EFFECT OF WATER AND AIR CURING CONDITIONS ON THE COMPRESSIVE STRENGTH OF CONCRETE INCORPORATING MINERAL AND CHEMICAL ADMIXTURES

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ABSTRACT

Curing conditions play a critical role in the strength development of concrete. In particular, determining the influence of different curing regimes on the mechanical performance of concrete incorporating both mineral and chemical admixtures is essential for the development of sustainable concrete technologies. In this study, the compressive strength of concrete produced by separately replacing 10% of the cement with either blast furnace slag or fly ash was investigated. For each binder system, three concrete mixtures were prepared: a control mixture containing a superplasticizer but no set accelerator or set retarder, a mixture containing a set accelerator, and a mixture incorporating a set retarder. Specimens were tested at curing ages of 7, 28, and 56 days under two different curing regimes. In the first regime, the specimens were continuously cured in water throughout the entire curing period, whereas in the second regime, they were stored under laboratory air conditions for the same duration. Accordingly, the effects of water curing and air curing on the compressive strength development of concrete containing different binder systems and chemical admixtures were comparatively evaluated. The results demonstrated that the compressive strength was governed by the combined effects of curing age, curing regime, mineral admixture type, and chemical admixture type. For all mixtures, specimens subjected to water curing exhibited higher compressive strengths than those exposed to air curing, with the difference becoming more pronounced at 28 and 56 days. Although water curing consistently resulted in higher absolute compressive strengths, the relative effects of the accelerating and retarding admixtures varied depending on curing condition, binder composition, and testing age. Although concrete incorporating 10% blast furnace slag and fly ash exhibited lower compressive strength than the control concrete at early ages, it exceeded the strength of the control concrete after 56 days of water curing. Furthermore, the set accelerator enhanced early-age strength development, whereas the set retarder promoted greater long-term strength development, particularly under water curing conditions.

Keywords: Air Curing, Chemical Admixtures, Compressive Strength, Fly Ash, Blast Furnace Slag, Water Curing.

INTRODUCTION

Concrete remains one of the most extensively utilized construction materials worldwide owing to its favorable mechanical properties, versatility, and economic advantages (Verma et al. 2026). Nevertheless, the substantial consumption of Portland cement and the environmental impacts associated with its production have increased the demand for more sustainable cement-based materials (Şanal 2018). In this context, the partial replacement of cement with supplementary cementitious materials (SCMs) has emerged as an effective approach to reducing cement consumption while improving concrete performance. Among the available SCMs, blast furnace slag and fly ash are widely utilized in concrete production due to their pozzolanic properties and potential to improve the long-term performance of concrete (Aruntaş et al. 2022). Furthermore, the utilization of these industrial by-products as partial cement replacements contributes to resource efficiency and environmental sustainability while influencing the mechanical and durability characteristics of concrete.

The mechanical performance of concrete containing mineral admixtures is strongly influenced by the hydration characteristics of the binder system and the development of its internal microstructure. Although the incorporation of blast furnace slag and fly ash may adversely affect the early-age mechanical performance of concrete due to their generally slower initial reaction rates compared with Portland cement, their continued hydraulic and pozzolanic reactions can contribute to improved mechanical properties at later ages (Tariq et al. 2025; Girish et al. 2026). The additional formation of cementitious hydration products can promote microstructural refinement and improve the mechanical performance of blended cement systems. Furthermore, previous studies have reported that the mechanical properties of cementitious materials incorporating SCMs are significantly influenced by curing conditions and testing age (Yaseen et al. 2024). These findings indicate that the performance of mineral-admixture concrete should be evaluated not only in terms of cement replacement but also by considering the environmental conditions governing its strength development.

Among the various factors influencing concrete performance, curing conditions are of critical importance, as they directly affect the progression of cement hydration and the subsequent development of compressive strength (Rahimi et al. 2023). Adequate curing provides the moisture necessary for the continuation of cement hydration and the reactions of SCMs (Kumar et al. 2025). Conversely, exposure to air curing conditions may cause moisture loss, restrict hydration, and consequently limit strength development. Ramezanianpour and Malhotra (1995) demonstrated that reducing the duration of moist curing adversely affects the compressive strength and pore structure of concrete containing slag and fly ash. Furthermore, concrete incorporating mineral admixtures may exhibit greater sensitivity to inadequate curing conditions than conventional Portland cement concrete (Bentur et al. 1989). Therefore, maintaining sufficient moisture during curing is essential for promoting hydration reactions and ensuring adequate strength development in concrete containing blast furnace slag and fly ash.

In addition to mineral admixtures, chemical admixtures are widely employed to regulate the setting characteristics and early-age behavior of concrete (Bedada et al. 2023). Set accelerators are generally introduced to shorten setting time and, depending on their composition, promote early strength development, whereas set retarders delay setting and modify the progression of hydration reactions (Lee et al. 2020). However, the effects of these admixtures on compressive strength are not necessarily uniform and may vary depending on binder composition, admixture dosage, curing conditions, and concrete age. In blended cementitious systems, interactions between chemical admixtures and SCMs may further influence hydration kinetics and strength development. Despite previous investigations into the individual effects of mineral and chemical admixtures on concrete properties, the combined influence of curing conditions and set-modifying admixtures on the compressive strength development of concrete incorporating blast furnace slag and fly ash remains insufficiently understood. Therefore, a systematic evaluation of these interacting parameters is necessary to clarify the influence of water and air curing on the strength development of concrete containing mineral admixtures and set accelerators or retarders.

Accordingly, the present study investigates the effects of curing conditions on the compressive strength development of concrete incorporating blast furnace slag, fly ash, and chemical admixtures. Portland cement was separately replaced with 10% blast furnace slag and 10% fly ash by mass, and the resulting mixtures were compared with conventional concrete without mineral admixtures. For each binder system, three mixtures were prepared: a reference mixture without chemical admixtures, a mixture containing a set accelerator, and a mixture incorporating a set retarder. Concrete specimens were

subjected to continuous water curing or laboratory air curing, and compressive strength tests were performed at 7, 28, and 56 days. Through this experimental approach, the combined effects of binder composition, chemical admixture type, curing regime, and curing age were systematically evaluated. The findings are intended to contribute to a better understanding of strength development in mineral-admixture concrete and to support the selection of appropriate curing practices for more sustainable concrete applications.

MATERIALS AND METHODS

Materials

Portland cement, blast furnace slag, and fly ash were employed as binder materials in the experimental study. Blast furnace slag and fly ash were separately incorporated as partial replacements for cement at a replacement level of 10% by mass. The visual appearances of these materials are presented in Figure 1, while their chemical compositions are summarized in Table 1.



Figure 1. Visual appearances of the binder materials: (a) Portland cement, (b) blast furnace slag and (c) fly ash

Table 1. Chemical composition of cement, blast furnace slag, and fly ash (wt.%)

Component	Cement	Blast Furnace Sag	Fly Ash
SiO_2	18.86	40.27	52.99
Al_2O_3	5.71	13.18	19.05
Fe_2O_3	3.09	0.75	9.52
CaO	62.70	28.07	3.75
MgO	1.16	7.45	3.64
SO_3	2.39	1.64	0.76
$Na_2O + 0.658\ K_2O$	0.92	—	2.92
Na_2O	—	0.61	—
K_2O	—	1.04	—
TiO_2	—	1.46	—
MnO	—	2.35	—
SrO	—	0.07	—
Cl^-	0.01	—	—
Insoluble residue	0.32	—	—
Loss on ignition	3.20	0.13	2.20
Free CaO	1.26	—	—

Crushed limestone aggregates were used in the production of concrete mixtures. Three aggregate size fractions, namely 0–5 mm, 5–11 mm, and 11–22 mm, were incorporated at proportions of 55%, 30%, and 15%, respectively, by mass of the total aggregate content. The particle size distribution of the combined aggregates is presented in Figure 2, while the specific gravity and water absorption values of each aggregate fraction are summarized in Table 2.

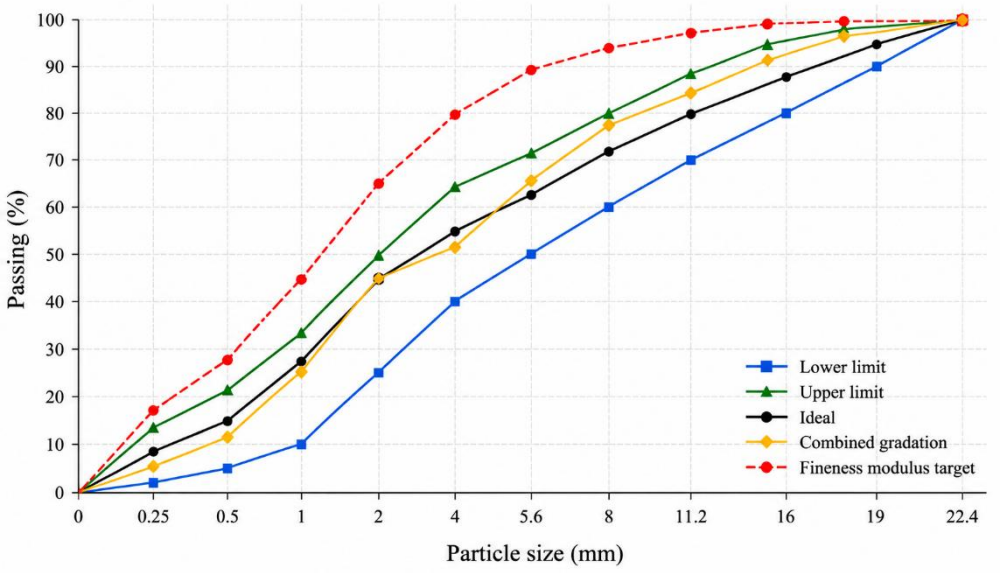


Figure 2. Gradation curve of the combined aggregates

Table 2. Specific gravity and water absorption properties of crushed limestone aggregates

Aggregate Size	Specific Gravity	Water Absorption (%)
0–5 mm	2.68	1.27
5–11 mm	2.72	0.67
11–22 mm	2.71	0.60

Three chemical admixtures were used in this study: a polycarboxylate ether-based superplasticizer, a calcium nitrate-based set accelerator, and a lignosulfonate-based set retarder. The superplasticizer (SP) was used to enhance the workability of the concrete mixtures, whereas the accelerator and retarder were employed to modify their setting behavior. The physical and chemical properties of these admixtures, as reported by the manufacturers, are presented in Table 3.

Table 3. Physical and chemical properties of the chemical admixtures

Property	Superplasticizer	Set Accelerator	Set Retarder
Chemical base	Polycarboxylate ether	Calcium nitrate salt	Lignosulfonate
Appearance	Brown liquid	Colorless liquid	Brown liquid
Density at 20°C (g/cm³)	1.058–1.098	1.26–1.30	1.14–1.19
pH	5.0–7.0	5.0–9.0	6.0–7.0
Chloride ion content (% by mass)	≤0.10	≤0.10	-
Alkali content (% by mass)	≤3.00	-	-

Mix Proportions

A total of nine concrete mixtures were designed to investigate the combined effects of mineral admixtures, set-modifying chemical admixtures, and curing conditions on compressive strength development. Three binder systems were used: 100% Portland cement (C), 90% Portland cement with 10% blast furnace slag (BFS), and 90% Portland cement with 10% fly ash (FA), by mass. For each binder system, three mixtures were prepared: a reference mixture without a set-modifying admixture, a mixture containing a set accelerator (ACC), and a mixture incorporating a set retarder (RET). Accordingly, the mixtures were designated as C, C-ACC, C-RET, BFS, BFS-ACC, BFS-RET, FA, FA-ACC, and FA-RET. The mixture proportions are summarized in Table 4.

Table 4. Mix proportions of the concrete mixtures

Mix ID	Cement (kg/m³)	Blast Furnace Slag (kg/m³)	Fly Ash (kg/m³)	Water (kg/m³)	Fine Agg. (kg/m³)	Medium Agg. (kg/m³)	Coarse Agg. (kg/m³)	SP (%)	ACC (%)	RET (%)
C	300.0	0.0	0.0	176.7	1071.3	581.7	286.7	1.0	0.0	0.0
C-ACC	300.0	0.0	0.0	176.7	1071.3	581.7	286.7	1.0	1.0	0.0
C-RET	300.0	0.0	0.0	176.7	1071.3	581.7	286.7	1.0	0.0	0.75
BFS	270.0	30.0	0.0	176.7	1070.4	581.2	286.4	1.0	0.0	0.0
BFS-ACC	270.0	30.0	0.0	176.7	1070.4	581.2	286.4	1.0	1.0	0.0
BFS-RET	270.0	30.0	0.0	176.7	1070.4	581.2	286.4	1.0	0.0	0.75
FA	270.0	0.0	30.0	176.7	1066.9	579.3	285.5	1.0	0.0	0.0
FA-ACC	270.0	0.0	30.0	176.7	1066.9	579.3	285.5	1.0	1.0	0.0
FA-RET	270.0	0.0	30.0	176.7	1066.9	579.3	285.5	1.0	0.0	0.75

The total binder content and water-to-binder ratio were 300 kg/m³ and 0.589, respectively. Crushed limestone aggregates with particle size ranges of 0–5, 5–11, and 11–22 mm were incorporated at proportions of 55%, 30%, and 15%, respectively, by total aggregate mass. A polycarboxylate ether-based superplasticizer was used in all concrete mixtures at a dosage of 1.0% by binder mass to improve workability. Additionally, the set accelerator and set retarder were incorporated into the corresponding mixtures at dosages of 1.0% and 0.75% by binder mass, respectively.

Concrete mixtures were prepared using a pan mixer operating at a rotational speed of 30 rpm. Initially, the binder materials and aggregates were dry-mixed for approximately 60 s. Water was then added, and mixing continued for another 120 s. Finally, the chemical admixtures were incorporated, followed by an additional 120 s of mixing to obtain a homogeneous concrete mixture. The main stages of concrete production are illustrated in Figure 3.



Figure 3. Stages of concrete mixing and production

Following mixing, the fresh concrete was placed into 100 × 100 × 100 mm cubic molds and compacted by vibration. The specimens were kept in their molds for 24 h under conditions designed to prevent moisture loss and disturbance, in accordance with TS EN 12390-2. After demolding, the specimens were divided into two groups and subjected to different curing regimes: water curing and air curing. For water curing, the specimens were fully immersed in a water tank maintained at a temperature of 20 ± 2 °C, in accordance with the standard curing requirements specified in TS EN 12390-2. In contrast, the air-cured specimens were stored under laboratory ambient conditions at a temperature of 20 ± 2 °C and a relative

humidity of 25–30%. Both curing regimes were maintained until the designated testing ages of 7, 28, and 56 days.

Test Procedure

Compressive strength tests were conducted on 100 × 100 × 100 mm cubic concrete specimens at 7, 28, and 56 days in accordance with TS EN 12390-3. The load was applied continuously at a constant stress rate of 0.6 ± 0.2 MPa/s, as specified in the standard. Prior to testing, the water-cured specimens were removed from the curing tank, and excess surface water was removed by wiping, whereas the air-cured specimens were tested directly without any additional treatment. For each mixture, curing condition, and testing age, three specimens were tested, and the arithmetic mean of their compressive strength values was calculated and reported as the representative compressive strength. The compressive strength testing procedure is illustrated in Figure 4.



Figure 4. Compressive strength test of concrete specimens

RESULTS AND DISCUSSION

Effect of Curing Conditions and Mineral Admixtures on Compressive Strength Development

The experimental results illustrating the effects of air and water curing on the compressive strength of different concrete mixtures are presented in Figure 5. For the control mixture, which contained neither blast furnace slag nor fly ash, strength development under air curing was limited. This behavior may be attributed to moisture loss, which restricts continued cement hydration. The compressive strength increased by only 3.32% between 7 and 28 days under air curing. At 56 days, the strength decreased by 5.52% relative to the 28-day value. This reduction may be associated with the effects of drying shrinkage resulting from moisture loss in the concrete specimens (de Sa et al. 2008).

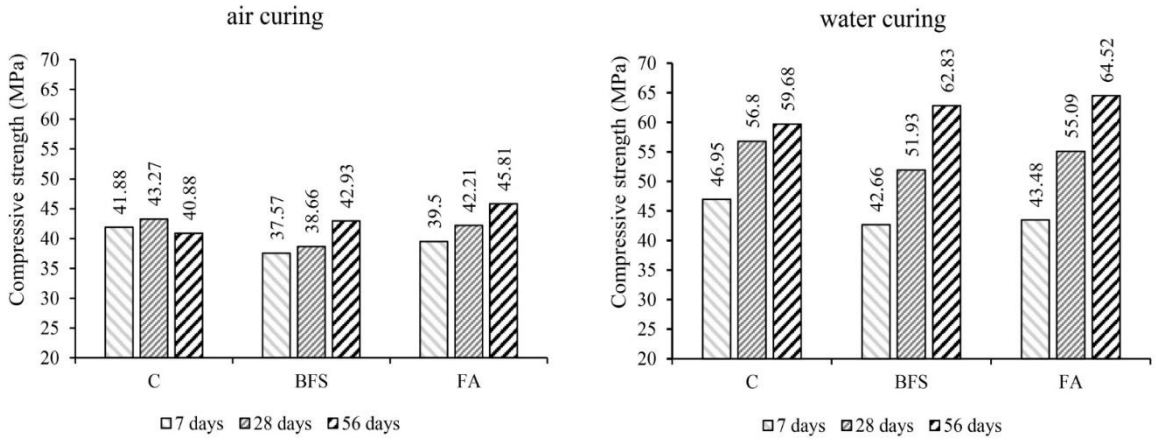
The water-cured control specimens exhibited higher compressive strengths than the air-cured specimens at all testing ages. Water curing supported strength development by maintaining the moisture required for continued hydration. At 7 days, the compressive strength of the water-cured control specimens was 12.11% higher than that of the air-cured specimens of the same age. Relative to the 7-day strength, the 28- and 56-day strengths under water curing increased by 20.98% and 27.11%, respectively. Thus, while strength development remained limited under air curing, it continued up to 56 days under water curing. These results highlight the importance of water curing in sustaining cement hydration and promoting the development of hydration products that contribute to strength (Yıldırım 2026).

Under air curing, both the BFS and FA mixtures exhibited lower compressive strengths than the control mixture at 7 and 28 days. At 7 days, the strengths of the BFS and FA specimens were 11.01% and 5.68% lower than that of the control specimens, respectively. The lower early-age strength of the BFS mixture may be associated with the slower development of the strength contribution from slag (Yang et al. 2020).

The contribution of fly ash may be related to the progressive development of its pozzolanic reactions with portlandite produced during cement hydration (Yıldırım et al. 2023; Golewski 2018).

Both mixtures containing mineral admixtures exhibited continued strength development up to 56 days. Relative to their respective 7-day strengths, the BFS mixture showed increases of 3.73% and 15.19% at 28 and 56 days, respectively, whereas the corresponding increases for the FA mixture were 6.86% and 15.97%. This later-age development is consistent with the increasing contribution of the latent hydraulic reactions of blast furnace slag and the pozzolanic reactions of fly ash over time (Yıldırım et al. 2025). At 56 days, the BFS and FA specimens exhibited compressive strengths 5.01% and 12.06% higher than that of the control specimens of the same age, respectively.

A comparison of the mixtures containing mineral admixtures under air curing showed that the FA mixture achieved higher compressive strengths than the BFS mixture at all testing ages. Using the BFS strengths as the reference, the FA strengths at 7, 28, and 56 days were 5.98%, 9.18%, and 6.71% higher, respectively. The relative difference between the two mixtures reached its maximum at 28 days and subsequently narrowed at 56 days. This narrowing was associated with strength increases of 11.05% for BFS and 8.53% for FA between 28 and 56 days. Therefore, under the air curing conditions investigated, FA exhibited a greater relative strength increase between 7 and 28 days, whereas BFS showed a greater relative increase between 28 and 56 days, reducing the strength difference between the two mixtures.



(a) (b)

Figure 5. Compressive strength of control, BFS, and FA mixtures after 7, 28, and 56 days of (a) air curing and (b) water curing.

Under water curing, the BFS and FA specimens exhibited lower compressive strengths than the control specimens at 7 and 28 days. At 7 days, the BFS and FA strengths were 9.14% and 7.39% lower than that of the control mixture, respectively; the corresponding differences at 28 days were 8.57% and 3.01%. This behavior may be associated with the time-dependent development of the latent hydraulic reactions of blast furnace slag and the pozzolanic reactions of fly ash, resulting in a more gradual contribution to strength (Yıldırım et al. 2025; Nedunuri et al. 2020).

Both mixtures containing mineral admixtures exhibited continued strength development with increasing curing duration. Relative to their respective 7-day strengths, the BFS mixture showed increases of 21.73% and 47.28% at 28 and 56 days, respectively, while the corresponding increases for the FA mixture were 26.70% and 48.39%. This development under water-curing may be attributed to the availability of moisture required for continued cement hydration and mineral admixture reactions. In particular, the strength development of the FA mixture is consistent with the findings of Ozer and Ozkul (2004) concerning the importance of curing conditions for mixtures containing pozzolanic binders. Marcos Ortega et al. (2017) also demonstrated that moisture conditions influence the microstructural development associated with hydration and pozzolanic reactions in fly ash cement mortars, supporting this interpretation. At 56 days, the compressive strengths of the BFS and FA mixtures reached 62.83 and 64.52 MPa, respectively, exceeding the control strength by 5.28% and 8.11%. Thus, the strength

differences observed at early ages shifted in favor of the mixtures containing mineral admixtures by 56 days.

A comparison of the BFS and FA mixtures under water curing showed that FA achieved higher compressive strengths at all testing ages. Using the BFS strengths as the reference, the FA strengths at 7, 28, and 56 days were 1.92%, 6.09%, and 2.69% higher, respectively. The narrowing of the relative difference after 28 days was associated with the greater relative strength gain of the BFS mixture during this period. Specifically, between 28 and 56 days, the compressive strength increased by 20.99% for BFS and 17.12% for FA. Accordingly, although the FA mixture maintained higher compressive strengths, the BFS mixture exhibited a greater relative strength increase between 28 and 56 days.

Effect of Chemical Admixtures on Compressive Strength under Water and Air Curing

Figure 6 presents the compressive strengths of the air-cured mixtures. At 7 days, the ACC increased strength by 10.9%, 8.1%, and 7.2% in the C, BFS, and FA systems, respectively, compared with the corresponding mixtures without chemical admixtures. In contrast, the RET reduced the respective strengths by 12.3%, 10.5%, and 13.6%. Thus, the two admixtures produced opposing early-age responses across all three binder systems.

The relative effects reversed at later ages. At 28 days, ACC mixtures were 7.7–9.7% weaker than their corresponding references, whereas RET mixtures were 5.9–11.4% stronger. This contrast persisted at 56 days: ACC produced relative strength reductions of 5.1–7.7%, while RET produced increases of 4.2–8.9%.

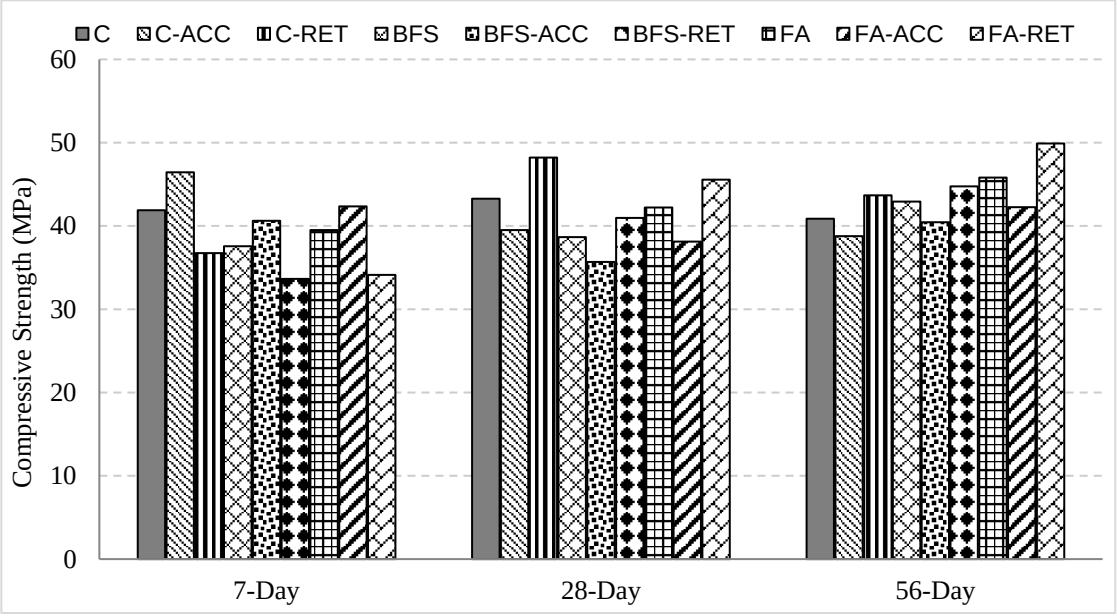


Figure 6. Compressive strength of air-cured concrete mixtures incorporating mineral and chemical admixtures at 7, 28, and 56 days

Figure 7 shows similar early-to-later-age reversals under water curing, although the absolute strength levels were higher than those of the corresponding air-cured mixtures at every test age. At 7 days, ACC increased the strengths of C, BFS, and FA by 7.8%, 5.3%, and 6.8%, respectively, with C-ACC reaching 50.63 MPa. At 28 days, however, ACC reduced strength by 6.7–8.0%, and at 56 days the reductions were 12.0%, 11.0%, and 8.9% for C-ACC, BFS-ACC, and FA-ACC, respectively. The limited increase in C-ACC strength from 52.30 MPa at 28 days to 52.49 MPa at 56 days contrasts with the increase from 56.80 to 59.68 MPa in the corresponding C reference.

RET again reduced early-age strength, by 8.6%, 9.6%, and 6.5% in the C, BFS, and FA systems at 7 days. By 28 days, these differences had become positive (2.7%, 7.0%, and 10.0%, respectively), and the corresponding advantages at 56 days were 4.6%, 4.1%, and 6.1%. FA-RET reached 68.48 MPa at 56 days, the highest compressive strength among the water-cured mixtures. The reversal indicates that the initial strength penalty associated with RET did not persist under continued water curing; it does not, by itself, identify the responsible hydration reactions.

Binder composition also influenced later-age development. Between 28 and 56 days, the water-cured BFS and FA reference mixtures gained 21.0% and 17.1% in strength, respectively, compared with 5.1% for the C reference. This pattern is consistent with the potential later-age contribution of SCMs described by Lothenbach et al. (2011), although compressive strength measurements alone cannot quantify the degrees of slag or fly ash reaction.

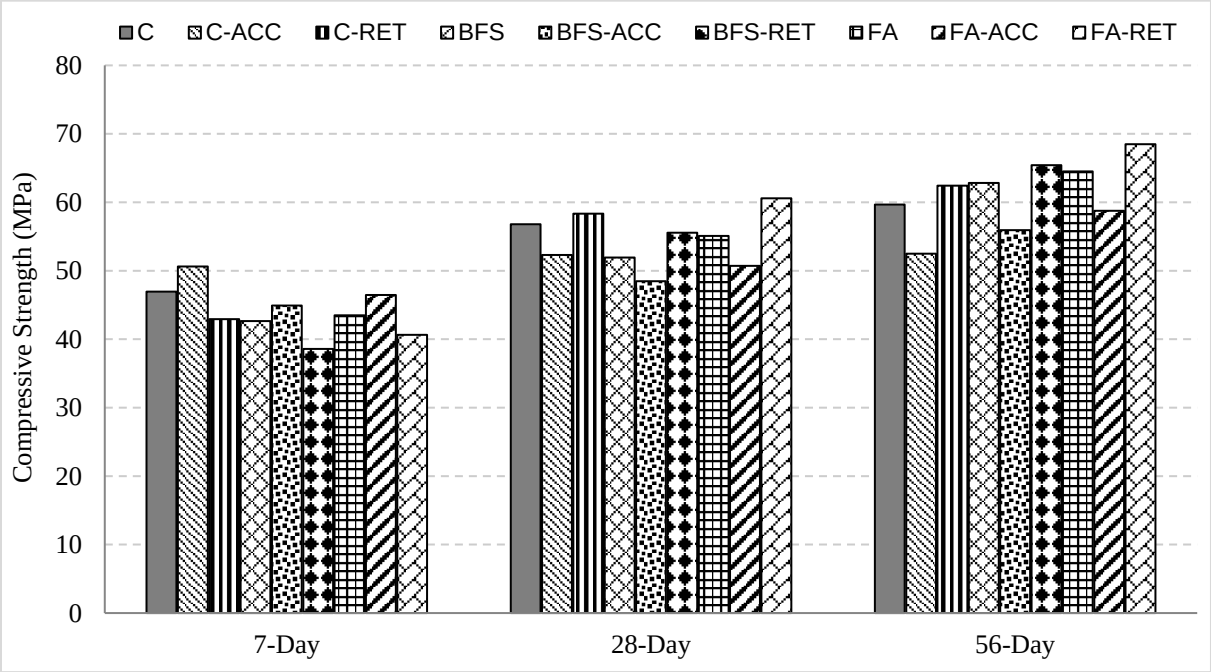


Figure 7. Compressive strength of water-cured concrete mixtures incorporating mineral and chemical admixtures at 7, 28, and 56 days

Figure 8 summarizes the admixture effects as percentage changes relative to the corresponding mixture with the same binder, curing condition, and test age but without an accelerator or retarder. All mixtures, including the references, contained the same dosage of polycarboxylate ether-based superplasticizer. At 7 days, ACC provided a larger relative strength increase under air curing than under water curing for each binder (7.2–10.9% versus 5.3–7.8%). Conversely, the early-age RET penalty was greater under air curing (10.5–13.6%) than under water curing (6.5–9.6%).

At 28 days, ACC had a negative relative effect for every binder under both curing conditions, while RET had a positive effect. Between 28 and 56 days, the relative ACC deficit became smaller under air curing but larger under water curing. By 56 days, the ACC reductions for C, BFS, and FA were 5.1%, 5.8%, and 7.7% under air curing, compared with 12.0%, 11.0%, and 8.9% under water curing. The corresponding RET gains ranged from 4.2% to 8.9% under air curing and from 4.1% to 6.1% under water curing.

The 7-day strength gains obtained with ACC are consistent with the early hydration response expected from a calcium nitrate-based accelerator. Dorn et al. (2023) specifically investigated calcium nitrate in Portland cement and reported an earlier onset of alite hydration and earlier development of hydration products. In a study involving both plain and blended cement systems, Oey et al. (2015) examined the effects of calcium nitrate on reaction, setting, and strength evolution, demonstrating the importance of binder composition when evaluating accelerator performance. The general review by Dorn et al. (2022) further emphasizes that accelerator effects depend on chemistry and dosage. These findings provide a more directly relevant basis for the early strength improvements than mechanisms reported for aluminium sulfate-based accelerators.

For RET, the early strength reductions are consistent with the retardation of silicate hydration by lignosulfonate-based admixtures. Bishop and Barron (2006) demonstrated that lignosulfonate can inhibit tricalcium silicate (C3S) hydration while affecting aluminate reactions differently; in their experiments, ettringite formation was not uniformly suppressed. This distinction shows that lignosulfonate does not

simply delay all cement reactions to the same extent. Young (1972) reviewed adsorption-related mechanisms of set retardation by organic admixtures, while Colombo et al. (2017) experimentally demonstrated that the setting and hydration response to calcium lignosulfonate depends on cement characteristics and admixture addition conditions. The higher strengths of the RET mixtures relative to their references at 28 and 56 days indicate that the initial strength disadvantage was subsequently overcome.

The response may also depend on interactions among the lignosulfonate retarder, the polycarboxylate ether-based superplasticizer present in every mixture, and the different binder systems. Ng and Justnes (2016) showed that the effects of lignosulfonate and polycarboxylate-based plasticizers on hydration and fresh properties vary in fly ash-blended cements; however, this does not establish the occurrence of a specific interaction in the present mixtures. Moisture availability offers an additional context for the curing-dependent results, as declining internal relative humidity can inhibit alite hydration (Flatt et al. 2011).

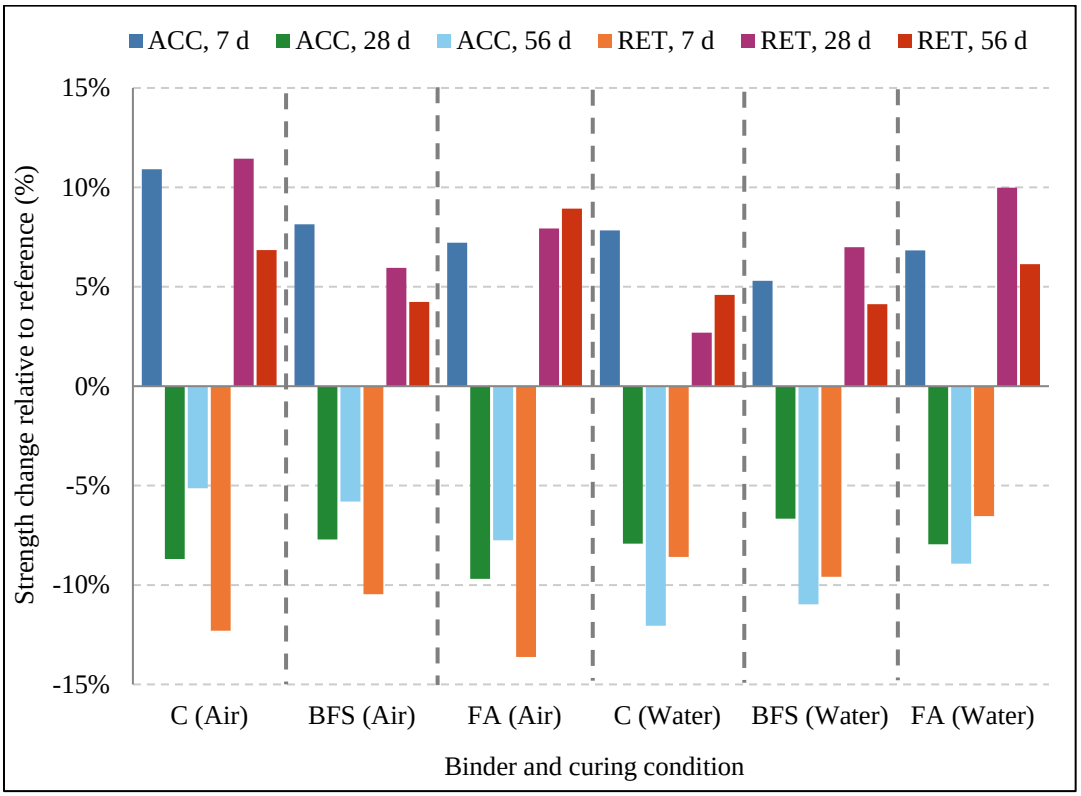


Figure 8. Relative changes in compressive strength due to accelerating and retarding admixtures under air and water curing at 7, 28, and 56 days

CONCLUSIONS

This study investigated the combined effects of curing conditions, mineral admixtures, and set-modifying chemical admixtures on the compressive strength development of concrete. Based on the experimental findings, the following conclusions can be drawn:

- Water curing consistently resulted in higher compressive strength than air curing across all concrete mixtures, regardless of binder composition or chemical admixture type. This highlights the critical role of adequate moisture availability in promoting strength development, particularly at later curing ages.
- Replacing 10% of cement with blast furnace slag or fly ash reduced strength relative to C at 7 and 28 days under both curing regimes, but the trend reversed at 56 days. Under water curing, BFS and FA reached 62.83 and 64.52 MPa, respectively, exceeding C (59.68 MPa).

- Relative to the corresponding references, ACC increased 7-day strength by 5.3–10.9%, whereas RET reduced it by 6.5–13.6%. At 28 and 56 days, ACC lowered strength and RET increased it in every binder system under both curing conditions
- Curing conditions also modified the relative admixture effects. At 7 days, ACC gains and RET losses were greater under air curing, whereas the relative ACC strength deficits at 56 days were greater under water curing, despite its higher absolute strengths.

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