Study of Self Compacting Concrete Utilizing Fly, Ash and Granite Waste

SK. Samad[1], P. Raja Sekhar[2]

[1]PG Student, Department of civil Engineering, Velaga Nageswara Rao (VNR) College of Engineering, (Approved by AICTE and affiliated to JNTUK, Kakinada), G.B.C. Road, Ponnur–522124, GUNTUR, A.P-(INDIA).
[2]Assistant Professor, Department of civil Engineering, Velaga Nageswara Rao (VNR)College of Engineering, (Approved by AICTE and affiliated to JNTUK, Kakinada), G.B.C. Road, Ponnur–522124, GUNTUR, A.P-(INDIA).

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Abstract - *The development of sustainable concrete has gained plenty of awareness in recent years. Researchers have conducted many experimental investigations for the manufacture of differentforms of concrete by using numerous low carbon footprint materials, such as granite waste andfly ash. The using of low carbon footprint materials in construction industry will minimize theexploitation of natural raw materials and promote sustainability in construction industry. This research thus aimed to investigate the influence of granite waste (GW) and fly ash on the production of self-compacting concrete (SCC). This research was conducted in two phases. In the first phase, the preliminary investigation was carried out for finding the maximum adding percentage of GW and fly ash in the successful production of SCC. The GW was used in the proportion of 0, 20, 40, 60, and 80% as an alternative to fine aggregate (i.e. sand) by weight, while, fly ash was substituted with cement in the proportion of 0, 20 and 30% by weight. The fresh characteristics (slump flow, T500 flow, V-funnel, J-ring, and L-box), mechanical characteristics (compressive strength and flexural strength) and durability characteristics (water absorption and ultrasonic pulse velocity) were evaluated. The findings of first phase revealed that the combined use of GW (up to 60%) and fly ash (up to 30%) in SCC has the potential to considerably enhance the fresh and water absorption properties (without adversely affecting strength characteristics). In the second phase, the percentage of fly ash (30%) was fixed and the percentage of granite waste (up to 60%) was varied.*

Key Words: Compressive strength, Flexural strength, Water absorption, Scanning electron microscope (SEM).

1. INTRODUCTION

Self-compacting concrete (SCC) is one of the major revolutions in the construction industry since its development in the later years of the 1980s. SCC is the advanced form of normally compacted concrete (NCC) that can effortlessly flow and spread inthe thinner and densely reinforced section without any additional vibration. SCC technology can be termed as ‘‘smart concreting construction” which demands less energy and lowoperatives and supports in faster casting with lower maintenance. It has various benefits over NCC, for instance, reduces labour cost and construction time, provides flexibility in designing, and produces a homogeneous concrete matrix without honeycombing. Further, SCC exhibits superior mechanical performance as compared to that of NCC due to thebetter-refined microstructure contributed by the presence of higher fine content in SCC.

1.1 Granite Industry Scenario

- The use of stone industry waste in the construction industry has gained a lot of interest worldwide. India holds varieties of stones, like, marble, granite, sandstone, limestone, and slate.

- Granite industry is one of the primary stone industries in India. Granite stone is a kind ofigneous rock that is formulated through the gradual crystallization of magma existing beneaththe earth.

- Granite has been exploited as a building or decorative stone throughout human history due to its inherent hardness and strong characteristic (Mendoza et al., 2014). According to the World Natural Stone Association report, in 2014, worldwide granite stone production accounted for approximately 349 million sqm/year, and India was the third-largest producer nation of granite stone in the world after China and Brazil (WNSA, 2014). As of 1st April 2015, India had a total of 46,320 million cum granite resources (IBM, 2018).

- Unfortunately, more than 30% is currently produced as granite waste (GW) during cutting and polishing of ornamental granite blocks in granite industries (Singh et al., 2017).

- This residue initially produced in wet slurry form, which is being thrown away inappropriately on the nearby dumping sites as shown in Chart-1) as a waste product.

- It then converts into dry form after some time due to the evaporation of water that becomes airborne, eventually causing health problems and affects the surrounding ecosystem (Ghannam et al., 2016).

1.2 Applications of GW

- Soil stabilization

- Ceramic industry
- Tile and bricks manufacturing
- Indoor and outdoor cladding and paving
- Desulfurization process
- Thermoset resin composites
- Road embankments
- Asphalt
- Masonry
- Paving blocks
- Cement-based products (mortar, NCC, and SCC)
- Polymer-based composite materials

1.3 Benefits of utilizing GW in construction

- It decreases the cost of construction products on using GW instead of cement and sand.
- It declines the heat of hydration on using GW instead of cement.
- It increases the resistance to external agents on using GW instead of cement and sand.
- It enhances strength.
- It minimizes emission of greenhouse gases like CO_2 and NO_X etc. in the production ofcement clinker on using GW as a replacement of cement.
- It conserves a substantial quantity of non-renewable energy on using GW as a replacementof cement.
- It protects the environment by preserving the significant amount of natural mined materials.
- It reduces waste disposal cost, which is continuously rising because of landfill tax.
- It opens a new recycling business.

2. METHODOLOGY

The physical and chemical characteristics of different ingredients in the formulation of SCC mixtures have been discussed in this section. Cement, fly ash, fine aggregate, coarse aggregate, granite waste (GW), water and superplasticizer have been used in the formulation of differentSCC mixtures. Scanning electron microscopic (SEM), X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques have been utilized to evaluate the chemical and microstructuralcharacteristics of different ingredients. The SCC mixture details and their mixing procedure have been discussed in this section.

- The testing procedures for fresh, mechanical, durability and microstructural characteristics have also been discussed in this section.
- Ordinary Portland cement (OPC; Ultratech brand) of 43 grades was used conforming to BIS: 8112 (1989), and its chemical composition and physical properties are presented. XRF technique was utilized to determine the oxide composition of cement.
- SEM image of cement particles. which indicates that particles of cement are angular andnon-spherical in shape.

Table -1: Physical properties of cement and fly ash

Physical properties	Cement	Fly ash
Consistency (%)	27	-
Specific gravity	3.16	2.28
Soundness (mm)	1	-
Initial setting time (minute)	120	-
Final setting time (minute)	241	-
Specific surface area (m^2/kg)	297	353
Compressive strength (MPa)		
3 days	23.7	-
7 days	34.5	-
28 days	45.8	-

Table -2: Chemical composition of cement and fly ash

Chemical composition (%)		
CaO	45.88	0.9
SiO_2	31.3	58.19
Al_2O_3	3.49	26.93
Fe_2O_3	3.3	4.27
Na_2O	0.22	0.07
K_2O	0.69	1.1
MgO	5.21	0.69
P_2O_5	0.05	0.21
MnO	0.05	0.06
LOI	3.97	0.45

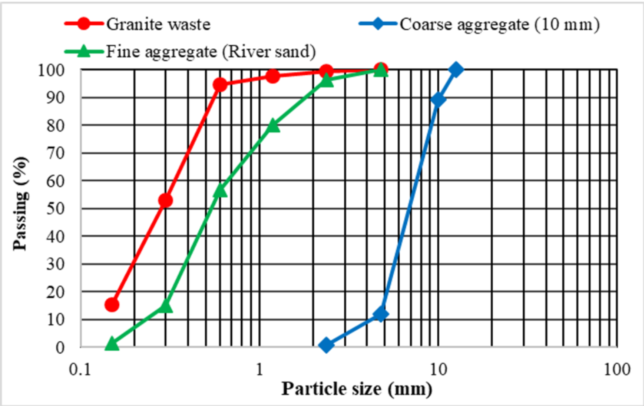

Chart -1: Sieve analysis of aggregates and granite waste

2.1 Research plan

This study was conducted in two phases. In the first phase, the preliminary investigation was carried out for finding the maximum adding percentage of GW and fly ash as a replacement of natural fine aggregate and cement in the successful production of SCC, respectively. For the first phase, fresh (slump flow, T500 time, V-funnel time, J-ring and L-box), mechanical (compressive and flexural strength), durability (water absorption) and microstructure (SEM and EDS) characteristics were performed.

In the second phase, the percentage of fly ash was fixed and the percentage of GW was varied. In this way, for the second phase, the comprehensive investigation for fly ash blended SCC (prepared with and without GW) was carried out by performing fresh, mechanical, durability, and microstructure characteristics. Additionally, impact resistance, fire resistance, economic and environmental characteristics were also evaluated for fly ash blended SCC.

2.2 Concrete mixture details

For the first phase, three series of SCC mixtures were prepared. Series-I included a control SCC mixture (i.e. 0% GW), and four other SCC mixtures prepared with GW as a partial substitute of fine aggregate in the different percentages of 20, 40, 60 and 80%. Series-II and IIIincluded a total of ten SCC mixtures prepared with same GW replacement as in series-I exceptthat the 20 and 30% cement content was partially replaced with fly ash in the series-II and III, respectively. Details of SCC mixtures (for preliminary investigation).

All the SCC mixtures were made by maintaining a fixed binder quantity of 546.79 kg/m^3 and effective water to binder ratio of 0.37. The SP dosage was adjusted to achieve slump flowin the range of 700 ± 30 mm. The mix ID of all the SCC mixtures. Typically, GXFY stands for X% substitution of fine aggregate with GW and Y% substitution of cement with fly ash.

2.3 Testing Procedure

This section addresses the procedure of different tests (fresh, mechanical, durability and microstructure characteristics) which were carried out on SCC mixtures in the fresh and hardened state. Fresh characteristics tests convey the early-age behaviour of concrete mixtures,which is required for proper placement of concrete mixtures and ensures its integrity in the fresh state. Whereas, mechanical, durability, impact and fire resistance and microstructure characteristics tests ensure the performance or integrity of concrete mixture in the hardened state. The procedure of different tests performed on concrete mixtures is discussed below.

2.4 Workability

SCC is the advanced type of NCC. The workability of NCC can be determined by performingany one or two tests like slump, compaction factor, flow table, and vee-bee consistometer, whereas there is no universal test for finding the workability of SCC. The SCC must fulfill three characteristics named flowing ability, passing ability, and segregation resistance, for achieving the satisfactory workability of freshly mixed concrete. The aforementioned SCC characteristics can be measured by performing following tests, such as slump flow, T500 time, V-funnel time, L-box, U-box and sieve segregation.

3. RESULTS

3.1 Compressive Strength

The compressive strength of the mixes at curing periods of 7 and 28 days, respectively. For all the series and curing durations, the compressive strength initially increased at the 20% replacement level of GW and then decreased with further increase of the GW content. However, at the replacement level of 40% GW, the SCC specimens showed comparable strength. The higher or comparable strength up to the 40% replacement level of GW may be attributed to the better filler effect, which was related to the small size and irregular shape of the GW particles.

- The smaller size GW particles effectively filled the gaps between the coarser fraction of aggregate particles as well as cement and sand particles.
- Moreover, the surface roughness of the GW particles made a proper interlocking with cement paste, leading to a better interfacial transition zone (ITZ) between the aggregate and paste matrix and thus improved the compressive strength.
- The SEM images are shown later inChart-1, which substantiates this claim.

- The inclusion of fly ash reduced the compressive strength for all curing periods, which may be primarily due to lower hydration products, as observed in the SEM and EDS analysis.
- However, the loss in compressive strength reduced as the curing days were prolonged. For example, the 7-day compressive strength values of the G0F30 mix reduced by 37.08% compared to the G0F0 mix, whereas the 28-day strength values of the G0F30 mix reduced by only 9.62% compared to the G0F0 mix.
- These results are in agreement with the observations of earlier researchers, who incorporated fly ash in SCC as a replacement for cement.
- The improvement with increased curing duration may be due to the continuous pozzolanic activity of the fly ash as the curing was prolonged.

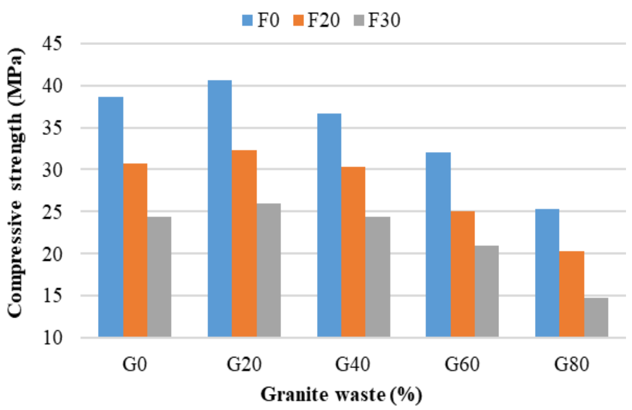

Chart -1: 7days compressive strength

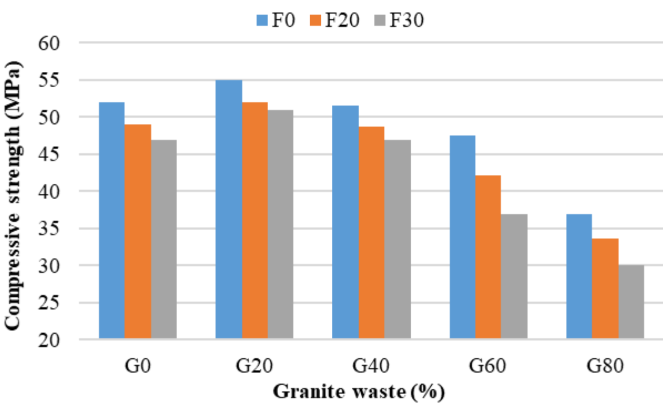

Chart -2: 28days compressive strength

3.2 Flexural strength

The results of the flexural strength of granite-based SCC mixes, prepared with and without flyash, at curing period of 28 days are shown in chart-2. The flexural strength increased with the replacement of fine aggregate by 20% GW for all the series and then decreased with further increase in the replacement level of GW. However, even at a 40% replacement level of GW, the SCC mixes showed improved flexural strength. The variation of the flexural strength values with the replacement level of GW and fly ash was similar to the variation observed for the compressive strength, except that the improved compressive strength was obtained up to a 20% replacement level only. The results indicated that GW had greater efficacy in the improvement of the flexural strength of the SCC mixture. The angular shape and rough surface of the GW particles may have provided stiff packing between the binder and aggregate phase, which resulted in improved flexural strength. The other causes of the improvement in flexural strength are similar to the reasons described for compressive strength. The results match the findings of earlier researchers, who reported the improvement in flexural strength with increase of GW content as a substitute for fine aggregate in NCC.

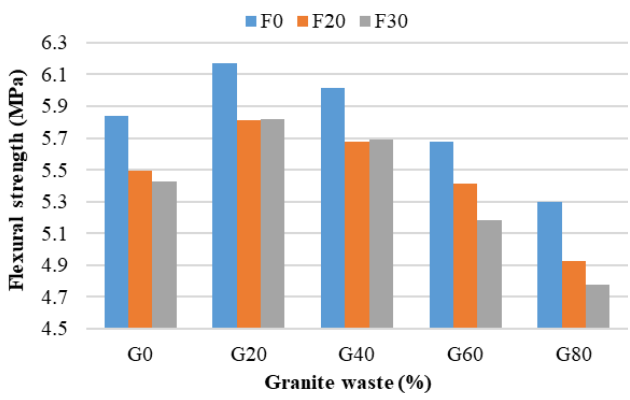

Chart -3: Influence of granite waste and fly ash on flexural strength of various SCC mixes

3.3 Scanning electron microscope

SEM images of selected SCC mixtures are taken for 28 days of curing. Minor cracks, voids, and weaker ITZ between the aggregate and cement paste matrix were observed in mixes prepared without GW.

- On the other hand, compact packing and stronger ITZ were observed between the aggregate and cement paste matrix in mixes prepared with 20% GW.
- This improved microstructure of the concrete matrix with the inclusion of GW may be the reason for the highest strength and lowest water absorption achieved at a 20% replacement level of GW in all the series.
- The SEM images of the mixes containing a higher content of GW were also analysed.

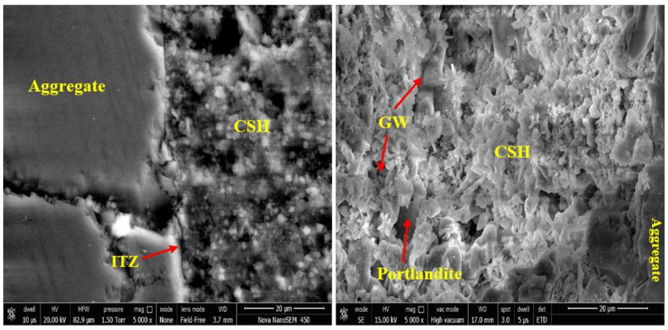

Fig-1 Scanning electron microscopic images of SCC mixes at different level of granite waste and fly ash

Table -3: Elemental composition of granite-based SCC mixes prepared with and without fly ash

Elements (symbol)	**G0F0**	**G20F0**	**G80F0**	**G0F20**	**G20F20**	**G80F20**	**G0F30**	**G20F30**	**80F30**
Oxygen (O)	48.11	50.23	52.4	52.86	51.42	42.05	42.17	48.96	51.26
Calcium (Ca)	19.21	18.56	23.08	22.92	20.48	22.89	21.85	19.53	25.79
Silicon (Si)	18.16	20.79	16.45	14.46	15.38	13.11	12.3	13.53	12.04
Aluminium (Al)	1.86	0.92	3.08	4.86	4.14	4.66	4.22	4.11	3.72
Potassium (K)	0	0.74	0.69	1.5	1.97	1.59	6.39	1.84	1.19
Iron (Fe)	1.48	0.85	0.54	2.02	2.15	1.83	1.52	1.9	2.14
Magnesium (Mg)	1.44	1.28	0.43	0	1.44	1.48	0.67	1.33	1.73
Sodium (Na)	1.23	0.62	0.18	0	0	3.5	0.46	0.36	0
Carbon (C)	8.5	6.01	2.87	1.37	3.02	7.91	9.88	8.44	2.14
Ca/Si ratio	1.058	0.893	1.403	1.585	1.332	1.746	1.776	1.443	2.142

4. CONCLUSIONS

- Incorporation of up to 30% GW declined the superplasticizer (SP) dosages of fly ash blended SCC. Moreover, all the fly ash blended SCC mixtures (prepared with and without GW) exhibited lower SP dosages than the Ordinary Portland cement (OPC) based controlSCC mixture.
- All the developed SCC mixtures exhibited enough filling ability, passing ability and segregation resistance and satisfied the criteria laid down by EFNARC standards.
- The bleeding for all the SCC mixtures was found within the satisfactory limit (0.1-2.5%).
- Fly ash blended SCC mixtures containing up to 40% GW showed higher compressive strength than the fly ash blended control SCC mixture (made without GW) for all the curingdays. Whereas, fly ash blended mixtures containing up to 40% GW showed better compressive strength than OPC based control SCC mixture for 180 and 365 days curing time.
- Fly ash blended SCC mixtures containing up to 50% GW showed higher tensile strength than the fly ash blended control SCC mixture for all the curing days.
- Whereas, fly ash blended mixtures containing up to 50% GW showed better tensile strength than OPC basedcontrol SCC mixture for 180 days curing time.
- The higher mechanical performance of fly ash blended SCC mixtures (made with GW) ascompared to OPC based control mixture was due to the filler effect of GW as well as pozzolanic activity of fly ash.
- The water permeability (i.e. water penetration depth), water absorption, percentage of permeable voids and sorptivity (i.e. the capillary rise of water) of the fly ash blended SCC mixtures containing up to 50% GW was lower than the fly ash blended control SCC mixture, which indicated the better impermeability of fly ash blended SCC mixtures (prepared with GW).
- Moreover, fly ash blended SCC mixture containing up to 50% GW also exhibited higher impermeability against water than the OPC based control SCC mixture.

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