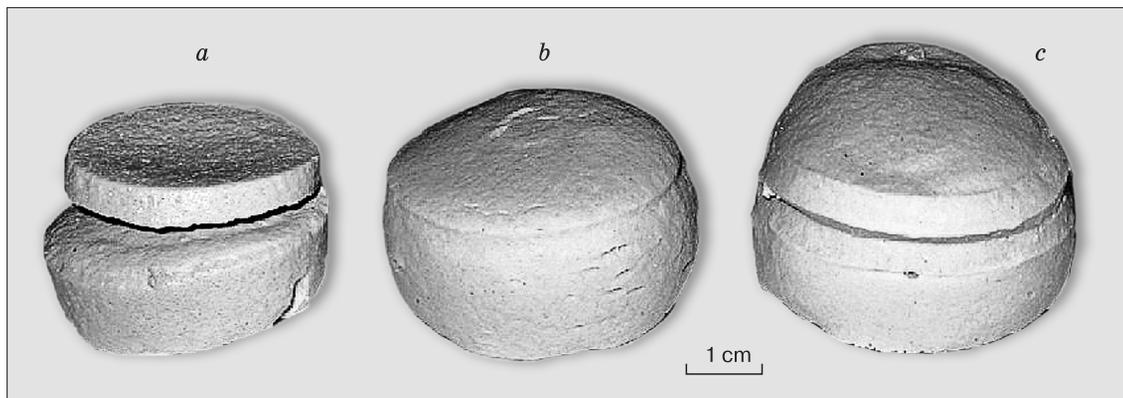
The YS dependence of the foaming process in the batch after its leaching for different time spans was explored on cylindrical pellets (see Fig. 2 for their



**Fig. 1. Kinetics of  $\text{SiO}_2$  yield (YS) at different temperatures:**

1 – 20 °C; 2 – 95 °C.

photographs after heating). The images show the volume and the apparent density of the foam silicate pellets to be proportional to YS. Growth of  $m$  along with YS likely causes an increase in the amount of liquid in the charge while sintering and/or its earlier appearance, which promotes better foaming. Thus, it is SSS rather than alkali that is responsible for the temperature of liquid formation. This inference is supported by the fact that pellets molded immediately after mixing crack and do not foam on heating, but foaming resumes as dry crystalline sodium silicate ( $\text{Na}_2\text{O} \cdot \text{SiO}_2 \cdot 9\text{H}_2\text{O}$ ) is used instead of alkali, with an equivalent amount of water added.



**Fig. 2.  $\text{SiO}_2$  yield ( $V_{\text{SiO}_2}$ ) plotted versus apparent density ( $\rho$ ) of diatomite-alkali charge after heating ( $T$ ) for different time spans ( $t$ ):**

a –  $V_{\text{SiO}_2} = 13.3\%$ ,  $\rho = 550 \text{ kg/m}^3$ ,  $T = 20^\circ\text{C}$ ,  $t = 60 \text{ min}$ ; b –  $V_{\text{SiO}_2} = 32.5\%$ ,  $\rho = 350 \text{ kg/m}^3$ ,  $T = 95^\circ\text{C}$ ,  $t = 10 \text{ min}$ ; c –  $V_{\text{SiO}_2} = 42.5\%$ ,  $\rho = 280 \text{ kg/m}^3$ ,  $T = 95^\circ\text{C}$ ,  $t = 30 \text{ min}$ .

Rising the heat-treatment temperature to 800 °C causes an about 10–15 % density increase of the pellets, possibly, as the liquid phase becomes progressively less viscous while the release of crystallization water ceases after 740 °C [Lazutkina *et al.*, 2006]. The samples develop sizeable open pores, up to 1 cm in diameter, by coalescence of smaller pores.

Further experiments were run with grains made from charges with different amounts of extracted SiO<sub>2</sub>. As YS increased from 13.3 to 42.5 %, the apparent density and the compressive strength of the grains changed from 580 to 290 kg/m<sup>3</sup> and from 7.8 to 1.7 MPa, respectively. Water uptake in all samples was within 2 vol.%. The thermal conductivities of the samples with the densities 290 and 580 kg/m<sup>3</sup> were 0.08 and 0.14 W/(m·K). The samples had a uniform structure consisting of closed cells with an average diameter of 1.5 mm. The cell surfaces had glassy luster and varied in color from stone to green-gray.

The suggested method can be used to obtain foam silicate which will allow minimizing destructive cryogenic effects being both a heat and water insula-

tor as it can prevent moisture from migration into vulnerable zones of foundations.

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