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The Use of Non-chloride based admixture for enhancing the mechanical properties of concrete: A Case Study of Costarcel-200

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ABSTRACT :

The use of chemical admixtures has gained popularity in recent times as they help to improve the fresh and hardened properties of concrete. This research investigated the use of a non-chloride admixtures; Costarcel-200 on concrete at certain percentages. Non-Chloride admixtures were added at 1%, 1.2%, 1.4% and 1.5% of the cement weight. Several cubes were cast and tests conducted on the concrete. The fresh concrete tests conducted were workability and wet density tests while the hard concrete tests were dry density tests at 7 and 28 days, compressive strength test at 7 and 28 days and flexural strength test at 28 days. The workability test conducted was slump test which showed that at 1.4% addition of admixtures, the highest value of slump was obtained. The wet density tests showed that at 1.0% addition of admixtures, the highest wet density was achieved which was 0.9% higher than the control. The 7-day dry density test showed that no significant increase in dry density was achieved with the addition of admixtures to the concrete rather reduction of 2.2% was seen at 1% addition while at 28 days, the highest dry density was achieved at 1.5% addition of admixtures which gave a 1.14% increase as compared with the control. The compressive strength test showed that the 7 days compressive strength gave the highest at 1.4% addition of admixture with 15.66 N/mm^2 while the lowest was at 1.2% addition with 12.33 N/mm^2 whereas the 28days test results showed that at 1.5% addition of admixture, a compressive strength of 25.66 N/mm^2, a 3.81% increase from the control. The flexural strength test showed that at 1.5% addition of admixture gave the highest flexural strength of 3.9 N/mm^2 while the lowest was the control which gave a flexural strength of 2.5 N/mm^2. This indicates that a 56% increase in flexural strength is achieved at 1.5% addition of non- chloride admixture as compared with the control.

KEYWORDS: density, admixtures, super plasticizers, workability, compressive strength, flexural strength.

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I. INTRODUCTION

Material optimization involves making the best or most effective use of a resource or changing an existing process in order to increase the occurrence of favourable outcomes and decrease the occurrence of undesirable outcomes. Concrete being the major component of most infrastructural facilities in the modern day society due to its wide area of application is made up of cement, fine aggregate, coarse aggregate, water and other admixtures in specified quantities. The properties of concrete as a construction material can be optimized through the use of admixtures and superplasticizers serves as a good admixture for achieving desired concrete properties. Superplasticizers are high-range water reducers that can increase the workability and strength of concrete without compromising its durability.

The use of superplasticizers has become increasingly popular in recent years due to their ability to improve the performance of concrete, especially in high-strength and high-performance applications thus the need for proper dosing. Superplasticizers were introduced as a means of reducing the water content of concrete while maintaining its workability and a wide range of superplasticizers have been developed, including sulfonated naphthalene formaldehyde condensate (SNF), sulfonated melamine formaldehyde condensate (SMF), and polycarboxylate ether (PCE). These superplasticizers are typically added to concrete in small quantities, with dosages ranging from 0.1% to 2% by weight of cement or as recommended by manufacturer.

Despite the benefits of superplasticizers, their use can also pose challenges. For instance, superplasticizers can cause slump loss if not properly dosed, resulting in a reduction in workability and an increase in the risk of cracking. The use of superplasticizers can make it more difficult to control the setting time of concrete, which can be a challenge in certain applications.

The goal of this work is to optimize the use of superplasticizers in concrete by determining the optimal dosage of superplasticizer that will result in the best performance of the concrete.

The early age properties of concrete such as workability, setting time and initial strength are continuously changing due to its transient behaviour hence the need to improve the properties of fresh concrete as per the requirements of the structures. Superplasticizer are added to the concrete to achieve a desired change in its properties.

This study hopes to help determine the optimal dosage of superplasticizer that will result in the best performance of the concrete, investigate the compressive strength of concrete produced after 7 days and 28 days when fully immersed in water at different dosage of Costarcel-200 for a (1:3:6) mix proportion at water cement ratio of 0.5.

The optimization of the right dosage of superplasticizer in concrete mix helps to achieve construction quality and the problem due to thermal cracking can also be avoided.

The right usage of superplasticizers are essential for high quality concrete and for promoting the improvement of concrete performance. They also increase the life of construction work and impart additional protection to the buildings by improving their life span. Chemical admixtures known as superplasticizers are applied to concrete to increase its workability and lower the water cement ratio. The wet density of concrete can be greatly increased with the application of superplasticizers. (Daniel and Orie, 2018). By spreading the cement granules in concrete, superplasticizers lower the amount of water required to obtain the specified workability. Both the workability and compressive strength of concrete increase with the use of superplasticizers; the workability improvement by the superplasticizer in the concrete is primarily brought on by an increase in the surface potential force. Superplasticizers can also speed up the rate of strength gain in concrete, which can result in shorter construction times.

A. Components of Concrete

The binding component of concrete, cement, is what gives the substance its strength and durability. The kind and quantity of cement used in concrete can significantly affect its strength and durability. To hydrate the cement and provide workability, water is used in concrete. However, the quantity of water used in concrete can have a big impact on how strong and long-lasting it is. The water-cement ratio is the most important factor influencing the properties of concrete. (Neville, 2011). Concrete uses aggregate to add bulk and lower the amount of cement required. The kind and quantity of aggregate used in concrete can significantly affect its strength, durability and workability. Admixtures are chemical additives added to concrete to enhance its properties.

B. Use of Superplasticizers in Concrete Production

Superplasticizers are high range water reducers. The use of superplasticizers has several benefits, including improved workability, a lower water-cement ratio and increased strength. In addition to reducing the amount of cement required in concrete, superplasticizers can also result in cost savings. The cost-effectiveness of using these admixtures as well as any potential drawbacks of using superplasticizers, such as an increased risk of segregation and bleeding, must be taken into account. Since attack by chemicals has been a major cause of corrosion and consequent damage of concrete structures, there is the need for the use of non-chloride based admixtures for improvement of concrete properties (Mainak, 2022).

C. Dosage Impact of superplasticizers on Flow

Depending on what the user wants to influence, the flow enhancement increases as plasticizer dosage increases. The smallest amount necessary to produce a dispersion effect is known as the critical dosage of a superplasticizer. Below this dosage, the effects of the superplasticizer are either not significant or at the very least difficult to observe in the tests conducted on the mix under consideration. Above this dosage, flow will increase continuously until a certain point at which surface saturation is reached. Beyond this saturation dosage, an additional dosage increase has little effect on the flow and segregation, bleeding, and a delay in hardening are possible to see (Aitcin and Neville, 2001). The volume fraction of fines and their various size distribution have a significant impact on segregation and bleeding. The saturation dosage is not or much less dependent on w/c, but it still has similar dependencies. The critical dosage for superplasticizers of the LS, PNS, and PMS types is higher than that for other PCE superplasticizers, and they also require a higher dosage to cause the paste to flow (Yang et al. 2015).

D. Properties of Concrete

Concrete is a widely used construction material due to its strength, durability, and low cost. The properties of concrete depend on several factors, such as its composition, curing conditions and environmental factors.

i Compressive Strength

This is the e maximum compressive stress that a concrete specimen can withstand before failing. It is an essential mechanical characteristic that specifies concrete's capacity to withstand compression or crushing. Olafusi et al. (2015) stated that using various admixtures can increase the compressive strength of concrete. Concrete cubes are tested in a compression testing machine to determine the compressive strength. Concrete's compressive strength is influenced by a number of variables, including the mix design, the curing environment, the age of the concrete, and the presence of superplasticizer (Khatib 2010). The mix design, which determines the type and proportion of cement, aggregates, water and other admixtures, is a key factor that affects compressive strength.

The British Standard offers guidelines for testing practices, specimen preparation, and acceptance standards. Concrete's compressive strength is an important mechanical characteristic that has an impact on the performance, safety, and durability of concrete structures.

ii. Tensile Strength

The tensile strength of concrete is the highest tensile stress that a concrete specimen can withstand before failing in tension. Literature shows that using various fiber types, such as steel, polypropylene and glass fibers, could increase the tensile strength of concrete.

iii Flexural Strength

Flexural strength is the highest stress a material can withstand before failing to bend. It is an important factor in the design and assessment of structural components like slabs, beams, and columns. The loading rate, size and shape of the specimen can all affect the flexural strength of concrete.

II. MATERIALS AND METHODS

A. Materials

The materials used in this study are cement (Dangote 3x), fine aggregate (river sand), coarse aggregate, potable water and superplasticizer (costarcel-200).

B. Methods

a. Workability

The workability of the superplasticized concrete was determined using Slump test.

Slump Test:

The most popular technique for assessing concrete's workability is the slump test. It is an easy test that entails adding fresh concrete to a standard metal cone, compacting it with a standard rod, and then taking the cone out to determine the slump of the concrete. The test is carried out in accordance with BS code for testing fresh concrete (BS1881 -108, 1978). Slump test, the steel slump cone is placed on a solid, impermeable, level base and filled with the fresh concrete in three equal layers. Each layer is tamped twenty five times to ensure compaction. The third layer is finished off level with the top of the cone. The cone is carefully lifted up, leaving a heap of concrete that settles or 'slumps' slightly. The upturned slump cone is placed on the base to act as a reference, and the difference in level between its top and the top of the concrete is measured and recorded to the nearest 10mm to give the slump of the concrete.

b. Mix Proportioning

Different types of concrete mixes were prepared using water-cement ratio of 0.5.

Using water, fine aggregate, coarse aggregate, cement and superplasticizer; Costarcel-200 (control, 1%, 1.2%, 1.4%, and 1.5%). The molds were coated with engine oil to ensure the removal of hardened concrete from mold was easy.

c. Testing of Specimens

Tests were carried out on the fresh concrete and hardened concrete.

The slump test and wet density were conducted on fresh concrete after mixing the concrete while the tests conducted on hardened concrete were dry density, compressive strength test and flexural strength.

d. Wet Density

This is the mass of a unit volume of fully wet concrete. The water-cement ratio, the kind and quantity of aggregate and the use of chemical admixtures are a few of the variables that affect the wet density of concrete. This is expressed in terms of kg/m^3.

To measure the wet density of concrete:

1. A cubic frame of 150mm x 150mm x 150mm that is large enough to hold the required volume of the concrete was used. The cube was cleaned and dried.

2. The weight of the empty cube was done on a scale and recorded.

3. The fresh concrete was poured into the cube until it was full. The sides of the container were gently tapped to remove any air pockets and to ensure that the concrete was packed tightly.

4. The container with the fresh concrete was weighed and recorded.

5. The density of the fresh concrete was calculated by dividing the weight of the concrete by the volume of the cube. The density will be expressed in units of weight per volume, such as pounds per cubic foot or kilograms per cubic meter.

e. Dry Density

This is the mass of a unit volume of fully dried concrete. Concrete's dry density is affected by a number of factors, including the type and quantity of aggregates, cement content, water cement ratio, and compaction technique. The dry density is usually expressed as either g/cm^3 or Kg/m^3. it is a measure of its unit weight and is determined by determining the density of the materials that go into it. The dry density of concrete is also impacted by the compaction technique used during construction. A higher compaction pressure and a longer compaction time has been found to increase the dry density of concrete alongside a decrease in the water cement ratio. (Simnani, 2017).

In conducting the dry density test of concrete according to the BS code, the following steps were involved:

1. A cylindrical or cubical concrete specimen was prepared according to the required dimensions specified in the code.

2. The concrete was allowed to cure and gain strength for a specified period of time, typically 28 days.

3. The dry specimen was weighed to determine its mass.

5. The volume of the specimen was measured using the water displacement method or other suitable techniques.

6. The dry density was calculated by dividing the mass of the specimen by its volume.

f. Compressive Strength

The compressive strength is determined by testing the concrete cubes in a compression testing machine.

Grade 25 concrete was cast using cube sizes of 150mm × 150mm × 150mm at varied quantities of composites conforming to BS 8110 and BS 1881-108. For the given parameters and levels. Demoulding was done after 24 hours thereafter the samples were transferred to curing tank maintained at room temperature. The cubes were tested for compressive strength on removal from the curing tank at 7days and 28days using compression machine and the strength determined from the equation:

$$F_c = \frac{P}{A} \quad \text{..........................eqn 3.1}$$

Where,

F_c = Compressive strength

P = Maximum load

A = Cross sectional area.

g. Flexural Strength

The flexural strength test of concrete was conducted according to the BS code (BS EN 12390-5)

1. The concrete paste was made with sand, water, aggregate and 1.5% of Costarcel-200.

2. After the paste was made, the beam cubes was cleaned with engine oil to enable easy removal of beams after the required curing time.

3. The mix was then added to the cubes of 500mm x 100mm x 100mm.

4. The concretes was then removed from the cubes after 24 hours and was fully immersed in water.

5. The concrete was allowed to cure and gain strength for a specified period of time, typically 7 and 28 days.

6. The specimen were placed on two supports, creating a span between them.

7. A gradually increasing load at the midpoint of the span was applied until the specimen failed

8. The maximum load at which the specimen fails and the corresponding deflection is recorded.

9. The flexural strength is calculated by using the formula specified in Equation 3.2

$$F = \frac{PL}{bd^2} \quad \text{..........................Eqn 3.2}$$

Where,

F= Flexural strength of concrete (N/mm^2)

P= Failure load (in N)

L= Effective span of beam (mm)

b= Breadth of the beam (mm)

d= Depth (mm)

III. RESULTS AND DISCUSSION

A. Superplasticizer Content as a Percentage of Cement Weight

The content of superplasticizers is shown in Table 3.1.

Table 3. 1: Superplasticizer Percentage According To Cement Weight

Number	Superplasticizer Percentage
1	1%
2	1.2%
3	1.4%
4	1.5%

The selected percentage (dosages) of costarcel-200 used in this research ranges from 1%, 1.2%, 1.4% and 1.5% as shown in Table 3.1. According to the product data sheet of costarcel-200, the recommended dosage range for costarcel-200 is between 1% -2% of cementitious material.

B. Slump Test

The result of the slump test is presented in Table 4.2

Table 3.2: Slump Test Result

Sample	Slump Height (mm)
Control	52
1%	167
1.2%	113
1.4%	202
1.5%	157

The result of the slump test at 0.5 w/c is shown below in Table 3.2. The result showed that control produced a slump of 52mm which indicates that it`s less workable and a more stiffer mix while 1.4 % addition of superplasticizer produced the highest slump of 202mm which indicates a more fluid and workable mix. There was an increase in the addition of 1.4% of superplasticizer by 288.4% as compared with the control. The result indicates that the addition of superplasticizer increases the workability of a mix, The superplasticizer significantly increased the workability of concrete due to deflocculation and adsorption of highly negative charges on cement particles. (Alsadey et al., 2022) .

A more fluid mix is typically needed in situations where the concrete needs to flow easily and fill intricate spaces or molds. For example where the concrete needs to fill complex formwork with intricate shapes or tight corners, a fluid mix is advantageous.

C. Compressive Strength Test For Costarcel-200 at 7days.

The result of the 7 days compressive strength test is presented in Table 3.3

Table 3.3: 7 Days Compressive Strength Test For SP Concrete

Sample Description	Dosage of Superplasticizer	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
3	0%	15.55	13.55
4	0%	11.55	
5	1%	16.22	14.11
6	1%	12	
9	1.2%	13.55	12.33
10	1.2%	11.11	
13	1.4%	13.55	15.66
16	1.4%	17.77	
18	1.5%	16.22	15.33
20	1.5%	14.44	

The average compressive strength for 7 days for different dosages of costarcel-200 which are Control, 1%, 1.2%, 1.4% and 1.5% are shown in Table 3.3. The tabulated results showed that 1.2% of superplasticizer added has the lowest average compressive strength of 12.33 N/mm^2 at 7 days while 1.4% of superplasticizer added has the highest average compressive strength of 15.66N/mm^2. This indicates that at day 7, the 1.4% has the highest ability to withstand a compressive load before it fails under compression. The result of the average compressive strength shows that when 1.4% of superplasticizer was added there was an increase in compressive strength by 15.57% and there was a reduction by 9% in the compressive strength when 1.2% of superplasticizer was added as compared with the control.

D. Compressive Strength Test at 28 days.

The result of the 28 days compressive strength test is presented in Table 3.4

Table 3.4: 28 Days Compressive Strength Test For SP Concrete

Sample Description	Dosage of Superplasticizer	Compressive strength (N/mm^2)	Average compressive strength(N/mm^2)
1	0%	25.64	24.62
2	0%	23.6	
7	1%	19.86	18.15
8	1%	16.44	
11	1.2%	19.33	22.55
12	1.2%	25.77	
14	1.4%	20.88	22.22
15	1.4%	23.55	
17	1.5%	27.11	25.56
19	1.5%	24	

The average compressive strength for 28 days for different dosages of costarcel-200 are shown in Table 4.4. The tabulated results showed that 1% of superplasticizer added has the lowest average compressive strength of 18.15 N/mm^2 at 28 days while 1.5% of superplasticizer added has the highest average compressive strength of 25.56 N/mm^2. This indicates that at day 28 the 1.5% has the highest ability to withstand in a compressive load before it fails under compression. The result of the average compressive strength shows that when 1.5% of superplasticizer was added there was an increase in compressive strength by 3.81% and there was a reduction by 26.27% in the compressive strength when 1% of superplasticizer was added as compared with the control

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E. Dry Density Test at 7 days.

The result of the 7 days dry density test is presented in Table 3.5

Table 3.5: 7 days Dry Density Result For SP Concrete

Sample Description	Dosage of Superplasticizer	Dry density(kg/m^3)	Average dry density(kg/m^3)
3	Control	2513.48	2462.96
4	Control	2412.44	
5	1%	2436.14	2433.33
6	1%	2430.51	
9	1.2%	2415.40	2408.59
10	1.2%	2401.77	
13	1.4%	2397.62	2415.69
16	1.4%	2433.77	
18	1.5%	2420.44	2426.07
20	1.5%	2431.70	

The dry density at 7 days using different dosages of costarcel-200 is as shown in Table 3.5. The results showed that control at 7 days have the highest average density of 2462.96 kg/m^3 while 1.2% of superplasticizer has the lowest average density of 2408.59 kg/m^3. There was no increase in the average dry density after the addition of different dosages of costarcel-200, the outcome show that there was a slight reduction of dry density after the addition of costarcel-200. The addition of 1.2% produced the highest reduction by 2.20% and addition of 1% produced the lowest reduction by 1.20% as compared with the control. But the difference in average dry density of all the dosages at 7 days slightly differs. This might be due to ongoing hydration and compaction processes in the concrete at this stage.

F. Dry Density Test at 28 days.

The result of the 28 days dry density test is presented in Table 3.5

Table 3.6: 28 days Dry Density Result For SP Concrete

Sample Description	Dosage of Superplasticizer	Dry density (kg/m^3)	Average dry density(kg/m^3)
1	Control	2469.33	2477.03
2	Control	2484.74	
7	1%	2388.74	2439.11
8	1%	2489.48	
11	1.2%	2410.96	2430.37
12	1.2%	2449.78	
14	1.4%	2440.88	2429.77
15	1.4%	2418.66	
17	1.5%	2548.74	2505.34
19	1.5%	2461.93	

The dry density at 28 days using different dosages of costarcel-200 as shown in Table 3.6. The results showed that addition of 1.5% superplasticizer at 28 days have the highest average density of 2505.34 kg/m^3 while 1.4% of superplasticizer has the lowest average density of 2429.77 kg/m^3. There was little increase in the average dry density after the addition of 1.5% dosage of costarcel-200 by 1.14%, and the outcome show that they was a reduction in average dry density after the addition of 1.4% of costarcel-200 by 1.90%. The addition of 1.5% produced an increase by 1.14% and addition of 1.4% produced a reduction by 1.90% as compared with the control. But the difference in average dry density of all the dosages at 28 days slightly differs. This might be due to ongoing hydration and compaction processes in the concrete.

G. Wet Density Test For SP Concrete.

The result of the wet density test is presented in Table 3.7

Table 3.7:Wet Density Result For SP Concrete

Description	Dosage	Wet density (kg/m^3)	Average wet density(kg/m^3)
1	Control	2503.70	2525.92
2	Control	2548.14	
5	1%	2548.14	2548.14
6	1%	2548.14	
9	1.2%	2488.88	2474.06
10	1.2%	2459.25	
13	1.4%	2488.88	2518.51
14	1.4%	2548.14	
17	1.5%	2577.77	2533.32
18	1.5%	2488.88	

Table 3.7 shows the wet density using different dosages of costarcel-200. The results showed that addition of 1% have the highest average density of 2548.14 kg/m^3 while 1.2% of superplasticizer has the lowest average density of 2474.06 kg/m^3. There was a slight increase in the average wet density after the addition of 1% dosage of costarcel-200 by 0.9%, and there was a reduction in average wet density after the addition of 1.2% of costarcel-200 by 2.1% as compared with the control.

H. Flexural Strength Test For SP Concrete at 28 days

The result of the 28 days flexural strength test is presented in Table 3.8

Table 3.8:28 days Result for Flexural Strength of Beam.

Beam number	Super-Plasticizer	Wet weight (kg)	Dry weight (kg)	Failure load (N)	Flexural strength (N/mm^2)	Average flexural strength (N/mm^2)
1	Costarcel 200 (1.5%)	14.1	12.400	7500	3.75	3.9
2	Costarcel 200 (1.5%)	14.3	12.250	8000	4	
3	Control	14.5	12.250	4000	2	2.5
4	Control	14.2	12.300	6000	3	

The flexural strength for 28 days for the control and 1.5% addition of costarcel-200 are shown in Table 3.8. The tabulated results showed that 1.5% addition of superplasticizer produced a flexural strength of 3.9 N/mm^2 at 28 days while the control had a flexural strength of 2.5 N/mm^2. There was an increase in the addition of 1.5% of superplasticizer by 56% as compared with the control. This indicates that in situations where concrete with high flexural strength are needed like, construction of bridges, beams and slabs, addition of superplasticizers such as costarcel-200 should be considered during this type of construction because this helps to prevent cracking or damages caused by heavy equipment or machinery as it ensures the durability and safety of structures under bending forces.

IV. CONCLUSION

This work has provided a guide on the effect of different dosages of costarcel-200 on concrete properties. The use of costarcel-200 impacted positively on the wet and dry densities, workability, compressive and flexural strength of the concrete within the permissible range. It can be concluded that the maximum compressive strength at 28 days can be achieved at 1.5% addition of the costarcel-200 admixture and such dosage is recommended for practical purposes.

REFERENCES

Aïtcin, P. C., & Neville, A. M. (2001). "High-Performance Concrete." Materials Science of Concrete, 1, 1-36 (12).

BS 1881-102:1983. (1983). Testing concrete Method for determination of slump.

BS 1881: Part 115 (1983) "Specification for Compression Testing Machines for Concrete"

D.E. Ogheneochuko and O. U. Orie (2018). Optimization Of Superplasticized Concrete, Using Taguchi Approach. A Case Study Of Hydroplast 200. Nigerian Journal of Technology (NIJOTECH). VOL 37. No. 3, July 2018, pp.611 - 618

Flatt, R. J. (2004). "Mechanisms of cement hydration." Proceedings of the Institution of Civil Engineers - Construction Materials (7)

Flatt, R. J., & Bowen, P. (2003). "Understanding the rheology of concrete." WoodheadPublishing 14 (7), 56-99https://doi.org/10.3403/00048831

Khatib, J. M. (2010). Early age strength prediction of OPC concrete with and without superplasticizer. Construction and Building Materials, 24(10), 1893-1901.

Olafusi, O. S., Adewuyi, A. P., Otunla, A. I. and Babalola, A. O. (2015). Evaluation of Fresh and Hardened Properties of Self-Compacting Concrete. Open Journal of Civil Engineering. Vol. 5, pp. 1 – 7.

MainakGhosal ,Arun Kumar Chakraborty (2022). Superplasticizer compatibility with cement properties (6), 3-15

.

Alsadey, S. and Omran, A. (2022). Effect of superplasticizer to enhance the properties of concrete. Design, Construction, Maintenance. Vol. 2, pp. 84 - 91.

Simnani, S. I. (2017). Effect of water-cement ratio on density of concrete. Journal of Emerging Technologies and Innovative Research. Vol. 4, Issue 10, pp. 483 - 485.

Mindess, S., Young, J. F., & Darwin, D. (2003). The use of superplasticizers in concrete technology and their impact on improving workability and strength of concrete (6), (7).

Neville A M (2005). Properties of concrete, Pearson Prentice Hall.

Neville, A. M. (2011). "Properties of Concrete." Pearson Education Limited (7), (23).

Tanyildizi, H., et al. (2019). "Effects of Temperature on Concrete Properties: A Comprehensive Review." Construction and Building Materials, 217, 639-652 (24).

Wong, H. S., & Buenfeld, N. R. (2003). The influence of superplasticisers on the transport properties of concrete. Cement and Concrete Research, 33(10), 1607-1615.

Yang, Y., Chen, C., Li, Y., Li, H., & Li, H. (2015). Effects of superplasticizer on mechanical properties and durability of high-performance concrete. Materials and Structures, 48(8), 2515-2524.