EFFECT OF MIXING METHODS OF NANO SILICA ON THE PROPERTIES OF RECYCLED AGGREGATE CONCRETE

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

In

Structural Engineering

Submitted By

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DECLARATION

I, **Sanjeev Kaur**, hereby declare that the work presented in this thesis entitled **"Effect of Mixing Methods of Nano Silica on the Properties of Recycled Aggregate Concrete"** in fulfillment of the requirement for the award of the degree of **Master of Engineering** in **Structural Engineering** submitted at **Civil Engineering Department, Thapar Institute of Engineering & Technology, Patiala,** is an authentic record of work carried out by me under the supervision of **Dr. Shakeel Ahmad Waseem, Assistant Professor, Civil Engineering Department, Islamic University of Science & Technology, Jammu and Kashmir and Dr. A.B. Danie Roy, Assistant Professor, Civil Engineering Department, Thapar Institute of Engineering & Technology, Patiala.**

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CERTIFICATE

This is to certify that the thesis entitled **"Effect of Mixing Methods of Nano silica on the Properties of Recycled Aggregate Concrete"** being submitted by **Sanjeev Kaur, Roll No: 801624025** in fulfillment of the requirement for the award of the degree of **Master of Engineering** in **Structural Engineering** is a bonafide work carried out by her under my guidance and that no part of this thesis has been submitted for award of any other degree.

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ABSTRACT

Concrete is generally a mixture of granular materials of diverse sizes and the size range of the created solid mix, covers varied intervals. The properties of the concrete in the fresh state (flow properties and workability) are governed by the particle size distribution (PSD), however, the properties of the concrete mix in the hardened state, such as strength and durability, are largely affected by the mix grading and the resultant particle packing. Another way to further enhance the packing of the particles is to increase the solid size range. Individually, the progress in nanoscience had caused a tremendous influence on the concrete industry. Over the past decade,nanomaterials have been used in the concrete industry. It has been shown by the research that incorporation of nanoparticles in cement environment could highly improve mechanical properties and durability of cement-based materials.

The research work on "effect of mixing methods of nano silica on the properties of recycled aggregates concrete (RAC)" aims at analyzing the effect of mixing methods on concrete with a view of their benefits for concrete production. The objective of research work was to determine the mixing method that gives more improvement in properties of RAC.

Concrete was design and tested as per IS code. As comparing of mixing methods of nano-silica in RAC, the presoaking of RAC in NS solution gives better performance than the direct mixing of NS in concrete. In this investigation, four series are considered. First and second series are controlled series that contains 100% Natural Course Aggregate (NCA) and 100% RAC, respectively. In the third series, 2% of NS used through direct mixing and in the fourth series, 2% of NS used through presoaked RAC in NS solution in concrete. Results show the better improvement in the mechanical and durability properties of presoaked RAC in NS as compared to the direct mixing of NS in concrete. The reduction in water absorption, sorptivity, RCPT and water permeability in presoaked RAC in NS as compared to the direct mixing. With presoaked RAC in NS fills the micro-cracks and pores and densified the microstructure, resulting in an improvement in properties.

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Chapter-1

Introduction

1.1 General

Use of recycled aggregates, as novel material in concrete production, solves many problems related to construction and demolition waste. Since the past decades, they are being utilized in many countries of the world. The concrete prepared with RACas partially or fully replacement of natural aggregates are known as recycled aggregate concrete. So, researchers are interested in the investigations of the properties of recycled aggregates. The results ofthe investigationsshowthat the properties of concrete containing recycled aggregates are badly affected by the poor quality of recycled aggregates because these are composed of natural aggregates and attached old mortar.The attached old mortar was responsible for the inferior properties of new concrete. Because recycled aggregates are more porous than the natural aggregates due to the attached old mortar.Some processing methods are used by many researchers for the removal of attached mortar from recycled aggregates before actually using them in concrete production. These methods are ultrasonic cleaning method to separate attached mortar, use of ball milling- method to remove old attached mortar from the original aggregates, use of heating and rubbing methods, use of microwave heating technology etc. Most methodsneeda greater amount of energy and some methods are difficult for working.

Tam et al.**(2007)** investigated a presoaking method for the removal of attached old mortar. The results show the improvement in compressive and flexural strength and modulus of concrete containing the treated recycled aggregates as compared to the untreated aggregates. **Kim et al**. **(2005)**used silica fume for coating the surface of recycled aggregates and results shows the significant improvement in the properties of concrete made from surface treated aggregates. In their investigation, firstly, recycled aggregates were oven dried and then they were immersed in a solutioncontaining silica fume and then these recycled aggregates were put in the oven for 24hours. **Yao et al. (2011)** adopted the similar presoaking approach used by Tam et al. In their study, recycled aggregates were immersed in sodium silicate, aluminum silicate and calcium bicarbonate solution for 24 hours. There was no significant improvement observed in the compressive strength of concrete prepared with these treated recycled aggregates.

Tam et al. (2007) and Li et al. (2005)used ordinary Portland cement and pozzolanic powders in simple techniques. The wet coating of Pozzolanic powders like Fly ash and silica fume were applied on the surface of recycled aggregates for the improvement of recycled aggregates but test results show that there is no significant improvement in the concrete made from coated recycled aggregates**. Ryouand Lee (2014)** used poly-carboxylate(PC) dispersant for improvement in recycled aggregates. On a rotary drum, the PC dispersant was sprayed on recycled aggregates for surface coating. The results showed 14-20% improvement in compressive strength of concrete prepared with surface coated recycled aggregates.

The recycled aggregate has weaker ITZ between the aggregates and cement paste. So, for the improvement in properties of recycled aggregates concrete, it is necessary to modify the microstructure. Theresults from many researchers showthe improvement in mechanical properties with modification of attached mortar. When recycled aggregates were treated with silica fume, the increase in compressive strength was 30% and 15% observed at 7 days and 28 days. Pre-treatment of recycled aggregates are helpful for the improvement of the properties but these processes before production lead to higher cost. Thus, this alters its application in concrete construction. The two-stage mixing approach can provide an effective method for improvement in properties of concrete.

In recent years, the nanoparticleswhich are used in concrete for the enhancement of the properties of concrete has gained high research potential. When nanoparticles reacted with $Ca(OH)_2$, it forms a greater amount of C-S-H gels in the system due to its higher surface area and extraordinary reactivityand also fills the pores and tiny cracks. Hence there isan improvement in the properties of recycled aggregates.

Zhang and Islam investigated that nano silica performs better due to its greater surface area than that of silica fume when these materials are used as supplementary materials in concrete. Nano silica is directly mixed with concrete ingredients which showthe improvement in properties of recycled aggregates concrete.

The other mixing method is the presoaking method. In this method, the oven dried recycled aggregates are immersed in NS solution for 48 hours, the nano-silica solution will be observed by the dry recycled aggregates and nanoparticleswill be settled on the surface of recycled aggregates and they fill themicrocracks below the surface of recycled aggregates.Due to this coating of NS on the surface of recycled aggregates, RA gets densified due to the highpozzolanic reaction and filling effect. There will be two ITZ in concrete, old ITZ,and new ITZ. The old ITZ will be porous ITZ between the old mortar and old aggregates and new ITZ will be the old aggregates and new mortar. These both ITZ can also be densified through pozzolanic reaction and filling effects of NS. Thus, there will be a strong bond between the recycled aggregates and new mortar that improves the properties of concrete.

In this study, the investigation of the properties of recycled aggregates concrete, compressive strength, tensile strength, water absorption, water permeability, sorptivity, RCPT and acid attack has been done. The results show from the experimental investigation that presoaked RCA in NS solution gives better performance than the direct mix.

1.2 Nano-Technology in Concrete

Nano derives from the Greek word "dwarf" which shows a billion. One nanometer is equal to the billions of a meter which is very small measurement. Nanotechnology generally used as "catch-all"explanation for any application at a very small scale. Nanotechnology defined as the understanding, control, and handling of matter on the order of nanoscale (i.e., less than 100 nm) to creatematerials with fundamentally new properties and functions.
Nanotechnology encompasses two main approaches as shown in Figure 1.1:

- The top-down method in which larger structures are condensed in size to the nanoscale although they preserve their unique properties deprived of atomic-level control or is decomposed from their larger structures to their slighter composite shares.
- The bottom-up method, also known as molecular nanotechnology or molecular manufacturing, is one in which constituents are engineered from atoms or molecular constituents through a process of assembly or self-assembly.

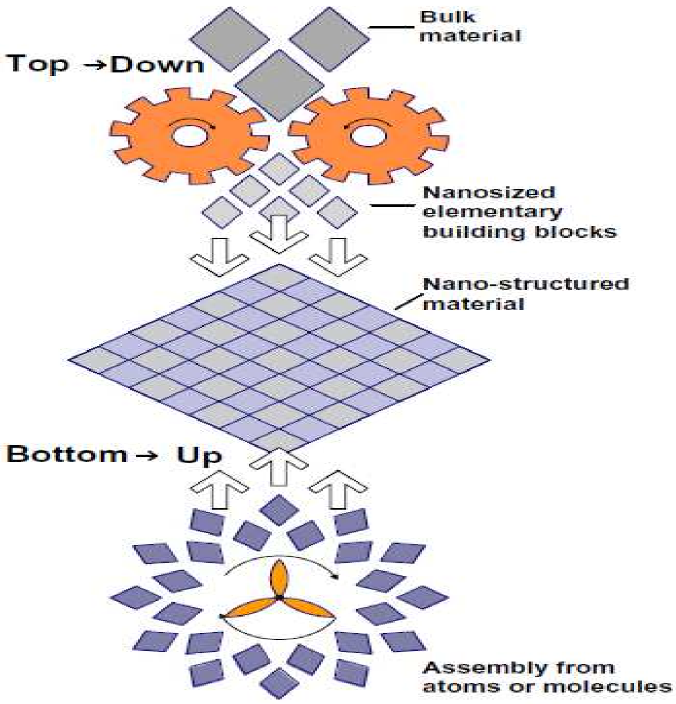


Figure 1.1 Approaches to Nanotechnology (Sanchez & Sobolev)

1.3 Definition of Nanotechnology with Concrete

The nanoscience and nanotechnologyare the mainly used terms that describe two key promenades of application of nanotechnology in concrete exploration. Nano-science is basically related to dimension and characterization of nano and microscale materials to greater understanding for how this structure affects performance and macro-scale properties through the use of advanced classification techniques and atomic or molecular level modeling. Nanoengineering covers the approaches of managing the structure at the nanometers to build up a new improved generation of tailored, multifunctional, cementitiouscomposites with better mechanical performance and durability, potentially having a range of novel properties such as: little electrical resistivity, self-sensing capabilities, self-cleaning, self-healing, high ductility, and self-control of cracks. Concrete can be nano-engineered by addition of nanosized building blocks or objects (e.g., nanoparticles and nanotubes) to handle material behavior and improve different properties by the embedment of molecules onto cement particles, cement phases, aggregates, and additives (includingnano-sized additives) to require surface functionality, which can be adapted to improve particular interfacial interactions.

1.4 Addition of Nano Materials in Concrete

Nanomaterials are very small sized particles with a particle size in Nanometers. Nanomaterials are used to increase the properties of concrete with the advantage of their small size. The small sizes of the particles have a huge surface area with extraordinary reactivity which shows high pozzolanic activity. With the very small percentage of cement, it gives very effective results. Nanomaterials fill the tiny cracks and pores in the microstructure of the concrete which improves the quality of recycled aggregates and hence improve the strength and permeability of RAC. After hydration, nanomaterials mixed with the cement concrete developsnanocrystalsof C-S-H gels. These nanocrystals filled in micro cracks of concrete improve its properties. The results show the increase in compressive strength, tensile strength, improvement in RCPT and water absorption.

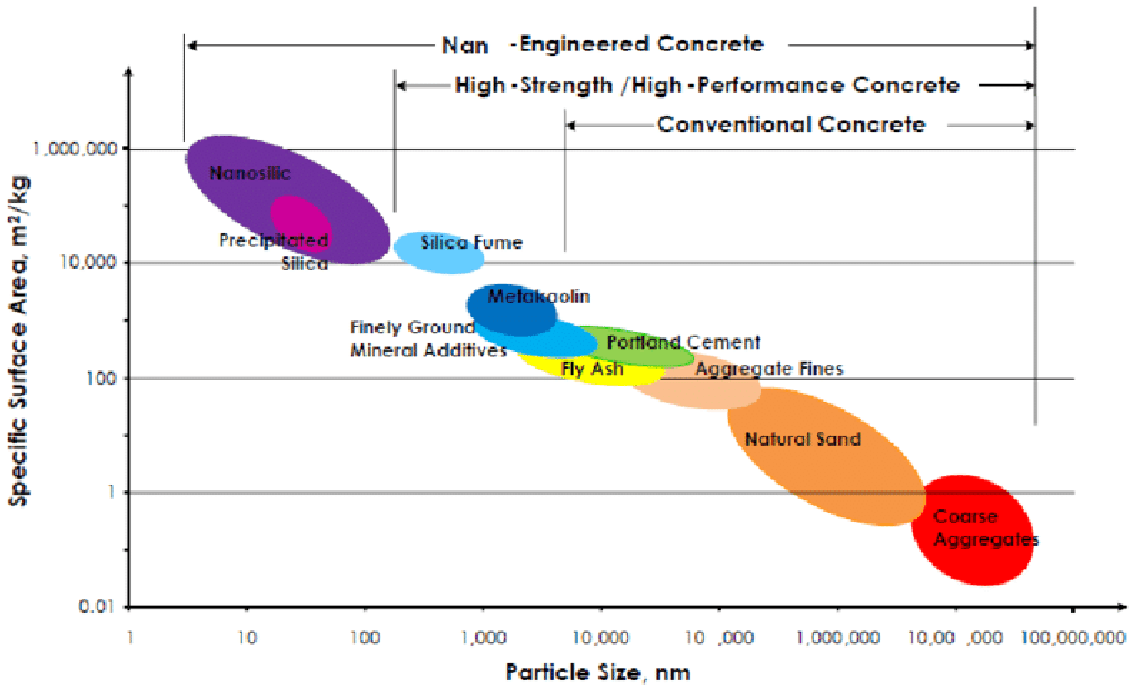


Figure1.2 Specific Surface Area and Particle size relation (Internet)

1.5 Mixing Methods of Nano-Silica

Nano-silica is used to improve the properties of recycled aggregate concrete. In this study, 3% of Nano-silica was used as a replacementfor cement. But, it is very important that how to mix the Nano-silica in concrete that gives an improvement in properties same as properties of concrete containing Natural aggregates. In this study, two methods were used for mixing of Nano-silica in concrete. These two methods were:

1. Direct mixing method
2. Presoaking of RCA in nano-silica solution

1. Direct mixing method

In this method, firstly, 3% Nano-silica mixed into the required amount of water. After this, this NS solution was added to the dry mix of concrete ingredients (cement, fine aggregates and recycled aggregates) in the mixer until a uniform and homogeneous mix was prepared.

2. Presoaking of RAC in nano-silica solution

In this case, NS solution was prepared as in the above method. Firstly, the recycled aggregates were oven dried for 48 hours and then these recycled aggregates were immersed into NS solution for 24 hours so that the water containing Nano-silica was filled into microcracks and pores of the RCA and also inserted on the surface. Thus, a higher amount of Nano-silica was in the ITZ of RCA and reacted with $Ca(OH)_2$ to form an additional C-S-H gel. Thus, more densifiedITZ was formed which improved the bond between the cement matrix and the RCA. The resulted concrete showed the higher strengths and better durability properties of RAC concrete.

Figure1.3Recycled aggregates **Figure1.4Presoaked recycled aggregates**

1.6 Dissertation Topic and its Importance

The research work is entitled as "Effect of Mixing Methods of Nano -silica on the Properties of Recycled Aggregate Concrete".

The objective of this topic is to investigate the effect of mixing methods of Nano-silica on concrete experimentally that may play a beneficial role in the construction field. In India, there is not much work has been done regarding mixing methods of Nano- silica. The optimum content of Nano- silica is very incompatible. The mixing methods of nano-silica used in concrete affect the properties of concrete. Thus there is a needto carry out the investigations on mixing methods of Nano- silica on the properties of RAC.

The advantages of mixing methods of Nano silica in RAC as follows:

1. Nano silica provides great reactivity with the extraordinary surface area that leads to a high degree of pozzolanic activity.
2. Nano silica helps to improve the microstructure.
3. Decreases the capillary porosity of the concrete matrix due to pozzolanic reaction and filler effect.
4. Nano silica helps to gain higher early strength as compared to other supplementary materials like silica fume.

Presoaking of RAC in NS solution improves the compressive strength and tensile strength of the concrete as compared to direct mixing method.Water absorption, sorptivity, the Water permeability of RAC containing presoaking in nano-silica solution is lower than that of direct mixing method of nano-silica. It is also seen that presoaking RAC in nano-silica solution shows better enhancement & improvement in the properties of RAC with direct mixing.

1.7 Objectives of the Research Work

The work entitled as "Effect of Mixing Methods of Nano-Silica on the Properties of Recycled Aggregate Concrete" aims at analyzing the effect of mixing methods of Nano-Silica on the concrete with a view of its benefits and sustainability for concrete construction.

The present study was related to investigating the effect of a Nanomaterial i.e. "Colloidal Nano Silica" on different mechanical properties and durability properties of recycled aggregate concrete. The main objective of the research work is:

- To study the effect of mixing methods of nano silica on the properties of recycled aggregate concrete.
- To compare the compressive strength, tensile strength, water permeability, water absorption, sorptivity, rapid chloride penetration test of recycled aggregate concrete incorporate the mixing methods of nano silica.

The above tests are to be performed at 2% of nano silica used as partial replacement of cement ar 28 days. The nano-silica used in two different mixing methods: Direct mixing method and Presoaking method.

1.8 Presentation of the Research Work

The study undertaken for this dissertation has been covered in seven chapters.

The first chapter of introduction discusses about the use of concrete, nanotechnology in concrete, its definition, additionof nano-sized materials, nano silica in concrete, mixing methods of nano silica and about the cement compositions incorporating nano-silica, Dissertation topic and its importance, Objectives of research work and followed by the scope of research work.

The second chapter is of Literature review in which research work is done on Nano-Silica in concrete is presented.

In the third chapter of the Experimental Program,the methodology of the study has been explained in which the collected data is tabulated and the various steps of the adopted methodology are discussed.

In the fourth chapter of Concrete Mix proportioning, the mix design required for the study has been presented.

In the fifthchapter of Results and Discussion, results of research work are analyzed. Various charts are prepared and detailed in this chapter.

The sixth chapter presents various Conclusions based upon the study carried out in present work.

Chapter -2

Literature Review

2.1 Recycled Aggregates

For the conservation of natural resources and saving the environment, it is very important to use of recycled aggregates in concrete production. But recycled aggregateshave poor quality due to attached mortar which always remains on the surface of it. Thus, with the utilization of recycled aggregates, resulted concrete has inferior properties. So, it is necessary to remove the attached mortar to improve its quality. Many methods are used to remove the mortar of recycled aggregates.

Lee and Ryou (2014) investigated the characterization of recycled coarse aggregate via a surface coating method. When RAC was used for concrete, water must be used due to the high porosity of RA and slump loss occurs during transportation. Hence, the workability of RAC is lower than that of other materials. The results show that with an increase in CRCA replacement, lessen the changes in the value of slumps. All the mixes, except for RCA, 100% had similar or higher compressive and tensile strengths as compared to control concretes.

Ismail and Ramli (2014) investigated the influence of surface-treated coarse recycled concrete aggregate in the compressive strength of concrete. For surface treatment of RCA, calcium metasilicate (CM) and nanosilica (NS) wasused at different concentrations. The slump of concrete with treated RAC decreased when the concentration of the material solution for RCA treatment increased. The compressive strength of RACtreated with CM was higher than that of RACtreated with NS. 10% of CM solution is the optimum concentration for treating the coarser RAC.

Rao et al. (2007) investigated the use of aggregates from recycled construction and demolition waste in concrete. For conservation of natural resources and preservation of the environment, it is necessary that recycled aggregates produced from construction and demolition waste can be used in concrete for lower level applications because recycled aggregate concrete has inferior properties than conventional concrete. Pozzolanic materials like flyash, condensed silica fume etc. can be used for improvement in properties of recycled aggregate concrete. Some of the major issues which act as barriers in promoting the more widespread use of recycled aggregates for recycled aggregate concrete. These issues including lack of appropriately located recyclingfacilities, the absence of appropriate technology, lack of awareness, lack of government support, non- existence of proper specifications/codes for reusing of recycled aggregate in concrete.

Tam et al. (2007) investigated the removal of cement mortar remains from recycled aggregate using pre-soaking approaches. Due to the adoption of recycled aggregate for construction, it is very important to improve its quality because the poor quality of RA limits its utilization. RA has poor quality due to its attached mortar remains on its surface. There were three different pre-soaking approaches namely $ReMortar_{(HCL)}$, $ReMortar_{(H2SO4)}$, $ReMortar_{(H3PO4)}$ used for reducing the old mortar of RA. The experimental results show that reduction in water absorption of pretreated RA with improvement in mechanical properties in RAC and there were no effects on chloride and sulfate contents due to the alkalinity of RAC.

Kou et al.(2007) investigated the influence of fly ash as a cement replacement on the properties of recycled aggregate concrete. The use high percentage of recycled aggregate in concrete worse the properties of recycled aggregate concrete. Twelve mixes were prepared with two different water/cement ratio of 0.45 and 0.55 respectively. The recycled aggregates were used as 0%, 20%, 50 % and 100% as replacements for natural aggregates. The fly ash contents used in all mixes were 0%, 25%, and 35% by weight of cement. The compressive strength, tensile strength and static modulus of elasticity decreased when recycled aggregates contents were increased. At the same recycled aggregate replacement level and W/C ratio, the use of fly decreases the compressive strength, tensile strength and static modulus of elasticity. With the increase in recycled aggregates contents increased, creep and drying shrinkage were increased and resistance to chloride ion penetration decreased. But the use of fly improves the resistance to chloride ion penetration and reduce the creep and drying shrinkage.

Kim et al. (2005) investigated the effects of surface treatment of pozzolanic materials on the cement mortar and concrete. Three pozzolanic materials sodium silicate, colloidal silica and silica fume were used for surface treatment. Due to surface treatment, the results show the improvement in properties of RA. The bulk density of RA was increased to 2.53 with the use of silica sol, 2.72 with sodium silicate and 2.44 with silica fume from 2.38 respectively. Water absorption and porosityweredecreased to 3.43% (silica sol), 4.10% (water glass sol.) and 4.51 %(silica fume) from 4.75 % respectively.When recycled fine aggregates wereused, the compressive strength of mortar was 45% weaker than that of natural fine aggregates. But increased up to 95% when surface treated recycled fine aggregates was used.

Tam et al. (2005) experimentally investigated the microstructural analysis of recycled aggregate concrete produced from a two-stage mixing approach. During the first stage of mixing, when 50% of water was used for mixing, filling up the old cracks and pores of RA due to the formation of a thin layer of cement slurry on the surface of RA. Due to filling the pores and cracks, concrete becomes denser and a strong interfacial transition zone formed which increase the compressive strength and other mechanical properties of recycled aggregate concrete. In the second stage, remaining water was used for complete mixing.

2.2 Nano Silica

For the improvement & enhancement of properties of recycled aggregate concrete, it is very important that use of supplementary materials which helps the improvement in properties. The use of supplementary materials also helps in conservation of natural resources & reduces the CO2 emissions & save the environment. The increase in the use of supplementary materials by replacement of cement also helps in sustainability in construction.

NS is a supplementary material which possesseshigh pozzolanic properties due to the high content of silicon dioxide particles (99%). When RAC is immersed in NS solution, the porous surface of recycled aggregates getsdensified due to the pozzolanic reaction and filling effect and the weak ITZ also getsdensified. **Shaikh et al. (2014)**

Many researchers have worked on the mechanical properties of concrete with Nano silica are discussed below.

2.2.1 Compressive Strength

There isa number of studies on the improvement in Compressive strength of the hardened concrete with nano silica available in published literature.**Givi et al. (2010); Ltifi et al. (2011); Berra et al. (2012); Zhang & Islam (2012); Aly et al. (2012); Hou et al. (2013); Mukharjee&Barai (2014); Haruehansapong et al. (2014); Shaikh et al. (2014); Adak et al.(2014); Guneyisi et al.(2016); Shaikh et al. (2017).** Due to the addition of Nano silica, there is an increase in the compressive strength of concrete that contains 25% and 50 % of recycled aggregates. The improvement in compressive strength is higher in concrete which contains25% of RCA than that of containing 50%. **Shaikh et al. (2014)**

The compressive strength increases at early ages due to the pozzolanic activity of nano silica **Ltifi et al. (2011)** & use of 3% of nano silica shows the compressive strength at 28 days equalized with control concrete. **Mukharjee & Barai (2014)**

Surface treated lightweight aggregates increased the compressive strength irrespective of NS incorporation & w/c ratio. The use of nano silica with the use of self-compacting concrete (with surface treated aggregates) shows higher compressive strength at 28 days. With the combined use of nano silica and surface treated aggregates, the values of compressive strength are 78.5, 65.0 and 49.0 for three different w/c ratios of 0.25, 0.37 and 0.50 respectively.**Guneyisi et al. (2016)**

Shaikh et al. (2017) studied the effects of two different mixing methods on the properties of recycled aggregates concrete. Presoaking of recycled aggregates in Nano silica solution shows 5% improvement in compressive strength as compared to direct mixing method of Nano silica during the mixing of concrete ingredients. With the mixing of both methods of Nano silica, the recycled aggregates concrete shows 20-25% improvement in compressive strength. The recycled aggregates concrete with presoaking method of NS shows 12% lower in compressive strength as compared to control concrete.

The geopolymer mortar with colloidal Nano silica and optimum content of 6% of fly ash to exhibit adequate compressive strength without heat under ambient curing. **Adak et al. (2014)**

Due to the pozzolanic activity & packing ability, cement mortar achieves higher compressive strength as compared to SF because the small size of NS can play important role in hydration process to generate C-S-H when it reacts with Calcium hydroxide. Concrete mortar with NS of particle size of 40mm achieves higher compressive strength as compared to a mortar with 12mm & 20mm and mortar with SF. Very small size of NS of 12mm & 20 mm causes poor dispersion & agglomeration.**Haruehansapong et al. (2014)**

With the incorporation of 2% NS, an increase in compressive strength at 3&7days of high volume fly ash concrete was 30% & 25% respectively. The same improvement was shown in high volume slag concrete. At 28 & 91 days, NS also increased the compressive strength of high volume fly ash concrete but there is no enhancement due to NS in high volume slag concrete at these ages.

2.2.2 Tensile Strength

In Fully recycled aggregates concrete, the tensile strength is lower than that of natural aggregate concrete due to weak ITZ present in RAC than that of NAC. But the incorporation of NS, which makes stronger ITZ by filling the voids, the enhancement of tensile strength was achieved. **Mukharjee & Barai (2014) & Giviet et al. (2010)**

With the incorporation of NS, concrete containing 25% & 50% RCA achieved more than 90% of the tensile strength of control concrete at 28 days. **Shaikh et al. (2014)**

In geopolymermortar, the use of 6% of NS increased the tensile strength of mortar. **Adak et al. s(2014)**

2.2.3 Water absorption

Due to the high porosity of recycled aggregates, the rate of water absorption of recycled aggregate concrete ismuch higher than that of conventional concrete. With the addition of NS, decrease the water absorption of recycled aggregate concrete & was found near control concrete. **Shaikh et al. (2017)**

With the use of 6% of NS, the decrease in water absorption in geopolymer mortar as compared to mortar without NS and control concrete. **Adak et al.(2014)**

2.2.4 Rapid Chloride Ion Penetration

The chloride ion penetration of fly ash & slag concrete with NS or SF was lower than that of control concrete. The concrete with NS or SF classified as "very low" due to charges passed below 1000 C. **Zhang & Islam (2012)**

The RCPT decreases with both mixing methods of NS (direct mixing methods and presoaking methods). Further, presoaking approach shows the reduction in chloride ion penetration about 8% as compared to direct mixing approach. In the presoaking approach, concrete classified as "low" and that indirect mixing approach concrete classified as "moderate". **Shaikh et al. (2017)**

With the increase, the content of NS, increase in chloride ion penetration and it acts to increase the hydration & fill the capillary pores. With the use of 2% NS, the chloride penetration depth decreased of concrete containing 25% & 50% RCA decreased by 31% & 28% respectively at 28 days, when it was compared with control concrete it shows the better resistance & increased it by 13%& 5% respectively at 28 days. **Shaikh et al. (2014)**

The NaOHconcentration in the samples remainsthe same for all mixes. The chloride ion penetration of geopolymer mortar with NS was lower than that of geopolymer mortar without NS. **Adak et al. (2014)**

2.2.5 Sorptivity

Due to the addition of NS & long time curing, in concrete with 25% & 50% RCA the sorptivity much lower at 28 days than that of at 7days. Reduce the sorptivity due to increase the content of NS. For 25% RCA replacement it achieved better resistance than that of control concrete & decreasing the sorptivity about 11% after 7days curing. **Shaikh et al. (2014)**

Due to the pozzolanic activity of NS, fineness & the formation of C-S-H, there was about 43% & 58% decreases in the sorptivity of RAC due to direct mixing method & presoaking method. **Shaikh et al. (2017)**

2.5.6 Water permeability

Due tothe poor quality of RA, the water permeability of RAC was higher than the NAC. but, with the incorporation of NS,improve the resistance of water permeability. The test results show that the concrete with NS had better resistance to water permeability than that of natural aggregate concrete

Chapter-3

Experimental Program

3.1 General

The objective of this study was to analyze the effect of mixing methods of nano silica on the recycled aggregate concrete and with a view to identifying their suitability and benefits for concrete construction. Four different mixeswerecast and out of four mixes, in two mixes nano silica used with two different methods (Direct mixing method and presoaking method). Various methods like compressive strength, tensile strength, ultrasonic pulse velocity, water absorption, water permeability, RCPT, sorptivity were studied. An experimental study was carried out to examine the above-mentioned mixes. Various properties of concretes were studied as explained below.

3.2 Materials Used

3.2.1 Cement

An Ordinary Portland cement of grade 43 confirming to IS-8112:1989, was used for the preparation of test specimens. Cement used was fresh & without any lumps with uniformly in this shading. The physical & chemical properties of OPC are given in Table 3.1.

Table 3.1 Physical properties of Ordinary Portland Cement

Physical property	**Results Obtained**	**IS: 8112-1989**
Normal Consistency(%)	30	....
Initial Setting Time (minutes)	49	30(min)
Final Setting Time (minutes)	238	600(max)
Fineness % by sieve analysis(retained on 90 um sieve)	2	10(max)
Specific gravity	3.06	....
7- day Compressive strength	35.24	33.0 (min)
28- day Compressive strength	46.29	43.0 (min)

3.2.2 Water

Normal tap water which was confirmed to IS:456-2000, used for both mixing and curing of test specimens. Test results are given in Table 3.2

Table 3.2 Properties of water

Properties	Observed value
pH	8.0
Suspended solids, mg/l	NIL

3.2.3 Natural coarse aggregates

Locally available coarse aggregates used in this study. Coarse aggregates have maximum size 20mm and 10mm. The coarse aggregates for all mix design were used in a proportion of 60:40 i.e. 60% of 20mm and 40% of 10mm. These aggregates were washed to remove dust and dirt and further dried to surface conditions.

3.2.3.1 Nominal sized 10mm aggregates

In this study, locally available coarse aggregates sieved through IS sieve for proper grading. The aggregates passing through a 20mm sieve and retained on the 10mm sieve used as 10mm Natural coarse aggregates. The properties and sieve analysis of 10mm sized aggregates are given in Table 3.3 and Table 3.4 respectively.

Table 3.3 Properties of 10mm sized aggregates

Sr. No	Characteristics	Value
1	Type	Crushed
2	Nominal size	10mm
3	Specific gravity	2.60
4	Total water absorption	0.94%
5	Fineness modulus	6.47
6	Los Angeles abrasion	24.3
7	Crushing value	19.4

Table 3.4 Sieve Analysis of 10mm Sized Aggregates

IS Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative %Weight Retained	Passing %
20mm	20.0	20	0.66	99.34
10mm	37.0	57	1.96	98.10
12.5mm	221.0	278	9.26	90.74
10mm	778.0	1056	35.20	64.80
4.75mm	1944.0	3000	100	0.00
Sum	∑=3000		∑C=147.02	

Fineness modulus of coarse aggregates 10mm = C+500/100 = 147.02+500/100 = 6.47

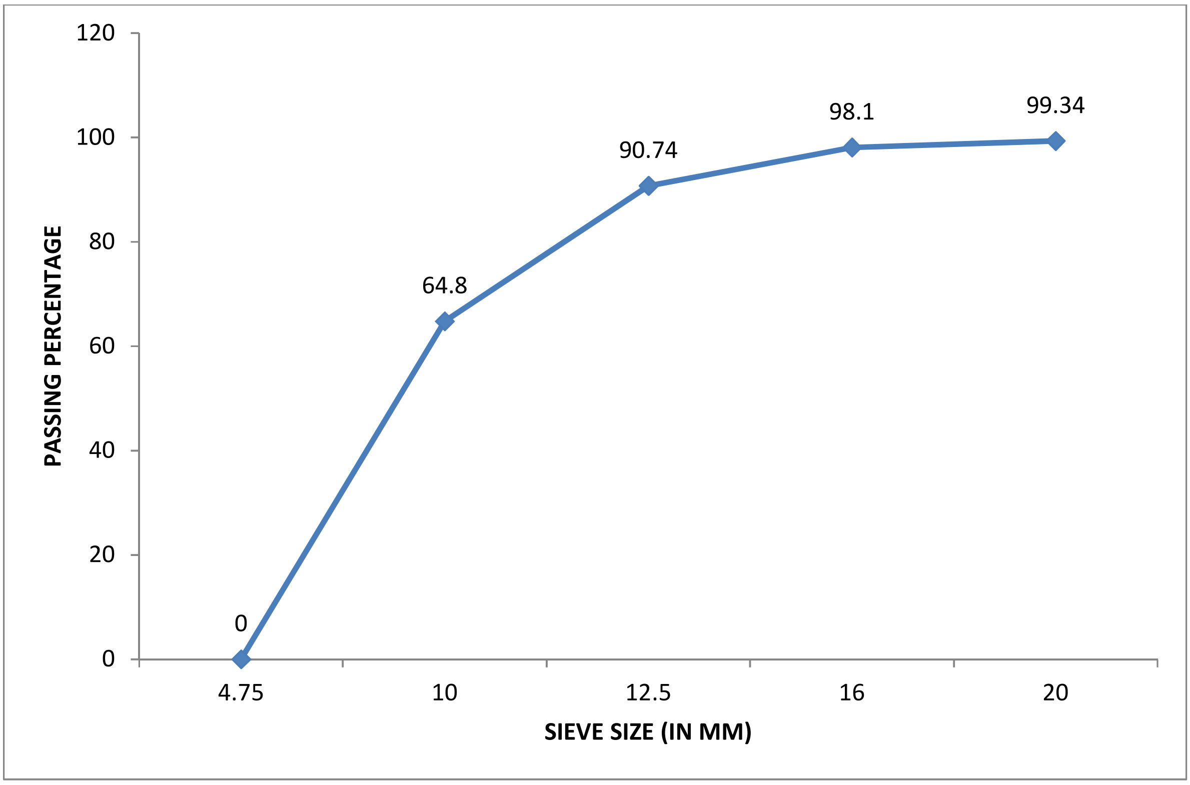


Figure 3.1 Sieve Analyses of 10mm Size Coarse Aggregates

3.2.3.2. Nominal sized 20 mm aggregates

After sieving, the aggregates passing through 40mm IS sieve but retained on the 20mm sieve were used as 20mm natural coarse aggregates The properties and sieve analysis of 20mm sized aggregates are given in Table 3.5 and Table 3.6 respectively.

Table 3.5 Properties of 20mm sized aggregates

Sr. No.	Characteristics	Value
1	Type	Crushed
2	Nominal size	20mm
3	Specific gravity	2.59
4	Total water absorption	1.01
5	Fineness modulus	7.11
6	Los Angeles abrasion	19.2
7	Crushing value	19.4

Table 3.6 Sieve Analysis of 20mm sized aggregates

IS Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Weight Retained	Passing %
40mm	0.0	0.0	0.0	100
20mm	67.0	67.0	2.23	97.77
10mm	197.0	264.0	8.80	91.20
12.5mm	280.0	544.0	18.13	81.87
10mm	1936.0	2480.0	82.66	17.33
4.75mm	520.0	3000.0	100.0	0.00
sum	3000.0		C= 211.82	

Fineness modulus of coarse aggregates 20mm = C+500/100 = 211.82+500/100 = 7.11

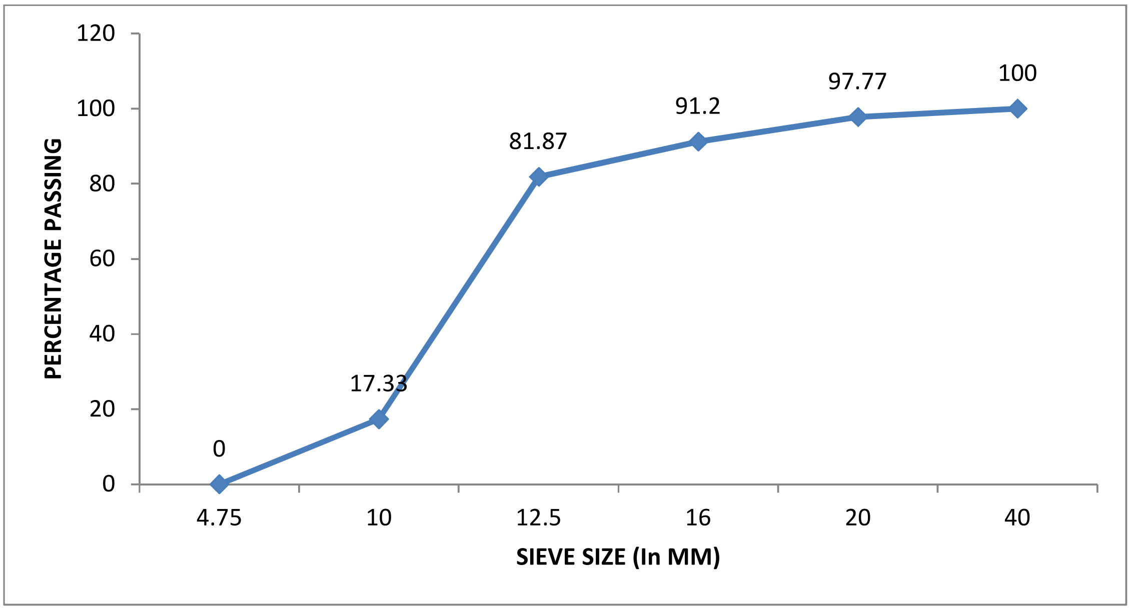


Figure 3.2 Sieve Analysis of 20mm size Coarse Aggregates

3.2.4. Fine Aggregates

Locally available sand was used in the study and confirmed to Indian Standard Specification IS 383- 1970. Firstly, the sand was sieved through a 4.75mm sieve for removal of any particles greater than 4.75mm in size and then sand was washed to remove the dust and dirt. Properties of F.A.used in the experimental work are presented in Table 3.6. To carry out sieve analysis, a set of IS sieve was used for sieving of F.A. is specified by Indian Standards as presented in Table 3.7. The F.A. belongs to Zone 2.

Table 3.7 Properties of Fine Aggregates

Sr. No.	**Characteristics**	**Value**
1	Specific gravity	2.68
2	Total water absorption	0.97
3	Fineness modulus	3.09
4	Grading zone	Zone 2

Table 3.8 Sieve Analysis of Fine Aggregates

IS Sieve Size	**Weight Retained (g)**	**Cumulative Weight Retained (g)**	**Cumulative % Weight Retained**	**Passing %**
4.75mm	75	75	7.5	92.5
2.36mm	119	194	19.4	80.6
1.18mm	235	429	42.90	57.10
600mm	141	570	57.0	43.00
300mm	215	865	86.5	13.5
150um	95	960	96.0	4.0
75um	29	989	30930	
Sum				

Fineness modulus of fine aggregate = F/100=322.40/100=3.22

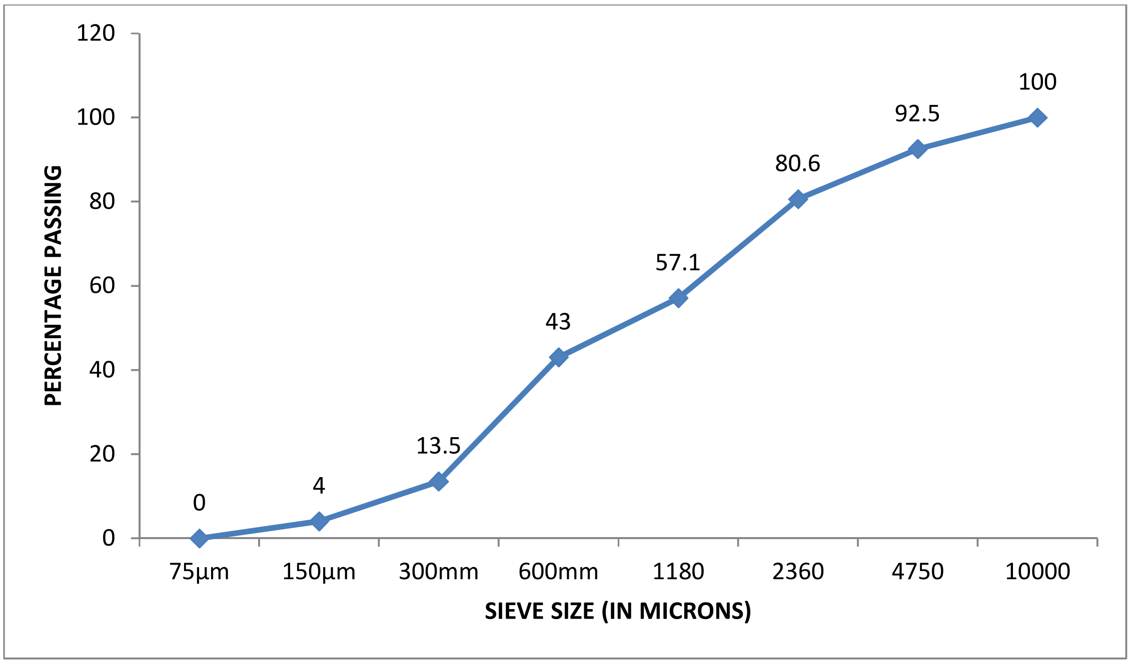


Figure 3.3 Sieve Analysis of Fine Aggregates

3.2.5 Recycled Coarse Aggregates

The recycled aggregates used in this study was prepared from the laboratory tested concrete cubes. These tested cubes concrete cubes were further crushed manually and subsequently crushed with the help of jaw crusher. Crushed material sieved through IS sieves for grading. The recycled aggregates passing through 40mm and retained on the 20mm used as 20mm recycled coarse aggregates. The recycled aggregates passing through 20mm and retained on the 10mm used as 10mm recycled coarse aggregates.

Figure 3.4. 10mm recycled aggregates **Figure 3.5. 20mm recycled aggregates**

3.2.5.1. 10mm Nominal Sized Aggregates

The properties and sieve analysis of 10mm sized aggregates are given in Table 3.9. and Table 3.10 respectively.

Table 3.9 Properties of 10mm Sized Recycled Aggregates

Sr. No.	Characteristics	Value
1	Type	Crushed
2	Nominal size	10mm
3	Specific gravity	2.3
4	Total water absorption	5.6
5	Fineness modulus	7.01
6	Los Angeles abrasion	27.4
7	Crushing value	21.5

Table 3.10. Sieve Analysis of 10mm Recycled Aggregates

IS Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Weight Retained	Passing %
20mm	0	0	0	100
16mm	0	0	0	100
12.5mm	113	113	3.76	96.24
10mm	2476	2589	82.53	17.47
4.75mm	411	3000	100	0
Sum			∑C = 201.68	

Fineness modulus of coarse aggregates 10mm = ∑C+500/100= 201.68+500/100 = 7.01

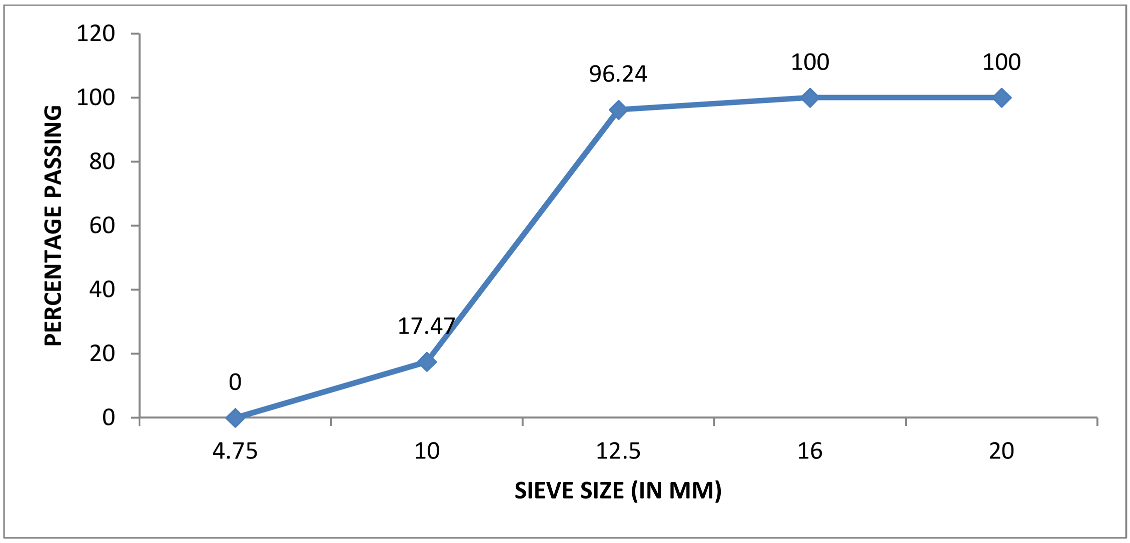


Figure 3.6 Sieve Analysis of 10mm sized Recycled Coarse Aggregates

3.2.5.2. 20mm Nominal Sized Aggregates

The properties and sieve analysis of 10mm sized aggregates are given in Table 3.11. and Table 3.12. respectively.

Table 3.11 Properties of 20mm Sized Aggregates

Sr. No.	Characteristics	Value
1	Type	Crushed
2	Nominal size	20mm
3	Specific gravity	2.5
4	Total water absorption	5.9
5	Fineness modulus	8.32
6	Los Angeles abrasion	31.8
7	Crushing value	24.3

Table 3.12 Sieve Analysis of 20mm Recycled Coarse aggregates

IS Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Weight Retained	Passing %
40mm	0	0	0	0
20mm	86	86	2.86	97.14
16mm	1362	1448	48.26	51.74
12.5mm	1073	2521	84.03	15.97
10mm	406	2927	97.56	2.44
4.75mm	73	3000	100	0
Sum			332.71	

Fineness modulus of coarse recycled aggregates 20mm = C+500/100= 332.71+500/100= 8.32

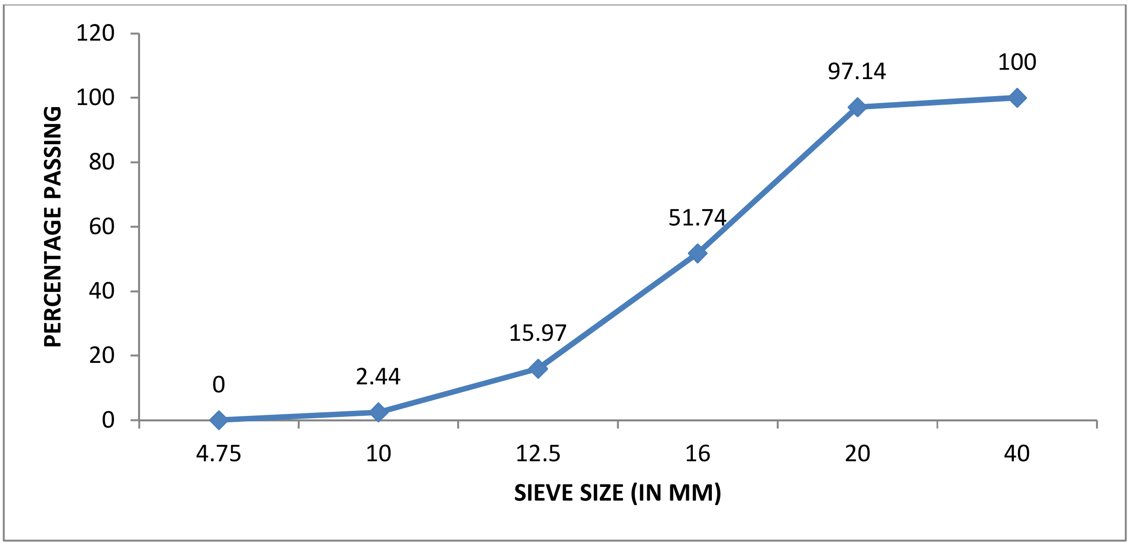


Figure 3.7 Sieve Analysis of 20mm Size Recycled Coarse Aggregates

Figure 3.8 IS Sieves used in the study

3.2.5.3. Mortar Test of Recycled Aggregates.

For the better performance of mortar in concrete production, It is very important that howtoremove the attached old mortar which causes the low quality of it. The quantity of attached mortar also affects the properties of the new concrete. Some treatment processes are used toremoving the old mortar. In this study, presoaking of RCA in hydrochloric acid used todetermining the quantity of attached mortar. The recycled aggregates were immersed in a solution of hydrochloric acid for 24 hours. Again, the recycled aggregates were taken out of the solution and rest for oven dry. when recycled aggregates dried properly, the weight was measured.

Calculations

Weight of 3 samples of recycled aggregates = 400 × 3 = 1200g

After oven dried Weight of 3 samples of recycled aggregates, M1 = 650g

$$\% \text{ Mortar content} = \frac{Mo - M1}{Mo}$$

$$= \frac{1200 - 650}{1200} \times 100$$

$$= 45.83\%$$

3.2.6 Nano Silica

Nano silica is highly pozzolanic material due to its extraordinary reactivity and huge surface area. It contains very fine particles. The size of these fine particles approximately 1000 times smaller than that of cement particles. In the present study, a colloidal form of Nano silica of sample **Cemsyn XTX** grade has been used i.e. nano-silica in dispersion with water in 40:60 ratio (40%nano silica).Nano silica used in this study was manufactured by Bee Chems HO:E-5, Panki Industrial Area, Site-1, Kanpur-208022, UP India. Specifications of colloidal nano-silica as given by the supplier are presented in Table3.13.

Table3.13 Specifications of Nano silica

S.No.	Parameter	Cemsyn XTX
1	Nano solids	29-31%
2	pH	9-10
3	Viscosity	12-13 Pascal Second
4	Specific Gravity	1.20-2.21
5	Description	Colloidal

3.2.7Casting of Specimens

All the concrete specimens were cast according to mix proportions given in Table 4.1. The required quantity of material was weighted for all four mix proportions. The standard size of cubes 150×150×150 mm and cylinder 100×200 mm was used. At least three samples were cast for each test. The adopted mixing procedure was as follows:

First of all, clean all the apparatus which was used for the mixing of all the concrete ingredients. The cement was weighted and put in a try and all the lumps or clusters present in cement are broken to get a uniform powder form. Coarse aggregates and sand were weighted and put in a try and mixed properly in dry condition. Then the weighted cement was added to the prepared mix of aggregates and sand and these all ingredients were mixed properly so that a uniform and homogeneous mix was obtained. Then water was added according to mix design:

In three mix M-0 (100% NCA), M-1 (100%RCA) and M-4 (Presoaking method of NS), the water was added to the dry mix at concrete.

In mix M-3 (Direct method of NS), firstly 3% NS added to weighted water and proper mixing of NS in the water, then added to dry mix.

For the casting of concrete specimens, all the moulds were cleaned and oiled properly. The mixture was poured into the mouldsand rest on the vibrating machine and was given vibrations for proper filling of material.For the removal of excess material, the top surface of moulds was scraped by a trowel and to achieve smooth finishing. After finishing, casting of 24 hours, all the specimens were removed from the moulds and cured in water for 28 days curing.

Figure 3.9Moulds filled by Concrete

Figure 3.10 Vibrating Machine used in study

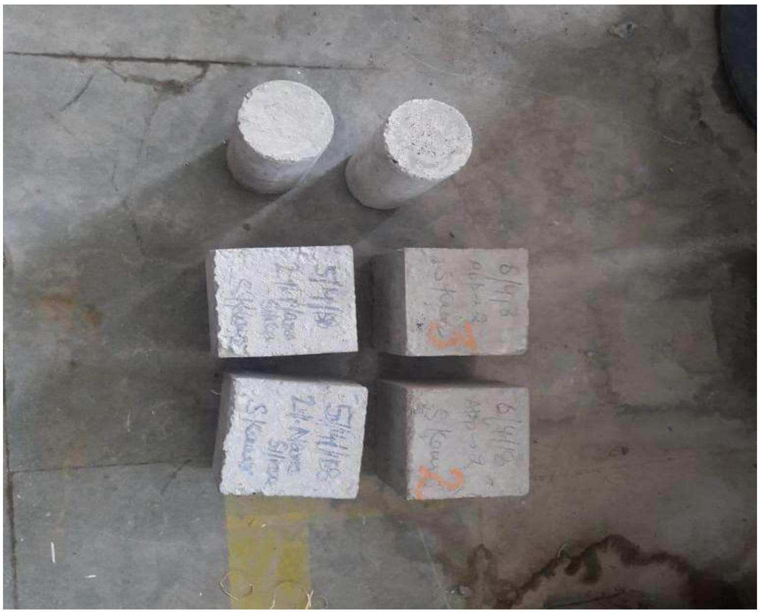


Figure 3.11 Concrete Specimens after De-molding

3.3 Testing Procedure

After the required period of curing, all the specimens were taken out of the curing tank and their surfaces were wiped off. The various tests were performed as listed as below:

1.Compressive strength of cubes at 28 days using compression testing machine.

2. Tensile strength of cylinder at 28 days using compression testing machine.

3. Water absorption test of cubes at 28 days.

4. Water Permeability test cubes at 28 days.

5. RCPT of the cylinder at 28 days.

6. Sorptivity test of cubes at 28 days

7. Acid attack test of cubes at 56 days

3.3.1 Properties of Fresh concrete

Workability The workability of fresh concrete is a composite property which includes the diverse requirements of stability, mobility, placeability,andinstability. Slump test is used for measuring the workability. In this study, slump test is performed as per code IS:1199-1959.

A. Slump test

The vertical settlement of unsupported fresh concrete, flowing to the sides and sinking in height is known as a slump. The slump is a measure indicating the consistency or workability of cement concrete. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. A workable concrete should not show any segregation or bleeding. The setup of the slump test is shown in Figure. 3.12.

Figure 3.12 Slump Test

Table 3.14 Values of Slump Test

Sr. No.	**Mix**	**Nano-silica %**	**Slump (mm)**
1	M-0	0	120
2	M-1	0	60
3	M-2	2	130
4	M-3	2	70

3.3.2. Properties of Hardened Concrete

A. Compressive Strength Test

For the compressive test, cube specimens of 150×150×150mm were cast as per IS Code:4031 (Part-1). After the casting, test samples were finished with a trowel. all specimens were demouldedafter 24 h and rest for curing in curing tank until testing. The compressive strength test of all specimens was performed at 28 days in the compression testing machine which is shown in the figure. The compressive strength was calculated as the givenformula:

$$fc = P/A$$

Where , fc = compressive strength (MPa)

P = Maximum load (N)

A = Cross section of a sample (mm²)

Figure 3.13 Compression Testing Machine used tothe study

Figure 3.14 Compressive Strength Test in CTM

B. Ultrasonic Pulse Velocity (UPV) Test

It is a non-destructive testing technique (NDT). The method consists of measuring the ultrasonic pulse velocity through the concrete with a generator and a receiver. This test can be performed on samples in the laboratory. The results are affected by a number of factors such as the surface and the maturity of concrete, the travel distance of the wave, the presence of reinforcement, mixture proportion, aggregate type and size, age of concrete, moisture content, etc., furthermore some factors significantly affecting UPV might have little influence on concrete strength. Table 3.13. shows the quality of concrete for different values of pulse velocity. The images of the UPV Testing Machine used in the laboratory is shown in Fig. 3.13.

Table 3.15 Criteria for Quality of Concrete

Pulse Velocity (m/s)	**Concrete Quality Grading**
Above 4500	Excellent
3500 – 4500	Good
3000 – 3500	Medium
Less than 3000	Doubtful

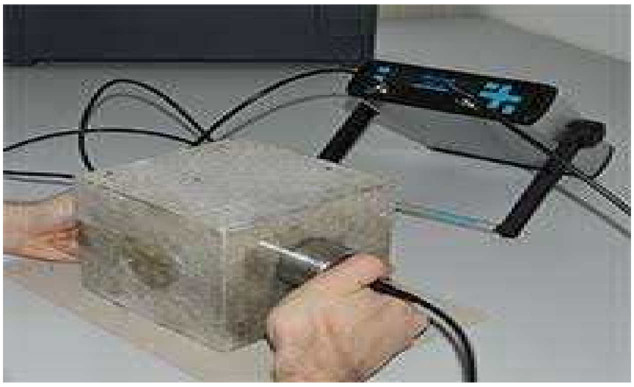


Figure 3.15. UPV Test of Concrete Cube

C. Rebound Hammer Test

Rebound hammer test is used to find out the in-situ compressive strength of concrete by using rebound hammer as per IS: 13311 (Part 2) – 1992.

The rebound of an elastic mass depends on the hardness of the surface against which its mass strikes. When the plunger of the rebound hammer is pressed against the surface of the concrete, the Spring-controlled mass rebounds and the extent of such a rebound depends upon the surface hardness of the concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound value is read from a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer.

The rebound hammer test and UPV test were conducted on cube test specimens for concrete mixes made with conventional aggregate and recycled coarse aggregate (for every percentage of replacement) to study the integrity in terms of homogeneity and also to assess the quality of the concrete at the age of 28 days after proper curing. Similarly, rebound hammer test and UPV test was carried out on concrete mixes with nano-silica along with conventional aggregate and recycled coarse aggregate.

Figure 3.16Apparatus for Rebound Hammer Test

Figure 3.17Rebound Hammer Test for Specimen

D. Tensile Strength Test

Tensile strength is one of an important property of the concrete. Tensile strength test is standard which is used to determine the tensile strength of concrete in an indirect way according to IS:5816-1970. The standard size of concrete cylinder 100×200 mm was placed horizontally between the plates of compression testing machine. The compression load was applied diametrically and uniformly along the length of the specimen until failure of the specimen along the vertical diameter. For the allowed the uniform distribution applied load and reduce the magnitude of high compressive stresses near the points of application of the load plates or strips of wood was placed between the specimens and loading plates of compression testing machine. Due to indirect stress generated,the concrete cylinder was split into two halves along the vertical plane.

The tensile strength along the vertical plane was calculated as given formula

$$ft = 2P/\pi DL$$

P = Compressive stress at failure[N]

D = diameter of cylinder[mm]

L = length of cylinder [mm]

Figure 3.18 Tensile Strength Test

E. Water Absorption Test

The following steps were carried out to perform the water absorption test as specified according to ASTM C642 - 97.

Oven Dry Mass

↓

Firstly, the mass of the concrete specimen was determined and it was dried in an oven at a temperature 100+5^{0}C for not less than 24h.

↓

After removing each specimen from the oven specimens were allowed to cool in dry air to a temperature of 20 to 25^{0}C and the mass was determined. If the specimen was comparatively dry when it was first determined and the second mass closely agrees with the first, consider it dry.

↓

If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24 h and again determine the mass.

↓

If the difference between values obtained from two successive values of mass exceeds 0.5% of the lesser value, return the specimens to the oven for an additional 24h drying period, and repeat the procedure until the difference between any two successive values is less than 0.5% of the lowest value obtained.This last value designated as A.

↓

Saturated Mass after Immersion

↓

The specimens were immersed after the final drying, cooling, and determination of mass, in water at approximately 21^{0}C for not less than 48h and until two successive values of mass of the surface dried sample at intervals of 24 h show an increase in mass of less than 0.5% of the larger value.

↓

The specimens were surface dried by removing surface moisture with a trowel, and determine the mass. The surface dried mass after immersion as designate as B.

Figure 3.19 Flow Chart showing steps for Water Absorption

Water absorption was calculated as

$$\text{water absorption\%} = [(B-A)/A] \times 100$$

Where,

A = Oven dry mass

B = Saturated mass

F. Water permeability

The water permeability test was performed according to code IS:3085. The following procedure was used for the water permeability test.

Calibrating the reservoir Reservoir was calibrated under operating pressure of 5kg/cm². With the reservoir drain, cock and shut-off valve between the reservoir and the cell closed air bleeder valve opened, the reservoir filled with the water. The reservoir drain cock opened to flush out any air and closed again. The reservoir refilled to a point above the zero marks of the Reservoir was calibrated under operating pressure of 5kg/cm². With the reservoir drain, cock and shut-off valve between the reservoir and the cell closed air bleeder valve opened, the reservoir filled with the water. The reservoir drain cock opened to flush out any air and closed again. The reservoir refilled to a point above the zero marks of the gauge glass scale; the bleeder valve was closed and air pressure of 5kg/cm² was applied.

Preparing the specimen The specimen was cleaned with a stiff wire brush remove all laitance.

Sealing the specimen The specimen was surface dried and the dimensions measured to 0.5mm. It was centered in the cell with the lower end resting on the ledge. The annular space between the specimen and the cell was tightly caulked to a depth of 10mm. The rest of the space was carefully filled with the bees-wax and rosin, level with the top of the specimen.

Testing the seal It was necessary that the seal was watertight. It was checked by very conveniently by bolting on the top cover plate, inverted the cell and applied an air pressure of 2kg/cm² from below. A little water poured on the exposed face of the specimen was used to detect any leaks through the seal which was shows as bubble along the ledge.

Assembling the apparatus After a satisfactory seal was obtained, the funnel was secured in position and the cell assembly connected to the reservoir. With the air bleeder valve, the valve between the reservoir and the cell and the drain- cock in the cell open, de-aired water was allowed to enter the reservoir. The reservoir water inlet and air bleeder valves were closed.

Running the rest With the system completely filled with water, a test pressure of 5kg/cm² was applied to the water reservoir and the initial reading of gauge-glass recorded. Permeability test was continued for about 72 hours after the steady state of flow has been reached and the outflow was considered an average of all the outflow measured during that period of 72 hours.

Figure 3.20 Water Permeability Test

Figure 3.21 Specimen in CTM Machine

Figure 3.22 Water Permeability Depth

G. Sorptivity

Sample conditioning Test specimen was placed in the environmental chamber at a temperature of 50 ± 2^{0}C and RH of RH of 80±3 % for 3 days. After the 3 days, place each specimen inside a sealable Container. Store the container at 23 6 2°C for at least 15 days before the start of the absorption procedure.

Procedure The specimens were removed from the storage container and recorded the mass of the conditioned specimen to the nearest 0.01 g before sealing of side surfaces.

The side surface of each specimen was sealed with a suitable sealing material. The end of the specimen was sealed that was not exposed to water using a loosely attached plastic sheet. The plastic sheet was secured used by an elastic band or another equivalent system.

Absorption Procedure

The mass of the sealed specimen was measured to the nearest 0.01 g and it was recorded as the initial mass for water absorption calculations. The support device was placed at the bottom of the pan and the pan was filled with tap water so that the water level is 1 to 3 mm above the top of the support device. Maintain the water level 1 to 3 mm above the top of the support device for the duration of the tests.

The timing device was started and immediately the test surface of the specimen was placed on the support device. The time and date of initial contact with water were recorded.

The mass was recorded at the intervalafterthe first contact with water. According to IS code, the first point at 60±2 sand the second point at 5 min±10 s. Subsequent measurements were within ± 2min of 10 min, 20 min, 30 min, and 60 min. The actual time was recorded to within ±10 s. The measurements wererecorded every hour, ±5 min, up to 6 h, from the first contact of the specimen with water and the time was recorded within ±1 min. After the initial 6 h, measurements were taken once a day up to 3 days, followed by 3 measurements at least 24 h apart during days 4 to 7; a final measurement was taken that is at least 24 h after the measurement at 7 days.

For each mass determination, the test specimen was removed from the pan, the timing device was stopped if the contact time is less than 10 min, and blot off any surface water with a dampened paper towel or cloth. After blotting to remove excess water, the specimen was inverted so that the wet surface did not come in contact with the balance pan.Within 15 s of removal from the pan, the mass was measured.Immediately the specimen was replaced on the support device and restart the timing device.

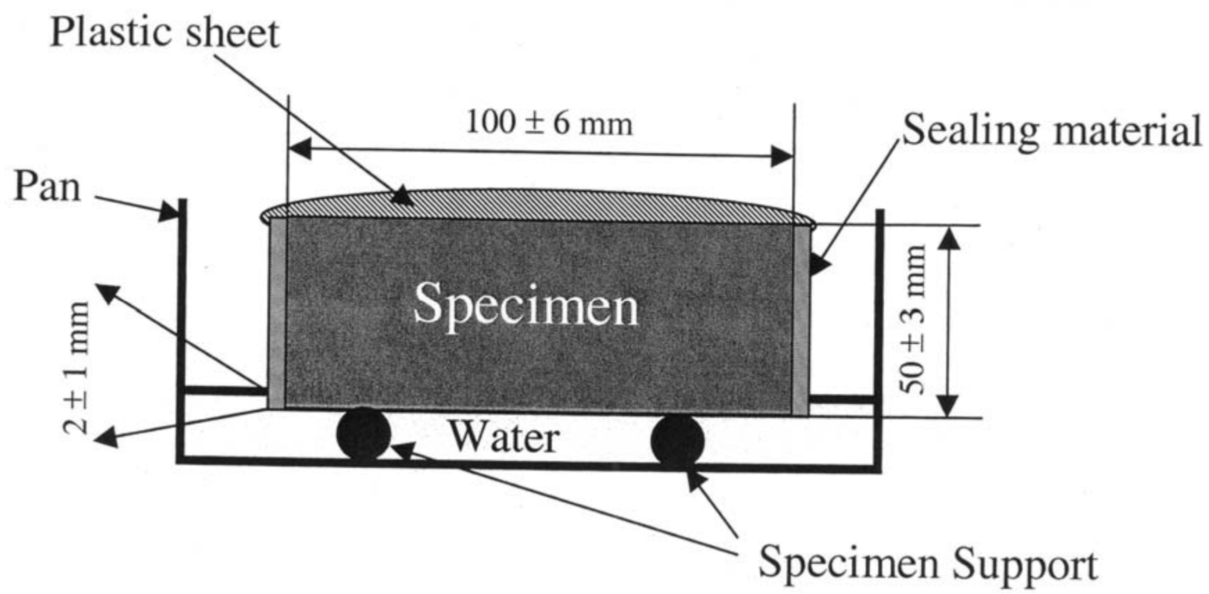


Figure 3.23 Arrangement for Sorptivity Test

H. Rapid Chloride Penetration Depth Test

The chloride ion penetration test was performed according to ASTM 1202. This method is very easy to perform. According to the procedure, after 28 days of curing 100mm diameter cylinder was cut into 50mm thick slices. Only one cylindrical surface was used to permit access of solutions in a single direction and another surface of the slice was sealed with epoxy. All the samples were immersed in a 3% sodium chloride solution. Further, these samples were placed out in a container with the water level being 20mm above the top surface. At least 3 samples of each mix used for rapid chloride penetration depth test. All the slice specimens were subjected to an applied DC voltage of 60v for 6 hours. The apparatus used in this test is shown in the figure. 3.19. One reservoir was filled with NaCl and other filled with NaOH solution. The total charge passed was determined. According to passed charged, concrete mixes classified as low, high or moderate Rapid chloride penetration.

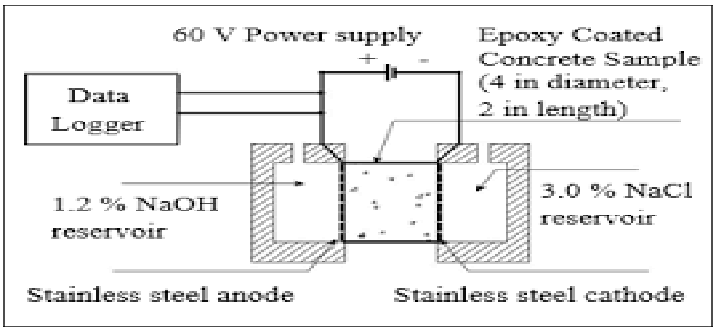


Figure 3.24 ASTM C1202 Test Setup. (Internet)

I. Acid Attack Test

.The concrete cube specimens of various concrete mixtures of size 150 mm were cast andafter 28 days of water curing, the specimens were removed from the curing tank and allowed todry for one day. The weights of concrete cube specimen were taken. The acid attack test onconcrete cube was conducted by immersing the cubes in the acid water after 56 days of curing.Sulphuric acid of 3% weight of water was added to water in which the concrete cubes were stored. After immersion of the concrete cubes were taken out of the acidwater.Then, the specimens were tested for compressive strength. The resistance of concrete toacid attack was found by the loss in compressive strength.

Chapter-4

Concrete Mixing Proportioning

Concrete has become an indispensable construction material. According to the present state-of-the-art, concrete has bypassed the stage of mere four component, that is cement, water, coarse aggregate and fine aggregate. it can be a combination of far more number of ingredients. Hence, it is all the more essential to do proportioning concrete mixes. The objective of proportioning concrete mixes is to arrive at the most economical and practical combination of different ingredients to produce concrete that will satisfy the performance requirements under special conditions to use.

4.1 Mix Design

In this study, M-30 grade concrete has been used for carrying out of the various investigation.

According to guidelines of IS:10262-2009, the following data are required for mix proportioning of an M30 grade of concrete.

Table 4.1.1 Stipulations for Proportioning

(a) Grade designation	M 40
(b) Type of cement	OPC 43 grade conforming to IS:8112
(c) Maximum nominal size of aggregate	20mm
(d) Minimum cement content	320 kg/m²
(e) Maximum water-cement ratio	0.50
(f) Workability	100mm (slump)
(g) Exposure condition	Severe
(h) Degree of supervision	Good
(i) Type of aggregate	Crushed angular aggregate
(j) Maximum cement content	450 kg/m³

4.1.2 Test Data for Materials

<table>
<tr><td>(a) Cement used</td><td>OPC 43 grade conforming to IS:8112</td></tr>
<tr><td>(b) Specific gravity
Cement
Coarse aggregate
Fine aggregate</td><td>
3.06
2.59
2.68</td></tr>
<tr><td>(c) Water absorption
(1) Coarse aggregate
(2) Fine aggregate</td><td>
1.01
0.97</td></tr>
<tr><td>(d) Free (surface) moisture
(1) Coarse aggregate
(2) Fine aggregate</td><td>
NIL
NIL</td></tr>
<tr><td>(e) Sieve analysis
(1) Coarse aggregate</td><td>
<table>
<tr><td>IS Sieve sizes mm</td><td colspan="2">Analysis of Coarse aggregate Fraction,% Passing</td><td colspan="3">Percentage Passing of Different Fractions</td><td>Percentage passing for graded aggregate as per table 2 (IS: 383)</td></tr>
<tr><td></td><td>20 to 10 mm</td><td>10mm down</td><td>60 percent</td><td>40 percent</td><td>Combined 100 percent</td><td></td></tr>
<tr><td>40</td><td>100</td><td>100</td><td>60</td><td>40</td><td>100</td><td>100</td></tr>
<tr><td>20</td><td>95.40</td><td>100</td><td>57.24</td><td>40</td><td>97.24</td><td>95-100</td></tr>
<tr><td>10</td><td>14.48</td><td>73.85</td><td>8.69</td><td>29.54</td><td>38.23</td><td>25-55</td></tr>
<tr><td>4.75</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0-10</td></tr>
</table>
</td></tr>
<tr><td>(2) Fine aggregate</td><td>Confirmed to grading Zone 2 of Table (IS: 383)</td></tr>
</table>

4.1.3 Design Compressive Strength for Mix Proportioning

$f'ck = fck + 1.65 \times s$

where, $f'ck$ = target average compressive strength, N/mm^2 at 28days

fck = characteristic compressive strength, N/mm^2 at 28days

s = standard deviation, N/mm^2

From Table 1(IS: 10262-2009), Standard Deviation = 5.0 N/mm^2

Therefore, design compressive strength = $30 + 1.65 \times 5.0 = 38.25$ N/mm^2

4.1.4 Selection of Water-Cement Ratio

From Table of (IS: 456), maximum water-cement ratio = 0.50

adopt water-cement ratio as 0.49

4.1.5 Selection of Water Content

From Table 2 (IS:10262-2009), maximum water content for 20mm aggregate = 186 litre

Estimated water content for 100m slump = $186 + 6/100 \times 186$

= 197 litre

4.1.6 Calculation of Cement Content

Water-Cement Ratio = 0.49

Water content = 197 litre

Cement content = 197/0.49 = 402.36kg/m^3

From Table 5 of IS 456, minimum cement content for severe exposure condition = 450 kg/m^3

450 kg/m^3 > 402.36 kg/m^3, Hence O.K.

4.1.7 Proportion of Volume of Coarse Aggregate and Fine Aggregate

From Table 3, the volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate grading Zone 2 = 0.62 per unit volume of total aggregate. This is valid for the water-cement ratio of 0.50. As the water-cement ratio is actually 0.49, the ratio is taken as 0.622 to reduce sand content (as per clause 4.4, A-7 IS: 10262-2009).

Volume of fine aggregate content = 1- 0.622 = 0.378 per unit volume of total aggregate.

4.1.8 Mix Calculation

(a) Volume of concrete	1 m^3
(b) Volume of cement	$\frac{\text{Mass of Cement}}{\text{Specific Gravity of Cement}} \times \frac{1}{1000}$ $= \frac{402.36}{3.06} \times \frac{1}{1000} = 0.1302$
(c) Volume of water	$\frac{\text{Mass of Water}}{\text{Specific Gravity of Water}} \times \frac{1}{1000}$ $= \frac{197.16}{1} \times \frac{1}{1000} = 0.19716$
(d) volume of all in aggregate	=[a- (b +c +d)}= 1-0.1302-0.19716 = 0.7233
(e) Mass of coarse Aggregate	= 0.67264 × 0.622 × 2.6×1000 = 1087.79 kg
(f) Mass of fine aggregate	= 0.67264× 0.378× 2.54× 1000 = 645.815 kg

4.1.9 Mix Proportioning for Trial Mix Based on Aggregate in SSD Condition

Cement= 402.36kg/m^3

Water= 197.16kg/m^3

Fine Aggregate= 645.815kg

Coarse Aggregate= 1087.79kg

Water- cement ratio= 0.49

Mix Proportions for various concrete mixes used in the study are given in Table 4.1.

Table 4.1: Mix Proportions for Various Mixes

Mix	Cement kg/m³	Water kg/m³	Coarse Aggregate kg/m³	Fine Aggregate kg/m³	Nano Silica kg/m³
M-1	402.36	197.16	1087.79	645.815	0
M-2	402.36	197.16	1087.79	645.815	0
M-3	394.31	197.16	1087.79	645.815	8.04
M-4	394.31	197.16	1087.79	645.815	8.04

4.2 Test Results of Concrete Mixes

Trial mixes were prepared for the M-30 mix design without nano silica (mix 0) using the results of all calculations as given in above. The aggregates used in trail mixes were saturated surface dry condition. The trial mixes were made with three different w/c ratios of 0.47, 0.48, 0.49. The mix at w/c ratio 0.49 gives the required strength of the M-30 mix. All four mixes were prepared using w/c ratio 0.49. First two mixes are control mixes prepared with 100% natural aggregates and 100% recycled aggregates respectively. In the third and fourth mix, 2% of Nano silica used in two different mixing methods (Direct method & presoaking method). The results of all lab experiments carried out using these mixes are given in chapter-5.

In this chapter, the mix design has been presented which was required for the study and all the calculations are also given.

Chapter -5

Results and Discussion

General

This chapter is concerned with the presentation of the results of the experiments performed towards the objective of the project. It includes results from compressive strength, UPV test, Rebound hammer test, tensile strength test, water absorption test, sorptivity. The results are supplemented by graphs in order to have a better analysis of the results.

5.1 UPV Test

The ultrasonic pulse velocity test is shown in Figure 5.1. The figure illustrates that UPV of recycled aggregate are lower than that those values of RAC which may be due to inferior quality of aggregates and more porous nature of RCA. However, UPV improve with use of nano silica.

Table. 5.1 UPV of Concrete (in m/s)

Sr. No.	Mix	Time (second)	Velocity (m/s)
1	M-0	23.46	6393
2	M-1	23.9	6276
3	M-2	23.7	6310
4	M-3	23.36	6420

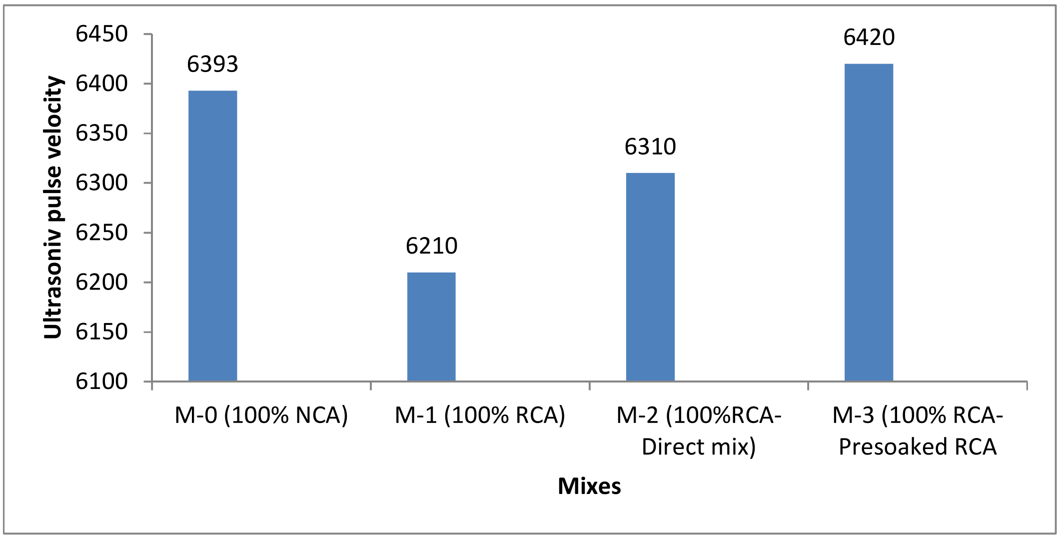


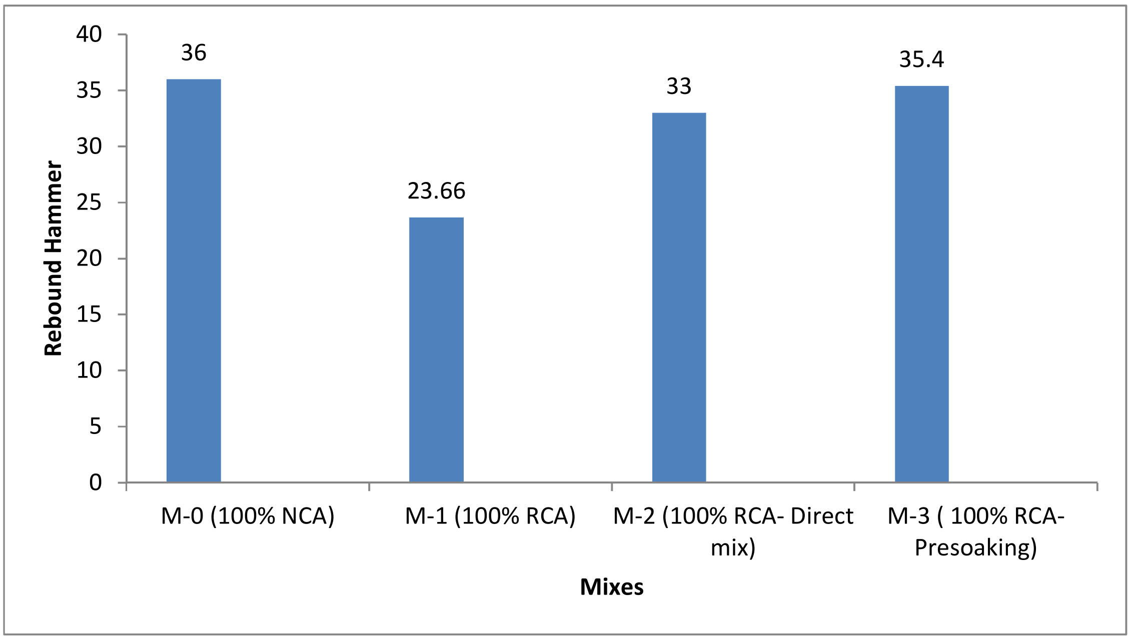
Figure 5.1 Graphical representation of UPV

5.2 Rebound Hammer

The results of the rebound hammer shown in Figure 5.2. The figure shows that the rebound hammer of concrete containing 100% RCA is lower than those values of NAC. The improvement in rebound hammer in concrete mixtures containing NS, which provided confirmation about reduction voids and denseness of the concrete mix. The results show that the rebound hammer of concrete containing presoaked RCA in NS solution has better improvement as compared to concrete with the direct mixing of NS.

Table 5.2 Rebound Hammer Test of Concrete Mixes

Sr. No.	Mix	Rebound hammer
1	M-0	36
2	M-1	25.66
3	M-2	33
4	M-3	35.40



5.2 Figure graphical representation of Rebound Hammer Test

5.3 Compressive Strength

Test of cubes of the standard size of 150×150×150mm was performed using a compression testing machine. The results for all mixes are given in Table 5.3 and Graphs 5.3 and 5.4. Three specimens of each mix were used to perform the test.

Table 5.3 Compressive Strength of concrete (in MPa)

Sr. No.	Mix	Compressive Strength (MPa)
1	M-0	37.73
2	M-1	26
3	M-2	34.70
4	M-3	36.10

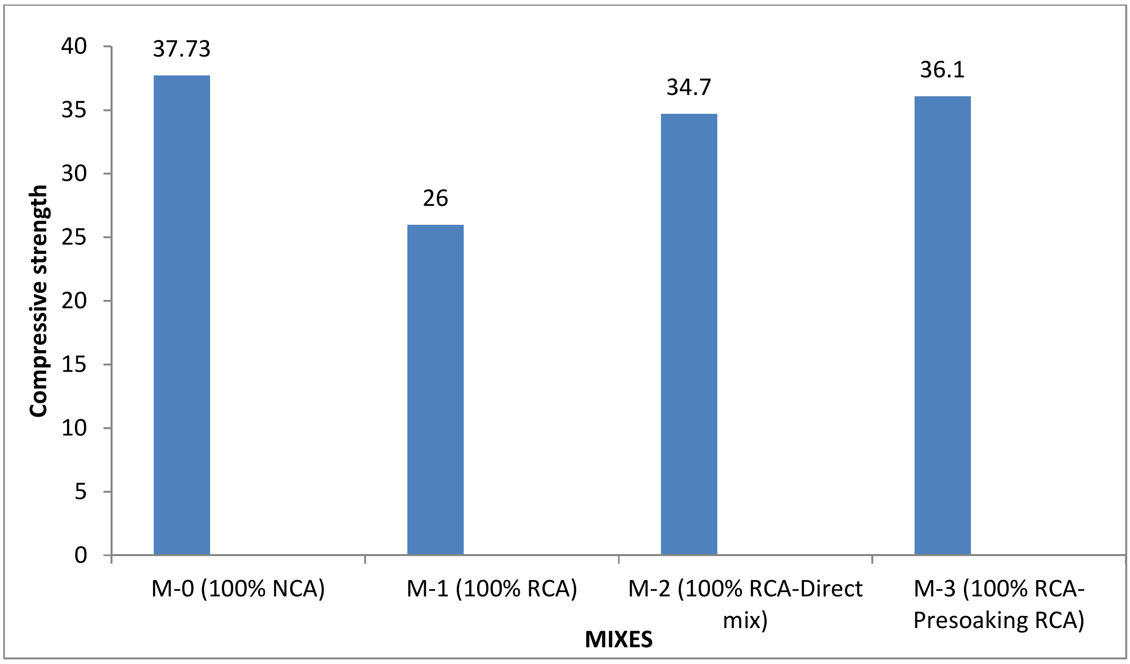


Figure 5.3 Bar graph representation of Compressive Strength of Concrete containing NCA and RCA

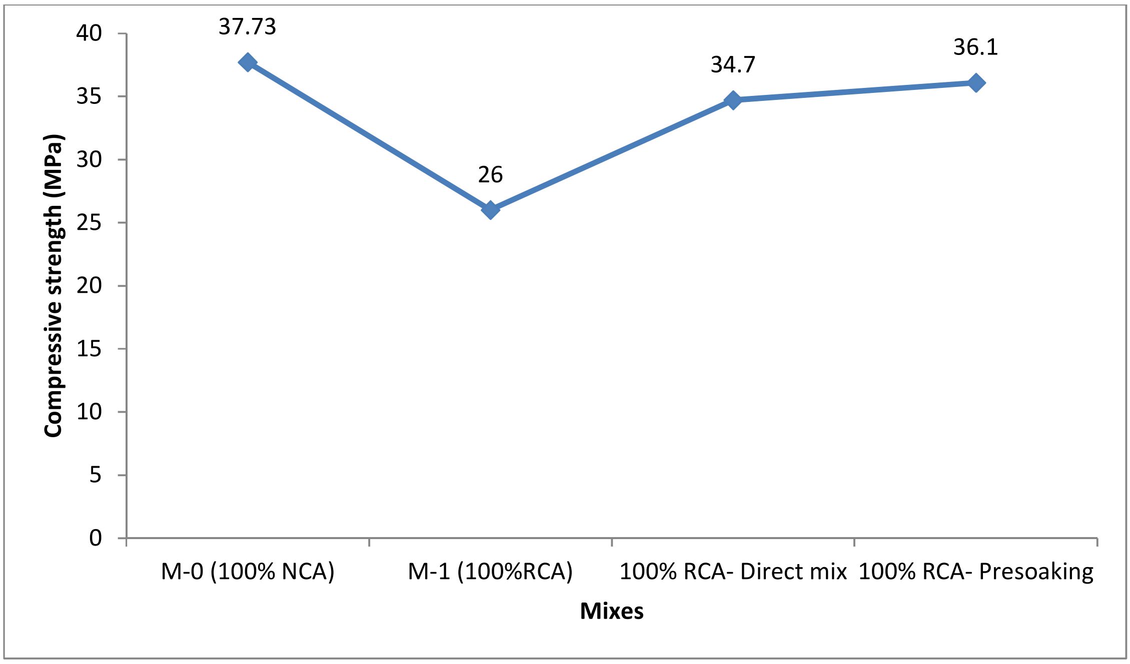


Figure 5.4 Line graph representation of compressivestrength of concrete containing NCA and RCA

It was evident in graphs that in concrete with 100% RCA (M-0), there was a decrease in compressive strength as compared to concrete containing 100% NCA. It can be seen from the Figures 5.3 & 5.4, the decrease in compressive strength for mix M-0 with respect to the control mix M-1 was observed to be 45.11% at the 28 days. This decline in compressive strength was due to the poor quality of RCA. Further, increase in compressive strength containing Nano silica concrete mixes than that of control mix (100% RCA). It can be seen in above in both figures that there is an increase in compressive strength 25% & 27% for direct mixing method & presoaking methods respectively as compared to control mix with 100% RCA (M-1). The presoaked RCA in NS solution gives equalized compressive strength as compared to concrete containing 100% NCA

5.4 Tensile Strength

Tensile strength tests of cylinders of standard sized 100×200 mm were using a compression testing machine. The results of all mixes are given in Table 5.4 and Figures 5.5 & 5.6. The tensile strength of concrete is a basic and important property which affected by the size of cracking in the concrete structure.

Table 5.4 Tensile Strength of concrete (in MPa)

Sr. No.	Mix	Tensile Strength (MPa)
1	M-0	3.52
2	M-1	1.95
3	M-2	3.28
4	M-3	3.98

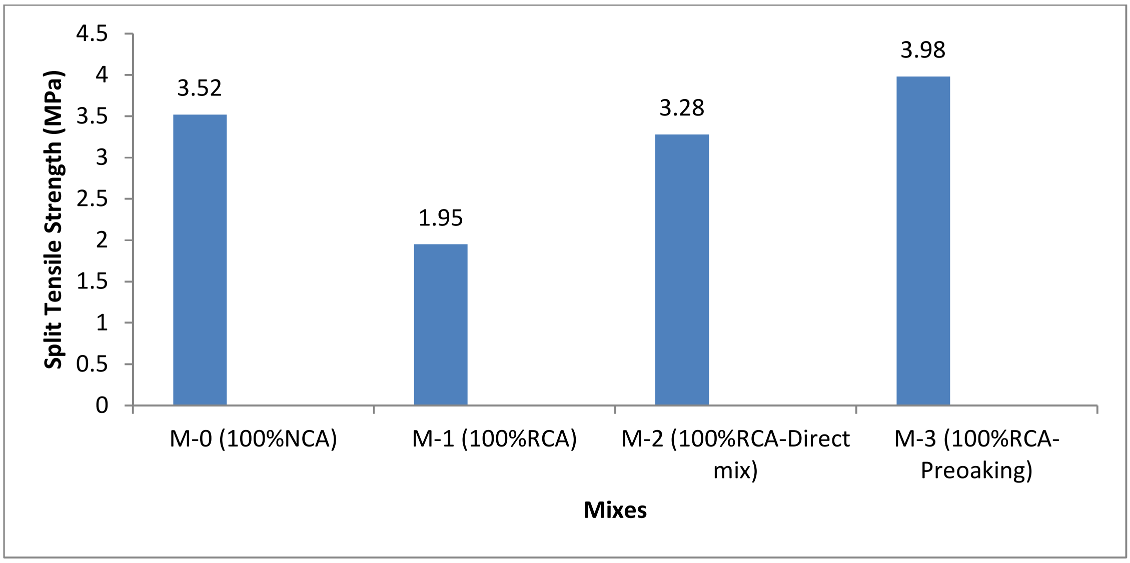


Figure 5.5 Bar graph representation ofSplit Tensile Strength of Concrete containing NCA and RCA

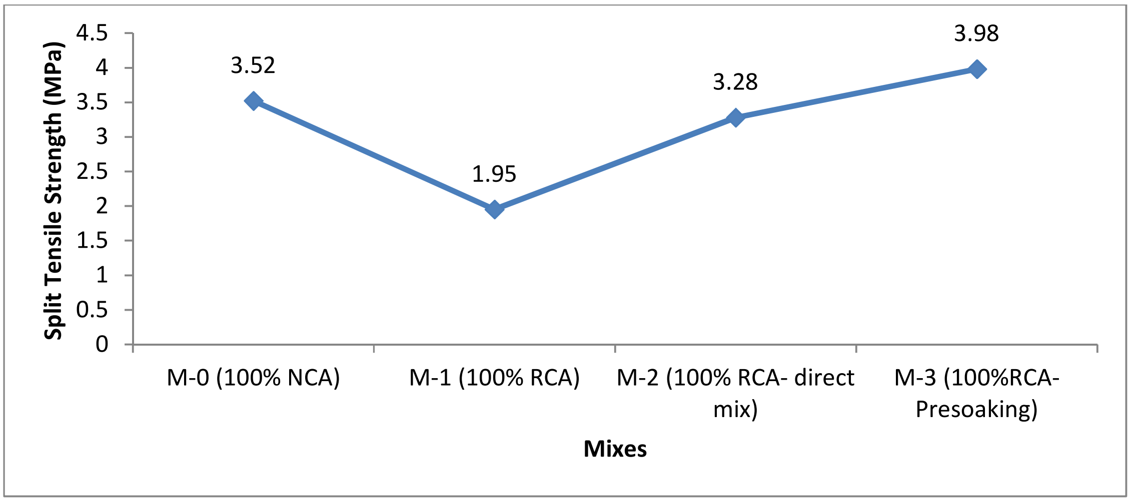


Figure 5.6 Line graph representation of Split Tensile Strength of Concrete containing NCA and RCA

It was evident from Graphs 5.5 & 5.6 that increase in tensile strength for a mix containing nano-silica was higher than concrete mix without nano-silica. As shown in the graph that the reduction in tensile strength when RCA used in concrete. The decrease in tensile strength for mix M-1 was observed to be 44% with respect to M-0 concrete containing 100% NCA. At 28 days, the increase in compressive strength for mixes M-2 (Direct mix) and M-3 (presoaking RCA) with respect to control mix M-1 (100% RCA) was observed to be 40% and 51% respectively. Also, shown in the graph that with presoaking method, the increase in compressive strength was 11% with respect to mix M-0 containing 100% NCA.

5.5 Water Absorption

Water absorption test carried out on cubes of the standard size of 150×150×150 mm. The test results of all mixes are given in Table 5.5 and in Graphs 5.7 & 5.8. The specimens were dried in an oven at 150^0C for 24 hours and then immersed in water and weight was checked at 28 days. then the percentage of water absorption was calculated. The absorbed water can fill in pores. when oven dried the samples the pores are emptied and get filled with water when immersed in water.

Table 5.5 Percentage Water Absorption of Concrete Mixes

Sr. No.	Mix	Nano silica (%)	Weight of dry sample(kg)	Weight of wet sample (kg)	Water absorbed (kg)	% absorption
1	M-0	0	8.417	8.628	0.211	2.50
2	M-1	0	7.953	8.326	0.373	4.69
3	M-2	2	7.926	8.125	0.199	2.54
4	M-3	2	8.039	8.189	0.150	1.86

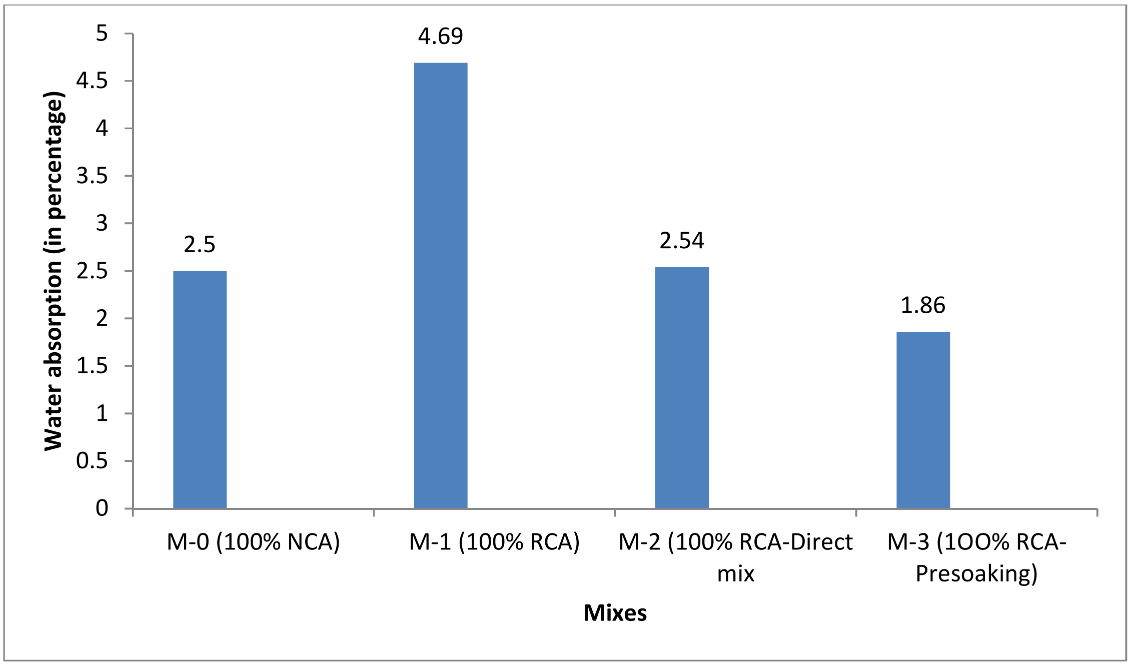


Figure 5.7 Bar graph representation of Water Absorption of Concrete containing NCA

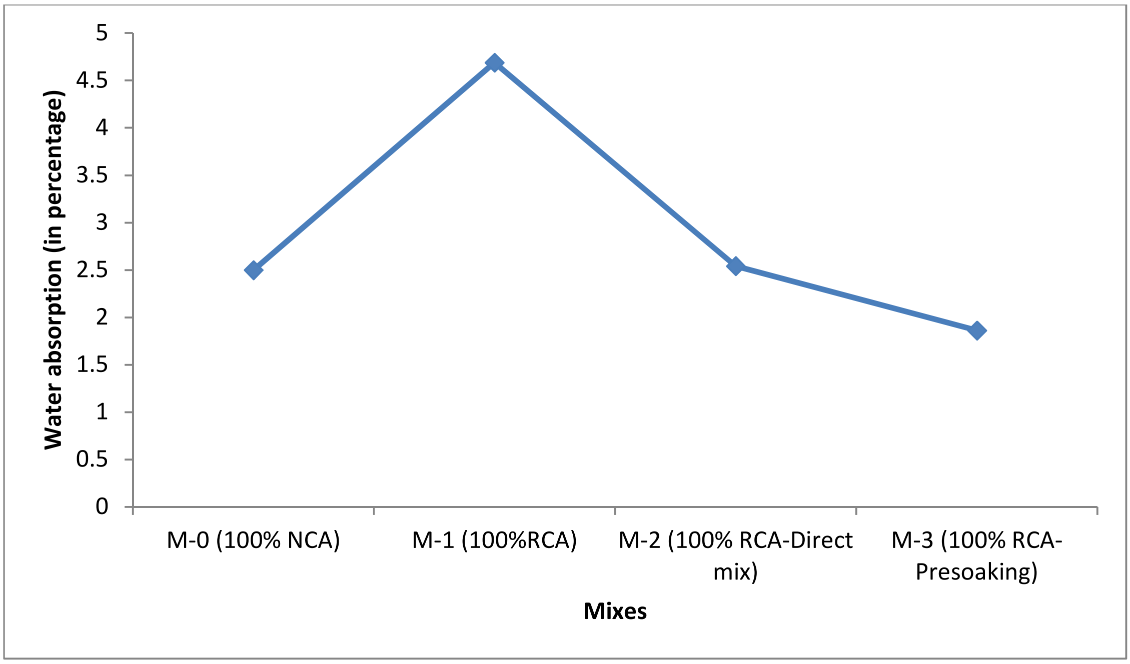


Figure 5.8 Line graph representation of Water Absorption of Concrete containing NCA and RCA

It was evident from the graphs that the increase in percentage water absorption for M-1 containing 100% recycled aggregates was higher than that of M-0 containing 100% NCA. It can be seen from the figure 5.7 & 5.8 at 28 days, the increase in percentage water absorption mix M-

1 with respect to M-0 was observed to be 46.69%. When NS was used as supplementary materials, the water absorption was decreased due to filler effect NS. The decrease in percentage water absorption was observed to be 43.92% and 60.34% for M-3 (100% RCA-Direct mix) and M-3 (100% RCA presoaking) respectively as compared to M-1 containing 100% recycled aggregates. It was shown in graphs that presoaking method gives better performance than that of the direct mix. The decrease in percentage water absorption was 25.60% for M-3 containing presoaked NS in solution with respect to M-0 containing 100% NCA.

5.6 Rapid Chloride Ion Penetration Test

The test results are given in Table 5.6 and Figures 5.9 and 5.10.

Table 5.6 Chloride Ion Penetration Test

Sr. No.	Mixes	Charged passed (Coulombs)
1	M-0	3870
2	M-1	5143
3	M-2	2500
4	M-3	2150

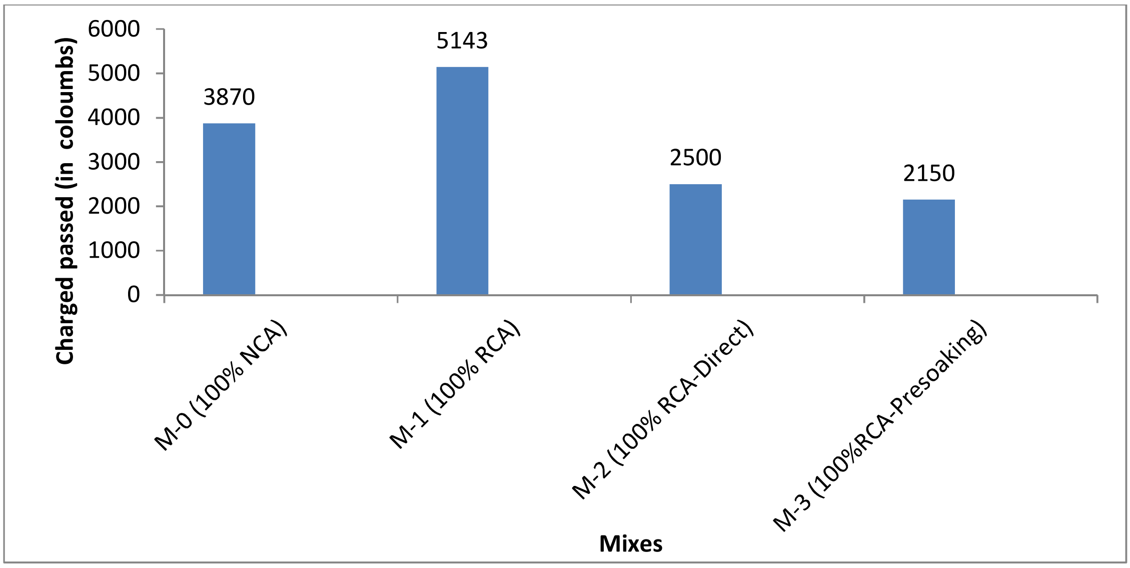


Figure 5.9 Bar graph representation of Water Absorption of Concrete containing NCA and RCA

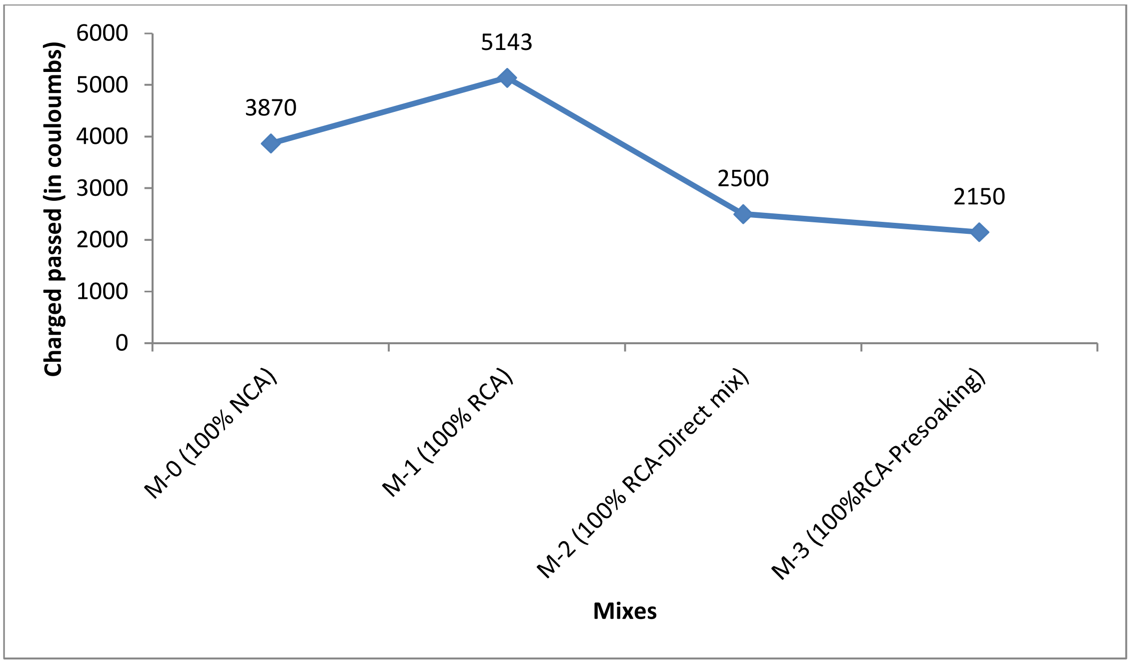


Figure 5.10Line graph representation of RCPT of Concrete containing NCA and RCA

It was evident from the graphs that increase in chloride ion penetration for mix M-1 containing 100% RCA than that of concrete containing 100% NCA. This increment due to inferior properties of recycled aggregates, while other ingredients like cement, water,and fine aggregates were the same for both mixes. Improvement in chloride ion penetration by reducing the charged passed, due to the addition of NS with two different mixing methods. It was shown in the graph that the decline in charged passed was 51.39% and 58.19% for M-2 (100% RCA- Direct mix) and M-3 (100% RCA- Presoaking) respectively as compared to M-1 (100% RCA). It can also be seen that the presoaking mixing method further shows the reduction in chloride ion penetration by 14% compared to direct mixing method of NS. The concrete containing presoaking RCA can be classified as "low" where as concrete containing direct mixing of NS can be classified as "moderate". It can also be seen that the chloride ion penetration resistance of both mixing methods improved the control concrete with 100% NCA.

5.7 Water Sorptivity

For the sorptivity test, cylinder pieces of 100×50 mm were used. At least 3 specimens were used for each mix. The tested values of all specimens for all four mixes are presented in Tables 5.7, 5.8, 5.9 & 5.10.

Table 5.7 Data collected and Calculations for 100% Natural Aggregate Concrete

Test Time		√Time (S½)	Mass (g)	Δ Mass (g)	ΔMass/area/densityof water = l (mm)
Days	Seconds				
1	0	0	933.0	0	0
	60	8	933.5	2.5	0.3083
	300	17	936.66	3.66	0.4514
	600	24	936.83	3.83	0.4724
	1200	35	937.16	4.06	0.5007
	1800	42	938	5	0.6167
	3600	60	938.33	5.33	0.6574
	7200	85	939.66	6.66	0.8214
	10800	104	940.5	7.5	0.9250
	14400	120	940.66	7.66	0.9456
	18000	134	941.16	8.16	1.0093
	21600	147	941.83	8.83	1.0891
2	92220	304	944.66	11.66	1.4382
3	193200	440	946.83	13.83	1.7058
4	268500	518	947.16	14.16	1.7465
5	432000	657	947.83	14.33	1.8292
6	527580	726	948.5	15.5	1.9118
7	622200	789	949.16	16.16	1.9932
8	691200	831	949.83	16.83	2.0759
		∑ = 5041			∑ = 20.49

Sorptivity = 4.06

Table 5.8 Data collected and Calculations for 100% Recycled Aggregate Concrete

Test Time		√Time	Mass (g) (S½)	Δ Mass (g)	ΔMass/area/density of water = l (mm)
Days	Seconds				
1	0	0	930.5	0	0
	60	8	932.5	2	0.2467
	300	17	933.5	3	0.3700
	600	24	934.0	3.5	0.4317
	1200	35	934.33	3.83	0.4724
	1800	42	935.5	5	0.6167
	3600	60	936.0	5.5	0.6784
	7200	85	938.0	7.5	0.9250
	10800	104	938.5	8	0.9867
	14400	120	939.5	9	1.1101
	18000	134	940.33	9.83	1.2124

	21600	147	940.83	10.33	1.2741
2	92220	304	945.83	15.33	1.8908
3	193200	440	948.83	18.33	2.2609
4	268500	518	950.83	20.33	2.5076
5	432000	657	952.66	22.16	2.7333
6	527580	726	955.0	24.5	3.0219
7	622200	789	956.38	25.88	3.1921
8	691200	831	957.5	27	3.3303
		∑ = 5041			∑ = 27.2611

Sorptivity =5.407

Table 5.9 Data collected and Calculations for 100% Recycled Aggregate Concrete with a Direct mix

Test Time		√Time	Mass (g) (S½)	Δ Mass (g)	ΔMass/area/density of water = l (mm)
Days	Seconds				
1	0	0	994.16	0	0
	60	8	996.33	2.17	0.2676
	300	17	996.83	2.67	0.3293
	600	24	997.5	3.34	0.41197
	1200	35	998.0	3.84	0.4736
	1800	42	998.5	4.34	0.5353
	3600	60	998.83	4.67	0.5760
	7200	85	1000.33	6.17	0.7610
	10800	104	1000.66	6.5	0.8017
	14400	120	1001.16	7	0.8634
	18000	134	1001.66	7.5	0.9250
	21600	147	1002	7.84	0.9670
2	92220	304	1005.16	11	1.3568
3	193200	440	1006.66	12.5	1.5418
4	268500	518	1007.33	13.17	1.6244
5	432000	657	1008.0	13.84	1.7071
6	527580	726	1008.83	14.67	1.8094
7	622200	789	1009.83	15.67	1.9328
8	691200	831	1010.5	16.34	2.0154
		∑ = 5041			∑ = 18.8995

Sorptivity =3.749

Table 5.10 Data collected and Calculations for 100% Recycled Aggregate Concrete with Presoaked RCA

Test Time		√Time	Mass (g) (S½)	Δ Mass (g)	ΔMass/area/density of water = l (mm)
Days	Seconds				
1	0	0	0	0	0
	60	8	969.83	0.5	0.0616
	300	17	970.83	1.25	0.1542
	600	24	971.0	2.67	0.3293
	1200	35	971.5	3.17	0.3910
	1800	42	971.83	3.5	0.4317
	3600	60	972.16	3.83	0.4724
	7200	85	973.33	5	0.6167
	10800	104	974	5.67	0.6994
	14400	120	974.16	5.83	0.7191
	18000	134	974.66	6.33	0.7807
	21600	147	975.16	6.83	0.8424
2	92220	304	977.83	9.5	1.171
3	193200	440	979.66	11.33	1.3975
4	268500	518	980.5	12.17	1.5011
5	432000	657	982	13.67	1.6861
6	527580	726	982.66	14.33	1.7675
7	622200	789	983.66	15.33	1.8908
8	691200	831	984	15.67	1.9328
		∑ = 5041			∑ = 16.8453

Sorptivity =3.34

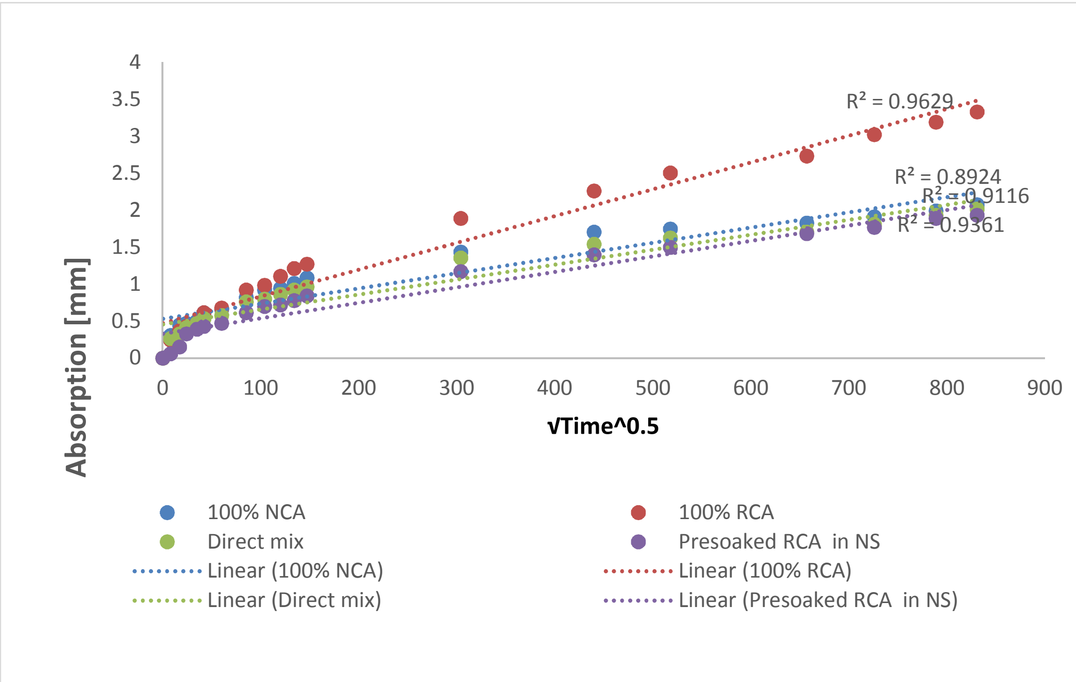


Figure 5.11 Line graph representation of the results of Sorptivity Test

The rate of absorption of water by the capillary rise of unsaturated concrete is a function of the permeability of the pore structure of concrete. For all four concrete mixes, the rate of water absorption shown in Figure. 5.11. The rate of water absorption of different concrete specimens up to 8 days was fitted by using linear regression and the equation. These results show the capillary action of all specimens during the testing days. Sorptivity of all mixes defined by the slope of the obtained line. It was shown in the graph that the volume of water absorbed by specimens increased with respect to the square root of time. The rate of water absorption of recycled aggregate was higher than that of natural aggregate concrete but it decreases when nano silica used in concrete and it was very close to concrete containing natural aggregates. It can be seen in the graph that the reduction in recycled aggregates was 30.66% and 38.28% was observed when nano silica used in concrete with direct mixing and presoaking method respectively. It was due to the high pozzolanic activity of nano-silica. The cumulative rate of water absorption of concrete with presoaked RCA was lower than that of direct mixing of nano-silica. This reduction due to a higher quantity of dissolved nano silica deposited on the surface of RCA during presoaking and also fills the micro-cracks below the surface and in resulting densified the structure. The more compact ITZ formed around the RCA.

5.8 Water Permeability

The experimental results show in the Table 5.11 and in Figures 5.12 & 5.13

Table 5.11 Water Permeability Test

Mix	Co-efficient of Permeability, Ks (m/sec) × 10^{-12}	Penetration depth (mm)
M-0	31.12	75
M-1	64.30	153
M-2	15.68	45
M-3	13.63	38

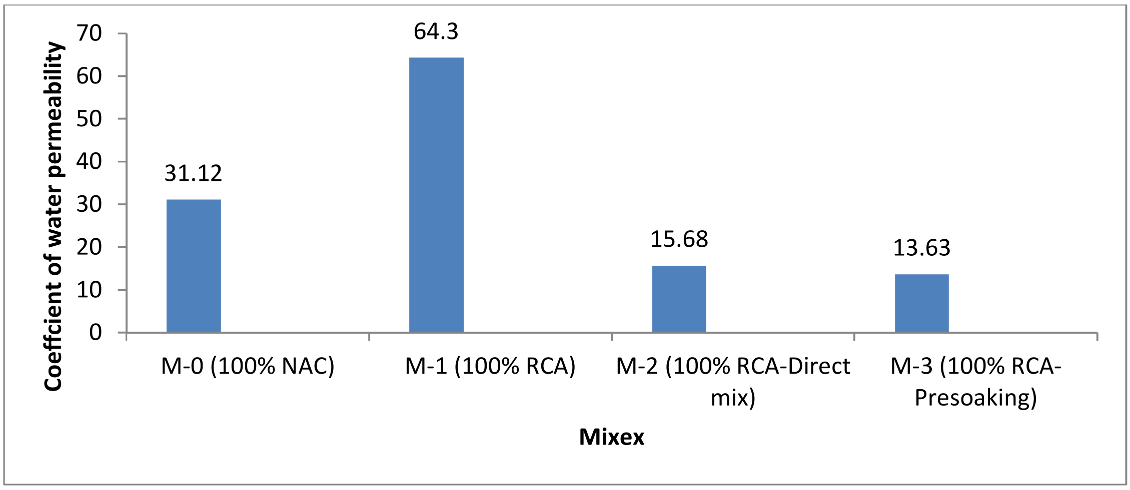


Figure 5.12 Bar graph representation of results of Permeability Test

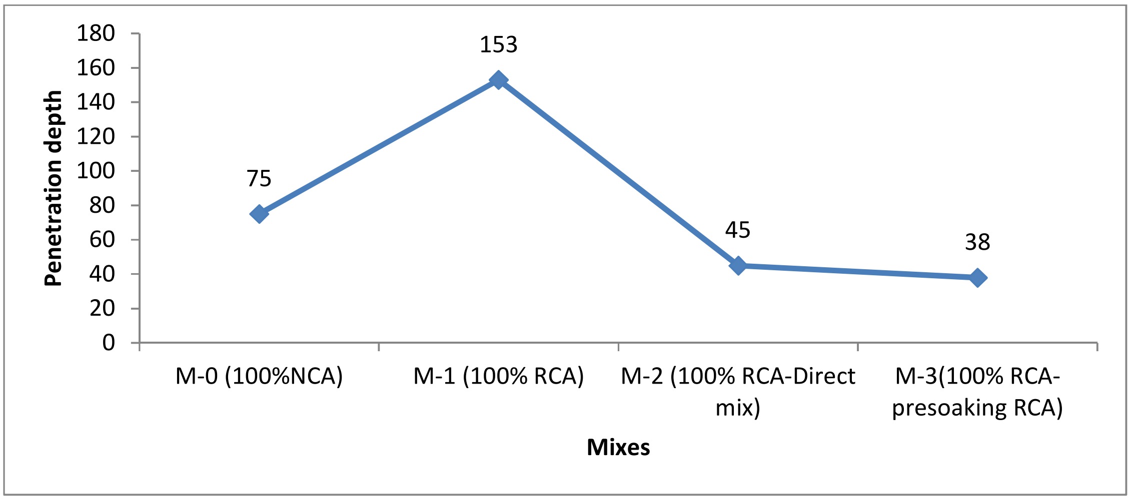


Figure 5.13 Line graph representation of results of Permeability Test

The variation of coefficient of water permeability of different mixes shown in Figure 5.13. The permeability of concrete increase with the replacement of natural aggregates with recycled aggregates. Further, reduction in water permeability with using of nano-silica. For mix M-1(100%RCA) showed an increment of 33.18% with respect to M-0(100%NCA). Again, for mixes with nano silica M-2 direct mix and M-3 (presoaking RCA), the decrement of water permeability was 48.62% and 47.94% respectively as compared to M-1 (100% RCA). The presoaking mixing method further shows the reduction in water permeability by 2.05% compared to direct mixing method of NS. The improvement in concrete due to the filler effect of a nano-sized particle of nano-silica. The voids in the concrete mix were filled by nano particles and there was no space for water to be absorbed in the voids and resulting in a reduction in water permeability.

5.9 Acid Attack Test

Table 5.12 shows the acid attack test results of average % loss of compressive strength of all mixes.

Table 5.12 Results of acid attack test

Mix	Compressive strength	Compressive strength after acid attack	% loss in compressive strength
M-0	37.73	35.5	2.23%
M-1	26	19.6	6.4%
M-2	34.70	30.88	11%
M-3	36.10	34.9	1.2%

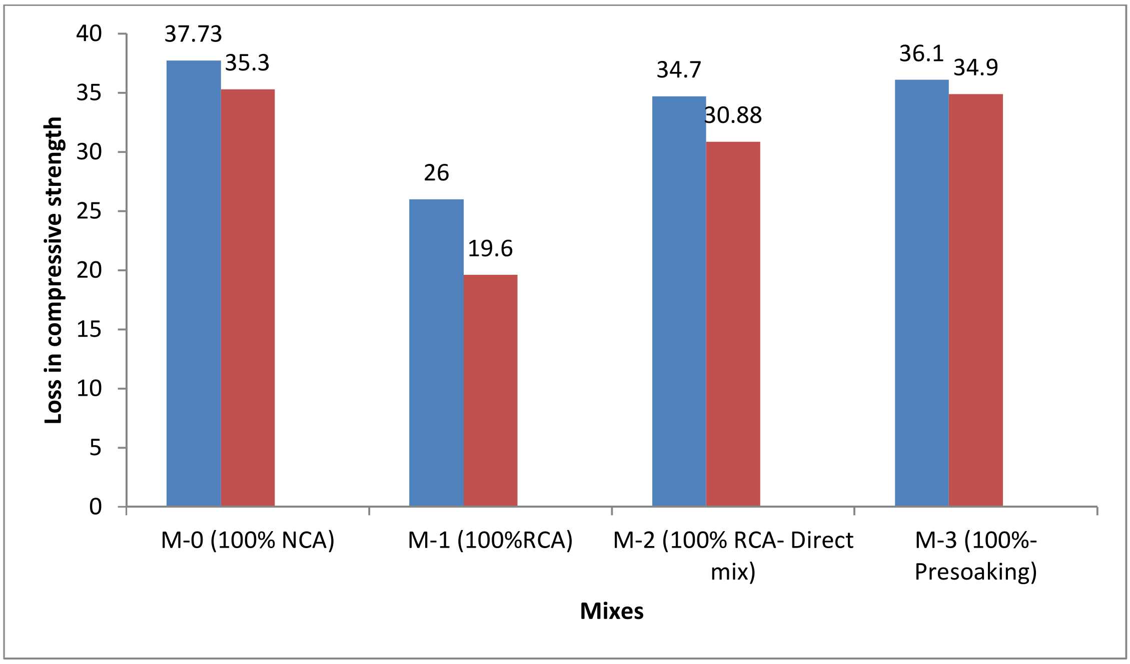


Figure 5.14 Bar graph representation of Strength loss in mixes

After exposure to sulphate solution,white patches were found on the surface of the concrete cubes.Concrete cubes immersed in sulphate solutionwere found to be visually intact after 56 days. Figure 5.14 shows the percentage strength loss variation in mixes. It can be seen that percentage strength loss after sulphate exposure decreases with both methods of nano silica and the pozzolanic effect of nanosilica helps in reducing the % strength loss. In the case of presoaking, there is less % loss in compressive strength as compared to the direct mixing of nano-silica.

Chapter-6

Conclusions

The experimental investigations show the explanation of better ITZ in a concrete mix with RCAs, when presoaked RCA in NS solution are usedupgrading compressive strength, tensile strength, low water absorption, sorptivity, RCPT and water permeability.

Based on the study, the following conclusions can be drawn:

1. Presoaking RCA in NS solution enhances the compressive strength of about 3.87% as compared to the direct mixing of NS during mixing. The recycled aggregate concretes containing NS mixed by both methods showed about 25-27% improvement in compressive strength. The concrete with presoaked RCA in NS solution is only 12% lower in compressive strength than that of control concrete containing NCA.
2. The RCA with NS mixed by both methods shows the 40-51% improvement in tensile strength. Further presoaked RCA exhibit 11% higher tensile strength as compared to control concrete containing NCA.
3. The water absorption of RCA containing NS by direct mixing and presoaking RCA in NS solution shows the 43.92% and 60.34% respectively lower than that of control concrete with 100% NCA. The water absorption of concrete containing presoaked RCA in NS solution is only 25.6% higher than the control concrete containing NCA. The cumulative rate of water absorption of concrete with presoaked RCA was lower than that of direct mixing of nano-silica. This reduction due to a higher quantity of dissolved nano silica deposited on the surface of RCA during presoaking and also fills the micro-cracks below the surface and resulting in densifying the structure.
4. Thereduction in chloride ion penetration in RCA due to the addition of nano silicawas observed in RCPT testing of both methods. The mix with presoaked RCA classified as "low" and mix with direct mixing classified as "Moderate". Especially in case of presoaking, there was 58.19% reduction in RCPT than the natural aggregate concrete.
5. The reduction in sorptivity of recycled aggregates concrete was 30.66% and 38.28% was observed when nano silica used in concrete with direct mixing and presoaking method respectively. It was due to the high pozzolanic activity of nano-silica.

6. For mixes with nano silica direct mix and presoaking RCA, the decrement of water permeability were 48.62% and 47.94% respectively as compared to 100% RCA. The presoaking mixing method further shows the reduction in water permeability by 2.05% compared to direct mixing method of NS. The improvement in concrete due to the filler effect of a nano-sized particle of nano-silica.
7. Percentage strength loss reduces with both methods of nanosilica whenthe specimen is subject to acid attack solution. The presoaking method shows better results.

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