Effect of Calcium Sulfoaluminate–Belite Cement for Partial Portland Cement Replacement on Its Mechanical Properties

Author : Saliltip Fongmool / Advisor : Associate Professor Dr. Kedsarin Pimraksa
Department of Industrial Chemistry, Faculty of Science, Chiang Mai University

Abstract

This study investigated the partial replacement of Portland cement (PC) with calcium sulfoaluminate–belite cement (CSA), with curing periods of 1, 3, and 7 days, to evaluate how different mix proportions affect the compressive strength of the blended cement.The mix proportion that achieved the highest compressive strength was subsequently selected to determine the appropriate gypsum content required for the hydration of the blended cement. The results indicated that increasing the CSA content up to 20 wt% enhanced compressive strength at curing ages of 3 and 7 days. At 7 days, mixtures containing 0%, 5%, 10%, 20% and 100% CSA with a water-to-cement ratio of 0.3 exhibited compressive strengths of 11.8, 12.7, 14.2, 14.4 and 35.5 MPa, respectively, with the 20% CSA mixture showing the highest strength, demonstrating its suitability for early-age strength development in the PC/CSA system. The 20% CSA mixture was then partially replaced with varying amounts of gypsum, With an increase in the gypsum content, the compressive strength decreased. Therefore, gypsum replacement should be maintained within an appropriate range, as excessive addition reduces the proportion of primary cementitious materials, which may adversely affect both strength and durability.

Introduction

Portland cement (PC) is the most widely used binder in construction; however, its production generates significant CO_2 emissions due to limestone calcination and high-temperature kiln processes. As a result, the cement industry contributes approximately 7–8% of global CO_2 emissions. Therefore, the development of alternative low-carbon binders has gained increasing attention.

Calcium sulfoaluminate–belite cement (CSA) is considered a promising alternative because it can be produced at lower temperatures and requires less limestone, resulting in lower CO_2 emissions. The main phases of CSA, including ye'elimite ($C_4A_3\hat{S}$) and belite (C_2S), contribute to its mechanical performance. In particular, ye'elimite reacts with calcium sulfate and water to form ettringite, which enhances early-age strength :

$$C_4A_3\hat{S} + 2C\hat{S}H_2 + 34H \rightarrow C_6A\hat{S}_3H_{32} + 2AH_3$$

(C = CaO, A = Al_2O_3, $\hat{S}$ = SO_3, H = H_2O)

Blending PC with CSA combines the advantages of both binders, where CSA improves early strength while PC supports strength development. In addition, gypsum content influences the formation of ettringite in the PC–CSA system. Therefore, this study investigates the effect of gypsum content on the mechanical properties of PC–CSA blended cement.

Methods

- **Materials**



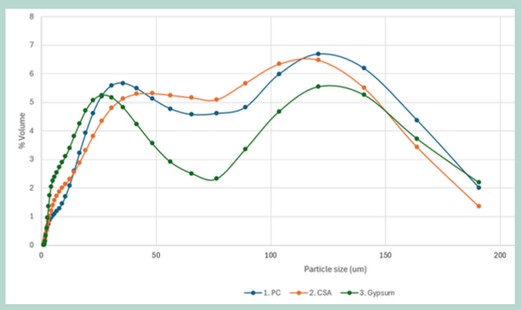


Figure 1. Particle Size Distribution Curves of Portland Cement, Calcium Sulfoaluminate Cement and Gypsum

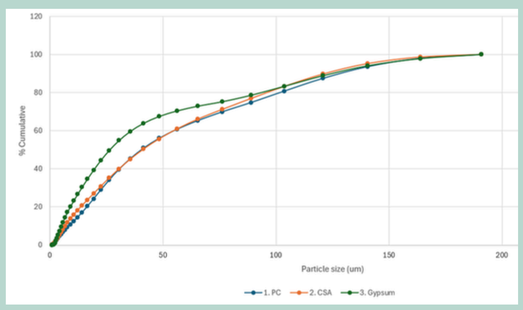


Figure 2. Cumulative Distribution Curves of Portland Cement, Calcium Sulfoaluminate Cement and Gypsum

- **Mix Proportions**

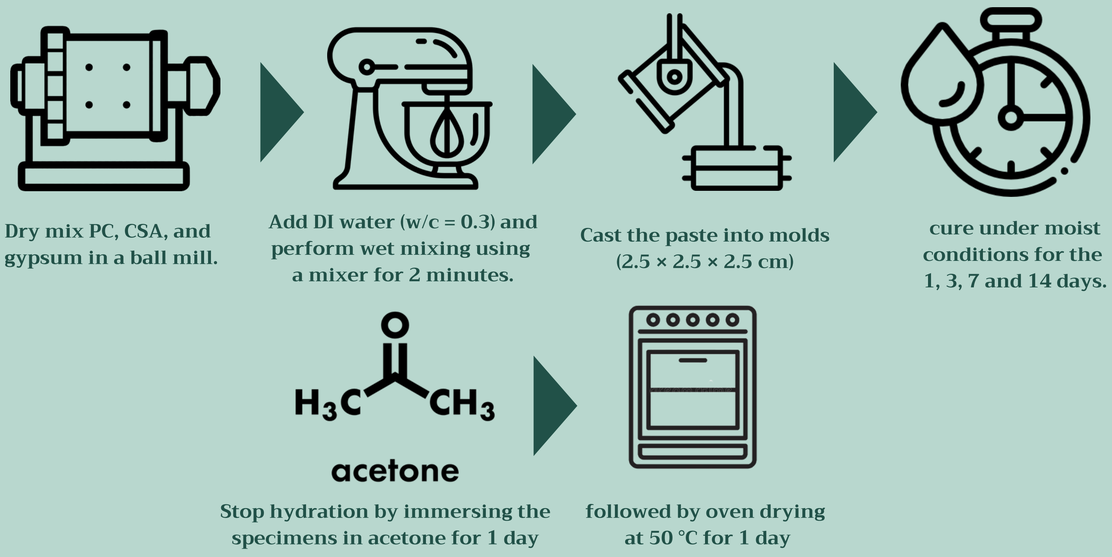
PC (wt%)	CSA (wt%)	Gypsum (wt%)	w/c ratio
100	0	5	0.3
95	5	6.2	0.3
90	10	7.4	0.3
80	20	9.8	0.3
0	100	29	0.3

Part1. Mix Proportions of PC–CSA Blended Systems

PC (wt%)	CSA (wt%)	Gypsum (wt%)	w/c ratio
80	20	5.88	0.3
80	20	7.84	0.3
80	20	9.8	0.3
80	20	11.76	0.3
80	20	13.72	0.3

Part2. Mix Proportions for Studying the Effect of Gypsum Content

- **Sample Preparation**



Results

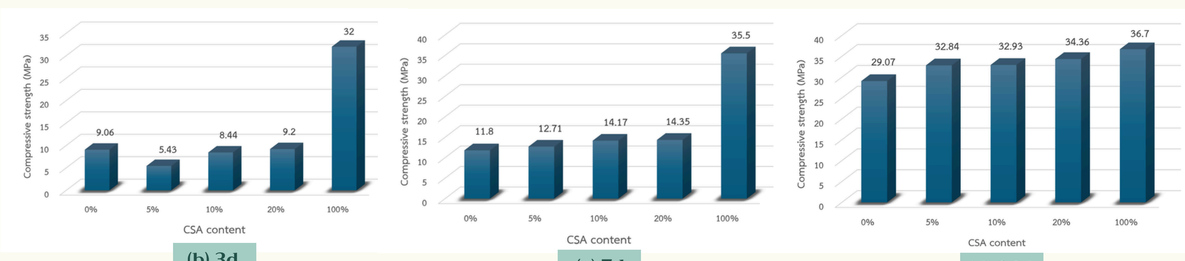
Part1. Effect of CSA Replacement

CSA (wt%)	1 days	3 days	7 days	14 days
0	2.16 g/cm3	2.20 g/cm3	2.20 g/cm3	2.21 g/cm3
5	2.13 g/cm3	2.13 g/cm3	2.20 g/cm3	2.22 g/cm3
10	2.10 g/cm3	2.15 g/cm3	2.20 g/cm3	2.22 g/cm3
20	2.13 g/cm3	2.16 g/cm3	2.23 g/cm3	2.27 g/cm3
100	2.09 g/cm3	2.06 g/cm3	2.09 g/cm3	2.11 g/cm3

Table 1. Density of PC–CSA Cement at Different CSA Contents



(a) 1d



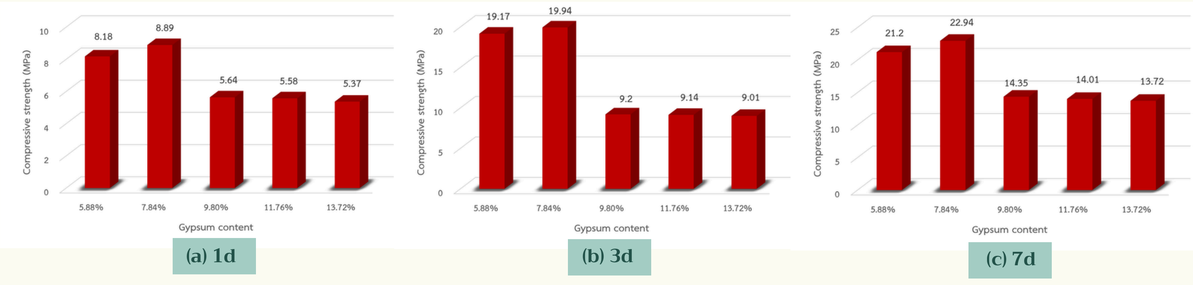
(b) 3d (c) 7d (d) 14d

Figure 3. Compressive Strength of PC–CSA Cement at Different CSA Contents ((a) 1d, (b) 3d, (c) 7d, (d) 14d)

Part2. Effect of Gypsum Content

Gypsum (wt%)	1 days	3 days	7 days
5.88	2.15 g/cm3	2.15 g/cm3	2.22 g/cm3
7.84	2.17 g/cm3	2.18 g/cm3	2.24 g/cm3
9.8	2.15 g/cm3	2.16 g/cm3	2.21g/cm3
11.76	2.15 g/cm3	2.16 g/cm3	2.20 g/cm3
13.72	2.14 g/cm3	2.15 g/cm3	2.20 g/cm3

Table 2. Density of PC–CSA Cement with Different Gypsum Contents



(a) 1d (b) 3d (c) 7d

Figure 4. Compressive Strength of PC–CSA Cement with Different Gypsum Contents ((a) 1d, (b) 3d, (c) 7d)

Conclusions

- Increasing the CSA content in the PC–CSA system significantly improved the early compressive strength, particularly at 3 days. This is because the ye'elimite phase ($C_4A_3\hat{S}$) in CSA reacts rapidly during hydration and reacts with sulfate to form ettringite, which accelerates the development of the cement structure at early ages. As a result, the mixture containing 20% CSA exhibited the highest compressive strength.
- The gypsum content significantly influenced the strength development of the PC–CSA system. The mixture with 7.84 wt% gypsum showed the highest compressive strength because this proportion is optimal for ettringite formation from the reaction of CSA. If the gypsum content is too low, the reaction may be incomplete and other phases may form instead, resulting in lower strength. Conversely, excessive gypsum reduces the proportion of the main binder phases (PC and CSA) and may introduce excess sulfate that interferes with hydration product formation, leading to a reduction in strength.

References

Huang, G., Pudasainee, D., Gupta, R., & Liu, W. V. (2021). Extending blending proportions of ordinary Portland cement and calcium sulfoaluminate cement blends: Its effects on setting, workability, and strength development. Higher Education Press.