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2026 FUKUOKA

The 12th International Conference on the Environmental and Technical Implications of Construction with Alternative Materials

Building a circular, sustainable society through construction with alternative materials and digital transformation

18–21 MAY 2026
FUKUOKA, JAPAN

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INFLUENCE OF A LIGNOSULFONATE-BASED ADDITIVE ON THE DEFORMATION CHARACTERISTICS OF A SWEDISH-DESIGNED GRAVEL WEARING COURSE

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1. INTRODUCTION

Gravel wearing courses (GWC) on unpaved roads are exposed to traffic and severe climate, including freeze–thaw and repeated wetting–drying, which can lead to rutting, surface degradation and increased maintenance needs. Chemical stabilization is one way to improve performance, and lignosulfonate products are of special interest because they are bio-based binders already used as dust suppressants on gravel roads. Lignin is contained in the cell walls of plants and obtained as a byproduct of the paper and lignocellulosic industries (Misra et al., 2011). Lignin, representing the third largest fraction of plant biomass, is a large complex polymer of phenylpropane and methoxy groups, a noncarbohydrate polyphenolic substance that encrusts plant cell walls and cements plant cells together (Kim et. al., 2012). Most lignin-based industrial products in the forms of binder, dispersant, emulsifier, and sequestrant are derived from sulfite lignin (International Lignin Institute 2008). Since lignosulphonates are by-products of other processes, they are relatively inexpensive and usually used as a dust control agent during gravel roads maintenance.

This paper summarizes the behaviour of a lignin-based stabilizer, Listab, in comparison with an unstabilized reference GWC, based on a laboratory study in which both mixtures were tested under controlled freeze–thaw cycles (FTCs) and soaking–drying cycles (SDCs) using a laboratory light weight deflectometer (LWD).

2. MATERIALS

2.1 Gravel wearing course

The GWC material (0/16 mm) was obtained from NCC Ballast Skärlunda near Norrköping, Sweden. Prticle size distribution tests showed a lack of fines and non-compliance with the gradation limits in TDOK 2013:0530 for gravel wearing courses, so a mineral filler was added at 9.3% of total mass to bring the gradation within the specified envelope as shown in Figure 1. This adjusted GWC without any stabilizer constitutes the unstabilized reference mixture in this paper.

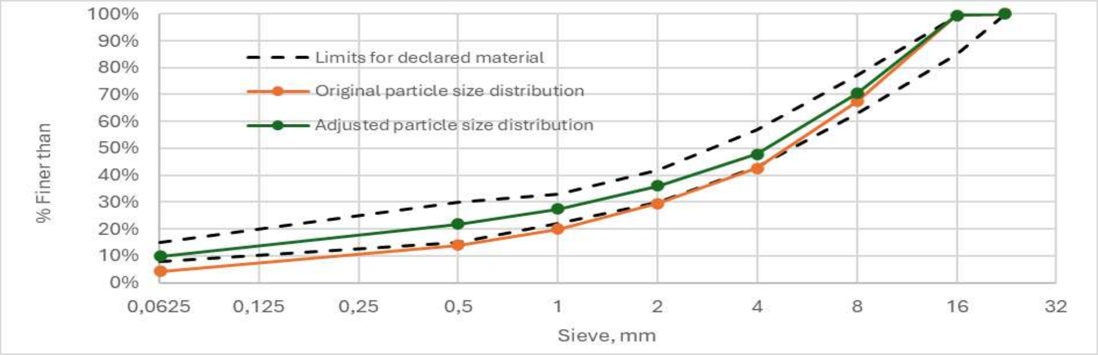

Figure 1. Particle size distribution of the gravel wearing course (0/16) before and after adjustment.

2.2 Listab (lignin stabilizer)

Listab is a sodium lignosulfonate product used as a lignin-based binder and dust-control agent. Lignosulfonates are derived from lignin, a polyphenolic component of plant cell walls and a by-product of pulp and biofuel industries, and are widely used in civil infrastructure as low-cost binders and dust suppressants.

In the study, Listab was applied to the adjusted 0/16 GWC at a dosage corresponding to 2 L/m² for 25 cm depth, which translates to approximately 3.8 ml/kg of dry GWC when using a dry density of 2126 kg/m³. According to the safety data sheet, Listab is not considered carcinogenic or organ-toxic, although discharges to wastewater systems and the environment should be avoided.

3. METHODS

Modified Proctor compaction tests (SS-EN 13286-2, 2010) were performed separately for the unstabilized GWC and the Listab-treated GWC to determine optimum moisture content (OMC) and maximum dry density (MDD) for each mixture. For each test, oven-dried material was compacted in a 100 mm mold in five layers with 25 blows per layer using a 4.5 kg hammer dropped from 457 mm height.

Moisture–density relationships were established and used to identify OMC and MDD for both mixtures. The unstabilized GWC showed the lowest maximum dry density among the studied mixtures in the original report, with MDD of approximately 2.18 g/cm³ at an OMC of 6.7%. Listab-treated GWC had its own MDD and OMC obtained from the compaction curve; these values were approximately 2.21 g/cm³ and 6.5% respectively.

CBR specimens with diameter 150 mm and height 120 mm were prepared for both the unstabilized and Listab-stabilized GWC. Each mixture was compacted at its own OMC and MDD using a 4.5 kg hammer with 56 blows per layer in five layers in a 150 mm mold, following SS-EN 13286-2 (2010) section 7.5.

A laboratory light weight deflectometer (LWD) designed for testing compacted materials in molds was used to measure central surface deformations on the tops of CBR samples. LWD applies a stationary impulse load on a loading plate resting on the compacted soil or gravel surface. A velocity sensor records the velocity of the plate or ground surface movements depending on the position of the sensor. The position and type of the deflection sensor are different in different LWD devices. The used LWD has a basic 10 kg falling mass. During the test, the falling mass impacts the plate, producing a load pulse of 7 kN. The central deflection of the tested material surface is measured through a hole in the loading plate by a highly accurate, seismic transducer (geophone).

Two forms of climate conditioning were applied independently to sets of unstabilized and Listab-stabilized CBR samples:

Freeze–thaw cycles (FTCs): Ten cycles were performed in a climatic chamber, with temperature varying between +20 °C and −17.5 °C over 24 hours for each cycle, according to SS-EN 1367-1 (2007), see Figure 2.
Soaking–drying cycles (SDCs): Five manual cycles were carried out; each cycle consisted of 4 hours immersion of the samples in water followed by 20 hours drying in an oven at 40 °C.

After ten FTCs or five SDCs, samples were drained (for SDCs) and immediately tested using the LWD. Thus, for both mixtures, three testing phases are considered, i.e. Unconditioned (no FTCs/SDCs), after 10 FTCs, after 5 SDCs.

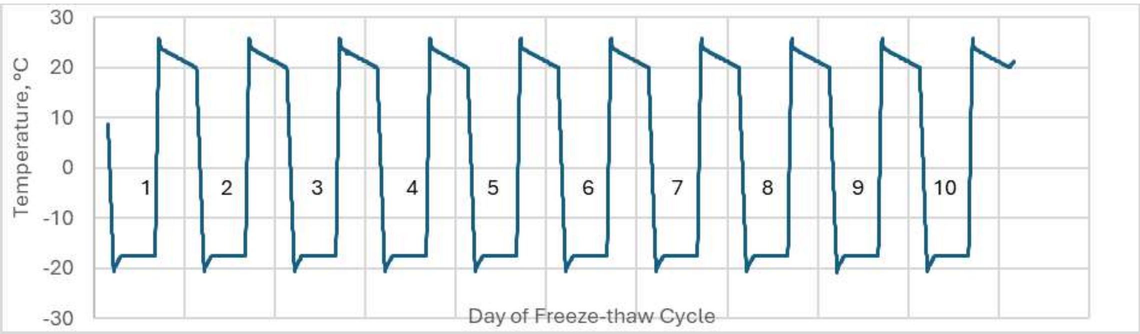

Figure 2. Schematic overview of freeze-thaw cycles.

4. RESULTS AND DISCUSSIONS

Figure 3 shows the average central deformation of the unstabilized and Listab stabilized GWC without climate simulation. The average deformation for the unstabilized GWC was 175 µm, while the Listab-stabilized GWC exhibited an average deformation of 190 µm.

This means that, under identical compaction conditions (each at its own OMC and MDD) and without climate conditioning, Listab treatment increased deformation relative to the unstabilized reference, indicating no improvement in stiffness or bearing capacity in this laboratory configuration.

The effect of ten FTCs on average deformation is presented in Figure 2. For the unstabilized GWC, the average deformation decreased from 175 µm (unconditioned) to 142 µm after ten FTCs. For the Listab-stabilized GWC, the average deformation decreased from 190 µm (unconditioned) to 169 µm after ten FTCs.

Both mixtures therefore exhibited reduced deformations after freeze–thaw conditioning, suggesting an increase in apparent stiffness. The absolute deformation values remained lower for the unstabilized GWC than for the Listab-stabilized mixture, both before and after FTCs.

The general reduction in deformation after FTCs can be attributed to increased particle-to-particle contacts due to freezing, moisture migration during thawing, and consequent densification of the material matrix. These mechanisms can apply to both unstabilized and lignin-stabilized GWC; no specific frost-related damage or instability was reported for Listab.

Also Figure 3 summarizes the effect of five SDCs on average deformation. For the unstabilized GWC, the average deformation decreased slightly from 175 µm (unconditioned) to 168 µm after SDCs, representing a small apparent improvement in stability but with limited change. For the Listab-stabilized GWC, the average deformation decreased from 190 µm to 150 µm after SDCs.

Expressed relative to the unstabilized GWC exposed to SDCs, the Listab-stabilized mixture showed approximately 11% lower deformation (150 µm vs 168 µm), which can be describes as a gain in stability compared to the reference subjected to the same number of SDCs. Thus, while Listab initially increased deformation relative to the unconditioned reference, after five wetting–drying cycles it yielded a lower final deformation than the reference mixture under identical conditioning. The improved stability after SDCs in general can be attributed to densification effects caused by repeated soaking and drying, and, in the case of stabilized mixtures, to the contribution of the stabilizer. For Listab, Thiès indicates that the lignin binder, together with repeated wetting–drying, leads to a more stable structure in terms of reduced deformation compared to the unstabilized GWC under the same climate treatment.

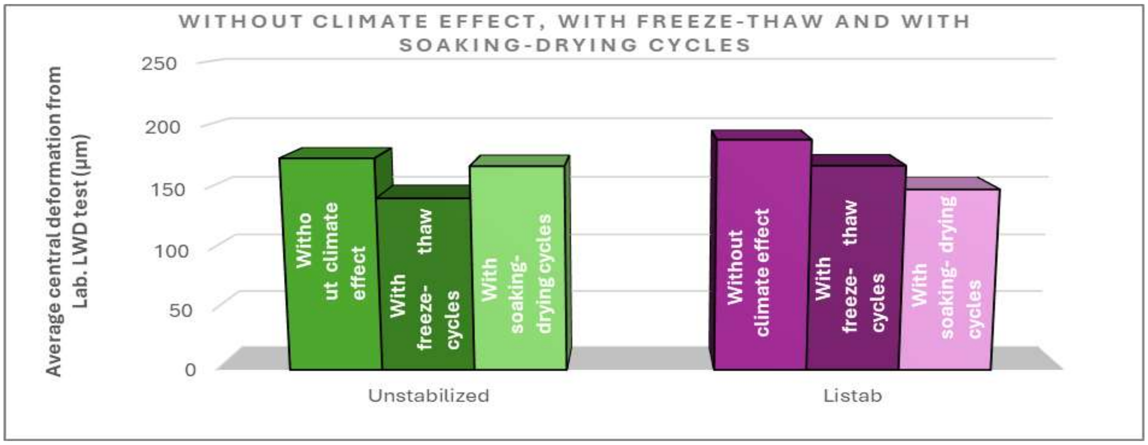

Figure 3. The average central deformation of the unstabilized and Listab stabilized GWC without climate simulation.

5. CONCLUSIONS

The results indicate that Listab does not enhance the initial stiffness of the tested gravel wearing course but can provide a stabilizing effect under repeated wetting–drying. Under unconditioned laboratory LWD testing, Listab treatment led to higher average deformation than the unstabilized reference (190 µm vs 175 µm), demonstrating no improvement in stiffness or bearing capacity in the initial state. After ten freeze–thaw cycles, both mixtures showed reduced deformations, reflecting increased apparent stiffness, yet the unstabilized GWC still exhibited lower deformations than the Listab-stabilized material (142 µm vs 169 µm), meaning Listab did not outperform the reference in freeze–thaw resistance. In contrast, after five soaking–drying cycles, Listab-stabilized GWC achieved a clearly lower deformation than the reference (150 µm vs 168 µm), corresponding to an approximate 11% gain in stability relative to the unstabilized material. Overall, Listab can therefore be regarded as neutral or slightly unfavourable in the unconditioned and freeze–thaw cases, but beneficial under soaking–drying conditions, where it enhances the long-term deformation resistance compared to an unstabilized GWC.

6. ACKNOWLEDGMENT

The author acknowledges the financial support and constructive collaboration of Trafikverket (the Swedish Transport Administration).

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