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Strength and Ductility Characteristics of Polymer-Modified CSA Cement Concrete

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Introduction

In this study, a variety of calciumsulfo aluminate (CSA) cement mortar systems are examined to be used for preplaced aggregate concrete. Contrary to Portland cement, CSA cement has a large proportion of minerals such as calciumsulfo aluminate (Ye'elimite) and di-calcium silicate (belite). The production of CSA cement clinkers consumes a relatively lower amount of limestone and can be operated at a lower temperature, which consequently requires less energy and reduces CO_2 emission than the production of Portland cement clinkers. This study employs two kinds of chemical admixtures, setting retarders and redispersible polymer powder, which primarily affect the workability and long term durability properties, respectively. This study reveals the strength development process of CSA cement mortars by employing various microstructural analyses. The strength development is comprehensively investigated in relation to the hydration reaction with varied ages.

Test Variables & Raw Materials

Table 1 – Mix Proportions of Mortars and Hardened Cement Pastes (HCP)

Mortar name	Mixture precursors (unit: kg/m^3)					HCP name	Mixture precursors (unit: kg/m^3)				
	Water	Mortar	Polymer	Retarder			Water	Cement	Polymer	Retarder	
				A	B					A	B
M-0-N	339	1785	0.0	0.00	0.00	B-0-N	512	1346	0.0	0.00	0.00
M-0-Y	339	1785	0.0	1.43	1.07	B-0-Y	512	1346	0.0	2.15	1.62
M-2-N	339	1785	17.9	0.00	0.00	B-2-N	512	1346	26.9	0.00	0.00
M-2-Y	339	1785	17.9	1.43	1.07	B-2-Y	512	1346	26.9	2.15	1.62
M-6-N	339	1785	53.6	0.00	0.00	B-6-N	512	1346	80.8	0.00	0.00
M-6-Y	339	1785	53.6	1.43	1.07	B-6-Y	512	1346	80.8	2.15	1.62
M-10-N	339	1785	89.3	0.00	0.00	B-10-N	512	1346	134.6	0.00	0.00
M-10-Y	339	1785	89.3	1.43	1.07	B-10-Y	512	1346	134.6	2.15	1.62

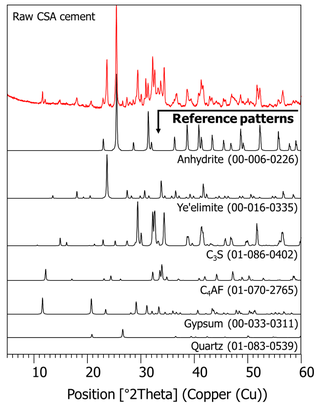


Figure 1 – Raw CSA Cement XRD

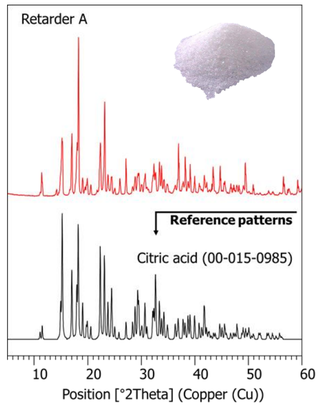


Figure 2 – Retarder A XRD

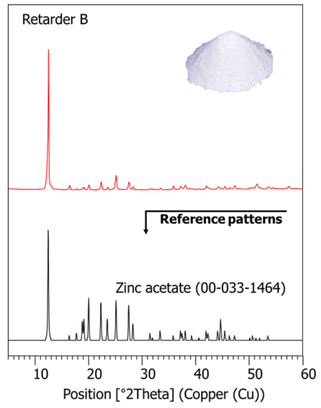


Figure 3 – Retarder B XRD

Table 2 – Oxide Composition of CSA Cement

Oxide (unit: wt. %)						
CaO	SO_3	SiO_2	Al_2O_3	MgO	Fe_2O_3	Others
54.6	14.6	12.4	11.8	2.3	2.3	2.0

Table 3 – Elemental Composition of Polymer Powder

Element (wt.%)				
Carbon	Hydrogen	Sulfur	Nitrogen	
71.1	7.7	0	0.7	

- ✓Test plan: 1) mortar: compressive strength test (50 mm cube specimen), 2) HCP (w/o sand): SEM/EDS, MIP, XRD analyses
- ✓Curing age: 2 h - 90 d (early – long term)
- ✓Raw CSA cement: much calcium sulfate (anhydrite) and ye'elimite phase giving early age strength achievement (**Figure 1 & Table 2**)
- ✓Retarder A & B: 1) Citric acid, 2) Zinc acetate (**Figure 2 & 3**)
- ✓Redispersible polymer powder: 1) red color, 2) large portion of carbon according to elemental analyzer (**Table 3**)

Results: Compressive Strength

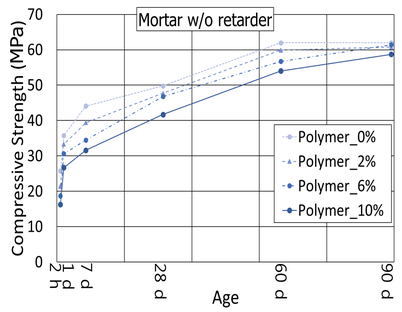


Figure 4 – Compressive Strength (w/o Retarder)

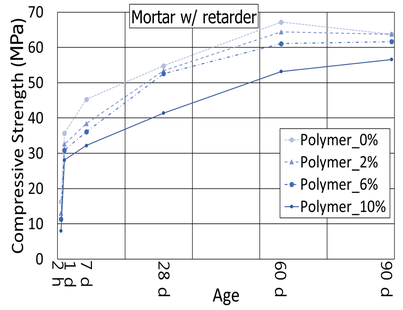


Figure 5 – Compressive Strength (w/ Retarder)

- ✓Regardless of the retarders, more dosage of polymer caused a lower strength at each age.
- ✓Regardless of the retarders, however, compressive strengths of mortars converged around 60 MPa at 90 days of curing.
- ✓Although retarding effect by polymer added to that by retarders at early age, the mortars with both retarders and polymers less than 6% acquired enhanced compressive strength since 28 days of curing.
- ✓Considering slow but steady strength increase of M-10-Y, all mortars are likely to sustain similar compressive strengths at the long-term age further after 90 days.

Results: MIP & X-Ray Diffraction

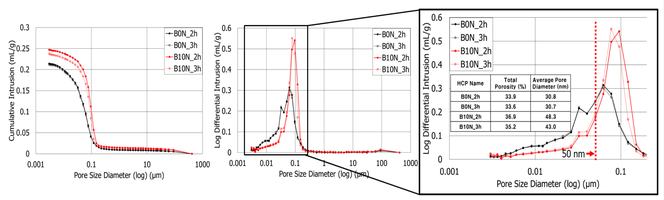
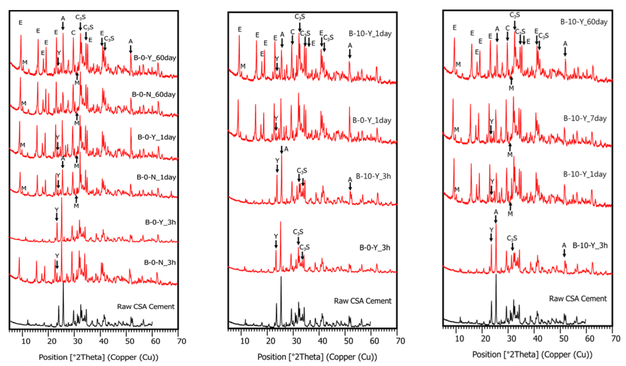


Figure 6 – Cumulative and Log Differential Intrusion (B-0-N, B-10-N at 2 h, 3 h)

(a) w/o Retarder **(b) w/ Retarder**

Figure 7 – Cumulative Intrusion with Varying Polymer (1~60 d)

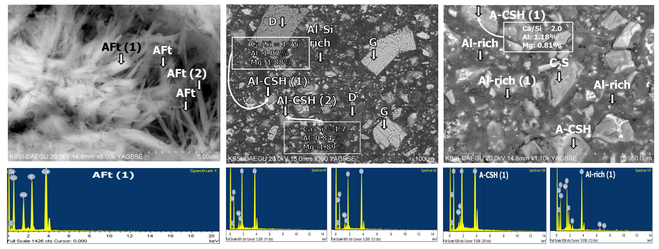


(a) B-0-N, B-0-Y **(b) B-0-Y, B-10-Y** **(c) B-10-Y**

Figure 8 – XRD Results of HCPs

- ✓At early ages less than 3 h, the use of retarders considerably restrained the hydration (**Figure 8**), however, it drastically reduced the porosity and average pore diameters along with the increasing polymer dosage at 60 days of curing (**Figure 7**).

Results: Scanning Electron Microscope



(a) B-0-N_1d **(b) B-10-N_2h** **(c) B-10-N_1d**

Figure 9 – SEM/EDS Results

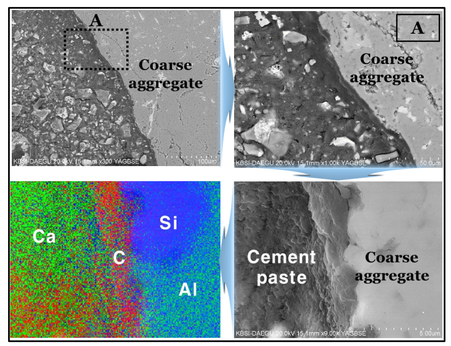


Figure 10 – SEM/EDS Results of Concrete ITZ with M-10-N

- ✓ After 1 day, hydration products like ettringite (AFt) and Al-rich CSH (A-CSH) phase were detected.
- ✓ Much carbon elements were detected at the Al-rich hydration product region in the specimens with polymer powder, which was confirmed by EDS spot analyses.
- ✓ The distribution of polymer powders was primariliy located along the concrete ITZ, which is a critical zone affecting mechanical and durability properties of the concretes (**Figure 10**).

Summary & Conclusions

1. Both polymer and retarders additively delayed the setting/hydration of cement at early age. Meanwhile, the mortars with retarders generally acquired higher compressive strengths than those without retarders after 28 days.
2. At early age less than 3 h, the inclusion of polymer made macro-pores and higher porosity of CSA cement pastes due to the surfactant effect of polymer powder.
3. At the age of 60 days, more polymer powder induced smaller pore size and lower porosity of CSA cement pastes, which indicates the improvement of long-term durability.
4. A majority of polymer powders were located along the concrete ITZ, which was observed by the elemental distribution of carbon, suggesting a favorable modification towards durable concretes.

Acknowledgements

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