Enhancing the Durability of Self-Compacted Concrete Cast Using Recycled Aggregates

Alaa a. Bashandy[1], Noha M. Soliman[1], Sherif S. Khadash[2]

[1]*Civil Engineering Department, Faculty of Engineering, Menoufia University, Egypt*
[2]*Civil Engineer, M.Sc. candidate*

ABSTRACTA Self-compacted concrete is the one that can be placed in the form and can go through obstruction by its own weight and without the need of vibration.The main objectives of this research is studying the main properties of self-compacting concrete cast using recycled aggregates (crushed concrete, crushed red bricks, and crushed ceramic compared to dolomite) and to study the feasibility of improving its durability. The experimental investigation was divided into two stages. The first was performed to obtain the main fresh and hardened properties. The second was conducted to study the durability enhancement by using three improving materials. Durability was evaluated under sulfate attack and chlorides attack. The fresh properties of were obtained in the term of slump test. The hardened properties were introduced in terms of compressive, splitting tensile, flexure, and bond strengths. Test results indicated that using suggested enhancing materials improve the recycled aggregate self-compacted concrete. Using waterproofing powder improved the durability against sulfates and chlorides compared to other suggested materials.

Keywords: Improve; Self-compacting; Durability; Recycled; Aggregate.

1. INTRODUCTION

Self-compacted concrete "SCC" is a concrete type, which need no compaction[*1*]. SCC is able to flow under its own weight to fill the formwork even within congested reinforcement. In general, for conventional concretes, a newly placed concrete is compacted by vibrating equipment. SCC was proposed in 1986 [*2*], but the prototype was first developed in Japan in 1988 [*3*].

SCC is not affected by the workers skills, the reinforcement shape, or amount. SCC can be pumped longer distances due to its high-fluidity and due to its resistance to segregation [*4*]. During the past years, the utilization of SCC in different countries has been steadily growing each year[*5*,*1*]. The using of mineral admixtures canimprove particle packing and decrease the permeability of concrete, which led to increasing the durability [*6*]. Silica fume, limestone powder, fly ash andgranulated blast furnace slag as industrial by-products or waste materials are generally used asmineral admixtures in SCC [*7*,*8*]. Besides the economicbenefits, such uses of waste materials inconcrete reduce environmental pollution[*9*].Also, the increasing demand on natural aggregate as concrete aggregate, researchers tries to provide alternatives. Using demolished building materials as recycled coarse aggregates consider the main alternative to natural aggregate[*10*,*11*,*12*,*13*]. The obtained concrete called recycled concrete aggregate "RCA". Its properties and quality depends on recycled aggregate type and demolishedmethod[*14*,*15*]. RCA have lower density,lower specific gravity, andhigher water absorption compared to concrete withnatural aggregate.Using recycled aggregate as replacement to natural aggregate is more efficient than using it individually[*16*]. Using of recycled aggregates as coarse

aggregate for SCC is nearly efficient[***16***,***17***,***18***,***19***].The Workability of the SCC with RCA reduced with the increase of the content of recycled coarse aggregate. Also, compressive and tensile splitting strengths of the SCC with RCA decreased with increasing recycled coarse aggregate content[***20***].The processing of recycled aggregates plays an important role in determining the strength and durability of RCA for normal concrete or SCC[***21***].Several efforts to enhancethe durability of RCA was conducted with several materials such as polymers or bacteria[***22***,***23***,***24***].

The main aim of this research to study the feasibility of enhancing the durability of self-compacted concrete "SCC" cast using recycled aggregates as recycled-aggregate self-compacted concrete "RA-SCC". The durability of RA-SCC studied in terms of sulfates and chlorides attack for different periods. Also, the effects of using several available enhancing materials to improve the durability of RA-SCC were studied.

2. RESEARCH SIGNIFICANCE

As the increase in using recycled aggregates with different concrete types due to the environmental and economic considerations, information on the quality of recycled aggregate concrete is still scarce. This study attempts to examine the ability of improving the durability of recycled aggregate SCC against sulfates and chlorides. This research is an attempt to provide useful information for the practical use of recycled aggregate in advanced concrete production.

3. MATERIALS AND METHOD

3.1. Properties of materials used

1.Cement*:** The cement used was the ordinary Portland cement, which was provided from the Suez factory. Its chemical and physical characteristics satisfy the Egyptian Standard Specifications 4756-1/2009 [25***] and Egyptian Code of Practice E.C.P. 373/2007[8].Table (1) shows the mechanical, physical and chemical properties of the cement used.

2. Fine aggregate: Natural sand was used as fine aggregates. Its characteristics satisfy the Egyptian Standard Specifications E.S.S. 1109/2007[***26***]. The grading curve of the sand used is shown in Fig. (1).The main physical and mechanical properties of fine aggregate used are given in Table (2).

3.Coarse aggregates:onenatural aggregates (dolomite) and three types of recycled aggregates (crushed concrete, crushed ceramic and crushed red bricks) were used as coarse aggregates. Their main physical and mechanical properties are given in Table (3). Their grading are shown in Fig. (2). They are as follow:

Dolomite:Natural dolomite was used as a natural coarse aggregate. The dolomite has a maximum nominal size of 10 mm. The Grading is according to ASTM C-33 with maximum nominal size of 10mm.

Crushed concrete:Recycledcrushed concrete from the demolished buildings was used as coarse aggregate.Concrete boulder was crushed in to particles with a maximum nominal size "M.N.S." of 10 mm. The particles were irregular and angular. Its grading is shown in Fig. (2). The physical and mechanical properties of crushed concrete are given in Table (3).

***Crushed ceramic*:**Crushed ceramic was used as recycled coarse aggregate. It was crushed in to particles with a M.N.S.of 10 mm. Its gradingand properties are shown in Table (3) and Fig. (2).

Crushed red brick: red brick from the demolition of buildings was used as recycled coarse aggregate. It was crushed into pieces with a M.N.S.of 10 mm. Its grading and properties are shown in Table (3) and Fig. (2).

4.Water*:**Tap water without special taste, smell, color, or turbidity was used for mixing and curing proceduresaccording to the Egyptian code of practice E.C.P. 203/2007[27***].

5.Concrete Admixtures:Two types of admixtures were used, chemical and pozzolanic as follow:

***Chemicaladmixture*:**A high range water reducer as super plasticizer under thecommercial name of Sika ViscoCrete 5920was used. It was provided from Sika Company in Egypt. Its main properties are shown in Table (4).

Pozzolanic additives: Silica fume is used as a fillers material for SCC to improve flowability, strength, and durability of concrete. It is very fine non-crystalline silica produced in electrical furnaces as a byproduct material of the production of silicon elemental. It is typically much more reactive, particularly at early ages because of its higher silicon dioxide content[10]. The chemical characteristics of silica fume are given in Table (5).

6Steel rebars:High tensile steel rebars (St. 52) of Ø16 mm diameter were used as embedded rebars in standard cubes of 150x150x150mm to evaluate the bond strength as shown in Fig. (3). Main properties of both steel types are satisfying E.S.S. 262/2011 [***28***]. Test results were illustrated in Table (6).

7.Durability enhancing admixtures

Water proofing Powder admixture:is a ready to use water proofing powder admixture for cement/sand mortars, screeds and renders for walls, facades, floor toppings, and jointingmortars under commercial name of Sikalite. Its advantages are; increase impermeability, improve workability without increasing water. Its main properties are given in Table (7).

***Emulsion for cement mortars*:**it is a synthetic rubber emulsion for adding to cement mortars, where good adhesion and water resistance are required under the commercial name of Sika top seal. The product is suitable for use in tropical and hot climatic conditions. Its main properties are given in Table (8).

Water proofing admixture:is aclear aqueous solution of special silicone derivatives with outstanding properties used mainly water-repellent treatment of porous building materialsunder the commercial name of Stonesil. It reduces the porosity of the surfaces and reduces dirt and water penetration therefore increases the lifetime of the building material .it water based environment friendly product. The properties of Stonesil are given in Table (9).

3.2.Tested Specimens

Mechanical Properties tests were conducted on the standard samples according the Egyptian Code of Practice (E.C.P. 203/2007)[***27***]. Cubes (100x100x100mm),cylinders (100 diameter and 200mm height) andprisms (100x100x500mm) were used to find were used to obtained compressive, tensile and flexural strengths, respectively without any compaction as SCC was used. To obtain the bond strength,standard cubes (150 x 150 x 150mm) with embedded high tensile steel rebars (St. 52 with 16mm diameter and 160mm length).Experimental program flow chart is shown in Fig. (4).

3.3.Concrete Samples

The main proportion of theSCCmix used was obtained based on previous researches conducted by Etman, 2006 [9]. Thecomponents of all mixes were the same except the coarse aggregates used. Natural as well as recycled aggregates were used as shown in Table (10).All specimens were kept at molds for 24 hours; after that, they removed from the molds and immerged in clean water at room temperature *(about 23°C and relative humidity of 68%)*up to testing time. Three specimens for each mix were tested.

Durability tests were performed after different periods of attack. Samples under chloride attack were. Chlorideattackwas simulated by immersing the concrete samples in NaCLsolution (concentration of 5%) for 2 and 4 months then they were tested then compared to control samples. sulfate attack was simulated by immersing the concrete samples in Na_2SO_4 solution (5% concentration) for 2, 4,and6 months then theywere tested.

3.4.Performed Tests

Main mechanical properties were obtained throw out four tests. The first was compressive strength test was carried out on standard concrete cubes of 100x100x100 mm dimensions according to E.C.P. 203-2007 [4]. A compression testing machine of 2000 KN capacity was used. The indirect tensile of concrete samples were determined based on E.C.P. 203-2007 [4]. Standard cylinders of dimensions of 100x200 mm were used to obtain the splitting tensile strength. Flexural testing machine of a capacity of 100 KN were used. Prisms of dimensions 100x100x500 mm were used to obtain the flexure strength. Also, slabs were tested using the same flexure testing machine. Tests were carried out on standard cubes of 150x150x150 mm dimensions with embedded rebars of ∅16 mm diameter and 160mm length, according to ASTM C39-86 as shown in Fig. (5). The same previous compression testing machine were used.

4. TEST RESULTS

4.1. Main Properties ofRA-SCC Samples

The fresh properties in terms of slump values as shown in Table (11) were studied.In addition, main mechanical properties of hardened concretewere studied. The main studied mechanical properties are compressive, splitting tensile, flexural and bond strengths as shown in Figures. (6) to (9).The samples were subjected to sulfate and chloride attack for different periods. The effect of using different improving techniques on the durability under the effect of sulfates for different mixes used isshown in Figs. (6) to (25). Figures (26) to (41) showed the effects of chlorides on the different mixes used.

4.1.1. Fresh Properties for RA-SCC samples

The fresh propertiesof studied RA-SCC studied in terms of slump values and T50 time of J-ring as shown in Table (11). The results indicated that the flowability of RA-SCC cast using crushed concrete increased by about 1.85%compared to SCC samples cast using dolomite as coarse aggregate, while RA-SCC cast using crushed ceramic and crushed red bricks decreased by about 2.32% and 7.75 % compared to control samples (SCC samples cast using dolomite as coarse aggregate). That may refer to the lower specific gravity as well as the noticed roughness of surfaces of recycled red bricks, which led to lower workability compared to using dolomite as natural aggregates.

The T50 results of SCC samples cast using crushed concrete decreased by about 16.3%compared to control sample. For samples cast using crushed ceramic,T50 results increased by about 23% and 9% compared to control samples.

When enhancing materials were used for RA-SCC cast using crushed concrete, the results indicated that the workability of RA-SCC samples enhanced by using Waterproofing powder, mortar emulsion, and surface paintby about 3.2%, 4.6%,and 2.3%, respectivelycompared to control samples.The workability of RA-SCC samples cast using crushed ceramics decreased when using Waterproofing powder, mortar emulsion, and surface paint by about 1.22%, 0.5%, and 3.6%, respectively compared to control samples. The workability of RA-SCC samples cast using crushed red brick decreased when using Waterproofing powder, mortar emulsion, and surface paintby about 8.7%, 7.5%, and 9.3%, respectively compared to control samples.

4.1.2. Main Mechanical Properties for Hardened RA-SCC

The hardened properties were studied in terms of compressive, splitting tensile, flexure and bond strengths as shown in Figs. (6) to (9).

The compressive strength of samples "OC-C"increased by about 10.3 %, while"OC-CR" and "OC-RB"decreased by about 9.8 % and5.7 %, respectively compared to control sample "OC-D". The splitting tensile of samples "OC-C" increased by about 10.7 %, while for samples"OC-CR" and"OC-RB"decreased by about 8.3 % and6.9 %, respectively compared to control sample "OC-D". The flexure strength of samples "OC-C" increased by about 10.9 %, "OC-CR" decreased by about 7.5 %,"OC-RB" decreased by about 5.6 % compared to control sample "OC-D". For the bond strength, "OC-C"samples increased by about 10.6 %, "OC-CR" decreased by about 9 %,"OC-RB" decreased by about 7.2 % compared to control sample "OC-D". The increasing of the strength values of "OC-C" samples may refer to the irregularity and the roughness of the particle surface of crushed concrete, which provides more cohesion

with concrete and its homogeneity with concrete, as they are nearly the same material. The lower values for "OC-RB" may refer to its lower crushing factor and its larger voids as shown in Table (3).

4.2. Durabilityof RA-SCC

In this section, the durability of samples without using any enhancing materialswas illustrated. The durability studied in terms of sulfate and chloride attack for 2, 4, and 6 months. The results of the compressive strength tests due to the attack of sulfate on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials showed in Figs. (10) to (13).Tensile strength results are illustrated in Figs. (14) to (17). Flexure strength results are illustrated in Figs. (18) to (21). Bond strength results illustrated in Figs. (22) to (25).

The results of the compressive strength tests due to the attack of chlorides on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (26) to (29). Tensile strength results are illustrated in Figs. (30) to (33). Flexure strength results are illustrated in Figs. (34) to (37). Bond strength results illustrated in Figs. (38) to (41).

Under sulfate attack, the compressivestrengths of sample "OC-D" decreased by about9.5%,9.4%, and 9.7%after 2, 4, and 6 months, respectively compared to its control sample "D-C".The tensile strengths of sample "OC-D" decreased by about 9.5%, 9.4%, and 8.8% after 2, 4, and 6 months, respectively compared to its control sample "D-C".Theflexure strengths of sample "OC-D" decreased by about8.9%, 8.4%, and 8.8% after 2, 4, and 6 months, respectively compared to its control sample "D-C".The bond strengths of sample "OC-D" decreased by about 9.4%, 9.7%, and 9.3% after 2, 4, and 6 months, respectively compared to its control sample "D-C". The compressive strengths of sample "OC-C"decreased by about 9.7%, 9.3%, and 9% after 2, 4, and 6 months, respectively compared to its control sample "C-C". The tensile strengths of sample "OC-C" decreased by about 9.4%, 9.5%, and 9.2% after 2, 4, and 6 months, respectively compared to its control sample "C-C".The flexure strengths of sample "OC-C" decreased by about8.9%, 8.5%, and 8.7% after 2, 4, and 6 months, respectively compared to its control sample "C-C". The bond strengths of sample "OC-C" decreased by about 9.7%, 9.5%, and 9.3% after 2, 4, and 6 months, respectively compared to its control sample "C-C". The compressive strengths of sample "OC- CR" decreased by about 9.7%, 9.6%, and 9.2%after 2, 4, and 6 months, respectively compared to its control sample " CR -C". The tensile strengths of sample "OC-CR" decreased by about 9.6%, 9.4%, and 9.1% after 2, 4, and 6 months, respectively compared to its control sample " CR-C".The flexure strengths of sample "OC-CR" decreased by about9.3%, 9.5%, and 8.8% after 2, 4, and 6 months, respectively compared to its control sample " CR-C". The bond strengths of sample "OC-CR" decreased by about 9.8%, 9.7%, and 9.4% after 2, 4, and 6 months, respectively compared to its control sample " CR-C". The compressive strengths of sample "OC-RB" decreased by about8.9%, 9.2%, and 9.01% after 2, 4, and 6 months, respectively compared to its control sample "RB-C". The tensile strengths of sample "OC-RB" decreased by about 9.2%, 9.01%, and 9%after 2, 4, and 6 months, respectively compared to its control sample "RB-C".The flexure strengths of sample "OC-RB" decreased by about 9.01%, 9.1%, and 9.2% after 2, 4, and 6 months, respectively compared to its control sample "RB -C". The bond strengths of sample "OC- RB" decreased by about 9.5%, 9.4%, and 9.7% after 2, 4, and 6 months, respectively compared to its control sample "RB -C". That may refer to the higher porosity of crushed red bricks, which caused sulfates to penetrate into concrete compared to crushed ceramics.

Under chlorides attack,the compressive strengths of sample "OC-D" decreased by about 9.4%, and 9.3% after 2, and 4 months, respectively compared to its control sample "D-C". The tensile strengths of sample "OC-D" decreased by about 9.4%, and 8.9% after 2, and 4 months, respectively compared to its control sample "D-C". The flexure strengths of sample "OC-D" decreased by about9.3%, and 8.4% after 2, and 4 months, respectively compared to its control sample "D-C". The bond strengths of sample "OC-D" decreased by about 9.3%, and 9.5% after 2, and 4 months, respectively compared to its control sample "D-C". The compressive strengths of sample "OC-C" decreased by about 9.8%, and 9.6% after 2, and 4 months, respectively compared to its control sample "C-C". The tensile strengths of sample "OC-C" decreased by about 9.4%, and 9.5% after 2, and 4 months, respectively compared to its control sample "C-C". The flexure strengths of sample "OC-C" decreased by about8.9%, and 9.01 after 2, and 4 months,

respectively compared to its control sample "C-C". The bond strengths of sample "OC-C" decreased by about 9.8%, and 9.6% after 2, and 4 months, respectively compared to its control sample "C-C". The compressive strengths of sample "OC- CR" decreased by about 9.7%, and 9.6 after 2, and 4 months, respectively compared to its control sample "CR -C". The tensile strengths of sample "OC-CR " decreased by about 9.2%, and 9.1% after 2, and 4 months, respectively compared to its control sample "CR-C".The flexure strengths of sample "OC-CR" decreased by about 9.6%, and 9.01% after 2, and 4 months, respectively compared to its control sample " CR-C". The bond strengths of sample "OC-CR" decreased by about 9.4%, and 9.2% after 2, and 4 months, respectively compared to its control sample " CR-C". The compressive strengths of sample "OC-RB" decreased by about 8.8%, and 9.2% after 2, and 4 months, respectively compared to its control sample " RB-C". The tensile strengths of sample "OC-RB " decreased by about 9.2%, and 8.4% after 2, and 4 months, respectively compared to its control sample " RB-C". The flexure strengths of sample "OC-RB" decreased by about8.6%, and 8.5% after 2, and 4 months, respectively compared to its control sample "RB -C". The bond strengths of sample "OC- RB" decreased by about 9.5%, and9.2% after 2, and 4 months, respectively compared to its control sample " RB-C". That may refer to the higher porosity of crushed red bricks, which caused sulfate to penetrate into concrete compared to crushed ceramics.

4.3. Improving theDurability of RA-SCC

Under sulfate attack, for RA-SCC samples cast using dolomite then enhanced by using Waterproofing powder, mortar emulsion, and surface paintthe durability improved in terms of compressive, splitting tensile, flexure and bond strengths by a range of 3.2-4.2% compared to RA-SCC samples without those materials (control samples). For RA-SCC samples cast using crushed concrete then enhanced by using Waterproofing powder, mortar emulsion, and surface paint, the durability improved in terms of compressive, splitting tensile, flexure and bond strengths by a range of 3.4-4.5% compared to RA-SCC samples without those materials (control samples). For RA-SCC samples cast usingcrushed ceramic, then enhanced by using Waterproofing powder, mortar emulsion, and surface paintthe durability improved in terms of compressive, splitting tensile, flexure and bond strengths by a range of 2.3-3.8% compared to RA-SCC samples without those materials (control samples). For RA-SCC samples cast usingcrushed red bricks then enhanced by using Waterproofing powder, mortar emulsion, and surface paintthe durability improved in terms of compressive, splitting tensile, flexure and bond strengths compared to RA-SCC samples without those materials (control samples). These results can be illustrated as follow:

4.3.1. Enhanced Durability under Sulfate Attack

The results of the durability-enhanced samples illustrated in this section as follow:

Effects on compressive strength

Compressive strength tests due to the attack ofsulfate on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (10) to (13).

When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion"E1" in samples "D-E1" increased the compressive strength by about 10%, 12%, and 9% after 2, 4, and 6 months,respectively compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2" in sample "D-E2" increased the compressive strength by about 11%, 12%, and 10% after 2, 4, and 6 months, respectivelycompared to control sample "D-E2" at 28-days test. Using surface paint "E3" in sample "D-E3" increased the compressive strength by about 11%, 11.6%, and 8% after 2, 4, and 6 months , respectively compared to control sample "D-E3" at 28-days test. When studyingthe effect of cast using dolomite with using different enhancing materials thenimmersing samples for a range of 2-6months, the compressive strength decreased by a range of about 9-10.5%, for "OC-D"but increased for by a range of about 10-13%, 11-15%, and 10-12% for "D-E1", "D-E2", and "D-E3", respectively compared to their control sample "D-C".

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, using mortar emulsion"E1" in samples "C-E1" increased the compressive strength by about 10.9%, 12%, and 9.2% after 2, 4, and 6 months, respectively compared to control sample "C-E1" at 28-days test. Using

Waterproofing powder"E2"in sample"C-E2" increased the compressive strength by about 11%, 12.1%, and 9.2% after 2, 4, and 6 months, respectively compared to control sample "C-E2" at 28-days test. Using surface paint" E3"in sample"D-E3" increased the compressive strength by about 11.3%, 12.2%, and 9.3% after 2, 4, and 6 months, respectively compared to control sample "C-E3" at 28-days test.For the effect of using different enhancing materials with recycled crushed concrete,then immersing samples for a range of 2-6months, the compressive strength decreased by a range of about 10-11.5%, for "OC-C" but increased for by a range of about11-14%, 12-17%, and 11.2-15%, respectively for "C-E1", "C-E2", and "C-E3" compared to their control sample "C-C".

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion"E1"in sample"CR-E1" increased the compressive strength by about 11.1%, 11.6%, and 8.9% after 2, 4, and 6 months, respectively compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the compressive strength by about 10.8%, 11.7%, and 9.2% after 2, 4, and 6 months, respectively compared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3" increased the compressive strength by about 11.1%, 11.3%, and 8.6% after 2, 4, and 6 months, respectively compared to control sample "CR-E3" at 28-days test. When considering the effect of using different enhancing materials with recycled crushed ceramic then immersing samples for a range of 2-6months, the compressive strength decreased by a range of about8.3-9.5%, for OC-CR, but increased for by a range of about9.3-10.8%, 12-14%, and 10.5-13%, respectively for "CR-E1", "CR-E2", and "CR-E3" compared to their control sample "CR-C".

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion"E1"in sample"RB-E1" increased the compressive strength by about 11.5%, 12.6%, and 9.2% after 2, 4, and 6 months, respectively compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2" increased the compressive strength by about 11.4%, 12.5%, and 9.3% after 2, 4, and 6 months, respectively compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the compressive strength by about 11.7%, 12.6%, and 8.9% after 2, 4, and 6 months, respectively compared to control sample "RB-E3" at 28-days test. For the effect of using different enhancing materials with crushed red bricks then immersing samples for a range of 2-6months, the compressive strength decreased by a range of about 7.5-8.9%, for "OC-RB" but increased for by a range of about 8.1-9.2%, 9.5-12.8%, and 10.3-11.7%, respectively for "RB-E1", "RB-E2", and "RB-E3" compared to their control sample "C-C".

Using waterproofing powderand mortar emulation improved the durabilitycompared to other suggested types due to its presence between the particles during concrete manufacturing.Using surface paints resists the aggressive weather for short periods compared to other methods due to the chemical reaction with sulfates and chlorides.

Effects on Splitting Tensile Strength

Tensile strength tests due to the attack ofsulfate on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (14) to (17). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion"E1"in sample"D-E1" increased the tensile strength by about 11.3%, 12.7%, and 9.6% after 2, 4, and 6 months, respectively compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2" increased the tensile strength by about 11.5%, 12.6%, and 9.6% after 2, 4, and 6 months, respectively compared to control sample "D-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the tensile strength by about 11.8%, 12.7%, and 9.7% after 2, 4, and 6 months, respectivelycompared to control sample "D-E3" at 28-days test. When studyingthe effect of using dolomite with different enhancing materials after immersing samples for a range of 2-6months, the tensile strength decreased by a range of about 9.25-10.5%, for "OC-D" but increased for by a range of about 10-12%, 11-13%, and 10-11.8% for "D-E1", "D-E2", and "D-E3", respectively compared to their control sample "D-C".

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, Using mortar emulsion"E1"in sample"C-E1" increased the tensile strength by about 11.6%, 12.9%, and 8.3% after 2, 4, and 6 months, respectively compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2" increased the tensile strength by about 11.5%, 12.7%, and 9.3% after 2, 4, and 6 months, respectively compared to control sample "C-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the tensile strength by about 11.6%, 13%, and 8.4% after 2, 4, and 6 months, respectively compared to control sample "C-E3" at 28-days test. For the effect of using different enhancing materials with recycled crushed concrete then immersing samples for a range of 2-6months, the tensile strength decreased by a range of about 9.3-10.2%,for "OC-C" but increased for by a range of about 10.5-12%, 11.1-15%, and 10.2-11.9%, respectively for "C-E1", "C-E2", and "C-E3" compared to their control sample "C-C".

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion"E1"in sample"CR-E1" increased the tensile strength by about 11.6%, 13.6%, and 9.7% after 2, 4, and 6 months, respectively compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the tensile strength by about 11.7%, 13.2%, and 10.3% after 2, 4, and 6 months, respectively compared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3" increased the tensile strength by about 11.6%, 13.7%, and 9.5% after 2, 4, and 6 months, respectively compared to control sample "CR-E3" at 28-days test. When considering the effect of using different enhancing materials with recycled crushed ceramic then immersing samples for a range of 2-6months, the tensile strength decreased by a range of about 9.6-10.4%, for OC-CR, but increased for by a range of about10.7-11.9%, 12.2-15%, and 10.3-11.6%, respectively for "CR-E1", "CR-E2", and "CR-E3" compared to their control sample "CR-C".

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion"E1"in sample"RB-E1" increased the tensile strength by about 13.3%, 15.7%, and 9.5% after 2, 4, and 6 months, respectively compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2" increased the tensile strength by about 12.9%, 15%, and 10.4% after 2, 4, and 6 months, respectively compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the tensile strength by about 13.5%, 16%, and 9.5% after 2, 4, and 6 months, respectively compared to control sample "RB-E3" at 28-days test. For the effect of using different enhancing materials with crushed red bricks then immersing samples for a range of 2-6months, the tensile strength decreased by a range of about 8.9-10.1%, for "OC-RB" but increased for by a range of about 11.2-13.8%, 11.9-15.6%, and 10.8-13.7%, respectively for "RB-E1", "RB-E2", and "RB-E3" compared to their control sample "C-C".

Effects on flexure strength

Flexure strength tests due to the attack ofsulfate on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (18) to (21). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion"E1"in sample"D-E1" increased the flexure strength by about 13.6%, 14.5%, and 9.5% after 2, 4, and 6 months, respectively compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2" increased the flexure strength by about 13.9%, 15.3%, and 10% after 2, 4, and 6 months, respectively compared to control sample "D-E2" at 28-days test. Using surface paint "E3"in sample"D-E3" increased the flexure strength by about 13.4%, 14.4%, and 9.6% after 2, 4, and 6 months, respectively compared to control sample "D-E3" at 28-days test. When studyingthe effect of using dolomite with different enhancing materials then immersing samples for a range of 2-6months, the flexure strength decreased by a range of about 8.8-10.1%, for "OC-D" but increased for by a range of about 11.4-13%, 12.1-16%, and 10.8-12% for "D-E1", "D-E2", and "D-E3", respectively compared to their control sample "D-C".

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, Using mortar emulsion"E1"in sample"C-E1" increased the flexure strength by about 13.5%, 15.1%, and 10.4% after 2, 4, and 6 months, respectively compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2" increased the flexure strength by about 13.8%, 15%, and

10.7% after 2, 4, and 6 months, respectively compared to control sample "C-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the flexure strength by about 14.1%, 14.7%, and 11.1% after 2, 4, and 6 months, respectivelycompared to control sample "C-E3" at 28-days test. For the effect of using different enhancing materials with recycled crushed concrete then immersing samples for a range of 2-6months, the flexure strength decreased by a range of about 11.2-12.1%, for "OC-C" but increased for by a range of about 11.6-13.2%, 12.7-16.1%, and 14.1-15.9%, respectively for "C-E1", "C-E2", and "C-E3" compared to their control sample "C-C".

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion"E1"in sample"CR-E1" increased the flexure strength by about 12.4%, 14.7%, and 10.4% after 2, 4, and 6 months, respectively compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the flexure strength by about 12.3%, 14.3%, and 10.3% after 2, 4, and 6 months, respectivelycompared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3" increased the flexure strength by about 10.4%, 12.3%, and 8.6% after 2, 4, and 6 months, respectively compared to control sample "CR-E3" at 28-days test. When considering the effect of using different enhancing materials with recycled crushed ceramic then immersing samples for a range of 2-6months, the flexure strength decreased by a range of about 9.3-10.7%, for "OC-CR", but increased for by a range of about11.2-12.9%, 11.9-15.4%, and 10.9-12.3%, respectively for "CR-E1", "CR-E2", and "CR-E3" compared to their control sample "CR-C".

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion"E1"in sample"RB-E1" increased the flexure strength by about 13.1%, 15.5%, and 8.9% after 2, 4, and 6 months, respectively compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2"increased the flexure strength by about 13.3%, 14.8%, and 8.2% after 2, 4, and 6 months, respectively compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the flexure strength by about 13.7%, 16.3%, and 9.3% after 2, 4, and 6 months, respectively compared to control sample "RB-E3" at 28-days test. For the effect of using different enhancing materials with crushed red bricks then immersing samples for a range of 2-6months, the flexure strength decreased by a range of about 8.8-9.7%, for "OC-RB" but increased for by a range of about 11.8-14.9%, 13.7-16.8%, and 11.5-13.6%, respectively for "RB-E1", "RB-E2", and "RB-E3" compared to their control sample "C-C".

Effects on bond strength

The bond strength tests due to the attack ofsulfate on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (22) to (25). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion"E1"in sample"D-E1" increased the bond strength by about 11.3%, 12.2%, and 10% after 2, 4, and 6 months, respectively compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2" increased the bond strength by about 11.7%, 12.3%, and 9.8% after 2, 4, and 6 months, respectively compared to control sample "D-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the bond strength by about 11.2%, 12.4%, and 9.9% after 2, 4, and 6 months, respectively compared to control sample "D -E3" at 28-days test. When studyingthe effect of using different enhancing materials with dolomite then immersing samples for a range of 2-6months, the bond strength decreased by a range of about 9.4-10.7%, for "OC-D" but increased for by a range of about 10.2-13.6%, 10.5-15.8%, and 9.8-12.2% for "D-E1", "D-E2", and "D-E3", respectively compared to their control sample "D-C".

When studying the effect of immersing time for samples cast using recycled crushed concrete, Using mortar emulsion"E1"in sample"C-E1" increased the bond strength by about 11.7%, 11.9%, and 9.6% after 2, 4, and 6 months, respectively compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2" increased the bond strength by about 11.3%, 12.1%, and 9.8% after 2, 4, and 6 months, respectively compared to control sample "C-E2"at 28-days test. Using surface paint " E3"in sample"D-E3" increased the bond strength by about 11.2%, 12%, and 9.7% after 2, 4, and 6 months, respectively compared to control sample "C -E3" at 28-days test. For the effect of using different enhancing materials with recycled crushed concrete then immersing samples for a range of 2-6months,

the bond strength decreased by a range of about 9.6-10.5%, for OC-C but increased for by a range of about 10.3-14%, 10.7-17.3%, and 10-12.8%, respectively for C-E1, C-E2, and C-E3 compared to their control sample "C-C".

When studying the effect of immersing time for samples cast using recycled crushed ceramic, using mortar emulsion"E1"in sample"CR-E1" increased the bond strength by about 12.5%, 13.2%, and 10.9% after 2, 4, and 6 months, respectively compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the bond strength by about 12.3%, 13.1%, and 11.3% after 2, 4, and 6 months, respectively compared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3" increased the bond strength by about 12.7%, 13.3%, and 10.9% after 2, 4, and 6 months, respectively compared to control sample "CR -E3" at 28-days test. When considering the effect of using different enhancing materials with recycled crushed ceramic then immersing samples for a range of 2-6months, the bond strength decreased by a range of about 9.8-10.7%, for "OC-CR", but increased for by a range of about10.6-13.5%, 10.9-17.2%, and 10.5-13.1%, respectively for "CR-E1", "CR-E2", and "CR-E3" compared to their control sample "CR-C".

When studying the effect of immersing time for samples cast using recycled crushed red bricks, using mortar emulsion"E1"in sample"RB-E1" increased the bond strength by about 11.6%, 13.2%, and 8.4% after 2, 4, and 6 months, respectively compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2" increased the bond strength by about 11.8%, 13.2%, and 8.5% after 2, 4, and 6 months, respectively compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the bond strength by about 11.7%, 13.1%, and 8.3% after 2, 4, and 6 months, respectively compared to control sample "RB-E3" at 28-days test. For the effect of using different enhancing materials with crushed red bricks then immersing samples for a range of 2-6months, the bond strength decreased by a range of about 9.5-10.9 %, for "OC-RB" but increased for by a range of about 10.4-12.9%, 11.1-15.8%, and 10.3-12.2%, respectively for "RB-E1", "RB-E2", and "RB-E3" compared to their control sample "C-C".

4.3.2. Enhanced Durability under Chloride Attack

The results of the durability-enhanced samples are illustrated in this section as follow:

Effects on compressive strength

The Compressive strength tests due to the attack ofChloride on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (26) to (29). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion"E1"in sample"D-E1" increased the compressive strength by about 10.8%, and 11.5%, respectively after 2, and 4 months compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2" increased the compressive strength by about 10.9%, and 11.3%, respectively after 2, and 4 months compared to control sample "D-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the compressive strength by about 10.6%, and 11.4%, respectively after 2, and 4 months compared to control sample "D-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, Using mortar emulsion "E1"in sample"C-E1" increased the compressive strength by about 11.7%, and 12.5%, respectively after 2, and 4 months compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2" increased the compressive strength by about 10.5%, and 11.3%, respectively after 2, and 4 months compared to control sample "C-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the compressive strength by about 13.2%, and 13.6%, respectively after 2, and 4 months compared to control sample "C-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion "E1"in sample"CR-E1" increased the compressive strength by about 10.8%, and 11.3%, respectively after 2, and 4 months compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the compressive strength by about 10.5%, and 11.3%, respectively after 2, and 4 months compared to control sample "CR-E2" at 28-days test. Using

surface paint " E3"in sample"CR-E3" increased the compressive strength by about 10.9%, and 11.9%, respectively after 2, and 4 months compared to control sample "CR-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion "E1"in sample"RB-E1" increased the compressive strength by about 12%, and 13.5%, respectively after 2, and 4 months compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2" increased the compressive strength by about 10.6%, and 11.7%, respectively after 2, and 4 months compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the compressive strength by about 13.4%, and 14.6%, respectively after 2, and 4 months compared to control sample "RB-E3" at 28-days test.

Effects on splitting tensile strength

The Tensile strength tests due to the attack ofChloride on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (30) to (33). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion "E1"in sample"D-E1" increased the tensile strength by about 12.1%, and 14.1%, respectively after 2, and 4 months compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2" increased the tensile strength by about 10.9%, and 12.2%, respectively after 2, and 4 months compared to control sample "D-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the tensile strength by about 14.6%, and 16.1%, respectively after 2, and 4 months compared to control sample "D-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, Using mortar emulsion "E1"in sample"C-E1" increased the tensile strength by about 12.2%, and 13.5%, respectively after 2, and 4 months compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2" increased the tensile strength by about 10.9%, and 13.3%, respectively after 2, and 4 months compared to control sample "C-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the tensile strength by about 14.3%, and 15.6%, respectively after 2, and 4 months compared to control sample "C-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion "E1"in sample"CR-E1" increased the tensile strength by about 13.2%, and 14%, respectively after 2, and 4 months compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the tensile strength by about 11%, and 11.7%, respectively after 2, and 4 months compared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3" increased the tensile strength by about 14.5%, and 15.4%, respectively after 2, and 4 months compared to control sample "CR-E3" at 28-days test

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion "E1"in sample"RB-E1" increased the tensile strength by about 13.8%, and 16.1%, respectively after 2, and 4 months compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2" increased the tensile strength by about 11.6%, and 13.7%, respectively after 2, and 4 months compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the tensile strength by about 16%, and 18.5%, respectively after 2, and 4 months compared to control sample "RB-E3" at 28-days test.

Effects on Flexure Strength

The Flexure strength tests due to the attack ofChloride on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (34) to (37). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion "E1"in sample"D-E1" increased the flexure strength by about 14.7%, and 16.5%, respectively after 2, and 4 months compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2" increased the flexure strength by about 11.9%, and 14.3%, respectively after 2, and 4 months compared to control sample "D-E2" at 28-days test. Using surface paint

" E3"in sample"D-E3" increased the flexure strength by about 17.5%, and 18.3%, respectively after 2, and 4 months compared to control sample "D-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, Using mortar emulsion "E1"in sample"C-E1" increased the flexure strength by about 13.1%, and 15.9%, respectively after 2, and 4 months compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2" increased the flexure strength by about 12.1%, and 13.8%, respectively after 2, and 4 months compared to control sample "C-E2" at 28-days test. Using surface paint " E3"in sample"D-E3" increased the flexure strength by about 14.9%, and 17.5%, respectively after 2, and 4 months compared to control sample "C-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion "E1"in sample"CR-E1" increased the flexure strength by about 12.9%, and 15.3%, respectively after 2, and 4 months compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2" increased the flexure strength by about 11.5%, and 13.7%, respectively after 2, and 4 months compared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3" increased the flexure strength by about 14.8%, and 16.8%, respectively after 2, and 4 months compared to control sample "CR-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion "E1"in sample"RB-E1" increased the flexure strength by about 13.4%, and 16.2%, respectively after 2, and 4 months compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2" increased the flexure strength by about 11.5%, and 13.6%, respectively after 2, and 4 months compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3" increased the flexure strength by about 17.7%, and 19.6%, respectively after 2, and 4 months compared to control sample "RB-E3" at 28-days test.

Effects on Bond Strength

The Bond strength tests due to the attack ofChloride on self-compacted concrete samples cast using different coarse aggregates, natural and recycled then enhanced using durability improving materials as shown in Figs. (38) to (41). When studying the effect of immersing time for samples cast usingdolomite, using mortar emulsion "E1"in sample"D-E1"decreased the bond strength by about 9.1%, and 7.7%, respectively after 2, and 4 months compared to control sample "D-E1" at 28-days test. Using Waterproofing powder"E2"in sample"D-E2"decreased the bond strength by about 8.5%, and 7.2%, respectively after 2, and 4 months compared to control sample "D-E2" at 28-days test. Using surface paint " E3"in sample"D-E3"decreased the bond strength by about 9.7%, and 8.2%, respectively after 2, and 4 months compared to control sample "D-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed concrete, Using mortar emulsion "E1"in sample"C-E1"decreased the bond strength by about 9.1%, and 7.6%, respectively after 2, and 4 months compared to control sample "C-E1" at 28-days test. Using Waterproofing powder"E2"in sample"C-E2"decreased the bond strength by about 8.8%, and 7.2%, respectively after 2, and 4 months compared to control sample "C-E2" at 28-days test. Using surface paint " E3"in sample"D-E3"decreased the bond strength by about 9.4%, and 7.9%, respectively after 2, and 4 months compared to control sample "C-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed ceramic, using mortar emulsion "E1"in sample"CR-E1"decreased the bond strength by about 9.2%, and 7.7%, respectively after 2, and 4 months compared to control sample "CR-E1" at 28-days test. Using Waterproofing powder"E2"in sample"CR-E2"decreased the bond strength by about 8.5%, and 7.2%, respectively after 2, and 4 months compared to control sample "CR-E2" at 28-days test. Using surface paint " E3"in sample"CR-E3"decreased the bond strength by about 9.6%, and 8.3%, respectively after 2, and 4 months compared to control sample "CR-E3" at 28-days test.

When studying the effect of immersing time for samples cast usingrecycled crushed redbricks, using mortar emulsion "E1"in sample"RB-E1"decreased the bond strength by about 8.2%, and 6.7%, respectively after 2, and 4 months compared to control sample "RB-E1" at 28-days test. Using Waterproofing powder"E2"in sample"RB-E2"decreased the bond strength by about 8.5%, and 7.2%,

respectively after 2, and 4 months compared to control sample "RB-E2" at 28-days test. Using surface paint " E3"in sample"RB-E3"decreased the bond strength by about 9.6%, and 8.3%, respectively after 2, and 4 months compared to control sample "RB-E3" at 28-days test.

5. CONCLUSIONS

Based on the conducted experimental program the following conclusions can be drawn:

1. Recycled aggregates concrete areless suitable for structural concrete compared to natural aggregates with an increasementin the strength by a range of about 29.5-34.5% compared to those samples cast using dolomite as natural coarse aggregate.
2. Using high range water reducers (super plasticizers) enhances the fresh concrete properties of RA-SCC.
3. For the workability of tested samples, using crushed concrete increasedthe workability by about 7.5% compared to those cast using dolomite as natural coarse aggregate.
4. For the workability of tested samples, the RA-SCC samples enhanced using Waterproofing powder, mortaremulsion, and surface paintincreased by about 3.2%, 1.22% and 8.7%.
5. Thecompressive strength of the RA-SCC cast using crushed concrete is higher than that cast using crushed ceramic then those cast using crushed bricks as coarse aggregates by about 2.4% and 2.8%, respectively.
6. The using of crushed concrete is nearly comparable to the using of dolomite as coarse aggregate for SCC than using crushed ceramics and crushed red brick as aggregates.
7. The durability of the self-compacted concrete with crushed concrete aggregate is higher than both self-compacted concretes cast using crushed ceramic and crushed bricks as coarse aggregates.
8. The compressive, tensile splitting and flexural strength values increase under the effect of sulfates for 2 and 4 months then start to decrease after 6 months *(in the range of this study)*.
9. The bond strength of RA-SCC concrete decrease over the time under the effect of chlorides due to the corrosion of steel rebars.
10. Using suggested enhancing materials improved the durability of RA-SCC samples against either sulfates or chlorides attack *(in the range of this study)*.

Generally, using recycled aggregate is nearly efficient but not like natural aggregates with self-compacted concrete. Using suggested enhancing materials improve the recycled aggregate self-compacted concrete "RA-SCC". Using waterproofing powderimproved the durability of RA-SCC against sulfate then using emulsion for mortarand finally using the surface paint. Using waterproofing powderimproved the durability of RA-SCC against chlorides then using the emulsion and finally using the surface paint.

References

1 ECP.360/2007. *Technical Specifications of Self-compacting Concrete*. Cairo, Egypt., 2012.

2 Okamura, H. Self-Compacted High-Performance Concrete. *Concrete International* (1997), 50-54.

3 Ozawa, K. Development of High Performance Concrete Based on the Durability Design of Concrete Structures. In *EASEC-2* (1989), 445-450.

4 Bartos, J. M. Measurement of Key Properties of Fresh Self- compacted Concrete. *CEN/PNR Workshop* (2001).

5 Domone and P. Self-compacting Concrete: An Analysis of 11 Years of Case Studies. *Cement and Concrete Composites*, 28, 2 (2006), 197-208.

6 Assie, S., Escadeillas, G., and Waller, V. Estimates of Self-compacting Concrete 'Potential' Durability. *Construction and Building Materials*, 21, 10 (2007), 1909-1917.

7 Felekoglu, B., Tosun, K., Baradan, B., Altun, A., and Uyulgan, B. The Effect of Fly Ash and Limestone Fillers on the Viscosity and Compressive Strength of Self-compacting Repair Mortars. *Construction and Building Materials*, 36, 9 (2006), 1719-1726.

8 Unal, O., Topcu, I. B., and Uygunoglu, T. Use of Marble Dust in Self-compacting Concrete. In *Proceedings of V. Symposium MERSEMO 2006 on Marble and Natural Stone.* (Afyon, Turkey 2006), 413-420.

9 Bosiljkov, V. B. SCC Mixes with Poorly Graded Aggregate and High Volume of Limestone Filler. *Cement and Concrete Research*, 33, 9 (2003), 1279-1286.

10 Australia, Cement Concrete and Aggregates. Use of Recycled Aggregates in Construction (2008).

11 Bashandy, A. A. and Etman, Z. A. Recycling of Demolished Building Materials as Concrete Coarse Aggregates in Egypt. In *The 8th Alexandria International Conference on Structural and Geotechnical Engineering AICSGE-8* (Alexandria, Egypt 2014), Faculty of Engineering, Alexandria University.

12 Batayneh, M., Marie, I., and Asi, I. Use of Selected Waste Materials In Concrete Mixes. *Waste Management Journal*, 27, 12 (2006), 1870-1876.

13 Oikonomou, N. D. Recycled Concrete Aggregates. *Cement and Concrete Composites*, 27, 2 (2005), 315-318.

14 Gull, I. Testing of Strength of Recycled Waste Concrete and its Applicability. *Journal Construction Engineering and Management*, 137, 1 (2011), 1-5.

15 Etxeberria, M., Vázquez, E., Marí, A., and Barra, M. Influence of Amount of Recycled Coarse Aggregates and Production Process on Properties of Recycled Aggregate Concrete. *Cement and Concrete Research*, 37, 5 (2007), 735-742.

16 Bandi, S. M., Patel, Y. J., and Vyas, V. H. Study on Fresh and Hardened Properties of Self Compacted Concrete Using Recycled Concrete Aggregate. *International Journal of Innovative Research in Science, Engineering and Technology "IJIRSET"*, 5, 5 (2016), 8616-8623.

17 Modani, O. P. and Mohitkar, V. M. Recycled Aggregate Self Compacting Concrete. *International Journal of Modern Trends in Engineering and Research "IJMTER"*, 2, 2 (2015), 48-57.

18 Modani, P. O. and Mohitkar, V. M. Self-compacting Concrete with Recycled Aggregate: A Solution for Sustainable Development. *International Journal of Civil and Structural Engineering*, 4, 3 (2014), 430-440.

19 Kou, S. C. and Poon, C. S. Properties of Self-compacting Concrete Prepared with Coarse and Fine Recycled Concrete Aggregates. *Cement and Concrete Composites*, 31 (2009), 622–627.

20 Silva, Y., Robayo, R., Mattey, P., Delvasto, S., and Gordillo, M. Optimizing the Use of Recycled Coarse Aggregate in Self-compacting Concrete. In *The 6th Amazon and Pacific Green Materials Congress and Sustainable Construction Materials LAT-RILEM Confrence* (2016), 375-384.

21 Reddy, C. S., Ratna-Sai, K. V., and R., Kumar P. Mechanical and Durability properties of Self Compacting Concrete with Recycled Concrete Aggregates. *International Journal of Scientific & Engineering Research*, 4, 5 (2013), 260-263.

22 Kou, S. C. and Poon, C. S. Enhancing the Durability Properties of Concrete Prepared with Coarse Recycled Aggregate. *Construction and Building Materials*, 35 (2012), 69-76.

23 Sahoo, K. K., Arakha, M., Sarkar, P., P., Davis R., and Jha, S. Enhancement of properties of recycled coarse aggregate concrete using bacteria. *International Journal of Smart and Nano Materials*, 7, 1 (2016), 22-38.

24 Spaeth, V. and Tegguer, A. D. Improvement of Recycled Concrete Aggregate Properties by Polymer Treatments. *International Journal of Sustainable Built Environment*, 2 (2013), 143-152.

25 E.S.S.4756-1/2009. *Portland Cement, Ordinary and Rapid Hardening*. Egyptian Standard Specification E.S.S. 4756-1, Cairo, Egypt, 2009.

26 E.S.S.1109/2008. *Aggregate*. Cairo, Egypt, 2008.

27 E.C.P.203/2007. *Egyptian Code of Practice: Design and Construction for Reinforced Concrete Structures*. Cairo, Egypt, 2007.

28 E.S.S.262/2011. *Egyptian Standard Specification for Steel Bars*. Cairo, Egypt, 2011.

29 Etman, Z.A. *The Production and Properties of Self-compacted Concrete*. M. Sc. Thesis, Faculty of Engineering, Menoufia University, Menoufia, Egypt, 2006.

30 Persson, B. Internal Frost Resistance and Salt Frost Scaling of Self-compacted Concrete. *Cement and Concrete Research*, 33 (2003), 373-379.

31 Makishima, O., Tanaka, H., Itoh, Y., Komada, K., and Satoh, F. Evaluation of Mechanical Properties and Durability of Super Quality Concrete. In *2nd International Symposium on Self-Compacted Concrete* (Tokyo, Japan 2001), 475-482.

32 The-European-Project-Group. *Specification and Guidelines for Self-compacting Concrete*. 2005.

33 Zhu, W., Quinn, J., and Bartos, P. J. M. Transport Properties and Durability of Self-compacted Concrete. In *2nd International Symposium on Self-Compacted Concrete* (Tokyo, Japan 2001), 451-458.

Table 1. Mechanical, physical and chemical properties of the cement.

Property	Value	Limits E.C.P. 373/2007
1- Specific gravity	3.15	--
2- Setting time		
Initial min.	80	Not less than 45 min
Final hrs.	8.3	Not more than 10 hrs
3- Fineness	2780 cm^2/gm	Not less than 2500 cm^2/gm
4- Soundness (Expansion)	4	Not more than 10 mm
5- Crushing strength (Kg/cm^2)		
3 days	19.0 MPa	Not less than 18.342
7 days	28.5 MPa	Not less than 27.513
28 days	38.5 MPa	36.684 MPa

Table 2. Physical and mechanical properties of sand used.

Property		Test results for sand
Specific gravity (S.S.D)		2.6
Volumetric weight	*(Kg/m^3)*	1.65
Voids ratio	*(%)*	35%
Absorption	*(%)*	0.78
Fineness modulus		2.61
Clay, silt, and fine dust		1.5% *(by weight)*
Percent of chloride		0.04 *(by weight)*

Table 3. Physical properties of the dolomite, crushed light brick crushed concrete and crushed red bricks used. *(As obtained by the test results)*

Property		**Dolomite**	**Crushed concrete**	**Crushed ceramic**	**Crushed red Bricks**
Specific gravity		2.64	2.5	2.6	1.6
Absorption	*(%)*	0.76	5	1.95	4
Aggregate crushing value (ACV)	*(%)*	18.5	35	29.75	45

Table 4. Characteristics of Sika Viscocrete 5-920 *(as provided by the manufacturer).*

Properties	Value
Density	1.08 kg/li. ± 0.005
PH-value	7.0 → 9.0
Appearance	Turbid liquid
Chloride content	Zero
Odor	None
Boiling	100

Table 5. Chemical characteristics of silica fume used*(as provided by the manufacturer).*

Silicon (SiO2)*(%)*		85-97
Calcium (CaO)*(%)*		< 1
Fineness as surface area	*(m^2/kg)*	15000 to 30000
Specific gravity		2.22
General use in concrete		Property enhancer

Table 6. Main mechanical properties of steel used *(as obtained from test results).*

Properties		St. 52
Yield strength	*(MPa)*	365
Ultimate strength	*(MPa)*	521

Table 7. Main properties of Sikalite*(as provided by the manufacturer).*

Properties	Value
Density	Approximately 0.9 kg/lt.
Chloride content	Nil (EN 934-2)
Dosage	2% by weight of cement.
Cleaning	Water immediately after use.

Table 8. Main properties of Sika Top Seal*(as provided by the manufacturer).*

Properties	Value
density	1.7+.2 kg/l
Crack bridging ability at 23°c	>1.0mm
Elongation at break	120-140%
Compressive strength	30-40 N/mm^2 after 28 days
bond strength	Approx 1 N/mm^2 after 28 days

Table 9. Main properties of Stonesil*(as provided by the manufacturer).*

Properties	Value
Finish	clear
color	Water white
Density *(at 25°C)*	Approx. 1.00 kg/lit.
Drying *(at 25°C, humidity =50%)*	recoat 3 hours hard dry : 16 hours

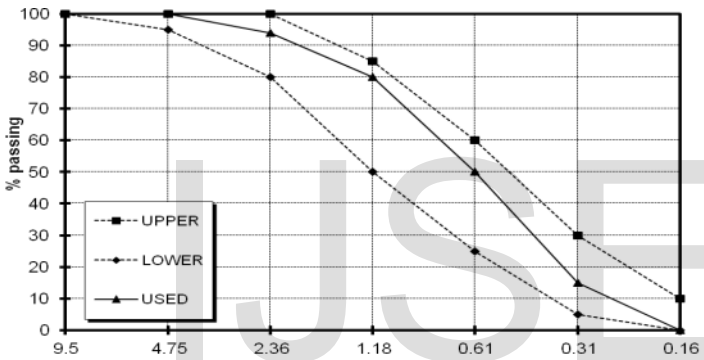
Table 10. Mixture proportions of concrete mixes used per cubic meter

Mix code	Components									
				C.A.C		Durability Enhancing Admixtures				
	Cement *(kg)*	Water *(kg)*	F.A *(kg)*	Type	t *(kg/m³)*	S.P.	silica fume	Sika top seal *(kg)*	Sikalite *(kg)*	Stonesil *(litter)*
OC-D	425 (4.23 KN)	145 (1.42 KN)	838 (8.24 KN)	Dolomite	685	--	--	--	--	--
D-C						11	44	--	--	--
D-E1						11	44	50	--	--
D-E2						11	44	--	9.25	--
D-E3						11	44	--	--	40
OC-C	425 (4.23 KN)	145 (1.42 KN)	838 (8.24 KN)	Crushed concrete	685	--	--	--	--	--
C-C						11	44	--	--	--
C-E1						11	44	50	--	--
C-E2						11	44	--	9.25	--
C-E3						11	44	--	--	55
OC-CR	425 (4.23 KN)	145 (1.42 KN)	838 (8.24 KN)	Crushed Ceramic	685	--	--	--	--	--
CR-C						11	44	--	--	--
CR-E1						11	44	50	--	--
CR-E2						11	44	--	9.25	--
CR-E3						11	44	--	--	55
OC-RB	425 (4.23 KN)	145 (1.42 KN)	838 (8.24 KN)	Crushed red brick	415.5	--	--	--	--	--
RB-C						7	27	--	--	--
RB-E1						7	27	30.5	--	--
RB-E2						7	27	--	9.25	--
RB-E3						7	27	--	--	37

OC=ordinary concrete, D=dolomite, C=crushed concrete, CR=crushed ceramics, RB=crushed red bricks

Table 11. Results of slump tests using recycled aggregates mixes .

Mixes		Slump Value *(mm)*	T50 *(Sec)*
Aggregate type	Code		
Dolomite	OC-D	660	5
	D-C	675	4
	D-E1	675	4
	D-E2	655	5.3
	D-E3	670	4.2
Crushed Concrete as recycled aggregate	OC-C	685	3.6
	C-C	720	3.3
	C-E1	720	3.3
	C-E2	709	3.5
	C-E3	702	3.4
Crushed ceramic as recycled aggregate	OC-CR	630	5.3
	CR-C	650	5.1
	CR-E1	650	5.1
	CR-E2	640	5.2
	CR-E3	623	5.5
Crushed Red Brick as recycled aggregate	OC-RB	565	6.1
	RB-C	580	6
	RB-E1	580	6
	RB-E2	550	6.3
	RB-E3	555	6.35



Sieve Size (mm)

Figure 1.Grading of Used Sand with F.M=2.61.

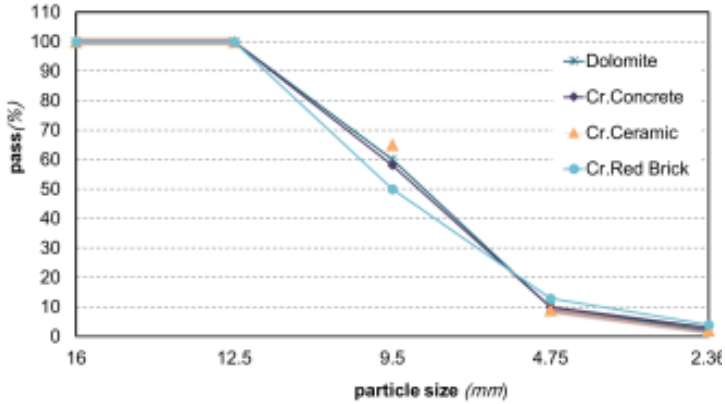


Figure 2.The particle size of aggregates used.

Figure 3.The bond strength samples.

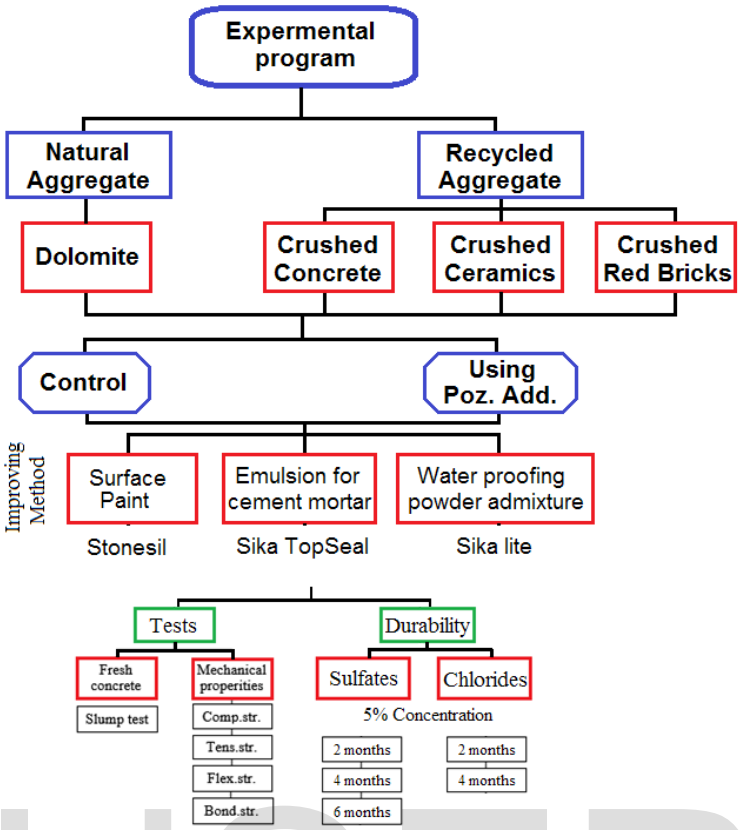


Figure 4.The flow chart of the experimental program.

Figure 5.Modes of failure of concrete specimens after the bond strength test.

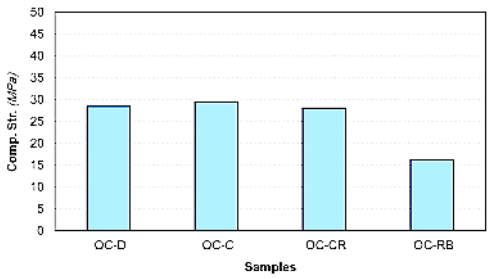


Figure 6. Compressive strength of SCC cast using different types of aggregates.

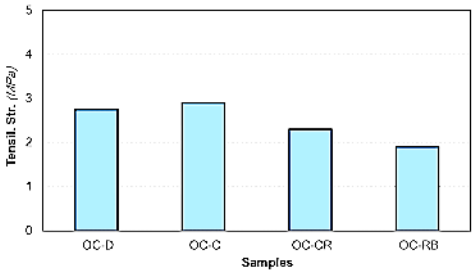


Figure 7.Tensile strength of SCC cast using different types of aggregates.

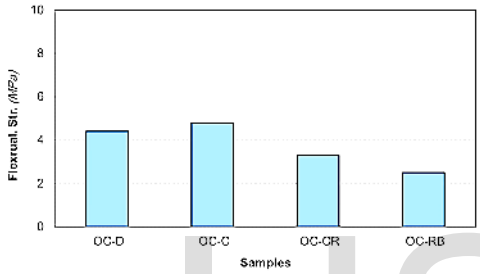


Figure 8. Flexural strength of SCC cast using different types of aggregates.

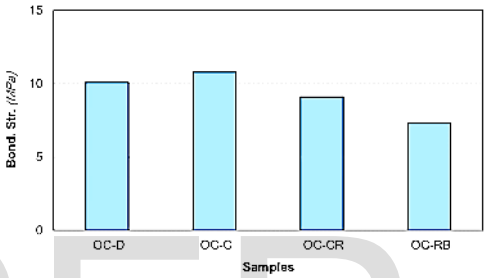


Figure 9. Bond strength of SCC cast using different types of aggregates.

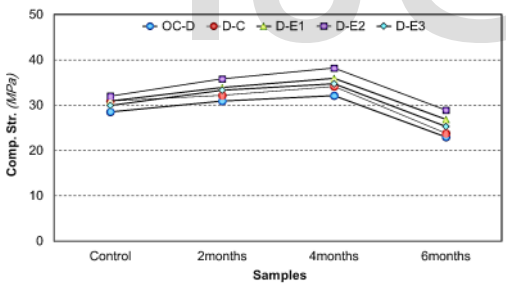


Figure 10. Compressive strength of SCC cast using dolomite under sulfate attack.

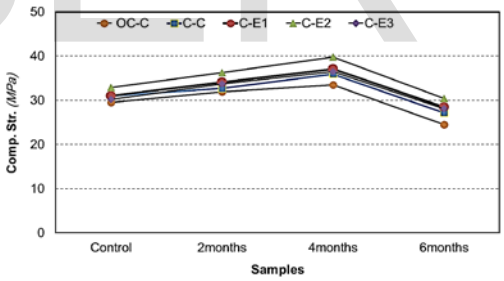


Figure 11. Compressive strength of RA-SCC cast using crushed concrete under sulfate attack.

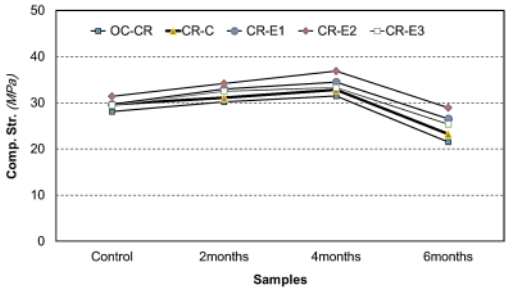


Figure 12. Compressive strength of RA-SCC cast using recycled crushed ceramic under sulfate attack.

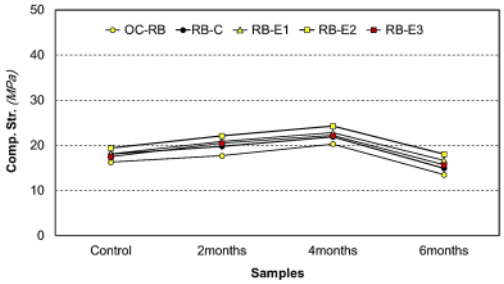


Figure 13. Compressive strength of RA-SCC cast usingrecycled crushed red bricksunder sulfate attack.

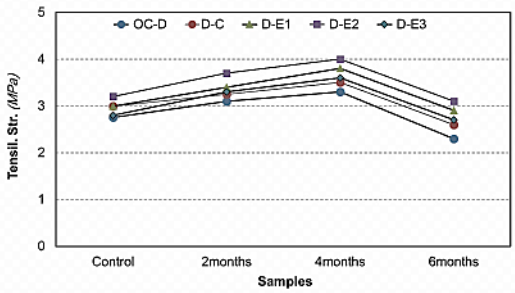


Figure 14. Tensile strength of SCC cast using dolomite under sulfate attack.

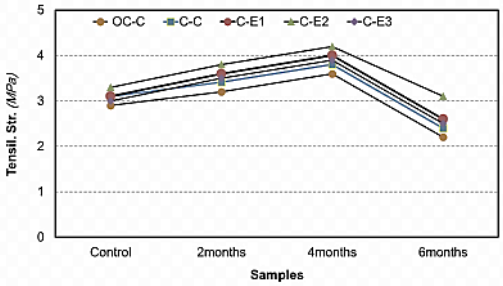


Figure 15. Tensile strength of RA-SCC cast using crushed concrete under sulfate attack.

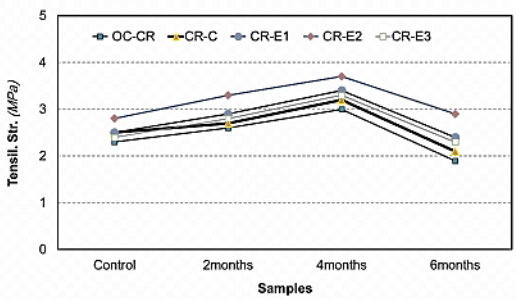


Figure16. Tensile strength of RA-SCC cast using recycled crushed ceramic under sulfate attack.

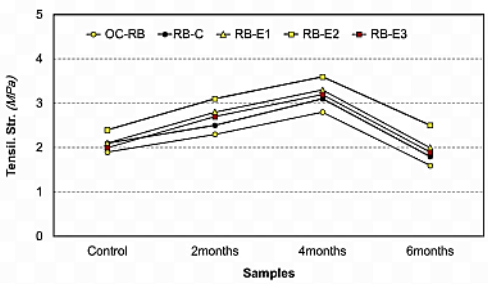


Figure 17. Tensile strength of RA-SCC cast using recycled crushed red bricksunder sulfate attack.

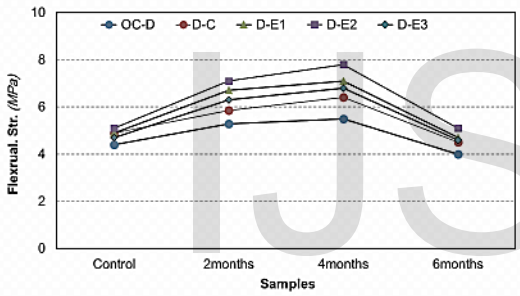


Figure 18. Flexrual strength of SCC cast using dolomite under sulfate attack.

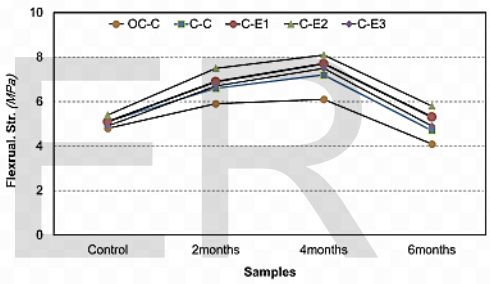


Figure 19. Flexrual strength of RA-SCC cast using crushed concrete under sulfate attack.

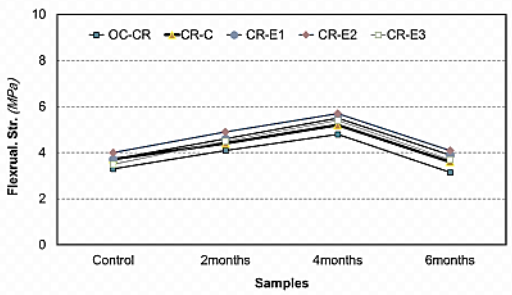


Figure20. Flexrual strength of RA-SCC cast recycled crushed ceramic under sulfate attack.

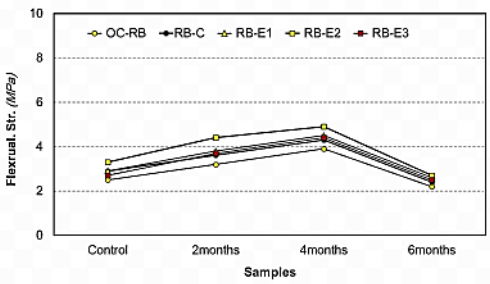


Figure 21. Flexrual strength of RA-SCC cast recycled crushed red bricksunder sulfate attack.

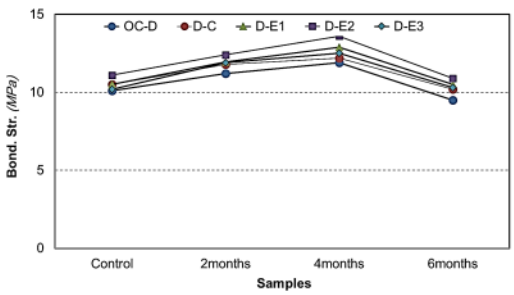


Figure 22.. Bond strength of SCC cast using dolomite under sulfate attack.

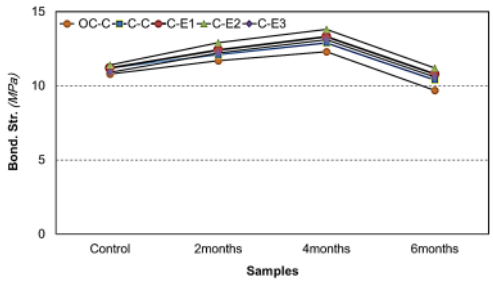


Figure 23. Bond strength of RA-SCC cast using recycled crushedconcrete under sulfate attack.

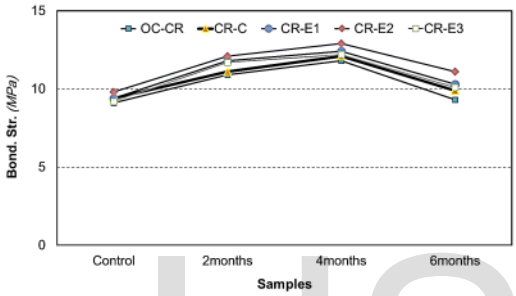


Figure 24. Bond strength of RA-SCC cast using recycled crushed ceramic under sulfate attack.

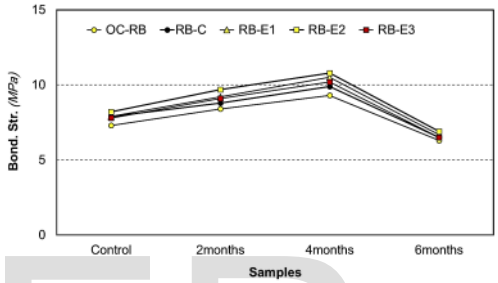


Figure 25. Bondstrength of RA-SCC cast using recycled crushed red bricksunder sulfate attack.

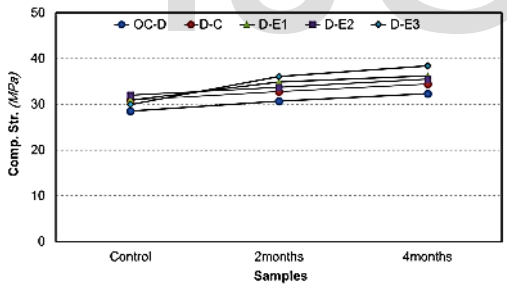


Figure 26. Compressive strength of SCC cast using dolomite under chlorides attack.

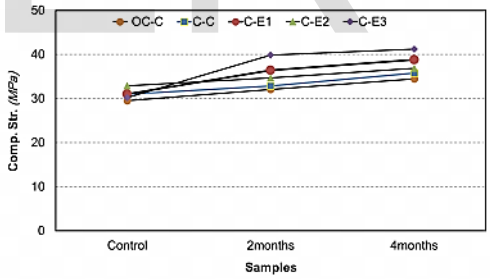


Figure 27. Compressive strength of RA-SCC cast using recycled crushedconcrete under chlorides attack.

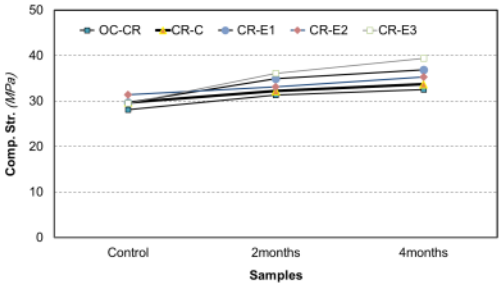


Figure 28. Compressive strength of RA-SCC cast using recycled crushed ceramic under chlorides attack.

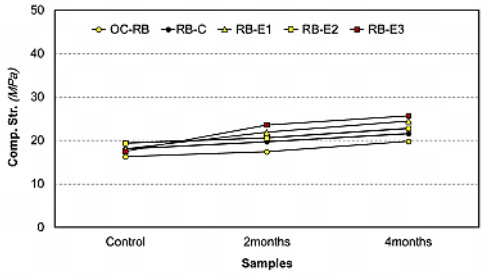


Figure 29. Compressive strength of RA-SCC cast usingrecycled crushed red bricks under chlorides attack.

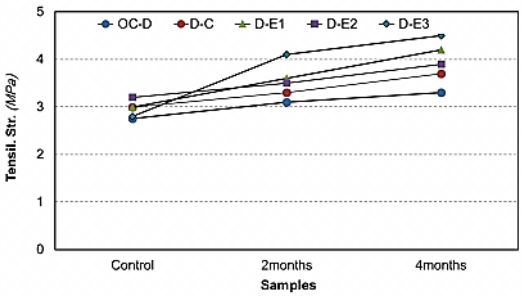


Figure 30. Tensile strength of SCC cast using dolomite under chlorides attack.

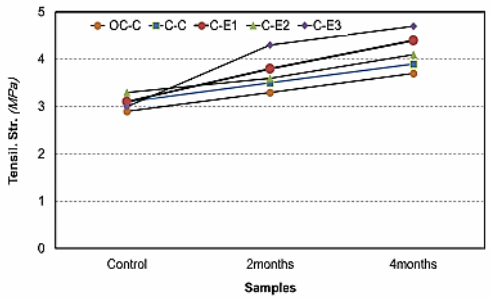


Figure 31. Tensile strength of RA-SCC cast using recycled crushed concrete under chlorides attack.

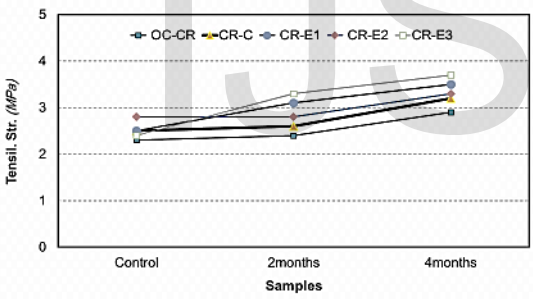


Figure 32. Tensile strength of RA-SCC cast using recycled crushed ceramic under chlorides attack.

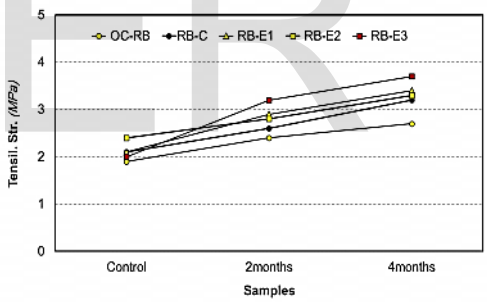
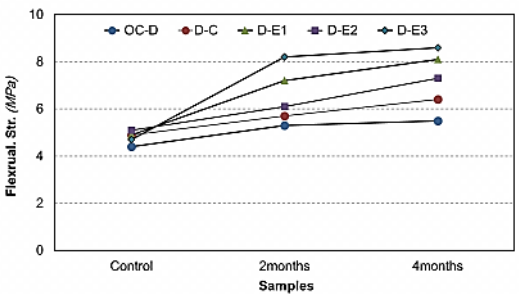


Figure 33. Tensile strength of RA-SCC cast using recycled crushed red bricksunder chlorides attack.



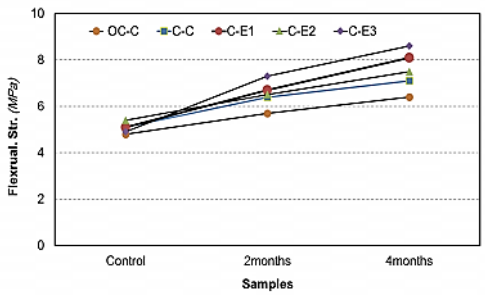


Figure 34. Flexural strength of SCC cast using dolomiteunder chlorides attack.

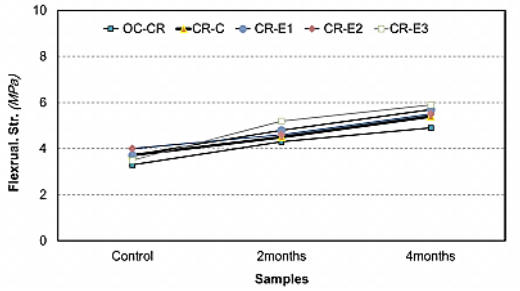


Figure 35. Flexural strength of RA-SCC cast using crushed concrete underchlorides attack.

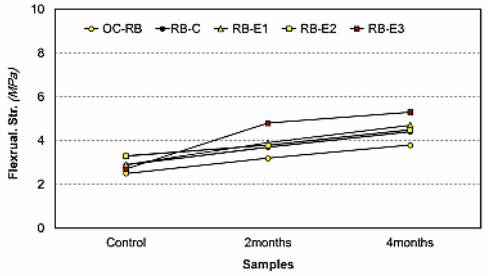


Figure36. Flexural strength of RA-SCC cast using recycled crushed ceramic under chlorides attack.

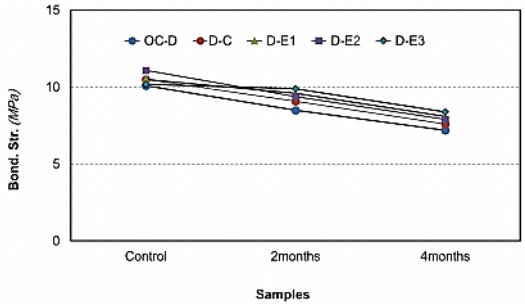


Figure 37. Flexural strength of RA-SCC cast using recycled crushed red bricksunder chlorides attack.

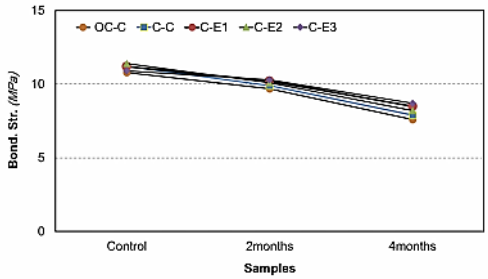


Figure 38. Bond strength of SCC cast using dolomiteunder chlorides attack.

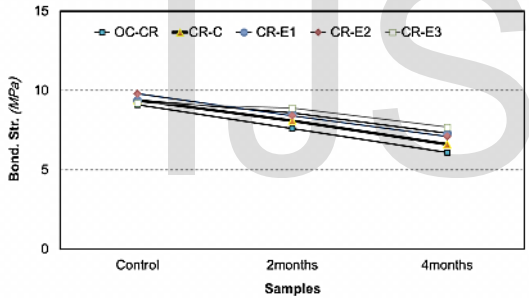


Figure 39. Bond strength of RA-SCC cast using crushed concrete underchloridesattack.

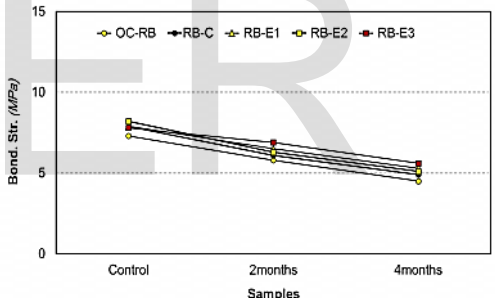


Figure 40. Bond strength of RA-SCC cast using recycled crushed ceramic under chlorides attack.

Figure 41. Bond strength of RA-SCC cast using crushed red bricks under chloridesattack.