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Effect of Sulphate Salt and Acid on the Strength Properties of Waste Tire Concrete

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Abstract

The indiscriminate disposal of waste rubber tyres poses significant environmental challenges, necessitating the investigation of their potential reuse as construction materials. This study investigated the effect of sulphate salt and sulphuric acid on the strength properties of concrete incorporating waste rubber tyre (WRT) as partial replacement for coarse aggregate. The objective was to evaluate the compressive strength, water absorption, and abrasion resistance of WRT concrete exposed to aggressive acid and salt environments. A total of 336 concrete cubes of 100 x 100 x 100 mm were produced at replacement levels of 0%, 10%, 20%, and 30% by weight of coarse aggregate, and cured in 5% and 10% concentrations of sulphuric acid and sulphate salt for 7, 14, 28, and 90 days. The results indicated a progressive reduction in workability with increasing WRT content, with zero slump recorded at 30% replacement. Compressive strength decreased with increasing WRT content but increased with curing age up to 28 days, after which a decline was observed at 90 days due to prolonged exposure to the aggressive media. Notably, concrete with 10% WRT replacement exhibited slightly higher compressive strength than the control at 90 days in both acid and salt environments, suggesting enhanced resistance to long-term chemical attack at low replacement levels. Water absorption increased with both WRT content and curing age, with values being slightly lower in salt environments compared to acid environments. The addition of WRT at 10% replacement improved abrasion resistance, while higher replacement levels (30%) significantly reduced it. It is recommended that up to 10% replacement of coarse aggregate with WRT is suitable for use in concrete, particularly in environments susceptible to acid or salt attack, as well as in pavements where abrasion resistance is required.

Keywords: Waste tire concrete, Sulphate attack, Acid attack, Compressive strength, Durability

Introduction

Concrete is a mixture of cement, sand, aggregate, and water with any other admixture which may be added to modify the placing and curing processes or the ultimate physical properties (Arthur, 2007). According to Siddiqui (2016) concrete in its most basic form is one of the world's oldest building materials, composed of simple and commonly available ingredients which when properly mixed and cured may last centuries. Concrete are composite materials comprising of sand, cement, coarse aggregate, fine aggregate, and water (Oyenuga, 2011). Because of its wide applicability in construction works, concrete is receiving wide range of attention from researchers with a view to find the alternative materials that can partially or wholly replace some of its conventional ingredients. Through this effort, a wide range of industrial and agricultural waste products are subject for investigation to see the possibility of their use as replacements to concrete ingredients. Siddiqui (2016) waste tire rubber is among the industrial waste product that are subject to current investigation in it use in concrete. The level at which stock piles of waste tire dominate the human environment have become a serious source of environmental concern (Adathodi & kumar, 2018). The most common disposal method of waste tire through burning pollutes the atmosphere by emitting hazardous carbon-monoxide gas (CO2) which depletes the ozone layer. Its disposal into landfills is also unacceptable because of the rapid depletion of available site for waste disposal, research show that about 13.5% of sulphate salt and sulphuric acid are naturally found on soil environment and also (Tantala, Lepore & Zandi, 1996). Hence, the reuse of these waste materials by using them in concretes as partial replacements to either coarse aggregate or fine aggregate 1 was considered an effective way of minimizing the environmental challenge associated with indiscriminate disposal of this waste product (Dhivya & Priyadharshini, 2022). Sulphuric acid is one of the most destructive acids to concrete and depending on its concentration and formation manner, can cause severe degradation and damage to concrete structures which come into contact with it. This acid may be produced in soils and groundwater through the oxidation of iron sulfide minerals in the form of pyrites or marcasite (Richardson, 2002). Sulphate attack occurs in concrete when concrete is in contact with a source of sulphate ions, which can be groundwater, soil, or rainwater. Sulphate attack usually manifests itself by cracking and spilling of concrete accompanied by expansion and/or loss of strength. The resistance of concrete to sulphate attack is determined by several factors, such as water/cement, permeability, and cement properties, which include fineness and cement composition (Kurama, Sritharan, Fleischman, Restrepo, Henry, Cleland & Bonelli, 2018).

MATERIALS AND METHOD

An experimental research approach was adopted for this study. Sieve analysis was performed on both fine and coarse aggregates to determine their particle size distribution and suitability for use in concrete production. The physical properties of the waste rubber tyre (WRT) aggregate were also determined prior to incorporation into the concrete mix. A mix ratio of 1:2:4 with a constant water/cement ratio of 0.6 was adopted to ensure adequate workability, given the inclusion of tyre rubber which was pre-soaked for 20 minutes before use. Prior to mixing, the required quantities of cement, sand, coarse aggregate, WRT, and water were weighed accurately. Cement and sand were first mixed dry, followed by the addition of coarse aggregate and WRT. The required quantity of water was then added, and all constituents were thoroughly mixed by hand shovel on a mixing platform until a homogeneous, workable, and consistent mixture was achieved.

Steel moulds were oiled in order to facilitate easy remoulding of the hardened concrete. The moulds

were filled with the mixed concrete, compacted and vibrated manually. The samples were marked for easy identification and left for 24 hours to harden. After demoulding, the samples were cured in water containing 5% and 10% sulphuric and sulphite salt respectively for 7, 14, and 28 and 56, days respectively. Compressive strength tests were carried out on the concrete cubes moulded using (100x 100x 100)mm steel moulds with varying percentages of tyre rubber (10, 20, 30) respectively by weight of course aggregates. Similarly, some of the samples were cast using 0% by volume of tyre rubber to serve as the control specimen, the concrete grade used was M 30. A total of thirty six (150) cubes were cast with each percentage.

Materials

The material used for this research work includes; coarse aggregate (crushed stones), fine aggregate (river sand), Ordinary Portland cement (binder), tire, rubber, water, sulphuric acid and sulphite salt (ASTM C128, ASTMC33/C33m-18)

Fine and coarse aggregate

The coarse aggregate used was crushed granite with maximum size of 20 mm sourced from a local area in Bauchi State. While the fine aggregate was cleaned natural sharp sand locally sourced conforming to ASTM C33 standard.

Cement

Ordinary Portland cement (OPC) with strength of 32. 5 MPa, was used for the experimental work. The cement was obtained from local cement vendors.

Preparation of waste rubber tire (WRT)

The waste rubber tyre (WRT) used for this research was sourced from scrap tyre dealers in the study area. The preparation of WRT aggregate involved manual cutting of medium truck tyres into pieces of approximately 20 mm size, measured using a metre rule in both the vertical and horizontal directions. A sharp knife moistened with water was used to facilitate cutting through the hard rubber material. The cut pieces were then washed thoroughly and sun-dried prior to use. The process was laborious due to the toughness of the tyre material, and achieving uniform aggregate sizes required considerable effort. A WRT aggregate size of 20 mm was consistently targeted throughout the preparation process.

Tests on Materials

Preliminary tests such as bulk density, specific gravity and setting time were carried out on some of the materials. Particle size distribution and water absorption of coarse and fine aggregate were also conducted to determine the properties and suitability of the constituent materials in the study (ASTM D7928; BS 812-103.1: 1985)

Bulk density of aggregate

The bulk density test was performed as per the requirements of part 2 of BS 812: 1995 (1999). The aggregates were tested at saturated and surface dry (SSD) condition. A clean and dry cylinder was weighed empty and recorded, W_1. The cylinder was filled with water, weighed and recorded, W_2. The cylinder was thereafter emptied and dried. It was then filled with aggregate in three layers; each layer was tamped 25 times with tamping rod before adding the next layer. After the third layer, it was levelled, weighed and recorded, W_3. The bulk density was calculated using equation (4).

Kg/m^3

$$\text{Bulk density} = \frac{\text{mass of compacted materials}}{\text{Volume of water}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The details are as shown in Appendix B, in tables 1 and 2 for the fine and coarse aggregates respectively.

Specific gravity of aggregate

The specific gravity was determined based on saturated and surface dry (SSD) condition of the aggregate. A clean and dry density bottle (50ml) was weighed and recorded as W_1. It was filled with sand half way, weighed and recorded as W_2. Water was then added until it reaches slightly above the sand level. It was shaken vigorously until no bubble was visible. Further, water was added until it reaches the brim of the bottle which was weighed and recorded as W_3. After, the bottle was emptied, rinsed and dried. It was filled with water, weighed and recorded as W_4.

For the granite stone, the same procedure to that of the sand was followed. Only that the density bottle used for sand was replaced with pycnometer for gravel. The specific gravity was calculated using equation below.

$$SG = \frac{\text{mass of solid}}{\text{Mass of equal volume of water}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Determination of physical properties of aggregate

Preliminary investigations were performed on the aggregate (both fine and coarse) to ascertain some of its physical properties. The physical properties investigated were restricted to those crucial for the study. The summary of the results obtained is presented in Appendix B, Table 5 and 6.

Particle size distribution of aggregate

Sieve analysis was conducted for both fine aggregate and coarse aggregate to determine the particle size distribution. For fine aggregate (5mm maximum size), the mass of sample used was 0.2kg while for coarse aggregate (20mm maximum size), the mass of sample used was 2kg as per requirements of BS 812-103.1: 1985 (2000). BS 410 sieves were used and the procedure was based on BS 882 (1992). The sieves were cleaned with a wire brush. The sieves were stacked in order of their sizes with the largest at the top. The weighted aggregate in dry condition were placed in the topmost sieve and the sieves stack was manually shaking vigorously for about 5 minutes. Mass retained on each sieve was measured; the percentage passing and percentage retained were tabulated and calculated.

Details of sieve analysis of the fine and course aggregates are presented in tables 13 and 14 respectively. The grading curves for the sand and the granite stone are presented in Figures 2 and 3 respectively. The particle size distribution indicated that the sand fell within zone II as per BS 882 (1973) classification and medium-coarse grading as per BS 882 (1992). Results of the sieve analysis show that the sand are within the limits specified in Table 4 of BS 882:1992. Equally, results of the sieve analysis showed that the gravel is within the limits specified in Table 3 of BS 882:1992. Thus, the aggregate was well graded and can be used for making good concrete.

Table 5 and 6 in Appendix B, show the particle size distribution of coarse aggregate used in the experiment. Weight retained and cumulative retained and passing of each sieve was calculated and the results obtained conformed to the requirement of ASTM C33 ranges of particle size distribution. This also shows that the aggregate used was well graded one.

Sieve analysis of waste rubber aggregate (WRA)

The result of the sieve analysis is presented in Table 7. It indicates that sieve size 25mm has the highest percentage passing for 10mm size as against sieve size 14mm, which has the lowest percentage passing and for 20mm, it indicates that sieve size 50mm has the highest percentage passing as against sieve size 14mm where the highest percentage was retained.

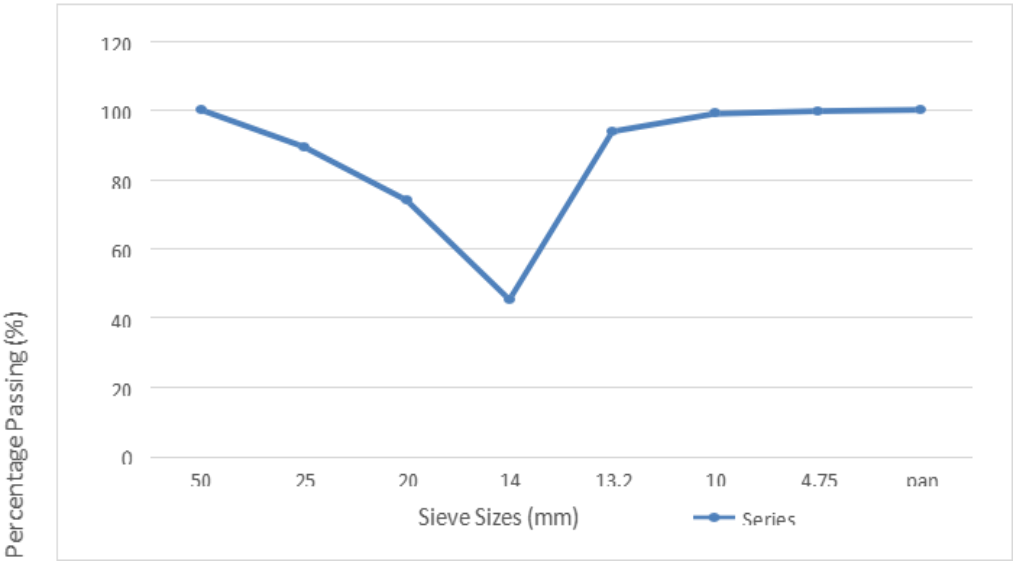


Figure1: Particle size distribution for 20mm WRA

Sieve analysis of cement

The result of the sieve analysis is presented in table 8. It indicates that sieve size 212µm has the highest percentage passing as against 75µm, which has the lowest percentage passing.

Specific gravity test of cement

The result of the specific gravity test of cement sample is as shown in the Table 10. The table shows that the specific gravity of ordinary Portland cement (OPC) used for the research was 3.15. This result conforms to ASTM C 150 (1994).

Bulk density of cement

The result of the bulk density of cement sample as shown in table 8 and was conducted in accordance to BS 812, Part 2 (1975) and the mean bulk density is 0.90kg/m^3.

Table 3: Result of Bulk Density Test of Cement

Test	Test 1	Test 2
Weight of empty container(W_1)kg	0.03	0.03
Weight of container + cement(W_2)kg	0.72	0.70
Weight of container + H_2O(W_3)kg	0.63	0.65
Weight of container (W_3-W_1)kg	0.60	0.62
Weight of cement (W_2-W_1)kg	0.69	0.67
Bulk density = W_3-W_1/W_2-W_1	0.87	0.93
Average mean	0.90	

Source: Laboratory work (2019)

Production of Concrete

The fine and coarse aggregate used were air-dried for 24 hours. The mix ratio used was standard BS mix for concrete grade 20, specifying a mix ratio of 1:2:4, 84 number of cubes were cast for the control concrete (0% replacement of course aggregate) for both compressive strength, water absorption and abrasion resistance tests. 252 number of cubes for 10%, 20% and 30% replacement of gravel for all the tests, given total of 336 cubes for the entire work. The tests were conducted at curing period of 7, 14, 28 and 90days.

Concrete mix design

The proportion of each ingredient for 48 cubes was shown in table 4 and the detail calculations are shown in Appendix A

Table 4. Concrete Mix Proportion of 0% replacement of WRT for 48 cubes (Control)

Quantity	Cement (kg)	Water (kg)	Coarse aggregate (kg)	Fine aggregate (kg)
$1m^3$	450	270	1628	751
$0.0504m^3$ (48 no. cubes)	22.68	13.608	82.05	37.85

Source: Laboratory work (2019)

Table 5: 10% replacement of WRA required for 48 cubes.

Quantity	Cement(kg)	Water(kg)	Coarse aggregate(kg)	10%WRT(kg)	Fine aggregate (kg)
$1m^3$	450	270	1465.2	162.8	751
$0.0504m^3$ (48no.cubes)	22.68	13.608	73.85	8.21	37.85

Source: Laboratory work (2019)

Table 6: 20% replacement of WRA required for 48 cubes.

Quantity	Cement(kg)	Water(kg)	Coarse aggregate(kg)	20%WRT(kg)	Fine aggregate (kg)
$1m^3$	450	270	1302	325.6	751
$0.0504m^3$ (48no.cubes)	22.68	13.608	65.62	16.41	37.85

Source: Laboratory work (2019)

Table 7: 30% replacement of WRA required for 48 cubes.

Quantity	Cement(kg)	Water(kg)	Coarse aggregate(kg)	30%WRT(kg)	Fine aggregate (kg)
$1m^3$	450	270	1139.6	488.4	751
$0.0504m^3$ (48no.cubes)	22.68	13.608	57.44	24.62	37.85

Source: Laboratory work (2019)

Workability test

The slump test was conducted in accordance with specified fresh concrete standard, BS 1881: part 102: 1983, Method for Determination of Slump.

Mixing, moulding and compaction of concrete cubes

The concrete was mixed in accordance with BS1881: Part 108: 1983, Method for Making Test Cube from Fresh Concrete. Cast iron moulds of 100 x 100 x 100 were used to produce the concrete cubes. The moulds were oiled to allow for easy removal of concrete cubes. The concrete was placed in approximately three equal layers and each layer was rammed with 25 strokes of 50mm round ended rod.

Curing of specimens

The cubes were allowed to stay for 24 hours before demolding, this is to avoid the damaging of cubes during demolding. The concrete cubes were completely immersed in a four different curing tanks containing 5%, 10% sulphuric acid and sulphate salt respectively, for the required period of hydration (7, 14, 28, and 90 days).

Density test

The density test for harden concrete cubes prepared for compressive strength test were determined in accordance with BS EN 12390, part 7 (2000). The densities were calculated using equation (7).

$$Density = \frac{mass\ in\ kg}{Volume\ in\ m^3} \quad \ldots\ldots (6)$$

Compressive strength test

The test was carried out in accordance with BS 1881: Part 116: 1983 Method for Determination of Compressive Strength of Concrete Cube. 48 concrete cubes of 100 x 100 x 100 were crushed at saturated surface dry condition. The crushing was carried out at 7, 14, 28 and 90days respectively, using the hydraulic crushing machine of 2000kN. The failure load was divided by the cross-sectional area to obtain the strength (as shown in Table 20 to 23).

Abrasion resistance test

The abrasion resistance test was carried out in accordance with African Regional Standard ARS 674: (1996). The surface of the concrete cubes was subjected to brushing by means of a wire brush. The brushing consists of one forward and backward motion per second for one minute i.e. 60 cycles. The masses of the cubes before brushing were recorded as M_1 and after brushing M_2 respectively. The mass of the detached matter i.e. $M_1 – M_2$ was recorded and the percentage weight loss of all the specimens were recorded and compared.

Water absorption test

Water Absorption test was carried out in accordance with Indian Standard (IS) 3495. Dry cubes were put in an oven at a temperature of 105°C to 115°C till constant mass is attained. The weight (W_1) of each cube is recorded after cooling them to room temperature. The cubes were then immersed in water for 24 hours. The specimens were then taken out of water and allow to attain surface dry, thereafter it was weighed again and recorded as W_2

X 100

The water absorption in % = $\frac{W2-w1}{W1}$ …… (7)

Acid environment

The hardened concrete cubes were immersed in 5% and 10% concentrations of sulphuric acid. The compressive strength of the samples was tested at 7, 14, 28 and 90days curing periods in order to compare the control samples and the WRT samples after acid attack.

Salts environment

The hardened concretes samples were similarly immersed in 5% and 10% concentrations of sulphate salt and the compressive strengths were also tested at 7, 14, 28 and 90days curing periods.

Workability Test on Fresh Concrete

The result shows that all mixtures containing RTW at different levels of replacements records low slumps compared to the control sample. A decrease in the workability with increase in the quantity (percentage) of RTW was recorded. The slum value for the control sample was higher than those containing RTW aggregates. A zero slump was recorded with the sample containing 30% RTW aggregate. The result was found to be in tandem with findings of previous studies such as Onuaguluchi and Panesar (2014) and Fakhri (2016) who reported decrease in workability of concretes incorporating rubber wastes. According to Onuaguluchi et al. (2014), the addition of rubber tends to increase the porosity of concrete, hence, increasing the water penetration depth and the water absorption coefficient of the concrete. A study by Martauz, and Vaclavik (2021) observed that addition of more than 10% rubber in concrete can cause severe reduction in workability. However, Najim and Hall (2013) observed that rubber concrete have acceptable workability up to 50% replacement level but can lead to significant drop in the strength of concrete. To improve the workability of rubber concretes, researchers have recommended the addition of adequate quantity of admixtures such as super plasticizer (Elchalakani, 2015; Awan, Javed, Yousaf, Aslam, Alabduljabbar & Mosavi, 2021).

Table 8: Slump Test for RTW Concrete at different Percentage Replacement

Content (%)		**Slump (mm)**
Gravel	RTW	
100	0	33
90	10	18
80	20	6
70	30	0

Source: Laboratory work (2019)

Durability of Rubber Concretes

The main aim of this study is to investigate the durability of concretes incorporating RTW as aggregates. To achieve this, the study investigated the compressive strengths and water absorption of concrete samples after attack from acid and salt media.

Table 9 Compressive Strength of RTW Aggregate Concrete in Acid Medium (5%)

Addition of RTW (%)	Compressive strength (KN/mm^2)			
	7days	**14days**	**28days**	**90days**
0%	16.8	25.3	27.6	25.8
10%	12.3	21.9	27.3	26.7
20%	8.2	18	23.3	20.4
30%	7.6	11.3	18.5	16.4

Table 10 Compressive strength of RTW aggregate concrete in Acid medium (10%)

Addition of RTW (%)	Compressive strength (KN/mm^2)			
	7days	**14days**	**28days**	**90days**
0%	15.4	22.6	25.2	22.1
10%	10.3	19.7	25.2	24.2
20%	7.4	17.2	18.2	16.7
30%	5.9	11.0	16.3	12.1

To investigate the effect of acid on the compressive strength of RTW aggregate concretes, the hardened concrete specimens were de-moulded after 24hours of casting and the cubes were cured under two curing condition (5% and 10% sulphuric acid). The compressive strengths of the control samples and those containing RTW aggregate cured in the acid environment was tested at 7, 14, 28 and 90 days curing period. Table 9 and 10 shows the results obtained.

The result shows a gradual reduction in the compressive strength with increase in the percentage of RTW aggregates in the concretes mixes. Similarly, there was increased in the compressive strength of all the samples with increase in the curing period up to the 28 days. However, the compressive strength was found to have decreased at the 90 days curing period for all the samples. This indicates a gradual level of destruction of the concrete samples at longer curing periods in acid medium. An analysis of the result shows that at 7days curing period, the control sample recorded higher average compressive strength (16.8 N/mm^2) compared to all samples containing 10% (12.3N/mm^2), 20% (8.2 N/mm^2) and 30% (7.6 N/mm^2) of rubber aggregates respectively. A similar trend was also observed at 14 and 28 days curing period.

There was however, a drop in the compressive strength of the control sample from 27.6 N/mm^2 at the 28 days to 25.8 N/mm^2 at the 90 days hydration period. A similar drop in strength was observed for all the three replacement levels (10%, 20% and 30%) of rubber aggregates at the 90 days curing period. The compressive strength of the sample containing 10% of RTW aggregates (26.7N/mm^2) was observed to be slightly higher than that of the control sample (25.8N/mm^2) at the 90 days curing period. The result suggests that samples containing 10% RTW have a slightly better resistance to acid attacks at longer curing age than the control sample. However, at higher percentage replacement of 20% and 30% the compressive strength of acid attacked rubber aggregate concretes reported lower compressive strength at all ages compared to the control samples. This same trend was observed for both specimens treated in 5% and 10% acid environments respectively. The compressive strengths for all the replacement levels were slightly higher in 5% acid environment compared to those in 10% acid medium indicating the adverse effect of higher concentration of acid on compressive strength of RTW concretes. Thus, the higher the concentration of acids, the greater the adverse effects on the compressive strength of the RTW aggregate concrete samples.

Several studies have reported similar findings of decreasing compressive strength of rubberised concretes compared to normal concrete (Thomas & Gupta, 2016; Ibrahim, Othman & Yusof, 2021; Martauz & Vaclavik, 2021). Various reasons have been adduced by different scholars for the decrease in strength of rubber concretes compared to conventional concretes. The following are some of the reasons identified by Martauz and Vaclavik (2021) for the decrease in the compressive strength of rubber concretes:

(1) With rubber concretes, there is a high likelihood of rapid development of cracks in the cement paste around the rubber aggregates because it is softer than conventional aggregates. This reason can leads to quick failure of the rubber concrete specimen under load, thus reducing its compressive strength.

(2) The bonding between rubber particles and cement paste is a weak bond compared to conventional aggregates; this can leads to cracks due to non-uniform distribution of applied stresses.

3) Due to low specific gravity of rubber and lack of bonding between rubber and other concrete ingredients, there is the tendency for the rubber to move upward during vibration leading to higher rubber concentration at the top layer. This non-homogeneous concrete sample leads to lower strength.

The finding that the compressive strength of RTW aggregate concrete, was lower than the control sample up to the 28 days curing period in this study was therefore, not surprising. It was however instructive that the entire specimen including the control sample indicated evidence of deterioration due to acid attack with only the 10% RTW aggregate concrete showing superior resistance than the control sample at 90 days.

3.2.2 Compressive strength of sulphate salt attacked RTW concretes

Table 11 Compressive strength of RTW aggregate concrete in Sulphate Salt medium (5%)

Addition of RTW (%)	Compressive strength (KN/mm^2)			
	7days	14 days	28days	90days
0%	15.7	26.3	29.2	26.5
10%	11.6	22.7	28.8	26.8
20%	9.2	18.2	24.8	21.6
30%	8.1	12.5	18.6	15.8

Table 12 Compressive strength of RTW aggregate concrete in Sulphate Salt medium (10%)

Addition of RTW (%)	Compressive strength (KN/mm^2)			
	7days	14days	28days	90days
0%	14.9	21.8	26.4	22.1
10%	10.2	19.1	25.1	23.3
20%	7.8	13.2	21.4	20.4
30%	7.2	11.1	16.7	12.6

The compressive strength of RTW aggregate concretes samples cured in sulphate salt medium (5% and 10% concentrations) was tested at 7, 14, 28 and 90 days. Table 11 and 12 presents the result of the compressive strength. The general trend for the compressive strength development of rubber concretes cured in salt medium was almost similar to those in acid medium. It was however observed that the compressive strength in the salt medium was slightly higher at all curing ages for the samples in salt compared to those in acid mediums. For example the compressive strength at 28 days for control samples cured in 5% salt was found to be 29.2N/mm2 as against 27.6N/mm2 recorded for samples in

5% acid at similar curing age. The result shows that the compressive strength of the control samples was higher than those containing RTW aggregates up to the 28 days curing period. As observed in the case of samples in acid medium, there was also a drop in the compressive strength at the 90 days curing for all the replacement levels of the rubber concretes and the control samples in the salt medium. Only the RTW concrete at 10% replacement level recorded slightly higher strength (26.8N/mm2) than the control sample (26.5N/mm2) at 90 days' hydration period. This underscores the earlier observation that rubber aggregates concretes particularly at less than 10% substitution levels has more resistance to aggressive (both acid and salt) environments compared to conventional aggregate concretes. The level of the destruction of the concretes at longer curing period was slightly lower in the salt environment compared to those treated in acid mediums.

Table 13: Water Absorption at 28days of RTW aggregate concrete in Acid Medium

Level of Addition of RTW (%)	Percentage Water absorption (5% acid)	Percentage Water absorption (%) (10% acid)
0%	6.0	7.4
10%	6.4	8.2
20%	8.1	8.6
30%	8.8	9.8

Table 14: Water Absorption at 90 days of RTW aggregate concrete in Acid Medium

Level of Addition of RTW (%)	Water absorption (%) (5% acid)	Water absorption (%) (10% acid)
0%	6.8	7.3
10%	7.3	8.8
20%	9.1	10.1
30%	10.4	11.3

Table 15: Water Absorption at 28days of RTW aggregate concrete in Sulphate salt Medium

	Water absorption (%)	
Replacement level of RTW	**5% salt**	**10% salt**
0%	4.7	5.8
10%	5.3	6.6
20%	6.7	7.7
30%	7.5	8.8

Table 16: Water Absorption at 90 days of RTW aggregate concrete in Sulphate salt Medium

	Water absorption (%)	
Replacement level of RTW	**5% salt**	**10% salt**
0%	5.3	6.7
10%	5.5	7.4
20%	7.9	8.8
30%	8.6	9.8

To examine the water absorption properties of acid attacked concretes incorporating WRT as aggregate. The fourth objective of the study was to investigate the water absorption properties of the concretes incorporating RTW aggregate and compared with the control sample. Tables 13 and 14 shows the result of water absorption for RTW aggregate concretes in acid medium. The results show that water absorption increases with increase in the content of rubber and curing age. The water absorption of samples containing RTW was higher than the control samples for all the samples cured in acid. At 28 days curing period, the water absorption of the control sample was 6.0% and 7.4% for samples in 5% and 10% acid concentrations respectively. At 30% level of replacement of RTW aggregate, the water absorption recorded was 8.8% and 9.8% respectively for 5% and 10% acid concentrations. At the 90 days curing, the control sample recorded 6.8% and 7.3% water absorption in the two acid mediums. Comparatively, the 30% RTW aggregate concrete recorded water absorption of 10.4% and 11.3% in the two acid mediums respectively.

The water absorption values for rubber concrete samples treated in sulphate salt mediums were found to be slightly lower compared to those in acid environments. The water absorption was also found to increase with increase in the percentage level of RTW aggregates in the concrete samples. The percentage water absorption for the control sample at 28 days was found to be 4.7% and 5.8% for the 5% and 10% sulphate salt mediums respectively. At 30% replacement of RTW aggregate, the water absorption at 28 days was 7.5% and 8.8% respectively for the two salt mediums. At the 90 days curing period, the control sample recorded 5.3% and 6.7% respectively for the two salt concentrations while the 30% RTW replacement level reported water absorption of 8.6% and 9.8% respectively.

Previous studies have shown that the incorporation of rubber aggregates into concretes leads to increase in the amount of water absorption of concrete specimens (Onuaguluchi et al. 2014; Martauz, & Vaclavik, 2021). Martauz, and Vaclavik (2021) established a direct relationship between the quantity of rubber and amount of water absorption of rubber concrete. The presence of rubber in concrete was found to increase the depth of penetration of water due to increase in the porosity of concrete. Increase in water absorption signifies weakening and more destruction of the concrete. According to Martauz, and Vaclavik (2021) as the cement water ratio increases, the internal voids also increase resulting in increase in the amount of water absorption for the increase in the rubber content. There was an increase in the amount of water absorption for all the mixes containing rubber aggregates compared to the control samples with increase in curing age. The result generally shows that, water absorption increases with increase in the rubber content and curing age. This could be as a result of open spaces created by the presence of rubber particles in the concrete.

Table 17 Abrasion Resistance of RTW Aggregate Concretes

Level of Addition of RTW (%)	Percentage loss in weight at 28 days	Percentage loss in weight for at 90 days.
0%	10	14
10%	8	12
20%	11	16
30%	9	19

The abrasion resistance test which sought to examine the behaviour or resistance of concrete surfaces against wearing and tearing due to rubbing, scraping and sliding of objects on concrete surfaces was carried out on the RTW aggregate concrete. The abrasion test in this study was carried out on concrete

samples incorporating RTW at 28 and 90 days respectively. The result shows that the loss in weight for samples containing 10% RTW was slightly higher than that of the control samples, while the resistance for the 20% replacement was comparable to that of the control sample. This suggests that the addition of rubber to concretes improves its abrasion resistance. At higher replacement of 30% however, the resistance was observed to have reduced significantly suggesting that at higher replacement levels, the resistance offered by rubber concrete is low. The result was found to be consistent with previous studies such as Thomas & Gupta (2016) who reported higher resistance to abrasion by concretes incorporating rubber wastes show that conventional control samples. Similarly, the study reveals that an increase in the rubber content decreased the amount of abrasion whereas with 50% replacement, the amount of wear reduction was 18% compared to those without.

Summary of Findings

The following summaries were made from the analysis of findings in this study.

The addition of RTW aggregates as replacement to coarse aggregate decreases the workability of concretes particularly at higher replacement levels of RTW.

I. There was a general reduction in the compressive strength of concrete with increase in the content of RTW aggregates in the concretes mixes.

II. The compressive strength of RTW concrete in both acid and salt environments initially increase with increase in curing age up to the 28days. However at longer age (90 days) there was a general reduction in the compressive strength indicating the gradual destruction of the concrete specimen due to the aggressive (acid & salt) environments.

III. Concrete samples containing 10% RTW in both acid and salt environment recorded slightly higher compressive strength at 90 days compared to the control samples. For example, the strength of the control sample in acid at 90 days (27.2N/mm^2) was slightly lower than the 28days strength (27.8N/mm^2) while that of samples with 10% RTW was (27.3 N/mm^2) at 28days and (26.7 N/mm^2) at 90days.

IV. The water absorption of the RTW concrete samples was higher than the control samples for all the samples cured in both acid and salt. At the 90 days curing period, the control sample recorded 6.8% and 7.3% water absorption in 5% and 10% acid mediums. Comparatively, the concretes with 30% RTW aggregate recorded water absorption of 10.4% and 11.3% in the two acid mediums respectively. Similar results were also obtained for samples cured in salt medium.

V. There was evidence of more aggressive destruction of RTW aggregate concrete samples in acid compared to those in salt environments. Similarly, the water absorption of samples in acid environments was higher than those in similar concentrations of sulphate salt.

VI. The addition of RTW aggregates also improves the concrete's resistance to abrasion. The result shows that the loss in weight for samples containing 10% RTW was higher than that of the control samples, while the resistance for the 20% replacement was comparable to that of the control sample. At higher replacement of 30% however, the resistance was observed to have reduced significantly suggesting that higher contents of RTW has poor effect on abrasion resistance.

Conclusion

It was concluded from this study that addition of RTW aggregates to concretes reduces its workability especially with higher content of RTW in the concrete mixes. Similarly the RTW aggregate concrete (up to 10% replacement level) has slightly better performance in terms of compressive strength and

abrasion resistance compared to the conventional (control) samples. The compressive strength of acid and salt attacked RTW concrete (not more than 10%) was slightly higher than that of conventional concrete over a long period of attack. This suggest that up to 10% RTW aggregate concrete can be used to effectively replace conventional aggregates particularly in aggressive acid and salt environments. The RTW aggregate concrete also exhibited a better resistance to abrasion than the conventional control samples. There was however, a gradual increase in the water absorption of both acid and salt attacked RTW concretes compared to the control sample particularly when higher content of RTW is used over a long period of time.

Contribution to Knowledge

The study has contributed to knowledge by providing empirical evidence of the performance of RTW aggregate in resisting attack from aggressive (salt and acid) environments especially over a long period of time.

Recommendations

I. It is recommended that up to 10% replacement of conventional aggregates with RTW can be used for concreting especially in environments that are prone to either acid or salt attacks.
II. Because RTW aggregate concrete shows better resistance to abrasion than control concrete samples, it is recommended for use in pavements and other environments where abrasive forces as a result of moving objects are expected.

Recommendation for Further Studies

I. Further studies should be carried out on the use of powdered rubber waste to replace cement in order to further examine its effect on concretes.
II. Pre-treatment of rubber, use of chemical and mineral admixtures to modify the characteristics of rubber and its effect on the properties of rubber concretes should be explored.
III. Studies should also be performed on the thermal efficiency and sounds insulation properties of rubber concretes to further highlights its performance in this directions.

Appendix A: Tables of Results

Table 1: Bulk Density of Fine aggregate

Description	Weight (kg)
Weight of empty cylinder, W_1	3.12
Weight of empty cylinder + water, W_2	5.048
Weight of empty cylinder + compacted sand, W_3	6.217
Weight of compacted sand = $W_3 - W_1$	3.097
Volume of water = $W_2 - W_1$ /1000	1.928/1000
Bulk density =	1606.33 (kg/m^3)

Source: Laboratory work (2026)

Table 2: Bulk Density of Course Aggregate

Description	Weight (kg)
Weight of empty cylinder, W_1	3.12
Weight of empty cylinder + water, W_2	5.048

Weight of empty cylinder + compacted gravel, W_3	6.249
Weight of compacted gravel = $W_3 - W_1$	3.129
Volume of water = $W_2 - W_1$ /1000	1.928/1000
Bulk density =	1622.93 (kg/m^3)

Source: Laboratory work (2026)

Table 3: Specific Gravity of Fine Aggregate

Fine aggregate Test	**Test**
Mass of bottle, m_1 (g)	27.50
Mass of bottle + fine aggregate, m_2 (g)	61.70
Mass of bottle +fine aggregate + water, m_3(g)	97.18
Mass of bottle full of water	75.99
Specific gravity Sg,	
Average specific gravity	2.63

Source: Laboratory work (2026)

Table 4: Specific Gravity of Coarse Aggregate

Coarse aggregate	**Test**
Mass of jar, m_1 (g)	601.24
Mass of jar + gravel, m_2 (g)	1225.98
Mass of jar + gravel + water, m_3 (g)	1966.52
Mass of jar fullof water, m4(g)	1560.92
Specific gravity Sg,	
Specific gravity	2.85

Source: Laboratory work (2026)

Table 5: Sieve Analysis of fine aggregate

BS sievesizes (mm)	**Weight retained(g)**	**Weight passing(g)**	**Percentage weight retained(%)**	**Percentage weight passing(%)**
5.00mm	25.94	977.50	2.59	97.41
2.36mm	67.69	909.81	6.92	93.08
1.18mm	251.30	658.51	27.62	72.38
600µm	276.60	381.91	42.00	58.00
300µm	293.44	89.47	76.63	23.37
150µm	69.84	19.63	78.06	21.94
75µm	13.13	6.50	66.89	33.11
Pan receiver	6.50	0.00	100.00	0.00

Source: Laboratory work (2026)

Table 6: Sieve Analysis of Coarse aggregate

BS Sieve sizes	**Weight Retained(g)**	**Weight Passing(g)**	**Percentage Weight Retained (%)**	**Percentage Weight Passing (%)**
20	0.00	2000	0.00	100
14	1389.26	627.75	68.88	31.12

BS Sieve sizes	Weight Retained(g)	Weight Passing(g)	Percentage Weight Retained (%)	Percentage Weight Passing (%)
10	416.45	213.50	66.11	33.89
6.30	193.43	22.27	89.68	10.32
5.0	14.12	9.10	60.81	39.19
Pan	9.10	0.00	100.0	0.00

Source: Laboratory work (2026)

Table 7: Result of Sieve Analysis of Waste Rubber Tire Aggregate (WRA) Sample for 20mm.

sieve (mm)	weight retained (g)	Percentage Retained (%)	Percentage Passing (%)
50.0	0	0	100
25.0	107	10.7	89.3
20.0	262	26.2	73.8
14.0	550	55	45
13.2	66	6.6	93.4
10.0	11	1.1	98.9
4.75	4	0.4	99.6
Pan	0	0	100

Sample: 1000g

Table 8: Result of Sieve Analysis of Cement Sample.

Sieve Size	Weight Retained (kg)	Percentage Retained (%)	Percentage Passing (%)
212µm	0	0	100
150µm	110	11	89
75µm	87	8.7	80.3
Pan	720	72	0

Table 9: Specific Gravity Test of Waste Rubber Tire Aggregate (WRA) for 20mm.

Description	Test 1 (kg)	Test 2 (kg)
Weight of empty density bottle (w_1)	0.60	0.60
Weight of empty density bottle + rubber (w_2)	0.95	1.10
Weight of density bottle + rubber +Water (w_3)	1.75	1.70
Weight of density bottle + Water (w_4)	1.60	1.55
Specific gravity	1.75	1.43
Average Specific gravity=1.59		

Table 10: Result of Specific Gravity Test of Cement

Test	Test 1	Test 2	Test 3
Volume of density bottle	600	600	600
Weight of empty density bottle(W_1)kg	0.60	0.60	0.60
Weight of density bottle + cement(W_2)kg	0.95	0.97	1.00
Weight of density bottle + cement + H_2O(W_3)kg	1.74	1.76	1.77
Weight of density bottle + H_2O(W_4)kg	1.50	1.50	1.50
Specific gravity, $G_S=W_2-W_1/(W_2-W_1)-(W_3-W_4)$	3.50	2.86	3.08
Average mean	3.15		

Table 11: Bulk Density Test of Waste Rubber Tire Aggregate (WRA) for 20mm.

Description	Test (kg)
Weight of cylinder, w_1	4.50
Weight of uncompacted rubber +cylinder,w_2	8.50
Weight of compacted rubber +cylinder, w_3	9.30
Weight of cylinder + water, w_4	11.10
Weight of un-compacted rubber, $w_{ur}=w_2-w_1$	4.00
Weight of compacted sand, $w_{cr}=w_3-w_1$	4.80
Volume of water, V=	0.0066m^3
Un-compacted bulk density =	606kg/m^3
Compacted bulk density =	727kg/m^3

Table 17. Slump Test for WRT Concrete at different Percentage Replacement

Content (%)		Slump (mm)
Gravel	**WRA**	
100	0	33
90	10	18
80	20	6
70	30	0

Table 18: Compressive strength test at 7 days

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
Control	5% Sulphuric acid	2.42	2420		122	12.2	
		2.40	2400	2413	176	17.6	14.8
		2.42	2420		146	14.6	
	10% Sulpuric acid	2.52	2520		210	21.0	
		2.32	2320	2380	148	14.8	15.4
		2.30	2300		106	10.6	
	5% Sulphite Salt	2.42	2420		120	12.0	
		2.40	2400	2413	100	10.0	11.3
		2.42	2420		120	12.0	
	10% Sulphaite salt	2.36	2360		196	19.6	
		2.40	2400	2403	121	12.1	14.9
		2.54	2540		130	13.0	
	5% Sulphuric acid	2.36	2360		122	12.2	
		2.32	2320	2347	112	11.2	12.3
		2.36	2360		136	13.6	
	10% Sulpuric acid	2.18	2180		108	10.8	
		2.20	2200	2207	170	17.0	15.3
		2.24	2240		180	18.0	
	5%	2.22	2220		88	8.8	

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
10% RT	Sulphite	2.24	2240	2227	96	9.6	10.6
	Salt	2.22	2220		136	13.6	
	10% Sulphaite	2.24	2240		106	10.6	
	salt	2.26	2260	2260	97	9.7	10.2
		2.28	2280		102	10.2	
	5% Sulphuric	2.08	2080		80	8.0	
	acid	2.30	2300	2250	86	8.6	7.6
		2.37	2370		60	6.0	
	10%	2.28	2280		104	10.4	
20% RT	Sulpuric acid	2.28	2280	2280	156	15.6	12.4
		2.28	2280		112	11.2	
	5%	2.38	2380		60	6.0	
	Sulphite	2.45	2450	2407	60	6.0	6.7
	Salt	2.39	2390		82	8.2	
	10% Sulphaite	2.27	2270		57	5.7	
	salt	2.25	2250	2257	84	8.4	7.8
		2.25	2250		92	9.2	
30% RT	5% Sulphuric	2.20	2200		61	6.1	
	acid	2.22	2220	2213	74	7.4	7.6
		2.22	2220		92	9.2	
	10%	2.15	2150		52	5.2	
	Sulpuric acid	2.28	2280	2237	65	6.5	5.9
		2.28	2280		59	5.9	
	5%	2.24	2240		72	7.2	
	Sulphite	2.42	2420	2290	80	8.0	7.3
	Salt	2.21	2210		66	6.6	
	10% Sulphite	2.15	2150		86	8.6	
	salt	2.28	2280	2237	73	7.3	7.2
		2.28	2280		57	5.7	

Source: Laboratory Work (2026)

Table 19: Compressive strength test at 14 days

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
	5%	2.26	2260		200	20.0	
	Sulphuric	2.32	2320	2300	220	22.0	22.7
	acid	2.32	2320		260	26.0	
	10%	2.38	2380		280	28.0	
Control	Sulpuric	2.40	2400	2380	240	24.0	26.0
	acid	2.36	2360		260	26.0	

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
	5%	2.26	2260		210	21.0	
	Sulphite	2.24	2240	2273	240	24.0	21.7
	Salt	2.32	2320		200	20.0	
	10%	2.42	2420		194	19.4	
	Sulphaite	2.40	2400	2413	215	21.5	19.8
	salt	2.42	2420		186	18.6	
	5%	2.52	2520		200	20.0	
	Sulphuric	2.32	2320	2380	180	18.0	20.0
	acid	2.30	2300		220	22.0	
	10%	2.32	2320		280	28.0	
10% RT	Sulpuric	2.36	2360	2340	200	20.0	24.7
	acid	2.34	2340		260	26.0	
	5%	2.38	2380		240	24.0	
	Sulphite	2.34	2340	2340	180	18.0	20.7
	Salt	2.30	2300		200	20.0	
	10%	2.36	2360		195	19.5	
	Sulphite salt	2.40	2400	2403	205	20.5	19.1
		2.54	2540		174	17.4	
	5%	2.28	2280		200	20.0	
	Sulphuric	2.36	2360	2326	160	16.0	18.0
	acid	2.34	2340		180	18.0	
	10%	2.24	2240		220	22.0	
20% RT	Sulpuric	2.42	2420	2290	260	26.0	23.3
	acid	2.21	2210		220	22.0	
	5%	2.24	2240		100	10.0	
	Sulphite	2.42	2420	2290	160	16.0	12.7
	Salt	2.21	2210		120	12.0	
	10%	2.41	2410		116	11.6	
	Sulphite salt	2.26	2260	2283	130	13.0	12.0
		2.18	2180		114	11.4	
30% RT	5%	2.52	2520		112	11.2	
	Sulphuric	2.42	2420	2453	116	11.6	11.3
	acid	2.42	2420		110	11.0	
	10%	2.30	2300		101	10.1	
	Sulpuric	2.46	2460	2387	124	12.4	11.0
	acid	2.40	2400		106	10.6	
	5%	2.15	2150		116	11.6	
	Sulphite	2.28	2280	2237	132	13.2	12.5
	Salt	2.28	2280		127	12.7	
	10%	2.34	2340		122	12.2	
	Sulphite salt	2.34	2340	2360	130	13.0	13.1

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
		2.40	2400		142	14.2	

Source: Laboratory Work (2026)

Table 20: Compressive strength test at 28 days

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
	5%	2.30	2300		260	36.0	
	Sulphuric	2.40	2400	2326	235	23.5	28.8
	acid	2.28	2280		355	35.5	
	10%	2.33	2330		320	32.0	
Control	Sulpuric	2.39	2390	2320	210	21.0	29.3
	acid	2.24	2240		350	35.0	
	5%	2.16	2160		208	20.8	
	Sulphite	2.14	2140	2176	320	32.0	29.6
	Salt	2.23	2230		360	36.0	
	10%	2.09	2090		280	28.0	
	Sulphaite	2.14	2140	2156	330	33.0	29.0
	salt	2.18	2180		260	26.0	
	5%	2.26	2260		28k5	28.5	
	Sulphuric	2.32	2320	2300	262	26.2	25.4
	acid	2.32	2320		215	21.5	
	10%	2.38	2380		310	31.0	
10% RT	Sulpuric	2.40	2400	2380	290	29.0	27.2
	acid	2.36	2360		215	21.5	
	5%	2.26	2260		320	32.0	
	Sulphite	2.24	2240	2273	290	29.0	28.0
	Salt	2.32	2320		230	23.0	
	10%	2.42	2420		335	33.5	
	Sulphaite	2.40	2400	2413	307	30.7	29.6
	salt	2.42	2420		246	24.6	
	5%	2.52	2520		270	27.0	
	Sulphuric	2.32	2320	2380	200	20.0	23.3
	acid	2.30	2300		200	20.0	
	10%	2.32	2320		220	22.0	
20% RT	Sulpuric	2.36	2360	2340	190	19.0	20.0
	acid	2.34	2340		190	19.0	
	5%	2.38	2380		240	24.0	
	Sulphite	2.34	2340	2340	270	27.0	24.7
	Salt	2.30	2300		230	23.0	

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
	10%	2.36	2360		285	28.5	
	Sulphaite	2.40	2400	2403	262	26.2	25.4
	salt	2.54	2540		215	21.5	
30% RT	5%	2.28	2280		252	25.2	
	Sulphuric	2.36	2360	2326	215	21.5	22.7
	acid	2.34	2340		210	21.0	
	10%	2.40	2400		186	18.6	
	Sulpuric	2.32	2320	2406	174	17.4	20.1
	acid	2.50	2500		208	20.8	
	5%	2.32	2320		216	21.6	
	Sulphite	2.34	2340	2300	220	22.0	20.9
	Salt	2.24	2240		192	19.2	
	10%	2.34	2340		241	24.1	
	Sulphite salt	2.37	2370	2400	267	26.7	22.7
		2.49	2490		172	17.2	

Source: Laboratory Work (2026)

Table 21: Compressive strength test at 56 day

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
	5% Sulphuric	2.30	2300		320	32.0	
	acid	2.46	2460	2387	380	38.0	35.4
		2.40	2400		360	36.0	
	10%	2.15	2150		360	36.0	
Control	Sulpuric acid	2.28	2280	2237	400	40.0	36.0
		2.28	2280		340	34.0	
	5%	2.34	2340		370	37.0	
	Sulphite	2.34	2340	2360	340	34.0	33.6
	Salt	2.40	2400		300	30.0	
	10% Sulphaite	2.36	2360		359	35.9	
	salt	2.50	2500	2420	389	38.9	35.3
		2.40	2400		312	31.2	
	5% Sulphuric	2.32	2320		340	34.0	
	acid	2.32	2320	2287	290	29.0	31.6
		2.22	2220		320	32.0	
	10%	2.24	2240		380	38.0	
10% RT	Sulpuric acid	2.42	2420	2290	370	37.0	36.4
		2.21	2210		340	34.0	
	5%	2.24	2240		220	22.0	
	Sulphite	2.42	2420	2290	250	25.0	24.0

Description	Curing Conditions	Mass (Kg)	Density (Kg/m^3)	Average Density (Kg/m^3)	Max. load (KN)	Strength KN/mm^2	Average Strength KN/mm^2
	Salt	2.21	2210		250	25.0	
	10% Sulphaite	2.41	2410		227	22.7	
	salt	2.26	2260	2283	256	25.6	25.4
		2.18	2180		278	27.8	
	5% Sulphuric	2.52	2520		270	27.0	
	acid	2.42	2420	2453	320	32.0	30.0
		2.42	2420		270	27.0	
	10%	2.26	2260		300	30.0	
20% RT	Sulpuric acid	2.32	2320	2300	310	31.0	30.4
		2.32	2320		296	29.6	
	5%	2.38	2380		200	20.0	
	Sulphite	2.40	2400	2380	200	20.0	20.4
	Salt	2.36	2360		210	21.0	
	10% Sulphaite	2.26	2260		295	29.5	
	salt	2.24	2240	2273	275	27.5	24.4
		2.32	2320		229	22.9	
30% RT	5% Sulphuric	2.42	2420		276	27.6	
	acid	2.40	2400	2413	234	23.4	25.4
		2.42	2420		233	23.3	
	10%	2.16	2160		190	19.0	
	Sulpuric acid	2.14	2140	2176	203	20.3	20.4
		2.23	2230		219	21.9	
	5%	2.09	2090		218	21.8	
	Sulphite	2.14	2140	2156	278	27.8	23.9
	Salt	2.18	2180		220	22.0	
	10% Sulphite	2.26	2260		256	25.6	
	salt	2.32	2320	2300	279	27.9	24.6
		2.32	2320		204	20.4	

Source: Laboratory Work (2026)

Table 22: Water Absorption Tests Results of 0%RT Concrete.

Age of Test	Curing conditions	Average Weight (W1)(g)	Average Weight (W2)(g)	Drying	W2-W1 (g)	% Average Water (%)
	5% acid	2128	2221		93	4.4
	10% acid	2273	2389		116	5.1
14 Days	5% Sulphite Salt	2147	2300		153	7.1
	10% Sulphite salt	2170	2298		123	5.5
	5% acid	2069	2193		124	6.0

Age of Test	Curing conditions	Average Weight (W1)(g)	Average Drying Weight (W2)(g)	W2-W1 (g)	% Average Water (%)
	10% acid	2042	2241	199	9.8
28 Days	5% Sulphite Salt	2076	2229	153	7.4
	10% Sulphite salt	2169	2313	132	6.1
	5% acid	2105	2249	144	6.8
	10% acid	2120	2246	126	5.9
56 Days	5% Sulphite Salt	2130	2062	68	3.3
	10% Sulphite salt	2216	2365	151	6.7

Source: Laboratory Work (2026)

Table 23: Water Absorption Tests Results of 10%RT Concrete

Age of Test	Curing methods	Average Weight (W1)(g)	Average Drying Weight (W2)(g)	W2-W1 (g)	% Average Water (%)
	5% acid	2169	2313	132	6.2
	10% acid	2170	2298	123	5.6
14 Days	5% Sulphite Salt	2216	2365	151	6.3
	10% Sulphite salt	2227	2354	127	5.3
	5% acid	2076	2209	133	6.0
	10% acid	2100	2251	151	6.7
28 Days	5% Sulphite Salt	2118	2302	184	8.0
	10% Sulphite salt	2100	2291	191	8.3
	5% acid	2089	2143	56	2.7
	10% acid	2117	2238	121	5.8
56 Days	5% Sulphite Salt	2236	2366	130	5.5
	10% Sulphite salt	2243	2382	139	6.2

Source: Laboratory Work (2026)

Table 24: Water Absorption Tests Results of 20%RT Concrete

Age of Test	Curing methods	Average Weight (W1)(g)	Average Drying Weight (W2)(g)	W2-W1 (g)	% Average Water (%)
	5% acid	2490	2546	56	22
	10% acid	2325	2366	41	17
14 Days	5% Sulphite Salt	2407	2456	49	20
	10% Sulphite salt	2413	2478	63	61

Age of Test	Curing methods	Average Weight (W1)(g)	Average Drying Weight (W2)(g)	W2-W1 (g)	% Average Water (%)
	5% acid	2394	2372	58	51
	10% acid	2429	2493	64	26
28 Days	5% Sulphite Salt	2390	2340	50	21
	10% Sulphite salt	2471	2528	57	23
	5% acid	2472	2512	40	16
	10% acid	2395	2447	52	21
56 Days	5% Sulphite Salt	2403	2448	45	19
	10% Sulphite salt	2418	2474	56	23

Source: Laboratory Work (2026)

Table 25: Water Absorption Tests Results of 30%RT Concrete

Age of Test	Curing methods	Average Weight (W1)(g)	Average Drying Weight (W2)(g)	W2-W1 (g)	% Average Water (%)
	5% acid	2128	2221	93	4.4
	10% acid	2273	2389	116	5.1
14 Days	5% Sulphite Salt	2147	2300	153	7.1
	10% Sulphite salt	2243	2382	139	6.2
	5% acid	2069	2193	124	6.0
	10% acid	2042	2241	199	9.8
28 Days	5% Sulphite Salt	2076	2229	153	7.4
	10% Sulphite salt	2128	2221	93	4.4
	5% acid	2105	2249	144	6.8
	10% acid	2120	2246	126	5.9
56 Days	5% Sulphite Salt	2130	2062	68	3.3
	10% Sulphite salt	2273	2389	116	5.1

Source: Laboratory Work (2026)

Table 26: Abrasion Resistance Test of 0% RT Samples.

Age of Test	Curing Conditions	Average Weight (g)	Average New Weight (g)	Weight Loss (g)	% Weight Loss (%)
	5% acid	2220	2217	2.7	0.17
14 Days	10% acid	2327	2324	3.3	0.14
	5% Sulphite Salt	2319	2313	6.3	0.27
	10% Sulphite salt	2277	2276	1.3	0.06
	5% acid	2289	2283	4.0	0.17
28 Days	10% acid	2307	2305	2.3	0.10
	5% Sulphite Salt	2267	2265	4.3	0.19
	10% Sulphite salt	2306	2304	2.0	0.09

	5% acid	2240	2237	2.3	0.11
56 Days	10% acid	2244	2243	1.0	0.04
	5% Sulphite Salt	2313	2311	2.3	0.11
	10% Sulphite salt	2394	2392	2	0.08

Source: Laboratory Work (2026)

Table 27: Abrasion Resistance Test of 10% RT Samples.

Age of Test	Curing Conditions	Average Weight (g)	Average New Weight (g)	Weight Loss (g)	% Weight Loss (%)
	5% acid	2220	2237	2	0.13
14 Days	10% acid	2288	2285	3	0.14
	5% Sulphite Salt	2306	2304	2	0.09
	10% Sulphite salt	2318	2246	4	0.22
	5% acid	2385	2384	1	0.04
28 Days	10% acid	2432	2431	1	0.19
	5% Sulphite Salt	2420	2418	2	0.27
	10% Sulphite salt	2394	2392	2	0.15
	5% acid	2384	2382	1	0.04
56 Days	10% acid	2417	2416	1	0.09
	5% Sulphite Salt	2377	2375	2	0.18
	10% Sulphite salt	2402	2399	3	0.12

Source: Laboratory Work (2026)

Table 28: Abrasion Resistance Test for 20% RT Samples.

Age of Test	Curing Conditions	Average Weight (g)	Average New Weight (g)	Weight Loss (g)	% Weight Loss (%)
	5% acid	2309	2308	1	0.04
14 Days	10% acid	2322	2321	1	0.04
	5% Sulphite Salt	2389	2387	2	0.08
	10% Sulphite salt	2346	2342	2	0.09
	5% acid	2326	2324	2	0.09
28 Days	10% acid	2420	2418	2	0.08
	5% Sulphite Salt	2373	2371	2	0.08
	10% Sulphite salt	2406	2403	3	0.12
	5% acid	2326	2324	2	0.09
56 Days	10% acid	2420	2418	2	0.08
	5% Sulphite Salt	2373	2371	2	0.08
	10% Sulphite salt	2406	2403	3	0.12

Source: Laboratory Work (2026)

Table 29: Abrasion Resistance Test for 30% RT Samples.

Age of Test	Curing Conditions	Average Weight (g)	Average New Weight (g)	Weight Loss (g)	% Weight Loss (%)
	5% acid	2402	2339	3	0.12
14 Days	10% acid	2304	2301	3	0.13

	5% Sulphite Salt	2403	2400	3	0.12
	10% Sulphite salt	2350	2345	5	0.21
	5% acid	2138	2134	4.3	0.18
28 Days	10% acid	2236	2233	2.0	0.09
	5% Sulphite Salt	2138	2134	2.6	0.12
	10% Sulphite salt	2264	2262	1.6	0.07
	5% acid	2199	2198	1.0	0.05
56 Days	10% acid	2138	2153	2.3	0.07
	5% Sulphite Salt	2236	2235	1.0	0.04
	10% Sulphite salt	2138	2138	0.3	0.02

Source: Laboratory Work (2026)

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