Sustainable use of granite waste and silica fume in the production of self-compacting concrete

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Abstract: ***Continuous stockpiling of granite industrial by-product enforced researchers to use this waste in a sustainable manner in concrete to reduce its adverse impacts on the ecosystem. On the other hand, self-compacting concrete (SCC) is being widely used which requires a higher quantity of cement and ultimately resulting in the substantial CO2 emission to the environment. The aim of this study is to produce economical, eco-efficient, durable, sustainable, and high-strength SCC using granite cutting waste (GCW) and silica fume (SF). This would help to beneficially use SF and minimize the need to use large quantities of cement in high- strength SCC production, thus significantly reducing CO2 emissions. Therefore, fresh, and hardened properties of self-compacting concrete (SCC) containing GCW and SF were assessed in this study. The GCW and SF was used at an increased step level as replacement of fine aggregate (i.e., river sand) and cement respectively up to an optimum limit. Slump flow, T500 time, V-funnel, L-box, and J-ring tests were performed to assess the fresh properties of SCC mixes, whereas, compressive strength, flexural strength, ultrasonic pulse velocity, water absorption and water permeability tests were conducted for measuring the hardened properties of SCC mixes. The microstructural investigation was carried out using the Scanning electron microscope (SEM) and X-Ray diffraction (XRD) techniques. This project report deals with the different studies done in the field of SCC regarding feasibility of GCW as a partial replacement of natural fine aggregate and inclusion of SF as partial cement replacement in the production of SCC. The use of GCW and SF improves the fresh and hardened state characteristics of concrete.***

Index Terms: Granite cutting waste, Silica fume, and Self-compacting concrete

I. INTRODUCTION

Densely populated country leads to high demand of infrastructure as it is the foundation for any country's development. Concrete is widely and extensively used to make strong and durable infrastructure. It is the second most utilized material after water in the world. Concrete is made up of cement, fine aggregate (i.e., river sand), coarse aggregate and water which attain its strength with time. To produce concrete excessive number of natural resources are used which are non-biodegradable and led to higher environmental degradation. In India, river sand exploitation is mostly accompanying construction activities. In our country, 70 million tons of sand was needed in the year 2018 annually. The annual rate of increment in sand demand is up to 7%. Generally, the fine aggregate content is about 35% to 45% by weight or volume of the total aggregate content. Today, continuous sand mining turned into serious environmental problems; for example, natural resources depletion, disrupts the river's ecosystem. Sand mining also increases the flow velocity of river which disturbs the flow-regime and erodes the river banks. To reduce the negative impacts of concrete production on the environment, several researchers in the whole world are investigating the industrial waste material as an alternative of components of concrete mix. As per the many researchers, the utilization of such waste material is beneficial for our society by making the concrete economical, durable and sustainable. For modern development, excess amount of cement is required during concrete production. Globally, India is the second largest country in cement production after China. Share of the cement production in China is approximately half of the world's cement production which is 2.5 billion metric tons in the year 2021. The biggest environmental issue about the production of cement is that it is one of the largest manufacturers of carbon dioxide (CO2). It emits about 8% of worldwide carbon dioxide produced by human activities. Therefore, the construction industry is aiming towards the utilization of industrial waste material as cement; such as ceramic waste, silica fume, slag, fly ash etc. to reduce the adverse impacts on environment and to produce durable and sustainable concrete.

Supplementary mineral admixtures are used to partially replace the binder material in SCC concrete mix production. Silica fume (SF) is one of the most extensively utilized mineral additive in concrete mix production. It can also be named by many other names like silica dust, micro silica, condensed silica or volatized silica. SF is a byproduct of smelting process of the ferrosilicon alloys or silicon metal production. These replacements are done to enhance its fresh, mechanical and durability properties due to its better pozzolanic effects than cement. The effective pozzolanic property gives more impermeable pore structure than plain cement concrete. The superior pozzolanic property of SF is because of its high amorphous silicon dioxide content (85-97%) and hundred times finer than the average cement particle which gives high specific surface area. SF gives exceptionally positive impacts on concrete as a cement substitute; for example, gives high strength concrete, increases durability, bonding strength and surface electrical resistivity, decreases permeability, resistivity against corrosive chemicals, reduction in expansion and many more. The availability of higher amount of silica in mix helps to prosper C-S-H gel generation. This process is the reason which helps to enhance the hardened properties of SCC mixes. In short, SF is used to revamp the properties of concrete. However, due to its low bulk density (130-430kg/m^2) and high surface area (13000-30,000m^2/kg) it introduces challenges in storage, loading, transportation and placement in concrete mixer. The practical problems are scattering and raising of dust as well as high labor and transportation cost.

The huge amount of different kind of industrial wastes; for example, granite waste, marble waste, glass waste, ceramic waste and etc. are consistently producing with the advancement in the industrialization in the whole world. As per the WNSA report, after China and Brazil the highest amount of granite blocks are produced in India. After sawing and polishing process, about 25%-30% of granite blocks are produced as granite solid waste in these industries. These hazardous and toxic industrial wastes have created problems in handling and disposing them which makes the land and air get polluted. Therefore, various investigations have been directed in last three decades by researchers to use the industrial by-product as the replacement of concrete components. Many researchers concluded that these substitutions not only make the concrete strong, durable, sustainable, and economical but also reduces the landfill overburden.

II. OBJECTIVE OF THE STUDY

The research work here represents the foremost replacement percentage of granite waste (GW) and silica fume (SF) of fine aggregate (FA) and cement respectively, to generate an eco-friendly SCC concrete. The replacement percentage of GW were 0%, 10%, 20% 30%, 40% and 50%and SF were 0%, 4%, 8%, 12%, 16% and 20%. As per the accessible literatures, no investigation is available with respect to the behavior of SCC concrete made with the combined use of GW along with the SF as a substitution of natural aggregate and cement respectively. Analysis of SCC mix production was evaluated with reference to fresh, mechanical and microstructural properties.

In this study, both materials GW and SF were taken together for SCC production because the surface texture of GW is rough, elongated and angular which increases its surface area and for that higher amount of binder material is required to make a compact packed matrix concrete. As, SF have very reactive pozzolanic property due to its fineness which improves the filler efficiency of GW and SF also forms CSH gel with calcium as per many authors which may result in the satisfied need of binder material for GW and make a dense and compact matrix which can improve the hardened properties of SCC mix.

To examine the performance of SCC in the fresh state, various tests such as slump flow, T500 time, V funnel time, J-ring flow and L-box height ratio tests were done. Hardened state properties were estimated using compressive strength, flexural strength, split tensile strength, ultrasonic pulse velocity and durability tests were done by acid attack, sulphate attack, fire attack and water absorption tests. Scanning Electron Microscope (SEM) analysis was performed to evaluate the microstructure analysis. After getting the results of the above-mentioned tests, the silica granite modified SCC mix concrete was denser, durable, and showed finer sustainability with respect to the control mix.

III. LITERATURE REVIEW

The granite waste material in one of the hazardous and toxic industrial waste and silica fume is the condensed fume ash which generates from the smelting process. The use of these waste materials improves the performance of the concrete. Here are some literature analyses of many authors for both the waste materials (GW and SF).

Summary of literature review of granite waste:

After studying the literature of many authors, the conclusion is that, By adding GW in concrete, there will be decrement in fresh properties. However, by incorporation of GW in concrete there is enhancement in hardened characteristics of concrete due to its rough and irregular morphology. Due to filler efficiency of GW, there is reduction in interconnected voids within the concrete matrix which leads to the lower percentage of permeable voids and higher strength (due to improved packing density which comes from the finer content of the GWA). As compared to control SCC mix, granite modified SCC mixes requires higher dosage of liquefier to improve the affected fresh characteristics of concrete. As compared to the NVC, in SCC the optimum GW replacement level is higher. The favorable results of GW modified concrete is due to the compact matrix of the concrete, which is a direct result of the rough and irregular surface of the GW. Tests to determine the optimum granite level: workability, compressive strength, flexural strength, durability tests (sulphate, chloride, and acid attacks), UPV, abrasive resistance. As per the SEM analysis, GW particles are more rough, angular, and elongated as compared to the naturally available sand.

Summary of literature review of silica fume:

After studying the literatures of many authors about silica fume, the conclusion is that, due to partial replacement of SF with cement, the mechanical properties, durability and microstructural analysis were improved and which was achieved due to very reactive pozzolanic property of SF. This pozzolanic property is achieved due to its fineness and high amorphous silicon dioxide which leads to high normal consistency.

When SF is added in concrete production, higher amount of super plasticizer is needed to maintain the fresh properties in acceptable limits and keep the water cement ratio constant. After adding the SF during concrete production, workability reduces due to its very large surface area (20,000-30,000 m^2/kg) which is even better for concrete mixes. As compared to any other cement replacements such as fly ash, ceramic waste, slag etc. SF gives better mechanical properties, durability and protects reinforcing steel bars from corrosion as it makes dense matrix concrete.

IV. MATERIALS AND METHODOLOGY

Description is given about the used material and the procedure of methodologies for this research work. The physical properties of the concrete constituents were determined first during the research work. Also, as per the physical and chemical properties of the constituents, the use of materials was evaluated. After that many SCC mixes were produced to get the maximum strengths, durability, and sustainability. Based on these evaluations, an optimum mix was obtained which was comparable to the control mix. This study used locally available materials such as ordinary Portland cement, silica fume, river sand, granite waste, coarse aggregate, water, and super plasticizer for SCC production. To evaluate the performance of the SCC containing GW and SF, many experiments were done to look over them.

MIX PROPORTIONS:

SCC is an advanced form of NVC which was created to attain some necessities like workability, passing ability and resistance to bleeding and segregation. In this investigation, SCC mixes were prepared in three series which were total eleven mixes. In series-I, control SCC mix (i.e., 0%GW and 0%SF) was prepared and in series-II, fine aggregate was partially replaced with GCW at different percentage contents of 10%, 20%, 30%, 40% and 50% and finally in series-III, fine aggregate and cement were partially substituted with optimum GCW percentage and 3%,6%,9%,12% and 15% content of SF respectively. The above-mentioned series of SCC concrete mixes are presented in Table 3.3 along with their details and mix IDs in which GXSY stands for X% replacement of FA with GW and Y% replacement of cement with SF. All SCC mixture were produced by keeping a constant binder amount of 530kg/m^3 and water-to-binder ratio of 0.38. The dose of SP was adjusted in every mix to attain the slump flow in the range of 690±20 mm.

Mix proportion of the concrete constituents (kg/m3)

Mix ID	w/c ratio	OPC	SF	FA	GW	Coarse aggregate	Water	SP dosage (%)
S0G0	0.38	530	-	995	-	680	201.4	1.2
S0G10	0.38	530	-	895.5	99.5	680	201.4	1
S0G20	0.38	530	-	796	199	680	201.4	1.1
SOG30	0.38	530	-	696.5	298.5	680	201.4	1.2
S0G40	0.38	530	-	597	398	680	201.4	1.4
S0G50	0.38	530	-	497.5	497.5	680	201.4	1.6
S4G30	0.38	508.8	21.2	696.5	298.5	680	201.4	2.2
S8G30	0.38	487.6	42.4	696.5	298.5	680	201.4	3
S12G30	0.38	466.4	63.6	696.5	298.5	680	201.4	3.7
S16G30	0.38	445.2	84.8	696.5	298.5	680	201.4	4.2
S20G30	0.38	424	106	696.5	298.5	680	201.4	4.9

*S12G30 stands for 12% of silica fume (SF) and 30% of granite waste (GW)

TESTING METHODOLOGY:

The fresh characteristics tests of SCC concrete were checked with respect to flowability, filling ability, passing ability and resistance against segregation as per the guidelines of EFNARC. Slump flow, T500 and V-funnel time tests were performed to evaluate the flowability or workability of the SCC concrete mixes, while to compute the filling and passing ability of the SCC concrete mix, L-box and J-ring tests were conducted.

Compressive strength test:

This test was performed to determine the influence of GW and SF on SCC mix specimens. It was evaluated for 7-, 28- and 90-day curing time. Three cubes of each mix of size 150*150*150 mm were taken from each controlled curing tank. To determine the compressive strength of SCC mix samples, a compression testing machine (CTM) of the 3000KN capacity and rate of loading maintained at 0.233 N/mm^2/sec was used for testing the strength of SCC mix specimens. The compressive strength test of SCC mix specimens was evaluated as specified in BIS: 516.

Flexural strength test:

This test was conducted to determine the impacts of GW and SF on flexural strength of SCC mix specimens. Flexural strength was evaluated as per BIS: 516(2018). Three prism specimens of each mix of size 100*100*500 mm were casted and the flexural strength of the beam specimens was determined at each water curing age of 7, 28 and 90 days. To assess the flexural strength of the SCC mix specimens, flexural testing machine of 350KN capacity which is two-point loading setup was used.

Split tensile strength test:

It was performed to determine the tensile strength of concrete samples, which is a destructive test that gives knowledge about ductility, tensile and yield strength of material. The evaluation of this test for SCC samples was done as per BIS: 5816. The test setup of split tensile strength test is shown in Fig. 3.7. In this study, this test was performed to determine the influence of GW and SF on split tensile strength of SCC mix specimens. Three cubes of each mix of size 150*150*150 mm were casted the split tensile strength SCC mix specimens was determined at each water curing age of 28 and 90 days.

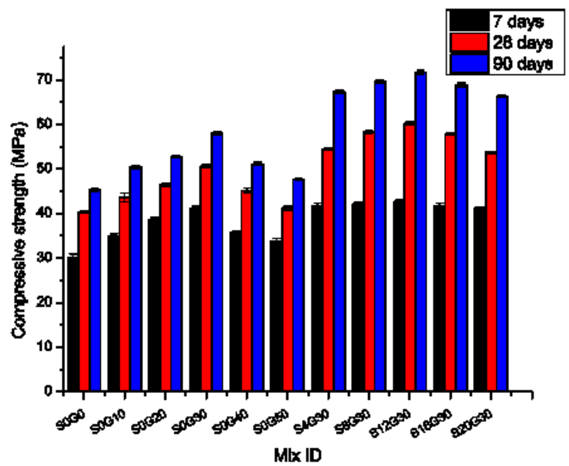
In addition, with above tests the following tests are also performed i.e., ultrasonic pulse velocity test, Water absorption test, Acid attack test, Sulphate attack test and SEM analysis and corresponding results were discussed.

V. RESULTS AND DISCUSSIONS

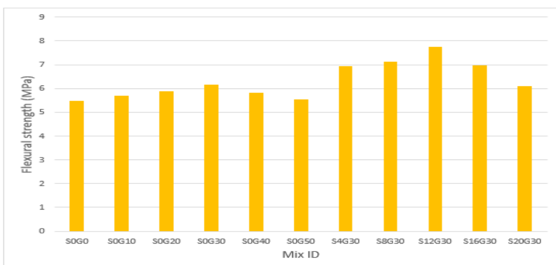
The results of all the properties of SCC mix containing SF and GW are represented here either in tabular form or in graphical form. Here, the objective of this chapter is to examine the impacts of these replaced materials on the properties of concrete mix by comparing the modified concrete mix with control mix. Initially, the fresh properties of concrete are examined and then hardened properties with microstructural analysis of SCC mix specimens.

Fresh state properties of SCC mixes

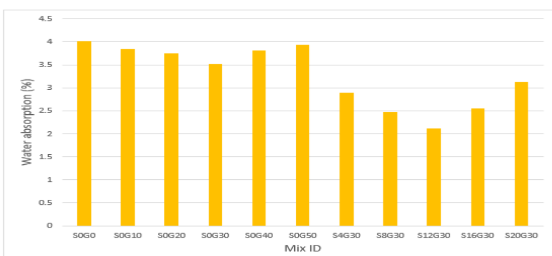
Mix ID	SP (%)	Slump (mm)	T500 sec (sec)	L-box	V-funnel (sec)	J-ring (mm)
S0G0	1.2	700	4.01	0.89	8.79	4.5
S0G10	1	700	3.97	0.92	8.13	3.5
S0G20	1.1	705	3.62	0.95	7.84	3
S0G30	1.2	710	3.43	0.94	6.07	4
S0G40	1.4	690	3.55	0.89	9.2	5
S0G50	1.6	685	5.15	0.85	11.5	5.5
S4G30	2.2	710	4.05	0.93	7.53	4.5
S8G30	3	705	4.7	0.89	8.54	6
S12G30	3.7	700	5.32	0.93	9.15	8.5
S16G30	4.2	680	6.19	0.82	13.77	9
S20G30	4.9	670	7.25	0.75	14.52	10.5



Compressive strengths of SCC mixes at varied water curing period



Flexural strength of 28-days water cured SCC specimens



Water absorption of SCC mix specimen

The outstanding surface morphology was obtained in Mix S12G30. This mix shows least permeable voids with negligible size, least width of cracks with best ITZ characteristics and very dense and compact matrix which are reasons for outstanding mechanical and durable properties.

VI. RESULTS AND DISCUSSIONS

As per this research work, SCC mix prepared with 12% of SF and 30% of GW as a partial replacement of cement and fine aggregate respectively, resulted in positive impacts on mechanical, durability and microstructural parameters of SCC mix and beneficial for making high strength concrete. Based on the results obtained from the study, following points can be concluded:

- The incorporation of GW as a partial replacement of sand in concrete production led to slight loss in workability which was balanced with addition of SP, whereas with the addition of SF in concrete mix resulted in higher amount of decrement in workability and which required excessive amount of SP dosage.
- For optimum Mix S12G30, maximum compressive strength enhancement was obtained at curing age of 7, 28 and 90 days which were 40.4%, 49.6% and 58% respectively more than the compressive strength of the control mix.
- In flexural and split tensile strength test of 28 days cured specimens, the optimum mix was better and comparable to control mix and the strength improvement was about 41.5% and 45.8% respectively. With the addition of SF in mix rapid increment in strength was recorded.
- The highest increment in UPV was recorded in mix prepared with both SF and GW as replacement of cement and fine aggregate. The better filler efficiency of GW and high C-S-H formation due to SF makes the dense compact concrete which improved the strength of concrete and enhancement in UPV value was recorded.
- The water absorption of SCC specimen was decreased with the addition of GW up to 30% of GW and with further addition of SF in optimum percentage of GW, more reduction in water absorption was recorded.
- The minimum percentage weight loss with exposure to 3% sulphuric acid solution for the SCC specimens prepared with only GW and with both SF and GW are 4.02% and 3.01% respectively which are 12% and 50% lower than of the control mix. The minimum percentage loss of compressive strength for both mixes are 23.94% and 20.63% respectively which are 11% and 29% lower than the control mix.
- In sulphate attack test, the reduction in percentage loss of compressive strength was observed in both mixes which were prepared with only GW as replacement and mixes prepared with SF and GW as replacement. As compared to the control mix, the reduction in percentage loss in compressive strength was obtained about 10.1% and 14.5% for mix with

GW only and mix with SF and GW respectively which shows that the addition of GW is the major factor to control the compressive strength loss.

- SEM analysis shows the dense and compact matrix with excellent ITZ for SCC Mix C12G30 which gives outstanding mechanical and durable properties as compared to control mix and SCC mix prepared with only GW as fine aggregate replacement.

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