Durability of Recycled Concrete Aggregate in Aggressive Environments

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Abstract: The main purpose of this research is to study the durability of recycled concrete as a partial replacement of coarse aggregate in corrosive environment. 10%, 20%, 30% and 40% by weight were used for recycled concrete. Concrete samples exposed to 10% concentration dilute sulfuric acid solution for 180 days. Mechanical tests such as compressive and tensile strength tests, physical tests such as ultrasonic pulse velocity, bulk density, porosity, specific gravity and water absorption tests were done to the samples after curing in normal water for 28 days and after submerged in dilute sulfuric acid for 180 days. Degradation increased with increasing of replacement. Test results showed that 10% and 20% partial replacement of recycled concrete aggregate still closely to reference samples. Noticeable deterioration was shown in mechanical and physical properties for 30% and 40% partial replacement of recycled concrete aggregate.

Key words: Recycled concrete, sulfuric acid, compressive strength, tensile strength, durability, partial replacement.

1. Introduction

Rapid industrial development causes serious problems all over the world such as depletion of natural aggregates and creates enormous amounts of waste materials from construction and demolition activities. One of the ways to reduce this problem is to utilize recycled concrete aggregate in the production of concrete [1]. At ambient temperature, using of recycled concrete as a partial coarse aggregate replacement in proportions 10%, 20% and 30% gives a best mechanical and physical properties test results [2]. Sulfuric acid is one of destructive acids to concrete and depending on its concentration and formation manner, can cause severe degradation and damage to the concrete structures with which it comes into contact. In steel iron industry, waste acids which are used for surface preparations may be disposed in waste water systems which will consequently result in attacks to underground concrete facilities [3]. Also certain bacteria convert sewage into sulfuric acid. Acids react

with calcium hydroxide of the hydrated Portland cement [4]. Acids generally attack and leach away the calcium compounds of the paste, they may not readily attack certain aggregate such as siliceous aggregates [5]. Sulfuric acid reacts with free lime and forms gypsum; wet-dry cycles of exposure to sulfuric acid increase the degree of concrete deterioration [6].

2. Experimental Works

2.1 Materials

Local sulfate resistance Portland cement type (I) was used in the mixes. Chemical and physical tests of cement are illustrated in Tables 1 and 2. The results showed that cement chemical analysis specify ASTM (American Society for Testing and Material) C114-07 [7].

Local sand was used as a fine aggregate in all mixes, sieve analysis test results illustrated in Table 3 and specify ASTM C136-01 [8]. Laboratory tests showed that specific gravity, water absorption and sulfates contents for fine aggregate are 2.6%, 1.6% and 0.27%, respectively.

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Local gravel was used as a coarse aggregate and specify ASTM C136-01 [8] with maximum grain size

Table 1 Chemical analysis of cement.

Compound type	Results (%)
SiO ₂	22.041
Al ₂ O ₃	3.531
Fe ₂ O ₃	3.783
CaO	63.21
MgO	2.282
SO ₃	2.401
L.O.I	0.643
I.R	0.97
L.S.R	0.89
C ₃ A	1.7

Table 2 Physical properties of cement.

Properties	Results
Initial setting time	122 min
Final setting time	176 min
Soundness	1 mm
Compressive strength at 3 days	26.6 N/mm ²
Compressive strength at 7 days	43 N/mm ²

Table 3 Sieve analysis of sand.

Sieve size (mm)	Passing (%)
9.5	100
4.75	95
2.36	93
1.18	79
0.6	61
0.3	28
0.15	0

10 mm. Laboratory tests showed that specific gravity, water absorption and sulfates contents for coarse aggregate are 2.64%, 0.9% and 0.07%, respectively.

Reference concrete samples were crushed and used as a partial replacement recycled coarse aggregate 10%, 20%, 30% and 40% by weight with maximum grain size 10 mm.

2.2 Materials Preparations

Concrete prepared for reference samples with mix proportion 1:2:4 (C:S:G (cement:sand:gravel)) by weight and w/c ratio 0.5 to obtain slump equal to 40 mm [9].

Reference concrete samples were reused as recycled coarse aggregates after crushing and sieving in proportions 10%, 20%, 30% and 40% by weight of

coarse aggregate. Concrete mix proportion is 1:2:4 (C:S:G & RCA (recycled concrete aggregate)) with w/c 0.52 to obtain slump equal to 40 mm [9].

2.3 Samples Casting and Curing

Steel cubes with 150 mm size and steel prisms (400 × 100 × 100) mm size were used to cast concrete specimens. Perfect compaction was achieved by using compacting vibrating table; concrete surface was leveled and covered by using polyethylene sheet for 24 h in ambient laboratory temperature 37 °C. Specimens cured in drinking water for 28 days and used in this experimental study (Fig. 1).

2.4 Samples Mechanical and Physical Tests

2.4.1 Compressive Strength

This test was done according to BS 1881: Part 116-1983 [10] for concrete cubes and the results represent average results of two cubes.

2.4.2 Tensile Strength

This test was done according to ASTM C293-02 [11] for concrete prisms (400 × 100 × 100) mm and the results represent average results of two prisms.

2.4.3 Ultrasonic Pulse Velocity

This test was done according to ASTM C597-02 [12] for concrete cubes and the results represent average results of two cubes.

2.4.4 Bulk Density

This test was done according to ASTM C642-97 [13] for concrete cubes and the results represent average results of two cubes.

Fig. 1 Recycled concrete aggregate.

2.4.5 Apparent Specific Gravity

This test was done according to ASTM C642-97 [13] for concrete cubes and the results represent average results of two cubes.

2.4.6 Apparent Porosity

This test was done according to ASTM C642-97 [13] for concrete cubes and the results represent average results of two cubes.

2.4.7 Water Absorption

This test was done according to ASTM C642-97 [13] for concrete cubes and the results represent average results of two cubes.

2.4.8 Slump Test

This test was done according to ASTM C143-01 [9] for all concrete mixtures and the average result equals to 40 mm.

3. Results and Discussion

The results of water curing samples indicated that compressive and flexural tensile strength for reference concrete samples with natural aggregate higher than for concrete with different recycled aggregates proportions. Maximum cube compressive strength is 31.3 MPa and flexural tensile strength is 3.5 MPa for reference samples.

Recycled concrete aggregate replacement in amounts 10%, 20%, 30%, and 40% decrease compressive and flexural tensile strength of water curing concrete, cube compressive strength and flexural tensile strength test results range respectively between 30.66 MPa, 3.1 MPa for 10% replacement to 24.22 MPa, 2.5 MPa for 40% replacement as shown in Table 4, Figs. 2 and 3. The reduction in compressive and flexural tensile strength may be due to a poor bond between cement paste and recycled aggregate particles which contain hydrated cement paste particles.

Compressive strength is a major indicator for many physical properties of concrete such as UPV (ultrasonic pulse velocity), bulk density, apparent specific gravity, porosity and water absorption. Increasing the compressive strength value means increasing the bulk density, specific gravity and UPV value and decreasing the porosity and water absorption percentage. UPV test results are 5.41 km/s for reference samples and range between 5.06 km/s to 5.37 km/s for recycled concrete aggregate replacement in proportions (10% to 40%) as shown in Table 5 and Fig. 4.

Bulk density test results are 2.309 g/cm³ for reference samples and range between 2.22 g/cm³ to

Table 4 Compressive and flexural tensile strength of recycled concrete in water (N/mm²).

Type of samples	Type of test	Compressive strength (MPa)	Flexural tensile strength (MPa)
Reference concrete		31.3	3.5
10 % RC replacement		30.66	3.1
20 % RC replacement		29.2	3.0
30 % RC replacement		27.6	2.9
40 % RC replacement		24.22	2.5

Fig. 2 Compressive strength results.

Fig. 3 Flexural tensile strength results.

2.302 g/cm³ for recycled concrete aggregate replacement in proportions (10% to 40%) as shown in Table 5 and Fig. 5.

Water absorption test results are 3.972% for reference samples and range between 3.977% to 3.991% for recycled concrete aggregate replacement in proportions (10% to 40%) as shown in Table 5 and Fig. 6.

Specific gravity test results are 2.538 for reference samples and range between 2.489 to 2.528 for recycled concrete aggregate replacement in proportions (10% to 40%) as shown in Table 5 and Fig. 7.

Porosity test results are 8.993% for reference samples and range between 9.370% to 10.98% for recycled concrete aggregate replacement in proportions (10% to 40%) as shown in Table 5 and Fig. 8.

Sulfuric acid is particularly aggressive because, in the addition to the sulfate attack of the aluminates phase, acid attack on Ca(OH)₂ and C-S-H takes place [14].

Dilute sulfuric acid is the main cause of concrete compressive strength deterioration because of the

Fig. 4 UPV results.

Fig. 5 Bulk density results.

Fig. 6 Water absorption results.

Fig. 7 Specific gravity results.

Fig. 8 Porosity results.

decomposition of calcium silicate hydrate compound [15].

The results of immersed samples in dilute sulfuric acid solution is lower than water curing samples.

The results of immersed samples in dilute sulfuric acid solution as shown in Table 6 indicated that compressive and flexural tensile strength for reference concrete samples with natural aggregate is higher than for concrete with different recycled aggregates proportions. Maximum cube compressive strength is 30.4 MPa and flexural tensile strength is 3.2 MPa for reference samples.

Table 5 Physical tests of recycled concrete samples in water.

Type of samples	Test type of U.P.V. (km/s)	Bulk density (gm/cm ³)	Water absorption (%)	Specific gravity	Porosity (%)
Reference concrete	5.41	2.309	3.972	2.538	8.993
10 % RC replacement	5.37	2.302	3.977	2.528	9.370
20 % RC replacement	5.3	2.278	3.981	2.520	10.678
30 % RC replacement	5.2	2.250	3.987	2.50	10.98
40 % RC replacement	5.06	2.22	3.991	2.489	11.2

Table 6 Compressive and flexural strength in acid (N/mm²).

Type of samples	Type of test	Compressive strength (MPa)	Flexural tensile strength (MPa)
Reference concrete		30.4	3.2
10 % RC replacement		29.16	2.9
20 % RC replacement		27.3	2.5
30 % RC replacement		23.8	2.1
40 % RC replacement		18.1	1.7

Table 7 Physical tests of RC in sulfuric acid solution.

Type of samples	Test type of U.P.V. (km/s)	Bulk density (gm/cm ³)	Water absorption (%)	Specific gravity	Porosity (%)
Reference concrete	5.33	2.2	3.98	2.5	9.07
10 % RC replacement	5.2	2.18	3.99	2.48	9.45
20 % RC replacement	4.9	2.08	4.08	2.44	10.9
30 % RC replacement	4.5	1.98	4.2	2.39	11.8
40 % RC replacement	4.1	1.64	4.31	2.32	13.09

Recycled concrete aggregate replacement in amounts (10%, 20%, 30% and 40%) decreases compressive and flexural tensile strength of immersed samples in dilute sulfuric acid solution concrete, cube compressive strength and flexural tensile strength test results range respectively between 29.16 MPa 2.9 MPa for 10% replacement to 18.1 MPa, 1.7 MPa for 40% replacement as shown in Table 6, Figs. 2 and 3.

UPV test results are 5.33 km/s for reference samples and range between 4.1 km/s to 5.2 km/s for recycled concrete aggregate replacement in proportions 10% to 40% as shown in Table 7 and Fig. 4.

Bulk density test results are 2.2 g/cm³ for reference samples and range between 1.64 m/cm³ to 2.18 m/cm³ for recycled concrete aggregate replacement in proportions 10% to 40% as shown in Table 7 and Fig. 5.

Water absorption test results are 3.98% for reference samples and range between 3.99% to 4.31% for recycled concrete aggregate replacement in proportions

10% to 40% as shown in Table 7 and Fig. 6.

Specific gravity test results are 2.50 for reference samples and range between 2.32 to 2.48 for recycled concrete aggregate replacement in proportions 10% to 40% as shown in Table 7 and Fig. 7.

Porosity test results are 9.07% for reference samples and range between 9.45% to 13.09% for recycled concrete aggregate replacement in proportions 10% to 40% as shown in Table 7 and Fig. 8.

4. Conclusions

The concrete samples with natural aggregate gives best mechanical and physical results for both samples cured in water and submerged in dilute sulfuric acid solutions.

The concrete samples with 10%, 20% and 30% partial replacement of coarse aggregate give mechanical and physical results close to reference samples cured in water.

The concrete samples with 10% and 20% partial

replacement of coarse aggregate deterioration results in dilute sulfuric acid solution give mechanical and physical results close to reference samples submerged in dilute sulfuric acid solutions.

30% and 40% partial replacement of coarse aggregate samples results deviates from both reference samples cured in water and submerged in dilute sulfuric acid solution.

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