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Review of Enhancing the Strength of Concrete with Recycled Aggregates Through the Addition of Silica Fume

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ABSTRACT

An experimental study was carried out to explore the performance of recycled aggregate concrete incorporating silica fume. Thirty concrete cubes measuring 6 inches each side were prepared in six batches using a 1:2:4 mix ratio and a water-cement ratio of 0.55. Each batch comprised five samples, with cement replaced by silica fume at rates of 0%, 5%, 10%, 15%, 20%, and 25%, while natural coarse aggregate was replaced by recycled coarse aggregate at a 50% rate. These specimens were cured for 28 days. Various tests including sieve analysis for fineness modulus of aggregates, water absorption, specific gravity tests, slump tests, and compressive strength tests on cubes were conducted. The results indicated that a 15% replacement of cement with silica fume yielded the highest compressive strength. Hence, the optimal dosage of silica fume in green concrete was determined to be 15%.

Keywords: Recycled Aggregate Concrete, Waste Recycling, Silica Fume, Particle Size Distribution Analysis, Water Absorption & Specific Gravity Measurement, Workability Test, Cube Compressive Strength Test.

I. INTRODUCTION

In recent years, there has been a surge in construction activities worldwide, leading to an escalating demand for construction materials. This surge, coupled with the annual demolition of numerous old buildings as part of urban renewal efforts, generates a significant volume of waste concrete, commonly known as construction and demolition (C&D) waste. This rapid accumulation of waste not only poses challenges in finding suitable disposal sites but also contributes to environmental degradation. To address these challenges, there is a pressing need to recycle this waste for use in new construction projects.

The management of this waste presents significant challenges, prompting efforts to repurpose it within the construction industry. This study aims to investigate the feasibility of using recycled coarse aggregates sourced from Nawabshah city in concrete construction. Typically, recycled aggregate concrete alone does not achieve high strength, thus the incorporation of silica fume (SF) is explored to enhance its strength. However, recycled aggregate concrete may still find application in situations where the load-bearing capacity of structural elements is not paramount.While previous research has primarily focused on the use of recycled coarse aggregates in structural concrete, the utilization of the fine fraction has been relatively limited. Nonetheless, in recent decades, there has been growing interest in the use of recycled coarse aggregates (RCA) in research endeavors, driven largely by the need to address the shortage of natural coarse aggregates (NCA).

II. LITERATURE REVIEW

Numerous researchers have conducted experimental studies over the years on various properties of recycled aggregate concrete from different regions, aiming to assess its compressive strength. The existing literature presents findings from several scholars, providing valuable support for this study.

Khaleel H Younis [1] stated that, This study investigates the behavior of recycled aggregate concrete (RAC) incorporating Silica fume (SF). SF was introduced at four different levels (5%, 10%, 15%, and 20%). A total of six mixes were prepared, including four mixes of RAC with varying SF content, one mix without SF, and one mix with natural coarse aggregate (NCA) serving as a reference. The findings indicate that both workability and mechanical strength of RAC are inferior to those of concrete made with NCA. Furthermore, the inclusion of SF has a detrimental effect on the workability of RAC. However, SF can be effectively utilized at concentrations ranging from 10% to 20% of the cement mass to enhance the mechanical properties of RAC, making them comparable to those of concrete containing NCA.

Amudhavalli & Mathew [2] studied This study examines the impact of silica fume on the strength and durability properties of concrete. The primary focus is on M35 grade concrete with varying degrees of cement replacement by silica fume, ranging from 0% to 20%. A comprehensive experimental investigation was conducted, assessing compressive strength, split tensile strength, and flexural strength at both 7 and 28 days of curing. The findings indicate that the inclusion of silica fume in concrete enhances its performance in terms of strength and durability.

Perumal & Sundararajan [3] observe the effect of partial replacement of cement with silica fume on the strength and durability properties of high grade concrete. Strength and durability properties for M60, M70 and M110 grades of HPC trial mixes and to arrive at the maximum levels of replacement of cement with Silica fume, investigations were taken. The strength & durability characteristics of these mixes are compared with the mixes without SF. Compressive strengths of 60N/mm^2, 70N/mm^2 and 110N/mm^2 at 28days were obtained by using 10percent replacement of cement with SF. The results also show that the SF concretes possess superior durability properties.

Kumar & Dhaka [4] write a review paper on partial replacement of cement with silica fume and its effects on concrete properties. The main parameter investigated in this study M-35 concrete mix with partial replacement by silica fume with varying 0, 5, 9, 12 and 15% by weight of cement. The paper presents a detailed experimental study on compressive strength, flexural strength and split tensile strength for 7 days and 28 days respectively. The results of experimental investigation indicate that the use of silica fume in concrete has increased the strength and durability at all ages when compared to normal concrete.

Ghutke & Bhandari [5] examine the influence of silica fume on concrete. Results showed that the silica fume is a good replacement of cement. The rate of strength gain in silica fume concrete is high. Workability of concrete decreases as increase with % of silica fume. The optimum value of compressive strength can be achieved in 10% replacement of silica fume. As strength of 15% replacement of cement by silica fume is more than normal concrete. The optimum silica fume replacement percentage varies from 10 % to 15 % replacement level.

Hanumesh, Varun & Harish [6] observes the mechanical Properties of concrete incorporating silica fume as partial replacement of cement. The main aim of this work is to study the mechanical properties of M20 grade control concrete and silica fume concrete with different percentages (5, 10, 15 and 20%) of silica fume as a partial replacement of cement. The result showed that the compressive strength of concrete is increased by the use of silica fume up to 10% replacement of cement. From 10% there is a decrease in compressive strength and The split tensile strength of concrete is increased by the use of silica fume up to 10% replacement of cement. From 10% there is a decrease in split tensile strength. The optimum percentage of replacement of cement by silica fume is 10% for M20 grade of concrete.

Shanmugapriya & Uma [7] carried an experimental Investigation on silica fume as a partial replacement of cement in high performance concrete. The concrete used in this investigation was proportioned to target a mean strength of 60MPa and designed as per ACI. The water cement ratio (W/C) adopted was 0.32 and the Super- plasticizer used was CONPLAST SP 430. Specimens such as cubes, beams and cylinders were cast for various mix proportions and tested at the age of 7, 14 and 28 days CI 211.4R-08. The investigation revealed that the partial replacement of cement by silica fume will develop sufficient compressive strength, flexural strength and split tensile strength for construction purposes. The optimum dosage of silica fume found to be 7.5% (by weight), when used as partial replacement of ordinary portland cement.

Alok [8] write a research paper on partial replacement of cement in M-30 concrete from silica fume and fly ash. Replacement levels of OPC by silica fume were 0%, 2.5%, 5% and 7.5% where replacement levels of ordinary portland cement by fly ash were 0%, 5%, 10% and 15% by weight. 1% super-plasticizer was used in all the test specimens for better workability at lower water cement ratio and to identify the sharp effects of silica fume and fly ash on the properties of concrete. Water-cement ratio was kept 0.43 in all cases. 43.1N/mm^2 was the maximum compressive strength which was obtained at replacement level of 7.5% by weight of SF and 20% by weight of FA with cement. 6.47N/mm^2 was the maximum flexural strength which was obtained at replacement level of 7.5% by weight of SF and 20% by weight of FA with cement. 2.573N/mm^2 was the maximum split tensile strength which was obtained at replacement level of 7.5% by weight of SF and 20% by weight of FA with cement.

Jain & Pawade [9] studied the characteristics of silica fume concrete. The physical properties of high strength silica fume concretes and their sensitivity to curing procedures were evaluated and compared with reference portland cement concretes, having either the same concrete content as the silica fume concrete or the same water to cementitious materials ratio. The experimental program comprised six levels of silica-fume contents (as partial replacement of cement by weight) at 0% (control mix), 5%, 10%, 15%, 20%, and 25%, with and without superplasticizer. It also included two mixes with 15% silica fume added to cement in normal concrete. Durability of silica fume mortar was tested in chemical environments of sulphate compounds, ammonium nitrate, calcium chloride, and various kinds of acids.

Roy & Sil [10] Studied the effect of partial replacement of cement by silica fume on hardened concrete. From the study it has been observed that maximum compressive strength (both cube and cylinder) is noted for 10% replacement of cement with silica fume and the values are higher (by 19.6% and 16.82% respectively) than those of the normal concrete (for cube and cylinder) whereas split tensile strength and flexural strength of the SF concrete (3.61N/mm^2 and 4.93N/mm^2 respectively) are increased by about 38.58% and 21.13% respectively over those (2.6N/mm^2 and 4.07N/mm^2 respectively) of the normal concrete when 10% of cement is replaced by SF.

Amarkhail [11] observed effects of silica fume on properties of High-strength concrete. He found that up to 10% cement may be replaced by silica fume without harming the concrete workability. Concrete containing 10% silica fume replacement achieved the highest compressive strength followed by 15% silica fume replacement with a small difference. Concrete with 15% silica fume content achieved the highest flexural strength.10% and 15% silica fume content as replacement of cement were found to be the optimum amount for significantly enhancement of compressive strength and flexural strength respectively.

Sasikumar & Tamilvanan [12] performed an experimental investigation on properties of silica fumes as a partial replacement of cement. Main parameter investigated in this study is M30 grade concrete with partial replacement of cement by silica fume 0%, 25%, 30%, 40% and 50%. The normal consistency increases about 40% when silica fume percentage increases from 0% to 25%. The optimum 7 and 28-day compressive strength has been obtained in the 25 % silica fume replacement level. Also the split tensile strength is high when using 25% silica fume replacement for cement.

Ajileye [13] cement replacement upto 10% with silica fume leads to increase in compressive strength for M30 grade of concrete. From 15% there is a decrease in compressive strength for 3, 7, 14 and 28 days curing period. Compressive strength of M30 grade of concrete was increased from 16.15% to 29.24% and decreased from 23.98% to 20.22%.

Sharma & Seema [14] examined the effect of partial replacement of cement with silica fume on compressive strength of concrete.M20 grade of concrete with W/C ratio as 0.5 and percentage replacement was 0%,10%,20%. The optimum compressive strength is obtained at 20% cement replacement by a Silica Fume at all age levels (i.e.24 hours,7& 28 days). The 28 days' compressive strength at 20% replacement was found to be 32.29 MPa with a slump value of 21 mm.

Pradhan and Dutta [15] investigated the effects of silica fume on conventional concrete The optimum compressive strength was obtained at 20% cement replacement by silica fume at 24 hours, 7days and 28 days. Higher compressive strength resembles that the concrete incorporated with silica fume was high strength concrete.

Srivastava [16] worked out the workability of concrete on optimum replacement of silica fume by cement. Workability reduces with the addition of silica fume. However, in some cases improved workability was observed. With the addition and variation of replacement levels of silica fume the compressive strength significantly increased by (6-57%). There was no change observed in the tensile and flexural strength of the concrete as compared to the conventional concrete.

III. MATERIALS & TESTING

A. MATERIALS DETAIL

Mix proportioning was done using ACI method. Details of ingredients proportioning are as follows.

Cement:

Ordinary Portland Cement (Lucky Cement) used in the mixes was obtained from the local market of Nawabshah city. Figure 1 shows the pictorial view of ingredients used in this research work.

Silica Fume:

Silica fume (SF) used in this research work was densified silica fume, obtained from the local market of Karachi city. Figure 2 shows the pictorial view of densified silica fume.

Coarse Aggregates:

Recycled aggregate concrete was sourced from Nawabshah city and processed by hammering to obtain aggregates with a minimum size of 25mm. Sieving was then conducted to isolate the recycled coarse aggregates. Additionally, natural coarse aggregates of similar size were procured from the local market in Nawabshah city.

Recycled coarse aggregates (RCA): Passing from 1" sieve and retained at sieve #4

Natural coarse aggregates (NCA): Passing from 1" sieve and retained at sieve #4

Fine aggregates:

Fine aggregates (Bolhari Sand) used in the mixes were obtained from the local market of Nawabshah City. The Sand was sieved to remove lumps and larger particles before used in the concrete.

Fine aggregates (FA): Passing from #4 sieve and retained at sieve of 200 micron

Mix proportion: 1:2:4

Specimen: Cubes: 6" x 6" x 6"

Percentage of Recycled coarse aggregates:

50% replacement of natural coarse aggregate with recycled aggregates as coarse aggregate is used in this research.

Percentage of silica fume:

0%, 5%, 10%, 15%, 20% and 25% replacement of cement with silica fume as binding material is used in this research.

Water cement ratio: 0.55 W/C

Standard procedure has been followed for mixing the ingredients and making the cubes. The prepared cubes are cured for 28 days in water.

Figure 1: Concrete ingredients

Figure 2: Densified Silica Fume

B. TESTING

- **Gradation of aggregates**

After hammering and removing the unwanted material from recycled coarse aggregate, sieve analysis of both the aggregates (natural & recycled) were done. Grading for nominal size coarse aggregate shall comply with ASTM C-33 standard gradations: 1-inch Nominal size coarse aggregate. Table 1 shows the gradation of natural

& recycled aggregates.

Table 1: Fineness modulus test results of natural & recycled coarse aggregate (Sample weight = 3500 grams)

S. No.	Sieve (mm)	Sieve #	Weight retained (g)		Commulative Weight Retained (g)		% Commulative wt. Retained		% Passing	
			NCA	RCA	NCA	RCA	NCA	RCA	NCA	RCA
1	37.50	1.5"	0	0	0	0	0	0	100	100
2	25.00	1"	0	100	0	100	0	2.86	100	97.14
3	19.00	3/4"	1260	940	1260	1040	36	29.71	64	70.29
4	12.50	1/2"	1720	1500	2980	2540	85.14	72.57	14.86	27.43
5	9.50	3/8"	420	380	3400	2920	97.14	84.43	2.86	15.57
6	4.75	#4	80	400	3480	3320	99.43	94.86	0.57	5.14
7	2.36	#8	0	80	3480	3400	99.43	97.14	0.57	2.86
8	Pan		20	100	3500	3500	100	100	0	0
Total			3500	3500			F.M=5.17	F.M=4.8		

- **Water absorption & Specific gravity test of aggregates**

Following the gradation of aggregates, both natural and recycled coarse aggregates underwent a washing process and were subsequently oven-dried to measure their water absorption and specific gravity (see Figure 4). The water absorption and specific gravity values of the aggregates are presented in Table 2.

Table 2: Water absorption and Specific gravity of NCA and RCA

Test	NCA	RCA
Water absorption (%)	0.76	6.56
Specific gravity	2.61	2.36

- **Workability**

To check the workability of concrete, slump cone test was done for all concrete mixes. The test was performed following the standard procedure prescribed by the relevant testing standard (figure 3). The obtained results are given in Table 3.

Figure 3: Pictorial view of Slump cone test

Figure 4: Water absorption and specific gravity test

Table 3: Workability by slump test

S.No	%SF	%RCA	% NCA	W/C Ratio	SLUMP (mm)
1	0	50	50	0.55	30
2	5	50	50	0.55	25
3	10	50	50	0.55	22
4	15	50	50	0.55	20
5	20	50	50	0.55	16
6	25	50	50	0.55	16

- **Preparing & curing of specimen**

Six batches of concrete samples were prepared, each batch adhering to a water-cement ratio of 0.55 and a mix ratio of 1:2:4. Within each batch, five specimens were created, each with dimensions of 6 inches by 6 inches, as detailed in Table 4. The preparation of molds, pouring of concrete, and compaction were carried out in accordance with ASTM 943-17 standards. After a period of 24 hours, the specimens were demolded and allowed to air dry. Subsequently, all specimens underwent curing by complete immersion in potable water for a duration of 28 days, as illustrated in Figure 5.

Table 4: Specimen details

Batch No.	No. of cubes	Cement	Silica fume	F.A	RCA	NCA	W/C ratio	Curing period
B1	5	100%	0%	100%	50%	50%	0.55	28 days
B2	5	95%	5%	100%	50%	50%	0.55	28 days
B3	5	90%	10%	100%	50%	50%	0.55	28 days
B4	5	85%	15%	100%	50%	50%	0.55	28 days
B5	5	80%	20%	100%	50%	50%	0.55	28 days
B6	5	75%	25%	100%	50%	50%	0.55	28 days

- **Compressive strength test of cubes**

After 28 days, the specimen was air-dried for 24 hours. Then, specimens were tested for compressive strength by using Automatic Compression Machine (ACM). The ACM was set to apply the load until failure (Figure 6). The compressive strength of each batch of cylinders is evaluated and is listed in Table 5.

Figure 5: Curing of specimens for 28 days

Figure 6: Cubes specimen under testing

Table 5: Average compressive strength of cubes for 28 days

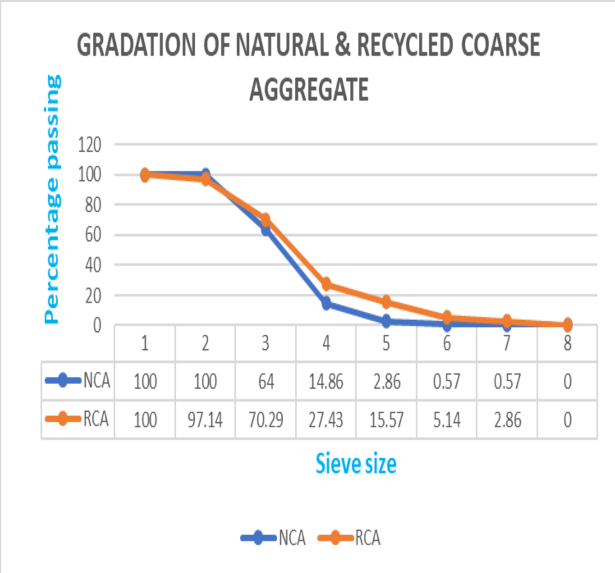
Batch No.	%SF	%RCA	%NCA	Loading (N)	Average Compressive Strength		% Change
					MPa	Psi	
1	0	50	50	542565	24.114	3497.438	....
2	5	50	50	590580	26.248	3806.938	+8.85
3	10	50	50	639450	28.42	4121.968	+17.85
4	15	50	50	667800	29.68	4304.716	+23.08
5	20	50	50	583020	25.912	3758.2176	+7.456
6	25	50	50	541935	24.086	3493.374	-0.116

IV. RESULTS AND DISCUSSION

The gradation curves of both natural coarse aggregates (NCA) and recycled coarse aggregates (RCA) exhibit a similar pattern, as illustrated in Figure 7. The trends of both curves are almost identical, with slight variations in range values across sieves.

In Figure 8, it is observed that the water absorption of RCA is 88.41% higher than that of NCA, while in Figure 9, the specific gravity of RCA is 10.59% lower than that of NCA. These differences in properties are primarily attributed to factors such as age, dryness, the presence of old cement attached to the aggregate, and higher water absorption due to recycled coarse aggregate (RCA) obtained from old mortar. This increased water absorption leads to a higher aggregate weight and consequently, a lower specific gravity. Moreover, RCA tends to absorb more water than NCA, resulting in higher water absorption. These findings underscore the importance of addressing the water requirement of aggregates when determining the water-cement ratio for concrete.

Figure 10 illustrates the results of the slump test, indicating a continuous decrease in the workability of the concrete mix as the replacement of silica fume increases. To ensure proper workability, either an increase in the water-cement ratio or the use of admixtures is necessary. However, in this study, the water-cement ratio remains constant as previously mentioned, and no plasticizer is utilized.



	1	2	3	4	5	6	7	8
NCA	100	100	64	14.86	2.86	0.57	0.57	0
RCA	100	97.14	70.29	27.43	15.57	5.14	2.86	0

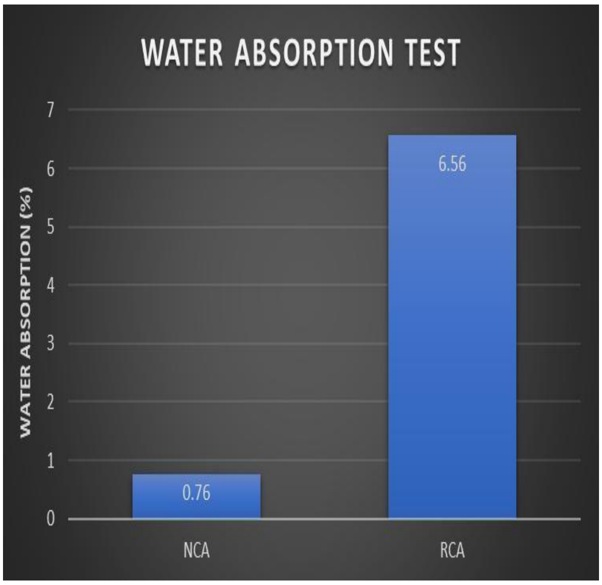


Figure 11 presents the average compressive strength results of concrete cubes made with varying percentages of silica fume replacement and recycled coarse aggregate substitution, with 28 days of curing. It is evident from the obtained results (Figure 12) that a 15% dosage of silica fume yields the optimum compressive strength, with a notable increase of 23.08%.

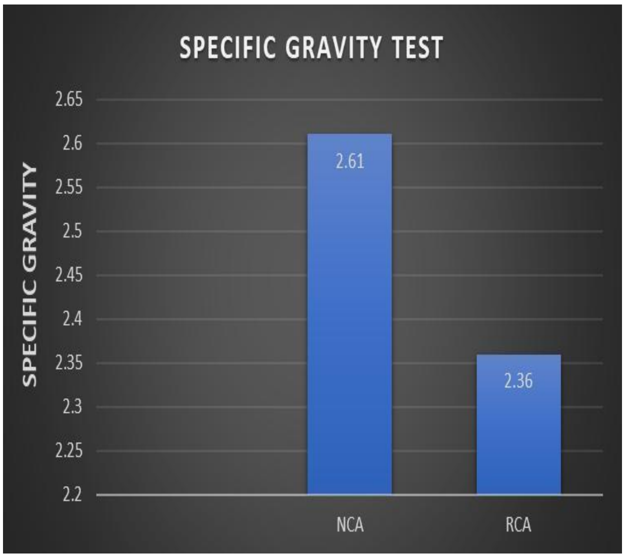


Figure 9: Comparison of specific gravity of aggregates

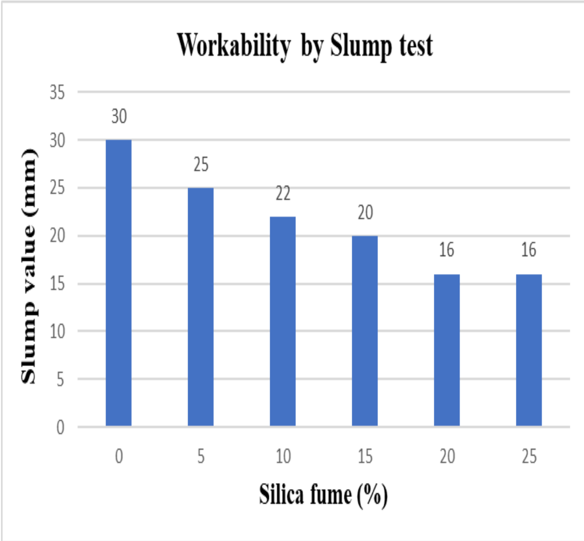


Figure 10: Bar chart of Slump test

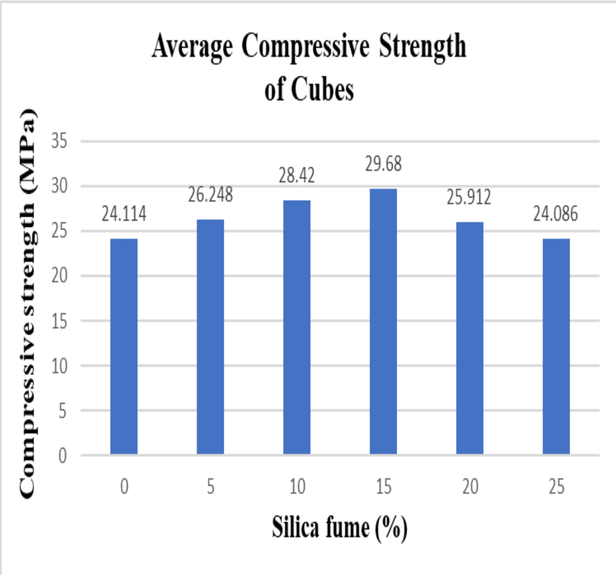


Figure 11: Average compressive strength at 28 days

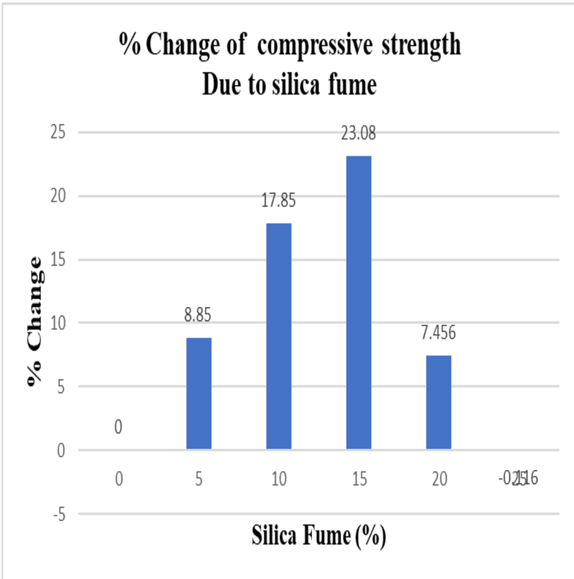


Figure 12: % Change in compressive strength

V. CONCLUSION

An experimental program was undertaken to investigate the utilization of recycled coarse aggregates, replacing 50% of natural coarse aggregates, and silica fume as replacements for cement at varying percentages (0%, 5%, 10%, 15%, 20%, and 25%) in the production of structural concrete. The gradation of both natural coarse aggregates (NCA) and recycled coarse aggregates (RCA) was analyzed, with the fineness modulus of RCA falling within the range of NCA.

The water absorption of recycled coarse aggregate was found to be approximately 88.41% higher than that of natural coarse aggregate, while the specific gravity of recycled coarse aggregate was observed to be 10.59% lower than that of natural coarse aggregate.

The slump test results indicated a consistent decrease in the workability of the concrete mix as the percentage replacement of silica fume increased.

Regarding compressive strength, it was observed that the strength increased with an increase in silica fume percentage up to 15%, after which it decreased with further increases in silica fume percentage (20% and 25%). A dosage of 15% silica fume was determined to be the optimum, resulting in a 23.08% increase in compressive strength.

Based on these findings, it can be concluded that this approach can be effectively utilized in applications where the load-carrying capacity of structural members is not the primary concern.

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