A

DISSERTATION REPORT

ON

"EFFECT OF DIFFERENT HYDROPHOBIC TREATMENTS ON PROPERTIES OF RECYCLED AGGREGATE CONCRETE"

Submitted in partial fulfillment of the requirements for the award of degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted by

RAMSWAROOP MANDOLIA

(2014PCS5308)

Under the esteemed guidance of

Dr. SANDEEP CHAUDHARY

Associate Professor

DEPARTMENT OF CIVIL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

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CERTIFICATE

This is to certify that the dissertation work entitled **"EFFECT OF DIFFERENT HYDROPHOBIC TREATMENTS ON PROPERTIES OF RECYCLED AGGREGATE CONCRETE"** which is being submitted by **RAMSWAROOP MANDOLIA (2014PCS5308)** in partial fulfillment for the award of the degree of Master of Technology in Structural Engineering, MNIT, Jaipur is a bonafide work done by him under my guidance and supervision.

Dr. SANDEEP CHAUDHARY

Associate Professor

Civil Engineering Department

Malaviya National Institute of Technology, Jaipur

Place: Jaipur

Date: 12.05.2017

DECLARATION

I hereby certify that the work which is being presented in the seminar report **"EFFECT OF DIFFERENT HYDROPHOBIC TREATMENTS ON PROPERTIES OF RECYCLED AGGREGATE CONCRETE"** in partial fulfillment of the requirements for the award of the Degree of Master of Technology and submitted in the Department of Civil Engineering of the Malaviya National Institute of Technology Jaipur is an authentic record of my own work carried out during a period from July 2016 to May 2017 under the supervision of **Dr. SANDEEP CHAUDHARY** Associate Professor, Department of Civil Engineering, Malaviya National Institute of Technology Jaipur, India.

RAMSWAROOP MANDOLIA

(**2014PCS5308)**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. SANDEEP CHAUDHARY

Associate Professor

Civil Engineering Department

Malaviya National Institute of Technology, Jaipur

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RAMSWAROOP MANDOLIA
(2014PCS5308)

ABSTRACT

The use of recycled materials in building construction product leads to sustainable development in construction. Natural resources necessary in construction, like water, raw materials and no-renewable energies, are limited. New building solutions that fulfill the same functions and reduce the resources consumption must be proposed. Recycled materials included in building materials come mainly from building demolition, mineral wastes, urban wastes and industrial wastes. The physical, mechanical and durability behavior depends on substances of recycled aggregates; their lower performance mainly comes due to high porosity, light weight, quality and quantity of adhered mortar and Deleterious Materials. The present experimental study investigates the effect of different hydrophobic treatments on recycled concrete aggregates. The experimental work performed consists of replacing recycled aggregates (10%, 20% and 30%) with natural coarse aggregate to the base composition. Three different treatments applied on recycled concrete (a) Mixing Based Treatment (b) Aggregate Based Treatment (c) Surface Based Treatment method, using hydrophobic agents and were compared with natural aggregate concrete. Concrete tests like compressive strength and flexural strength at the age of 7 and 28 days were obtained. Durability tests like Acid attack, Sulphate attack, Chloride attack, Din permeability and Sorptivity test were performed. The Microstructure studies and NDT test were also performed.

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INTRODUCTION

1.1 Construction industry in India

The construction industry in India is booming. Already at 10 per cent of the GDP, it has been growing at an annual rate of 10 per cent over the last 10 years as against the world average of 5.5 per cent per annum. The built-up area is expected to swell almost five times from 21 billion sq ft in 2005 to approximately 104 billion sq ft by 2030. Buildings are at the core of all our demands water, energy and material — but they also create waste. This waste, generated in the construction, maintenance and disposal phases of a building, is called construction and demolition (C&D) waste. This includes waste from demolished structures, renovations in the real estate sector and construction and repair of roads, flyovers, bridges etc.

1.2 C&D waste generation in India:

The Union ministry of forests and environment (MoEF) has confessed there is no systematic database on C&D waste. As per the estimates of Centre for Science and Environment (CSE), since 2005, India has newly constructed 5.75 billion sq m of additional floor space with almost **one billion sq m in 2013 itself**. If (according to the Technology Information, Forecasting and Assessment Council's, or TIFAC's, thumb rule**) a new construction generates 40-60 kg of C&D waste per sq m**, then taking an average of 50 kg per sq m, **India must have generated 50 million tonne(MT) of C&D waste in 2013.** Over the last eight years, it would have produced 287 MT of this waste. This estimate only accounts for new construction. Demolition and renovation/repair-related waste of the older stock generates additional waste. The waste produced per sq m of demolition is 10 times that generated during construction: as per TIFAC, 300-500 kg of waste per sq m. If it is assumed that five per cent of the existing building stock gets demolished and rebuilt completely annually, then about 288 MT more of C&D waste would have been generated in 2013 alone because of demolitions. TIFAC also says building repair produces 40-50 kg per sq m of waste. Assuming that one-third of the existing building stock underwent some sort of repair or renovation in 2013, India must have generated an average of 193 MT of C&D waste just from repair and renovation in that year. The total C&D waste generated in India just by buildings in one year 2013 amounts to a humungous 530 MT.

1.3 Small steps to make resource from waste in India

MCD-ILFS-IEISL initiative in Delhi: C&D waste is being recycled into aggregates which are converted to Ready Mix Concrete, pavement blocks, kerb stones and concrete bricks.

YUVA and CIDCO initiative in Navi Mumbai: This has recycled 1500 tonnes of C&D waste between the years 2002-2006. But operations shut down as no policy and market support was present.

1.4 Recycled Aggregates

These days use of recycled compounds in building materials is one of the researching lines proposed to integrate sustainable development criteria in construction. The concept of sustainability is related with the evaluation and reduction of natural resources consumption, environmental impact, risks for human safety and systems used in the industrialized societies. Natural resources are necessary in construction, like water and raw materials. New building components that having same properties must be proposed. The sustainability is the environmental impact as a result of the human activity when it has an intensive character. All material and processes involved have to guarantee health and integrity of the person and environment in contact with them. Recycled compounds that can be included in building materials come mainly from building demolition, mineral wastes, urban wastes and industrial wastes and by-products. Social interest is focused on ecological, environmental aspects and public administrations in industrialized countries which are promoting researching programs on recycling as a solution for waste management. Building materials producers and manufacturers are mainly interested on value added solutions, reduction of waste management costs and economical efficiency. Researchers are interested in technological properties of the new building materials and their application possibilities. Therefore, ecological, environmental, economical and technological aspects have to be present at the beginning. The inclusion of recycled materials in mortar and concrete can be part of the binder compound, aggregate or reinforcement. The mortar and concrete cannot be considered simply as a waste disposal, but a technological material. Therefore, the product obtained must have technological properties according to its use for building purposes. The main uses of mortar and concrete in buildings are structure, joint material, finishing, substrates, insulation layers and the recycling proposals should be focused in one of them.

IL&FS concrete recycling plant, Burari Delhi

Figure 1.1 Concrete Recycling Plant and Products

Chapter: 2

LITERATURE REVIEW

J. M. Aldred et al. (2000) reported that using hydrophobic admixture in dried concrete, water permeability reduced up to 77% to the control concrete. It was noticed that by using hydrophobic admixture with 0.6 w/c ratio, initially saturated and dried cubes reduced water transportation. The higher w/c ratio of concrete produced more voids which were a reason for greater water transport mechanism. There was no influence of admixture for lower w /c treated concrete on water transport mechanism.

H Kus (2003) investigated the long-term durability of silicon-based water repellents of an external concrete wall and produced comparative statement between artificial and natural accelerators.

Kiyoshi Eguchi et al. (2005) reported that the production of recycled aggregates is very simple in present conditions. The compressive strength and modulus of elasticity may reduce by increasing ratio of recycled aggregates to control concrete. Environmental degradation also reduced by using recycled process.

Paulo Helene (2008) reported that as per guideline of "German Committee for Reinforced Concrete" for the capillary mechanism, there must be at least 50% reduction to control concrete for efficient surface hydrophobic agents. The dispersed silane didn't perform in water as per guideline of "National Cooperative Highway Research Program" and Vries et al. Hydrophobic treated concrete shown inefficient under water pressure, the water pressure kept on concrete for this study was (120 kgf/m^2)/ 12cm water depth. The results exhibited permeable and insufficient waterproofed. Surface treated by silane concrete not able to protected evaporation. Concrete may allow to exit and enter the moisture. The researcher suggested that before applying surface treated concrete must be analyzed water exposure condition. The effectiveness can be increased by increase no of applying coats and first coat has higher waterproofing protected capacity, lower viscous agents and good solvents more efficient when applying more coating. For sorptivity of concrete show more efficient when silane dispersed by solvent compared to water, sorptivity reduced by 2.12 times when water applied and 7.0 times reduced when solvent applied.

Farid Debieb et al. (2010) in their study reported that the physical properties of recycled aggregates like water absorption increased, light in weight and more quantity of present mortar. The durability may reduce due to high water absorption capacity and high porosity. Higher porous contaminated recycled aggregates increased resistance capacity of freeze-thaw cycles.

CAI Ning et al. (2010) conducted studies on concrete protection by silane hydrophobic agents their different concentrations and different agents by surface treatments. Water absorption capacity of concrete reduced to increase the concentration of hydrophobic agents and contact angle increased with the increment higher concentrated agents. Their conclusion was penetration depth of highly concentrated agents were more as compared to lower concentrated agents.

Claudio Javier Zega and Ángel Antonio Di Maio (2011) in their study reported that the fine recycled aggregates with 20% and 30% replacement to natural aggregates had the same mechanical properties in comparison to natural fine aggregates concrete. By using pasticizer/admixture, durability behavior was obtained with reduced the water cement ratio.

Ya-Guang Zhu et al. (2012) reported that mechanical and physical properties reduced due to the replacement of recycled aggregate with natural aggregates. Water absorption reduced by surface based treatment, their effectiveness depends on numbers of coats and their concentrations. The compressive strength of sample decreased with increased dose of silane for mixing based treated recycled concrete.

D. Matias et al. (2013) in their study reported that the porosity of recycled aggregate concrete increased with higher water-cement ratio. The mortar quantity reduced at high w/c ratio so that workability and water absorption increase.

Hongsong Wang et al. (2013) reported that the effective results were achieved by deep impregnation of water proof silane material. In the case of waterproofing silane, SiOH groups react with water to form Si-O-Si group which is highly water repellents. Sorptivity decreased due to protecting layer on the concrete surface. Silane-based materials are not harmful to ecosystem and human.

F. Tittarelli et al. (2014) had investigated that the due to hydrophobic admixture reduced the capillary water absorption capacity of no fines concrete, carbonation depth increased due to more micro voids availability. The mechanical performance slightly affected by adding of hydrophobic admixture at the dose of 0.5% and 1.0 % by weight of cement weight.

Luc Courard and Annelise Cousture (2014) investigated that heritage building were affected by the natural climate that concrete deterioration may be protected by hydrophobic surface based treatment. Thermal Shocks and ultra violate rays played the main role to break Si-O-Si solvent bond molecules of surface concrete. Surface treated concrete not able to protect in/out moisture absorption, water absorption capacity reduced such treated concrete. Durability increased by solvent hydrophobic treatment. Repeated treatment need for a long time protection of concrete.

Valerie Spaeth and Assia Djerbi Tegguer (2014) reported that the effects on physical properties of recycled aggregates might increase by using siloxane/silane polymerization. They focused on recycled aggregate treatments, aggregates were dipped in different agents, and the combination of two agents and their effect were tested. A microfilm developed on recycled aggregates due to dip treatment so that water absorption capacity reduced. The combination of different showed more efficient for physical properties.

Evgeniya V. Tkach et al. (2015) presented that the effect of modified complex hydrophobization and hydrophobic tragers on high performance modified concretes. These treatments feasible for hydro-engineering concrete, water penetration reduced by treated concrete. These treated concretes may be used in reinforced concrete for roads, foundations, drainage for its particular purpose.

Sandro Weisheit et al. (2015) reported that surface based treated high-performance concrete, DIN permeability show better result comparative to untreated concrete. An untreated concrete surface has more porous when surface based coating applied on it porous filled by coated agents and made a uniform film on it. Roughness and the inhomogeneous main reason for reduced the water repellency. Three types of concrete sample were used for observed contact angle on untreated, treated and weathered surface, measured contact angle between the water drop and surfaces than reported treated surface shown high contact result to others. In High-performance concrete, water penetration rate showed very slow due to their denseness.

Loganina Valentina Ivanovna et al. (2015) reported that the quality and cost of hydrophobic surface based treatment might be optimized. The analytical methods were used for observations.

Ahmed Shaban and Abdel-Hay (2015) in their study reported the 50% replacement with recycled to natural aggregates as the best ratio, at 28 days the maximum result of mechanical properties were obtained from surface based treated recycled concrete.

Tkach Evgeniya (2016) had investigated the methodology to improve hydrophobic properties of industrial wastes added in concrete. Hydrophobic traeger made by the combination of melted bitumen and fly ash with the ratio of 1 part fly ash and 2 part melted bitumen, mechanical and durability performance showed effectively result when applied the same agent. Modified concrete microstructure presented uniform porous structure that reason for lower porosity.

Zhichao Liu and Will Hansen (2016) reported that the freeze-thaw durability have efficient on silane surface based treated concrete, such concrete has high water-cement ratio. This treatment not able to prevent the bulk moisture absorption by silane treated surfaces, micro bulk cracking formation were generated due to poor air void system.

Luís Evangelista and Jorge de Brito (2016) in their study reported that capillary absorption showed same trends of mixes with volumetric replacement ratios of FNA with FRA of 10%, 30%, 50% and 100%. The age effects were noticeable; Carbonation resistance reduced due to RCA, FRA and High water/cement ratio main reason to increased porosity to the cement paste, so that increases water absorption capacity of recycled aggregate concrete.

Chapter: 3

OBJECT OF THE PROJECT

The objective of the present investigation is to study the effect of hydrophobic treatment on recycled aggregate concrete, three different mixes were prepared by varying the aggregate replacements and three different treatment methods were applied for same work.

- To improve the properties of recycled aggregate concrete by utilising various hydrophobic treatments.
- To replace up to 30% of natural coarse aggregate with coarse recycled aggregate.
- To examine feasible site friendly hydrophobic treatments to improve the properties of recycled aggregate concrete.
- To investigate the mechanical and durability properties of such concrete.
- To investigate NDT test of such concrete.
- To conduct the microstructure studies of hydrophobic recycled concrete.

Chapter: 4

MATERIALS AND METHODOLOGY

4.1 General

The present experimental study on the inclusion of recycled products in cement-based building materials can be structured in several stages, to obtain an integrated and practical solution. The products susceptible of been included must be low cost, easily available and its recycling must be high value added. On the other hand, neither the products nor the processes involved can be toxic or hazardous, in order to avoid health risks. The physical, chemical properties and compatibility, when mixed with cement, must also be studied.

The one or more possible uses of the mortar or concrete containing the residual can be proposed. The physical and mechanical properties of the cement-based composite, in the fresh and the hardened state, necessary for the selected use can be defined. The experimental study can be designed. The aim of the experimental design is to relate the dosage variables and the properties to be measured in the fresh and the hardened state of the composite. All the producing and casting parameters of the final material for the use or uses defined previously must be included in this experimental stage, to get as close as possible to the real application of the final product.

As a result of the experimental study, if the values obtained to fulfill the wanted properties, an optimization process can be conducted. The optimization leads to achieve as many technical advantages as possible.

Normally, the optimization process involves several steps, varying some dosage, casting or curing parameters and fixing the rest as constant. This procedure guarantees the reproducibility of the process and allows the study of the parameters interaction or separately and a feedback of the process in any point of the research, if it is necessary.

The last stage concerns with the real application of the final material. Building materials producers should take part in this stage.

The materials were used in the experimental study is brought from Jaipur nearby quarries.

4.2 MATERIALS

4.2.1 Cement

The used in preparing the concrete was OPC 43 grade is confirming to IS: 8112 2013.The properties of cement typically measured in the laboratory include normal consistency, setting time, soundness, fineness and compressive strength.

The normal consistency and setting time are determined using the Vicat apparatus. Normal consistency is an empirical measure that indicates the minimum water required to produce a certain level of fluidity in the cement paste. It also enables the design of the paste for the setting time and compressive strength experiments.

The initial setting time is important to assess the time available for concreting operations (transportation, placement, consolidation, and finishing), while the final setting time indicates the attainment of a specific form concrete beyond this point cannot be remolded.

The Compressive strength of cement is measured in mortar because of the poor dimensional stability of the cement paste (high shrinkage), as well as the fact the by using mortars, one can actually check the binding strength of cement paste, which reflects its true action in concrete. The codes have strict requirements not only in terms of the 28 day strength but also for the intermediate strengths 7 days.

The soundness of cement is related to its ability to retain its volume upon hydration and is measured using the Le Chatelier apparatus.

Cement: OPC 43 Grade testing results as per IS: 8112 2013

- Normal Consistency: 30.5%
- Initial Setting Time: 115 Min.
- Final Setting Time: 210 Min.
- 7 Days Compressive Strength: 33.2 MPa
- 28 Days compressive Strength: 43.2 MPa
- Fineness(% retained on 90 micron): 1.0%

4.2.2 Aggregates

The type of natural fine aggregates used in this study is locally available sand. The kind of natural coarse aggregates used for this study is crushed angular which is locally available. The maximum size of aggregates used is 20mm. Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Aggregates were considered as physically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that the aggregates occupy 70–80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. To know more about the concrete, it is very essential that one should know more about the aggregates which constitute major volume in concrete. Without the study of the aggregate in depth and range, the study of the concrete is incomplete. Cement is the only factory made the standard component in concrete. Other ingredients, likes water and aggregates are natural materials and can vary to any extent in many of their properties. The depth and range of studies that are required to be made in respect of aggregates to understand their widely varying effects and influence on the properties of concrete cannot be underrated.

Physical Properties of aggregates were tested and reported as follows.

4.2.2.1 Sieve Analysis: According to IS: 383 1970.

Coarse Aggregates 20mm

SIEVE (mm)	Wt. Retained (gm)	Percentage Retained (gm)	Cumulative Percentage Retained	Percentage Passing
40	0	0	0	100
20	373	18.65	18.65	81.35
10	1516	75.8	94.45	5.55
4.75	108	5.4	99.85	0.15
Pan	3	0.15	100	0
Total	2000			

Coarse Aggregates 10mm

SIEVE (mm)	Wt. Retained (gm)	Percentage Retained (gm)	Cumulative Percentage Retained	Percentage passing
40	0	0	0	100
20	0	0	0	100
10	59	2.95	2.95	97.05
4.75	1110	55.5	58.45	41.55
Pan	831	41.55	100	0
Total	2000			

Fine Aggregate (Sand)

SIEVE (mm)	Wt. Retained (gm)	Percentage Retained (gm)	Cumulative Percentage Retained	Percentage Passing
4.75 mm	5	0.5	0.5	99.5
2.36 mm	36	3.6	4.1	95.9
1.18mm	238	23.8	27.9	72.1
600 µm	279	27.9	55.8	44.2
300 µm	357	35.7	91.5	8.5
150 µm	71	7.1	98.6	1.4
75 µm	8	0.8	99.4	0.6
Pan	6	0.6	100	0
Total	1000			

4.2.2.2 Water Absorption

- Coarse Aggregates : 0.24%
- Fine Aggregates: 2.16%
- Recycled Aggregates: 3.85%

4.2.3 Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. In practice, very often great control on properties of cement and aggregate is exercised, but the control on the quality of water is often neglected. Since the quality of water affects the strength, it is necessary for us to go into the purity and quality of water.

4.2.4 Recycled Aggregates

Recycled aggregates can be broadly subdivided into two main categories: RCA are derived predominantly from crushed concrete rubbles and RA created from the rather broad field of C&DW such as brick-based RA and asphalt-based RA. The level of impurities in the second category is usually medium to high and can significantly affect the strength and performance when recycled in concrete; therefore aggregates in this category are often used for secondary applications and are of little interest for use in concrete. Another barrier facing the use of this category in concrete are the limitation and provisions set in standards such as IS: 383:1970. In this standard, restrictions were put on the maximum masonry content, fines content, asphalt, acid-soluble sulphate, and other contaminant material such as glass, plastics, and metals. In addition, rejection by the public and the concrete industry, particularly in places where there is a good reserve of proven natural aggregate has been a barrier.

The unused, rejected and broken cement concrete cubes of natural aggregates were used for recycled aggregates. They were crushed manually; recycled aggregates were passing 20mm sieve and retained at sieve 12.5mm gradation used.

4.2.4.1 Specific Gravity

Specific gravity is the ratio of the density (mass of a unit volume) of a substance to the density (mass of the same unit volume) of a reference substance. Apparent specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance. The reference substance is nearly always water for liquids or air for gasses. Temperature and pressure must be specified for both the sample and the reference. Pressure is nearly always 1 atm equal to 101.325 KPa.

Coarse Aggregate (20mm) = 2.69

Coarse Aggregate (10mm) = 2.69

Fine Aggregate = 2.63

Recycled aggregates = 2.63

Cement =3.15

4.2.5 Chemical Admixture (Superplasticizer)

- Super plasticizers constitute a relatively new category and improved version of plasticizer, the use of which was developed in Japan and Germany during 1960 and 1970 respectively. They are chemically different from normal plasticizers.
- Uses of super plasticizer permit the reduction of water to the extent up to 30 percent without reducing workability in contrast to the possible reduction up to 15 percent in case of plasticizers. The use of super plasticizer is practiced for production of flowing, self-compacting and for the production of high strength and high performance concrete.
- The mechanisms of action of super plasticizer are more or less same as explained earlier in case of ordinary plasticizer. Only thing is that the super plasticizer is more powerful as dispersing agents and they are high range water reducers. They are called High Range Water Reducers in American literature. It is the use of super plasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 MPa or more.
- India is catching up with the use of super plasticizer in the construction of high rise buildings, long span bridges and the recently become popular Ready Mixed Concrete Industry. Common builders and Government departments are yet to take-up the use of this useful material.

4.2.5.1 Typical Properties of Superplasticizer

- **Physical State :** Brown liquid
- The dosage used @0.4% by weight of cementious material.

4.2.6 Sodium Silicate

When used in cement paste, sodium silicate solution deflocculates the clay mineral components and lime paste. This is achieved through a combination of effects, including absorption of the aggregate surface, donation of sodium ions (Na^+) and precipitation of calcium ions (Ca^{++}) in the paste. The real effect of this deflocculation process is a reduction in an amount of water needed to keep the cement paste in a pumpable viscosity range. Sodium silicate is preferred as a deflocculator in the preparation of stable solutions of fusible clay for casting into the pores of the plaster molds. In fusible clay which is easily pumpable, silicates act as a stabilizer for any alkali present. Because less water is needed the fusible clay is denser and therefore the resulting piece is stronger. It takes less time to set in the mold and there is less shrinkage as it dries. In the processing of raw clay, silicates depressant action is used to remove impurities such as quartz, feldspar, mica, iron oxide etc.

4.2.7 Silane

Silane/siloxanes are commonly used as hydrophobic agents for concrete's sealer work. The silane particles penetrate within the concrete; they do not react chemically to density the concrete. The silane and siloxane particles will work in concert to create a hydrophobic barrier that will block out water and moisture. It impregnates into the open pores of the substrate to stop water absorption maintaining the breathing character of the substrate and imparts water repellency to cementitious materials. The larger particles of siloxane will remain on the surface of the concrete to provide the brunt of this barrier; the silane particles will complement the barrier, reinforcing it to make it stronger.

4.3 Mix Design: According to IS: 10262 2009

Recycled products are necessary to ensure the recycled concrete product is free from dirt, clay, wood, plastic and organic materials.

The unused, rejected and broken cement concrete cubes of natural aggregates were used for obtaining recycled aggregates. They were crushed manually; recycled aggregates were passing 20mm sieve and retained at sieve 12.5mm gradation were used.

Concrete Mix Design of M-30 concrete was prepared with and without recycled concrete. Then recycled aggregates replacement fractions (10%, 20% and 30%) with natural coarse aggregate were introduced to the base composition. Concrete mix design was done according to IS: 10262 2009 for the grade M-30. The target mean strength was 38.25 N/mm^2. The water-cement ratio was 0.40 and the 20mm and 10mm aggregate were taken in 50-50% proportions. The fine aggregate was of zone-II according to IS: 383 1970. Water was the normal potable water. The casting was done for compressive and durability testing of cubes (100mm x 100mm x 100mm) and for flexure strength beams (100mm x 100mm x 500mm) were casted.

The quantities of materials per cubic meter of concrete as followed.

Water/cement = 0.40

Maximum nominal size of aggregate = 20mm

20mm: 10mm = 50%:50%, Fine Aggregate = Zone II (IS: 383 1970)

Water used = Potable water

Control Concrete

Cement (kg)	Sand (Kg)	Coarse Aggregate(Kg)		Water (kg)	Super plasticizer (Kg) by weight of cement
		10mm	20mm		
410	**649.35**	**589.27**	**589.27**	**164**	**1.64**
1	1.584	1.437	1.437	0.40	**0.40**

RCA 10%

Cement (kg)	Sand (Kg)	Coarse Aggregate(Kg)			Water (kg)	Super plasticizer (Kg) by weight of cement
		10mm	20mm	Recycled Aggregates		
410	**649.35**	**530.34**	**530.34**	**117.85**	**168.53**	**1.64**

RCA 20%

Cement (kg)	Sand (Kg)	Coarse Aggregate(Kg)			Water (kg)	Super plasticizer (Kg) by weight of cement
		10mm	20mm	Recycled Aggregates		
410	**649.35**	**471.41**	**471.41**	**235.70**	**173.07**	**1.64**

RCA30%

Cement (kg)	Sand (Kg)	Coarse Aggregate(Kg)			Water (kg)	Super plasticizer (Kg) by weight of cement
		10mm	20mm	Recycled Aggregates		
410	**649.35**	**412.49**	**412.49**	**353.55**	**177.61**	**1.64**

Treatments

Recycled Aggregate

Mixing Based Treatment

Aggregate Based Aggregate

Surface Based Treatment

Figure 4.1 Different Treatment Methods

Different concrete fractions and applied different treatments on concrete as followed.

Control Concrete

- RCA 10%
- RCA 20%
- RCA 30%

Mixing Based Treatment

- RCA 10%, with 0.1% Na_2SiO_3
- RCA 20%, with 0.2% Na_2SiO_3
- RCA 30%, with 0.3% Na_2SiO_3

Aggregate based Treatment

- RCA 10%, Dip with 30% Na_2SiO_3
- RCA 20%, Dip with 30% Na_2SiO_3
- RCA 30%, Dip with 30% Na_2SiO_3

Surface Based Treatment

- RCA 10%, with 0.1% Na_2SiO_3
- RCA 20%, with 0.2% Na_2SiO_3
- RCA 30%, with 0.3% Na_2SiO_3

4.3.1 Control concrete: Control concrete made by above given mix design data, the natural graded aggregates were used, no recycled aggregated incorporating such mix. Therefore mixing the material and casting the cubes.

RCA 10%: The 10% recycled aggregates were replaced to the natural aggregates remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

RCA 20%: The 20% recycled aggregates were replaced to the natural aggregates remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

RCA 30%: The 30% recycled aggregates were replaced to the natural aggregates remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

4.3.2 Mixing Based Treatment: A dose of hydrophobic agent (sodium silicate) mixing in water before water added to concrete during concrete mixing, mixing procedure same to control concrete.

RCA 10%: The 10% recycled aggregates were replaced to the natural aggregates, 0.10% sodium silicate were added, remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

RCA 20%: The 20% recycled aggregates were replaced to the natural aggregates, 0.20% sodium silicate were added, remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

RCA 30%: The 30% recycled aggregates were replaced to the natural aggregates, 0.20% sodium silicate were added, remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

4.3.3 Aggregate Based Treatment: Procedure as given below

- Water absorption was observed of recycled aggregate.
- Recycled aggregates were dip in the water for 24 hours for saturation.
- Drying in ventilated oven at a temp. 110 ˚± 5 C for 24 hours.
- A solution was made by adding 30% sodium silicate in water.
- After drying process, when aggregates temperature same to the room temperature, the aggregates were dipped in hydrophobic solution for five minutes.
- Again drying at 20˚ C maintained room temperature for 24 hours.
- After 24 hours aggregates were ready to use for mixing process.

RCA 10%: The 10% treated recycled aggregates were replaced to the natural aggregates, remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

RCA 20%: The 20% treated recycled aggregates were replaced to the natural aggregates, remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

RCA 30%: The 30% treated recycled aggregates were replaced to the natural aggregates, remains other materials as per mix design data, water absorption of recycled aggregates applied for constant workability.

4.3.4 Surface Based Treatment: The surface silane treatment concrete was applied by using 100 g/m^2 of silane painting on recycled aggregate concrete surfaces.

- The specimens were removed from the molds after 1 day; then the cubes were cured in a water tank at 27 ± 1 °C the ages of 28 days.
- Air Dried: In preparation of the surface water repellent treatment concrete some of the cubes were taken out of the water tank at the age of 28 days then stored in a controlled laboratory environment at 23 °C and a relative humidity of 50% for 14 days.
- Then the specimen surface was cleaned by compressed air and the silane was applied on the specimen surface by brushing. The specimens were then stored in the same laboratory conditions for another 7 days in order to allow the applied materials to dry.
- The depth of silane impregnation is a very important factor to evaluate the effectiveness of the surface water repellent treatment.
- Oven Dried: To achieve different surface moisture conditions before the coating of silane, one sample was oven dried at 60 °C for 24 h.

  These samples were used for durability test.

4.4 Mixing Procedure

All mixtures were mixed in conventional blade-type mixer. Mixing procedures were same for normal concrete and concrete incorporating recycled aggregates.

Before adding water to the concrete mix coarse and fine aggregate (together with recycled aggregates, if applicable) and cement were loaded in the mixture and mixed for 3-5 minutes. Superplastcizer was added to water then water was added gradually to the mix for a period of about 2 minutes, followed by mixing for 5 minutes to produce a uniform mix.

After the concrete has been mixed, immediately filled the cube moulds (100mm x 100mm x 100mm) and beams (100mm x 100mm x 500mm), they were compacted by vibration. Any air trapped in the concrete will reduce the strength of the cube. Hence, the cubes had been fully compacted. Care must also be taken not to over compact the concrete as this may cause segregation of the aggregates and cement paste in the mix. This may also reduce the final compressive strength**.** The period of vibration shall not be more than 2 minutes at the specified speed of 12000 ± 400 vibrations per minute. The samples then demoulded 24 hours later and were put in water tank for 7 and 28 days. Test cubes should be demoulded between 16 and 24 hours after they have been made. If after this period of time the concrete has not achieved sufficient strength to enable demoulding without damaging the cube then the demoulding should be delayed for a further 24 hours. When removing the concrete cube from the mould, take the mould apart completely. Take care not to damage the cube because, if any cracking is caused, the compressive strength may be reduced. At the end of that period remove the cube from the mould and immediately submerge in clean and fresh water and keep there until taken out just prior to breaking. The water in which the cubes are submerged shall be renewed after every 7 days and shall be maintained at a temperature of 27° ± 2°C, kept wet till it is placed in machine for testing.

5 Testing

5.1 Compressive Strength: According to IS: 516 1959.

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed by definition; the compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally as a result of a compressive test.

5.2 Flexural Strength: According to IS: 516 1959.

The tensile strength of concrete is of value in estimating the load under which crack will develop. The absence of cracking is of considerable importance in maintaining the continuity of a concrete structure and preventing corrosion of reinforcement. Maximum Tensile stress reached in the bottom fiber of the test bean is known as Modulus of rupture. The test performed by 4 point loading method.

- Place the specimen in the testing machine such that the load shall be applied to the uppermost surface as cast in the mould, along two lines spaced 133.3mm for the 500mm long beam. The axis of the load device.
- Apply load carefully without shock @180kg/min. for 100mm specimen till specimen fails. The appearance of fractured faces of concrete and any usual features in the type of failure should be noted.

5.3 Durability

The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. It also includes the effects of quality and serviceability of concrete when exposed to sulphate and chloride attacks.

5.3.1 Din Permeability Test

The permeability test gives a measure of the resistance of concrete against the penetration of water exerting pressure as per DIN 1048 part 5 which can be used to measure water permeability of concrete in which maximum aggregate particle size up to 32 mm and specimens used for determining the water permeability.

For this Test 150mm × 150mm cubes were used, after demoulding the cubes was cured for 28 days in a temperature (27 Degree) controlled curing tank. Cubes dried in oven at 100°C temperature for 72 Hours. Concrete specimens were exposed to a water pressure of 0.5 N/mm^2 acting normal to the mould- filling direction, for a period of 72 hours. The pressure has been released; the specimen was removed and split down the center with the face which was exposed to water facing down. The maximum depth of penetration in the cubes was measured. The mean of the maximum depth of penetration obtained from three specimens thus tested was taken as the test result.

5.3.2 Resistance against Acid Attack

This test was carried out on the 100×100×100 mm Concrete cubes. Cubes were casted and demoulded after 24 hours and were tested at the end of 28 days of normal curing. After the normal curing of 28 days the specimens were oven dried and the initial weight was taken. 3% sulphuric acid (H_2SO_4) by weight of water was added in water. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the solution after 7 and 28 days of continuous soaking. The surfaces of the Cubes were cleaned, weighed and then tested in the compressive testing machine under the uniform rate of loading of 140 $kg/cm^2/min$. The changes in strength of the concrete cube were calculated as per IS: 516 1959. Difference of soaked acid in percentage at 7 and 28 days were reported and compressive strength at the age of 7 and 28 days were also reported.

5.3.3 Resistance against Sulphate Attack

This test was carried out on the 100×100×100 mm Concrete cubes. Cubes were casted and demoulded after 24 hours and were tested at the end of 28 days of normal curing. After the normal curing of 28 days the specimens were oven dried and the initial weight was taken. 3% Magnesium Sulphate ($MgSO_4$) by weight of water was added with water. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the solution after 7, 28 days of continuous soaking. The surfaces of the cubes were cleaned, weighed & then tested in the compressive testing machine under the uniform rate of loading of 140 $kg/cm^2/min$. The changes in strength of the concrete cubes were calculated as per IS: 516 1959. Difference of soaked acid in percentage at 7 and 28 days reported and compressive strength at the age of 7 and 28 days also reported.

5.3.4 Resistance against Chloride Attack

This test was carried out on the 100×100×100 mm concrete cubes. Cubes were casted and demoulded after 24 hours and were tested at the end of 28 days of normal curing. After the normal curing of 28 days the specimens were oven dried and the initial weight was taken. 30% Sodium Chloride (NaCl) by weight of water was added with water. The concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the solution after 7, 28 days of continuous soaking. The surfaces of the Cubes were cleaned and split into two parts. 1% of the $AgNO_3$ solution was spread over and noted that the NaCl penetrated part showed a different color compared with the wet area of the split surface. The impregnation depth of the NaCl penetration was measured by a caliper gauge at six different positions and the average value was reported.

5.3.5 Sorptivity

This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The specimen is conditioned in an environment at a standard relative humidity to induce a consistent moisture condition in the capillary pore system. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete is dominated by capillary suction during initial contact with water

- After the normal curing of 28 days the specimens were oven dried and the initial weight was taken.
- The four adjacent sides of concrete cubes were coated with wax, the top and the bottom surface were left uncoated.
- The cubes were immersed in water, upto 5mm from the bottom for 72 hours.
- The final weight of cubes were taken at the time interval of 10 minutes, 20 minutes, 30 minutes, 1Hour, 3 Hours, 12Hours, 24 Hours, 48 Hours and 72 Hours.

5.3.6 Ultrasonic Pulse Velocity Test

The Specimens were subjected to Pulse velocity test as per 13311 Parts 1. The time taken by the ultrasonic pulse to travel through the specimen between transducer and receiver held in contact with the specimen was noted. The path length divided by the time taken gives the pulse velocity, the quality grading of the cement concrete were obtained.

S. No	Ultrasonic Pulse Velocity for Concrete (Km/Sec)	Concrete Quality Grading
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtful

Chloride Attack **Acid Attack**

DIN Permeability Test

Figure 5.1 Different Durability Tests

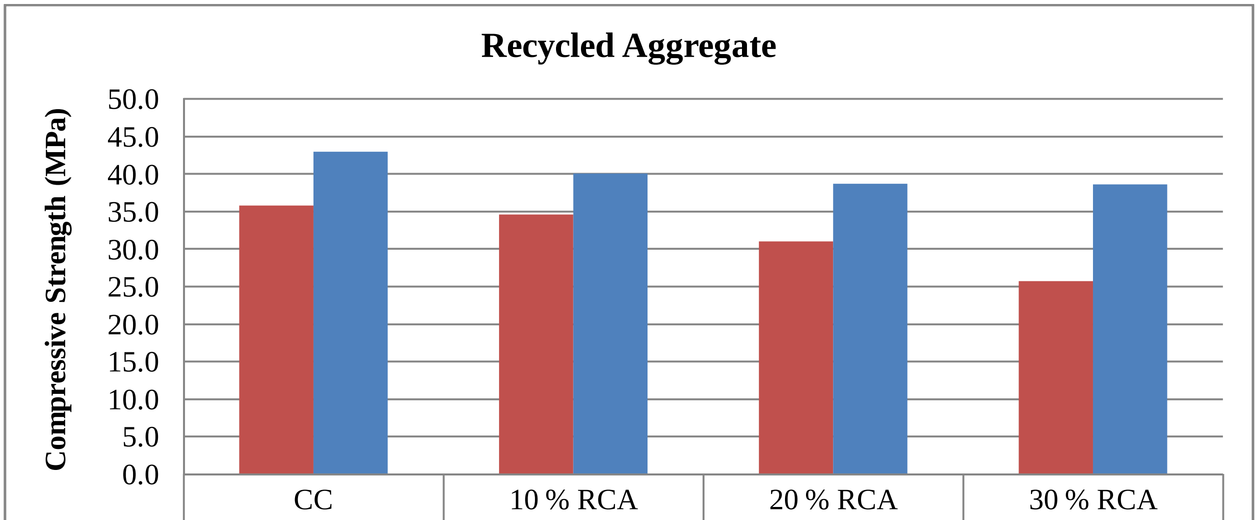
COMPRESSIVE STRENGTH 7 DAYS TESTING

Cube (mm) 100×100×100	Load (KN)	Compressive Strength (N/mm^2)	Av. Compressive Strength (N/mm^2)
Natural Aggregates			
1	365	36.5	
2	355	35.5	35.8
3	355	35.5	
10 % RCA			
1	340	34.0	
2	350	35.0	34.6
3	350	35.0	
20 % RCA			
1	280	28.0	
2	320	32.0	31.0
3	330	33.0	
30 % RCA			
1	280	28.0	
2	250	25.0	25.7
3	240	24.0	
Mixing Base Treatment			
10% RCA with 0.1%Na_2SiO_3			
1	280	28.0	
2	300	30.0	32.6
3	400	40.0	
20% RCA with 0.2%Na_2SiO_3			
1	405	40.5	
2	400	40.0	38.5
3	350	35.0	
30% RCA with 0.3%Na_2SiO_3			
1	340	34.0	
2	340	34.0	33.3
3	320	32.0	
Aggregate Base Treatment			
10% RCA Dip with 30%Na_2SiO_3			
1	370	37.0	
2	400	40.0	38.1
3	375	37.5	
20% RCA Dip with 30%Na_2SiO_3			
1	350	35.0	
2	325	32.5	34.8
3	370	37.0	
30% RCA Dip with 30%Na_2SiO_3			
1	255	25.5	
2	225	22.5	24.5
3	255	25.5	

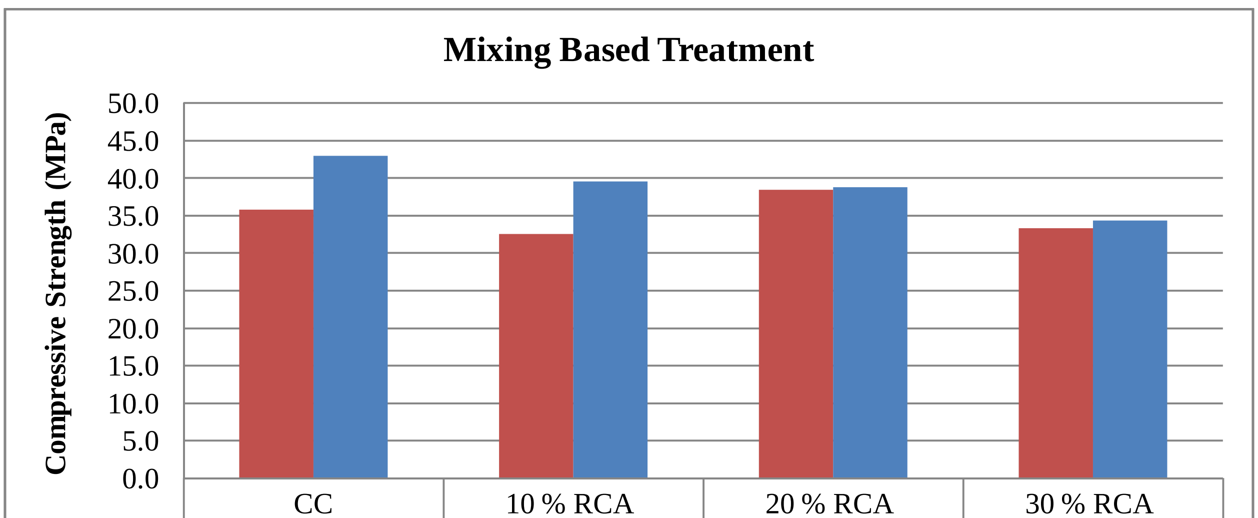
COMPRESSIVE STRENGTH 28 DAYS TESTING

Cube (mm) 100×100×100	Load (KN)	Compressive Strength (N/mm^2)	Av. Compressive Strength (N/mm^2)
Natural Aggregates			
1	460	46.0	
2	425	42.5	43.0
3	405	40.5	
10 % RCA			
1	420	42.0	
2	380	38.0	40.1
3	405	40.5	
20 % RCA			
1	418	41.8	
2	360	36.0	38.7
3	385	38.5	
30 % RCA			
1	410	41.0	
2	420	42.0	38.6
3	418	41.8	
Mixing Base Treatment			
10% RCA with 0.1%Na_2SiO_3			
1	434	43.4	
2	356	35.6	39.6
3	400	40.0	
20% RCA with 0.2%Na_2SiO_3			
1	372	37.2	
2	398	39.8	38.8
3	395	39.5	
30% RCA with 0.3%Na_2SiO_3			
1	340	34.0	
2	353	35.3	34.4
3	341	34.1	
Aggregate Base Treatment			
10% RCA Dip with 30%Na_2SiO_3			
1	242	24.2	
2	344	34.4	39.8
3	365	36.5	
20% RCA Dip with 30%Na_2SiO_3			
1	375	37.5	
2	330	33.0	35.8
3	370	37.0	
30% RCA Dip with 30%Na_2SiO_3			
1	284	28.4	
2	270	27.0	27.6
3	275	27.5	

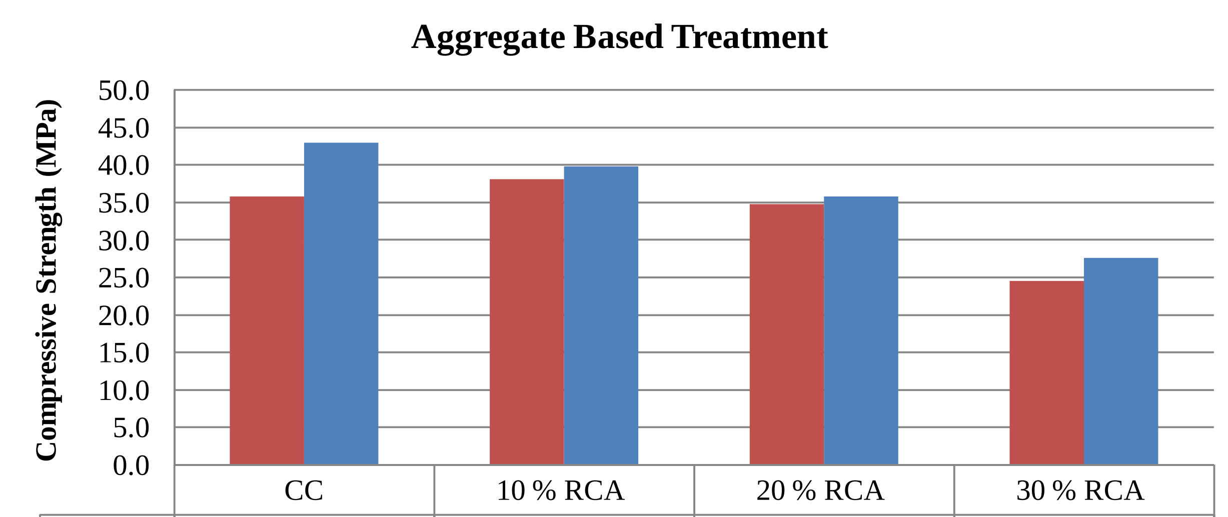
Compressive Strength of Concrete (7 and 28 Days)



	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	35.8	34.6	31.0	25.7
28 Days	43.0	40.1	38.7	38.6

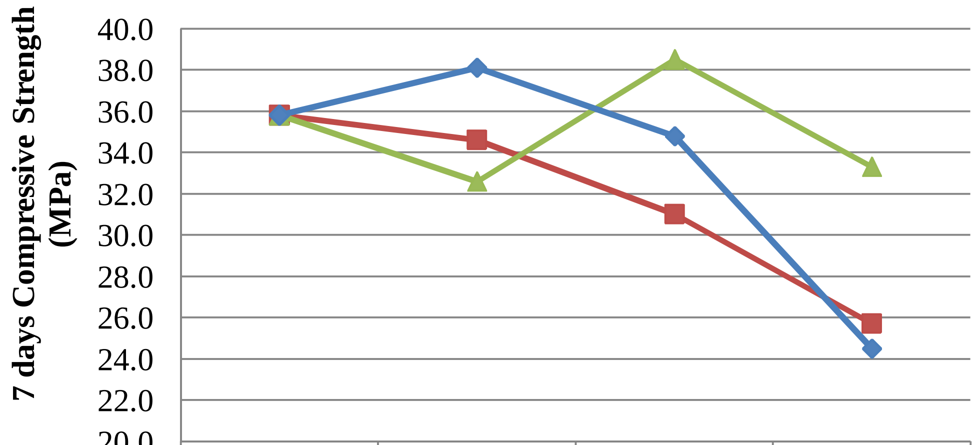


	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	35.8	32.6	38.5	33.3
28 Days	43.0	39.6	38.8	34.4



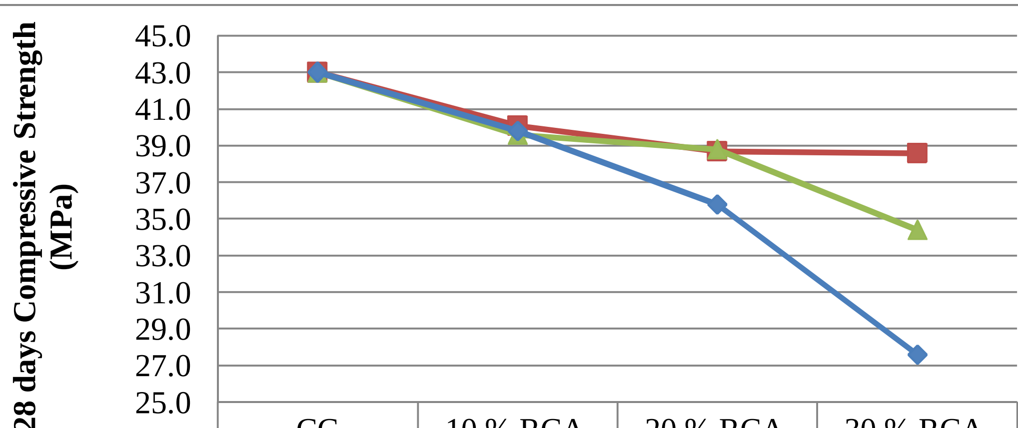
	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	35.8	38.1	34.8	24.5
28 Days	43.0	39.8	35.8	27.6

Compressive Strength of Concrete (7 Days) incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment and Mixing based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	35.8	34.6	31.0	25.7
Mixing Based Treatment	35.8	32.6	38.5	33.3
Aggregate Based Treatment	35.8	38.1	34.8	24.5

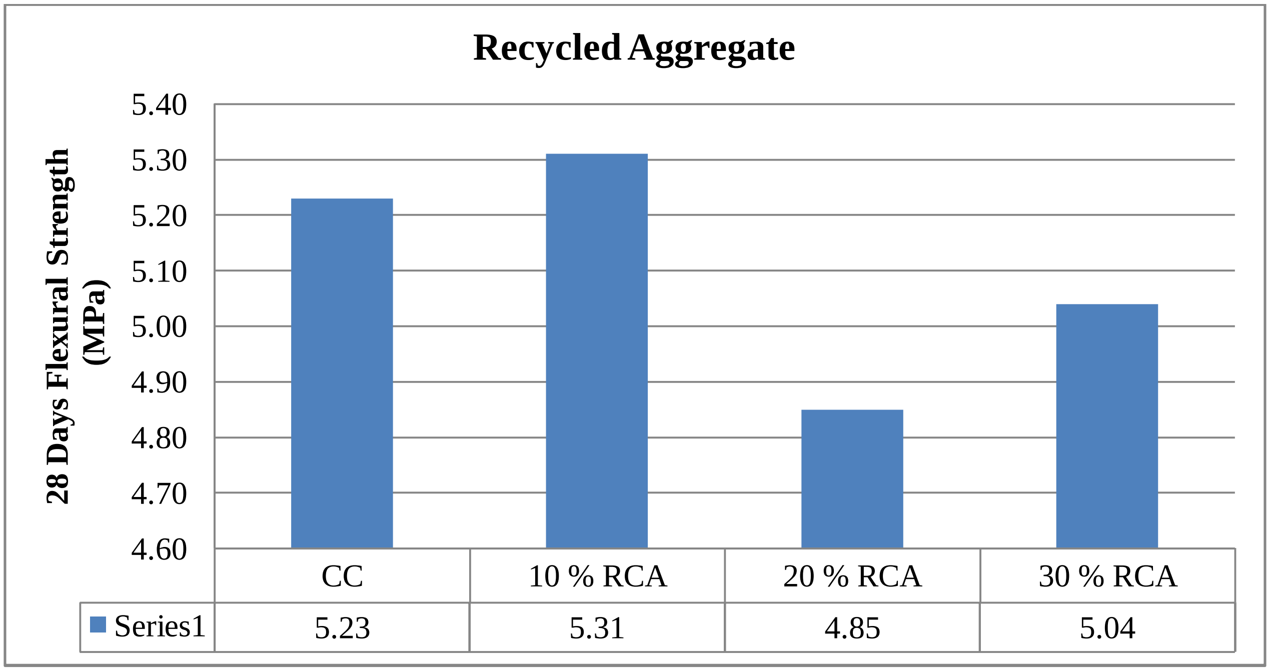
Compressive Strength of Concrete (28 Days) incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment and Mixing based treatment)

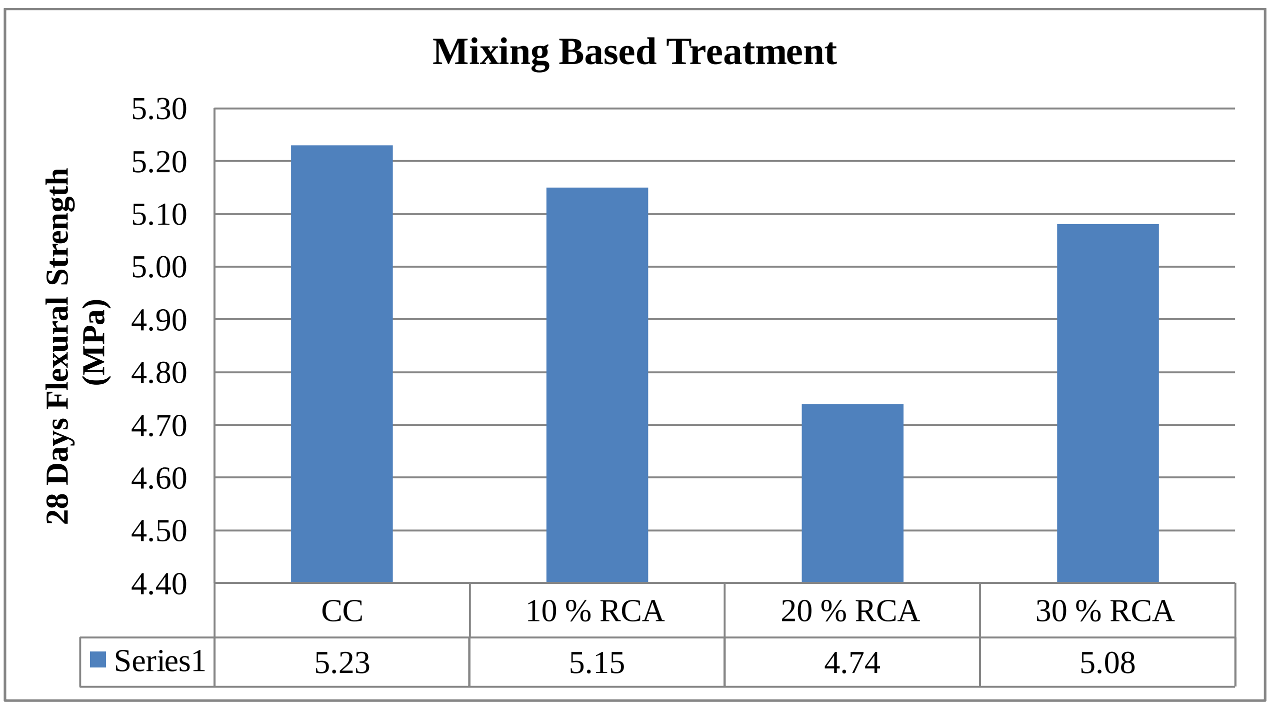


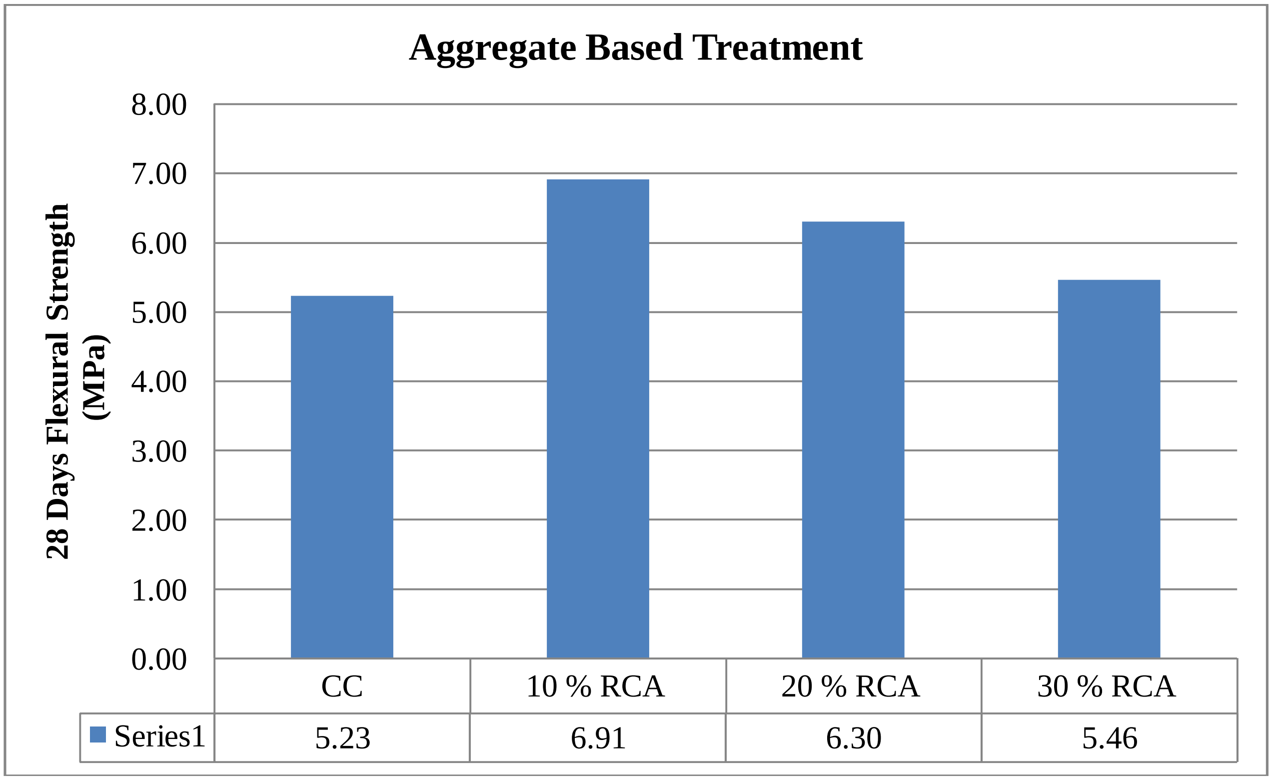
	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	43.0	40.1	38.7	38.6
Mixing Based Treatment	43.0	39.6	38.8	34.4
Aggregate Based Treatment	43.0	39.8	35.8	27.6

FLEXURAL STRENGTH 28 DAYS TESTING

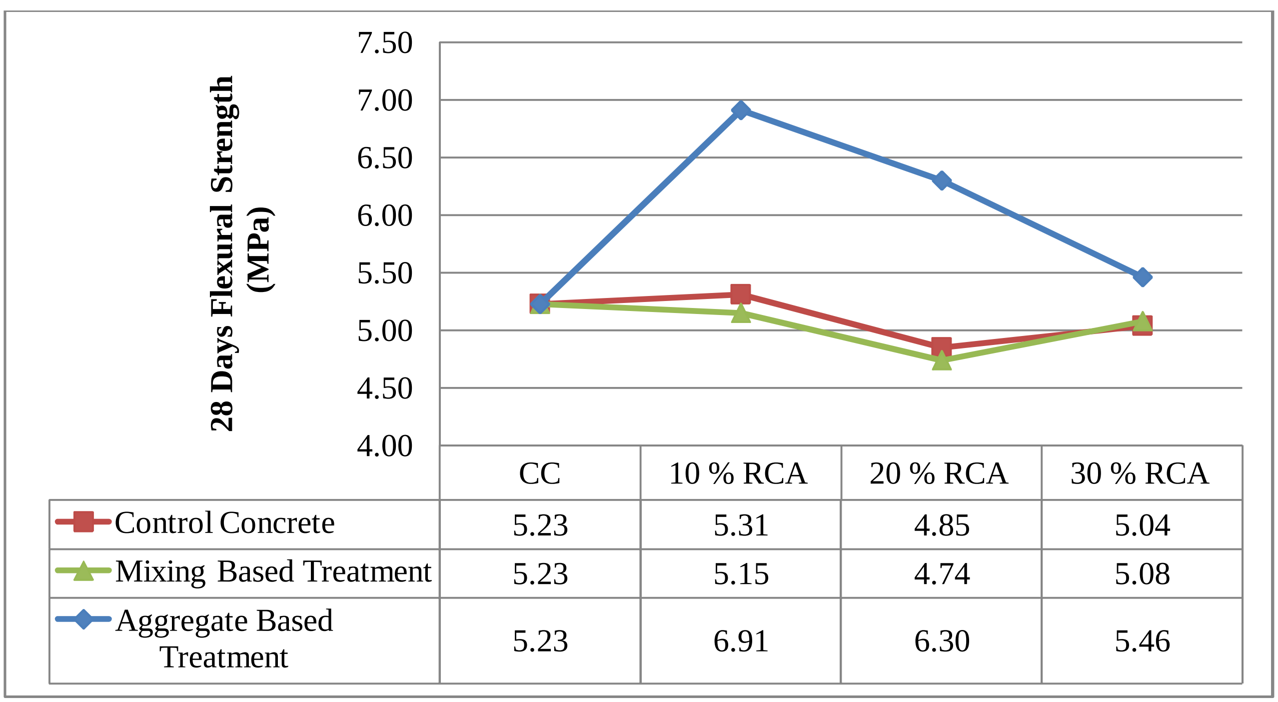
BEAM (mm) (100x100x500)	Load (KN)	Flexural Strength (N/mm^2)	Av. Flexural Strength (N/mm^2)
Natural Aggregates			
1	12.53	5.012	
2	13.25	5.300	5.23
3	13.48	5.392	
10 % RCA			
1	14.32	5.728	
2	12.27	4.908	5.31
3	13.26	5.304	
20 % RCA			
1	12.46	4.984	
2	12.22	4.888	4.85
3	11.66	4.664	
30 % RCA			
1	11.92	4.768	
2	13.26	5.304	5.04
3	12.65	5.060	
Mixing Base Treatment			
10% RCA with 0.1%Na_2SiO_3			
1	14.15	5.660	
2	12.86	5.144	5.15
3	11.64	4.656	
20% RCA with 0.2%Na_2SiO_3			
1	11.80	4.720	
2	11.90	4.760	4.74
3	11.85	4.740	
30% RCA with 0.3%Na_2SiO_3			
1	12.86	5.144	
2	12.60	5.040	5.08
3	12.65	5.060	
Aggregate Base Treatment			
10% RCA Dip with 30%Na_2SiO_3			
1	17.16	6.864	
2	17.61	7.044	6.91
3	17.04	6.816	
20% RCA Dip with 30%Na_2SiO_3			
1	14.80	5.920	
2	14.96	5.984	6.30
3	17.52	7.008	
30% RCA Dip with 30%Na_2SiO_3			
1	13.02	5.208	
2	13.58	5.432	5.46
3	14.32	5.728	


Recycled Aggregate
28 Days Flexural Strength (MPa)
5.40
5.30
5.20
5.10
5.00
4.90
4.80
4.70
4.60
CC
10 % RCA
20 % RCA
30 % RCA
Series1
5.23
5.31
4.85
5.04


Mixing Based Treatment
28 Days Flexural Strength (MPa)
5.30
5.20
5.10
5.00
4.90
4.80
4.70
4.60
4.50
4.40
CC
10 % RCA
20 % RCA
30 % RCA
Series1
5.23
5.15
4.74
5.08



Flexural Strength of Concrete (28 Days) incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment and Mixing based treatment)



MOISTURE CONTENT 28 DAYS TESTING

Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av Moisture Content in %
Natural Aggregates				
1	2.478	2.465	0.527	
2	2.553	2.538	0.591	0.569
3	2.564	2.549	0.588	
10 % RCA				
1	2.534	2.526	0.317	
2	2.567	2.553	0.548	0.431
3	2.574	2.563	0.429	
20 % RCA				
1	2.474	2.466	0.324	
2	2.566	2.559	0.274	0.290
3	2.568	2.561	0.273	
30 % RCA				
1	2.488	2.481	0.282	
2	2.528	2.522	0.238	0.253
3	2.522	2.516	0.238	
Mixing Base Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	2.484	2.472	0.485	
2	2.478	2.469	0.365	0.418
3	2.483	2.473	0.404	
20% RCA with 0.2%Na_2SiO_3				
1	2.517	2.507	0.399	
2	2.587	2.575	0.466	0.432
3	2.565	2.554	0.431	
30% RCA with 0.3%Na_2SiO_3				
1	2.454	2.439	0.615	
2	2.533	2.518	0.596	0.562
3	2.541	2.529	0.474	
Aggregate Base Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2.480	2.437	1.764	
2	2.496	2.462	1.381	1.453
3	2.501	2.471	1.214	
20% RCA Dip with 30%Na_2SiO_3				
1	2.470	2.435	1.437	
2	2.438	2.400	1.583	1.518
3	2.448	2.411	1.535	

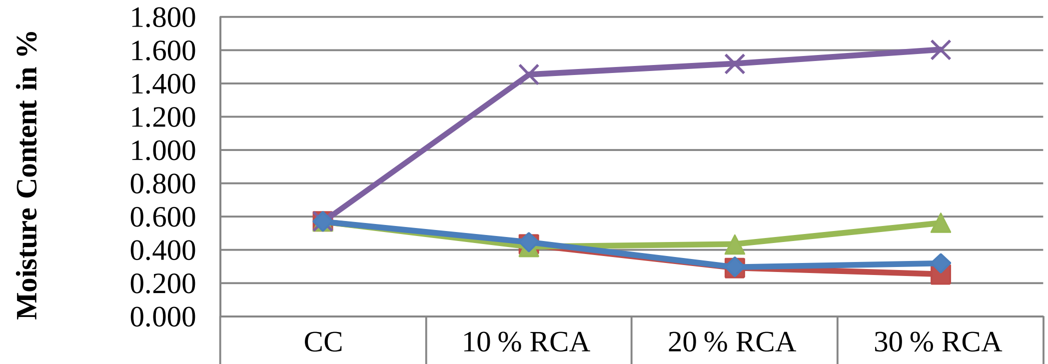
Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av Moisture Content in %
30% RCA Dip with 30%Na_2SiO_3				
1	2.446	2.408	1.578	
2	2.398	2.355	1.826	1.601
3	2.536	2.501	1.399	
Surface Based Treatment				
10 % RCA				
1	2.568	2.556	0.469	
2	2.551	2.540	0.433	0.445
3	2.562	2.551	0.431	
20 % RCA				
1	2.610	2.602	0.307	
2	2.564	2.558	0.235	0.297
3	2.589	2.580	0.349	
30 % RCA				
1	2.492	2.484	0.322	
2	2.510	2.502	0.320	0.319
3	2.541	2.533	0.316	

WATER ABSORPTION (28 DAYS) TESTING

Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av. Water Content in %
Natural Aggregates				
1	2.476	2.465	0.446	
2	2.548	2.538	0.394	0.411
3	2.559	2.549	0.392	
10 % RCA				
1	2.542	2.526	0.633	
2	2.564	2.553	0.431	0.537
3	2.577	2.563	0.546	
20 % RCA				
1	2.484	2.466	0.730	
2	2.575	2.559	0.625	0.673
3	2.578	2.561	0.664	
30 % RCA				
1	2.506	2.481	1.008	
2	2.544	2.522	0.872	0.892
3	2.536	2.516	0.795	
Mixing Based Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	2.485	2.472	0.526	
2	2.481	2.469	0.486	0.499
3	2.485	2.473	0.485	

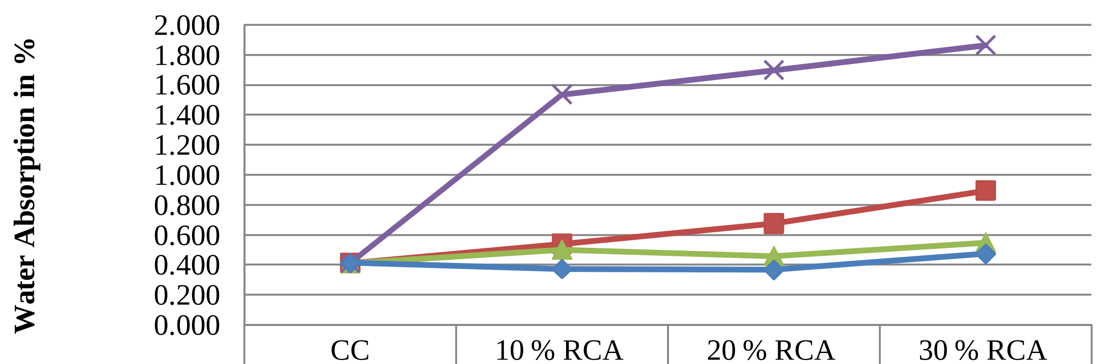
Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av. Water Content in %
20% RCA with 0.2%Na_2SiO_3				
1	2.518	2.507	0.439	
2	2.587	2.575	0.466	0.458
3	2.566	2.554	0.470	
30% RCA with 0.3%Na_2SiO_3				
1	2.453	2.439	0.574	
2	2.531	2.518	0.516	0.548
3	2.543	2.529	0.554	
Aggregate Based Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2.479	2.437	1.723	
2	2.500	2.462	1.543	1.534
3	2.504	2.471	1.335	
20% RCA Dip with 30%Na_2SiO_3				
1	2.474	2.435	1.602	
2	2.443	2.400	1.792	1.698
3	2.452	2.411	1.701	
30% RCA Dip with 30%Na_2SiO_3				
1	2.456	2.408	1.993	
2	2.402	2.355	1.996	1.863
3	2.541	2.501	1.599	
Surface Based Treatment				
10 % RCA				
1	2.515	2.506	0.359	
2	2.447	2.439	0.328	0.372
3	2.571	2.560	0.430	
20 % RCA				
1	2.524	2.512	0.478	
2	2.387	2.380	0.294	0.366
3	2.462	2.454	0.326	
30 % RCA				
1	2.415	2.402	0.541	
2	2.481	2.471	0.405	0.473
3	2.551	2.539	0.473	

Moisture Content of Concrete (28 Days) incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	0.569	0.431	0.290	0.253
Mixed Based Concrete	0.569	0.418	0.432	0.562
Aggregate Based Concrete	0.569	1.453	1.518	1.601
Surface Based Concrete	0.569	0.445	0.297	0.319

Water Absorption of Concrete (28 Days) incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	0.411	0.537	0.673	0.892
Mixed Based Concrete	0.411	0.499	0.458	0.548
Aggregate Based Concrete	0.411	1.534	1.698	1.863
Surface Based Concrete	0.411	0.372	0.366	0.473

7 DAYS COMPRESSIVE STRENGTH OF CONCRETE WITH SULPHURIC ACID (3%, H_2SO_4) ATTACK

Cube (mm) 100×100×100	Load (KN)	Compressive Strength (N/mm^2)	Av. Compressive Strength (N/mm^2)
Natural Aggregate			
1	380	38.0	
2	380	38.0	38.0
10 % RCA			
1	380	38.0	
2	400	40.0	39.0
20 % RCA			
1	430	43.0	
2	400	40.0	41.5
30 % RCA			
1	340	34.0	
2	350	35.0	34.5
Mixing Based Treatment			
10% RCA with 0.1%Na_2SiO_3			
1	405	40.5	
2	465	46.5	43.5
20% RCA with 0.2%Na_2SiO_3			
1	430	43.0	
2	420	42.0	41.5
30% RCA with 0.3%Na_2SiO_3			
1	380	38.0	
2	380	38.0	38.0
Aggregate Based Treatment			
10% RCA Dip with 30%Na_2SiO_3			
1	370	37.5	
2	380	38.0	37.5
20% RCA Dip with 30%Na_2SiO_3			
1	400	40.0	
2	360	36.0	38.0
30% RCA Dip with 30%Na_2SiO_3			
1	300	30.0	
2	290	29.0	29.5
Surface Based Treatment			
10% RCA			
1	410	41.0	
2	390	39.0	40.0
20% RCA			
1	420	42.0	
2	430	43.0	41.5

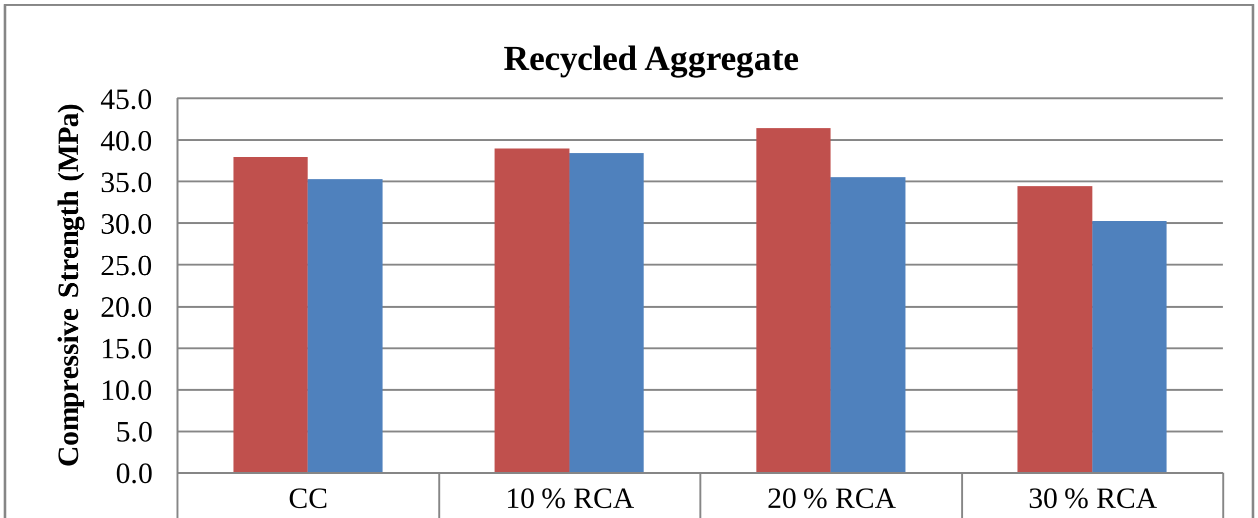
30% RCA			
Cube (mm) 100×100×100	**Load (KN)**	**Compressive Strength (N/mm^2)**	**Av. Compressive Strength (N/mm^2)**
1	360	36.0	
2	340	34.0	35.0

28 DAYS COMPRESSIVE STRENGTH OF CONCRETE WITH SULPHURIC ACID (3%, H_2SO_4) ATTACK

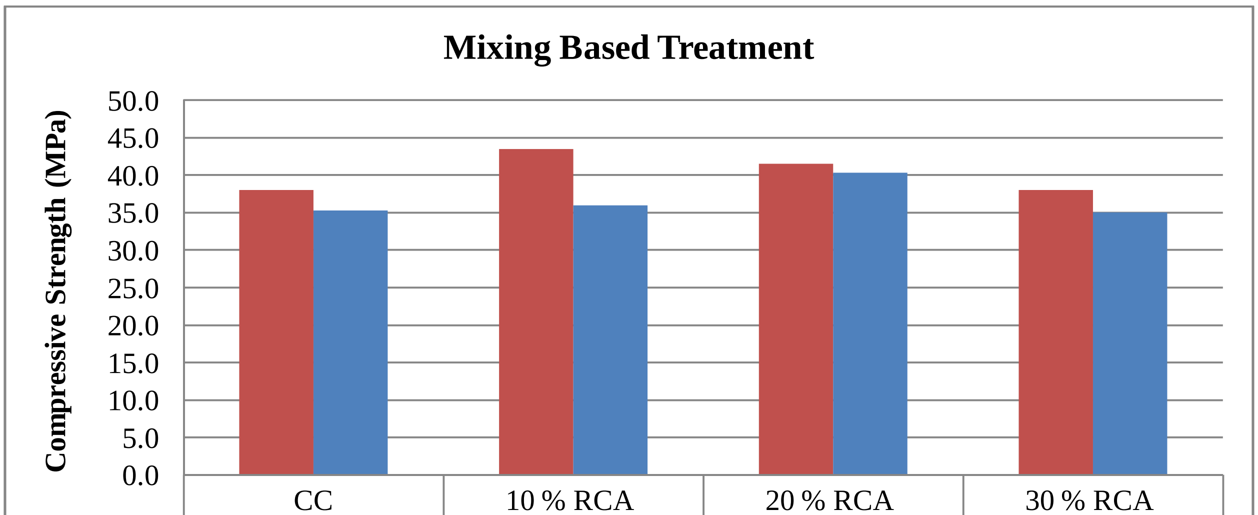
Cube (mm) 100×100×100	Load (KN)	Compressive Strength (N/mm^2)	Av. Compressive Strength (N/mm^2)
Natural Aggregate			
1	360	36.0	
2	345	34.5	35.3
10 % RCA			
1	410	41.0	
2	360	36.0	38.5
20 % RCA			
1	350	35.0	
2	360	36.0	35.5
30 % RCA			
1	310	31.0	
2	295	29.5	30.3
Mixing Based Treatment			
10% RCA with 0.1%Na_2SiO_3			
1	370	37.0	
2	350	35.0	36.0
20% RCA with 0.2%Na_2SiO_3			
1	410	41.0	
2	395	39.5	40.3
30% RCA with 0.3%Na_2SiO_3			
1	340	34.0	
2	360	36.0	35.0
Aggregate Based Treatment			
10% RCA Dip with 30%Na_2SiO_3			
1	280	28.0	
2	300	30.0	29.0
20% RCA Dip with 30%Na_2SiO_3			
1	310	31.0	
2	340	34.0	32.5
30% RCA Dip with 30%Na_2SiO_3			
1	270	27.0	
2	280	28.0	27.5

Surface Based Treatment			
Cube (mm) 100×100×100	**Load (KN)**	**Compressive Strength (N/mm^2)**	**Av. Compressive Strength (N/mm^2)**
10% RCA			
1	390	39.0	
2	370	37.0	38.0
20% RCA			
1	395	39.5	
2	375	37.5	38.5
30% RCA			
1	360	36.0	
2	310	31.0	33.5

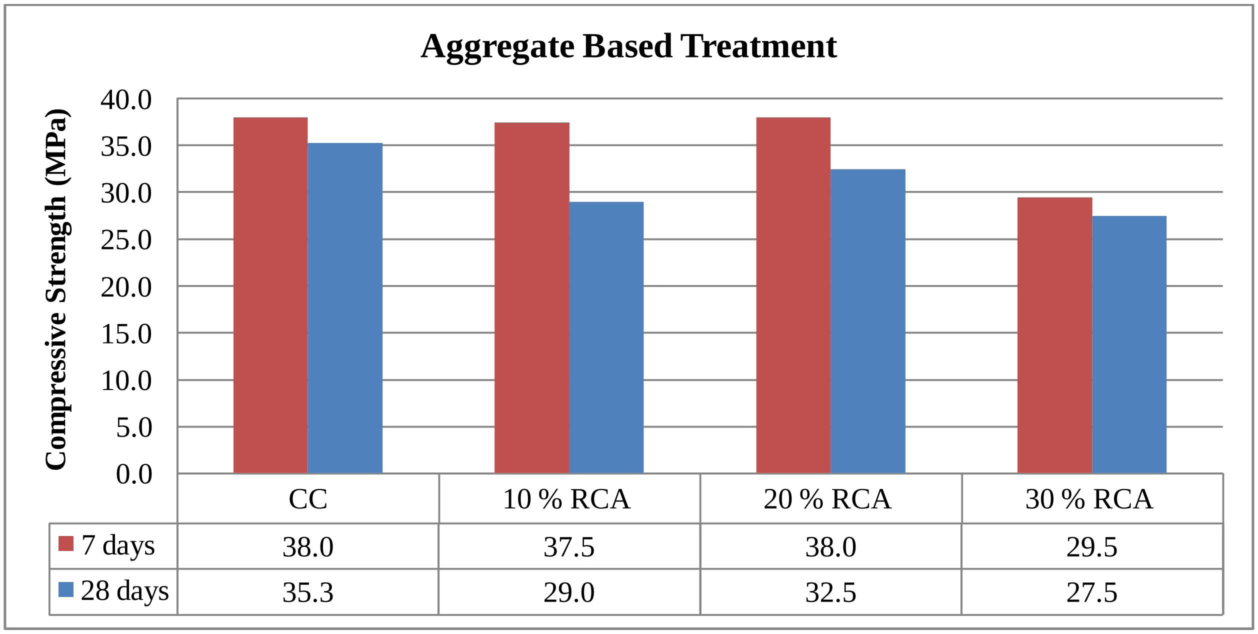
Compressive Strength of Concrete (7 and 28 Days) with Sulphuric Acid (3%, H_2SO_4) Attack

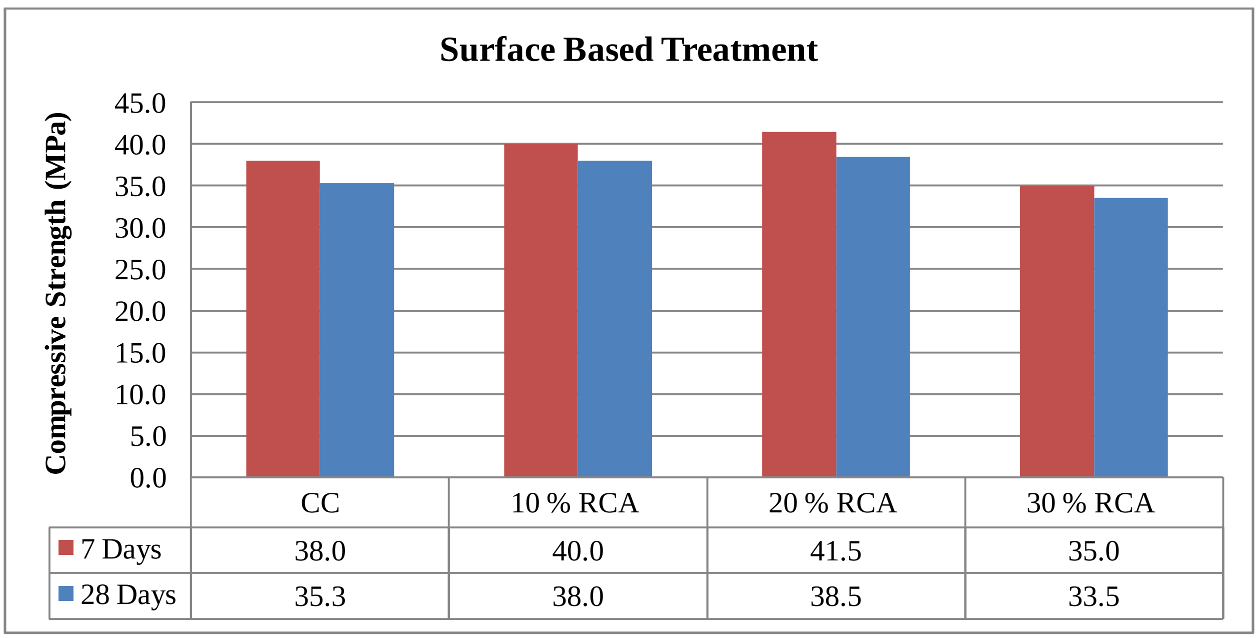


	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	38.0	39.0	41.5	34.5
28 days	35.3	38.5	35.5	30.3

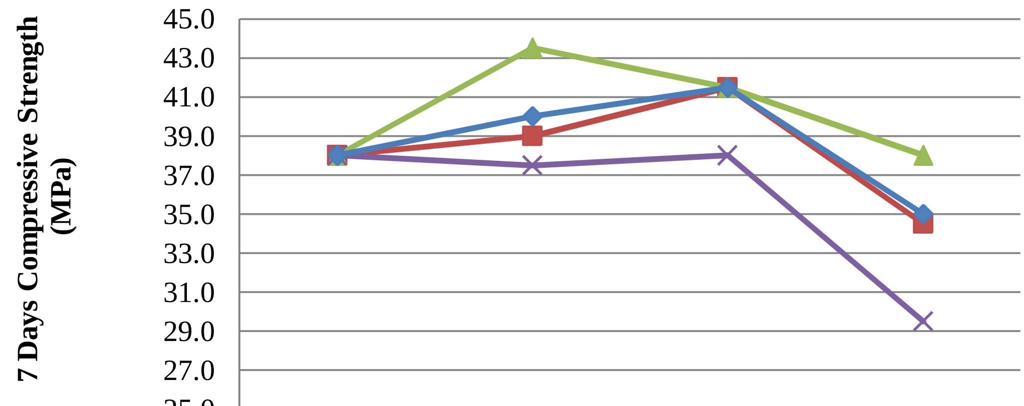


	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	38.0	43.5	41.5	38.0
28 Days	35.3	36.0	40.3	35.0


Aggregate Based Treatment
Compressive Strength (MPa)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
CC
10 % RCA
20 % RCA
30 % RCA
7 days
28 days
38.0
37.5
38.0
29.5
35.3
29.0
32.5
27.5

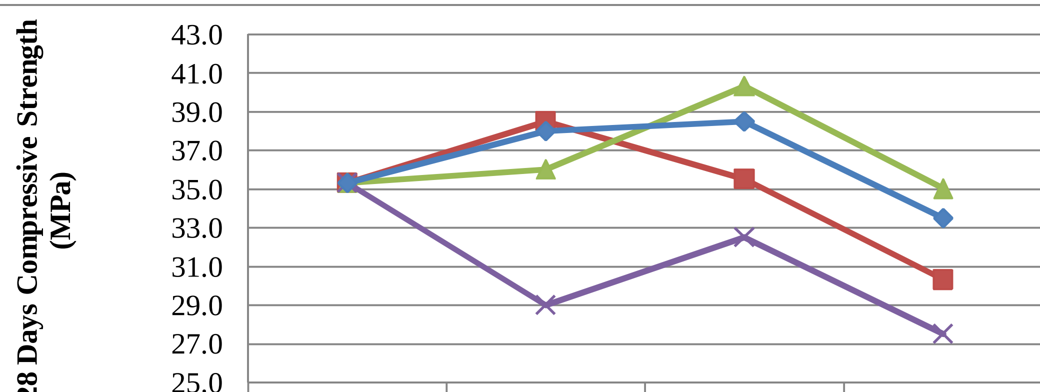

Surface Based Treatment
Compressive Strength (MPa)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
CC
10 % RCA
20 % RCA
30 % RCA
7 Days
28 Days
38.0
40.0
41.5
35.0
35.3
38.0
38.5
33.5

Compressive Strength of Concrete (7 Days) with Sulphuric Acid (3%, H_2SO_4) Attack incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	38.0	39.0	41.5	34.5
Mixing Based Treatment	38.0	43.5	41.5	38.0
Aggregate Based Treatment	38.0	37.5	38.0	29.5
Surface Based Treatment	38.0	40.0	41.5	35.0

Compressive Strength of Concrete (28 Days) with Sulphuric Acid (3%, H_2SO_4) Attack incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	35.3	38.5	35.5	30.3
Mixing Based Treatment	35.3	36.0	40.3	35.0
Aggregate Based Treatment	35.3	29.0	32.5	27.5
Surface Based Treatment	35.3	38.0	38.5	33.5

7 DAYS WATER ABSORPTION WITH 3%, H_2SO_4 ATTACK

Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av. Water Content in %
Natural Aggregate				
1	2.502	2.523	0.839	
2	2.460	2.478	0.732	0.786
10 % RCA				
1	2.599	2.620	0.808	
2	2.611	2.631	0.766	0.787
20 % RCA				
1	2.582	2.603	0.813	
2	2.516	2.536	0.795	0.804
30 % RCA				
1	2.442	2.465	0.942	
2	2.546	2.570	0.943	0.942
Mixing Based Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	2.589	2.610	0.811	
2	2.528	2.548	0.791	0.801
20% RCA with 0.2%Na_2SiO_3				
1	2.504	2.530	1.038	
2	2.496	2.523	1.082	1.060
30% RCA with 0.3%Na_2SiO_3				
1	2.461	2.486	1.016	
2	2.500	2.538	1.520	1.268
Aggregate Based Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2.512	2.532	0.796	
2	2.519	2.535	0.635	0.716
20% RCA Dip with 30%Na_2SiO_3				
1	2.405	2.424	0.790	
2	2.519	2.537	0.715	0.752
30% RCA Dip with 30%Na_2SiO_3				
1	2.384	2.396	0.503	
2	2.444	2.448	0.164	0.334
Surface Based Treatment				
10 % RCA				
1	2.530	2.549	0.751	
2	2.526	2.544	0.713	0.732
20 % RCA				
1	2.424	2.441	0.701	
2	2.561	2.579	0.703	0.702
30 % RCA				
1	2.544	2.561	0.668	
2	2.481	2.497	0.645	0.657

28 DAYS WATER ABSORPTION WITH 3%, H_2SO_4 ATTACK

Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av. Water Content in %
Natural Aggregate				
1	2.535	2.542	0.276	
2	2.465	2.471	0.243	0.260
10 % RCA				
1	2.528	2.532	0.158	
2	2.540	2.550	0.394	0.276
20 % RCA				
1	2.450	2.459	0.367	0.418
2	2.562	2.574	0.468	
30 % RCA				
1	2.475	2.488	0.525	
2	2.396	2.418	0.918	0.722
Mixing Based Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	2.517	2.520	0.119	
2	2.552	2.553	0.039	0.079
20% RCA with 0.2%Na_2SiO_3				
1	2.485	2.487	0.080	
2	2.553	2.565	0.470	0.275
30% RCA with 0.3%Na_2SiO_3				
1	2.428	2.436	0.329	
2	2.491	2.504	0.522	0.426
Aggregate Based Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2.535	2.512	-0.907	
2	2.534	2.522	-0.474	-0.690
20% RCA Dip with 30%Na_2SiO_3				
1	2.451	2.451	0.000	
2	2.527	2.548	0.831	0.416
30% RCA Dip with 30%Na_2SiO_3				
1	2.388	2.386	-0.084	
2	2.444	2.443	-0.041	-0.062
Surface Based Treatment				
10 % RCA				
1	2.606	2.598	-0.307	
2	2.530	2.497	-1.304	-0.806
20 % RCA				
1	2.498	2.492	-0.240	
2	2.494	2.484	-0.401	-0.321
30 % RCA				
1	2.498	2.495	-0.120	
2	2.411	2.411	0.000	-0.060

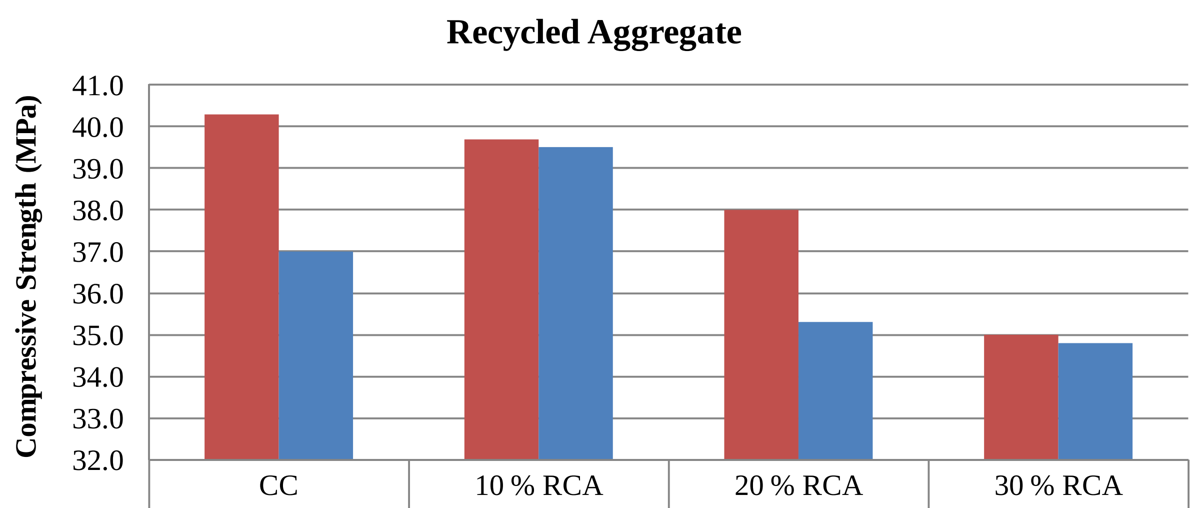
7 DAYS COMPRESSIVE STRENGTH OF CONCRETE WITH MAGNESIUM SULPHATE ATTACK (3%, $MgSO_4$)

Cube (mm) 100×100×100	**Load (KN)**	**Compressive Strength (N/mm^2)**	**Av. Compressive Strength (N/mm^2)**
Natural Aggregate			
1	410	41.0	
2	395	39.5	40.3
10 % RCA			
1	400	40.0	
2	395	39.5	39.7
20 % RCA			
1	410	41.0	
2	350	35.0	38.0
30 % RCA			
1	340	34.0	
2	360	36.0	35.0
Mixing Based Treatment			
10% RCA with 0.1% Na_2SiO_3			
1	380	38.0	
2	365	36.5	37.3
20% RCA with 0.2% Na_2SiO_3			
1	430	43.0	
2	375	37.5	40.4
30% RCA with 0.3% Na_2SiO_3			
1	430	43.0	
2	380	38.0	40.5
Aggregate Based Treatment			
10% RCA Dip with 30% Na_2SiO_3			
1	340	34.0	
2	365	36.5	35.3
20% RCA Dip with 30% Na_2SiO_3			
1	340	34.0	
2	320	32.0	33.0
30% RCA Dip with 30% Na_2SiO_3			
1	320	32.0	
2	320	32.0	32.0
Surface Based Treatment			
10% RCA			
1	415	41.5	
2	395	39.5	40.5
20% RCA			
1	430	43.0	
2	400	40.0	41.5
30% RCA			
1	410		
2	405	40.5	40.8

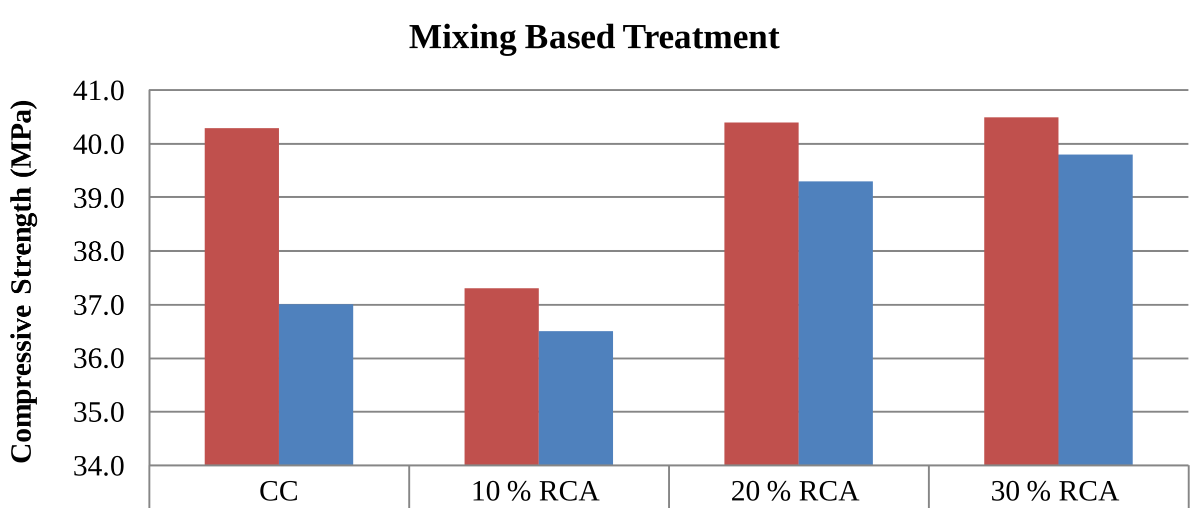
COMPRESSIVE STRENGTH OF (28 Days) CONCRETE WITH MAGNESIUM SULPHATE ATTACK (3%, $MgSO_4$)

Cube (mm) 100×100×100	Load (KN)	Compressive Strength (N/mm^2)	Av. Compressive Strength (N/mm^2)
Natural Aggregate			
1	360	36.0	
2	380	38.0	37.0
10 % RCA			
1	425	42.5	
2	365	36.5	39.5
20 % RCA			
1	365	36.5	
2	340	34.0	35.3
30 % RCA			
1	370	37.0	
2	325	32.5	34.8
Mixing Based Treatment			
10% RCA with 0.1%Na_2SiO_3			
1	385	38.5	
2	345	34.5	36.5
20% RCA with 0.2%Na_2SiO_3			
1	425	42.5	
2	360	36.0	39.3
30% RCA with 0.3%Na_2SiO_3			
1	405	40.5	
2	390	39.0	39.8
Aggregate Based Treatment			
10% RCA Dip with 30%Na_2SiO_3			
1	285	28.5	
2	295	29.5	29.0
20% RCA Dip with 30%Na_2SiO_3			
1	370	37.0	
2	340	34.0	35.5
30% RCA Dip with 30%Na_2SiO_3			
1	330	33.0	
2	280	28.0	30.5
Surface Based Treatment			
10% RCA			
1	400	40.0	
2	380	38.0	39.0
20% RCA			
1	420	42.0	
2	380	38.0	40.0
30% RCA			
1	395	39.5	
2	400	40.0	39.8

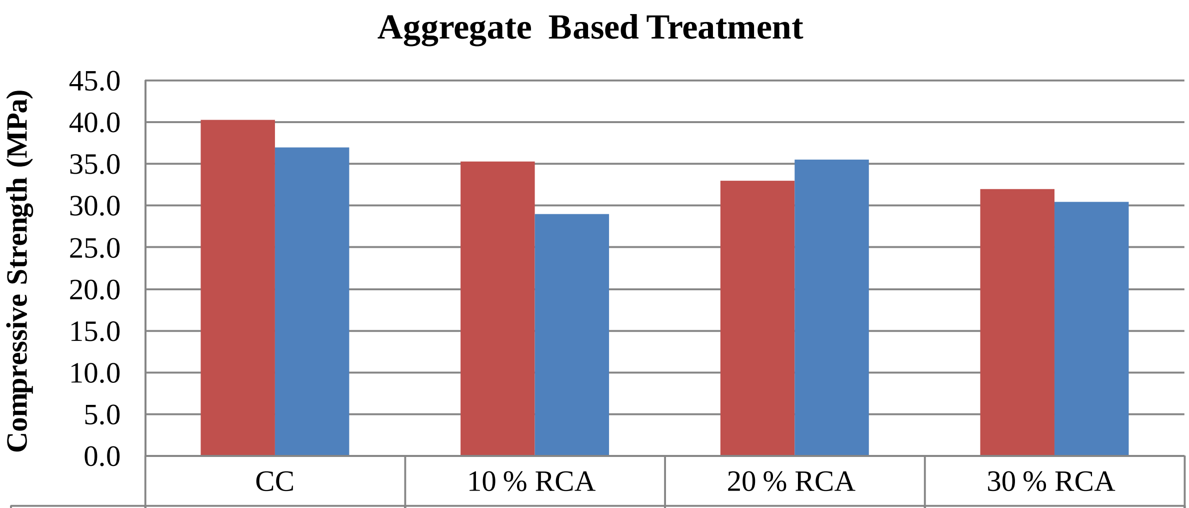
Compressive Strength of Concrete (7 and 28 Days) with Magnesium Sulphate (3%, $MgSO_4$) Attack



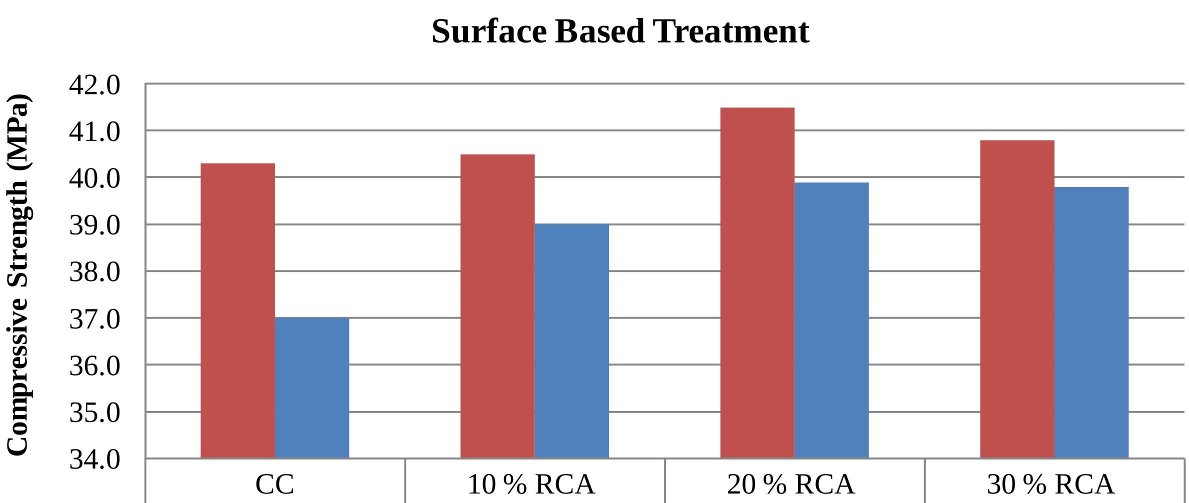
	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	40.3	39.7	38.0	35.0
28 Days	37.0	39.5	35.3	34.8



	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	40.3	37.3	40.4	40.5
28 Days	37.0	36.5	39.3	39.8

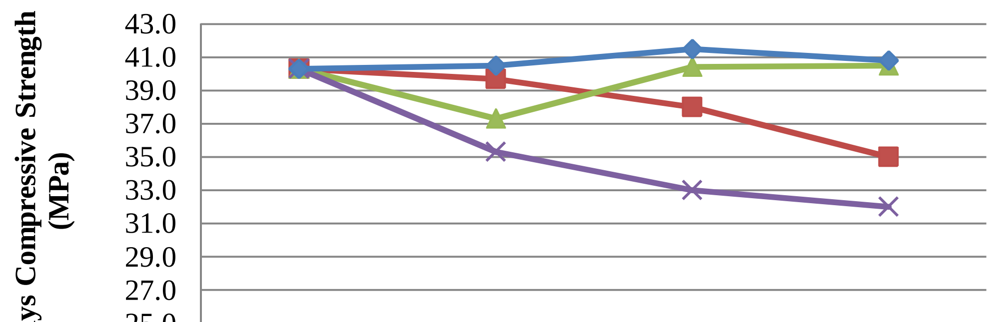


	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	40.3	35.3	33.0	32.0
28 Days	37.0	29.0	35.5	30.5



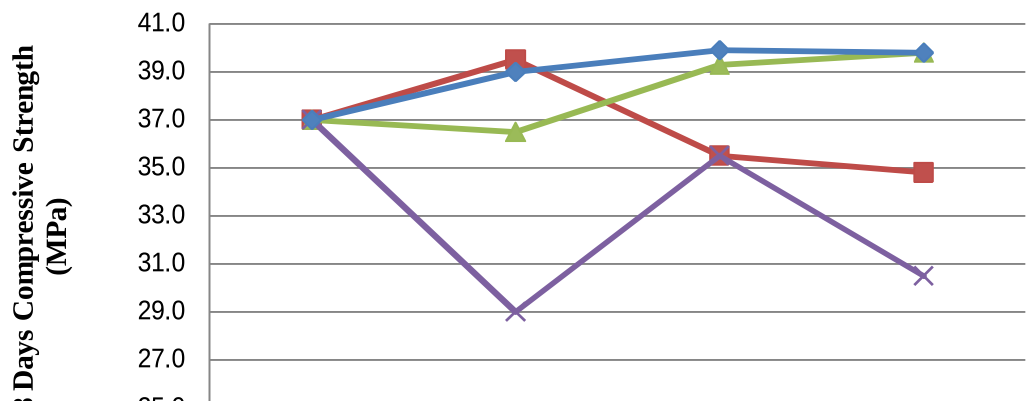
	CC	10 % RCA	20 % RCA	30 % RCA
7 Days	40.3	40.5	41.5	40.8
28 Days	37.0	39.0	39.9	39.8

Compressive Strength of Concrete (7 Days) with Magnesium Sulphate (3%, $MgSO_4$) Attack incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	40.3	39.7	38.0	35.0
Mixing Based Treatment	40.3	37.3	40.4	40.5
Aggregate Based Treatment	40.3	35.3	33.0	32.0
Surface Based Treatment	40.3	40.5	41.5	40.8

Compressive Strength of Concrete (28 Days) with Magnesium Sulphate (3%, $MgSO_4$) Attack incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment)



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	37.0	39.5	35.5	34.8
Mixing Based Treatment	37.0	36.5	39.3	39.8
Aggregate Based Treatment	37.0	29.0	35.5	30.5
Surface Based Treatment	37.0	39.0	39.9	39.8

7 DAYS WATER ABSORPTION WITH 3%, $MgSO_4$ ATTACK

Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av. Water Content in %
Natural Aggregate				
1	2.554	2.570	0.626	
2	2.658	2.675	0.640	0.633
10 % RCA				
1	2.395	2.415	0.835	
2	2.648	2.669	0.793	0.814
20 % RCA				
1	2.493	2.518	1.003	
2	2.624	2.648	0.915	0.959
30 % RCA				
1	2.514	2.552	1.512	
2	2.348	2.362	0.596	1.054
Mixing Based Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	2.518	2.545	1.072	
2	2.627	2.646	0.723	0.898
20% RCA with 0.2%Na_2SiO_3				
1	2.442	2.458	0.655	
2	2.489	2.512	0.924	0.790
30% RCA with 0.3%Na_2SiO_3				
1	2.555	2.570	0.587	
2	2.367	2.385	0.760	0.674
Aggregate Based Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2.420	2.442	0.909	
2	2.361	2.380	0.805	0.857
20% RCA Dip with 30%Na_2SiO_3				
1	2.458	2.483	1.017	
2	2.715	2.739	0.884	0.951
30% RCA Dip with 30%Na_2SiO_3				
1	2.349	2.380	1.320	
2	2.411	2.436	1.037	1.178
Surface Based Treatment				
10 % RCA				
1	2.456	2.465	0.366	
2	2.515	2.528	0.517	0.442
20 % RCA				
1	2.424	2.441	0.701	
2	2.561	2.579	0.703	0.702
30 % RCA				
1	2.544	2.561	0.668	
2	2.481	2.497	0.645	0.657

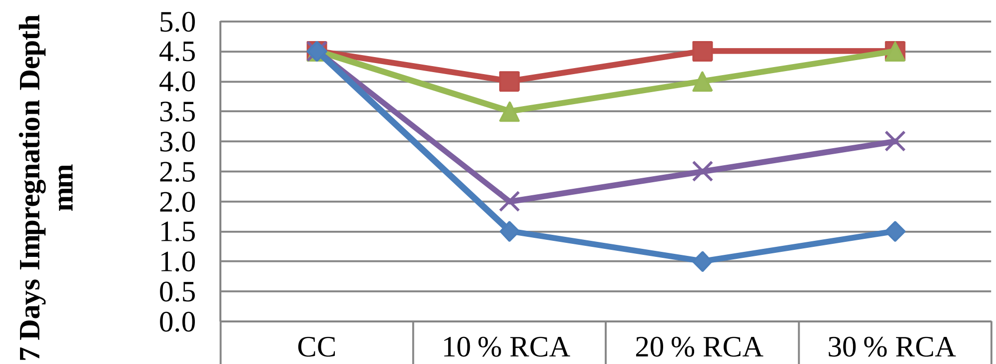
28 DAYS WATER ABSORPTION WITH 3%, $MgSO_4$ ATTACK

Cube (mm) 100×100×100	Initial Weight (kg)	Final Weight (kg)	% Changes	Av. Water Content in %
Natural Aggregate				
1	2.506	2.526	0.798	
2	2.604	2.609	0.192	0.495
10 % RCA				
1	2.506	2.526	0.798	
2	2.604	2.622	0.691	0.745
20 % RCA				
1	2.468	2.488	0.810	0.843
2	2.512	2.534	0.876	
30 % RCA				
1	2.345	2.368	0.981	
2	2.365	2.385	0.846	0.913
Mixing Based Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	2.513	2.534	0.836	
2	2.654	2.672	0.678	0.757
20% RCA with 0.2%Na_2SiO_3				
1	2.461	2.479	0.731	
2	2.497	2.512	0.601	0.666
30% RCA with 0.3%Na_2SiO_3				
1	2.531	2.546	0.593	
2	2.348	2.364	0.681	0.637
Aggregate Based Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2.437	2.459	0.903	
2	2.498	2.517	0.761	0.832
20% RCA Dip with 30%Na_2SiO_3				
1	2.501	2.526	1.000	
2	2.431	2.451	0.823	0.911
30% RCA Dip with 30%Na_2SiO_3				
1	2.396	2.412	0.668	
2	2.365	2.385	0.846	0.757
Surface Based Treatment				
10 % RCA				
1	2.428	2.440	0.494	
2	2.567	2.575	0.312	0.403
20 % RCA				
1	2.433	2.445	0.493	
2	2.445	2.455	0.409	0.451
30 % RCA				
1	2.435	2.450	0.616	
2	2.438	2.448	0.410	0.513

Impregnation Depth of Concrete with Sodium Chloride (30%, NaCl) Attack

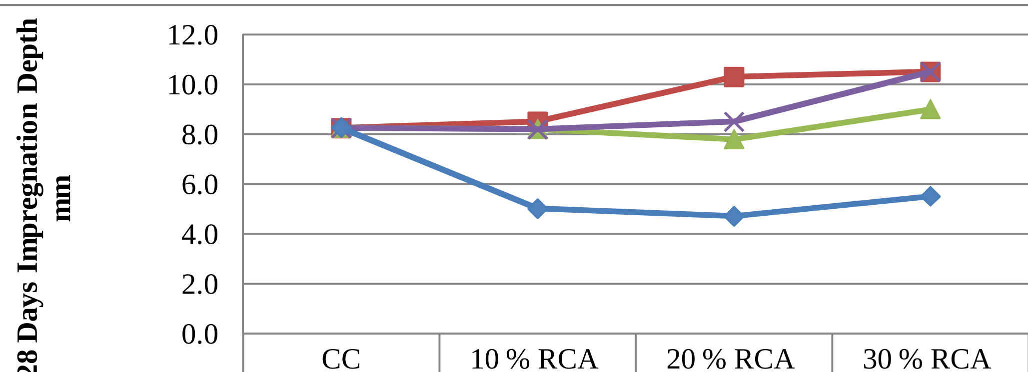
Cube (mm) 100×100×100	7 Days Depth (mm)	7 Days Depth Av.(mm)	28 Days Depth (mm)	28 Days Depth Av.(mm)
Natural Aggregate				
1	5		8.5	
2	4	4.5	8	8.25
10 % RCA				
1	5		8.5	
2	3	4	8.5	8.5
20 % RCA				
1	5		9.5	
2	4	4.5	11	10.25
30 % RCA				
1	5		11	
2	4	4.5	10	10.5
Mixing Based Treatment				
10% RCA with 0.1%Na_2SiO_3				
1	4		8	
2	3	3.5	8.5	8.25
20% RCA with 0.2%Na_2SiO_3				
1	5		8.5	
2	3	4	7	7.75
30% RCA with 0.3%Na_2SiO_3				
1	6		8	
2	3	4.5	10	9
Aggregate Based Treatment				
10% RCA Dip with 30%Na_2SiO_3				
1	2		7.5	
2	2	2	9	8.25
20% RCA Dip with 30%Na_2SiO_3				
1	2		8	
2	3	2.5	9	8.5
30% RCA Dip with 30%Na_2SiO_3				
1	3	3	12	
2	3		9	10.5
Surface Based Treatment				
10 % RCA				
1	2		6	
2	1	1.5	4	5
20 % RCA				
1	1		5	
2	1	1	4.5	4.75
30 % RCA				
1	2		6	
2	1	1.5	5	5.5

Impregnation Depth of Concrete (7 Days) with Sodium Chloride (30%, NaCl) Attack incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment



	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	4.5	4.0	4.5	4.5
Mixing Based Treatment	4.5	3.5	4.0	4.5
Aggregate Based Treatment	4.5	2.0	2.5	3.0
Surface Based Treatment	4.5	1.5	1.0	1.5

Impregnation Depth of concrete (28 Days) with Sodium Chloride (30%, NaCl) Attack incorporating recycled aggregate (Natural Aggregate, Recycled Concrete, Aggregate based treatment, Mixing based treatment and Surface based treatment



	CC	10 % RCA	20 % RCA	30 % RCA
Conctrol Conncrete	8.3	8.5	10.3	10.5
Mixing Based Treatment	8.3	8.2	7.8	9.0
Aggregate Based Treatment	8.3	8.2	8.5	10.5
Surface Based Treatment	8.3	5.0	4.7	5.5

Water Absorption of Din Permeability Testing

Cube (mm) 100×100×100	Initial Weight (Kg)	Final Weight (Kg)	% Changes	Av. Water Absorption %	Impregnation Depth (mm)	Av Impregnation Depth (mm)
Natural Aggregate						
1	8.277	8.316	0.471		45	
2	7.783	7.818	0.450	0.501	42	45
3	7.912	7.958	0.581		48	
10 % RCA						
1	8.395	8.465	0.834		59	
2	8.694	8.751	0.656	0.759	51	55
3	8.367	8.433	0.789		55	
20 % RCA						
1	7.854	7.954	1.273		72	
2	8.084	8.165	1.002	1.156	58	63.33
3	7.871	7.965	1.194		60	
30 % RCA						
1	8.100	8.352	3.111		83	
2	7.064	7.156	1.302	1.861	79	77.66
3	8.215	8.311	1.169		71	
Mixing Based Treatment						
10% RCA with 0.1%Na_2SiO_3						
1	8.260	8.300	0.484		42	
2	8.260	8.295	0.424	0.436	35	37.66
3	8.512	8.546	0.399		36	
20% RCA with 0.2%Na_2SiO_3						
1	8.270	8.300	0.363		24	
2	8.109	8.146	0.456	0.394	36	30
3	8.240	8.270	0.364		30	
30% RCA with 0.3%Na_2SiO_3						
1	8.150	8.183	0.405		36	
2	8.612	8.672	0.697	0.626	38	38.66
3	7.864	7.925	0.776		42	
Aggregate Based Treatment						
10% RCA Dip with 30%Na_2SiO_3						
1	8.294	8.356	0.748		59	
2	8.078	8.132	0.668	0.748	47	57.33
3	8.326	8.395	0.829		66	
20% RCA Dip with 30%Na_2SiO_3						
1	8.252	8.356	1.260		62	

2	8.05	8.125	0.932	1.136	48	58
3	8.132	8.231	1.217		64	
30% RCA Dip with 30%Na_2SiO_3						
1	8.191	8.326	1.648		81	
2	7.886	8.112	2.866	2.012	91	80.66
3	7.892	8.012	1.521		70	
Surface Based Treatment						
10 % RCA						
1	8.240	8.267	0.328		21	
2	8.290	8.328	0.458	0.408	27	25
3	8.651	8.689	0.439		27	
20 % RCA						
1	8.426	8.45	0.285		20	
2	8.166	8.19	0.294	0.328	28	26
3	8.139	8.172	0.405		30	
30 % RCA						
1	8.245	8.278	0.400		26	
2	8.193	8.245	0.635	0.494	39	33
3	8.274	8.311	0.447		34	

ULTRASONIC PULSE VELOCITY TEST

Cube (mm) (150×150×150)	Pulse Velocity (Km/Sec)	Av. Pulse Velocity (Km/Sec)
Natural Aggregate		
1	4.26	
2	4.95	4.60
3	4.59	
10 % RCA		
1	4.55	
2	4.32	4.43
3	4.42	
20 % RCA		
1	4.73	
2	4.75	4.68
3	4.56	
30 % RCA		
1	4.61	
2	4.66	4.37
3	3.84	
Mixing Based Treatment		
10% RCA with 0.1%Na_2SiO_3		
1	4.36	
2	4.82	4.55
3	4.47	

Cube (mm) (150×150×150)	Pulse Velocity (Km/Sec)	Av. Pulse Velocity (Km/Sec)
20% RCA with 0.2%Na_2SiO_3		
1	4.87	
2	4.68	4.82
3	4.91	
30% RCA with 0.3%Na_2SiO_3		
1	4.57	
2	4.65	4.57
3	4.49	
Aggregate Based Treatment		
10% RCA Dip with 30%Na_2SiO_3		
1	4.85	
2	4.62	4.84
3	5.05	
20% RCA Dip with 30%Na_2SiO_3		
1	4.67	
2	4.61	4.62
3	4.58	
30% RCA Dip with 30%Na_2SiO_3		
1	3.69	
2	4.16	3.87
3	3.76	
Surface Based Treatment		
10 % RCA		
1	4.43	
2	4.47	4.42
3	4.36	
20 % RCA		
1	4.35	
2	4.68	4.56
3	4.65	
30 % RCA		
1	4.61	
2	4.97	4.77
3	4.73	

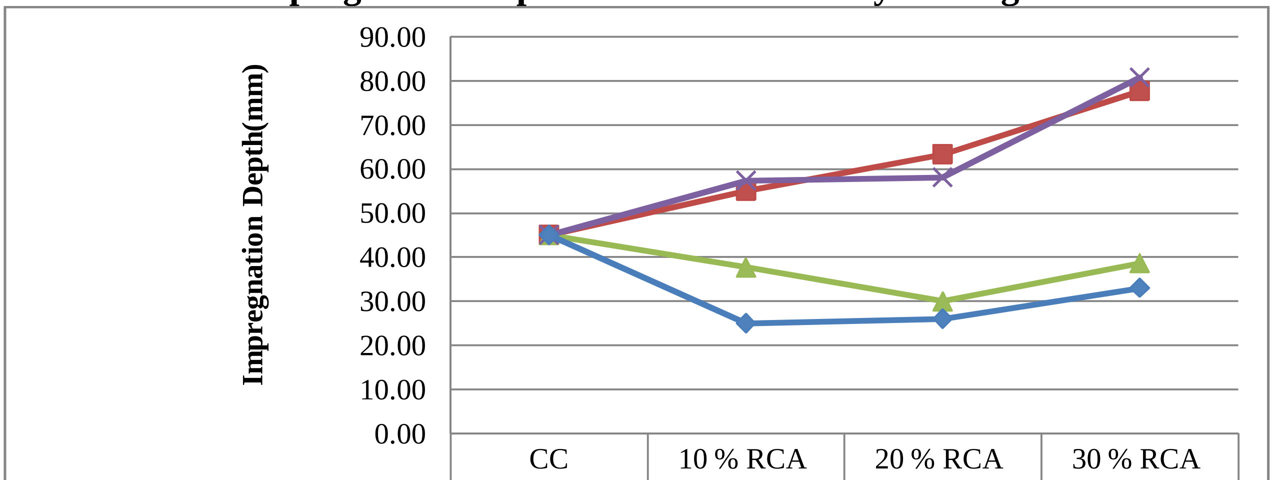
SORPTIVITY

Sample	Initial Wt	Av Initial Wt	10min	Av. 10min	20min	Av. 20min	30min	Av. 30min	60min	Av. 60min
RN(1)	2440	2476.5	2442	2478.5	2443	2479	2444	2479.5	2446	2481.5
RN(2)	2513		2515		2515		2515		2517	

R10(1)	2507	2516.5	2509	2518	2510	2519	2511	2518.5	2517	2523.5
R10(2)	2526		2527		2528		2526		2530	
R20(1)	2442	2489	2447	2493	2448	2494	2450	2495.5	2452	2497.5
R20(2)	2536		2539		2540		2541		2543	
R30(1)	2508	2482	2511	2486.5	2513	2488.5	2514	2489.5	2517	2491.5
R30(2)	2456		2462		2464		2465		2466	
RM10(1)	2444	2444.5	2449	2448	2450	2449	2452	2450.5	2453	2452
RM10(2)	2445		2447		2448		2449		2451	
RM20(1)	2483	2516	2487	2519.5	2489	2521.5	2490	2522.5	2492	2523.5
RM20(2)	2549		2552		2554		2555		2555	
RM30(1)	2488	2451	2492	2455.5	2494	2457	2496	2459.5	2498	2461
RM30(2)	2414		2419		2420		2423		2424	
RD10(1)	2409	2423	2413	2426	2414	2428	2415	2429.5	2417	2431.5
RD10(2)	2437		2439		2442		2444		2446	
RD20(1)	2405	2391.5	2407	2395.5	2410	2398	2412	2400	2414	2402
RD20(2)	2378		2384		2386		2388		2390	
RD30(1)	2300	2325	2309	2333.5	2312	2336	2314	2338.5	2319	2342.5
RD30(2)	2350		2358		2360		2363		2366	
RS10(1)	2508	2413.5	2509	2414.5	2510	2415.5	2510	2415.5	2511	2416
RS10(2)	2319		2320		2321		2321		2321	
RS20(1)	2343	2372	2344	2373	2345	2374	2345	2374.5	2346	2374.5
RS20(2)	2401		2402		2403		2404		2403	
RS30(1)	2475	2445.5	2476	2446.5	2479	2448	2479	2448.5	2479	2448.5
RS30(2)	2416		2417		2417		2418		2418	

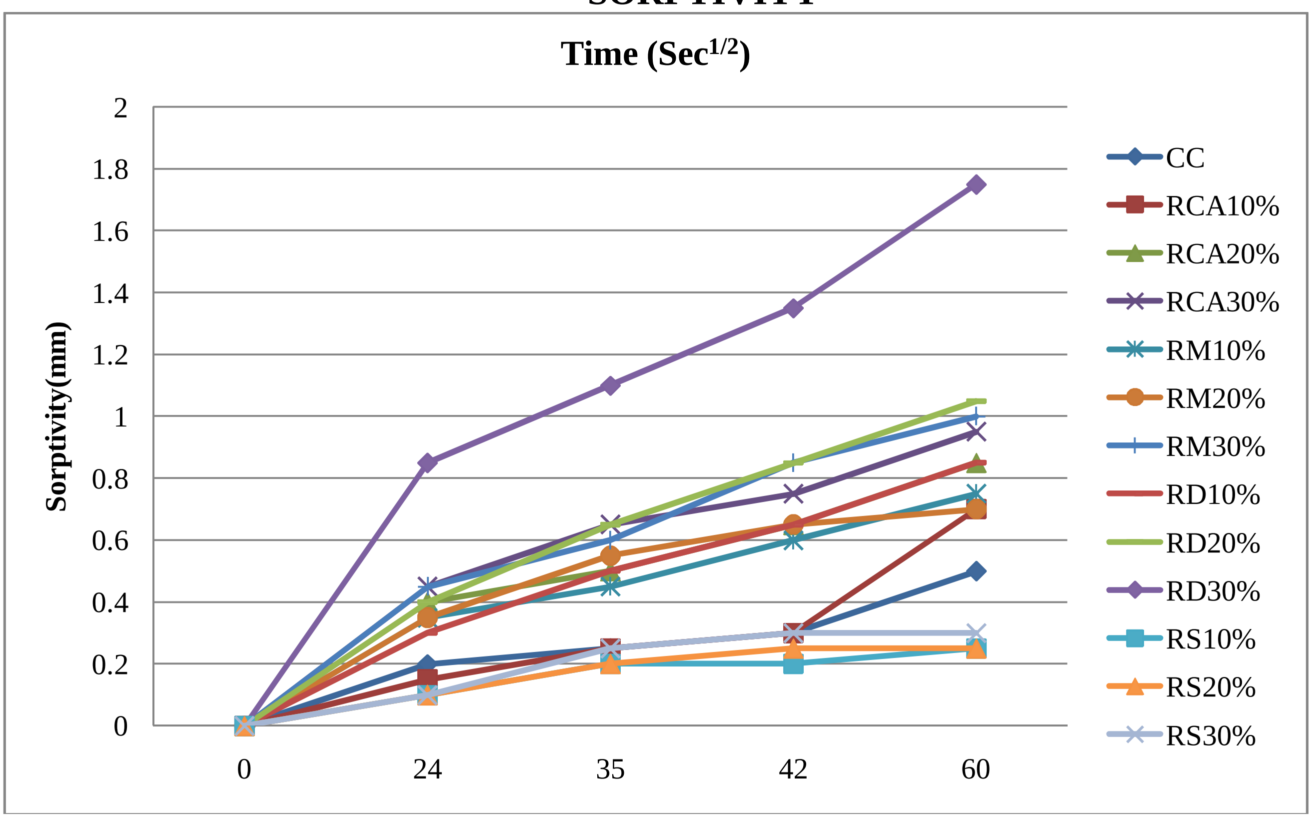
T	CC	RC 10%	RC 20%	RC 30%	RM 10%	RM 20%	RM 30%	RD 10%	RD 20%	RD 30%	RS 10%	RS 20%	RS 30%
0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0.20	0.15	0.40	0.45	0.35	0.35	0.45	0.30	0.40	0.85	0.10	0.10	0.10
35	0.25	0.25	0.50	0.65	0.45	0.55	0.60	0.50	0.65	1.10	0.20	0.20	0.25
42	0.30	0.30	0.65	0.75	0.60	0.65	0.85	0.65	0.85	1.35	0.20	0.25	0.30
60	0.50	0.70	0.85	0.95	0.75	0.70	1.00	0.85	1.05	1.75	0.25	0.25	0.30

Impregnation Depth of Din Permeability Testing



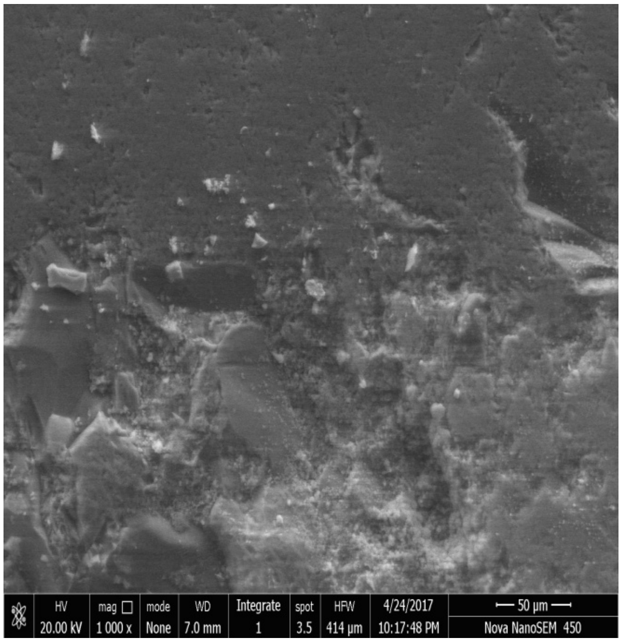
	CC	10 % RCA	20 % RCA	30 % RCA
Control Concrete	45.00	55.00	63.33	77.66
Mixing Based Treatment	45.00	37.66	30.00	38.66
Aggregate Based Treatment	45.00	57.33	58.00	80.66
Surface Based Treatment	45.00	25.00	26.00	33.00

SORPTIVITY

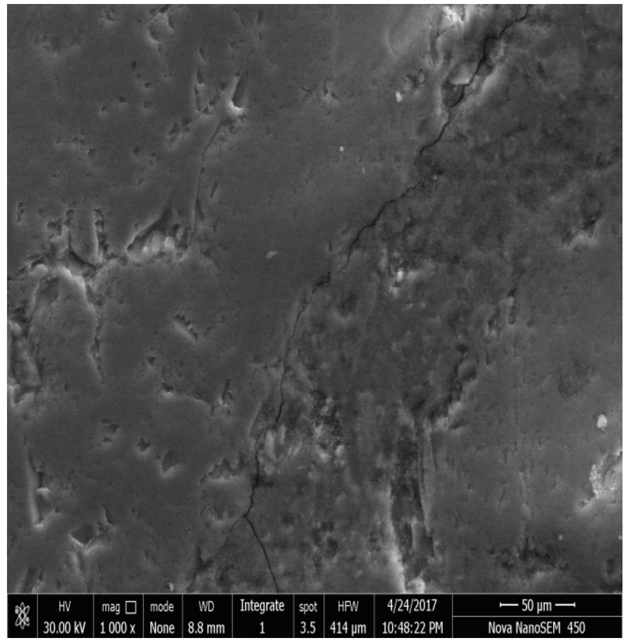


Chapter: 6

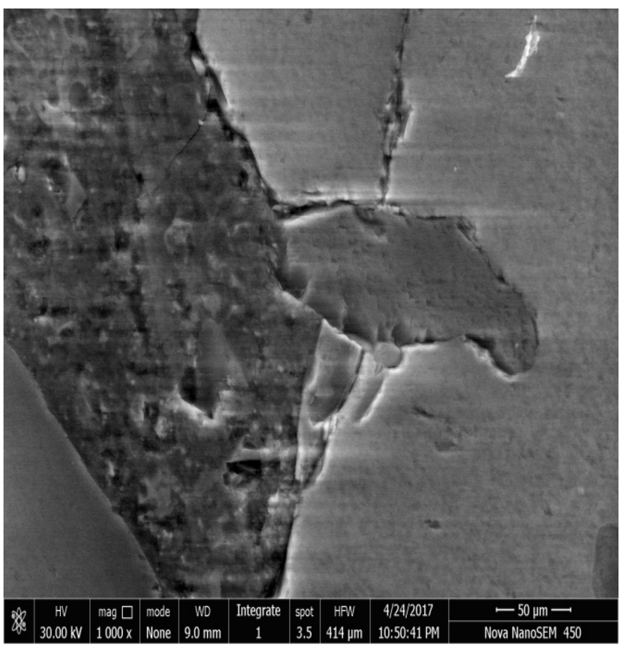
Microstructure Study: (SEM and Optical Microscopic Images)



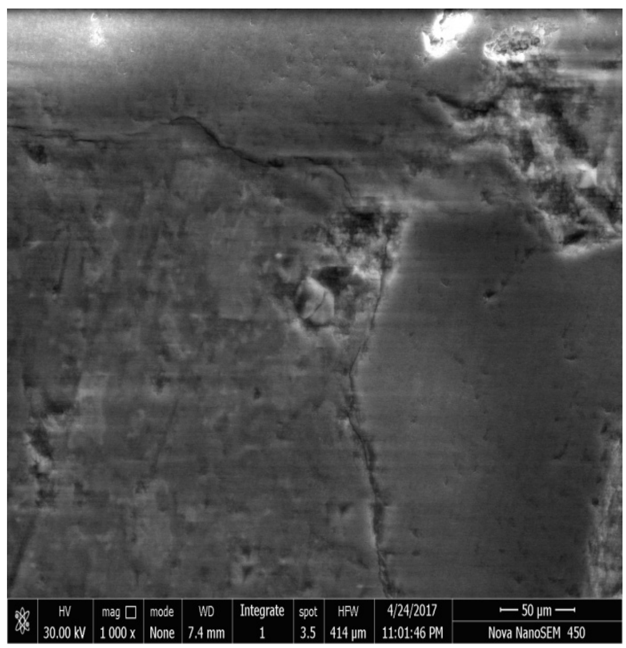
Control Concrete



RCA 10%

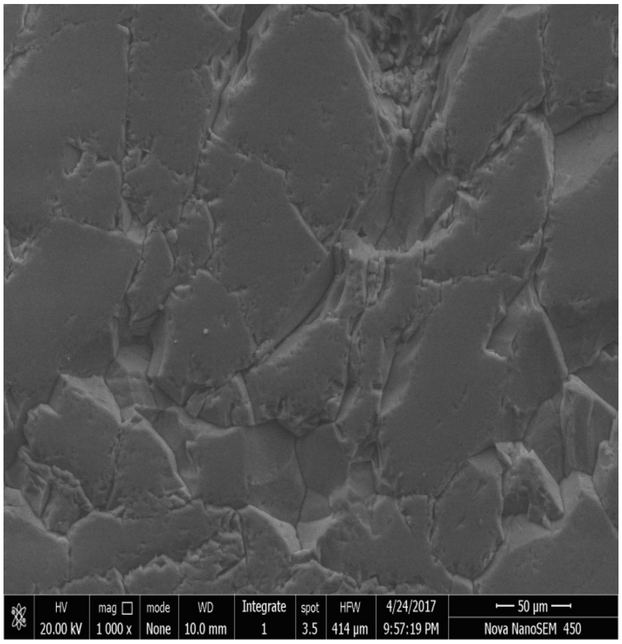


RCA 20%

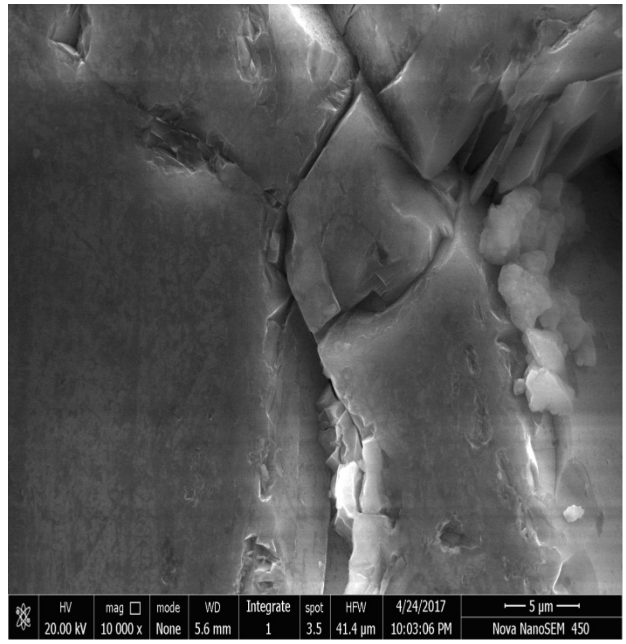


RCA 30%

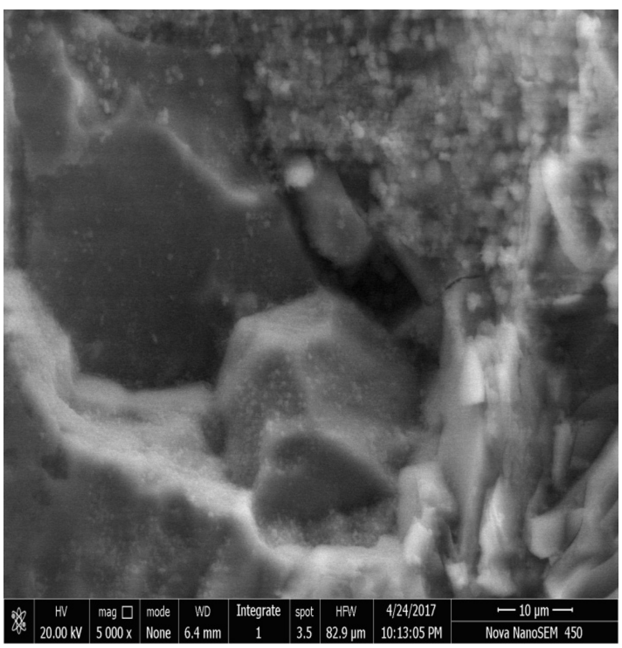
Figure: 6.1 SEM IMAGES



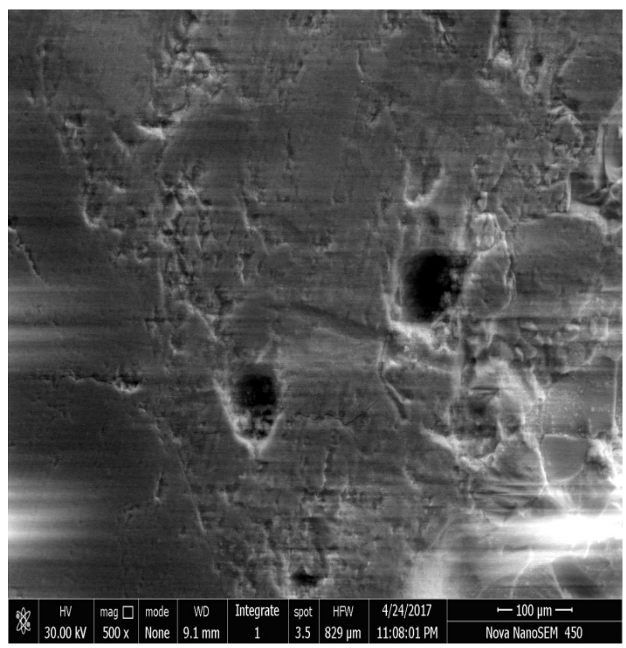
Mixing Based Treatment RCA 10%



Mixing Based Treatment RCA 20%

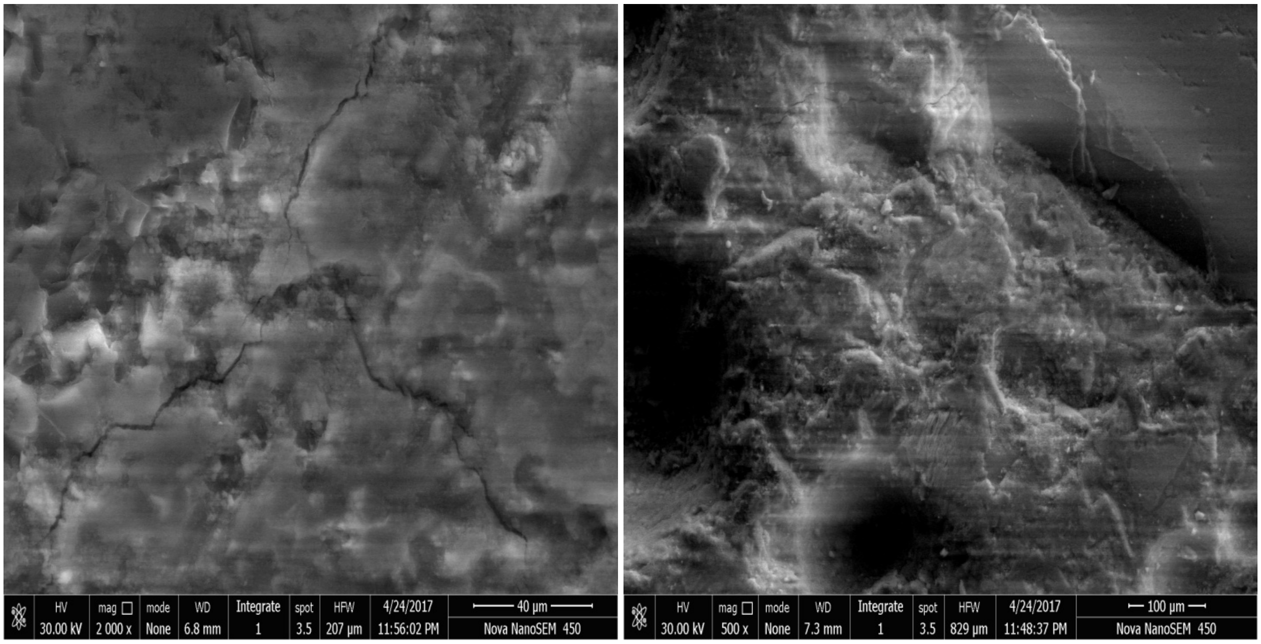


Mixing Based Treatment RCA 30%

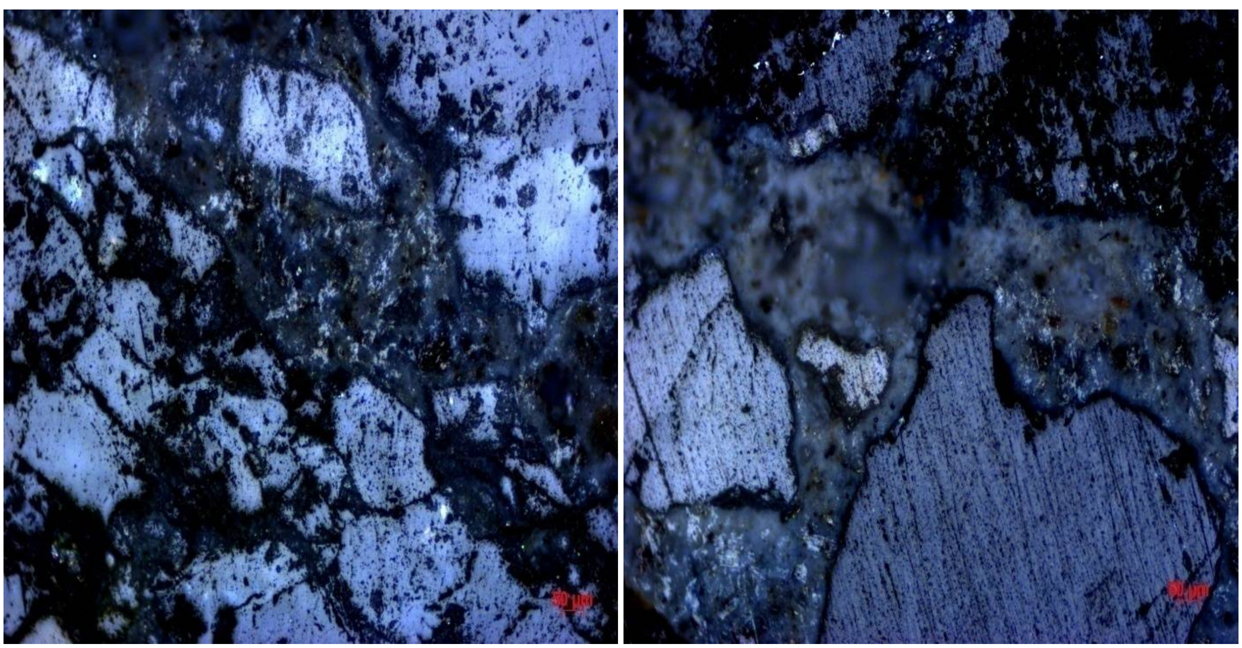


Aggregate Based Treatment RCA 10%

Figure: 6.2 SEM IMAGES

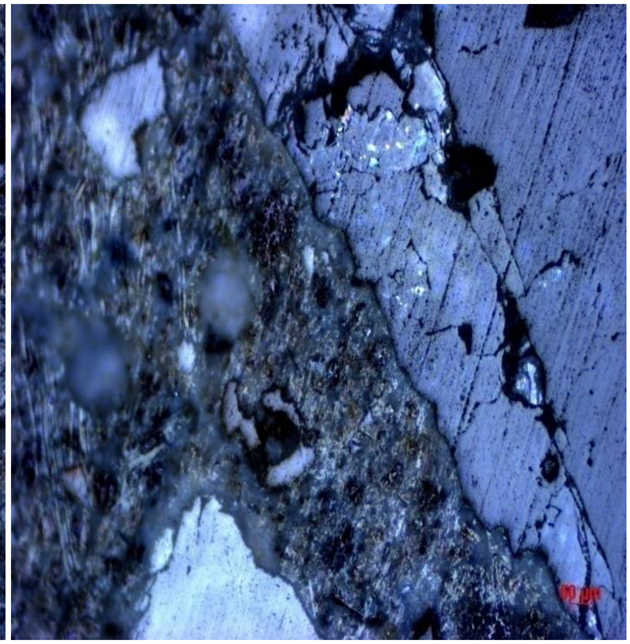


Aggregate Based Treatment RCA20%. Aggregate Based Treatment RCA 30%

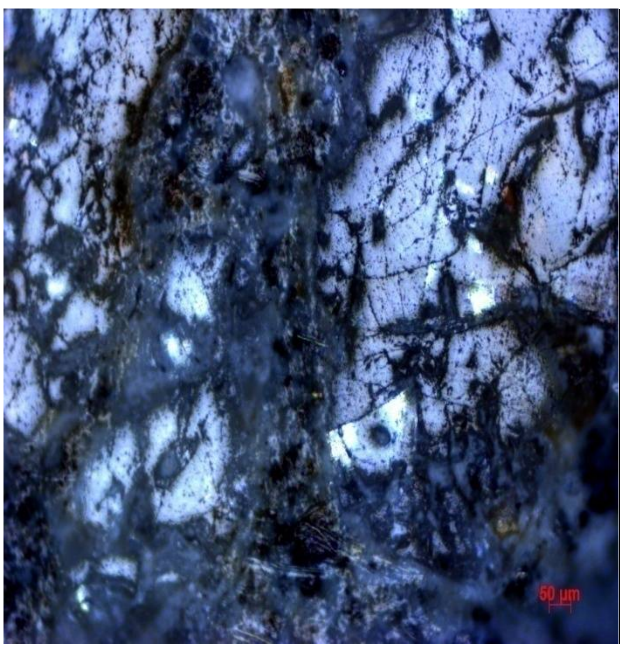


Control Concrete **RCA 10%**

Figure: 6.3 SEM AND OPTICAL MICROSCOPIC IMAGES

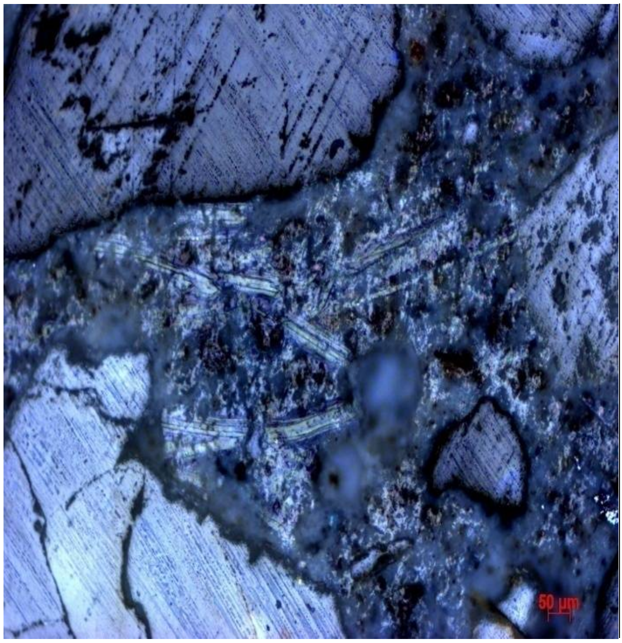


RCA 20% **RCA 30%**

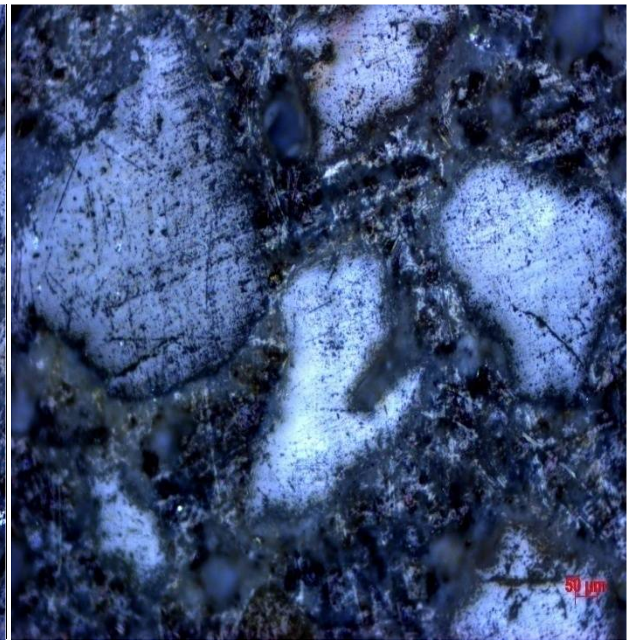


Mixing Based Treatment RCA 10% **Mixing Based Treatment RCA 20%**

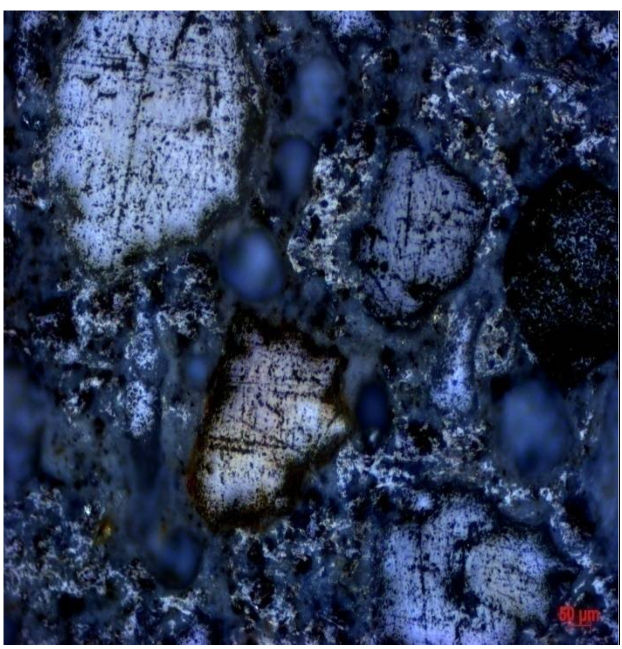
Figure: 6.4 OPTICAL MICROSCOPIC IMAGES



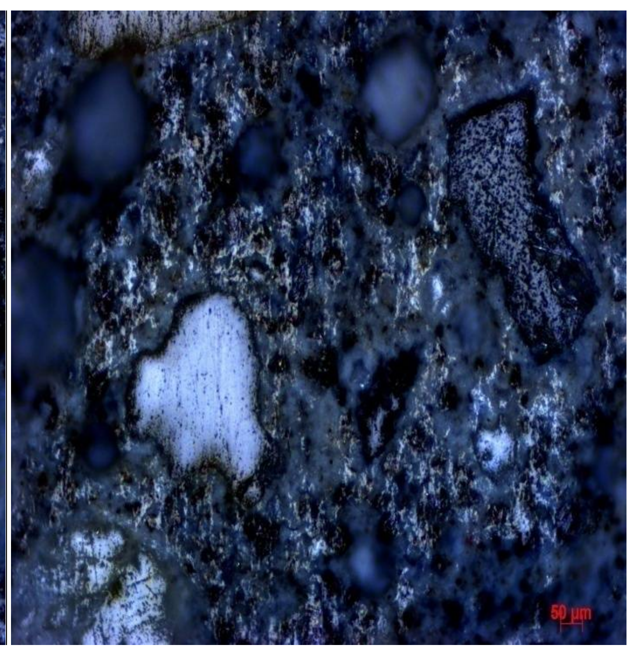
Mixing Based Treatment RCA 30%



Aggregate Based Treatment RCA 10%



Aggregate Based Treatment RCA20%.



Aggregate Based Treatment RCA 30%

Figure: 6.5 OPTICAL MICROSCOPIC IMAGES

Chapter: 7

Discussions

7.1 Recycled Aggregate Concrete: RCA 30%

- Compressive Strength 7 days: Reduced by 28.21% to control concrete.
- Compressive Strength 28 days: Reduced by 10.23% to control concrete.
- Increasing the recycled aggregates content reduced the compressive strength at 7 and 28 days.
- Flexural Strength: Reduced by 3.63% to Control Concrete.
- The trends in the flexural strength are same for both recycled aggregates and mixing based treated concrete.
- Water Absorption: Increased by 117.03% to control concrete.
- 3% Sulphuric Acid Solution Attack 28days: Reduced Compressive Strength by 14.16% to control concrete.
- 3% Magnesium Sulphate Solution Attack 28days: Reduced Compressive Strength by 5.95% to control concrete.
- 30% Sodium Chloride Attack 28 days: Increased Impregnation Depth by 21.9% to control concrete.
- Din Permeability: Increased Impregnation Depth by 72.22% to control concrete.
- Sorptivity: Higher to control concrete.

7.2 Mixing Based Treatment: Treated RCA20%

General Observations: Easy to mixing and processing. It is economical and concrete loss in workability during mixing process.

- Compressive Strength 7 days: Increased by 7.54% to control concrete.

- Treated RCA20 % shown maximum compressive strength result to all concrete fractions at 7 Days.
- Compressive Strength 28 days: Reduced by 9.77% to control concrete.
- Flexural Strength of Treated RCA 10% Reduced by 1.53% to control concrete.
- Flexural strength of Treated RCA 20% shown lowest result to all fractions.
- Water Absorption: Increased by 11.44% to control concrete.
- 3% Sulphuric Acid Solution attack 28days: Increased Compressive Strength by 14.16% to control concrete.
- 3% Magnesium Sulphate Solution attack 28days: Increased Compressive Strength by 6.22% to control concrete.
- 30% Sodium Chloride attack 28 days: Reduced Impregnation Depth by 4.88% to control concrete.
- Din Permeability: Reduced Impregnation Depth by 33.33% to control concrete.
- Sorptivity: Increased to control concrete.

7.3 Aggregate Based Treatment: Treated RCA 10%

General observations: The advantage of this treatment is improvement in workability during mixing, Flexural strength increased and Difficult in working; time consuming work and required high quality control are disadvantages.

- Compressive Strength 7 days: Increased by 6.42% to control concrete.
- Compressive Strength 28 days: Reduced by 7.44% to control concrete.
- Treated RCA 30% shown lowest compressive result to all fractions.
- Flexural Strength: Increased by 32.12% to control concrete.
- Treated RCA 10% shown peak flexural strength.
- Water Absorption: Increased by 273.23% to control concrete.

- 3% Sulphuric Acid Solution attack 28days: Reduced Compressive Strength by 17.85% to control concrete.
- 3% Magnesium Sulphate Solution attack 28days: Reduced Compressive Strength by 21.62% to control concrete.
- 30% Sodium Chloride attack 28 days: Reduced Impregnation Depth by 21.9% to RCA 30.
- Din Permeability: Increased Impregnation Depth by 22.89% to control concrete.
- Sorptivity: Increased to control concrete.

7.4 Surface Based Treatment: Treated RCA 20%.

General observations: Easy working but Costly.

- Water Absorption: Reduced by 11.44% to control concrete.
- 3% Sulphuric Acid Solution attack 28days: Increased Compressive Strength by 9.07% to control concrete.
- 3% Magnesium Sulphate Solution attack 28days: Increased Compressive Strength by 7.84% to control concrete.
- 30% Sodium Chloride attack 28 days: Reduced Impregnation Depth by 42.68% to control concrete.
- Din Permeability: Reduced Impregnation Depth by 42.22% to control concrete.
- Din Permeability: Treated RCA 10% shown lowest impregnation depth to all fractions and same series.
- Din Permeability: The untreated RCA series and treated RCA series shown same trends.

7.5 Microstructures Study

Control Concrete: The control concrete looked very dance, no porous and voids were presented in SEM images and optical images. No gapes were founded between the interfaces zone to natural aggregates, the bonding of natural aggregates and CSH gel was stronger.

Recycled Aggregate Concrete: Due to used the recycled aggregates the porosity was increased, micro cracks in aggregates and in cement paste were developed and large sizes voids were shown in images. As increments of recycled aggregates fractions the porosity and micro cracks were increased. Bonding with recycled aggregates to cement paste seems looked weaker. Treated RCA 10% shown better result comparative to treated 20% and 30%. Treated RCA 30% images shown large voids and more voids. Joints also looked weaker in same series.

Mixing Based Treatment: By using the sodium silicate as hydrophobic agents the voids of recycled aggregate concrete were filled by such agents, the voids size was reduced**,** micro cracks also filled by same agents. The effectiveness of hydrophobic agents was reduced by increments of recycled aggregates in concrete. Treated upto RCA 20% concrete shown almost same results, Treated RCA30% shown more micro cracks in recycled aggregates and in cement paste.

Aggregates Based Treatment: The SEM and optical Images of bonding between natural aggregates, recycled aggregates and cement paste looked very porous, large gaped and weaker. Many cracks and large sizes voids were founded. The denseness was reduced with increments of recycled fractions. The thin film of hydrophobic agents was developed around the aggregates so that bonding was weaker and voids not filled by cement paste, water and cement not reached to the aggregates so that large voids were produced. Treated RCA 10% shown better result comparative to the same series. Treated RCA 30% shown poorest result.

7.6 Ultrasonic Pulse Velocity Test: The pulse velocity transmission depends on the quality of concrete such as density, presence of micro cracks, pores etc. The decrease in velocity which was subjected to increasing recycled aggregates quantity in control concrete. The Mixing based treated concrete, surface based treated concrete and control concrete shows almost same UPV results. The aggregates based treatment (Treated RCA30%) shows the laser UPV results compared to all concrete fractions. The quality range of all treated and untreated concrete were in good and excellent quality.

Chapter: 8

Conclusions

- The recycled aggregates contain significant amount of adhered mortar and have high water absorption.
- The aggregate based treatment causing deposition of thin film resulted in deterioration of concrete properties. Polymeric solutions other than sodium silicate can be studied in future.
- The mixing based treatment provided a viable solution by overcoming the weaknesses in untreated recycled aggregate concrete.
- The surface based treatments have influential role in improving the durability properties. However, the high cost in executing the treatment can be a setback.
- The mixing based treatment observed that easy in working and no high quality control required so that such treatment is ready to use for constructions.
- The aggregates based treatment needs high quality control and very lengthy process. Any mistake may give adverse effects of concretes.
- Surface Based treatment can be uses on concrete structure where micro cracks were produced, manufactured defects like voids in concrete. It’s make an even surface on honey combined surface of concrete.

Chapter: 9

Recommendations

- The observations obtained from the study indicate that mixing based treatment provide an economical and site friendly process for recycled concrete.
- The mechanical and durability properties of mixing based recycled aggregate concrete are nearly equal to that of control concrete.
- The optimization of hydrophobic agent dose can be studies in future.
- The cost analysis can be studies in future scopes.
- Surface based treatments on old concrete surfaces can be studies in future scopes.

Chapter: 10

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