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Effects of Superplasticizers, Retarders, and Workability Retention Admixtures on the Fresh and Hardened Properties of Concrete

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Abstract Currently, maintaining the quality of ready-mix concrete during long-distance transportation is challenging, as climatic variations affect its properties. To address this issue, the use of next-generation admixtures is proposed to enhance both the physical and mechanical properties of concrete in its fresh and hardened states, employing superplasticizers (S), retarders (R), and workability-retaining agents (M). Among the tested mixtures, D0.54%S0.48%R1.01%M exhibited the best performance by maintaining its consistency for up to 7 hours and extending workability by an additional 6 hours compared to the reference sample. Furthermore, with the use of R and M admixtures, this sample achieved a final setting time of 13 hours and 21 minutes—a 331% increase relative to the reference—and demonstrated one of the highest compressive strengths, reaching 45.39 MPa after 28 days. The unit weight and yield results indicate that the concrete falls within the normal-weight category, although these values may vary with atmospheric conditions. In conclusion, next-generation admixtures effectively preserved consistency and extended setting time during prolonged transportation, while significantly enhancing compressive strength at 3, 7, and 28 days.

Keywords Fresh Concrete, Retarder, Plasticizer, Slump Loss, Compressive Strength

1. Introduction

In peripheral urban areas, access to modern construction technologies, such as ready-mix concrete, is often limited due to distance constraints. This limitation affects the quality of fresh concrete and poses challenges for its transportation and placement [1], [2]. Superplasticizers were first introduced in the 1960s as high-range water reducers, initially added on-site to improve the workability of concrete already containing lignosulfonate-based water reducers. Their use facilitated concrete placement without increasing segregation or compromising strength [3]. Meyer [4] demonstrated that superplasticizers could be used to regulate concrete consistency, enhance flowability, and produce high-quality concrete with a low water-cement ratio. His work established practical guidelines for raw material selection, admixture dosing, and performance testing, along with German standards for the application of superplasticizers in concrete. Brooks [5] investigated the influence of supplementary cementitious materials, including silica fume (SF), metakaolin (MK), fly ash (FA), and ground granulated blast-furnace slag (GGBS), on the setting time of high-strength concrete. The study found that replacing a portion of cement with mineral admixtures generally delayed setting times, with GGBS exhibiting the most pronounced effect at replacement levels of 40% or higher. In contrast, the delay observed for MK was significant only up to a replacement level of 10%.

Anon [6] explored the environmental benefits of properly applied chemical admixtures in construction materials, highlighting their role in energy efficiency and groundwater protection. The study also reviewed raw materials used in plasticizers and superplasticizers, as well as other admixtures such as waterproofing agents and stabilizers. Another study by Dong et al. [7] examined the application of hot-mix asphalt modifiers to reduce paving and compaction temperatures in tunnels and other specialized environments. Their findings indicated that these modifiers do not adversely affect the combustion performance of asphalt. Building on these findings, there is an urgent need to employ chemical admixtures to mitigate the mechanical deficiencies of both fresh and hardened concrete [8]. The absence of admixtures compromises concrete consistency, affecting its workability and proper application on-site, particularly in rural areas where ready-mix concrete plants are not always available, or where long waiting times are common. This study focuses on evaluating the impact of advanced admixtures on the properties of ready-mix concrete in both fresh and hardened states. The experimental design included both control and experimental groups with different concrete mix designs, following standards such as NTP 339.035 [9] and ASTM C143 [10] for consistency, NTP 339.082 [11] and ASTM C403 [12] for setting time, and NTP 339.034 [13] and ASTM C39 [14] for compressive strength. The selection of materials and admixtures was carefully considered, including superplasticizers (S), retarders (R), and workability-retaining admixtures (M). The methodology involves preliminary testing to optimize admixture dosages and ensure the quality of mix designs, with all tests conducted in specialized laboratories.

2. Materials and Methods

The materials used in this research were sourced from the Jun ń region, located at approximately 3,350 meters above sea level. Their evaluation was conducted following the Peruvian Technical Standard (NTP) and ASTM standards. Accordingly, sample collection and aggregate characterization were carried out, along with control tests on both fresh and hardened concrete. The study also adhered to regulations governing the processes and parameters of ready-mix concrete and curing, ensuring strict laboratory control in accordance with NTP 400.010 [15], NTP 400.043 [16], NTP 400.022 [17] and NTP 400.012 [18]. Additionally, for a clearer description of the samples, nomenclatures were assigned as presented in Table 1.

Table 1. Admixture Combinations and Dosages

Mix design			
Reference sample (REF)			
Sample ID	**Master Rheobuild 1003 (Superplasticizer)**	**Master Set 770R (Set Retarder)**	**Master Sure Z60 (Workability Retainer)**
D0.54%S	0.54%	-	-
D0.54%S0.30%R	0.54%	0.30%	-
D0.54%S0.39%R	0.54%	0.39%	-
D0.54%S0.48%R	0.54%	0.48%	-
D0.54%S0.30%R0.41%M	0.54%	0.30%	0.41%
D0.54%S0.39%R0.41%M	0.54%	0.39%	0.41%
D0.54%S0.48%R0.41%M	0.54%	0.48%	0.41%
D0.54%S0.30%R0.71%M	0.54%	0.30%	0.71%
D0.54%S0.39%R0.71%M	0.54%	0.39%	0.71%
D0.54%S0.48%R0.71%M	0.54%	0.48%	0.71%
D0.54%S0.30%R1.01%M	0.54%	0.30%	1.01%
D0.54%S0.39%R1.01%M	0.54%	0.39%	1.01%
D0.54%S0.48%R1.01%M	0.54%	0.48%	1.01%

2.1. Coarse and Fine Aggregates

For coarse aggregate, crushed stone with a nominal size of ¾" was used, sourced from the district of Orcotuna in the province of Concepción, Junín region. The UTM coordinates of the site are 468042E and 1325010.3N, at an altitude of 3,304 meters above sea level. The particle size distribution complies with the specifications presented in Table 2.

Table 2. Gradation Analysis of Coarse Aggregate

Sieve Size	Weight Retained (g)	% Retained	% Cumulative Retained	% Cumulative Passing
2”	0.0	0.0	0.0	100
1½”	0.0	0.0	0.0	100
1”	0.0	0.0	0.0	100
¾”	85.3	4.0	4.0	96.0
½”	957.0	45.0	49.0	51.0
3/8”	426.3	20.1	69.0	30.9
#4	599.7	28.2	97.3	2.7
#8	52.5	2.5	99.8	0.2
#16	0.7	0.0	99.8	0.2
#30	0.6	0.0	99.8	0.2
#50	0.5	0.0	99.9	0.1
#100	0.7	0.0	99.9	0.1
Pan	2.1	0.1	100.0	0.0

The specific gravity and absorption, as shown in Table 3, were determined by drying the sample at a temperature of 110 ℃ ± 5 ℃. The sample was then allowed to cool in a well-ventilated area for 1 to 3 hours for test samples larger than 1½”, until the aggregate reached approximately 50 ℃. Immediately after, the aggregate was immersed in water for a period of 24 ± 4 hours [19].

Table 3. Specific Gravity and Absorption of Coarse Aggregate

Property	Value
Bulk Specific Gravity (Kg/cm³)	2.61
Saturated Surface-Dry (SSD) Specific Gravity (Kg/cm³)	2.64
Apparent Specific Gravity (Kg/cm³)	2.70
Water Absorption (%)	1.15

For fine aggregate, river sand sourced from Mito, located in the province of Concepción, Junín region, on the right bank of the Mantaro River, was used. The UTM coordinates of the site are 464042.6E and 1318579.7N, at an altitude of 3,286 meters above sea level. The specific gravity and absorption were determined by placing a 500-gram sample of prepared material into a flask, which was then filled with water up to approximately the 500 cm³ mark at a temperature of 23 ± 2 ℃. After one hour, additional water was added to reach exactly 500 cm³, and the total weight of the introduced water was measured with an accuracy of 0.1 g. The fine aggregate was then removed from the flask, dried to a constant weight at 110 ±5 ℃, and cooled to room temperature in a desiccator for 30 minutes [17]. The specific gravity and absorption values obtained are shown in Table 4. The fine and coarse aggregates are presented in Figure 1.

Table 4. Specific Gravity and Absorption of Fine Aggregate

Property	Value
Bulk Specific Gravity (Kg/cm³)	2.6
Saturated Surface-Dry (SSD) Specific Gravity (Kg/cm³)	2.63
Apparent Specific Gravity (Kg/cm³)	2.67
Water Absorption (%)	1.01

Figure 1. Fine and coarse aggregates used in the mix design

2.2. Cement

Portland Andino Type I cement was used, selected for its high demand in Huancayo and its suitable properties for general-purpose construction without restrictions. Portland cement is a readily available product in the market, sold in bags with a net weight of 42.5 kg and a volume capacity of one cubic foot. When mixed with water—either alone or with sand, stone, or similar materials—it undergoes a slow chemical reaction, eventually hardening into a solid mass. Essentially, it is a finely ground clinker produced by heating specific mixtures of lime, alumina, iron, and silica at high temperatures. Table 5 presents the main components, which constitute 90% of the cement composition [20].

Table 5. Principal Cement Compounds

Name	Abbreviation
Tricalcium Silicate ($3CaO \cdot SiO_2$)	C3S
Dicalcium Silicate ($2CaO \cdot SiO_2$)	C2S
Tricalcium Aluminate ($3CaO \cdot Al_2O_3$)	C3A
Tetracalcium Aluminoferrite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$)	C4AF

2.3. Next-Generation Admixtures

These admixtures are formulated using advanced raw materials such as polycarboxylates, microsilica, polymers, and chemical catalysts. They play a crucial role in enhancing the performance of concrete and mortar, particularly in response to the demands of placement processes, volumetric stability, durability, high strength, and the efficiency of cementitious materials due to water reduction [21]. Furthermore, the use of admixtures containing geopolymers and polycarboxylates, high-impact superplasticizers according to the Argos timeline [22] (Figure 2), has become increasingly prevalent since the 20th century. Due to their composition, sustainability, and the benefits they provide to concrete as previously indicated, the following specific admixtures were selected for this study: MasterRheobuild 1003 (superplasticizer), Master Set 770R (retarder), and MasterSure Z 60 (workability-retaining agent). The process used to determine the admixture dosage is shown in Figure 3.

2.3.1. Superplasticizer Admixture

MasterRheobuild 1003 is a high-range water-reducing admixture designed to produce rheoplastic concrete. This type of concrete flows easily while maintaining high plasticity for longer periods compared to conventional superplasticized concrete. It reduces the water content required in the mix by 12% or more while maintaining a specific concrete consistency [23], and can achieve a slump ranging from 200 to 280 mm (8 to 11 inches) when needed. While commercial technical sheets often detail application methods, physical properties, and precautions, they may not always specify the exact chemical properties. However, common chemical components found in superplasticizer admixtures typically fall within the ranges indicated in Table 6 [24]. The recommended dosage for MasterRheobuild 1003 is 650 to 1600 mL per 100 kg (10 to 25 fluid ounces per 100 pounds) of cementitious material.

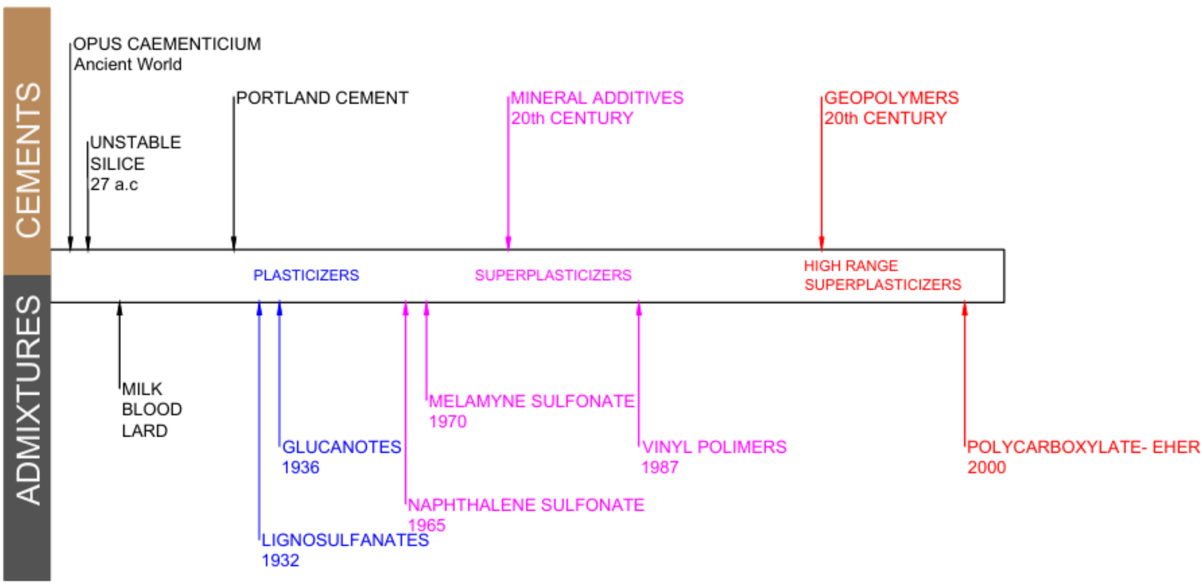

Figure 2. Timeline of key developments in cements and concrete admixtures

Figure 3. Steps in the admixture dosage determination process: (a) initial solution, (b) dilution, and (c) weighing

Table 6. Common Chemical Components in Superplasticizer Admixtures

Component	Approximate Percentage
Lignosulfonates	30–60%
Organic Acids	5–15%
Carbohydrates	5–10%
Water	20–40%
Others (emulsifiers, stabilizers)	5–10%

2.3.2. Retarding Admixture

Master Set R770 is described as an initial retarding, mid-range water-reducing, multi-component, and chloride-free admixture. Concrete mixed with this admixture achieves a water reduction of 5% to 15% and can exhibit a slump ranging from 15 to 115 mm. It effectively extends the setting time, with the degree of extension dependent on the dosage used. Similar to other commercial admixtures, manufacturer technical sheets typically indicate the mode of use, physical components, and precautions; however, information on the specific chemical composition is often unavailable. Nevertheless, retarding admixtures usually contain components like those shown in Table 7 [25].

Table 7. Common Chemical Properties in Retarding Admixtures

Component	Approximate Percentage
Calcium Lignosulfonate	20–40%
Citric or Tartaric Acid	1–5%
Modified Sugar	0.5–2%
Water	As solvent

The recommended dosage for Set R770 is 400 to 560 mL per 100 kg of cementitious material, particularly for concrete mixtures in hot climates. Caution is advised if temperatures fall below 15 ℃, as both the initial and final setting times may be significantly extended, requiring additional precautions to protect the concrete.

2.3.3. Workability-Retaining Admixture

MasterSure Z 60 is a workability-retaining admixture that provides flexible degrees of slump retention without retardation. Generally, these types of admixtures enhance one or more desirable properties of concrete without reducing water content, altering setting time, or negatively affecting the fresh or hardened properties, as specified by NTP regulations. Admixtures primarily used for dry-cast concrete production are excluded from this category [23]. While the exact composition may vary, typical components found in workability-retaining admixtures are detailed in Table 8 [25]. MasterSure Z 60, the specific product used in this study, is available in 208-liter (55-gallon) drums, 1040-liter (275-gallon) tanks, and bulk formats. It should be stored at temperatures above 5 ℃ (40 ℉). The recommended dosage ranges from 195 to 780 mL per 100 kg (3 to 12 fluid ounces per 100 pounds) of cementitious material.

Table 8. Common Chemical Properties in Workability-Retaining Admixtures

Component	Percentage by Weight
Polycarboxylate Polymer	10 – 30%
Cellulose Ethers	0.5 – 2%
Citric Acid	0.1 – 1.0%
Modified Sugars	0.1 – 0.5%
Sodium / Potassium Silicate	0 – 1%
Surfactants (non-ionic, anionic)	0.1 – 0.5%
Deionized Water	65 – 85%

2.4. Specimen Preparation Procedure

The investigation was conducted in the central region of Peru, specifically in the Mantaro Valley near Huancayo. This area features a temperate, dry, and cold climate. Notably, during the months of June and August, there is an increased incidence of frost, making the control of entrapped air within the concrete crucial due to potential volumetric changes. Furthermore, the location is not directly exposed to severe weathering or sulfate attacks based on the prevailing climatic factors. These conditions guided the selection of the water-cementitious material ratio for the mix design.

Considering the intended use of the concrete in slabs, columns, and structural plates, which require guaranteed transportability and placement over extended periods, a plastic consistency requirement (slump) between 3” and 4” was defined based on Table 9, which shows the workability for various structural elements for its application in the mix design. Accordingly, a series of specimens were prepared as detailed in Table 10.

Table 9. Recommended Slump Ranges for Various Structural Elements

Structural Element	Maximum Slump	Minimum Slump
Footings and reinforced retaining walls	3”	1”
Simple foundations and underpinning	3”	1”
Beams and reinforced walls	4”	1”
Columns	4”	2”
Slabs and pavements	3”	1”
Cyclopean Concrete	2”	1”

Table 10. Number of Specimens

Specimen Type	**Number of Specimens**
Slump test for slump loss	140
Setting time determination	47
4" x 8" cylinders for compressive strength (27.46 MPa)	139
TOTAL	326

Table 11. Reference Mix Design (Without Admixtures)

Material	Specific Gravity (kg/m^3)	Dry Weight (kg/m^3)	Volume (m^3)	Saturated Surface-Dry (SSD) Weight (kg/m^3)	Adjusted Weight (kg/m^3)
Cement	3150	329.12	0.104	329	329
Sand	1000	187	0.187	206	206
Water	2600	1030.20	0.396	1030	1030
Stone	2610	748.87	0.287	749	749
Air	-	2.00	0.020	-	-
Total	-	-	1.000	-	2320

Table 12. Admixture Dosages for Mix Designs per $1m^3$

Admixture Combination	Specific Gravity (kg/m^3)	Volume (m^3)	Dry Design per $1m^3$ (kg)	Corrected Design per $1m^3$ (kg)	
D0.54%S	YD = 1210	VD = 0.002	DD = 2.07	DD` = 2.1	Kg
D0.54%S0.3%R	YD = 1210 YS = 1120	VD = 0.002 VS = 0.001	DD = 2.07 DS = 0.995	DD` = 2.1 DS` = 1.0	Kg
D0.54%S0.39%R		VD = 0.002 VS = 0.001	DD = 2.07 DS = 1.29	DD` = 2.1 DS` = 1.3	Kg
D0.54%S0.48%R		VD = 0.002 VS = 0.001	DD = 2.07 DS = 1.584	DD` = 2.1 DS` = 1.6	Kg
D0.54%S0.30%R0.41%M	YD = 1210 YS = 1120 YR = 1040	VD = 0.002 VS = 0.001 VR = 0.001	DD = 2.07 DS = 0.995 DR = 1.33	DD` = 2.1 DS` = 1.0 DR` = 1.3	Kg
D0.54%S0.30%R0.71%M		VD = 0.002 VS = 0.001 VR = 0.002	DD = 2.07 DS = 0.995 DR = 2.33	DD` = 2.1 DS` = 1.0 DR` = 2.3	Kg
D0.54%S0.30%R1.01%M		VD = 0.002 VS = 0.001 VR = 0.003	DD = 2.07 DS = 0.995 DR = 3.32	DD` = 2.1 DS` = 1.0 DR` = 3.3	Kg
D0.54%S0.39%R0.41%M		VD = 0.002 VS = 0.001 VR = 0.001	DD = 2.07 DS = 1.29 DR = 1.334	DD` = 2.1 DS` = 1.3 DR` = 1.3	Kg
D0.54%S0.39%R0.71%M		VD = 0.002 VS = 0.001 VR = 0.002	DD = 2.07 DS = 1.29 DR = 2.327	DD` = 2.1 DS` = 1.3 DR` = 2.3	Kg
D0.54%S0.39%R1.01%M		VD = 0.002 VS = 0.001 VR = 0.003	DD = 2.07 DS = 1.29 DR = 3.32	DD` = 2.1 DS` = 1.3 DR` = 3.3	Kg
D0.54%S0.48%R0.41%M		VD = 0.002 VS = 0.001 VR = 0.001	DD = 2.07 DS = 1.584 DR = 1.33	DD` = 2.1 DS` = 1.6 DR` = 1.3	Kg
D0.54%S0.48%R0.71%M		VD = 0.002 VS = 0.001 VR = 0.002	DD = 2.07 DS = 1.584 DR = 2.33	DD` = 2.1 DS` = 1.6 DR` = 2.3	Kg
D0.54%S0.48%R1.01%M		VD = 0.002 VS = 0.001 VR = 0.003	DD = 2.07 DS = 1.584 DR = 3.319	DD` = 2.1 DS` = 1.6 DR` = 3.3	Kg

The mix designs were based on the Fuller method, targeting a design compressive strength (f'c) of 28 MPa for all samples. A total of 14 mix designs were developed, all maintaining a water-cementitious material (w/cm) ratio of 0.57. The primary mix design without any admixtures is detailed in Table 11. One design served as a control concrete using only the superplasticizer (MasterRheobuild 1003) at a dosage of 0.54%. Subsequently, designs incorporating varying dosages of the retarding admixture (Master Set R770) and the workability-retaining admixture (MasterSure Z 60) were prepared. The dosages considered for Master Set R770 were 0.30%, 0.39%, and 0.48%. For MasterSure Z 60, the dosages were 0.41%, 0.71%, and 1.01%. The final 12 mix designs involved combinations of 2 or 3 admixtures, as detailed in Table 12.

2.5. Fresh Concrete Testing

2.5.1. Consistency

To measure the consistency of the mix, the slump test was performed using the Abrams cone. The cone is kept stationary after lifting, and 25 strokes are applied to each layer with a smooth steel tamping rod of 600 mm in length and 16 mm in diameter [26]. Then, the distance between the original height of the cone and the average height of the settled concrete is measured, as shown in Figure 4.

Figure 4. Slump Measurement

2.5.2. Setting Time

The setting time test was measured by considering penetration resistance over time using the Vicat needle, as shown in Figure 5. Chemical processes influenced by environmental factors, mix temperature, and ingredients were also considered [27].

Figure 5. Setting Time Determination using the Vicat Needle

2.5.3. Complementary Tests

The unit weight test helped establish the density of the concrete. This test is closely related to the concrete yield, due to the similar procedure it presents. Thus, the yield test shows the volume of fresh concrete produced by the inputs included in the mixture. For the procedure of the unit weight and yield test, NTP 339.046 [28] and ASTM C138 [29] were considered, respectively.

2.6. Hardened Concrete Testing

2.6.1. Compressive Strength

Starting from taking fresh samples and performing the respective curing, as shown in Figure 6a, according to NTP 339.183 [30] and under laboratory conditions to perform the compressive strength test as shown in Figure 6b, which refers to the application of a load on the cylinder to be tested, this process was performed at a specified rate according to the size of the cylinder. The parameters and processes were based on NTP 339.034 [31] and ASTM C39 [32].

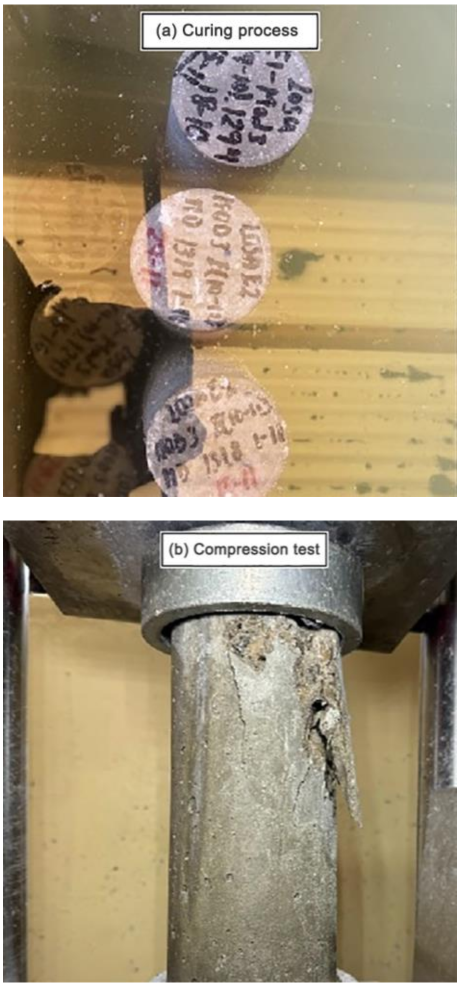

Figure 6. Curing Process and Compression Test

3. Results

3.1. Consistency

As observed in Table 13, the reference sample loses its consistency rapidly within 1 hour, with a final slump of 5.08 cm. In contrast, the D0.54%S0.48%R sample, which contains the highest dosage of retarding admixture, maintains its workability for a longer time, reaching a final slump of 5.72 cm after 2 hours and 30 minutes compared to the final slump of the reference sample. Likewise, the D0.54%S0.39%R and D0.54%S0.39%R samples show a more gradual reduction in slump, with a final slump of 6.35 cm for both. The difference in these is of 2 hours with respect to the final slump of the reference sample. The D0.54%S sample, although without retarder, retains greater fluidity with a final slump of 6.99 cm, differentiating in 30 minutes from the final slump of the reference sample.

Based on the obtained results, the D0.54%S0.30%R1.01%M sample exhibited a final slump of 6.99 cm, with an extended time of 4 hours compared to the reference sample. The D0.54%S0.30%R0.71%M sample had a final slump of 6.35 cm, with a difference of 3 hours relative to the reference sample. Meanwhile, the D0.54%S0.30%R0.41%M sample, also with a final slump of 6.35 cm, extended the slump loss time by 2 hours and 30 minutes compared to the reference sample.

Furthermore, the D0.54%S0.48%R1.01%M sample, which considers the maximum dosage of both the retarder and the workability-retaining admixture, exhibited a final slump of 6.35 cm, with an extended slump loss time of 6 hours compared to the reference sample. Similarly, the D0.54%S0.48%R0.71%M sample followed a comparable trend. Finally, the D0.54%S0.48%R0.41%M sample had a final slump of 5.72 cm, with a prolonged slump loss time of 5 hours relative to the reference sample.

The classification of concrete consistency based on slump is divided into three categories:

- Dry: Slump between 0 and 5 cm
- Plastic: Slump between 5 and 12 cm
- Fluid: Slump greater than 12 cm

In this study, all final slump values for the tested samples fall within the Plastic consistency range, except for the reference sample, which has a Plastic consistency approaching the Dry category. Table 14 presents the initial slump values of the reference sample, the slump loss over time, and the percentage variation relative to different admixture dosages.

Figure 7 shows the variation in Initial Slump (cm) and the % Increase for different mix designs. The reference sample has the lowest slump, while the other designs with added admixtures reach between 20 and 23 cm. The percentage increase rises drastically to 240% compared to the reference sample and stabilizes in the other samples. This indicates a significant increase in workability by modifying the mix proportions. It is evident that, when compared to the reference sample, the other designs considerably improve workability, reflected in a higher Initial Slump. The percentage increase quickly reaches 240%, showing that the changes in the mix generate more fluid and uniform consistencies across all designs.

Table 15 presents the time at which the initial slump was lost for each mix design, as well as the percentage increase compared to the reference mix.

Figure 8 combines red bars, representing time in minutes, with a blue line and markers indicating the percentage variation relative to the reference sample. The initial time for the reference sample is 60 minutes, increasing to 180 minutes for samples such as D0.54%S0.3%R. The D0.54%S0.48%R1.01%M design exhibits the longest time, reaching 420 minutes, along with a 700% variation, indicating a significant increase in the observed behavior.

Table 13. Slump Loss over Time by Mix Design

Time	(min)	00:00	00:30	01:00	01:30	02:00	02:30	03:00	03:30	04:00	04:30	05:00	05:30	06:00	06:30	07:00
Slump (cm) by Mix Design	REF	9.53	6.99	5.08	-	-	-	-	-	-	-	-	-	-	-	-
	D0.54%S	17.15	10.16	7.62	6.99	-	-	-	-	-	-	-	-	-	-	-
	D0.54%S0.3%R	21.59	17.78	14.61	11.43	9.53	8.89	6.35	-	-	-	-	-	-	-	-
	D0.54%S0.39%R	21.59	19.05	14.61	12.7	10.8	9.53	6.35	-	-	-	-	-	-	-	-
	D0.54%S0.48%R	21.59	17.15	16.51	13.34	12.7	8.89	7.62	5.72	-	-	-	-	-	-	-
	D0.54%S0.30%R0.41%M	22.86	17.15	16.51	11.43	11.43	11.43	8.26	6.35	-	-	-	-	-	-	-
	D0.54%S0.30%R0.71%M	22.86	20.32	17.78	14.61	13.97	11.43	10.16	6.99	6.35	-	-	-	-	-	-
	D0.54%S0.30%R1.01%M	22.86	22.86	20.32	17.78	17.78	17.15	14.61	12.07	10.8	8.89	6.99	-	-	-	-
	D0.54%S0.39%R0.41%M	21.59	17.15	17.15	13.34	10.16	8.89	8.89	4.45	-	-	-	-	-	-	-
	D0.54%S0.39%R0.71%M	22.23	20.32	20.32	19.05	16.51	15.88	11.43	9.53	6.99	-	-	-	-	-	-
	D0.54%S0.39%R1.01%M	22.86	22.23	22.23	20.32	19.69	19.05	17.15	13.97	10.16	8.89	7.62	5.08	-	-	-
	D0.54%S0.48%R0.41%M	22.86	19.69	18.42	16.51	15.24	12.07	11.43	10.16	9.53	8.89	8.89	7.62	5.72	-	-
	D0.54%S0.48%R0.71%M	22.86	20.32	19.69	18.42	17.15	15.24	15.24	13.34	11.43	11.43	10.8	10.16	6.99	-	-
	D0.54%S0.48%R1.01%M	22.86	20.32	20.32	20.32	19.69	19.69	19.05	15.88	15.24	14.61	12.07	10.16	8.89	8.26	6.35

Table 14. Initial Slump Values and Percentage Increase over Reference

Mix Design	Initial Slump (cm)	% Increase vs. REF
REF	9.53	100%
D0.54%S	17.15	180%
D0.54%S0.3%R	21.59	227%
D0.54%S0.39%R	21.59	227%
D0.54%S0.48%R	21.59	227%
D0.54%S0.3%R0.41%M	22.86	240%
D0.54%S0.30%R0.71%M	22.86	240%
D0.54%S0.30%R1.01%M	22.86	240%
D0.54%S0.39%R0.41%M	21.59	227%
D0.54%S0.39%R0.71%M	22.23	233%
D0.54%S0.39%R1.01%M	22.86	240%
D0.54%S0.48%R0.41%M	22.86	240%
D0.54%S0.48%R0.71%M	22.86	240%
D0.54%S0.48%R1.01%M	22.86	240%

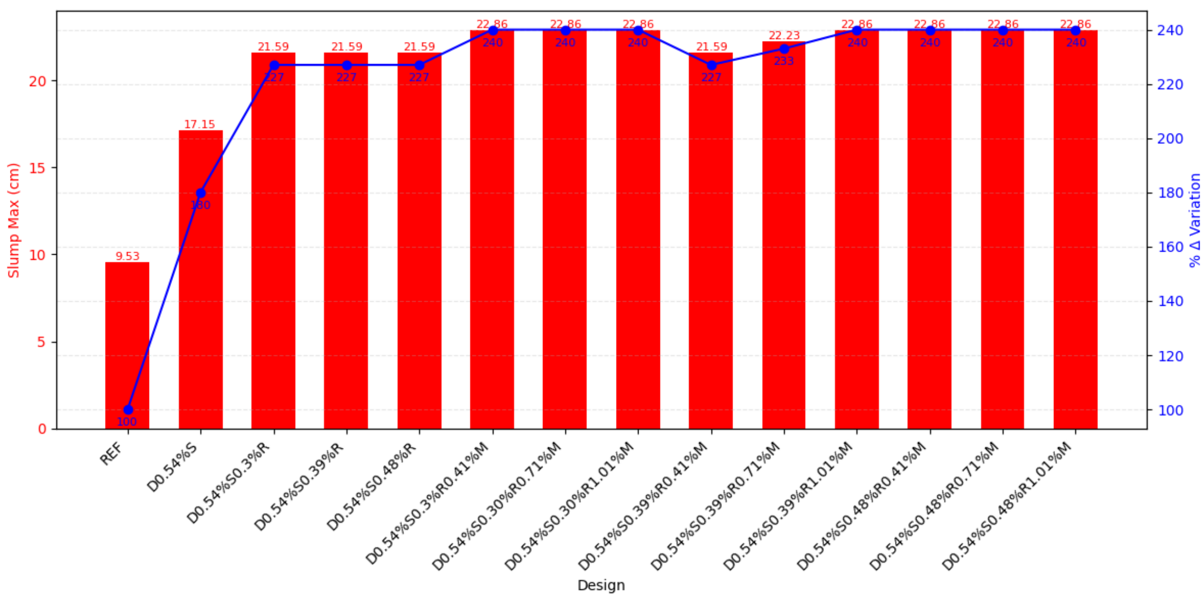

Figure 7. Initial Slump Values and Percentage Increase in Relation to Reference Mix

Table 15. Time to Slump Loss and Percentage Increase Compared to Reference Mix

Mix Design	Time to Slump Loss (min)	% Increase vs. REF
REF	60	100%
D0.54%S	90	150%
D0.54%S0.3%R	180	300%
D0.54%S0.39%R	180	300%
D0.54%S0.48%R	180	300%
D0.54%S0.3%R0.41%M	300	500%
D0.54%S0.30%R0.71%M	210	350%
D0.54%S0.30%R1.01%M	240	400%
D0.54%S0.39%R0.41%M	210	350%
D0.54%S0.39%R0.71%M	240	400%
D0.54%S0.39%R1.01%M	330	550%
D0.54%S0.48%R0.41%M	360	600%
D0.54%S0.48%R0.71%M	360	600%
D0.54%S0.48%R1.01%M	420	700%

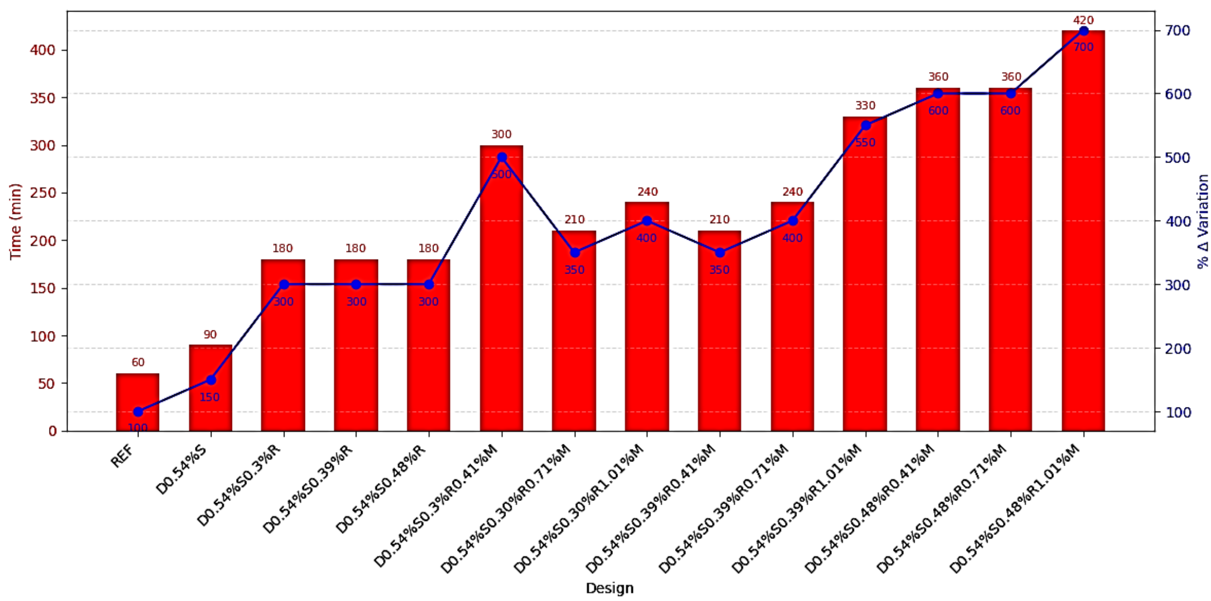

Figure 8. Time to Slump Loss of Samples in Relation to Percentage Increase

3.2. Setting Time

Table 16 shows that the initial setting time for the D0.54%S0.30%R1.01%M sample is approximately 7 hours, while for the D0.54%S0.30%R0.71%M sample, it is 6 hours and 2 minutes, and for the D0.54%S0.3%R0.41%M sample, it is 6 hours and 28 minutes. These samples used the minimum dose of retarder with different doses of workability-retaining admixture.

Next, the initial setting time for the D0.54%S0.39%R1.01%M sample is 8 hours and 39 minutes, while for D0.54%S0.39%R0.71%M, it is 8 hours and 44 minutes, and for D0.54%S0.39%R0.41%M, it is 7 hours and 35 minutes. These samples used the medium dose of retarder with varying doses of workability-retaining admixture.

Finally, the initial setting time for the D0.54%S0.48%R1.01%M sample is 11 hours and 38 minutes, while for D0.54%S0.48%R0.71%M, it is 10 hours and 42 minutes, and for D0.54%S0.48%R0.41%M, it is 11 hours and 52 minutes. These samples used the maximum dose of retarder with different doses of workability-retaining admixture (0.41%, 0.71%, and 1.01%).

Figure 9 compares the initial and final setting times for various samples. The reference sample has an initial setting time of 3:01 hours and a final setting time of 4:02 hours.

When admixtures are added, these times increase significantly. For example, the D0.54%S0.48%R sample reaches an initial setting time of 8:56 hours (261% of the reference sample) and a final setting time of 10:31 hours (261% of the reference sample).

Samples such as D0.54%S0.48%R0.41%M exhibit the longest initial and final setting times, at 11:52 hours and 13:46 hours, respectively. In general, the admixtures proportionally delay both setting times.

3.3. Compressive Strength in Hardened Concrete

Table 17 shows that between 3 and 7 days, the development of compressive strength accelerates, surpassing 27.46 MPa, with strength continuing to increase up to 28 days. However, the rate of increase slows after 7 days.

Table 16. Setting Time and Percentage Increase

Mix Design	Initial Setting Time (h:min)	% Increase Initial Setting	Final Setting Time (h:min)	% Increase Final Setting
REF	03:01	100%	04:02	100%
D0.54%S	04:28	148%	05:57	148%
D0.54%S0.3%R	05:42	189%	07:01	174%
D0.54%S0.39%R	06:57	230%	08:34	212%
D0.54%S0.48%R	08:56	296%	10:31	261%
D0.54%S0.3%R0.41%M	06:28	214%	07:55	196%
D0.54%S0.30%R0.71%M	06:02	200%	08:04	200%
D0.54%S0.30%R1.01%M	06:46	224%	08:33	212%
D0.54%S0.39%R0.41%M	07:35	251%	10:18	255%
D0.54%S0.39%R0.71%M	08:44	290%	10:34	262%
D0.54%S0.39%R1.01%M	08:39	287%	11:00	273%
D0.54%S0.48%R0.41%M	11:52	393%	13:46	341%
D0.54%S0.48%R0.71%M	10:42	355%	12:43	315%
D0.54%S0.48%R1.01%M	11:38	386%	13:21	331%

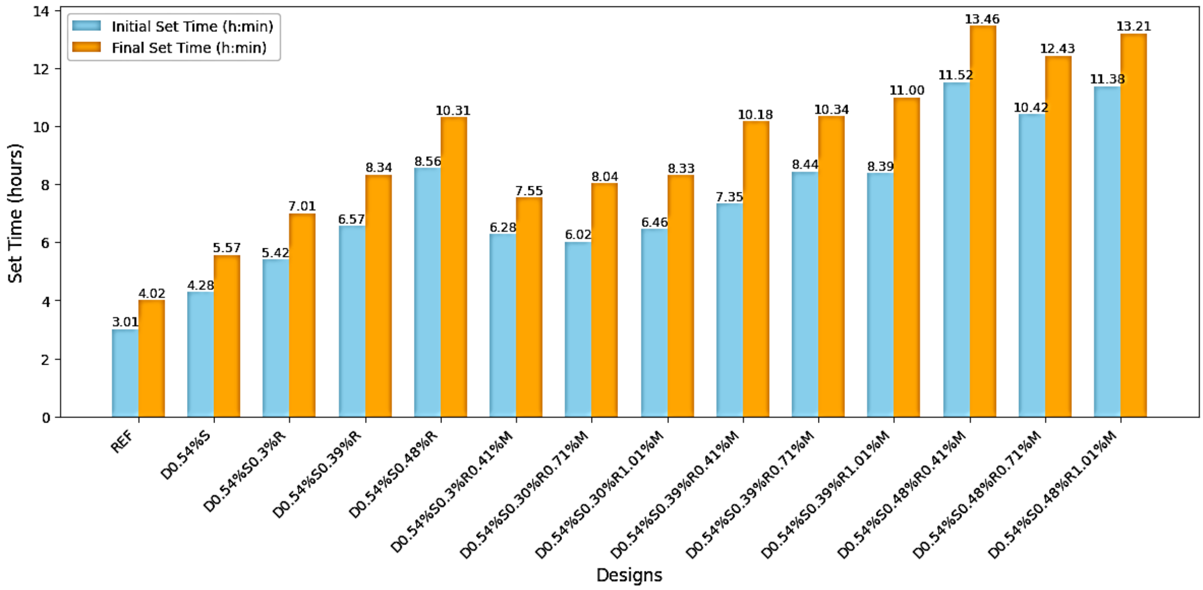

Figure 9. Initial and Final Setting Time Variation Across Mix Designs

Table 17. Compressive Strength at 3, 7, and 28 Days

Mix Design	Age (MPa)		
	3 days	7 days	28 days
REF	19.67	28.51	39.38
D0.54%S	21.46	29.01	41.67
D0.54%S0.3%R	27.62	36.67	46.03
D0.54%S0.39%R	22.77	33.11	41.39
D0.54%S0.48%R	26.70	37.03	45.81
D0.54%S0.3%R0.41%M	27.49	37.07	44.51
D0.54%S0.30%R0.71%M	23.11	32.07	40.40
D0.54%S0.30%R1.01%M	22.68	31.66	42.04
D0.54%S0.39%R0.41%M	21.91	31.15	43.39
D0.54%S0.39%R0.71%M	22.60	33.07	41.79
D0.54%S0.39%R1.01%M	25.13	34.94	44.51
D0.54%S0.48%R0.41%M	27.82	38.21	47.14
D0.54%S0.48%R0.71%M	23.50	33.53	44.44
D0.54%S0.48%R1.01%M	24.85	33.71	45.39

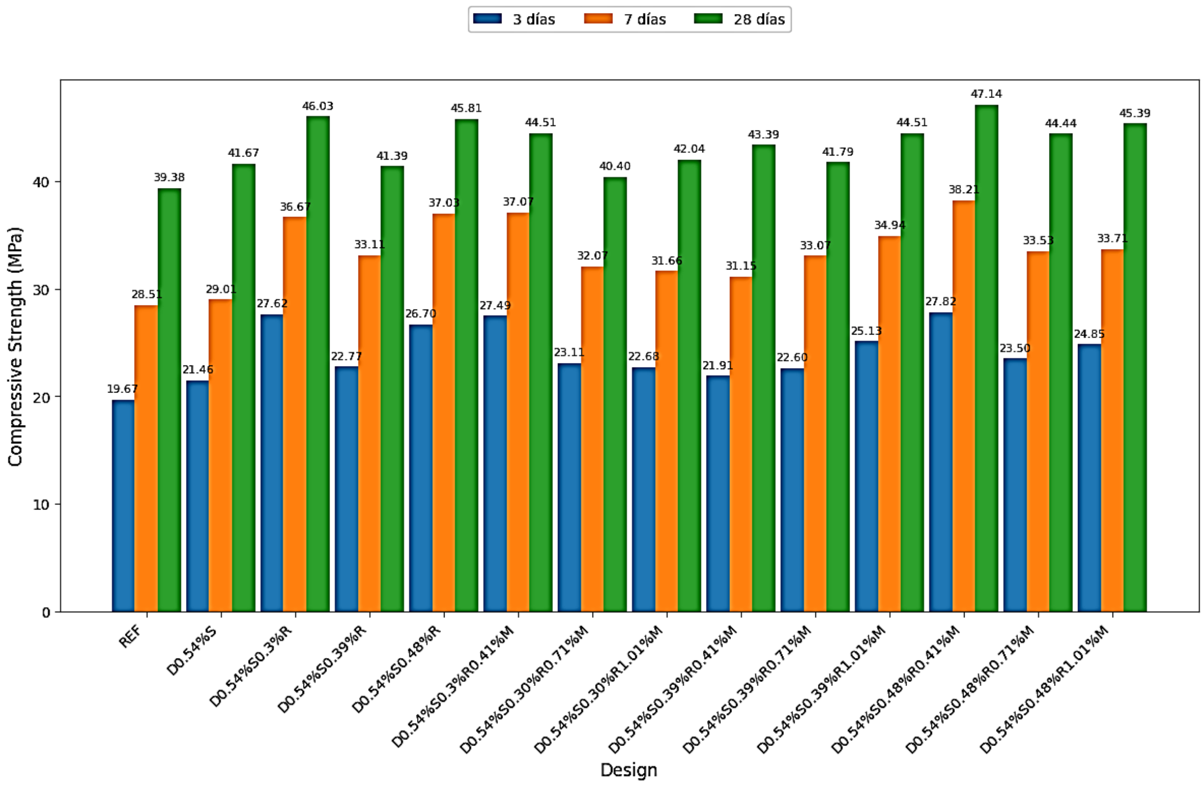

Figure 10. Compressive Strength of All Tested Mix Designs

In Figure 10, the reference sample reaches 28.51 MPa at 7 days and 39.38 MPa at 28 days. Among the samples with 0.30% retardant admixture and different dosages of workability-retaining admixture, D0.54%S0.3%R exhibits the highest strength, reaching 46.03 MPa at 28 days. For 0.39% retardant admixture, the D0.54%S0.39%R1.01%M sample achieves the highest strength, reaching 44.51 MPa at 28 days. Similarly, for 0.48% retardant admixture, the D0.54%S0.48%R0.41%M sample attains the highest strength at 47.14 MPa at 28 days.

Figure 11 illustrates the fracture patterns observed in the tested specimens. The most frequent failure modes were columnar failure and upper shear failure under applied loads.

3.4. Additional Tests on Hardened Concrete

Table 18 presents additional test results, including temperature, unit weight, and yield. Regarding concrete and ambient temperature, the D0.54%S0.39%R0.41%M sample exhibited the largest difference, approximately 4 ℃ compared to the other samples. For unit weight, the variation reached 0.89% relative to the reference sample, indicating that all samples remained relatively uniform for normal concrete. In terms of yield, a slight variation of approximately 1% was observed compared to the reference. However, a defect in the concrete was noted, as well as entrapped air, although the percentage of entrapped air relative to the reference sample was minimal.

Figure 12 illustrates the relationship between unit weight (N/m^3), slump (cm), and concrete temperature (℃) for various mix designs.

The gray bars represent unit weight, remaining stable between 23,044 and 23,318 N/m^3. The blue line indicates slump, starting at 9.53 cm and reaching a maximum of 22.86 cm in most samples. The red dashed line represents concrete temperature, ranging between 11.50 ℃ and 15 ℃, with moderate variations among samples. As slump increases, unit weight remains constant, while temperature fluctuates slightly without a clear pattern, possibly due to mixing conditions or the specific additives used.

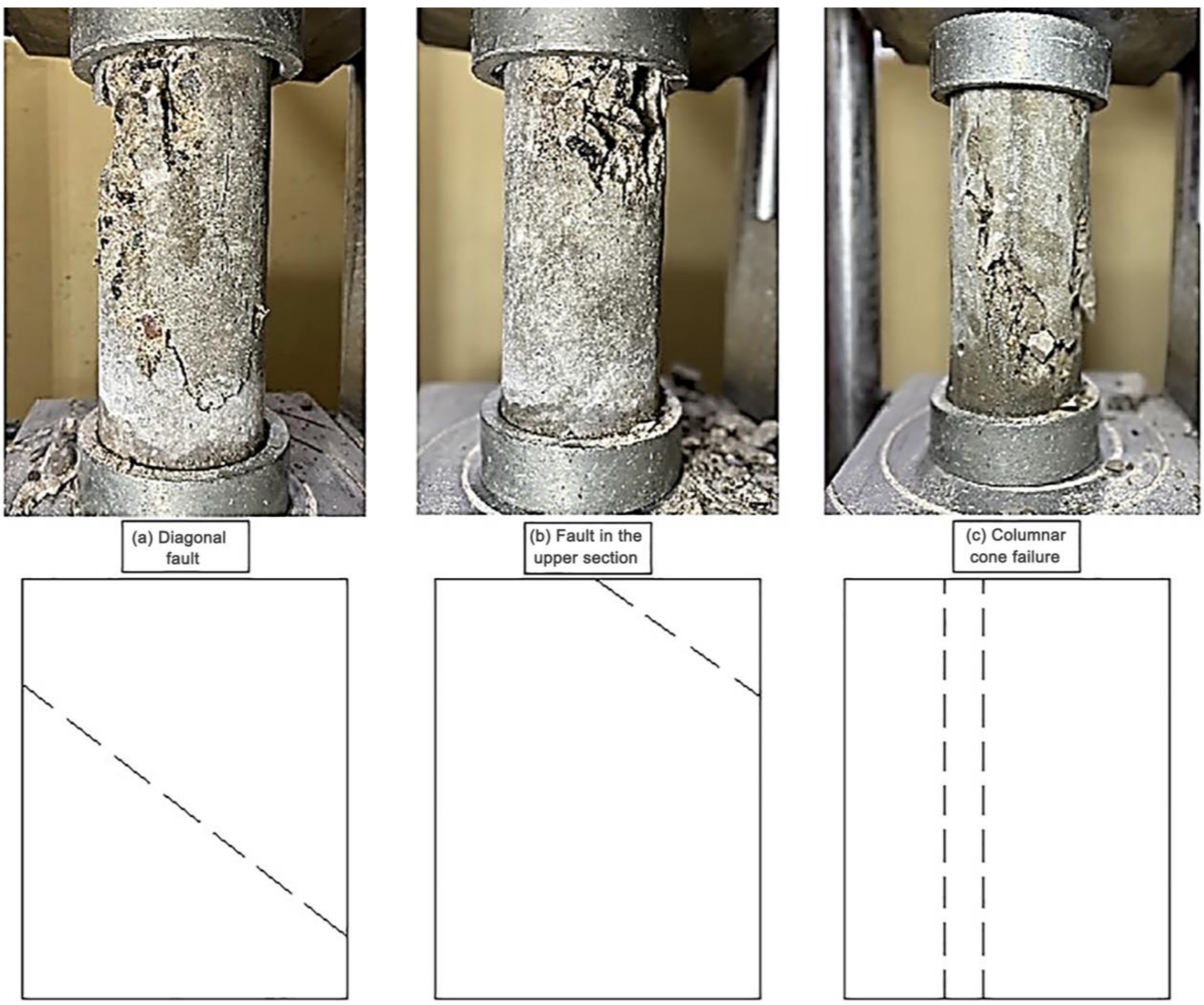

Figure 11. Common failure modes of concrete cylinders under compressive loading: (a) Diagonal fracture, (b) Fracture in the upper section, (c) Columnar cone failure

Table 18. Results of Complementary Hardened Concrete Tests

Mix Design	UNIT WEIGHT			TEMPERATURE		YIELD	
	Unit Weight (N/m³)	Unit Weight Variation (%)	Slump (cm)	Concrete (℃)	Ambient (℃)	Yield	Yield Variation (%)
REF	23171	100.00%	9.53	12.00	10.90	0.98	100%
D0.54%S	23377	100.89%	17.15	12.00	11.80	0.98	100%
D0.54%S0.3%R	23044	99.45%	21.59	12.50	11.00	0.99	101%
D0.54%S0.39%R	23260	100.38%	21.59	14.50	12.50	0.98	100%
D0.54%S0.48%R	23318	100.64%	21.59	12.50	10.60	0.98	100%
D0.54%S0.3%R0.41%M	23181	100.04%	22.86	14.50	13.00	0.98	100%
D0.54%S0.30%R0.71%M	23269	100.42%	22.86	14.50	14.00	0.98	100%
D0.54%S0.30%R1.01%M	23063	99.53%	22.86	15.00	15.50	0.99	101%
D0.54%S0.39%R0.41%M	23142	99.87%	21.59	14.50	10.30	0.98	100%
D0.54%S0.39%R0.71%M	23201	100.13%	22.23	13.50	10.70	0.98	100%
D0.54%S0.39%R1.01%M	23181	100.04%	22.86	14.50	13.60	0.98	100%
D0.54%S0.48%R0.41%M	23171	100.00%	22.86	12.00	9.70	0.98	100%
D0.54%S0.48%R0.71%M	23338	100.72%	22.86	11.50	9.00	0.98	100%
D0.54%S0.48%R1.01%M	23318	100.64%	22.86	12.50	10.70	0.98	100%

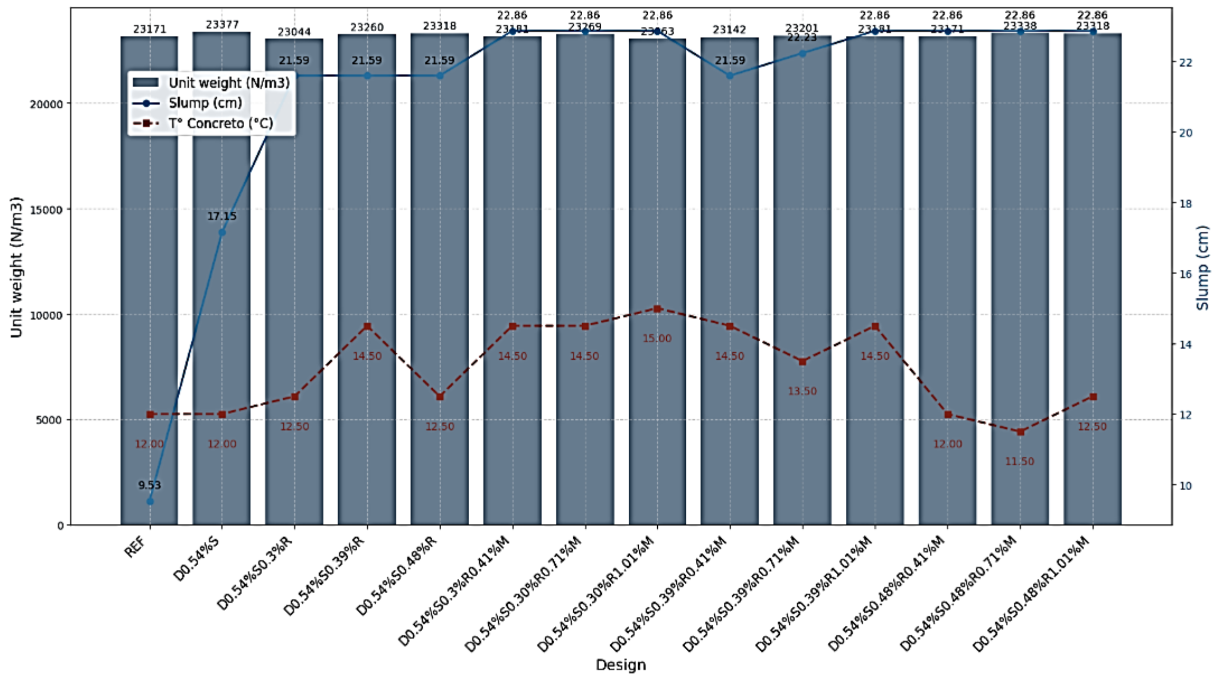

Figure 12. Relationship Between Unit Weight, Slump, and Concrete Temperature

4. Discussions

The results obtained in this study demonstrate a significant influence of next-generation additives on the properties of both fresh and hardened concrete. The superplasticizer Master Rheobuild 1003 does not contribute to consistency retention. However, the Master Set 770R retarder has minimal significance in consistency loss. The Master Sure Z60 workability-retaining additive, with dosages of 0.41%, 0.71%, and 1.01%, successfully maintains consistency over time, reaching a minimum slump of 8.89 cm after a maximum of 7 hours.

Similarly, in the study conducted by Sotomayor [33], the use of a workability-retaining additive (1.2% dosage), retarder, and water reducer resulted in a slump loss over 180 minutes down to 8.89 cm, which is a shorter duration compared to the findings of this study. Additionally, another study [34], reported improvements with the use of a superabsorbent polymer additive, which enhanced internal curing and crack self-healing but led to a reduction in compressive strength. On the other hand, an increase in superplasticizers such as dmax [35] resulted in a 3.2% reduction in compressive strength, although it helped maintain slump flow. Other studies [36] have also used superplasticizers with the primary objective of preserving workability.

In some cases, compressive strength showed a slight increase depending on the dosage used. The highest recorded value at 28 days was obtained with the D0.54%S0.48%R0.41%M mix, showing a 19.7% increase compared to the reference sample. Similarly, another study reported a statistically significant difference in strength development at 3, 7, and 28 days, with variations of 55%, 77%, and 100%, respectively [37]. Furthermore, another research [5] employed a 40% dose of shrinkage-reducing admixture to develop high-strength concrete.

Another important consideration is the variation in the mix design proportions when using the admixtures according to the dosages detailed in Table 12. Utilizing the Master Rheobuild 1003 admixture resulted in a 16.7% reduction in cement content, while the amounts of fine and coarse aggregate were reduced by 4.90%. Consequently, increasing the admixture dosage or employing the other admixtures used, such as Set R770 and MasterSure Z 60, leads to further reductions in fine and coarse aggregate quantities, approximately 0.60%. This indicates that these admixtures, by occupying volume within the mix design, reduce the required cement content for a given water-cementitious material ratio and decrease the overall quantity of aggregates needed.

The concrete temperatures recorded in this study fall within the acceptable range established by the National Building Code, which specifies that concrete temperature should be between 10 ℃ and 30 ℃ to ensure its quality [38]. The unit weight and yield tests indicate that the concrete used falls within the normal-weight category, as determined by the mix design, with a minimum yield of 0.98, which can be adjusted to reach unity. However, based on the obtained results, the values remain within the permissible range for the yield test [39]. Finally, the entrapped air percentage is considered adequate for the climate of Huancayo, although it can be increased if required by specific project conditions [40].

5. Conclusions

Next-generation admixtures significantly influenced the properties of both fresh and hardened concrete, enhancing its characteristics and, most importantly, preserving the setting time during prolonged transportation until placement, ensuring high-quality concrete for optimal performance.

In the reference sample, a loss of consistency was observed after 1 hour, reducing from 9.53 cm (plastic consistency) to 5.08 cm, approaching a dry consistency. The use of a superplasticizer extended the time before consistency loss by 30 minutes compared to the final slump of the reference sample. Additionally, the Master Set 770R retarder and, particularly, the Master Sure Z60 workability-retaining additive, further delayed the loss of consistency, extending the time by up to 6 additional hours relative to the reference sample's final slump.

The setting time was crucial in maintaining concrete consistency. The Master Set 770R retarder, applied at 0.30%, 0.39%, and 0.48% dosages, significantly affected the setting time. The initial setting time was recorded at 3 hours and 1 minute, while the final setting time reached 4 hours and 2 minutes in the reference sample. The strength and maturity increment at 3, 7, and 28 days were 55%, 77%, and 100%, respectively. Furthermore, the required compressive strength was exceeded by up to 22% in 28 days, with consistent strength increases at all measured ages.

The evaluation of complementary tests was essential, as they impact transportation and placement processes and serve as key indicators alongside the fundamental properties assessed in this study. These tests are particularly relevant in relation to climatic conditions and on-site mixing procedures.

Based on the results, controlling dosage and optimizing mix design resources are necessary for the ready-mix concrete industry. Given that materials such as cement represent a significant cost percentage in concrete production, resource optimization is essential while maintaining high-quality standards.

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