Chemical additives to boost strength development of BCSA cement at colder temperatures

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Abstract

BCSA cement is known for its rapid setting and strength gain that make it an ideal material for rapid repair of pavements. However, at low temperatures the setting time increases and the strength gain is not rapid. At very low temperatures it may be impossible to achieve setting and adequate strength properties. In this research, admixtures were used to overcome the negative effects of low temperatures on the setting and strength gain of BCSA cement paste.

Aluminum sulfate was used to accelerate hydration and two different salts (Sodium Chloride and Calcium Chloride) were used to depress the freezing point of the mixing water. Samples were cured at 40, 14, 0 and -20°F. The results showed that 1.5% and 2% Aluminum Sulfate by weight of cement has a positive effect at all low temperatures except -20 °F. The combined effect of 2% Sodium Chloride with 1% and 2% Aluminum Sulfate is considerably better than its counter parts at 14°F.

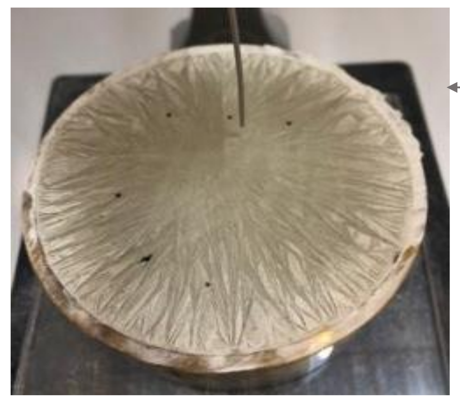
Background

Cement-based materials in cold environments face reduced rates of strength development which causes delay in construction operations and may result in unexpected failures due to weaker strength than expected. There are different solutions to address this problem like: preheating aggregates and water, use of large amounts of cement, increasing ambient temperature by external heating systems, insulating surfaces to block heat loss, addition of admixtures to accelerate the setting of concrete, and utilizing cements that have high hydration heat at early ages.

There is less work done on the performance of BCSA cement at low temperatures. Although it is capable in producing high hydration heat and gaining high strength at early ages, even BCSA cement has slower strength gain and setting in very cold temperatures. So, the objective of this study is to figure out what admixtures can economically reduce setting times and improve strength gain individually or in combination.

Methods & Results

To determine the setting time, Vicat Needle Penetration test and Penetration Resistance test were performed on paste and mortar samples of BCSA cement. All samples at lower temperatures had a layer of frost at surface that made it difficult to perform penetration setting time test. The frost interfered with setting time results by providing resistance to needle penetration that was not relate to cement hydration.



Frost appeared on paste sample at 0°F - Vicat Needle Penetration test

Penetration Resistance test mold with the mortar sample at -20°F

Cement pastes after Vicat Needle test - left sample is a couple days after test and the right sample is a few minutes after test at room temperature

Methods & Results (Cont'd)

Cold temperature works as a strong retarder for strength development. As shown below, the mortar cubes were still pasty at initial ages of curing. The mode of compressive failure was also different at later ages with a weak plane forming down the center of the samples, rather than a cone-type failure.

Pasty mortar at initial ages (2hrs & 3hrs) at subzero temperatures

Mortar cube cured at -20°F with no admixtures after 28 days

The effect of Aluminum Sulfate is shown in Figures 1 and 2. These figures also show the effect of Aluminum Sulfate with NaCl and $CaCl_2$.

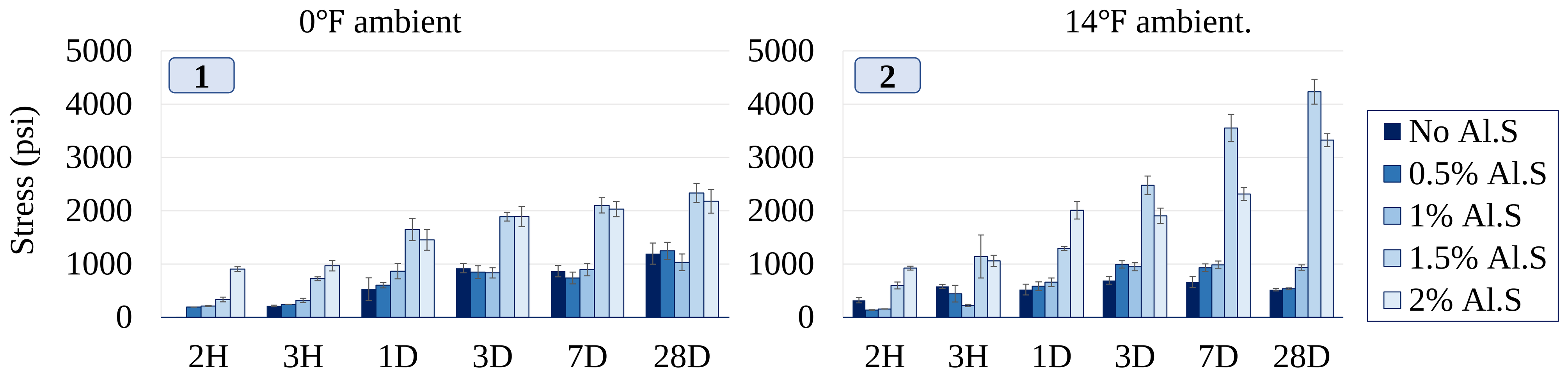


Figure 1 - Effect of Aluminum Sulfate (Al.S) on compressive strength

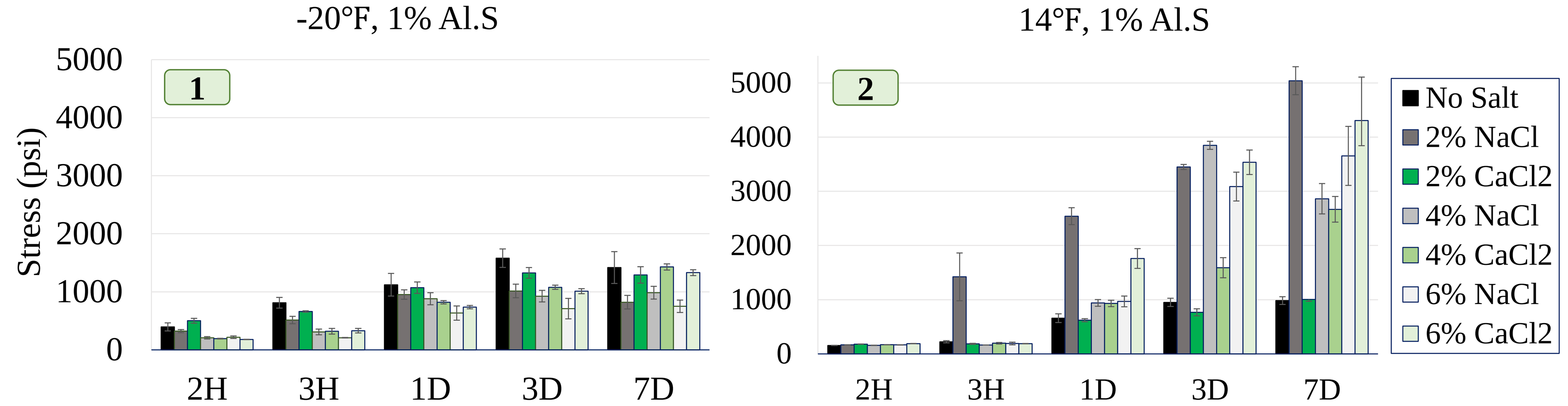


Figure 2 - Comparison of two salts in combination with Aluminum Sulfate (Al.S)

The XRD analysis of paste samples cured for 2 hours at four different temperatures are also demonstrated below. The identified compounds are Ye'elimite (Y), Ettrigite (E), Calcite (C), Belite (B), and Anhidrite (Anh).

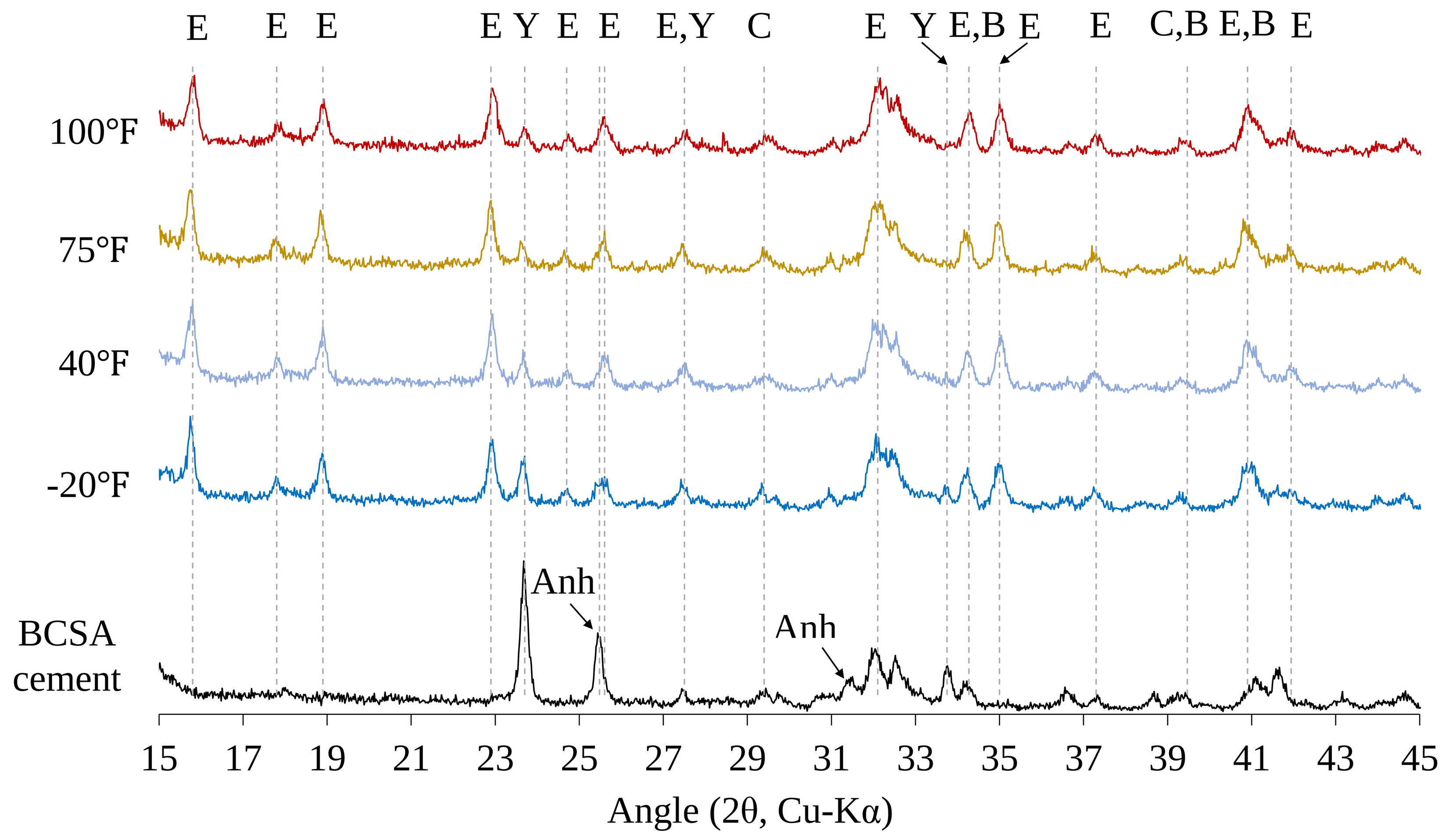


Figure 3 – XRD patterns for BCSA cement and pastes cured at various temperatures

Methods & Results (Cont'd)

The thermal analysis was also performed using thermocouples to track heat production in mortar samples at lower temperatures. Figure 4 shows the results of mortars with containing Aluminum Sulfate cured at 40°F. The black dots show the penetration resistance test.

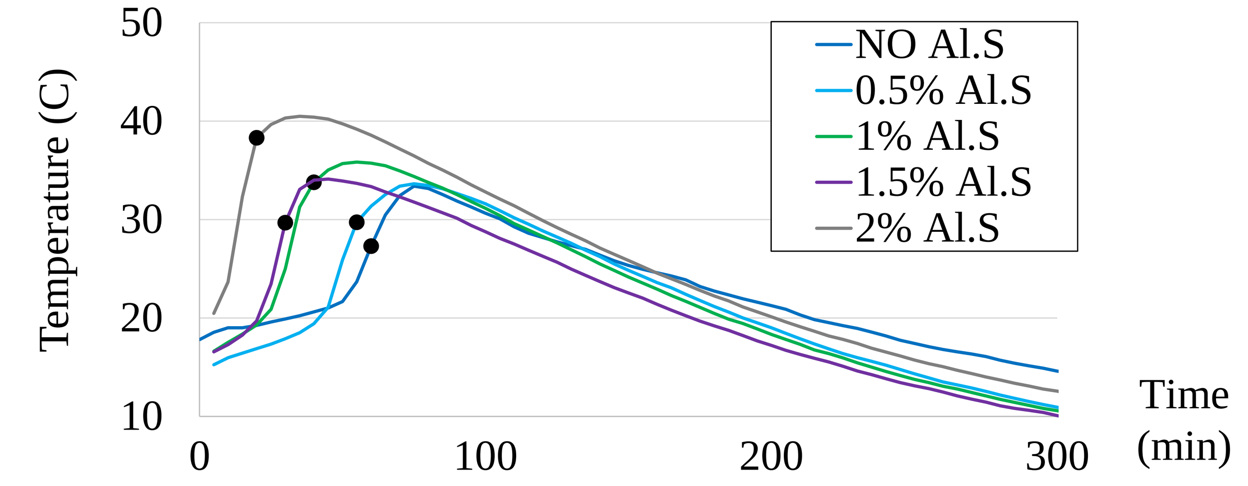


Figure 4 – Thermal analysis results with corresponding setting times

Discussion

The negative effect of cold temperature on the free water inside the matrix is undeniable. This phenomenon has direct effect on decreasing hydration rate which accounts for the lower results of compressive strengths. The cold temperature turns the free water in the pore solution to ice particles and lessens or ceases the hydration especially at the edges and outer surfaces. However, hydration occurs at the core of cubes, if only at a slow rate. This is seen from the results achieved by XRD analysis.

To depress the freezing point of water and contribute to hydration, two salts were used in a series of cubes with various doses in combination with an accelerator. It was observed that by increasing the amount of salt in mixture, the viscosity would decrease and the mix gain more fluidity. These salts were less effective at the lowest temperature but contributed to better strength gain at 14F.

Conclusion

In summary, to improve setting and strength gain of BCSA cement at very low temperatures, combinations of salt and aluminum sulfate were used as admixtures. Conclusions were as follows:

- Individual use of 1.5% and 2% Aluminum Sulfate showed an acceptable increase of compressive strength at 0°F and 14°F
- Binary effect of 2% Sodium Chloride with Aluminum Sulfate yielded considerable increase in compressive strength at 14°F
- No positive synergetic effect of any salt and accelerator was seen at -20°F
- Calcium Chloride had better influence relative to Sodium Chloride at -20°F
- XRD results demonstrated the adverse effect of colder temperatures in hydration of Ye'elimite and weaker pore structure relative to higher temperatures.

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