INNOVATIVE STABILIZATION OF FROZEN SAND WITH CSA CEMENT FOR COLD-REGION ENGINEERING APPLICATIONS

Frozen soil forms when temperatures drop below 0°C. In these conditions, water in soil pores freezes, increasing the soil's strength and stiffness. In Kazakhstan, seasonal freezing in the Kostanay, Akmola, and Pavlodar regions affects road construction due to severe winters. On a global scale, frozen soil covers about 24% of the world's surface area and has significant impact on contemporary construction, ecosystems, and climate change.

In engineering practice, frozen ground is commonly classified as permafrost, seasonal frozen ground, and transient frozen soil. For road engineering, freezing can bring practical short-term benefits, including temporary load-bearing capacity in winter, reduced permeability under freezing, and natural structural stiffness during subzero conditions.

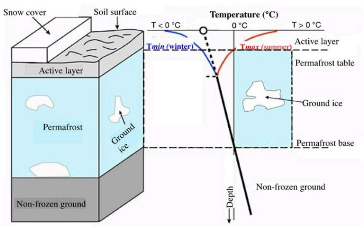

Figure 1. Permafrost

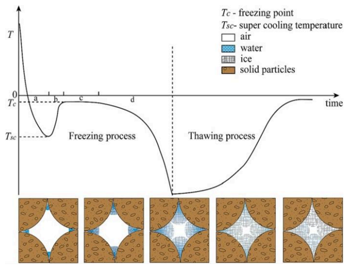

Figure 2. Freezing and Thawing process in Frozen soil

At the same time, road engineers face persistent challenges associated with seasonal cycles. Seasonal thawing leads to pavement cracking, differential settlement, and subsidence. Thaw-induced CO_2 and CH_4 emissions worsen environmental impacts. These factors reinforce the need for stabilization methods that maintain strength through seasonal cycles.

Frozen soils exhibit distinct mechanical properties due to temperature effects and ice formation. Their behaviour depends on temperature, salinity, stress, moisture content, and strain rate. Despite the significance of the problem, relatively few studies explore eco-friendly binders for road subgrades in permafrost zones.

This study positions its scientific novelty around a clear limitation in prior work: many studies focus on uniaxial tests or rely on non-eco-friendly binders, which constrains green innovation. As an alternative, Calcium Sulfoaluminate (CSA) cement is highlighted for its eco-friendly profile (~50% less CO_2 emission compared to OPC), rapid strength development, freeze–thaw resistance, and durability in harsh environments.

The research objective is to study the influence of cement content, curing, and confining pressure on CSA-cemented frozen sand through triaxial compression testing.

The experimental program uses quartz sand (0.4–0.9 mm, SP graded) as the soil and CSA cement as the binder at 5% and 10%. Specimens are cured for 3, 14, and 28 days at −10°C, then tested under confining pressures from 100 to 3000 kPa. The strain rate is $1.67 \times 10^{-6}\ s^{-1}$.

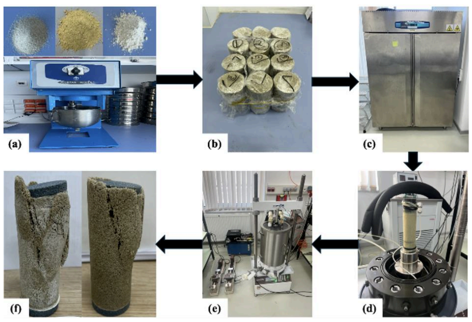

Figure 3. Pictorial illustration of the testing procedures (a) Sample preparation (b) Test samples (c) Environmental chamber (d) Test sample on the base pedestal (e) Triaxial testing using the ETAS (f) Sheared samples

The results are presented through stress–strain curves. First, the study compares uncemented frozen sand and 5% CSA-cemented frozen sand across curing times, with separate plots for uncemented behaviour and for 3, 14, and 28 days.

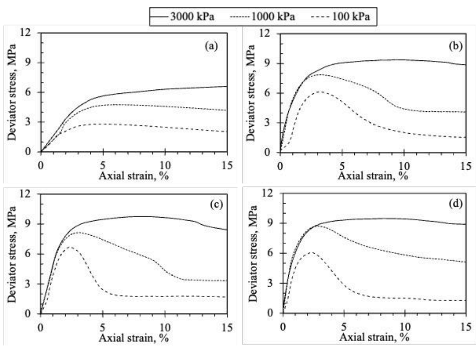

Figure 4. Stress-strain curves of uncemented and 5% CSA-cemented frozen sand at different curing days: (a) uncemented, (b) 3 days, (c) 14 days, and (d) 28 days

A second set of curves reports cemented frozen sand with 10% CSA at 3, 14, and 28 days of curing.

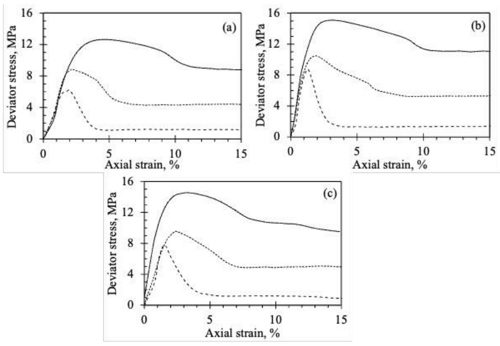

Figure 5. Stress–strain curves of cemented frozen sand with 10% CSA at different curing times: (a) 3 days, (b) 14 days, and (c) 28 days

The study concludes that CSA-cemented frozen sand achieves 15.08 MPa at high confinement. CSA significantly improves the strength, stiffness, and ductility of frozen sand. Overall, the results demonstrate a practical innovation for stabilizing frozen ground to support safer, longer-lasting roads in cold-region conditions.

Authors: Sung-Woo Moon, PhD – Associate Professor, Department of Civil and Environmental Engineering
James Innocent Ocheme – PhD Doctoral Candidate, Nazarbayev University
Editor: Editorial Team of Jolshy Journal (KazdorNII Bulletin)