

Performance Evaluation of Nano-Silica Stabilized Recycled Aggregate Concrete for Medium Strength Structural Grades

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ABSTRACT: The use of recycled concrete aggregate (RCA) in concrete, either as a partial or full substitute for natural coarse aggregate, is gaining interest in the construction industry because it lowers the need for new aggregate. Also, using RCA helps solve the environmental issues caused by concrete waste and reduces the harmful impact of extracting aggregate from natural sources. This paper gives a detailed review of using RCA in concrete based on experimental findings. It covers the most important physical, mechanical, and chemical properties of RCA. However, more attention is given to how RCA affects the fresh and hardened properties and the durability of concrete. This project shows that recycled aggregates from concrete specimens can be used to make high-quality concrete. Concrete waste from broken cubes was collected, and a mix of 20% natural and 60% recycled aggregate was used to make fresh M35 grade concrete. In this study, the 28-day cube compressive strength using PPC was measured, and for mixes with 60% RCA, the strength results were 16%, 21%, 75%, and 100% for 3 days, 7 days, and 28 days respectively. In this work, the mechanical properties of recycled coarse aggregate were studied. Nanosilica was used as a partial replacement for Portland pozzolana cement, at 1.5% of the total cement weight, and M-Sand was used as the fine aggregate. Strength tests like compressive strength, split tensile strength, and flexural strength were conducted on M35 grade concrete with 60% RAC. Durability tests such as permeability and acid attack on concrete cubes were also carried out. To examine the microstructure of the concrete, XRD and SEM analyses were performed. This paper also highlights the gaps in current knowledge about RCA and RCA concrete and suggests areas for future research.

KEYWORDS: Recycled aggregate concrete, M-Sand, Nanosilica, SEM, XRD, Acid exposure, Permeability.

I. INTRODUCTION

Demolishing old and broken buildings and traffic systems, and building new ones in their place, is something that happens a lot around the world today. This is often due to a variety of reasons, such as buildings being used for different purposes, their structures becoming weak over time, city layouts being changed, roads expanding, traffic increasing, and natural events like earthquakes, fires, or floods. The main way to handle this waste material used to be throwing it away in landfills, which leads to a large amount of construction waste, becoming a big problem for the environment.

A possible solution to this is to recycle the broken concrete and use it to make a substitute material for regular concrete. This recycled concrete is made by crushing the old concrete twice, then washing and removing things like metal bars, paper, wood, plastic, and drywall. The concrete made with this recycled material is called recycled aggregate concrete (RAC). The main goal of this study is to look at the basic qualities of RAC, and how they compare to the qualities of traditional concrete made with natural materials. Fine recycled aggregate is not used in this process because it's generally not suitable for making strong concrete. Concrete is the most commonly used building material around the world. It is a solid material made from cement, aggregates, water, and sometimes special additives. Aggregates make up a big part of the mix, usually including sand, crushed stone, and gravel. These are inert materials that do not change in the mix. More than 80% of the total aggregate market is used in construction, mainly for buildings and roadways.

1.1 CEMENT:

Concrete is a material that is used today and will be used in the future. It is widely used in different structures, from homes to factories, from bridges to airports, making it one of the most studied materials in the 21st century. With the fast-growing population and the increase in technology, there is a need to improve the strength and durability of concrete. Out of the materials used in making concrete, cement is very important due to its size and ability to stick things together. So, to improve the properties of concrete, it is important to understand how cement reacts with water and find better replacements for it.

1.2 Composition and Hydration:

Cement can be described as a solid mix of calcium silicates and other calcium-based materials that have the ability to harden when mixed with water. The four main components of cement are Tri-calcium silicate (C3S), Di-calcium silicate (C2S), Tri-calcium aluminate (C3A), and Tetra-calcium alumina-ferrite (C4AF). C stands for calcium oxide, S for silicon dioxide, A for aluminum oxide, and F for iron oxide. Tri-calcium silicate and Di-calcium silicate are the main ones that give concrete strength, together making up about 70% of cement. Dry cement does not stick things together, so it cannot be used to make concrete on its own. When mixed with water, a chemical reaction called hydration occurs. The results of this reaction are C-S-H gel and calcium hydroxide. Calcium hydroxide has a small surface area and doesn't help much with the strength of concrete. During hydration, aluminates form a product called ettringite, which has a needle shape and helps with the early strength of concrete. C-S-H gel refers to calcium silicate hydrates, making up about 60% of the volume of a completely hydrated cement paste. It has a structure of short fibers that can be either crystalline or amorphous. Due to its gel-like structure, it can hold other inert materials because of Van der Waal forces. It is the main part that contributes to the strength of concrete.

1.3 NANOTECHNOLOGY IN CONCRETE:

Nanotechnology is an emerging field that deals with understanding and controlling matter at a very small scale, between 1 and 100 nanometers. It's not just about making things smaller; it's about using the unique properties of materials at that scale, which can have special physical, chemical, mechanical, and optical characteristics. Nanotechnology has a big impact in construction, helping to improve the durability, performance, energy efficiency, and safety of buildings. It also makes maintenance easier and improves living comfort. Basic construction materials like cement, concrete, and steel can benefit from nanotechnology. Adding nanoparticles can make concrete stronger, more durable, self-cleaning, and easier to compact.

1.4 NANOSILICA:

Recently, nanotechnology has been introduced into civil engineering applications. One of the most commonly used nanomaterials in this field is nanosilica (NS). It was the first product to replace micro silica. Studies on concrete at the nano level have produced better results than using silica fume in traditional concrete. Nanosilica has a higher pozzolanic nature, meaning it can react with free lime during the hydration process and form extra C-S-H gel, which increases the strength, impermeability, and durability of concrete. The use of nanotechnology in concrete has led to a widespread adoption of nanosilica in concrete. Different methods of producing nanosilica exist, varying from expensive to more affordable ones. The size and properties of nanosilica particles depend on the production method. Several types of nanosilica particles are recommended for use in concrete. However, the dry powder form of nanosilica is hard to mix into concrete and requires special types of nano super plasticizers. The effective use of nanosilica can improve the cementation properties of C-S-H.

Concrete is the most widely used material in the building industry, so improving its quality is essential.

Concrete is a highly varied material made by mixing finely powdered cement, aggregates of various sizes, and water, which have inherent physical, chemical, and mechanical properties. Cement can be partly replaced by mineral admixtures such as fly ash, silica fume, and metakaolin, which have certain properties similar to cement. Adding nanomaterials can lead to the creation of concrete composites with improved properties. The use of nanomaterials like nanosilica in concrete is an example of nanotechnology applied to construction. If nanoparticles are combined with cement-based materials, the resulting material has some outstanding features. Nanosilica improves the microstructure and lowers the water permeability, making concrete more dense and durable. In high-performance concrete, nanosilica improves the cohesion between particles, reduces segregation and bleeding. Some issues like a longer setting time and lower compressive strength at high percentages can be overcome with the use of nanosilica.

II. LITERATURE SURVEY

1) Haider A Ibrahim*, Mohammed B Mahdi, Basim J Abbas. (2020) This research looks at how fiber and silica fume affect the performance of pervious concrete pavements that use waste recycled concrete aggregate. The study uses recycled coarse aggregates from construction and demolition sites to create eco-friendly concrete. The results show that using recycled aggregates has a small effect on hydraulic conductivity and not much on compressive, tensile, or flexural strengths. However, silica fume and glass fibers have a bigger impact on hydraulic conductivity and improve the flexural and splitting tensile strengths of pervious concrete.

2) Rajeeb Kumar¹, Shilpa Pal², Neelesh Jadaun³, Rohit (2019) This study looks at how polymer-treated recycled concrete aggregates perform under different curing conditions. The research aims to use these materials in structural concrete. The study improves the performance of recycled aggregates by treating them with polymer to reduce water absorption. Hardened concrete properties of recycled aggregates for M35 grade were tested under normal, open-air, and polythene curing conditions. Different replacements were done, like 100% natural aggregate, 100% recycled aggregate, and 100% polymer-treated recycled aggregate. Durability tests, such as water absorption and permeability, were also carried out. The results show that treating recycled aggregate improves its properties, making it more durable and stronger than untreated recycled aggregate.

3) Quanmin Peng^{a,b}, Li Wang^a, Qun Lu^{a,c}. (2018) This study examines how the amount of recycled coarse aggregate affects the fatigue performance of recycled aggregate concrete (RAC). An experiment was conducted to test the compressive fatigue residual strength of RAC with different replacement percentages. The results show that as the percentage of recycled aggregate increases, fatigue life, residual strength, and residual stiffness all decrease. Regression analysis was used to find the residual strength and stiffness degradation curves, and the effect of replacement percentage on these curves was discussed. The study shows that fatigue life, residual strength, and residual secant modulus all decrease with higher RCA replacement, but to different degrees.

4) Sidam Gangaram¹, Vankadothu Bhikshma², Maganti Janardhana (2018) Recycled aggregate concrete (RAC) is important for preserving natural resources for future generations. This study focuses on the strength and durability of RAC made by replacing 100% natural aggregates with recycled aggregates, for M20 and M30 grades. The study presents results from tests on compressive strength, split tensile strength, flexural strength, and permeability. The results show that replacing natural aggregates with recycled ones for M20 and M30 grades gives good results. This replacement is beneficial and should be encouraged for achieving higher concrete grades.

5) Nagaraja Ba, Vinay K V a, Keerthi Gowda B S a, Karisiddappa b. (2017) Crushed concrete debris, which passes through a 20 mm sieve and is retained on a 10 mm sieve, is used as coarse aggregate for making economical cement concrete. The study compares the compressive strength of conventional concrete with concrete made with crushed debris. Replacement percentages of debris were tested from 10%, 20%, up to 100%. The highest compressive strength was recorded at 30% replacement, with a value of 31.11 MPa. Concrete with debris showed higher compressive strength than conventional concrete. Additionally, concrete with debris and 10 mm long banana fibers (1% of cementitious material) had the highest compressive strength. The study also found that recycled aggregates have higher water absorption and moisture content. The porosity of the mortar, which absorbs more water, is a main reason for the lower compressive strength.

6) Marco Pepe a, Romildo Dias Toledo Filho b, Eduardus A.B. Koenders c, Enzo Martinelli. (2016) This paper proposes a way to predict and control the compressive strength of recycled aggregate concrete by considering the specific features of recycled concrete aggregates. The method is meant to generalize previous rules and account for the higher porosity of RCAs. Although mainly conceptual, the method is supported by a lot of experimental results that show how factors like the source and processing of RCAs, the replacement ratio, water-to-cement ratio, water absorption capacity, and initial moisture conditions affect compressive strength. The study shows that the compressive strength of RAC can be predicted by focusing on one key parameter: water absorption capacity, which indicates the 'quality' of RCAs. Future work aims to control other properties of RAC.

7) Shi-cong Kou a,b, Chi-sun Poon a. (2015) This paper presents experimental results on how the quality of parent concrete affects the properties of recycled aggregates and the mechanical and durability properties of normal and high-

performance recycled aggregate concrete. Parent concrete with strength grades from 30 to 100 MPa was crushed into coarse aggregates (<20 mm) and then used to make new normal and high-performance RAC mixes. The results show that the compressive strength of normal and high-performance RAC made with recycled aggregates from 80 and 100 MPa parent concrete is similar.

III. METHODOLOGY AND EXPERIMENTAL INVESTIGATION

Exemplar An experiment was planned to gather enough information on the strength and durability of concrete made with 60% recycled aggregate, 1.5% nano-silica by weight of cement, and M-sand as the fine aggregate. Tests were done on the materials to understand their physical properties. The results were studied to find out how the recycled aggregates, along with nano-silica and M-sand, affect the strength of the concrete. M35 grade concrete was used for the mix design.

M35 grade mixes were used to see how the use of recycled coarse aggregate with nano-silica and M-sand influences the performance. The concrete was cured normally. The water to cement ratio was kept at 0.38 for the RAC M35 mix. Several trial mixes were made to reach the target strength for M35 concrete. Fresh concrete tests like slump flow and compaction factor were carried out. Hardened concrete tests included compressive strength of cubes (150mm x 150mm x 150mm), split tensile strength of cylinders (150mm x 300mm), and flexural strength of prisms (500mm x 100mm x 100mm) tested at 3, 7, and 28 days. A permeability test was done on concrete cylinders (100mm x 100mm) after 28 days of curing. Bond strength tests were also conducted on cubes after 28 days of curing. For acid attack tests, cubes (100mm x 100mm x 100mm) were cured for 28 days and then exposed to 0.1% and 0.3% acidic solutions. After that, the cubes were tested for weight loss and residual compressive strength. Microstructure analysis was done using SEM and XRD tests on powdered concrete samples.

Table 3.1 Specimens cast for strength and durability tests

Name of the Test	RAC M35
Number of cubes cast for compressive strength	9
Number of cylinders cast for split tensile strength	9
Number of prisms cast for flexural strength	9
Number of cylinder for permeability	3
Number of cubes cast for acid attack	24
Number of cubes cast for bond strength	3
Total number of sample cast	57

Table -3.2 Physical properties of cement (PPC) (IS 1489 Part-1 - 1991)

S.NO	PROPERTY	VALUE
1.	Specific gravity	2.94
2.	Fineness of cement by sieving	2%
3.	Normal consistency	30
4.	Setting time Initial setting time	168 min
	Final setting time	284 min
5.	Compressive strength	
	3days	16.00 MPa
	7days	26.00 MPa
	28days	42.01 MPa

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Table 3.3 Physical properties of fine aggregate: M-sand

S.NO	PROPERTY	Value
1	Grading of sand	Zone II as per IS 383
2	Specific gravity	2.57
3	Bulk density Loose state Compacted state	1.77 g/cc 2.00 g/cc
4	Fineness modulus	2.80

Table 3.4 Sieve analysis of Fine aggregate: M-sand

Weight of sample taken = 1000gms

Sl. No	IS Sieve	Weight Retained (g)	% Weight retained	Cumulative Weight retained	% Passing
2	4.75mm	2.1	0.21	0.21	99.79
2	4.75mm	2.1	0.21	0.21	99.79
3	2.36mm	126.5	12.65	12.86	87.14
4	1.18mm	240	24	36.86	63.14
5	600 µm	238.2	23.82	60.68	39.32
6	300 µm	266	26.6	87.28	12.72
7	150 µm	127.2	12.72	100	100
Fineness modulus = 2.98					

Table 3.5 Sieve Analysis of Recycled Coarse Aggregate

Sl. No	IS Sieve	Weight Retained (Kg)	% Weight Retained	Cumulative Weight Retained	% Passing
1	80 mm	0.00	0.00	0.00	100.00
2	40 mm	0.00	0.00	0.00	100.00
3	20 mm	292	14.6	14.6	85.4
4	10 mm	1704	85.2	99.8	0.2
5	4.75 mm	2	0.1	99.9	0.1
6	2.36 mm	0.23	0.1	100.00	0.00
7	1.18 mm	0.00	0.00	100.00	0.00
8	600 µm	0.00	0.00	100.00	0.00
9	300 µm	0.00	0.00	100.00	0.00
10	150 µm	0.00	0.00	100.00	0.00
Fineness Modulus = 7.14					

Table 3.6 Physical properties of Recycled Coarse Aggregate

Sl. No	PROPERTY	VALUE
1	Specific gravity	2.74

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2	Bulk density Loose state Compacted state	1.45 g/cc 1.60 g/cc
3	Fineness modulus	6.62
4	Water absorption 1. 20mm	1.02%

Table 3.7 Sieve Analysis of Coarse Aggregate

S.No.	IS Sieve	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative % Weight Retained	% Passing
1	80mm	0	0	0	100
2	40mm	0	0	0	100
3	20mm	118.5	5.925	5.925	94.075
4	10mm	1881.5	94.075	100	0
5	4.75mm	0	0	100	0
6	2.36mm	0	0	100	0
7	1.18mm	0	0	100	0
8	0.6mm	0	0	100	0
9	0.3mm	0	0	100	0
10	0.15mm	0	0	100	0

Fineness modulus = 7.05925

Table 3.8 Physical properties of Coarse Aggregate

Sl. No	PROPERTY	VALUE
1	Specific gravity	2.82
2	Bulk density Loose state Compacted state	1.45 g/cc 1.60 g/cc
3	Fineness modulus	6.62
4	Water absorption 20mm 10mm	0.81% 0.78%

IV. EXPERIMENTAL RESULTS

5.1 COMPRESSIVE STRENGTH OF CONCRETE OF RAC M35

Average Compressive strength(N/mm ²) of RAC M35			
Sample No	3 days	7 days	28 days
1	15.11	23.1	44.9
2	14.88.	23.1	44.9

3	15.55	24	44.5
Average	15.18	23.4	44.8

5.2 SPLIT TENSILE STRENGTH OF CONCRETE OF RAC M35

Average Split Tensile Strength(N/mm ²) of RAC M35			
Sample No	3 days	7 days	28 days
1	1.13	1.98	2.4
2	1.273	1.84	2.5
3	1.556	1.98	2.3
Average	1.32	1.93	2.4

5.3 FLEXURAL STRENGTH OF CONCRETE OF RAC M35

Average Flexural Strength(N/mm ²)of RAC M35			
Sample No	3 days	7 days	28 days
1	4.4	5.8	8.2
2	4.4	5.1	7.6
3	4.5	5.9	6.1
Average	4.4	5.6	7.3

5.4.1 Acid attack of RAC M35 grade concrete of 0.1% H₂S0₄

Sl. NO	Age (days)	Weight of cube before immersion (g)	Weight of cube after removal from acid tank (0.1% of H ₂ SO ₄) (g)	Weight reduction (%)	Average % weight reduction	Compressive strength (N/mm ²)	Average Age Compressive strength (N/mm ²)
1	14	2632	2605	1.03	1.15	40.00	40.67
2		2622	2599	0.88		41.00	
3		2672	2631	1.53		41.00	
4	28	2672	2636	1.35	2.06	41.50	39.50
5		2798	2736	2.22		39.50	
6		2684	2614	2.61		38.00	
7	42	2634	2588	1.75	2.22	36.00	36.00
8		2666	2600	2.48		37.00	
9		2732	2665	2.45		35.00	
10	56	2676	2600	2.84	2.72	35.00	34.50
11		2738	2674	2.34		33.50	
12		2622	2544	2.97		33.00	

5.4.2 Acid attack of RAC M35 grade concrete of 0.3% H2SO4

Sl. NO	Age (days)	Weight of cube before immersion (g)	Weight of cube after removal from acid tank (0.3% of H2SO4) (g)	Weight reduction (%)	Average % weight reduction	Compressive strength (N/mm ²)	Average Age Compressive strength (N/mm ²)
1	14	2718	2685	1.21	1.23	39.50	39.50
2		2730	2709	0.77		40.00	
3		2656	2611	1.69		39.00	
4	28	2618	2586	1.22	1.93	38.00	37.17
5		2716	2656	2.21		37.00	
6		2718	2654	2.35		36.50	
7	42	2718	2600	2.40	2.58	35.00	35.00
8		2664	2604	2.54		36.00	
9		2672	2615	2.79		34.00	
10	56	2676	2588	3.29	3.1	34.00	32.50
11		2738	2624	4.16		32.50	
12		2622	2569	2.02		31.00	

VI. CONCLUSION

Experiments A study was carried out using 60% recycled concrete with 1.5% Nanosilica added by weight of cement. Tests were done on compressive strength, split tensile strength, flexural strength, how acid affects concrete, permeability, SEM images, and XRD analysis.

Based on the test results, the following conclusions were made:

1. The compressive strength at 3, 7, and 28 days was higher than expected for M35 concrete. So, using recycled aggregate concrete (RAC) can provide better strength and is suitable for construction.
2. There was little variation in split tensile and flexural strength of RAC M35 at 3, 7, and 28 days of curing.
3. Both grades of concrete showed weight loss after exposure to 0.1% and 0.3% H2SO4 for 14, 28, 42, and 56 days.
4. The compressive strength decreased gradually after 42 and 56 days of exposure to 0.1% and 0.3% H2SO4 in both grades.
5. The permeability of RAC M30 and RAC M35 was lower than standard concrete (GWT). Nanosilica helped reduce water flow in the concrete.
6. SEM images showed that Nanosilica filled some voids and pores, and also showed the transition zone in the concrete.
7. In XRD analysis, two theta values were found for matched compounds, and their crystallite size was calculated. When concrete is exposed to harsh environments and cyclic loading, crystal growth happens, leading to cracks and deterioration together.

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