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Research Article

Strength and Durability Properties of Concrete Containing Pumice and Scoria as Supplementary Cementitious Material

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Concrete structures suffer serious deterioration under a corrosive environment. Consequently, the service life of these concrete structures is decreased and deteriorates under combined attack of sulphate and chlorides. Most studies confined on single deteriorating factor such as sulphate attack only or chloride attack only but the current study focused on the influence of natural pumice (NP) and natural scoria (NS) on the strength performance of concrete exposed to the combined attack of sulphate and chloride. Portland cement (PLC) was replaced with NP or NS at a substitution level of 10%. Concrete samples were cured in water for the curing period of 28 days. Afterwards, the specimens were immersed in 5% sodium sulphate (Na_2SO_4), 5% sodium chloride ($NaCl$), and combined sodium sulphate and chloride solutions for additional curing of 28, 56, and 90 days. The results were compared between concrete mixes with NP or NS and control mix (CT) with PLC. The effects of sulphate, chloride, and combined sulphate and chloride were evaluated in terms of change in weight, variation in compressive strength, and degree of damage. Conclusively, the application of NP and NS has extraordinary potential to be utilized as a cementitious material in concrete to increase the resistance against aggressive salts.

1. Introduction

Concrete has been a dominant construction material for the infrastructure around the globe [1]. It is estimated that the global production is over 10000 million tons [2]. The development in concrete technology has led the material to be the choice for the construction of structures which are exposed to extreme conditions [3]. Despite concrete being the chief construction material, the concrete structures made with Ordinary Portland cement (OPC) tend to depreciate faster when exposed to extreme conditions.

Structures exposed to extreme conditions are such as waste water treatment plants and marine structures [4]. Researchers have studied the durability of concrete under different extreme conditions [5–10]. It was singled out that sulphate, chloride, and their associated cations are the most aggressive chemicals affecting concrete durability. The concrete durability becomes a major concern since the capacity to withstand imposed load decreases with time. Moreover, the cost of repair and replacement of deteriorated structures becomes astronomical [11, 12].

Nowadays, there is prevailing interest to reduce the cement content and enhance concrete strength and durability by using Supplementary Cementing Materials (SCMs) and make more durable and sustainable concrete with good structural properties [13, 14]. The properties of fresh and hardened concrete are improved by addition of SCMs, and the cement content is reduced simultaneously [13]. Downrightly, the SCMs' addition improves workability and flow [13], produces less porous and denser concrete which increase resistance to chemical attack [15], shock absorbing ability is enhanced [16, 17], and compressive and flexural strengths are enhanced [13].

Furthermore, SCMs produce the additional Calcium-silicate-hydrate (C-S-H) gel from the pozzolanic reaction between the calcium hydroxide (C-H) that forms from the cement hydration [13]. The C-S-H gel together with the packing effect of fine and coarse aggregate increases compatibility of concrete, thus reducing permeability and protection of steel reinforcement against corrosion [18, 19]. Different research studies have been investigating the concrete with SCMs immersed in the sulphate and chloride environment as follows.

Kannan and Ganesan [20] investigated the chemical and chloride resistance of self-compacting concrete incorporated with rice husk and metakaolin and declared that concrete incorporated with metakaolin and rice husk leads to improvement in the strength and reducing permeability when compared to the control mix.

Mangi et al. [1] investigated the effects of sodium and chloride attack on concrete blended with coal bottom ashes for the exposure period of 90 days, and it was found that incorporation of coal bottom ashes reduces the negative effects of sulphate and chloride salts and increases the concrete resistance against the aggressive environment.

Aksogan et al. [14] investigated the durability performance of concrete where the fine aggregate was replaced by calemanite and barite and cement by corn stalk, wheat straw, and sunflower stalk ashes immersed in 5% Na_2SO_4 for 180 days and stated that, upon addition of corn stalk, wheat straw, and sunflower stalk ashes, the chemical resistance of concrete was improved.

Demir et al. [21] replaced cement with the combination of fly ash, bottom ashes, and blast-furnace slag and evaluated the performance of Ordinary Portland Cement (OPC) mortars under 5% Na_2SO_4 solution for 360 days. It was found the blended cement mortar has a compressive strength of 2% greater than that of OPC when cement is replaced with 5% fly ash, 5% blast-furnace slag, and 5% bottom ash.

Othman et al. [22] investigated the sulphate resistance of foamed concrete containing processed spent bleaching earth (PSBE) as the cement replacement. The sulphate resistance was evaluated in terms of expansion, loss in mass, and loss in compressive strength after 52 weeks of immersion time. It was found that concrete containing 30% PSBE is more durable than the control specimen after immersion in 5% sodium sulphate. However, the investigation was based on single attack only.

Al-Swaidani and Aliyan [7] investigated the sulphate resistance of mortars by partially replacing cement with scoria. The sulphate resistance of mortars was performed by immersing the mortar samples in 5% Na2SO4 solution for 52 weeks and declared that, upon addition of scoria, the sulphate resistance of mortars is improved. The investigation was done only on single deteriorating factor, that is, sulphate attack only.

Jaya et al. [23] investigated the potential of using rice husk ashes (RHA) as the cement replacement in concrete under seawater attack by wetting and drying cycles. Cement was replaced with RHA at the substitution level of 0%, 10%, 20%, 30%, and 40%. Compressive strength and chloride ion permeability were evaluated. Incorporation of RHA was found to reduce calcium hydroxide formation during hydration seawater attack. The investigation was based on single attack only.

Natural pumice (NP) and natural scoria (NS) are natural materials that can be used as eco-friendly materials in the construction industry. Cement production requires energy, and much CO_2 is released but utilization of NS and NS reduces energy demand and CO_2 [13, 24]. NP and NS are pyroclastic materials rich in silica, alumina, and iron oxide [24]. Around the globe, NP and NS have been utilized as fine and coarse aggregates in concrete production and building blocks [13]. Top and Vapur investigated the utility of NP as course aggregates in light-weight geopolymer concrete [25]. Then again, NP and NS have been used as fine and coarse aggregates for nonstructural concrete and mortar [17, 26, 27].

Mboya et al. [13] indicated that NP and NS as the cement replacement can enhance the strength and durability of concrete but studies on concrete containing NP and NS under the combined exposure of sulphate and chloride are rarely reported. In addition, no research has evaluated the properties of concrete NP and NS under the combined exposure of sulphate and chloride solutions. Moreover, the earlier inputs by Mboya et al. [13] validated that the compressive strength of concrete incorporated with NP and NS was satisfactory at a 10% substitution level. The 10% substitution level of cement with NP and NS has been adopted. Therefore, the work presented explores the application of NP and NS as SCMs in concrete under the combined effect of sulphate and chloride solution exposure conditions. Strength, change in weight, and degree of damage are evaluated.

2. Materials and Methods

2.1. Materials

2.1.1. Binder. In the current study, Portland Limestone Cement (PLC) type II (Twiga plus) class 42.5 N conforming to Tanzanian standard TZS727:2002 in accordance with the British standard BS 12:1996 13 and SS-EN 197-1 CEM II/A-L was used [28]. PLC was obtained from local dealers around Arusha city, Tanzania.

Pumice stone with white colored fragments was collected from Ikuti in Mbeya region, and scoria stone with red colored fragments was collected from Uchira in Kilimanjaro region. Both were collected in Tanzania. A disc mill model 4A100L6T1 SN 535277 was used to mill pumice and scoria stones to produce a fine powder of pumice and scoria marked NP and NS, respectively, at a rate of 2 kg/h and sieved through 75 μm in accordance with BS 410 [29], visually presented in Figure 1, and analyzed to determine

(a)

(b)

Figure 1: Pumice and scoria powder used in the study.

chemical and physical properties. Automatic Blaine Apparatus (AIM-391-3) SN 2001 from Aimil Ltd., India was used to determine fineness of the NP and NS powder [30]. The density of PLC, NP, and NS was determined according to SS-EN 197-1 and ASTM D 854 [31, 32]. The chemical and physical properties of binders are outlined under the result section.

2.1.2. Aggregates. Fine and coarse aggregates were obtained from local dealers. Properties of fine and coarse aggregates such as specific gravity and water absorption were determined, guided by the standard. ASTM C127 [33] and ASTM C128 [34] were employed to determine aforementioned properties, respectively. Particle size requirement for aggregates was done to conform to BS EN 933-1:2012 [35]. Grading and blending of fine and coarse aggregates were done to conform with PD 6682-1 and BS 12620 specifications [36, 37].

The particle size distribution and properties of fine and coarse aggregates used in the study are shown in Figure 2 and Table 1, respectively. To achieve desired properties of fresh and hardened concrete, fine and coarse aggregates were graded and blended together to obtain the right proportions [36]. BS EN 12620 was used to blend coarse and fine aggregates in proportions of 33% to 67% fine to coarse aggregates [36]. The blended aggregates showed fineness modulus (FM) of 5.1 and specific gravity (SG) of 2.6. The specific gravity of aggregates was found to be between 2.4 and 2.8 which suggest that the aggregates used were normal weight aggregates [13].

2.1.3. Water. Potable tap water was used for washing aggregates and mixing and curing of concrete. Water used was free from suspended particles, and the pH value was 6. The amount of water added during mixing reacts with cement to form the hydration products which bind the aggregates together, which also affect the workability of the concrete and strength properties. Mixing water was free from chemical contamination and safe for human consumption [38].

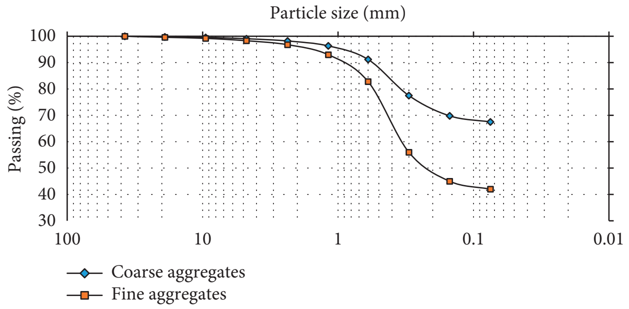

Figure 2: The particle size distribution of aggregates used in the study.

2.2. Mix Proportioning. Concrete grade M25 was adopted in this study, and the concrete samples were made by partially replacing cement with NP or NS. BS 1881-116 [39], BS EN 12390-2 [40], and BS EN 206 [41] were used as guidelines for concrete mixing, casting, and testing of fresh and hardened properties of concrete, respectively. Three streams of test specimens were under consideration; the first stream was the concrete made with only Portland cement (0% replacement) (hereafter, referred as CT), the second stream was the concrete made with partial replacement of cement by NP, and the third stream was the concrete made with partial replacement of cement with NS. Cement was replaced by 10% in second and third streams, as illustrated in Table 2.

2.3. Sample Preparation. Concrete mixes were prepared by using an electric mixer. The weighed PLC and fine and coarse aggregates were all together put into the concrete mixer and mixed thorough, followed by addition of NP and NS and mixed through. Weighed water was added and mixed throughout to have a homogeneous mixture. Standard cubes of 150 mm size were used to prepare concrete cubes with and without NP and NS. A total of 108 specimens were prepared, and three cubes from each stream were selected for testing in the corrosive environment. Concrete specimens were left to allow setting at a room temperature of 25 ± 3°C after casting. The

Table 1: Properties of aggregates used in the study.

Properties	Coarse aggregates	Fine aggregates
Maximum size (mm)	20	4.75
Water absorption (%)	0.8	1.3
Specific gravity	2.96	2.65
Bulk density (kg/m^3)	2956	2649
Moisture content (%)	3.5	4.57
Fineness modulus	6.6	2.2

Table 2: Concrete mix design.

Components (kg/m^3)	Percent of PLC replacement (wt. %)	
	0	10
Cement	380	342
NP/NS	0	38
Fine aggregate	552	552
Coarse aggregate	1243	1243
Water	205	205

demoulding of cubes was done after 24 h, and then, the specimens were cured in water for 7 and 28 days to obtain the designed strength. Specimens were taken out of the water tank after 7 and 28 days and left out for 24 h to allow drying under controlled laboratory conditions. Compaction and curing equipment used complied with BS EN 12390-2 [40] and BS 1881-116 [39].

2.4. Continuous Immersion Test. A methodology similar to earlier studies [1, 4] was adopted, where 9 specimens of CT, 9 specimens of S1, and 9 specimens of S2 were immersed in 5% Na_2SO_4, 5% NaCl, and combination 5% Na_2SO_4 and 5% NaCl for 28, 56, and 90 days, respectively. The remaining specimens were submerged in water for additional curing of 28, 56, and 90 days.

2.5. Testing. The CT specimens were weighed and tested without immersing them into the corrosive environment. Before submerging concrete mixes in the corrosive environment, all specimens were weighed. After the continuous immersion test of samples in the corrosive environment, the samples were weighed again. The mass loss was assessed by using the recorded weights at each exposure condition. The compressive strength testing machine conforming to BS EN 12390-2 [40] and BS 1881-116 [39] was used to measure the strength of concrete samples. The crushing loads were obtained in accordance with BS EN 12390-3:2019 [42]. Their degree of damage was evaluated by using equation (1) as described by Mangi et al. [1]:

$$D_i = 1 - \frac{\sigma_i}{\sigma_0}, \quad (1)$$

where D_i is the degree of damage after certain immersing period, σ_i is the compressive strength of concrete after certain immersing time, and σ_0 is the initial compressive strength of concrete. In the current study, the σ_0 value represents the compressive strength of CT, S1, and S2 at the age of 28 days before being shifted into sulphate and chloride solutions.

3. Results and Discussion

3.1. Physical and Chemical Properties of PLC, NP, and NS. *X*-ray Fluorescence (XRF) was used to analyze chemical composition of PLC, NP, and NS. The results are presented in Table 3. The total of silica, aluminum oxide, and iron oxide was found to be 74.76% and 67.34% for NP and NS, respectively. This implies that NS and NP meet the standard criteria to be considered as pozzolanic materials according to ASTM C618 [43]. Physical properties of PLC, NP, and NS are presented in Table 4.

3.2. Workability. Slump cone method was used to evaluate the workability of concrete with accordance to ASTM C143 [44]. Workability results of the concrete mix CT (control mix), S1 (concrete containing NP), and S2 (concrete containing NS) are shown in Table 5. The slump results reveal that slump decreases with increase of cement replacement, and this is due to the presence of NP and NS which upon their addition, increases silicon concentration which increases water demand in order to produce workable concrete [45]. This result was also observed by Mboya et al. [13] and Adesanya and Raheem [45] when SCMs were used as partial substitution of cement in concrete production.

3.3. Weight Loss. The weight of the concrete specimen was taken before and after immersing the specimen in water, sulphate, chloride, and combination of sulphate and chloride solution. The detailed results of mass loss are provided in Figure 3. The result reveals that both types of concrete do not change their weight when immersed in water. The significant change in weight is noted when both types of specimens are immersed in 5% Na_2SO_4, 5% NaCl, and the combination of both. The highest weight loss was noticed in CT at 56 days, while the lowest was observed in both S1 and S2 when exposed to 5% Na_2SO_4. Concrete with NP and NS has lower values compared to the control mix because of the denser structure which reduces salts' penetration.

It was also agreed by Xu et al. [46] that higher amounts of sulphate ions, gypsum, and ettringite are influenced by more hydration products which provide growth in weight of the specimen containing 30% fly ash in 5% Na_2SO_4 [1]. Under combined sulphate and chloride, there is significant mass loss from 28 days up to 90 days, and CT concrete is more affected, and this is mainly attributed by formation of more ettringite and gypsum. This concurs with the findings of Maes and De Belie [47] where the investigation was performed to evaluate the effect of combined attack of chloride and sulphate on concrete and mortar.

Incorporation of NP and NS reduces the hydration process; moreover, it reduces the penetration of salt in concrete, thus no significant loss in weight in S1 and S2. This assures that incorporation of SCMs in concrete (S1 and S2) could reduce the permeability of corrosive species which cause corrosion in reinforced structures and failure of

Table 3: Chemical properties of PLC, NP, and NS.

Chemical properties	Material		
	PLC	NP	NS
SiO_2	17.9	55.91	39.07
CaO	60.9	0.52	10.32
Al_2O_3	5.5	14.55	12.80
Fe_2O_3	2.9	4.30	15.47
MgO	0.5	0.21	4.82
TiO_2	—	0.55	3.84
K_2O	0.22	5.01	0.62
MnO	0.36	0.36	0.22
Na_2O	—	4.95	0.40
Loss on ignition	8.4	8.79	10.73

Table 4: Physical properties of PLC, NP, and NS.

Physical properties	Material		
	PLC	NP	NS
Density (kg/m^3)	3010	2390	2930
Blaine-specific surface area (m^2/kg)	431	507	575
Initial setting time (minutes)	148	—	—
Soundness (mm)	1.5	—	—
Compressive strength 28 days (MPa)	45	—	—

Table 5: Concrete workability.

Concrete mix	Slump value (mm)
Control mix (CT)	68
Concrete with 10% NP (S1)	60
Concrete with 10% NS (S2)	60

structure [48, 49]. Thus suggesting that incorporation of NP and NS prohibits penetration of aggressive salts making concrete adequate under 5% NaCl and 5% Na_2SO_4 and combination of both 5% NaCl and 5% Na_2SO_4.

3.4. Compressive Strength Variation. The strength comparison between concrete with natural pumice (S1) and concrete with natural scoria (S2) with reference to CT (concrete without natural pumice and scoria) under different exposure conditions at the age of 28, 56, and 90 days was used to assess the variation in compressive strength. At the early age of 28 days, the increase in compressive strength was slow for S1 (concrete containing NP) and S2 (concrete containing NS) when immersed in 5% Na_2SO_4 solution but significant increase in compressive strength is noticeable at the age of 56 and 90 days.

The concrete samples S1 (concrete containing NP) and S2 (concrete containing NS) under 5% NaCl have significant reduction of strength. Moreover, similar observation is noticed in concrete specimens exposed in the combined 5% Na_2SO_4 and NaCl solution. The performance of concrete was superior under water and Na_2SO_4 solution. Concrete containing pumice (S1) has 12.11% and 9.9% higher strength than the control mix (CT) in water and in 5% Na_2SO_4 solution, respectively, at the age 56 days, and concrete containing scoria (S2) has 6.3% and 4.6% higher strength than the control mix (CT) in water and 5% Na_2SO_4 solution, respectively, at the age of 56 days. For 90 days cured samples, concrete containing pumice has 7.7% and 15.4% in water and 5% Na_2SO_4 solution, respectively, while concrete containing scoria has 3.04% and 13.6% in water and 5% Na_2SO_4 solution, respectively.

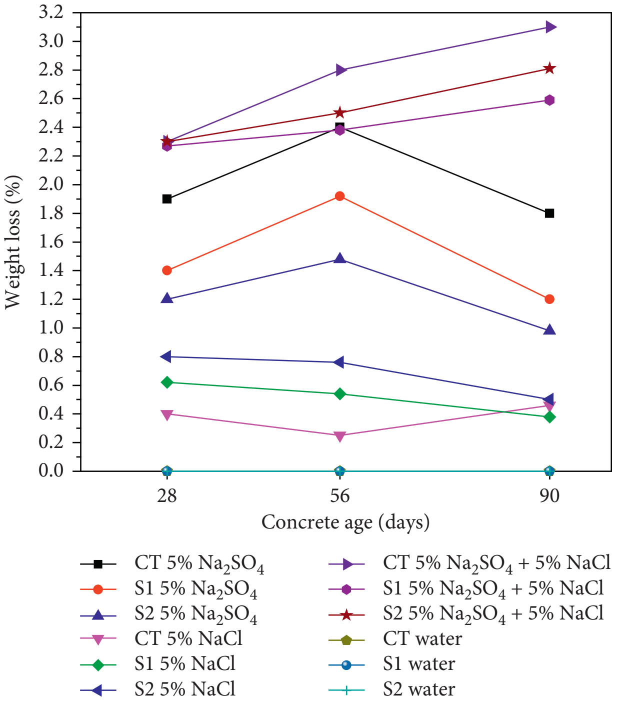

Figure 3: Weight loss of CT, S1, and S2 immersed in sulphate, chloride, and combined sulphate and chloride solution.

The concrete containing pumice (S1) and scoria (S2) showed the drop of strength under 5% NaCl exposure condition. Under the combination of both 5% Na_2SO_4 and NaCl solution, concrete containing pumice has 8% and concrete containing scoria has 7.3% higher strength than the control mix (CT) at the age of 90 days. Figure 4 demonstrates the differential in compressive of concrete specimens S1 and S2 under Na_2SO_4 and NaCl solutions at different concrete ages.

3.5. Compressive Strength of the Specimens under Water, Sulphate, and Chloride Solutions. The compressive strength for the dried samples was determined after the immersion test. The compressive strength of 28, 56, and 90 days immersed samples in potable water is presented in Figure 5. The results demonstrate that the performance of concrete samples S1 (34.3 MPa) and S2 (33.4) is higher than the CT (31.9 MPa) at 28 days when immersed in water; this indicates that the pozzolanic reaction initiated the growth of strength in concrete samples S1 and S2. For instance, the compressive strength of S1 is higher by 12.11% and 7.7% as compared to CT at 56 and 90 days, respectively. S2 compressive strength is higher by 6.3% and 3.04% as compared to CT at 56 and 90 days, respectively. It was noted that, under the presence of

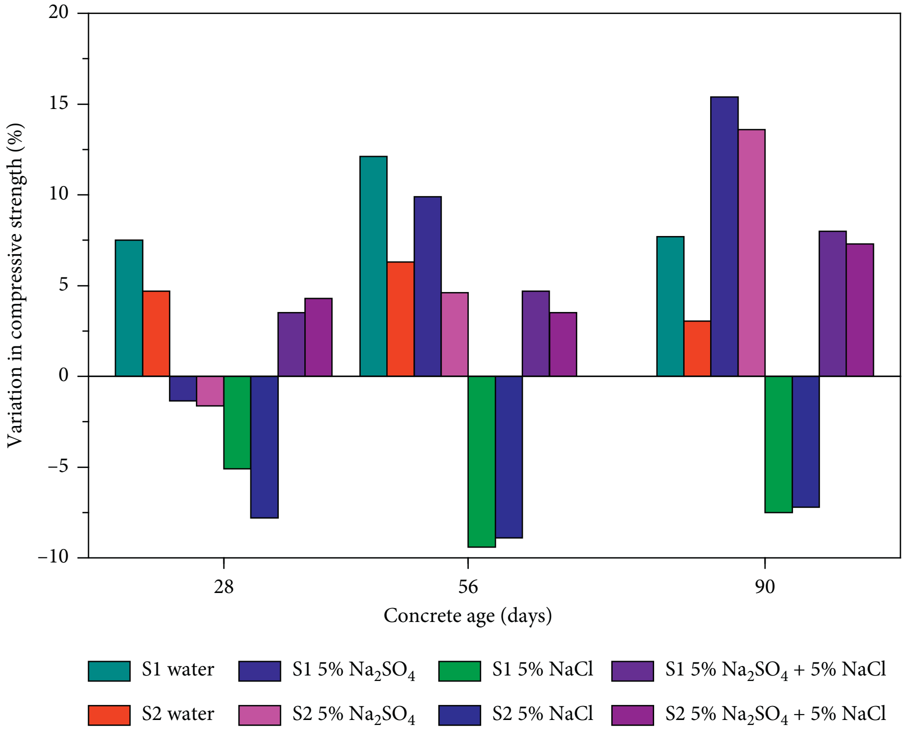

Figure 4: Compressive strength variation of CT, S1, and S2 immersed in water, sulphate, and chloride at different concrete ages.

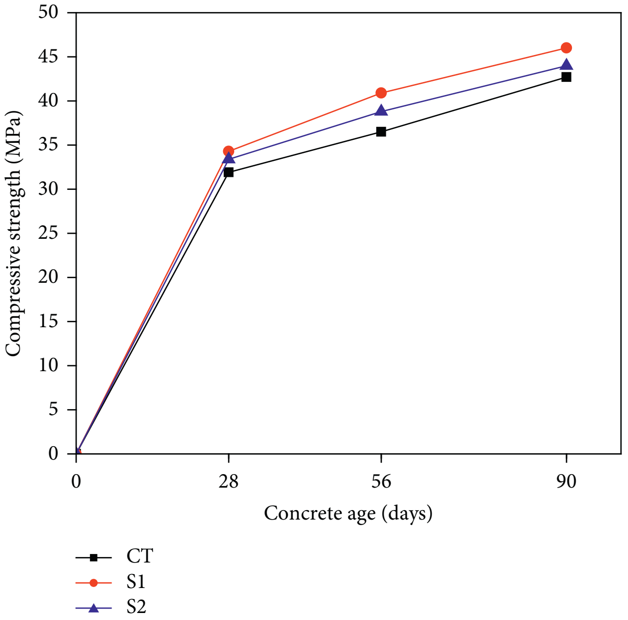

Figure 5: Compressive strength of CT, S1, and S2 immersed in potable water.

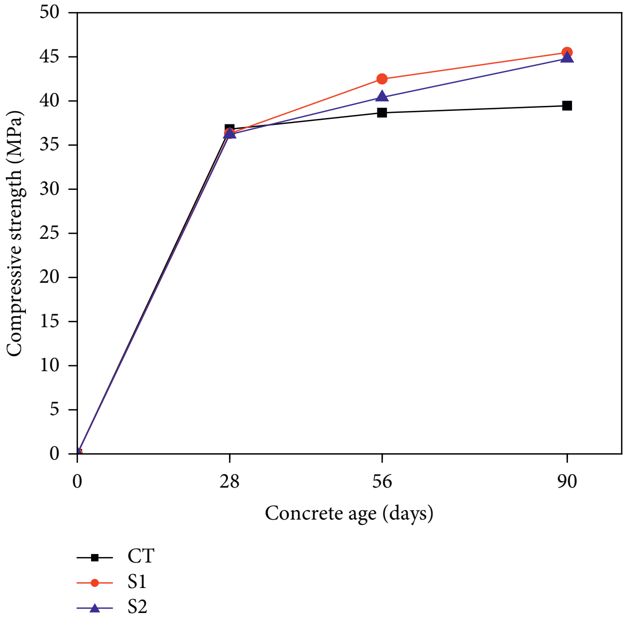

Figure 6: Compressive strength of CT, S1, and S2 immersed in the sulphate solution.

pumice and scoria, the pozzolanic reaction took place after 28 days and kept on increasing with the concrete age.

The compressive strength of samples immersed in 5% sodium sulphate curing for different exposure time is presented in Figure 6, and the physical characteristics are presented in Table 6. From Figure 6, concrete samples under the 5% Na_2SO_4 exposure condition show that the performance of concrete samples containing pumice (S1) and scoria (S2) was found to be comparable with concrete without pumice and scoria (CT) at 28 days of immersion. It was noted that concrete samples with and without pumice and scoria after exposure to the sulphate solution have no significant damage caused for the short-term exposure. The compressive strength of S1 was found to be outstanding as

Table 6: Physical characteristics of concrete mixes after exposure to the sulphate solution: slight peeling of the surface is visible.

Sample	Curing days		
	28	56	90
CT			
S1			
S2			

compared to CT by 9.9% and 15.4% at 56 and 90 days, respectively. The same trend is observed in S2 where strength was superior as compared to CT by 4.6% and 13.6% at 56 and 90 days, respectively. This concurs with the findings observed by Mangi et al. [1] as they investigated on OPC concrete with coal bottom ashes exposed to the sulphate solution for 90 days exposure time.

Moreover, the findings in the current study concur with the findings reported by Demir et al. [21] where OPC mortar with blast-furnace slag, bottom ash, and fly ash as SMCs was investigated where mortar samples were immersed in the Na_2SO_4 solution for 360 days and strength performance of blended mortar was 2% greater than that of OPC mortar. It was previously declared that samples immersed in lower proportions of Na_2SO_4 (0.27–1.8%) for 300 days had no significant damage caused on mortar properties.

It was also acknowledged that diffusion of sulphate ions in pores of the concrete accelerates the chemical reaction between cement hydration products. The chemical reaction of Na_2SO_4 and sulphate ions with Ca $(OH)_2$ and monosulphate gives gypsum and ettringite (crystal needle) in concrete pores [50, 51]. Addition of pozzolanic materials makes the concrete denser by decreasing the Ca $(OH)_2$ content; at the same time, development of corrosive species becomes hard to grow [52]. Pumice and scoria remove lime liberated during cement hydration and C_3A dilution [7]. It was experimentally found that pumice and scoria-blended concrete has better performance and was found to resist the effect of the Na_2SO_4 solution. The performance of pumice and scoria-blended concrete is attributed by refinement of pore sizes that limits ingress of sulphate ions [53, 54].

The compressive strength of samples immersed in 5% sodium chloride curing for different exposure time is presented in Figure 7, and the physical characteristics are presented in Table 7. The strength development of S1 and S2 was found to be lower than CT in the NaCl exposure environment. The same trend has been found in the concrete containing 5% coal bottom ashes [1] and concrete containing 5% rice husk ashes [55]. The chloro-aluminate produced in the chloride solution is the reason for strength deterioration, and the deterioration took place by de-calcifications, and the deterioration is notable at later ages [56, 57]. At the same time, leaching of calcium hydroxide, permeable C-S-H gel formation, and de-calcification effects of NaCl take place in concrete [55].

It is also known that chlorides promote the leaching of Ca $(OH)_2$ and the formation of porous C-S-H involving complex reactions [58]. Physical appearance of concrete is affected due to disturbance created in the hydration process by the presence of chlorides which affect the pore sizes. From experimental results, CT in 5% NaCl solution gains its strength up to 56 days, and the strength declines after 90 days of immersion time. The performance of S1 and S2 was found to be lower than CT but it was noted that there is continual growth of strength in S1 and S2. It was acknowledged that, under 5% NaCl, the pozzolanic reaction becomes slow and takes more time to recover [1]. Thus, the performance of S1 and S2 was unsatisfactory under sodium chloride.

The compressive strength of samples immersed in 5% sodium sulphate and chloride curing for different exposure times is presented in Figure 8, and physical characteristics of concrete mixes after exposure to the sulphate and chloride

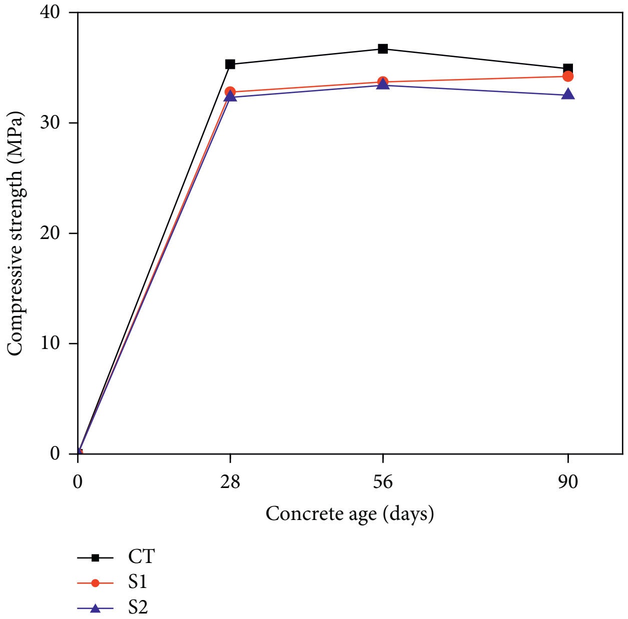

Figure 7: Compressive strength of concrete CT, S1, and S2 immersed in the chloride solution.

Table 7: Physical characteristics of concrete mixes after exposure to the chloride solution: without significant surface damage.

Sample	Curing days		
	28	56	90
CT			
S1			
S2			

solution are presented in Table 8. Under the combined exposure of sodium chloride and sulphate, the concrete blended with pumice (S1) and scoria (S2) performed better than the control mix at exposure periods of 28, 56, and 90 days. At 28 days, the performance of S1 and S2 was 4.5% and 1.3% greater than CT, respectively. A superior performance is observed at early ages. The compressive strength of S1 concrete is 3.3% and 8% greater than the CT at 56 and 90 days, respectively. Its counterpart, S2 has 2.3% and 7.3% at 56 and 90 days, respectively.

The decline in compressive strength of CT, S1, and S2 can be explained as follows; both sulphate and chloride bind with C_3A to form ettringite, gypsum, and, sometimes, Friedel's salt. However, for Friedel's salt, chlorides' reaction product is not stable under the sodium sulphate solution [59]; as time of immersion is increased, Friedel's

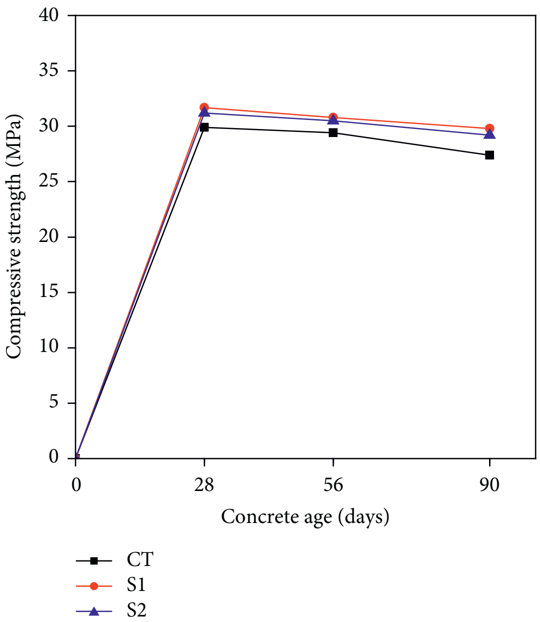

Figure 8: Compressive strength of CT, S1, and S2 immersed in the combined solution of sulphate and chloride.

Table 8: Physical characteristics of concrete mixes after exposure to sulphate and chloride solution: large peeling of the surface visible.

Sample	Curing days		
	28	56	90
CT			
S1			
S2			

salt will disappear, more ettringite and gypsum will form, and deterioration will occur at later ages. Moreover, ettringite may induce expansion in concrete which may cause a certain cracking in concrete [4]. This cracking leads to increase of chloride penetrability in concrete. The S1 and S2 performance was influenced by the dense microstructure due to the pozzolanic reaction of pumice and scoria so that the penetration of chloride ions becomes less.

3.6. Degree of Damage. The extent of deterioration of concrete specimens immersed in water, sulphate, and chloride was obtained by using equation (1) and graphically

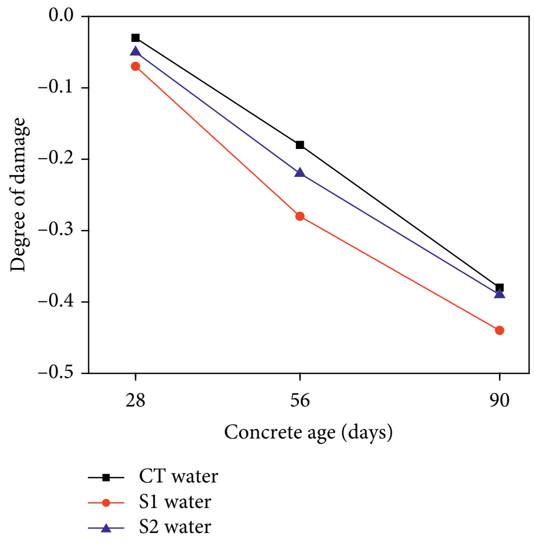

Figure 9: Degree of damage CT, S1, and S2 scoria immersed in water.

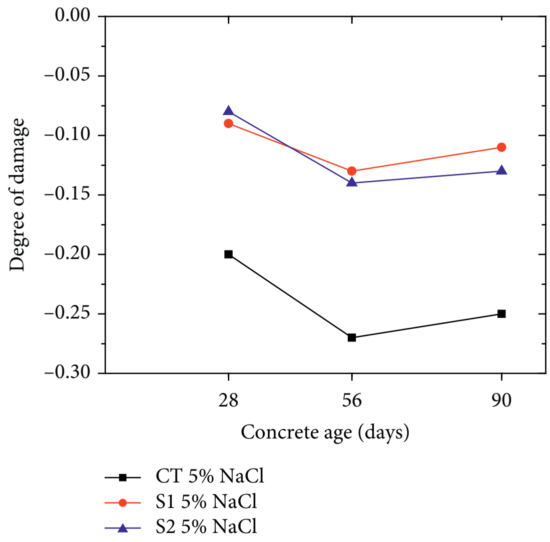

Figure 11: Degree of damage of CT, S1, and S2 immersed in the chloride solution.

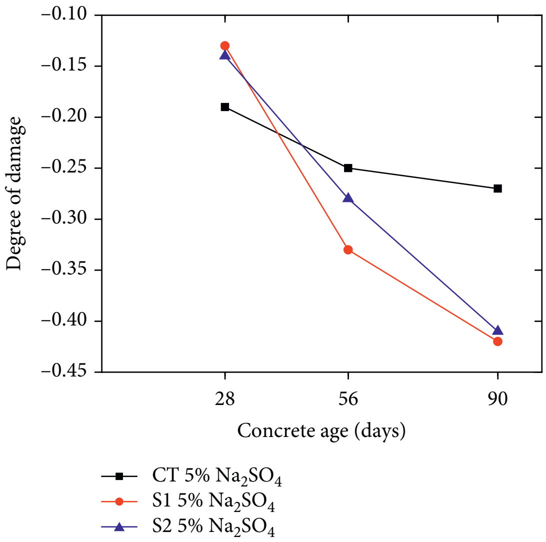

Figure 10: Degree of damage of CT, S1, and S2 immersed in the sulphate solution.

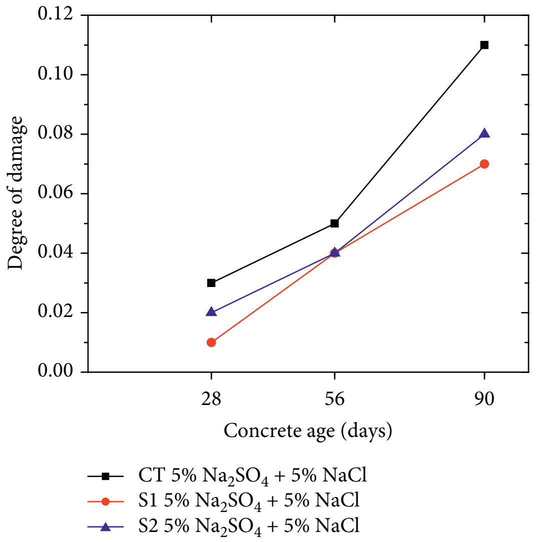

Figure 12: Degree of damage of CT, S1, and S2 immersed in the combined sulphate and chloride solution.

presented in Figures 9–12. The results reveal that the degree of damage of the control mix (CT) is highest at all exposure conditions except for the sodium chloride exposure where the degree of damage is highest. Moreover, the concrete containing pumice (S1) and scoria (S2) has less degree of damage at all exposure conditions except for the sodium chloride exposure.

However, the higher were noticed in CT concrete 0.02, 0.04, and 0.11 under the combined exposure of sulphate and chloride for 28, 56, and 90 days, respectively. S1 has 0.01, 0.04, and 0.08 under the combined exposure of sulphate and chloride for 28, 56, and 90 days, respectively, while S2 has 0.02, 0.04, and 0.7 of 28, 56, and 90 days, respectively. The degree of damage was highest in the control mix (CT) because of the porous structure formed due to chemical corrosion. Due to increase of permeability, the sulphate and chloride solutions can more easily penetrate into interior of concrete; as a result, the porosity is increased, and the effective area is decreased. [3]. The increase in the degree of damage reduces the bearing capacity of concrete structures, and it will reach a degree, and the concrete structure will fail completely [60]. The lower the degree of damage, the higher is the strength and durability of concrete.

4. Conclusions

The present study investigated the compressive strength, degree of damage, and physical properties of the cement-NP/NS blended normal concrete (with design strength of 25 MPa) subjected to combined sodium sulphate and sodium chloride solutions. The blended concrete mixes containing 10% NP/NS showed a greater compressive strength than the control mixes, implying that the inclusion of NP/NS led to improved compressive strength both at the ordinary and aggressive environment. Following are the conclusions drawn on the presented experimental results:

(1) The study indicated the successfulness of pumice and scoria as SCMs to replacement of OPC in concrete under normal and aggressive environments

(2) The concrete S1 (concrete with pumice) and S2 (concrete with scoria) has outperformed concrete CT under sulphate, chloride, and combined sulphate and chloride solutions showing that incorporation of natural pumice and scoria has great potential of alleviating penetration of aggressive salts in concrete structures

(3) The degree of damage of concrete is reduced with the incorporation of natural pumice and scoria, and it is obvious concrete incorporated with natural pumice and scoria has less deterioration caused by aggressive salt solutions

Data Availability

The data used to support the findings of this study are included within this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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