

Advances in Silicate Accelerators for Shotcrete

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INTRODUCTION

Sodium silicate has long history of use in construction and geotechnical applications due to its versatility and reliable performance. In shotcrete placement, sodium silicate solutions were widely used as alkaline rapid-set accelerators from the 1960s through late 1990s, most commonly in wet-mix systems for tunnel linings and ground support.

Typical dosages were relatively high (13-17% by mass of cement), which often led to reduced long-term compressive strength. This limitation helped drive the development of alkali-free accelerators, which offered improved handling and more consistent performance.

Today, the industry is transitioning toward low carbon cements blended with higher levels of Supplementary Cementitious Materials (SCMs) or non-reactive calcium carbonate filler. These changes require accelerators formulated to react effectively with both the cement and the SCMs.

This article highlights new silicate-based accelerators that have shown promising results in field trials and can complement the use of low carbon cement. Compared with historical dosage rates, these modified silicates are used at lower concentrations, further improving overall cost economics relative to alkali-free accelerators.

SILICATE: KEY PROPERTIES AND SAFETY OVERVIEW

Silicates are inorganic, non-toxic, non-carcinogenic, and non-volatile. They are recognized as safe for food contact applications and are NSF certified for drinking water systems. Conventional sodium silicates are alkaline, and the preferred grade for shotcrete applications has a pH of ~11.2. This moderate alkalinity requires proper handling practices and PPE to prevent skin and eye contact. However, with greater use of remotely manipulated shotcrete nozzle equipment, the risk of direct exposure has been significantly reduced.

While a pH of 11.2 is high, it falls within the typical pH range for many soaps and detergents. In relation to cement and other alkaline accelerators — particularly sodium aluminate — sodium silicate has much lower alkalinity:

- Sodium silicate pH: ~11.2
- Cement mortar pH: ~12.5
- Sodium aluminate pH: ~13.5

As the principal safety concerns associated with alkaline accelerators arise from their pH and alkali content, a low alkali silicate accelerator containing roughly half the alkali content of conventional silicates is a safer and more effective alternative (Table 1). Reducing the alkalinity, makes sodium silicate more reactive and allows a wider dosage window with less risk of introducing excess sodium into the cement.

Properties	Conventional sodium silicate	Novel, high ratio sodium silicate
SiO ₂ :Na ₂ O	3.2	4.5
Total Solids	37%	25%
Silica as SiO ₂	28.7%	20.3%
Alkali as Na ₂ O	8.9%	4.7%
pH	>11.3	~11
Viscosity	180 cp	60 cp

Table 1: Silicates — Typical Properties

LOW-ALKALI SODIUM SILICATE ACCELERATOR

Shotcrete placement in underground construction must develop rapid set and high-early-age strength. This is typically achieved using set accelerators, which modify early cement hydration, especially reactions associated with C₃A and C₃S.

Soluble sodium silicate provides rapid setting by reaction with calcium in the cement paste to form solid calcium silicate. Over time, this precipitate transforms into a hydrated calcium silicate gel (Prudencio 1996), like the gel produced during hydration of clinkers in the cement.

While conventional silicate accelerators can enhance cement hydration and increase early-age strength, they have been reported to reduce later-age strength (Prudencio 1998).

A novel sodium silicate with a low alkali and a high SiO₂/Na₂O ratio (originally developed for select geotechnical and oil field applications) was evaluated as a shotcrete accelerator in both laboratory and field tests. The objective of the study was to determine whether the novel low alkali high ratio silicate accelerator can maintain early strength benefits while reducing the tendency for later age strength



Spraying the panels and outdoor curing

loss during curing that is often observed with conventional silicate accelerators (Elsayed, Soliman, El Naggar 2023).

TEST PROGRAM OVERVIEW & RESULTS

A wet-mix concrete mixture with portland limestone cement (GUL) and microsilica (MS), a w/cm of 0.43, and a polycarboxylate high-range water reducer was shotcreted into panels and cored for testing. The baseline mixture proportions are shown in Table 2.

Four accelerated shotcrete mixtures and a control were compared: Novel, low-alkali sodium silicate A1 at 4% and 6%, conventional sodium silicate A2 at 6%, and AF-alkali-free aluminum sulfate-based accelerator at 6% (accelerator dosage by binder mass).

Concrete was shotcreted into field panels. Panels were protected immediately after spraying, then cured using a wet burlap and protected with heated outdoor measures. Cores were later transferred to a humidity chamber until tested.

Cores were tested for compressive strength, and the

results after 7, 14, and 28 days of curing are shown in Fig. 1. The novel low-alkali silicate (A1) outperformed the conventional silicate accelerator (A2) at all curing ages and exhibited a significantly reduced tendency for lower later age strength observed with conventional silicate

Composition	Weight (kg/m ³)
GUL Cement	410
Microsilica	40
Concrete sand	1,693
Air(entrained)	4.2
Water	194
High-Range Water Reducer	2

Table 2: Concrete Mixture Design

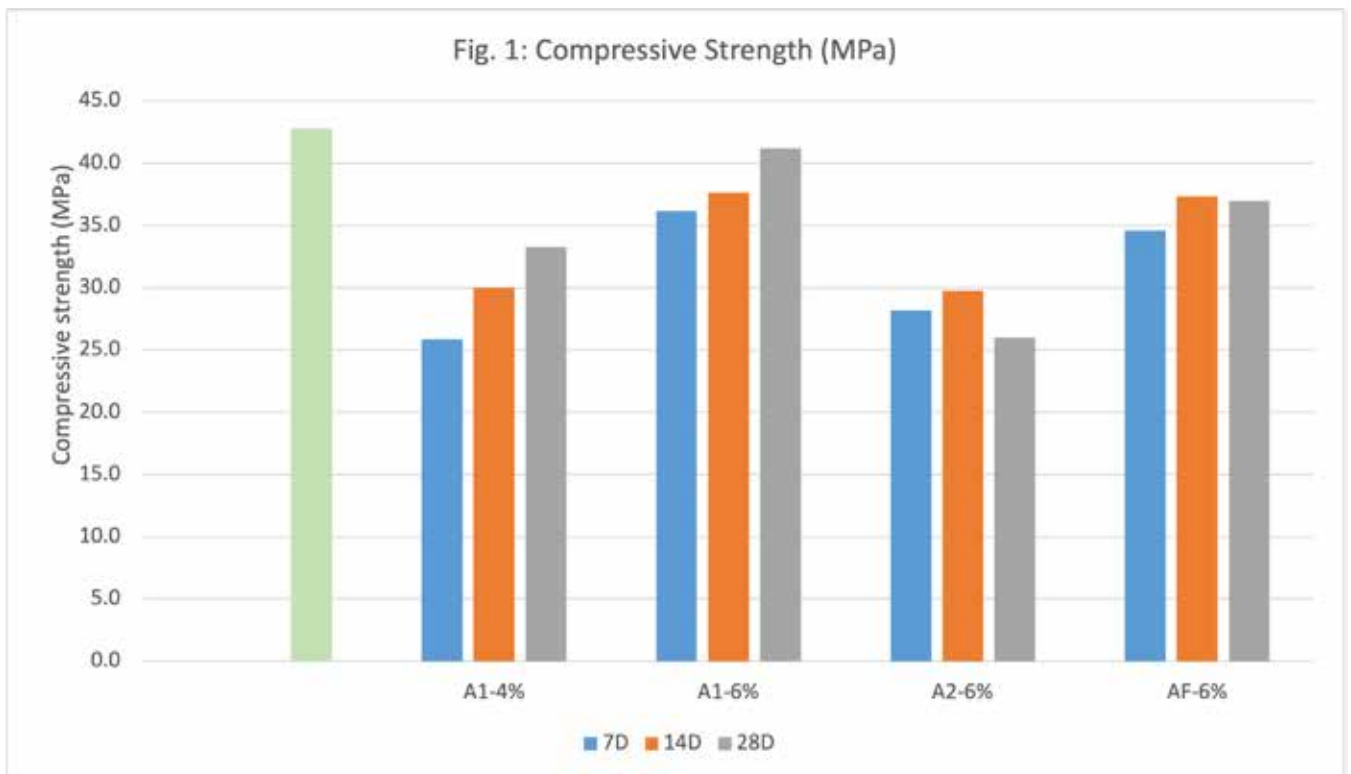


Fig. 1: Compressive Strength (MPa) Chart; A1 - novel low alkali sodium silicate; A2 - conventional sodium silicate; AF - Alkali free, aluminum sulphate based

accelerators. At a 6% dosage, the low alkali silicate (A1) and the alkali free accelerator (AF) demonstrated comparable compressive strength at both early and later ages.

These results support additional testing to optimize dosage and to evaluate performance across other concrete mixture designs.

ALUMINUM MODIFIED SILICATES

A major challenge facing our industry is the increasing amount of supplementary cementitious material in portland limestone cement and the resulting strength development. The next innovative sodium silicate is an aluminum-modified silicate, where a reactive aluminum end group is attached to the silicate molecule. The presence of aluminum reduces sodium mobility and introduces additional mechanisms that promote the setting of both cementitious and pozzolanic components.

In this study, panels were also shotcreted using the aluminum-modified sodium silicate (AAAS) and compared against two versions of a commonly used alkali-free accelerator. AAAS achieved over 3 MPa (450 psi) compressive strength in 30 minutes. Fig. 2 illustrates the compressive strength at 7 and 28 days. Additional field trials are scheduled to further confirm the performance and to optimize dosage levels.

CONCLUSIONS

New silicate accelerators have demonstrated strong performance in preliminary field tests and are now being evaluated at lower dosage levels than those historically used.

Low alkalinity silicate has gained industry attention

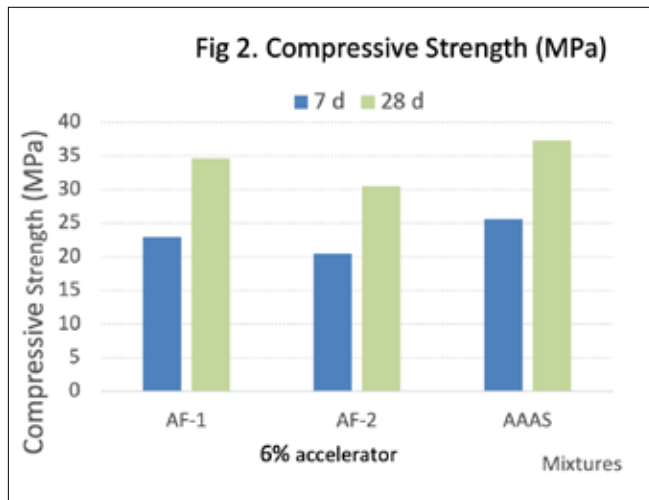


Fig. 2: Compressive Strength (MPa) at 7 and 28 days

as a potential solution to long-term strength loss, while also offering opportunities to further enhance other key performance properties in shotcrete mixes. Aluminum-modified silicates have notably enhanced strength development of shotcrete produced with a low-carbon cement.

Ongoing laboratory and field work will continue to assess the performance of new silicate accelerators across a wide range of shotcrete mix designs and field conditions. This work will support greater use of more cost-effective formulations where performance criteria are met.

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