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COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE INCORPORATING SILICA FUME

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ABSTRACT

An experimental research has been conducted to utilize the behaviour of recycled aggregate concrete made with silica fume. 30 concrete cubes of (6″x 6″x 6″) size with 1:2:4 mix, and 0.55 water cement ratio were prepared in six (06) batches. Each batch consists of 05 samples. Six (06) batches were made with 0%, 5%, 10%, 15%, 20% and 25% replacement of cement with silica fume and 50% replacement of natural coarse aggregate with recycled coarse aggregate. Specimens were then cured for 28 days. Fineness modulus of aggregates, water absorption and specific gravity test of aggregates, slump test, and compressive strength test of cubes were conducted. 15% replacement of cement with silica fume gives better result in compressive strength. Therefore, 15% replacement is concluded as a optimum dosage of the silica fume in green concrete.

Keywords: Recycled Aggregate Concrete, Demolishing Waste, Silica Fume, Sieve Analysis, Water Absorption & Specific Gravity Test, Slump Test, Compressive Strength Test.

I. INTRODUCTION

In recent decades, number of constructions is seen to build everywhere around the world. Constructions of different types of structures are increasing day by day. Hence, the requirement of construction materials is increasing at large scale everyday that results to depletion of natural resources. On the other hand, a considerable number of old buildings are demolished annually due to urban renewal, creating significant amount of waste concrete, known as the construction and demolition (C & D) waste. This rapid increase in waste is resulting not only in finding the suitable ground for landfills but also creating environmental degradation. To overcome such problems, use of this waste after recycling in new construction is the need of the day.

The management of this waste is considerably increasing the serious problems. The purpose of this study is to re-utilize this valuable waste in construction industries. For this, an experimental study has been done to verify the strength of concrete with using recycled coarse aggregates obtained from Nawabshah city. Generally, recycled aggregate concrete not gain high strength alone, so we use silica fume (SF) which is used to achieve high strength. However, recycled aggregate concrete can be used where load carrying capacity of a structural member is not of prime importance.

Several researchers have worked for the use of recycled coarse aggregate in structural concrete, whereas the use of the fine fraction is limited. However, during the last few decades the use of recycled coarse aggregate (RCA) has achieved a great interest in research, mainly because to overcome the shortage of natural coarse aggregate (NCA).

II. LITERATURE REVIEW

A number of experimental studies have been carried out by numerous researchers since long time on the different properties of recycled aggregate concrete of different regions in order to evaluate the compressive strength of recycled aggregate concrete. Available literature is presented of various scholars as follows, which supports this work.

Khaleel H Younis [1] stated that, this research deals with the behaviour of recycled aggregate concrete(RAC) made with Silica fume (SF). Silica fume was used at four contents (5%, 10%, 15%, and 20%). The total number of mix was six(06). Four mixes of RAC made with these contents of silica fume (SF), one mix was made without

SF and one mix was made with natural coarse aggregate (NCA) as a reference mix. The outcomes of this study reveals that workability and mechanical performance of RAC are lower than that of of made NCA. Also silica fume (SF) has adverse influence on workability of the RAC. Silica fume (SF) can be used at contents of (10-20%) of cement mass to obtain mechanical performance for the RAC comparable to the concrete include NCA.

Amudhavalli & Mathew [2] studied the effect of silica fume on the strength and durability characteristics of concrete. The main parameter investigated in this study is M35 grade concrete with partial replacement of cement by silica fume by 0, 5, 10, 15 and by 20%. A detailed experimental study in compressive strength, split tensile strength, flexural strength at age of 7 and 28 day was carried out. Results shows that silica fume in concrete has improved the performance of concrete in strength as well as in durability aspect.

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.

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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 were collected from Nawabshah city. The collected recycled aggregate concrete was hammered to get aggregate of minimum size of 25mm. Sieving was done to get the recycled coarse aggregates. Similar sized natural coarse aggregates (Conventional aggregates) were obtained from local market of Nawabshah city.

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

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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**

After gradation of aggregates, natural & recycled coarse aggregates were washed & oven-dried to check the water absorption & specific gravity (Figure 4). Table 2 shows the water absorption & specific gravity of aggregates.

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 (06) batches of concrete samples were made using 0.55 water cement ratio and 1:2:4 mix. Each batch contained 05 specimens having dimensions 6”x6”. Table 4 shows specimen details. Mould preparation, pouring of concrete & compaction was done in accordance with ASTM 943-17. After 24 hours, the specimens were demoulded and left to air dry. All the specimens were cured by fully immersing in potable water for 28 days (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 were 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

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IV. RESULTS AND DISCUSSION

The curve of gradation of both the materials (NCA and RCA) shows same pattern shows in Figure 7. The trend of both curves is almost similar, with minor differences in range values over a sieve. Water absorption of RCA is observed 88.41% more than water absorption of NCA (Figure 8) and specific gravity of RCA is observed 10.59% less than specific gravity of NCA (Figure 9). The difference in the properties is mainly due to the age, dryness and old cement attached with the aggregate and more water requirement. Recycled coarse aggregate (NCA) obtained from old mortar sucks more water causes in increment the weight of the aggregates, thus results in lesser specific gravity. Also, the same sucks more quantity of the water than NCA and leads to higher water absorption. This is clearly indicates that water requirement of the aggregate must be addressed, while choosing the water/cement ratio of the concrete. The result of slump test shown in Figure 10 shows that there is continuous decrease in workability of concrete mix, as replacement of silica fume increased. This requires the increase in water cement ratio or the use of admixture to ensure proper workability of the mix. However, in this research work the w/c ratio is kept same as mentioned earlier and no plasticizer is used. The average results of compressive strength of concrete cubes made with 0%, 5%, 10%, 15%, 20% & 25% replacement of cement with silica fume & 50% replacement of natural coarse aggregate with recycled coarse aggregates is shown in Figure 11 with (28 days curing). It is observed from the obtained results 15% dosage of silica fume is concluded as optimum dosage with 23.08% increase in compressive strength (Figure 12).

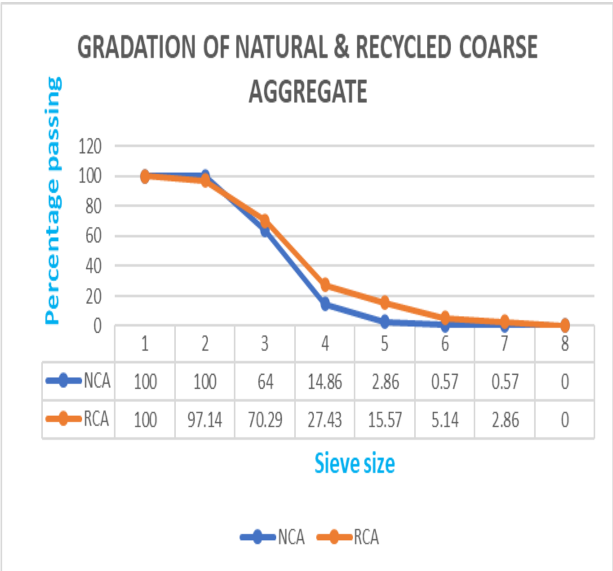

Figure 7: Comparison of Gradation of aggregates

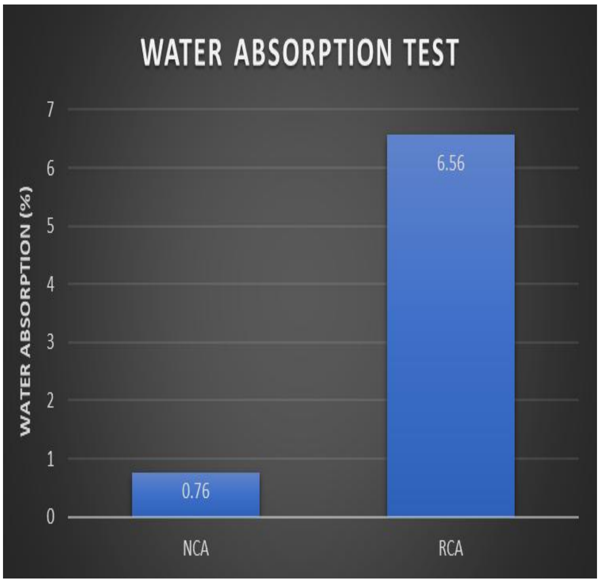

Figure 8: Comparison of water absorption of aggregates

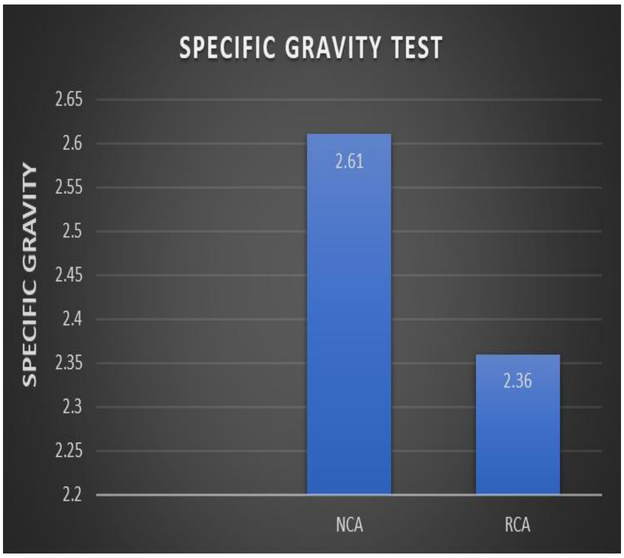

Figure 9: Comparison of specific gravity of aggregates

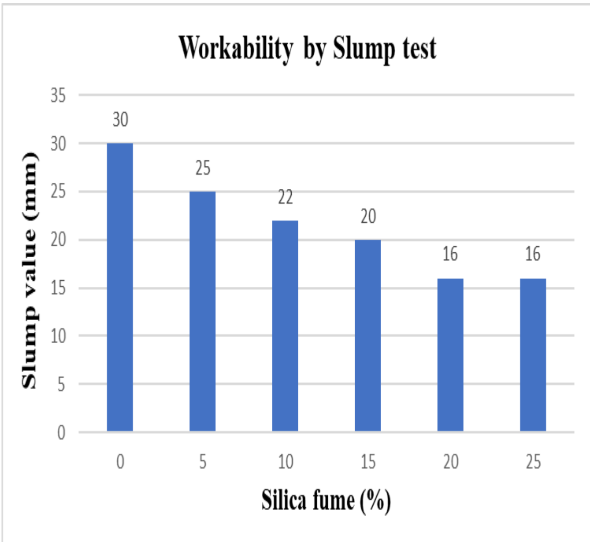

Figure 10: Bar chart of Slump test

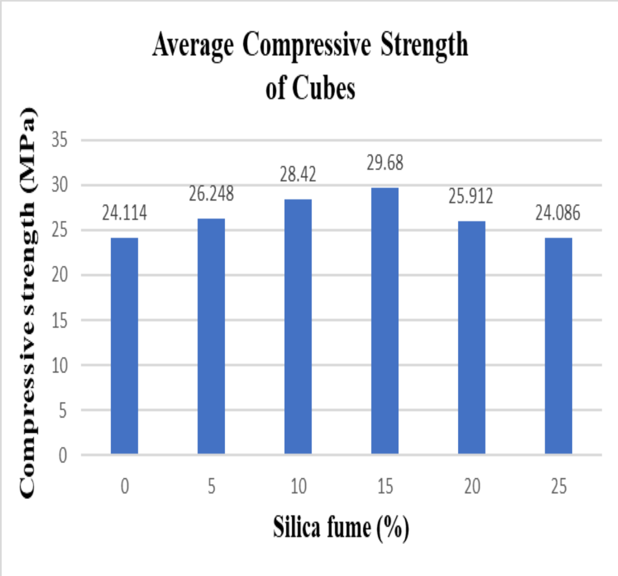

Figure 11: Average compressive strength at 28 days

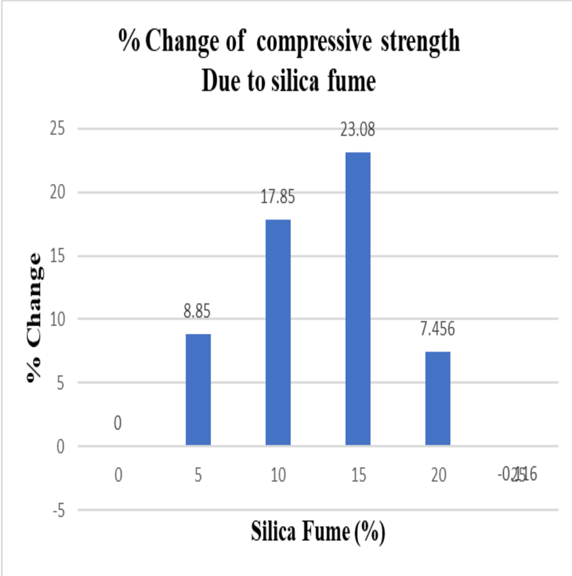

Figure 12: % Change in compressive strength

V. CONCLUSION

An experimental program was conducted to study these of recycled coarse aggregates as 50% replacements of natural coarse aggregates and silica fume as (0, 5, 10, 15, 20 and 25%) replacement of cement in the production of structural concrete. The gradation of NCA and RCA was conducted. The fineness modulus of RCA obtained is also within the range of fineness modulus of NCA. Water absorption of recycled coarse aggregate is about 88.41% higher than the water absorption of of the natural coarse aggregate. Specific gravity of recycled coarse aggregate is observed 10.59% less than the specific gravity of natural coarse aggregate. The result of slump test shows there is continuous decrease in workability of concrete mix, as replacement of silica fume increased. Compressive strength is increased with the increase of the silica fume percentage (0%, 5%,10% and 15%) and then reduced with increase of silica fume percentage (20%, 25%). 15% dosage of silica fume is concluded as optimum dosage with 23.08% increase in compressive strength. Based on the results it can be concluded that the approach can effectively be used in those areas where the load carrying capacity of structural members is not of primary importance.

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