Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 44 No. 8
August 2023

Evaluation of Physical Salt Attack on the Mechanical Properties of Spun Concrete

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Abstract: The article's main focus is on spun concrete created with various chemical admixtures and subjected to prolonged contact to salt-saturated ground water that is hostile and a cyclical temperature gradient. 64 prismatic spun concrete specimens were processed several times (75–120 times) throughout the course of an extended experimental study under a variety of harsh environmental conditions. Drying was place at a temperature of 45 to 50 °C after prismatic specimens had been soaked in water or saline. It was discovered that the physical salt assault and temperature gradient's long-term multi-cycle effects on concrete's compressive strength, Young's modulus, and durability were detrimental. However, chemical admixtures enhanced the structure of spun concrete, greatly enhancing its physical-mechanical characteristics and durability.

Keywords: spun concrete; durability; PSA; temperature; cyclic wetting-drying; chemical admixtures

1. Introduction

The major causes of reinforced concrete constructions degrading before their time include corrosion of the protective layer of reinforcement and subsequent corrosion of the reinforcement. The protective covering of metal is peeled off by metal corrosion products, which also causes the cross-section of longitudinal and transverse reinforcement to shrink. The transverse reinforcement then cracks, causing irreversible degradation.

The residual water-cement ratio (W/C), hardening conditions, compaction level, alternating wetting and drying conditions, freezing and thawing, bacterial corrosion, and attacks by various chemicals (e.g., chlorides and sulphates) are some of the factors covered in the scientific literature that affect concrete corrosion. The most harmful and aggressive component, however, is the physical salt assault on concrete caused by salty groundwater, which results in considerable financial costs. Physical salt attack (PSA) damage develops when pressure builds inside the pores of concrete due to the accumulation of crystallised groundwater salts (sodium chloride, sodium carbonate, and sodium sulphate). The Middle East, North Africa, a few states in the United States, and Australia are among the dry regions where this kind of salt weathering is most frequently seen [1].

The most damage seems to result from the cyclic wetting and drying of salt in solid cement paste because it enables salts to get to the evaporating surface through capillary action. Salt crystallisation can take place either directly on the paste's surface or within a specific layer, depending on the paste's structure. In the first scenario, type 1 corrosion results from the steady drop in calcium hydroxide concentration in the next layer of hardened cement paste due to an increase in its solubility in the presence of salts. Water evaporates off the product's surface and the pores of the top layer of the concrete if the pores are large enough (0.2 m). Salt then crystallises in the pores of the dried cement paste, causing corrosion type three (deterioration). Although the exact process of concrete fracture is unclear, there are a number of theories as to why hardened cement paste degrades when exposed to saltwater in the presence of surface evaporation [2].

One of the earliest theories on the pressure for salt crystallisation within the pores of hardened cement paste suggested that it was brought on by increasing tensile strains. Because the crystallisation pressure is negligible and cannot account for all of the cement paste's degradation, the validity of this idea is called into doubt. According to a second theory, the growth of neoplasms is what causes the degradation brought on by potassium salts. As a result, internal tensions develop that lead to crack forms, which help an aggressive medium penetrate deeply into the concrete together with the salt buildup in the pores. When concrete is saturated with salt, the wedging action of water can also cause degradation because it creates alternate strains under cycle wetting and drying, osmotic pressures, and variations in the thermal expansion coefficients of hardened cement paste and salts. A third theory is that an increase in the amount of salt crystals at the conversion phase from less to more hydrated is the major cause of the degradation of hardened cement paste subjected to cyclic wetting with saline and drying. The most harmful condition of concrete is generally agreed to be when it is first dried at a temperature over the salts' phase transition point, then wetted at a lower temperature with the production of expanding crystalline hydrates. None of the aforementioned ideas offers a complete explanation for the complicated events in this particular example that characterise the deteriorating process of hardened cement paste under the aggressive action of saltwater. It appears that a combination of all the aforementioned components determines the rusting mechanism. Numerous research on the parameters affecting concrete durability are available in the scientific literature, including those on physical salt attack (PSA) [3–13], cyclic wetting and drying (CWD) [14–16], the water–cement ratio of the initial concrete mix [14,17–19], and chemical admixtures [20].

Because spun concrete is substantially more costly, time-consuming, and complex, the vast majority of research [21] focus on the durability and dependability of vibrated concrete rather than spun concrete. The research papers that claim that exposure to saline initially improves the structure of concrete [14] and that the detrimental effects of pressure from salt crystals growing in concrete pores are only apparent after prolonged exposure also take into account the effects of PSA and CWD on the physical-mechanical properties of vibrated concrete. Numerous research on the parameters affecting concrete durability are available in the scientific literature, including those on physical salt attack (PSA) [3–13], cyclic wetting and drying (CWD) [14–16], the water–cement ratio of the initial concrete mix [14,17–19], and chemical admixtures [20].

Experimental results presented by Liu et al. [14] showed that after 80 CWD cycles of a sulphate attack, the compressive strength of vibrated concrete increased by 12%. The corrosion that results from repeated wetting and drying of concrete was exacerbated by soaking [14]. Another extremely important aspect that affects a concrete structure's longevity and is closely connected to the one described above is the temperature at which it operates and the gradient of that temperature throughout the day. For example, in the deserts of Asia, North Africa, or Australia, the surface temperature of a structure frequently fluctuates from +60 °C during the day to 20 °C at night, which causes elongation-shortening (swelling-shrinkage) forces that destroy concrete. Wetting and drying in the zone of contact with the ground create the same swelling-shrinkage stresses of hardened cement paste that are brought on by the capillary filtration of groundwater brought on by wind. In a thorough examination of how climate change affects the degradation of concrete infrastructure is provided. Despite the fact that an example from Australia was used in the research, all drylands have inherent issues. The researchers examining how an operating temperature affects the characteristics of vibrated concrete noted that the long-term effects of the temperature gradient on the mechanical properties of concrete were negative and subject to the composition of the concrete mix (water-cement ratio), the magnitude of the temperature gradient and the frequency of variations, groundwater aggressiveness (chemical composition), capillary soil-water migration in concrete, the humidity, and the temperature gradient's frequency.

When the steady-state temperature increased from 20 to 200 C, concrete showed a modest loss of strength, according to a review of the literature by D.J. Naus. The situation was very different when it came to seasonal and daily periodic fluctuations in temperature. Concrete's mechanical qualities were damaged by cyclical fluctuations and changes in CWD-induced strain, which expedited the onset and development of damage and ultimately led to disintegration. According to D. Chen et al., the loss rate of the Young's modulus was about 12% lower when the temperature gradient was between 1.1 and 32.2 C (matching actual climatic circumstances). According to the findings of V. Korovyakov et al., increasing the amount of cementitious components when the W/C ratio doesn't exceed 0.34 is one method for improving the cracking resistance of concrete in a hot (up to 50 °C) and dry climate. contains a study on recycled aggregate concretes that were subjected to temperatures as high as 200 and 400 C.

2. Materials and Technique of Investigation

2.1. Materials and Concrete Mixture Design

2.1.1. Cement

The cement utilised was Portland slag cement with a 40 MPa compressive strength. Table 1 lists the primary mechanical and physical characteristics of it, and [22] goes into further depth about these characteristics.

Table 1. The main physical–mechanical properties of Portland slag cement.

Parameter	Unit	Value
Normal consistence of cement grout	%	26.2
Initial setting time	hour	3.25
Final setting time	hour	4.75
Griding fineness	%	85.0
Volumetric density	kN/m^3	26.5

.1.2. Aggregates

Sand with particle sizes ranging from 0.14 to 1.25 mm was used as a fine aggregate, and granite rubble with particle sizes ranging from 2.50 to 25.00 mm was utilised as a coarse aggregate, to make the concrete mix. The maximum amount of particles generated with a diameter of 20 to 25 mm was 10% by weight. The coarse aggregate's maximum particle size complied with technological and design standards by not being more than one-third the thickness of thin-walled specimens' walls. Table 2 provides information on the aggregates' mechanical and physical characteristics.

Table 2. The physical-mechanical properties of fine and coarse aggregates.

Properties	Units	Coarse Aggregate	Fine Aggregate
Volumetric density	kN/m^3	15.10	13.50
Volumetric compacted density	kN/m^3	17.00	16.40

Amount of contaminant	%	0.10	0.20
Grade of crushed stone	MPa	100	-
Humidity ratio	%		2.20
Fineness modulus	-		1.24

2.1.3. Water

Potable water from the water supply system was used to produce the concrete mix.

2.1.4. Chemical Admixtures—Superplasticizers

The effects of chemical admixtures on the mechanical and physical characteristics of spun concrete were examined using three different types of superplasticizers (Table 3).

Table 3. Chemical admixtures used in the experimental investigation.

Type of Chemical Admixture	Description of the Chemical Origin of Admixture
C-3	Synthetic product based on sulphonated napht ‘’’’’’halene formaldehyde resin
Dofen	Oligomeric compound based on sodium salt and naphthalene sulfonic acid
ACF-3M	Acetone–formaldehyde resin

The effective quantity of the admixtures was calculated using data from the authors' earlier study. All admixtures were mixed with water before being added to the concrete mixtures.

2.1.5. The Composition of the Concrete Mix

Heavy concrete with a compressive strength of 60–70 MPa specimens were obtained for durability investigations on spun concrete. In concrete combinations, the amounts of sand, crushed stone, cement, and water were 400, 1280, 565, and 164–209 kg/m3, respectively. Part of the water and cement admixtures were removed from concrete mixes during the centrifugation process. As a result, the initial water-cement ratio ranged between 0.29 and 0.37 before dropping to the residual water-cement ratio of 0.28 to 0.30. To make the consistency of the concrete mix comparable to that of the concrete mix made without admixtures, the compositions of the concrete mixes, including chemical admixtures, were chosen. The water-to-cement ratio was changed to achieve this. The amount of chemical admixtures present and the concrete's initial water-to-cement ratio (W/C).

Table 4. The content of chemical admixtures in concrete mixes and $(W/C)_{in}$ ratio under the same consistence of the concrete mix.

No.	Admixture Type	Content of Admixture (% of Cement Mass)	$(W/C)_{in}$ Ratio
1	C-3	1.00	0.29
2	Dofen	1.00	0.30
3	ACF-3M	0.15	0.37
4	Admixture-free	-	0.37

The composition of concrete mixtures prepared without chemical admixtures corresponded to those used to manufacture spun poles for overhead power lines and provide a compressive strength of spun concrete of 60 MPa.

3. The Assessment of the Mechanical Properties of the Specimens

The concrete resistance coefficients and [25]—corresponding to the predicted compressive strength fc and the starting Young's modulus E—were used to assess spun concrete's resistance to harsh environmental conditions. The degree to which the original mechanical characteristics of spun concrete were retained was expressed by these dimensionless coefficients. The resistance coefficient, which measures the degree of preservation, is the comparison of the mechanical property indicators for exposed concrete to those for unexposed concrete.

The experiment values and coefficients for the influence of the various hostile environmental factors were determined by the study. Conditional three-digit indices were chosen to represent the mechanical qualities since making the spun concrete examples required the application of several chemical admixtures and durability testing revealed the variable impacts of the environmental circumstances. Each index lists the kind of chemical admixture employed as well as the temperature and method of soaking the fundamental specimens.

The grade of the chemical admixture is indicated by the first digit of an index:

1. Concrete mixture without additives.
2. Acetone-formaldehyde resin ACF-3M, Dofen, and C-3 superplasticizers are all included in the first, second, and third concrete mixtures, respectively.

The second digit represents the ambient exposure temperature: 0. A temperature of 18 to 22 degrees Celsius is used to preserve specimens; a temperature of 45 to 50 degrees Celsius is used to dry specimens.

The third number represents the ambient temperatures for the primary specimens in the wetting phase at 20–25 °C:

1. Normal temperature and humidity.
2. Water.
3. Saline.

The resistance of spun concrete to temperature variations was estimated with reference to the coefficients:

$\alpha 1 = fc,i,1,1/fc,i,0,0$ (1) $\beta 1 = Ec,i,1,1/Ec,i,0,0$ (2)

where $f_{c,i,1,1}$ and $E_{c,i,1,1}$ are, respectively, the prismatic compressive strength and the Young's modulus of spun concrete subjected to alternate wetting in water at 20–25 °C and drying in the air at 45–50 °C; $f_{c,i,0,0}$, and $E_{c,i,0,0}$ are indicators for the relevant mechanical properties under normal temperature and humidity.

When analysing the durability of concrete, the assessment of the resistance to the combined (simultaneous) impact of several types of harsh environmental conditions is crucial. The experiments looked into how well the materials held up under the combinedly demanding conditions of salinity and temperature changes. The coefficients were used to assess the durability:

$\alpha 2 = fc,i,1,2/fc,i,0,0$ (3) $\beta 2 = Ec,i,1,2/Ec,i,0,0$ (4)

where $f_{c,i,1,2}$ and $E_{c,i,1,2}$ are, respectively, the prismatic compressive strength and the initial Young's modulus subjected to alternate wetting in saline at 20–25 °C and drying in the air at 45–50 °C.

One of the key factors affecting durability in dry and hot climates is resistance to the corrosive effects of salts. Concrete corrosion class 3, which incorporates all environmental interactions, is used to reinforced concrete and concrete structures utilised as supports in desert environments. These mechanisms are connected to the creation and buildup of salts that are poorly soluble. Internal tensions and destructive processes result from a rise in salt volume during conversion to the solid phase, or the stage of crystal formation. The crystallisation of reaction products and salts that enter the pores of hardened cement paste from the outside in the form of a solution may cause similar events. Temperature has a significant impact on how quickly the processes go forward. As a result, corrosion class 3 advances significantly more quickly in a desert's hot environment than it does in other difficult climates' low temperatures. Regrettably, present regulations do not offer a way to assess concrete's corrosion resistance. In this situation, it appears that the well-known approach developed by Skramtaev is the most often used methodology for an expedited determination including cycles of saturation in an aggressive salt solution followed by drying. The Skramtaev technique should concentrate largely on the temperature mode of drying since disregarding this aspect may lead to problems with the durability of spun concrete, according to earlier experiments conducted by the authors [23] and preliminary short-term research on its durability [24].

Therefore, while determining the effect of salt crystallisation on the mechanical characteristics, the authors of the current work concurred to omit temperature. The approach and methods for measuring corrosion resistance were improved in order to accomplish this aim. Unlike the resistance tests the authors report in [37], the drying temperature was decreased from 100–105°C to 45–50°C, lengthening the period. The resistance coefficients were used to evaluate the experimental data and the formulae below were used to determine them.

$$\alpha 3 = \alpha 2/\alpha 1 = fc,i,1,2/fc,i,1,1 \quad (5)$$

$$\beta 3 = \beta 2/\beta 1 = Ec,i,1,2/Ec,i,1,1 \quad (6)$$

The compressive strength or initial Young's modulus of spinning concrete was made using the same concrete mix additive, and the outcomes of soaking in an equal number of cycles in water and saltwater were compared in order to determine these coefficients. The samples were moistened and then dried in the air at the same temperature.

4. Experimental Results and Analysis

4.1. Experimental Results

Tables 5-7 list the key characteristics of the cross-sections and the outcomes of short-term axial compression tests on prismatic specimens used as controls (not subjected) and those submitted to various harsh settings.

Table 5 lists the key characteristics of the cross-sections and the outcomes of axial compression tests performed on control spun concrete prismatic specimens kept in their original environment.

Number of CWD Cycles	Type of Chemical Admixture	Code of Prism Specimen	Specimen Wall Thickness *t* (cm)	Compressive Strength f_c (MPa)	Average Compressive Strength $\bar{f_c}$ (MPa)	Initial Young's Modulus E_c (GPa)	Average Initial Young's Modulus $\bar{E_c}$ (GPa)
75	Admixture-free	1141 1146	7.40 7.20	55.1 59.2	57.2	40.8 38.8	39.8
	ACF-3M	1415 1417	9.80 9.50	60.0 56.2	58.1	37.3 36.0	36.7
	Dofen	1054 1058	9.20 9.55	71.7 68.7	70.2	41.2 38. 8	40.0
	C-3	1225 1226	9.80 9.70	69.0 73.6	71.3	38.6 40.4	39.5
120	Admixture-free	1125 1128	8.25 8.05	62.1 57.5	59.8	37.4 34. 8	36.1
	ACF-3M	1385 1388	9.55 9.50	58.4 62.0	60.2	36.5 39.	38.2

						9	
	Dofen	1065 1068	9.40 9.50	69.2 66.4	67.8	38.8 37.2	38.0
	C-3	1235 1238	9.60 9.65	70.0 73.6	71.8	39.6 37. 8	38.7

Table 6. Main parameters of the cross-sections and the results of short-term axial compression tests on spun concrete prismatic specimens soaked in water and dried in the air at 45–50 °C following 75 and 120 cycles, respectively.

Number of CWD Cycles	Type of Chemical Admixture	Code of Prism Specimen	Specimen Wall Thickness *t* (cm)	Compressive Strength f_c (MPa)	Average Compressive Strength $\bar{f}_c$ (MPa)	Initial Young's Modulus E_c (GPa)	Average Initial Young's Modulus $\bar{E}_c$ (GPa)
	Admixture-free	1142 1144 1143	7.45 7.50 7.40	48.8 53.6 44.0	48.8	28.86 - 35.10	32.0
	ACF-3M	1418 1413 1412	9.90 8.95 9.65	48.9 56.2 50.8	52.0	32.30 33.27 34.18	33.3
75	Dofen	1052 1057	9.75 9.70	49.1 60.7	58.4	36.58 41.40	39,0
		1055	9.25	65.3		39.02	
	C-3	1222 1221	9.50 9.35	63.4 61.4	59.9	39.04 38.56	39.1
		1224	9.95	55.0		39.65	
	Admixture-free	1122 1124 1126	8.20 8.30 8.00	37.0 41.7 36.2	38.3	18.5 26. 3 21.2	22.0
	ACF-3M	1382 1384 1386	9.50 9.65 9.60	40.5 39.8 44.2	41.5	24.4 26. 8 26.8	26.0
120	Dofen	1062 1064	9.55 9.55	54.8 50.6	50.8	33.2 27.6	29.6
		1066	9.60	47.0		28.0	
	C-3	1232 1234	9.65 9.70	53.0 59.8	56.0	29.4 34.2	31.3
		1236	9.60	55.2		30.3	

Table 7. Main parameters of the cross-sections and the results of short-term axial compression tests on spun concrete prismatic specimens soaked in saline and dried in the air at 45–50 °C following 75 and 120 cycles respectively.

Number of CWD Cycles	Type of Chemical Admixture	Code of Prism Specimen	Specimen Wall Thickness *t* (cm)	Compressive Strength f_c (MPa)	Average Compressive Strength $\bar{f}_c$ (MPa)	Initial Young's Modulus E_c (GPa)	Average Initial Young's Modulus $\bar{E}_c$ (GPa)
	Admixture-free	1148 1145 1147	7.50 7.25 7.15	62.7 64.5 59.7	62.3	43.0 43.8 41.6	42.8
	ACF-3M	1411 1416 1414	9.50 9.35 9.00	55.0 58.8 47.2	53.7	39.8 37.7 38.8	38.8
75	Dofen	1053 1056	9.00 8.90	57,9 61.4	62.8	42.0 40.4	41.6
		1051	9.25	69.0		42.3	
	C-3	1228 1223	9.15 9.65	69.4 64.2	64.5	41.6 43.0	43.0
		1227	9.15	59.8		44.5	

Table 8. *Cont.*

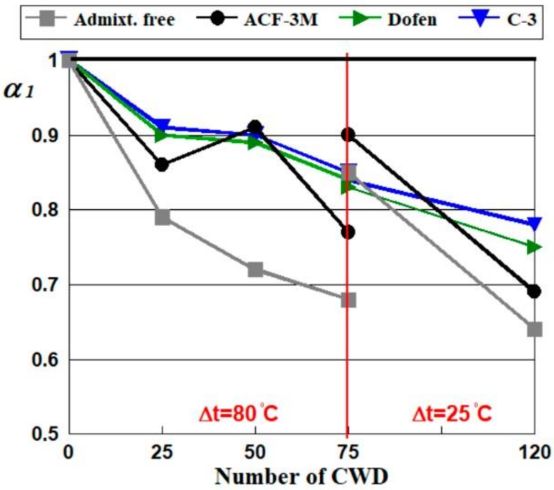
Number of CWD Cycles	Type of Chemical Admixture	Code of Prism Specimen	Specimen Wall Thickness *t* (cm)	Compressive Strength f_c (MPa)	Average Compressive Strength $\bar{f}_c$ (MPa)	Initial Young's Modulus E_c (GPa)	Average Initial Young's Modulus $\bar{E}_c$ (GPa)
	Admixture-free	1121 1123 1127	8.20 8.35 7.90	33.9 38.0 32.2	34.7	26.4 29.0 26.8	27.4
	ACF-3M	1381 1383 1387	9.60 9.50 9.75	35.9 33.2 39.2	36.1	26.6 26.1 28.6	27.1
120	Dofen	1061 1063	9.45 9.55	50.8 45.1	47.7	29.4 26.4	29.3
		1067	9.60	47.2		32.1	

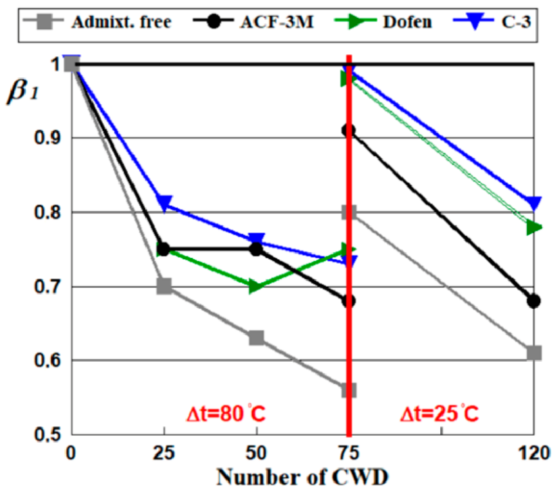
	C-3	1231 1233	9.60 9.65	49.9 55.1	52.4	28.2 32.0	30.2
		1237	9.65	52.2		30.4	

The findings of the prior investigation utilised to contrast the findings of the experimental investigation were reported in. Similar specimens were used in the studies, which entailed soaking them in water or saline for 25, 50, and 75 cycles before air-drying them at a temperature of 100–105 C.

4.2. The Resistance of Spun Concrete to Temperature Variations

The presence of temperature variations has a negative impact on the mechanical properties and consequently durability, even though they are small (t 25) and last a long time (with a large number of CWD cycles), according to test results after 75 and 120 cycles of alternately drying concrete in the air and wetting it in water. The experimental values of the resistance coefficients 1 and 1 as displayed in Table 9 and Figure 1 demonstrate this.





(a) (b)

Figure 1. Diagrams of the relationships of the resistance coefficients of spun concrete α_1 (by Equation (1)) (a) and β_1 (by Equation (2)) (b) subject to the number of wetting cycles in water, drying in the air and the temperature gradient considering the type of the chemical admixture used.

Table 9. The resistance coefficients of spun concrete α_1 and β_1 subject to the number of wetting cycles in water at a temperature of 20–25 °C and drying in the air at 45–50 °C, considering the type of chemical admixture used.

Type of Chemical Admixture	Resistance Coefficient α_1 (by Equation (1))		Resistance Coefficient β_1 (by Equation (2))	
	Number of Wetting Cycles in Water and Drying in the Air at 45–50 °C		Number of Wetting Cycles in Water and Drying in the Air at 45–50 °C	
	75	**120**	**75**	**120**

Admixture-free	0.85	0.64	0.80	0.61
ACF-3M	0.90	0.69	0.91	0.68
Dofen	0.83	0.75	0.98	0.78
C-3	0.84	0.78	0.99	0.81

The results analysis showed that the chemical admixtures significantly improved the resilience of spun concrete to temperature changes. According to Figure 1 and Table 9, after 75 cycles of CWD, the resistance coefficient 1 produced with the additives Dofen, C-3, and ACF-3M ranged between 0.83-0.90 and coefficient 1 varied between 0.91-0.99. These coefficients were 0.85 and 0.80 for conventional spun concrete, respectively. Overall, 75 soaking and air-drying cycles and a minor temperature difference of t 25 C resulted in a moderate reduction in the strain index of admixture-containing concrete [20]. Although admixture-free spun concrete's Young's modulus dropped by around 20%, its admixture-containing counterpart's compressive strength dropped from 10 to 15%

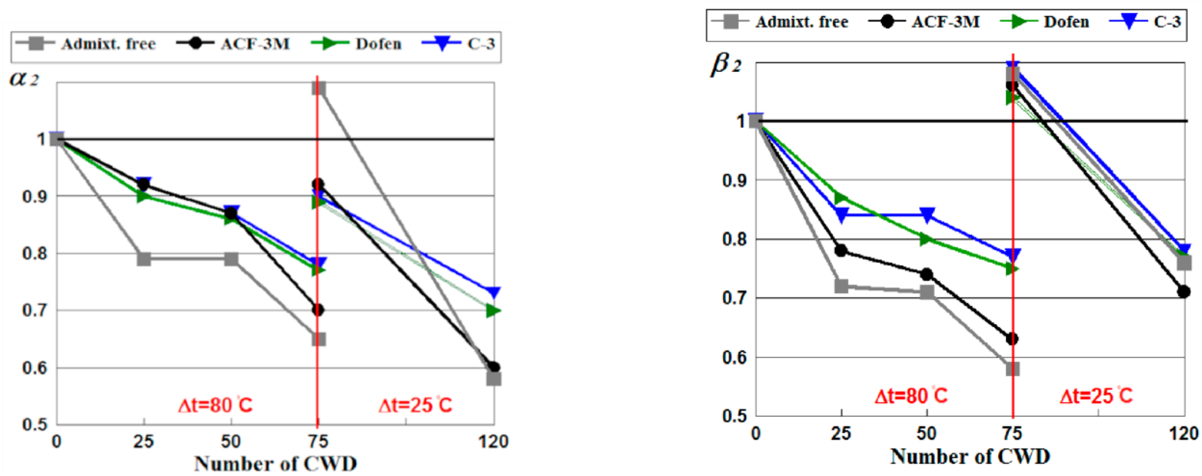
The previous experiments conducted by the authors of and displayed in Figure 1 showed that dramatic variations in temperature (wetting at a temperature of 20–25 °C and drying in the air at 100–105 °C), following 75 cycles of CWD of spun concrete containing superplasticizers Dofen and C-3 significantly reduced the initial water–cement ratio in the concrete mix, while compressive strength decreased by around 15% and the Young’s modulus dropped by approximately 25%. Meanwhile, the compressive strength and Young’s modulus of the control specimens decreased by 32 and 44%, respectively.

The "jump" in the experimental data diagram in Figure 3 is due to the fact that mechanical properties and durability of the traditional spun concrete (control) were significantly impacted by a cyclic drop in temperature from 100–105°C to 20–25°C. Figure 3 and Table 10 demonstrate that after 120 cycles of CWD, the resistance coefficients 1 produced with admixtures Dofen and C-3 varied in average value between 0.75 and 0.78, while the resistance coefficients 1 produced without admim. The aforementioned suggests that a decrease in temperature gradient seen throughout the studies did not entirely rule out the influence of temperature on mechanical qualities. The amount of a detrimental effect on the mechanical qualities was shown to depend on the number of CWD cycles and the gradient of temperature changes during the wetting-drying processes while drying in the air and wetting in water alternately.

According to the way the indicators of durability changed as the number of CWD cycles increased, it was possible that the microdefects in the concrete structure that were found to be brought on by environmental temperature variations prevented the various types of concrete from having a denser structure. Concrete made with the additives C-3 and Dofen tended to become repressed after 75 cycles of CWD, whereas admixture-free concrete and concrete made with ACF-3M remained stabl developed vigorously. The aforementioned detrimental effect of the temperature gradient began to appear considerably more quickly and the drop in the resistance coefficients 1 and 1 were more pronounced somewhere between 75 and 120 cycles of CWD. It should be mentioned that due to the needed obtained moisture surplus, these experiments showed a reduced beneficial effect of concrete wetting on the strength and strain qualities indicated in the additional l hydration of hardened cement paste. Under 1.5–2 year old concrete, 75 and 120 cycle tests were conducted. When spun concrete of this age was maintained under typical temperature-wetting conditions, previous studies shown that it only strengthened by 5-7% annually. By taking into account the composition of the concrete mix, it can be explained why the destruction of concrete containing the additive ACF-3M progressed similarly to that of admixture-free concrete. The starting water-cement ratios were 0.37, which indicated that throughout the centrifugation process, more microcapillaries developed in the concrete of the made goods and the density of concrete reduced in comparison to concrete containing admixtures C-3 or Dofen. As a result, the stresses caused by swelling-shrinkage during the wetting-drying processes of concrete had a higher detrimental effect on the stress and strain characteristics of lower-density concrete, hence reducing its resistance to tensile strains.

4.3. The Resistance of Spun Concrete to the Integrated Impact of Temperature Variations and Saline

Data on the impact of chemical admixtures on the mechanical characteristics of spun concrete were acquired and are shown in Table 9 and Figure 2 in order to evaluate the resistance of spun concrete to the combined effects of temperature fluctuations and salinity.



(a) (b)

Figure 2. Diagrams of the relationships of the resistance coefficients of spun concrete α_2 by Equation (3) (**a**) and β_2 by Equation to (4) (**b**) subject to the number of wetting cycles in saline, drying in the air and the temperature gradient considering the type of the chemical admixtures used.

Although slight, the combined effect of saline and temperature variations caused microcracks to form throughout the entire structure, which were then smoothed out by the newly formed salt crystals' positive effects on the stress and strain characteristics in the pores and microcracks. The effect of the cyclic temperature difference caused microcracks to form between the coarse aggregate that formed on the product's outer surface during centrifugation and on the layer of cement paste, allowing the salty solution to seep through. It formed crystals, gathered, and created internal pressure, which accelerated the coarse aggregate's separation from the hardened cement paste and increased cracking.

Table 10. The experimental values of the resistance coefficients of spun concrete α_2 and β_2 subject to the number of the cycles of alternate wetting in saline and drying in the air and the temperature gradient considering the type of the chemical admixture used.

Type of Chemical AdMixture	Resistance Coefficient α_2 (by Equation (3))		Resistance Coefficient β_2 (by Equation (4))	
	Number of Wetting Cycles in Saline and Drying in the Air at 45–50 °C		Number of Wetting Cycles in Saline and Drying in the Air at 45–50 °C	
	75	120	75	120

Admixture-free	1.09	0.58	1.08	0.76
ACF-3M	0.92	0.60	1.06	0.71
Dofen	0.89	0.70	1.04	0.77
C-3	0.90	0.73	1.09	0.78

Resistance coefficients 2 and 2 in accordance with (3) and (4), respectively, were used to assess the combined impact of the aforementioned parameters on the mechanical characteristics.

Figure 2 demonstrates that coefficient 2 was higher than 1 after 75 cycles of CWD. After 75 cycles of CWD, coefficient 2 was likewise greater than coefficient 1. In addition, for all evaluated varieties of spun concrete, coefficient 2 was higher than 1. After 75 cycles of CWD, the chemical admixture-containing concrete's compressive strength dropped to 10%; in contrast, the compressive strength of spun concrete without chemical admixtures was 10% greater than that of the control specimens. This supported the finding that saline boosted spun concrete's strength up to a specific number of CWD cycles by causing new crystal forms to grow in the material's pores and microcracks. The same pattern was seen when talking about the initial Young's modulus of spun concrete that had been subjected to temperature and salinity changes. Compressive strength and the initial Young's modulus in the case of the combined effect of the temperature gradient and saline showed a greater negative effect from the temperature gradient rather than a positive effect from salt crystallisation in concrete pores at some point between 75 and 120 cycles (or possibly earlier). The outcomes shown below support this assertion.

4.4. Resistance of Spun Concrete to Corrosion

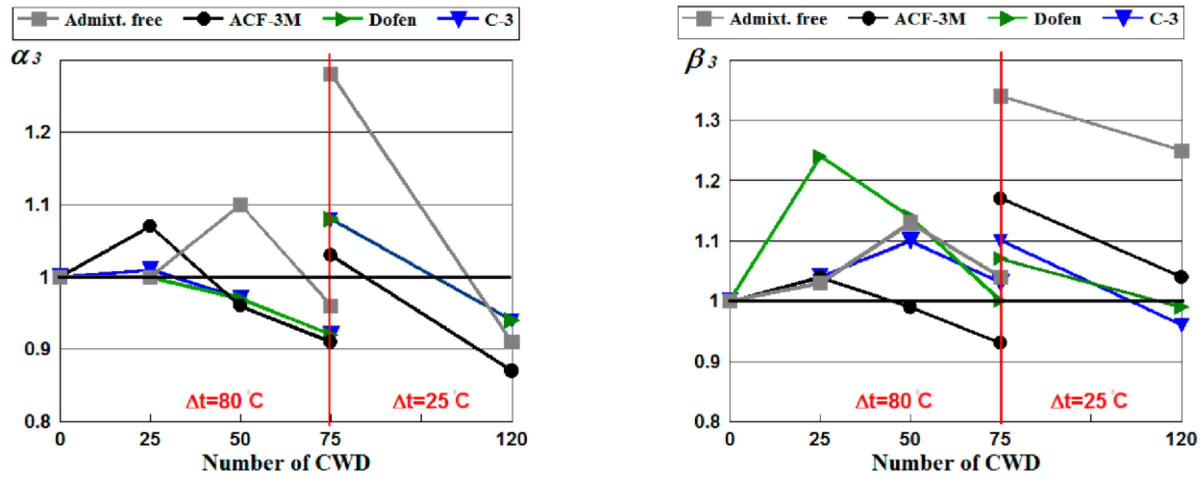
The coefficients were established taking into account the outcomes of experiments conducted at a lower drying temperature in order to evaluate the resistance of spun concrete against salt corrosion.

The results of using formulae (5) and (6) are shown in Table 11 and Figure 3 as values.

Saline improved the strain and stress characteristics of spun concrete in the run of up to 75 cycles of CWD, as shown in Figure 3. The kind of chemical admixture used affected the values of corrosion resistance coefficients. Concrete without admixtures had coefficients of 3 = 1.28 and 1.34, but concrete with admixtures such as C-3 or Dofen had coefficients of 1.08 and 1.07–1.10, respectively.

Table 11. The experimental values of the resistance coefficients of spun concrete to corrosion α_3 and β_3 subject to the number of CWD cycles under the 25 °C temperature gradient of wetting and drying processes.

Type of Chemical Admixture	**Resistance Coefficient α_3 (by Equation (5))**		**Resistance Coefficient β_3 (by Equation (6))**	
	Number of CWD Cycles at a Temperature Gradient of 25 °C		**Number of CWD Cycles at a Temperature Gradient of 25 °C**	
	75	**120**	**75**	**120**
Admixture-free	1.28	0.91	1.34	1.25
ACF-3M	1.03	0.87	1.17	1.04
Dofen	1.08	0.94	1.07	0.99
C-3	1.08	0.94	1.10	0.96



(a) (b)

Figure 3. The diagrams of the relationships of the resistance coefficients of spun concrete to corrosion α_3 by Equation (5) (a) and β_3 by Equation (6) (b) subject to the number of wetting cycles in saline, drying in the air and the temperature gradient considering the type of the chemical admixtures used.

By using admixtures, it was feasible to lower the initial water-cement ratio of the concrete mix, which produced a denser and more homogenous structure (Table 4). This rise in these indicators under the influence of was evident from the increase in these indicators (Figure 1). In contrast to its inner surface, a spun concrete product's outside surface is dense and has little porosity. Larger particles are pushed to the formwork's outside wall by centrifugation, a particular technique for compacting concrete, while smaller particles are pushed towards the cross-section's central cylindrical hole. In addition, centrifugation pushes extra water away from the outer surface of the concrete mix and towards the interior. The density of the inner layer is subsequently reduced as a result of the formation of microcapillary gaps in the cross-section that are directed from the outer surface to the core.

Under the effect of saline, salt crystallisation occurs in the pores, giving the concrete a more homogenous structure, especially on the inner, more porous surface. Up to a certain number of cycles, salt crystallisation has a favourable impact on the stress and strain characteristics of more porous and heterogeneous concrete. The information in Figure 3 and Table 11 demonstrates that salt crystallisation increased the compressive strength and Young's modulus of admixture-containing concrete and that these values were greater than those for admixture-free concrete.

Table 12. The experimental values of the resistance coefficients of spun concrete to corrosion α_3 and β_3 subject to the number or CWD cycles under the 80 ˚C temperature gradient of wetting and drying processes.

Type of Chemical Admixture	**Resistance Coefficient α_3 by Equation (5)**			**Resistance Coefficient β_3 by Equation (6)**		
	Number of CWD Cycles at a Temperature Gradient of 80 ˚C			**Number of CWD Cycles at a Temperature Gradient of 80 ˚C**		
	25	**50**	**75**	**25**	**50**	**75**
Admixture-free	1.00	1.10	0.96	1.03	1.13	1.04

ACF-3M	1.07	0.96	0.91	1.04	0.99	0.93
Dofen	1.00	0.97	0.92	1.24	1.14	1.00
C-3	1.01	0.97	0.92	1.04	1.10	1.03

The mechanical characteristics of concrete are negatively impacted by temperature decreases and alternating swelling-shrinkage caused by cyclic wetting-drying (CWD), which can also result in microcracks, the size of which is largely dependent on the temperature gradient during CWD.

However, Figure 3 demonstrates that salt crystallisation still had a beneficial impact on the tension and strain after 75 cycles of CWD with just modest temperature variations. Additionally, it demonstrates that the type of chemical additive used has a little impact on how resistant spun concrete is to corrosion, making it challenging to choose the most efficient one. It should be highlighted that the C-3 admixture was determined to be the most successful in our situation and complied with all indicators of resistance. The mechanical characteristics of spun concrete are improved by CWD in saline at a normal drying temperature for up to 75 cycles. The process of microcrack formation in concrete actually stops under a large number of CWD cycles, and the beneficial effect of corrosion class 3 on the stress and strain characteristics of concrete (removing defects) becomes the detrimental one because an adverse effect of the pressure of growing salt crystals on the walls of pores and microcracks in concrete is observed. Figure 3 demonstrates that for all types of concrete under investigation, the effect of salts on concrete strength relative to the initial strength of control specimens turns negative after 120 cycles of CWD and decreases compressive strength by 6–13%. For admixture-free concrete, the influence of salts on Young's modulus is still relatively considerable. However, as compared to the Young's modulus of control specimens, this impact is detrimental for concrete containing admixtures.

Thus, it is expected that the amount of salt in the groundwater, the magnitude of the temperature gradient, and the number of CWD cycles would all affect how much concrete is destroyed and how quickly it is destroyed.

5. Conclusions

Through the use of experimental techniques, it has been possible to demonstrate the long-term, cyclical negative impact of the temperature gradient on the compressive strength, Young's modulus, and durability of spun concrete. Along with the produced swelling-shrinkage (elongation-shortening) stresses, the reduction in compressive strength and Young's modulus, which was dependent on the temperature gradient and the length of the cyclic effect, may harm the concrete structure. The compressive strength and Young's modulus of admixture-free spun concrete were lowered by an average of 35% and 40%, respectively, by the temperature gradient after 120 cycles of concrete being wetted in water and dried in the air at a temperature of around 25 C.

The Young's modulus of spun concrete using admixtures—superplasticizers C-3 and Dofen and lowering the initial water-cement ratio—was lowered to around 20%, while the compressive strength was decreased to 25%. The original water-cement ratio of the concrete mix was only marginally decreased by the spinning concrete containing the additive ACF-3M, which resulted in a 30% reduction in the Young's modulus and compressive strength. It has been discovered that the influence of salts dissolved in water has a twofold impact on compressive strength and stresses. At the beginning of the process, cyclic wetting and drying in saline enhanced the physical-mechanical characteristics of concrete, which is why over time, salt crystallisation happened in the pores and microcracks of concrete that had a diverse prehistory of development, The long-term combined effect of temperature changes and salt on concrete revealed that a positive corrosion class 3 effect on the stress and strain properties turns negative due to a more pronounced effect of the pressure of growing salt crystals on the wall of the pores and microcracks in concrete. After 120 cycles, the Young's modulus and compressive strength of spun concrete containing additive ACF-3M and admixture-free spun concrete under the influence of temperature changes and CWD reduced by about 40% and 25%, respectively. With the addition of C-3 and Dofen, concrete's compressive strength and Young's modulus decreased by 30 and 25%, respectively.It was discovered that the criteria for the concrete structure, i.e., the amount of pores and microcracks in concrete, largely influenced the spun concrete's resistance to corrosion. The mechanical characteristics and subsequently durability of spun concrete were significantly and favourably impacted by chemical admixtures that enhanced the structure.

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