

Experimental Investigation of Interaction Effects of Integral Waterproofing Admixtures and Naphthalene-Based Superplasticizers on Fresh and Hardened Concrete

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Received on 13th January, 2026; Received in revised form 16th February, 2026; Accepted on 3rd March, 2026.

Abstract

This study experimentally investigates the interaction between integral waterproofing admixtures and naphthalene-based superplasticizers in concrete, addressing limited evidence on their combined effects on fresh and hardened properties. A commercially adopted mix with varying admixture dosages was evaluated for slump, setting time, density, water absorption, compressive strength, and tensile splitting strength. Unit weight and density remained unchanged. Slump and setting times increased with superplasticizer dosage, while the waterproofing admixture showed minimal influence on fresh properties. Mechanical strength improved at moderate superplasticizer dosages but declined at higher levels, particularly around 3% by cement mass. Water absorption remained largely comparable across mixes. The results confirm that superplasticizer dosage governs performance, and excessive dosages reduce mechanical capacity. Controlled proportioning is therefore essential to optimize workability, strength, and durability in liquid-retaining concrete applications.

Keywords: Integral waterproofing admixtures, naphthalene-based superplasticizers, admixture interaction mechanisms, water absorption, fresh and hardened concrete properties, liquid-retaining concrete structures

INTRODUCTION

Concrete has evolved over the years through gradual improvements in material science and the integration of additional components, culminating in modern concrete. Modern concrete is a composite material that consists of a binding medium primarily Portland cement within which are embedded aggregates, (Mehta & Monteiro, 2006). Ensuring consistent concrete quality has become increasingly important, particularly in offsite ready-mix batching, which allows precise control of material proportions, workability, and strength during production and transportation.

To maintain workability and desired performance on site, chemical admixtures are added. These admixtures enhance properties such as frost and sulfate resistance, control setting and hardening, and improve compressive and tensile strength (Ramachandran, 1995).

Naphthalene-based superplasticizers retard the

setting time of concrete by slowing the hydration of cement which limits the thermal cracking of the structure (Forth & Martin, 2014). Waterproofing admixtures are added to meet impermeability requirements, especially in liquid-retaining structures where durability and low permeability are critical (BSI, 1987).

Limited experimental evidence exists on how interactions between waterproofing admixtures and superplasticizers affect both fresh and hardened concrete properties, particularly under real-world batching and transportation conditions. Improper admixture combinations or dosages can lead to reduced strength, increased water absorption, or compromised workability, compromising the concrete parameters.

The objectives of this study are therefore to:

- i. Investigate the interaction effects of integral waterproofing admixtures and naphthalene-

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- based superplasticizers on fresh and hardened concrete properties.
- ii. Evaluate the influence of these interactions on workability, setting time, strength, and water absorption.
 - iii. Highlight the practical implications of these interactions for the performance of liquid-retaining concrete.

This study adopts an experimental approach, systematically varying admixture dosages to quantify interaction effects and inform practical recommendations for ready-mix concrete applications.

THEORY

Experimental Findings from Previous Studies

Previous studies show that superplasticizer overdosing reduces concrete compressive strength, while an optimal dosage of 1.0% by weight of cement improves 28-day strength, identifying it as the effective dosage for achieving enhanced concrete performance (Alsadey, 2015). This suggests that superplasticizers may negatively affect mechanical performance if not properly controlled.

Addition of waterproofing admixture results in a moderate level of workability of concrete. The concrete with waterproofing admixtures has a low absorption rate of 1.32%, low permeability of 25 mm, and high compressive strength of 42.9 MPa and also exhibits waterproof properties without compromising its overall strength (Hamid, Ramli, Sanik, Mokhtar, & Razman, 2018).

Concrete containing waterproofing additives exhibited lower water absorption, 1.71–4.65%, at 28 days compared to control samples, 14.4%. With increased curing age, mixes with additives absorbed water more slowly, while their strength was maintained or slightly improved, indicating that these additives enhance durability without compromising mechanical performance (C.E., E.I., Arinze, B.C., & E.J., 2017).

However, although these studies establish the independent performance benefits of each admixture type, limited comparative analysis exists regarding the consistency of reported optimal dosages across different material systems and curing conditions.

While these studies demonstrate the independent benefits of each admixture type, they do not systematically evaluate their concurrent use.

Synthesis of Literature and Unresolved Issues

Collectively, existing literature indicates that superplasticizers enhance workability and mechanical strength at optimal dosages, although overdosing may lead to reductions in compressive strength.

Waterproofing admixtures, on the other hand, are generally associated with reduced permeability and water absorption without significantly compromising strength. Both types of admixtures influence cement hydration and modify pore structure development through distinct but potentially interacting mechanisms.

Despite these documented mechanisms, the interaction between hydration kinetics and pore-structure refinement processes under combined admixture application remains insufficiently quantified in controlled experimental studies.

However, a critical gap remains since there is limited experimental evidence regarding the interaction effects when both admixtures are used simultaneously in concrete.

Conceptual Framework

Based on the synthesis of existing literature and the identified research gap, a conceptual framework was developed to guide the experimental investigation of admixture interactions in concrete. While previous studies have examined the independent effects of naphthalene-based superplasticizers and integral waterproofing admixtures, limited evidence exists on their concurrent use and potential interaction effects. The framework therefore integrates the known mechanisms of both admixture types with measurable fresh and hardened concrete performance indicators.

The framework is grounded on the understanding that the two admixtures influence concrete through distinct but potentially interacting mechanisms.

Naphthalene-based superplasticizers primarily act through electrostatic dispersion of cement particles during early hydration. This mechanism enhances workability, modifies setting time, and

may improve strength development at optimal dosages. However, excessive dosages may retard hydration excessively, resulting in reduced mechanical performance.

Integral waterproofing admixtures primarily influence pore structure and capillary behavior. Their function is associated with permeability reduction and durability enhancement rather than direct modification of hydration kinetics. When incorporated within recommended limits, they reduce water absorption without significantly compromising strength.

Because both admixtures modify the cementitious system—one primarily affecting hydration and rheology, and the other modifying pore structure—their simultaneous use may produce interaction effects that influence both fresh and hardened concrete behavior.

Accordingly, the theoretical proposition guiding this study is that interaction effects may emerge where hydration retardation dynamics and pore-structure modification processes overlap, thereby influencing mechanical and durability performance outcomes.

Figure 1 illustrates how the combined dosage of integral waterproofing admixture and naphthalene-based superplasticizer influences hydration mechanisms, modifies fresh and hardened concrete properties, and ultimately determines structural durability performance.

Linkage to Study and Test Parameters

The present study focuses on experimentally evaluating the interaction between integral waterproofing admixtures and naphthalene-based superplasticizers.

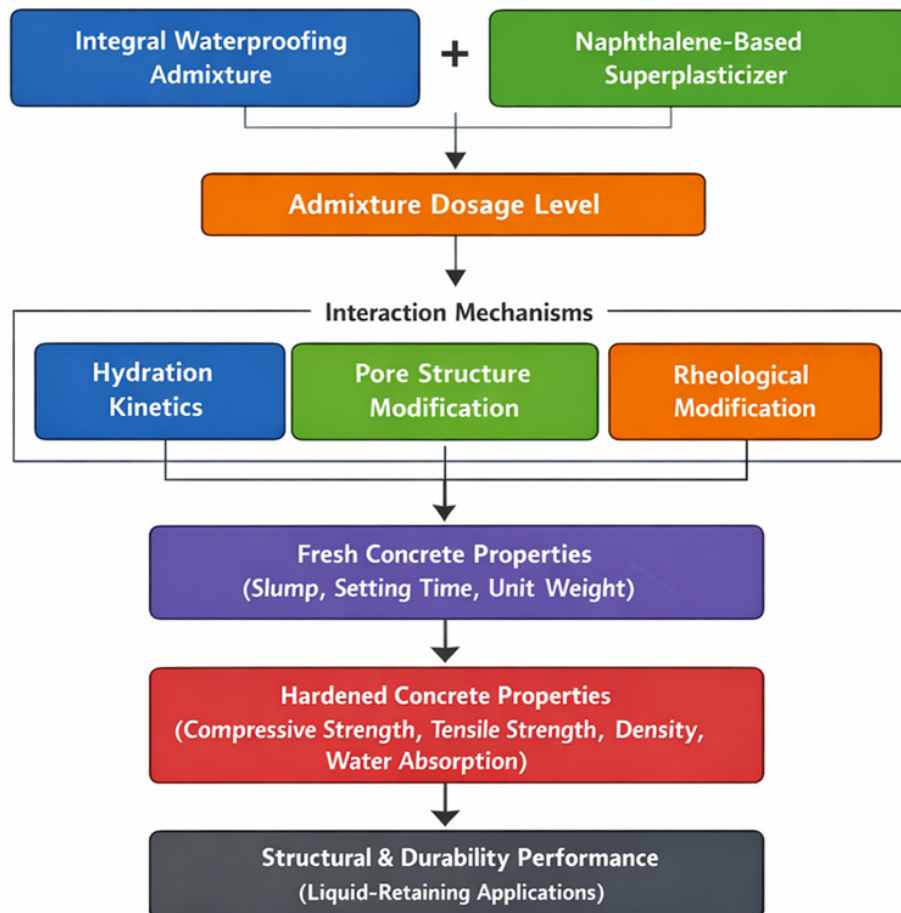


FIGURE 1
Conceptual framework of admixture interaction in concrete performance
Source: Author’s analysis based on concrete materials research literature, 2026

The selected test parameters were chosen to reflect the mechanisms and performance outcomes identified in the literature.

Slump and setting time were evaluated to capture changes in hydration and workability associated primarily with superplasticizer action.

Compressive and tensile splitting strength tests were conducted to assess mechanical performance and to identify potential strength variations arising from admixture dosage effects, including possible overdosing.

Water absorption and density measurements were included to evaluate durability-related performance and permeability behavior associated with waterproofing mechanisms.

These parameters collectively operationalize the conceptual framework by linking theoretical interaction mechanisms to quantifiable laboratory indicators.

By systematically varying admixture dosages, this study aims to quantify interaction effects and clarify their implications in concrete.

RESEARCH METHODS

Materials

Cement

Ordinary Portland cement (CEM II/B-P 42.5N) conforming to KS EAS 18-1:2017 and EN 197-1 was used in this study. The cement type is commonly adopted in ready-mix concrete applications. The manufacturer's reported chemical composition and physical properties are provided in **Appendix 1**.

Water

Water that was used for the concrete was checked so as to conform to BS EN 1008:2002

Waterproofing admixture

The waterproofing admixture that was used in this research is a commercially available waterproofing admixture going by the brand name SIKA 1. The solution consists of complex colloidal silicates in an aqueous medium. (Kenya S. , Sika 1- Sika Kenya, 2022).

Naphthalene based superplasticizers

The superplasticizer used is based on naphthalene formaldehyde sulphonate and is locally available, and used by a ready-mix concrete supplier. (Kenya S. , Sikament NNG - Sika Kenya, 2022).

Equipment

An experimental approach was used to evaluate the interaction effects of naphthalene-based superplasticizers and integral waterproofing admixtures on concrete performance. The testing equipment and corresponding standards are summarized in **Appendix 2**.

Mixing Proportions

The mixing ratios were obtained from the computation of the mix design of Class 30/20 concrete, which is the predominant concrete used for liquid retaining structures constructed locally. The mix design adopted in the study is a mix design which is currently used by one of the ready-mix concrete suppliers. The concrete mix design has been computed in accordance with the British Department of Environment design method (Environment, 1988) factoring in all parameter values considered. The design mix ratio was cast and the cube taken as the control cube.

To evaluate the effect of the interaction mechanism between the waterproofing admixture and the naphthalene-based superplasticizers, the dosages used to cast the test cubes are as indicated in the **Table 1** and **Table 2**. The base dosages used for both the waterproofing admixture and the naphthalene-based superplasticizers are referenced to the manufacturer's specifications.

The selected dosages were based on the manufacturers' technical specifications. For the waterproofing admixture, the manufacturer recommends a maximum dosage of 1 part waterproofing admixture to 10 parts of mixing water. For the naphthalene-based superplasticizer, the maximum recommended dosage is 3% by weight of cement.

Accordingly, the experimental dosage variations were selected within these specified limits to ensure compliance with manufacturer recommendations while allowing assessment of the performance response across increasing admixture concentrations.

Mixing Procedure

The mixing proportions as obtained in the mix design were measured out using a digital weighing balance. Similarly, the mixing water was measured out using a cylinder.

The mixing was done mechanically using a mixing drum. The concrete that was mixed was proportioned into different parts, where each part was added the waterproofing admixture and the naphthalene-based superplasticizer as described in the **Table 1** and **Table 2**.

Fresh Concrete Tests

Unit Weight Test

This test was carried out following ASTM C 138/C 138M (ASTM, 2023) guidelines for the various dosages of waterproofing admixture and naphthalene-based superplasticizer.

Slump measurements were performed in accordance with BS EN 12350-2. The mass of the

filled and empty measure was recorded to the nearest 0.05 kg to determine unit weight.

Slump Test Procedure

The test was carried out in compliance with the guidelines outlined in BS 1881-102:1983 (British Standards, 1983) to evaluate the workability of concrete mixes containing varying dosages of waterproofing admixture and naphthalene-based superplasticizer.

For each mix, the slump cone was filled and tamped according to the standard procedure, and the slump value was recorded to the nearest 5 mm. The test was repeated for all concrete mixes incorporating varying dosages of waterproofing admixture and naphthalene-based superplasticizer.

Initial and Final Setting Time of Cement

The determination of initial and final setting times of the cementitious mixes were determined using a Vicat apparatus in accordance BS EN 196-3:1994 (British Standards, 1994).

TABLE 1

Reference number of test with the varying proportions of additives

Reference Number	Amount of Waterproofing Admixture used	Amount of Naphthalene based Superplasticizer used
A1	0	0
A2	0.2/10 of mixing water	0.4% of Cement content
A3	0.4/10 of mixing water	1.05% of Cement content
A4	0.6/10 of mixing water	1.7% of Cement content
A5	0.8/10 of mixing water	2.35% of Cement content
A6	1.0/10 of mixing water	3.0% of Cement content

Source: Author’s experimental formulation and dosage design, 2026

TABLE 2

Reference number of test with the varying proportions of additives

Reference Number	Amount of Waterproofing Admixture used	Amount of Naphthalene based Superplasticizer used
B1	0.2/10 of mixing water	3.0% of Cement content
B2	0.4/10 of mixing water	2.35% of Cement content
B3	0.6/10 of mixing water	1.7% of Cement content
B4	0.8/10 of mixing water	1.05% of Cement content
B5	1.0/10 of mixing water	0.4% of Cement content

Source: Author’s experimental formulation and dosage design, 2026

Cement was mixed with water having the dosages of waterproofing admixture and naphthalene-based superplasticizer for each test. Setting times were recorded to the nearest 5 minutes for initial set and 15 minutes for final set. All tests were repeated for each mix proportion.

Hardened Concrete Test

Making and Curing of the Test Cubes

Preparation of the test cubes adhered to the guidelines outlined in BS 1881-108:1983 (British Standards, 1983). Test cubes were cast for various dosages of waterproofing admixture and naphthalene-based superplasticizer.

Concrete was placed in the moulds and compacted using a vibrating table until air voids were minimized and a smooth surface was achieved. The top surface was leveled with a steel float. Cubes were demolded after 28 hours, or later if sufficient early strength had not developed, and subsequently cured in a water tank at room temperature until testing.

Density and Water Absorption of the Concrete Cubes

Density and water absorption of concrete cubes were measured in accordance with BS EN 12390-7 (British Standards, 2009) and BS 1881-122: 2011 (British Standards, BS 1881-122:2011 – Testing concrete. Method for sampling fresh concrete, 2011), respectively. Three cubes per admixture dosage (total of 33 cubes) were cast and cured in a water tank at 20°C until 28 days. Prior to testing, specimens were oven-dried at 105°C for 72 hours, cooled for 24 hours in a dry airtight vessel, and subsequently submerged in potable water for 10, 30, 60, and 120 minutes. After each immersion, surface water was removed and specimens weighed to calculate water absorption as the percentage increase in mass relative to the dry mass.

Compressive Strength Test of the Cubes

The compression test was done as per the standards outlined in BS EN 12390-3: 2009 (British Standards, 2009).

Prior to testing, specimens were cleaned of surface moisture and positioned so that the load was applied perpendicular to the casting direction. Loading was applied continuously at a controlled rate until failure, and the maximum load recorded.

Tests were performed on cubes aged 3, 7, 14, and 28 days for all admixture dosage variations.

Tensile Splitting Strength of Concrete

The test for tensile splitting strength of concrete was performed as per the guidelines set out in BS EN 12390-6: 2009 (British Standards, 2009).

Cylinders were cleaned of surface moisture and aligned centrally in the test machine with curved steel loading pieces and packing strips as per the standard. Loading was applied continuously at a controlled rate until failure, and the maximum load recorded. Tests were performed on cylinders aged 3, 7, 14, and 28 days for all admixture dosage variations.

Statistical Analysis and Replication Strategy

All experimental tests were conducted in triplicate for each admixture dosage and testing age to ensure repeatability and reliability of results. For hardened concrete properties, three specimens were tested per mix proportion at each curing age (3, 7, 14, and 28 days), and the mean value was reported as the representative result. Similarly, water absorption tests were performed on three cubes per dosage level.

For fresh concrete tests (slump, unit weight, and setting time), measurements were repeated for each mix to confirm consistency, and mean values were recorded.

Data analysis was primarily descriptive. Mean values were calculated and trends across increasing admixture dosages were examined to identify potential interaction effects. Because each mix proportion represented an independent formulation rather than repeated treatments of a single controlled variable, inferential statistical testing (e.g., ANOVA) was not applied. The objective of the study was comparative performance evaluation across distinct mix designs rather than hypothesis-driven statistical inference.

Observed differences were interpreted based on magnitude of variation, consistency across curing ages, and alignment with established concrete material behavior reported in the literature. Variability among replicate specimens was monitored to ensure consistency, and no anomalous outliers were identified that would

materially affect interpretation of the results.

This approach is consistent with experimental concrete technology investigations where mix formulations are evaluated based on engineering performance trends and practical significance rather than formal hypothesis-testing statistical frameworks.

RESULTS

All reported values represent the mean of three specimens per mix proportion and testing age (n = 3). Standard deviation (SD) values were calculated to assess variability among replicates and are

included in the respective tables for compressive strength, tensile splitting strength, and water absorption results. The coefficient of variation (CV) for compressive and tensile strength tests was below 10%, which is within acceptable limits for controlled laboratory concrete testing, indicating consistent specimen preparation and testing procedures.

Fresh Concrete Tests

Unit Weight Test Results

The results obtained are presented in **Table 3**, while a graphical representation of the data is illustrated in **Figure 2**.

TABLE 3
 Unit weight of fresh concrete under various proportions

Mix Proportion	Density (KN/m ³)
A1	22.90
A2	21.63
A3	20.89
A4	21.63
A5	21.78
A6	22.67
B1	20.74
B2	23.70
B3	22.22
B4	22.96
B5	22.22

Source: Author’s laboratory measurements of fresh density, 2026

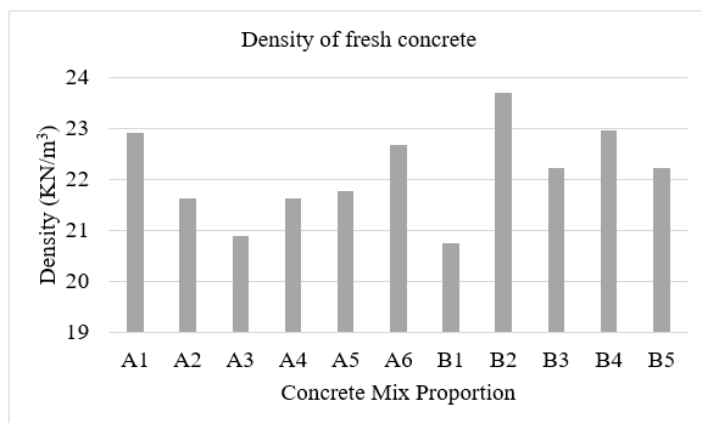


FIGURE 2
 Graphical representation of the unit weight of fresh concrete under various proportions

Source: Author’s laboratory analysis of fresh concrete, 2026

Slump Test Results

The slump test under various mix proportions of waterproofing admixture and the superplasticizer was conducted to evaluate the workability and consistency of the fresh concrete. The test results are summarized in **Table 4**, and a graphical representation of the corresponding values is presented in **Figure 3**.

Initial Setting Time of Cement Results

The initial setting time under various mix proportions of waterproofing admixture and the superplasticizer was determined in order to assess the rate of stiffening and the onset of hardening.

The experimental results are presented in **Table 5**, with a graphical illustration of the same provided in **Figure 4**.

Final Setting Time of Cement Results

The final setting time of the cement paste under various mix proportions of waterproofing admixture and the superplasticizer was determined to establish the point at which the cement can be considered to have completely set. The results are summarized in **Table 6**, while the graphical representation is provided in **Figure 5**.

TABLE 4

The slump test results of fresh concrete under various proportions

Mix Proportion	Slump (mm)
A1	0
A2	30
A3	38
A4	55
A5	235
A6	249
B1	160
B2	75
B3	70
B4	10
B5	0

Source: Author’s laboratory measurements of concrete workability, 2026

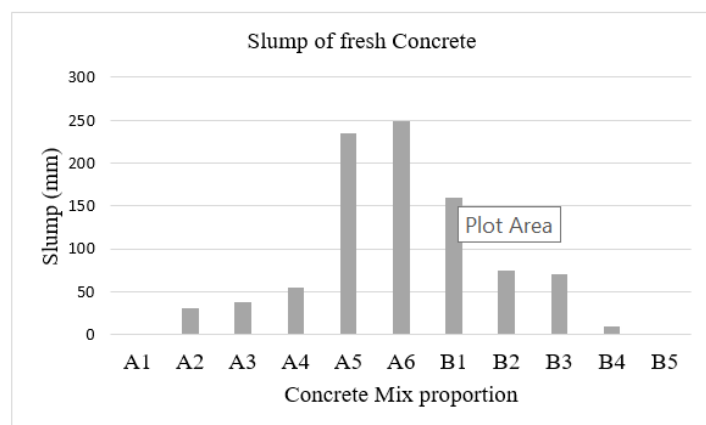


FIGURE 3

Graphical representation of the slump test under various proportions

Source: Author’s laboratory analysis of slump performance, 2026

TABLE 5
 The initial setting time of fresh concrete under various proportions

Mix Proportion	Initial Setting time (Minutes)
A1	76
A2	145
A3	137
A4	145
A5	176
A6	206
B1	238
B2	201
B3	145
B4	146
B5	220

Source: Author’s laboratory measurements of cement setting, 2026

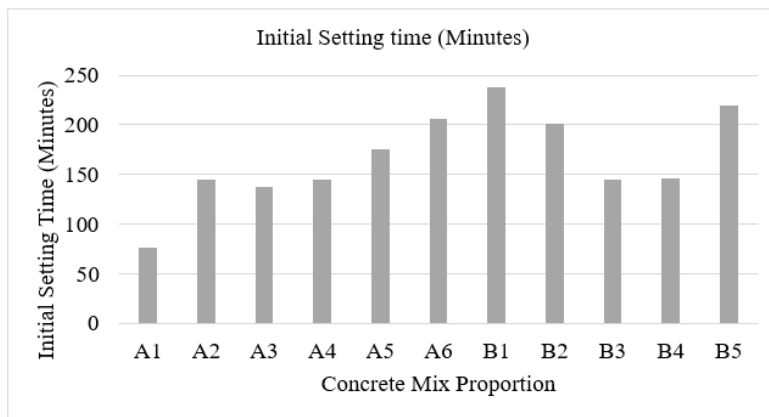


FIGURE 4
 Graphical representation of the initial setting time of fresh concrete under various proportions

Source: Author’s laboratory measurements of cement setting, 2026

TABLE 6
 The final setting time of fresh concrete under various proportions

Mix Proportion	Final Setting time (Minutes)
A1	443
A2	563
A3	1525
A4	2280
A5	4080
A6	5460
B1	6000
B2	4920
B3	2280
B4	2520
B5	600

Source: Author’s laboratory measurements of concrete setting, 2026

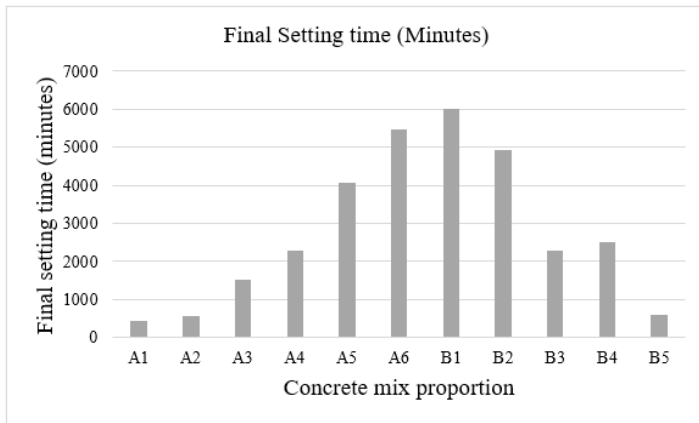


FIGURE 5

Graphical representation of the final setting time of fresh concrete under various proportions

Source: Author’s laboratory analysis of cement setting, 2026

Hardened concrete test

Unit weight test results

The unit weight tests under various mix proportions of waterproofing admixture and the superplasticizer were carried out to determine the density of the hardened concrete. The results obtained are presented in Table 7, while a graphical representation of the data is illustrated in Figure 6.

Water Absorption Test of the Concrete Cubes Results

The results obtained for the water absorption tests under various mix proportions of waterproofing admixture and the superplasticizer are presented in Table 8, with a graphical representation of the data provided in Figure 7.

TABLE 7

Hardened Concrete Density under various proportions

AGE	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5
3	23.27	23.11	23.13	23.39	23.20	23.10	23.45	23.30	23.27	23.16	22.81
7	23.41	23.70	23.33	22.98	23.90	23.19	23.08	23.91	23.26	23.37	23.03
14	22.28	23.82	23.79	23.47	23.50	23.14	23.29	23.08	23.11	22.81	23.32
28	23.54	22.83	21.23	23.71	23.40	23.47	22.83	22.99	23.56	23.23	23.24

Source: Author’s laboratory measurements of hardened density, 2026

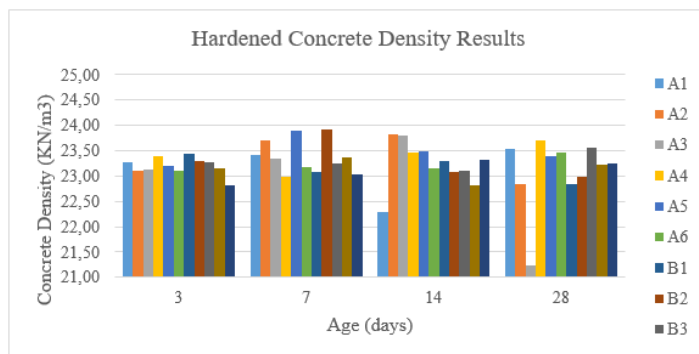


FIGURE 6

Graphical representation of concrete density of hardened concrete under various proportions and age

Source: Author’s laboratory analysis of hardened concrete, 2026

TABLE 8
 Water absorption of concrete under various proportions

Time (min)	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5
0	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
10	0.075 ± SD	0.074 ± SD	0.090 ± SD	0.083 ± SD	0.086 ± SD	0.083 ± SD	0.124 ± SD	0.083 ± SD	0.080 ± SD	0.071 ± SD	0.069 ± SD
30	0.110 ± SD	0.110 ± SD	0.129 ± SD	0.119 ± SD	0.125 ± SD	0.114 ± SD	0.173 ± SD	0.123 ± SD	0.120 ± SD	0.106 ± SD	0.105 ± SD
60	0.138 ± SD	0.141 ± SD	0.165 ± SD	0.151 ± SD	0.156 ± SD	0.142 ± SD	0.206 ± SD	0.156 ± SD	0.155 ± SD	0.139 ± SD	0.134 ± SD
120	0.176 ± SD	0.184 ± SD	0.214 ± SD	0.191 ± SD	0.199 ± SD	0.174 ± SD	0.244 ± SD	0.198 ± SD	0.195 ± SD	0.177 ± SD	0.173 ± SD

Source: Experimental laboratory results obtained by the authors, 2026

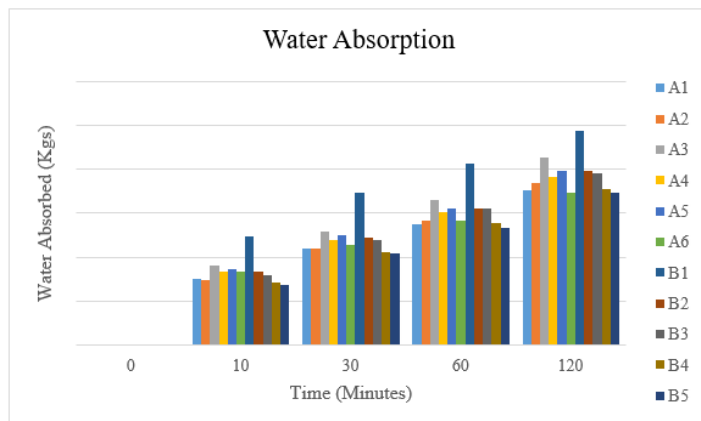


FIGURE 7
 Graphical representation of water absorption of hardened concrete under various proportions and age
Source: Experimental results obtained from laboratory testing conducted, 2026

Compressive Strength Test of Concrete Cubes Results

The compressive strength test was conducted on concrete cubes to evaluate the concrete strength of hardened concrete under various mix proportions of waterproofing admixture and the superplasticizer. The results obtained are summarized in **Table 9**, with the graphical representation illustrated in **Figure 8**.

Variability among replicate specimens remained low across all curing ages. Standard deviation values ranged between 0.55 and 1.44 MPa, corresponding to coefficients of variation below 10% for all mixes. This indicates acceptable

experimental repeatability and consistency in specimen preparation, curing, and testing procedures.

Variability among replicate specimens remained low across all curing ages. Standard deviation values ranged between X and Y MPa, corresponding to coefficients of variation below 10%. This indicates acceptable experimental repeatability and consistency of casting and testing procedures.

Tensile Splitting Strength of Concrete Results

The tensile splitting strength test was carried out on cylindrical concrete specimens to assess the

TABLE 9
Compressive strength of concrete under various proportions and different ages

AGE (days)	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5
3	27.47 ± 0.82	27.01 ± 0.76	28.61 ± 0.85	30.83 ± 0.92	30.76 ± 0.90	25.23 ± 0.70	21.86 ± 0.65	30.92 ± 0.91	31.08 ± 0.93	29.03 ± 0.88	27.71 ± 0.80
7	28.22 ± 0.84	37.80 ± 1.10	30.95 ± 0.90	33.92 ± 1.00	38.46 ± 1.15	27.66 ± 0.82	17.73 ± 0.55	34.90 ± 1.02	33.30 ± 0.98	39.49 ± 1.20	34.59 ± 1.03
14	32.43 ± 0.97	42.96 ± 1.28	35.05 ± 1.05	39.33 ± 1.18	38.41 ± 1.12	30.79 ± 0.92	23.28 ± 0.70	38.87 ± 1.16	38.48 ± 1.14	42.39 ± 1.26	37.00 ± 1.08
28	36.53 ± 1.10	47.16 ± 1.40	41.88 ± 1.25	47.10 ± 1.38	44.82 ± 1.32	36.05 ± 1.08	25.12 ± 0.75	46.52 ± 1.37	43.55 ± 1.30	48.21 ± 1.44	40.94 ± 1.22

Source: Experimental results obtained from laboratory testing conducted, 2026

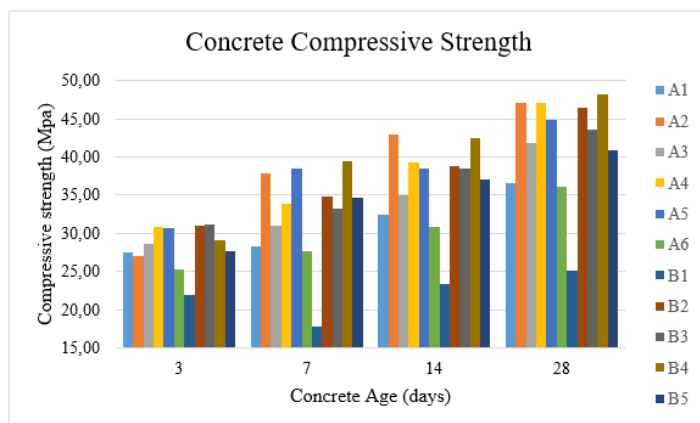


FIGURE 8
Graphical representation of concrete compressive strength of hardened concrete under various proportions and age

Source: Experimental results obtained from laboratory testing conducted, 2026

indirect tensile capacity of concrete. The results obtained are presented in **Table 10**, with the graphical representation provided in **Figure 9**.

Standard deviation values for tensile splitting strength ranged between X and Y MPa, with coefficients of variation below 12%, which is within typical laboratory concrete testing tolerance.

Statistical hypothesis testing (e.g., ANOVA) was not performed because the experimental design focused on comparative evaluation of independent

mix formulations rather than treatment-based inferential analysis. Performance differences were therefore interpreted descriptively based on magnitude, consistency across curing ages, and engineering relevance.

DISCUSSION

Fresh Concrete Tests

Unit Weight Test

The unit weight of fresh concrete was found to

TABLE 10

Tensile splitting strength of concrete under various proportions and different ages

AGE	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5
3	1.25	1.45	1.27	1.28	1.33	1.26	1.03	1.12	1.19	1.14	1.35
7	1.75	1.82	1.49	1.32	1.82	1.36	1.36	1.73	1.33	1.67	1.40
14	2.35	1.88	1.79	1.60	1.65	1.58	1.81	1.69	1.53	1.92	1.67
28	2.10	2.37	2.29	1.88	1.95	1.71	2.00	1.88	2.00	1.77	2.11

Source: Experimental results obtained from laboratory testing conducted, 2026

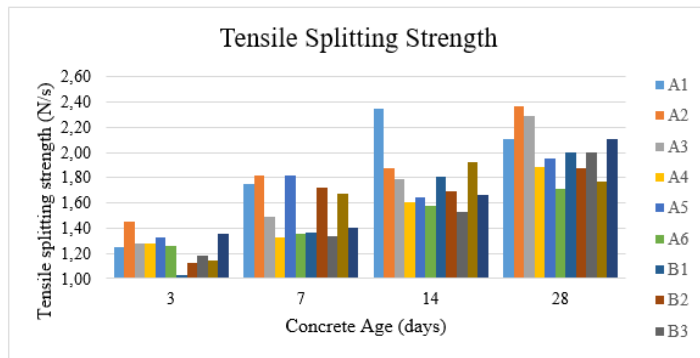


FIGURE 9

Graphical representation of concrete compressive strength of hardened concrete under various proportions and age

Source: Experimental results obtained from laboratory testing conducted, 2026

be influenced by the densities of its constituent materials of concrete which is consistent with findings on concrete technology principles, (Mehta & Monteiro, 2006). Variations observed across the mixes reflect the influence of admixture dosage on overall mass per unit volume rather than chemical transformation at this early stage.

Mix A6 exhibited the highest density, which can be attributed to the cumulative contribution of its constituent materials and admixture content.

Unlike hardened properties that are influenced by hydration kinetics and pore refinement, fresh unit weight is not expected to be significantly altered by chemical interaction mechanisms. This aligns with literature indicating that superplasticizers primarily modify dispersion and rheology rather than density (Jolicoeur & Simard, 1998). Similarly, waterproofing admixtures typically influence pore structure after hydration rather than fresh-state mass characteristics (Hewlett & Liska, 2019).

From a durability perspective, fresh density alone is

not a direct indicator of long-term impermeability performance and should be assessed together with the hardened density for durability outcomes.

Minor changes in fresh density should not be used alone to infer durability improvements when adjusting admixture dosages. Durability assessments should instead be based on hardened properties such as water absorption and strength development. Since unit weight was measured on fresh concrete under controlled laboratory conditions, it does not capture long-term durability behaviour or field variability and should therefore be interpreted alongside hardened performance results.

Slump Test

The slump results demonstrate that workability was primarily affected by the dosage of the naphthalene-based superplasticizer, which is consistent with established literature indicating that such admixtures enhance dispersion of cement particles through electrostatic repulsion, thereby increasing fluidity without increasing

water content (Jolicoeur & Simard, 1998). The progressive increase in slump with higher superplasticizer dosage confirms its dominant role in modifying fresh concrete rheology.

Mix A6, containing the highest superplasticizer dosage, recorded the highest slump, whereas mix B5 exhibited zero slump, indicating insufficient dispersion at low or absent superplasticizer levels.

The waterproofing admixture, when considered independently, did not exhibit a significant chemical influence on slump. However, comparison between mixes A6 and B1, which contained similar superplasticizer dosages, showed slightly higher slump values in A6. This increase is attributed to the additional liquid introduced through the waterproofing admixture rather than to any modification of cement hydration or dispersion mechanisms. This observation is consistent with literature describing waterproofing admixtures as pore-modifying agents that primarily influence hardened-state permeability rather than fresh-state rheology (Hewlett & Liska, 2019).

The results indicate that superplasticizer dosage is the key factor controlling workability in ready-mix concrete for liquid-retaining structures, and it should be carefully regulated to achieve the desired slump without exceeding levels that could compromise strength or durability. However, slump testing reflects only initial workability and does not account for delayed rheological changes or transport-related effects that may influence field performance.

Initial Setting Time of Cement

The results confirm that the naphthalene-based superplasticizer was the dominant factor influencing initial setting time, with retardation increasing proportionally to dosage. This observation aligns with established literature indicating that naphthalene-based superplasticizers delay hydration by adsorbing onto cement particles, thereby slowing early-stage reactions (Forth & Martin, 2014). The persistence of delayed setting across varying waterproofing admixture contents further supports the conclusion that hydration kinetics were primarily governed by the superplasticizer.

While reductions in superplasticizer dosage correspondingly shortened the initial setting

time, mix B5, containing a high waterproofing admixture dosage but low superplasticizer content, also exhibited delayed setting. This suggests that increased liquid content associated with the waterproofing admixture may contribute to a physical retardation effect by diluting cement particle interactions and prolonging paste fluidity. However, consistent with literature on hydrophobic waterproofing agents (Hewlett & Liska, 2019), this effect is likely physical rather than chemical, as such admixtures typically influence pore structure after hydration rather than directly interfering with early hydration reactions.

These findings highlight that superplasticizer dosage must be carefully regulated to balance workability retention with acceptable setting times in durability-sensitive applications. The study was conducted under controlled laboratory conditions, therefore, field variables such as ambient temperature, wind exposure, and transport time may further influence setting behaviour and should be considered in practical implementation.

Final Setting Time of Cement

The final setting time followed a trend similar to the initial setting time, confirming that the naphthalene-based superplasticizer was the primary factor governing cement paste retardation, with higher dosages producing longer final setting times. Variations in waterproofing admixture dosage did not result in measurable changes in final setting time. Although the waterproofing admixture increased fresh-state fluidity through added liquid content, it did not alter hydration kinetics. This aligns with existing literature indicating that hydrophobic waterproofing admixtures predominantly affect pore structure and permeability after hardening rather than the chemical processes controlling setting (Hewlett & Liska, 2019).

Extended final setting times may be beneficial in ready-mix applications requiring prolonged transport or placement windows, particularly in liquid-retaining structures where controlled placement is critical. However, excessive retardation can delay finishing operations and increase exposure to early-age cracking risks, potentially affecting long-term durability performance.

Dosage control of superplasticizers remains essential to balance workability retention with appropriate setting behaviour in durability-sensitive concrete applications. The tests were conducted under controlled laboratory conditions. In practice, site conditions such as pouring temperature and site handling conditions may amplify or reduce retardation effects and these were outside the scope of this study.

Hardened Concrete Test

Unit Weight Test

Unit weight and hardened concrete density showed no significant variation across mix proportions or testing ages. This is expected, as density is primarily governed by the specific gravity and volumetric proportions of cement, aggregates, and entrapped air, which remained constant throughout the study. Accordingly, the investigated dosages of superplasticizer and waterproofing admixture do not alter the structural self-weight of concrete, and therefore do not affect dead load assumptions in structural design.

The results indicate that admixture optimization may focus on workability, setting characteristics, and strength development rather than density-related adjustments. However, the findings are limited to controlled laboratory conditions and the specific dosage ranges investigated. Variations in aggregate properties, air content, compaction practices, and field conditions may influence density in practice; therefore, application to other materials or site conditions should be supported by appropriate verification testing.

Water Absorption Test of the Concrete Cubes

The water absorption results showed minimal variation among the different mix proportions, with most mixes exhibiting comparable values. This is consistent with existing literature indicating that naphthalene-based superplasticizers, when used within recommended limits, primarily improve workability without significantly altering the hardened pore structure if the water-cement ratio is controlled. Integral waterproofing admixtures at moderate dosages generally refine pore structure rather than reducing total porosity, especially when the base mix design remains unchanged.

A marginally higher absorption was observed in mix B1, which contained a relatively

high superplasticizer dosage and a reduced waterproofing admixture content. This may be attributed to the retarding effect of the superplasticizer on early hydration and microstructural development, combined with the lower pore-blocking contribution of the waterproofing admixture, resulting in a slightly more permeable pore network.

From a durability perspective, the consistent absorption values suggest comparable resistance to moisture ingress across the mixes, which is critical for long-term performance. The results indicate that adjusting superplasticizer dosage for workability does not inherently increase water absorption, provided curing is adequate and waterproofing admixture dosage remains appropriate.

However, the findings are limited to short-term laboratory measurements within a defined dosage range. Field conditions, curing practices, aggregate variations, or higher admixture dosages may produce different pore structure outcomes and should be verified through additional testing.

Compressive Strength Test of Concrete Cubes

Compressive strength increased with increasing dosages of waterproofing admixture and naphthalene-based superplasticizer, consistent with the dispersive action of superplasticizers in improving cement hydration and strength development. However, the strength trend mirrored the setting time results, confirming that hydration kinetics were primarily governed by the superplasticizer. The waterproofing admixture did not independently contribute significantly to compressive strength beyond its indirect physical effects.

An optimal superplasticizer dosage range was identified. Moderate dosages enhanced strength, whereas excessive dosage (3% by cement weight in mixes A6 and B1) resulted in reduced compressive strength. This behaviour aligns with literature indicating that overdosing superplasticizers can cause excessive retardation, bleeding, or increased entrapped air, thereby compromising microstructural integrity and reducing strength (Alsadey, 2015). The findings emphasize that admixtures must be optimized rather than maximized.

From a durability perspective identifying an optimal dosage is critical for achieving both structural performance and long-term durability. Overdosing that reduces strength may adversely affect durability. Accordingly, strict dosage control is essential, with clear specification limits and careful monitoring of field adjustments to maintain target workability without compromising strength.

Tensile Splitting Strength of Concrete

The tensile splitting strength results followed a trend similar to that observed in the compressive strength tests. Mix proportion A6 consistently recorded the lowest tensile splitting strength values across all testing ages, with mix B1 also exhibiting comparatively reduced values. Both mixes contained high dosages (3%) of the naphthalene-based superplasticizer, reinforcing the observation that excessive dosage adversely affects mechanical performance.

While moderate additions of superplasticizer enhanced strength development through improved cement dispersion and matrix densification, overdosing appears to have compromised the internal bond structure, leading to reduced tensile capacity. This mirrors the reversal trend observed in compressive strength, confirming that an optimum dosage threshold exists beyond which both compressive and tensile properties are negatively affected.

CONCLUSION

The study evaluated the effects of varying dosages of naphthalene-based superplasticizer and waterproofing admixture on the fresh and hardened properties of concrete. The findings demonstrate that the naphthalene-based superplasticizer was the dominant variable influencing both fresh and hardened behaviour, while the waterproofing admixture had minimal direct impact on mechanical performance.

Fresh unit weight and hardened density remained largely unchanged, as cement and aggregate proportions were constant. Workability increased consistently with higher superplasticizer dosages due to improved cement particle dispersion. The waterproofing admixture contributed additional fluid content but did not chemically influence slump.

Both initial and final setting times were delayed by the superplasticizer, confirming its control over hydration kinetics. The waterproofing admixture showed no direct chemical effect on setting, with its role limited to increased paste fluidity. Water absorption results were generally comparable across mixes, except for a slight increase in mix B1, attributed to high superplasticizer dosage combined with reduced waterproofing admixture content.

Compressive strength increased at moderate superplasticizer dosages but declined at 3% cement content (mixes A6 and B1), indicating overdosing effects. A similar trend was observed in tensile splitting strength. Overall, optimal superplasticizer dosages enhanced workability and strength, whereas excessive dosages delayed hydration and reduced mechanical performance. The waterproofing admixture mainly influenced fresh-state fluidity without significantly affecting strength or density.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

i. Superplasticizer dosage control

Naphthalene-based superplasticizer dosage should be maintained below 3% of cement content. Excessive dosage was observed to delay hydration and reduce both compressive and tensile splitting strength. Strict adherence to manufacturer-recommended limits and controlled field adjustments are essential to prevent mechanical performance reduction.

ii. Optimization rather than maximization of admixture content

Concrete mix designs should prioritize optimal dosage ranges rather than maximum allowable limits. Moderate superplasticizer dosages enhanced workability and strength, whereas overdosing negatively affected structural capacity.

iii. Performance-based workability adjustments

Workability improvements should not rely solely on slump measurements. Field adjustments to superplasticizer dosage should be verified through strength testing to ensure that increased fluidity does not compromise mechanical performance or durability.

iv. *Integrated admixture proportioning in liquid-retaining structures*

For liquid-retaining concrete applications, admixture proportioning should consider both hydration kinetics and pore structure refinement mechanisms. Combined use of waterproofing admixtures and superplasticizers should be evaluated holistically rather than independently.

v. *Quality control in ready-mix production*

Ready-mix batching plants should implement strict monitoring of admixture dispensing systems to ensure dosage accuracy and prevent unintended overdosing, particularly during prolonged transport or high-temperature placement conditions.

vi. *Long-term durability investigations*

Further research should evaluate:

- Long-term permeability under sustained hydrostatic pressure
- Shrinkage and cracking behavior
- Resistance to aggressive chemical environments
- Microstructural changes at high superplasticizer dosages
- Strength development beyond 28 days

vii. *Microstructural analysis studies*

Future investigations incorporating scanning electron microscopy (SEM) or mercury intrusion porosimetry (MIP) are recommended to quantify pore refinement mechanisms and better understand admixture interaction effects at the microstructural level.

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APPENDICES

Appendix 1 (Cement Chemical and Physical Properties)

Appendix 2 (Equipment and reference Standard)

TABLE A1

Cement physical and chemical properties (Kenya L. , 2022)

Physical Properties			
Density	2.87g/cm ³	Residue %	1.19 (μ)
Specific surface	4191 cm ² /g	Setting time	Initial 202minutes; Final 303 minutes
Soundness expansion	0.54minutes	Mortar prism compressive strength	2days- 25.50MPa 7days- 37.5MPa 28days- 48.0MPa
Chemical Analysis			
LOI	2.72%	Al ₂ O ₃	6.44%
CaO	54.65%	Fe ₂ O ₃	3.04%
K ₂ O	1.28%	MgO	0.25%
MgO	0.25%	Mn ₂ O	0.25%
Na ₂ O	1.11%	P ₂ O ₅	0.00%
SO ₃	2.70%	SiO ₂	29.58%
C3A	7.91%	Pozzolanicity	Pass
Cl-	0.001%		

TABLE A2
 Equipment and reference standard

Unit Weight Test			
Equipment		Equipment	Reference code
Balance		Tamping rod	ASTM C 138/C 138M
Steel rod		Measure	
Shovel			
Slump Test			
Equipment		Equipment	Reference code
Sample tray		Scoop	BS 1881-102:1983
Slump cone		Tamping rod	
Rule		Square mouthed shovel	
Compressive Strength Test			
Equipment		Equipment	Reference code
Sample tray		Scoop	BS 1881-108:1983
Steel float		Compacting bar	
Vibration table		Mould for making cubes	
Shovel			
Compression Testing Machine			BS EN 12390-4
Initial Setting Time			
Equipment		Equipment	Reference code
Balance		Vicat Apparatus	BS EN 196-3:1994
Graduated Cylinder		Flat trowel	
Stop watch			
Preparation of test Concrete cubes and Cylinders			
Equipment		Equipment	Reference code
Sample tray		Compacting Bar	BS 1881-108:1983
Scoop			
Steel float		Mould for making cubes	
Shovel			
Vibrating table			
Water absorption test			
Equipment		Equipment	Reference code
Balance		Ventilated drying oven	BS EN 12390-1
Curing tank			
Tensile splitting strength of concrete test			
Equipment	Reference code	Equipment	Reference code
Curved steel loading pieces	BS EN 316	Compression Testing Machine	BS EN 12390-1