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Utilization of granite sawing waste in self compacting concrete

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Preliminary note

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The self-compacting concrete must contain mineral admixtures to improve the flow properties. The granite sawing waste can be utilized as mineral admixture in the self-compacting concrete. The results obtained by XRD and SEM methods show that there is a promising future for the use of this waste material as filler in self-compacting concrete, along with fly ash. The results show that the granite sawing waste and fly ash can be used to improve the properties and cost-effectiveness of the self-compacting concrete.

Key words:
self-compacting concrete, granite sawing waste, fly ash, mechanical properties

Prethodno priopćenje

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Uporaba granitne prašine u samozbijajućem betonu

Samozbijajući beton treba sadržavati mineralne dodatke za poboljšanje svojstava tečenja betona. Kao mineralni dodatak u samozbijajućem betonu može se koristiti granitna prašina. Rezultati ispitivanja rentgenskom difrakcijom (XRD) te skeniranje elektronskim mikroskopom (SEM) pokazali su da postoji obećavajuća budućnost za korištenje ovog otpadnog materijala kao punila u samozbijajućim betonima, uz dodatak letećeg pepela. Rezultati su pokazali da je moguće koristiti granitnu prašinu i leteći pepeo da bi se poboljšala svojstva i ekonomska isplativost samozbijajućeg betona.

Ključne riječi:
samozbijajući beton, granitna prašina, leteći pepeo, mehanička svojstva

Vorherige Mitteilung

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Anwendung von Granitpulver in selbstverdichtendem Beton

Selbstverdichtender Beton muss mineralische Zusätze enthalten, die das Fließverhalten des Betons verbessern. Als mineralische Zusätze kann Granitpulver angewandt werden. Resultate von auf XRD und SEM Methoden beruhenden Versuchen haben gezeigt, dass der Anwendung dieses Abfallstoffes als Füllmittel für selbstverdichtenden Beton, unter dem Zusatz von Flugasche, eine vielversprechende Zukunft bevorsteht. Des Weiteren zeigen die Resultate, dass Granitpulver und Flugasche angewandt werden können, um Eigenschaften und Wirtschaftlichkeit selbstverdichtenden Betons zu verbessern.

Schlüsselwörter:
selbstverdichtender Beton, Granitpulver, Flugasche, mechanische Eigenschaften

1. Introduction

Since its introduction in the later years of 1980's Self Compacting Concrete (SCC) has brought a revolutionary change in construction industry. Since the production process is much easier than the conventional concrete, it is widely used in mass concreting works, bridge constructions, metro rail constructions etc. The quality of concrete produced with SCC is much better than the ordinary concrete [1]. Another advantage is that less skilled labour is required in order for it to be placed, finished and made good after casting. As the shortage of skilled site labour in construction continues to increase in many countries, this is an additional advantage of the material which will become increasingly important [2]. SCC mixes always contain a powerful superplasticizer and often use a large quantity of powder materials and/or viscosity-modifying admixtures. The superplasticizer is necessary for producing a highly fluid concrete mix (low yield value) while the powder materials or viscosity agents are required to maintain stability (sufficient viscosity) of the mix, hence reducing bleeding and segregation/settlement. The powder materials used often include limestone powder, pulverised fuel ash (PFA), granulated ground blast furnace slag etc. Furthermore, coarse aggregate content is much lower in SCC mixes than in traditional vibrated concrete mixes to reduce the risk of blocking of concrete flow by congested reinforcement and narrow openings in the formwork [3]. Excellent deformability, good stability and low risk of blockage are the basic requirements for successful casting of SCC [4]. The hardened properties are of paramount interest to structural designers and users, and much data have also been obtained on all aspects of these [5]. Self-compactibility testing method stipulations are not universally accepted rules. Degree of toleration depends on the engineering judgement, material type and variety. Proper concrete mixtures can be produced by trial and error method [6]. Many different test methods have been developed in attempts to characterize the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly no single method has been found which characterizes all the relevant workability aspects so each mix design should be tested by more than one test method in order to obtain different workability parameters [7]. Granite have diverse applications because of its versatile characteristics, such as high durability and resistance to scratches, stains, cracks, spills, heat, cold, and moisture. Unfortunately, a considerable and increasing amount of solid wastes from granite industries are generated in cutting and polishing [8]. These wastes are currently disposed in landfills with increasing cost and negative environmental impact, which affects the economic and environmental sustainability of such industrial productions, as well as public health [9]. In recent decades, environmental considerations have become a main concern, and efforts to reuse granite wastes have been undertaken. The main aim of sustainable development is to reduce the usage of natural resources by proper recycling. In India more than 40 % of Granite Sawing Waste (GSW) is produced in Tamilnadu, India, which is resulting from cutting and polishing processes. These processes result in mixture of water and fine particles which after drying becomes a potential problem to the environment. Therefore, the present work is aimed at developing a concrete using the GSW, an industrial waste as a replacement material for the cement. Granite waste coarser in size resulting from cutting process has successfully been used instead of coarse aggregates by many researchers [10, 11]. It is also used to produce colored cement mortars and ceramic products [12, 13].

Some authors have utilized bio mass as a filler material for SCC like olive residue biomass [14]. Some researchers have utilized blast furnace slag as an admixture for self compacting concrete [15]. The viscosity criterion was validated by using another skeleton of aggregates and different natures of cement, limestone filler and high range water reducers [16]. The limestone powder and basalt powder have been utilized in SCC which shows that it is economical to use them in SCC [17]. GSW has successfully been used a replacement material for sand in ordinary concrete [18]. They have concluded that the replacement of natural sand by granite waste is favorable for concrete without adversely affecting strength and durability properties.

In the present study, a suitable mix has been developed with required characteristics of SCC. The Granite polishing process yields fine granite powder which is disposed in the nearby areas without any treatment. This waste material is utilized in this work and referred as Granite Sawing Waste (GSW). Since fly ash (FA) is a successful mineral admixture which imparts workability the effect of GSW may further be improved by utilization of FA. In this work experiments were carried out for the effective replacement of cement with GSW (0 %, 5 %, 10 %, 15 %, 20 %) and FA (25 %). Several tests such as slump flow, V-funnel, L-box, U-box were carried out to determine optimum parameters for the self-compactability of mixtures. Test on compressive strength, split tensile strength, flexural strength and deformation characteristics of the specimens were also studied.

2. Experimental programme

2.1. Materials

Ordinary portland cement of 43 Grade having specifications as per IS 8112:1989 reaffirmed in 2005 was used in the experiments. 43 grade ordinary Portland cement manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker. No material will be added after burning other than gypsum. The fineness by Blaines air permeability test as per IS 4031 (Part 2)-1988 was 299 m^2/kg, the specific gravity was 3.11 g/cm^3 and the 28 day compressive strength was 48.5 N/

mm^2. The important consideration in the design of mix for SCC is to limit the coarse aggregate content. The coarse aggregate percentage was fixed as 50 % by volume. The crushed stone aggregates with 95 % of aggregates smaller than size 16mm was selected to avoid any blocking effect of SCC. Ordinary river sand with specific gravity 2.6 g/cm^3 lying in Zone II was used.

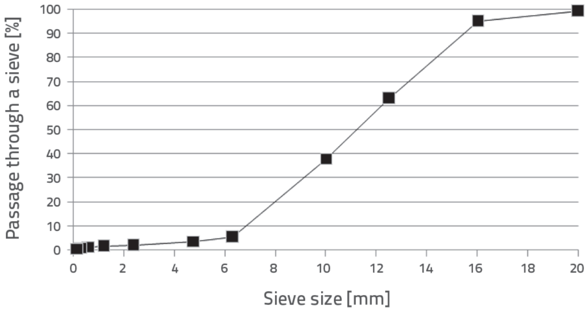

Figure 1. Grading of coarse aggregate used

Conplast SP430 was used as super plasticizer which is a chloride free, superplasticising admixture based on selected sulphonated naphthalene polymers. It is supplied as a brown solution which instantly disperses in water. Conplast SP430 disperses the fine particles in the concrete mix, enabling the water content of the concrete to perform more effectively. The very high levels of water reduction is possible which allow major increase in strength to be obtained. The GSW and FA were used as mineral admixtures. Class F fly ash was obtained from Mettur thermal power plant station near Mettur dam, India. The specific gravity of fly ash was found to be 2.1 g/cm^3. The GSW from granite industries in Pudukotttai District, Tamilnadu, India was used. Since the granite powder was fine, hydrometer analysis was carried out on the granite powder to determine the particle size distribution. From hydrometer analysis it was found that the coefficient of curvature was 1.95 and coefficient of uniformity was 7.82. The specific gravity of the granite powder was found to be 2.59 g/cm^3. The characteristic properties and mineralogical composition of these two mineral admixtures and the cement are given in Table 1.

Table 1. Properties of ordinary portland cement and mineral admixtures

Component	**Cement** [%]	**Granite sawing waste** [%]	**Fly ash** [%]
CaO	63,5	3,6	5,9
SiO_2	21,5	61,4	45
Al_2O_3	5,5	16,3	30
Fe_2O_3	0,55	3,6	11
MgO	1,5	1,7	2,25
SO_3	1,2	0,05	1,5
LOI	1,0	5,0	1,0
Alkali	0,12	6,2	2,1
Insoluble residue	0,8	0,9	0,2

From the XRD results shown in Fig 2, it is understood that the GSW used has more than 60 % of silica content which can give possible filling effect in SCC. Around 16.3 % of alumina in GSW and 30 % in FA assures some pozzolonic reaction in concrete which may contribute to the compressive strength. The remaining part of GSW consists of Cao (3.6 %), Fe_2O_3 (3.6 %) and some residues presence of which has very less influence on strength.

The GSW and FA are having specific amount of silica and alumina which suggested a potential pozzolonic reaction and a quasi cementitious nature. Fly ash as a additive to be used in concrete should contain at least 25 % reactive silica, which is satisfied in GSW also. Another limitation is that the sum of ferric oxide (Fe_2O_3), alumina (Al_2O_3) and silica (SiO_2) must be at least 70 % in

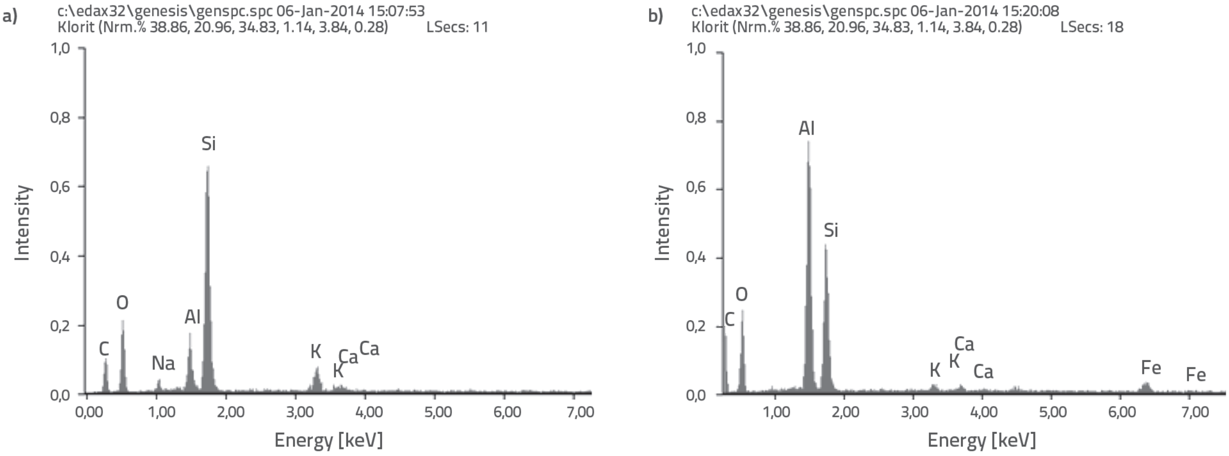

Figure 2. XRD results of granite sawing waste and fly ash

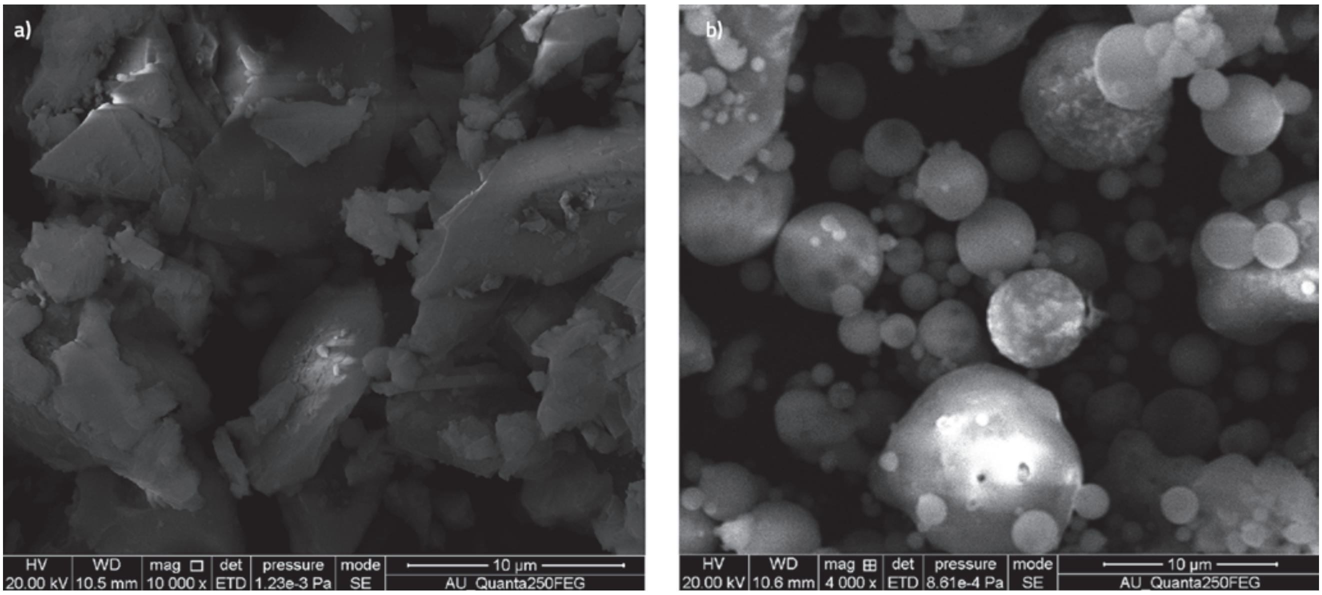

Figure 3. Comparison of scanning electron micrographs of granite sawing waste and fly ash

fly ash for possible use in concrete: the sum of these oxides is over 80 % in the chosen GSW, leading to the belief that it may be useful for concrete mixes. Although seemingly high, the GSW's alkali content (as Na$_2$O equivalent) was not available freely and therefore it is believed that it will be not able to contribute to any potential alkali-aggregate reaction.

After evaluating the SEM graph (Scanning Electron Micrographs) shown in Figure 3, the particle's shape, texture and morphology showed that granite particles are highly irregular. Evaluation of the particles' shape, texture and morphology showed the GSW grains to be slightly larger, more angular, more porous and of greater specific surface and roughness than a typical fly ash sample which is spherical in nature.

2.2. Mixture proportions

One of the best and popular method for mix design of SCC was given by Okamura [1]. This method initially depends on the cement paste and mortar tests before considering the properties of the super plasticizer, cement, fine aggregate and other mineral admixtures. EFNARC specifications and guidelines based on Okamura was used to decide the mix proportions. One control and four mixtures with mineral admixtures were prepared and examined to quantify the properties of SCC. Table 2 presents the composition and labeling of the SCC mixtures. In the mixtures, cement was replaced with GSW at the contents of 0 %, 5 %, 10 %, 15 %, 20 % and Fly Ash 25 % by mass. After some preliminary experiments with varied powder content and super plasticizer dosage, the water–powder ratio by volume (w/p) was selected as 1.05 and the total powder content was fixed at 528 kg/m^3. Super plasticizer dosage by trial and error was 1.25 % by weight of powder.

2.3. Fresh concrete tests

A separate batch was prepared for all mixtures. The sequence of mixing consisted of homogenizing the sand, the coarse aggregate, GSW, FA and cement in a lab mixer. After incorporation of water, superplasticizer was finally introduced to the wet mixture. The dispersion of super plasiticizers is a critical part in mixing. In order to sustain the equilibrium viscosity, longer mixing times are required. Optimum mixing time and order should be examined at pre-tests for each type of plant. The results of pre-tests showed that a total mixing time

Table 2. Mix proportions

Mixture Composition	SCC I	SCC II	SCC III	SCC IV	SCC V
Cement [kg/m^3]	431	409,5	388	366,5	345
Fly ash [kg/m^3]	97	97	97	97	97
Granite [kg/m^3]	-	21,5	43	64,5	86
Fine Aggregate [kg/m^3]	913	913	913	913	913
Coarse Aggregate [kg/m^3]	755	755	755	755	755
Water [kg/m^3]	194	194	194	194	194
Super plasticizer (by weight of powder)	1,25 %	1,25 %	1,25 %	1,25 %	1,25 %

Table 3. EFNARC specifications for SCC

Property	Test method	Typical range
Filling Ability	Slump flow T_{50} cm slump flow V - funnel	650-800 mm 2-7 s 8-12 s
Passing Ability	L - box (H_2/H_1) U - box (R_1-R_2)	0,8-1 0-30 mm
Segregation Resistance	V - funnel T_5 min	+3 s

Figure 4. Fresh Properties of SCC: J Ring, V Funnel and Slump flow

of 3-4 min is enough to stabilize the slump flow and V-funnel flow values. Thirty five percent of the batch was used for fresh concrete tests.

The other part was used to prepare cube and cylindrical specimens without any vibration in order to determine the mechanical properties. The specimens were cured in water at 20°C right up until the testing day. For determining the self-compactability properties (slump flow, T50 time, V-flow time, L-box blocking ratio) tests were performed. All fresh test measurements were repeated and the average of measurements was given. In order to reduce the effect of workability loss on variability of test results, the fresh-state properties of mixtures were determined in a period of 20 min after mixing. Before testing, fresh SCC was remixed for 30 seconds. The order of testing was:

a) Spread flow test and measurement of T_{50} time
b) V-flow test
c) L-box test
d) U-box test
e) J-ring.

During slump flow test, the required time for SCC to reach 500 mm slump diameter and final diameter of concrete circle formed by SCC were measured. For the experiment of V funnel, required time for the self compacting concrete to flow thorough V funnel by virtue of its own weight was measured. In the L Box test, the control gate was suddenly opened and the SCC was allowed to flow thorough horizontal part of L box. After the flow was stopped, the heights of concrete at the end and at the beginning was measured and the blocking ratio is the ratio between height at end and height at beginning.

The slump flow values of the different SCC mixes was measured to be the mean spread diameter of concrete between 650mm and 800mm. In order to achieve good balance between deformability and stability, a low water powder ratio was selected. The GSW and FA act as good filler material but they do not affect the cohesiveness of the mix. Therefore the T50 values were found to be around 5-6 sec. The slump flow values were found to be between 700 mm and 750 mm. The blocking ratio was observed to be within 0.8 to 0.9 which ensures adequate viscosity of the mix.

The results of fresh concrete properties like flowability and passing ability are shown in Table 4. Since the preliminary tests were conducted to decide the mix proportions and super plasticizer dosage, all the SCC mixes satisfied the self compactability criteria. They showed a similar trend of flow properties. Initially it was felt that the angular nature of GSW may affect the flowability and self compacting nature. Since the fly ash contains spherical particles tending to improve the cohesiveness and the effect of angularity was minimized, improved the flow parameters.

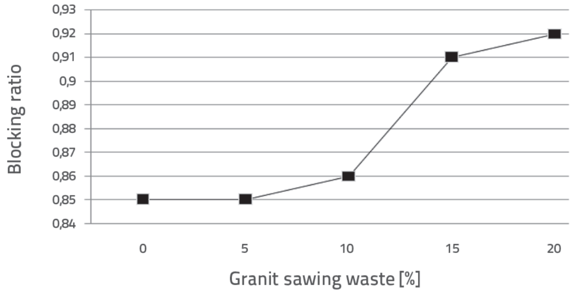

Figure 5. Influence of GSW on blocking ratio

Table 4. Results of fresh properties of SCC (Self Compacting Concrete)

Granite sawing waste (GSW) [%]	Slump flow [mm]	T_{50} cm Slump flow	V-funnel [s]	L- box H_2/H_1	U-box R_1-R_2	J-ring
SCC I [0 %]	730	5	8,66	0,85	6	5,3
SCC II [5 %]	740	5	8,75	0,85	6	5,3
SCC III [10 %]	735	4	8,48	0,86	4	5,8
SCC IV [15 %]	735	4	8,24	0,91	5	7,5
SCC V [20 %]	740	4	8,27	0,92	4	7,7

Table 5. Mean, standard deviation (SD) and coefficient of variation (COV %) of hardened concrete test results

Hardened concrete property		SCC I	SCC II	SCC III	SCC IV	SCC V
7 days Compressive Strength of Concrete [MPa]	Mean	24,48	25,00	26,13	22,22	19,20
	SD	0,459	0,815	0,255	0,908	0,564
	COV	1,87	3,26	0,97	4,08	2,93
28 days Compressive Strength of Concrete [MPa]	Mean	32,88	33,36	34,80	30,20	28,00
	SD	0,933	0,437	0,976	0,875	0,313
	COV	2,83	1,31	2,81	2,89	1,12
7 days Split Tensile Strength of Concrete [MPa]	Mean	1,83	1,55	1,69	1,55	1,55
	SD	0,020	0,079	0,092	0,079	0,056
	COV	1,09	5,09	5,44	5,09	3,61
28 days Split Tensile Strength of Concrete [MPa]	Mean	2,82	2,55	2,55	2,55	2,55
	SD	0,118	0,052	0,168	0,087	0,036
	COV	4,18	2,04	6,58	3,41	1,41
28 days Modulus of Elasticity [GPa]	Mean	27,87	28,41	28,43	26,42	25,42
	SD	0,112	0,727	0,072	0,461	0,522
	COV	0,40	2,56	0,25	1,74	2,05

2.4. Properties of hardened concrete

The compressive strength was obtained on cubes of 150 mm size. Specimens were demoulded one day after casting and then cured in water at approximately 20 °C until testing was carried out at 7 and 28 days age. Three specimens of each mixture were tested and the mean value was reported. The splitting tensile strength was determined at 28 days on cylinders measuring 150 mm diameter and 300 mm height and cured in water until the date of test according the IS : 5816-1970 [29]. Three specimens of each mixture were tested and the mean value was reported.

The modulus of elasticity was determined according to IS 516 -1959 [30] Methods of tests for strength of concrete. 150 mm diameter and 300 mm height cylinder specimens were cured in water and tested at age of 28 days for different mixtures. Average results obtained from three individual specimens for compressive strength and three for tensile strength and determination of modulus of elasticity from each concrete mixture was reported. In Table 5 the mean, standard deviation and coefficient of variation of test results are given. The lower standard deviation and lower coefficient of variation of test results can be correlated to the enhanced homogeneity of SCC mixes prepared.

The SCC mix was designed for M30 mix per Indian standard code (C25/30 concrete mix design). The test results show that concrete made with 25 % of FA as cement replacement achieved a target mean strength of 32.8 N/mm^2. This concrete can be regarded as control concrete. The concrete with 5 % of GSW attained better compressive (1.5 % greater) and comparable tensile strength than the control mix. The one with 10 % GSW attained 5.8 % greater strength than the control mix, beyond which the usage of GSW is not improving compressive strength of concrete. But a comparable result nearer to control mix is obtained. The values of split tensile strength show that the GSW reduces the split tensile strength of concrete. While visually inspecting the failure surfaces, it was found that the shearing of the aggregate grains occur at lesser percentages of GSW contents demonstrating higher mortar strength. When GSW content increased bond failure occurs and this may be due to the effect of lower mortar strength. The reduction in the tensile strength is not only due to reduced cement content and may also be due to the availability of free water resulting from the lesser absorption of water of GSW particles. But the water content was kept constant for all mixes to find out the effect of addition of water. The GSW when added in small quantity helps to improve the modulus of elasticity but there is a reduction in elastic modulus after some proportions. This effect is similar as in the case of compressive strength.

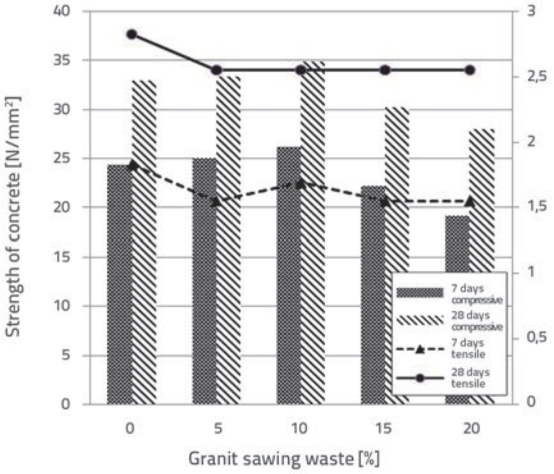

Figure 6. Influence of GSW on mechanical properties of concrete

Table 6 summarizes the effect of GSW on density and UPV. There is some reduction in the density of concrete made with granite waste. But there is a improvement in the density values at 28 days compared to 7 days. This may be probably due to successive formation of pore structure of GSW grains. Ultrasonic pulse velocity values are higher in all the mixes ranging from 4.81 to 5.01 km/s which confirms the quality and uniformity of concrete to be excellent.

Table 6. Density and ultrasonic pulse velocity of concrete mixes with granite sawing waste

Granite sawing waste (GSW) [%]	**Density** [kg/m³] **/ Ultrasonic pulse velocity** [km/s]	
	7 days	28 days
SCC I [0 %]	2385 / 4,81	2391 / 4,89
SCC II [5 %]	2345 / 4,83	2362 / 4,87
SCC III [10 %]	2291 / 4,81	2290 / 4,91
SCC IV [15 %]	2246 / 4,86	2256 / 5,01
SCC V [20 %]	2198 / 4,86	2210 / 4,90

2.5. Flexural strength

The flexural strength test was conducted using five numbers of 100 x 150 x 1700 mm size reinforced concrete beams reinforced as shown in Figure 7. The beams were subjected to four point bending test. The beams were instrumented with three LVDT's in the pure bending region. The load was applied in small increments using a hydraulic jack. The load was measured using a load cell. The behavior of the specimen in terms of crack development, the failure mode and the ultimate load were observed during the test. The deflection at 750 mm, 500 mm, 375 mm from the support were recorded using LVDT's. The moment Vs maximum deflection of the beam is a major criterion in determining the flexural performance of the reinforced concrete beams. At each load increment, the load was held constant and the deflections were recorded.

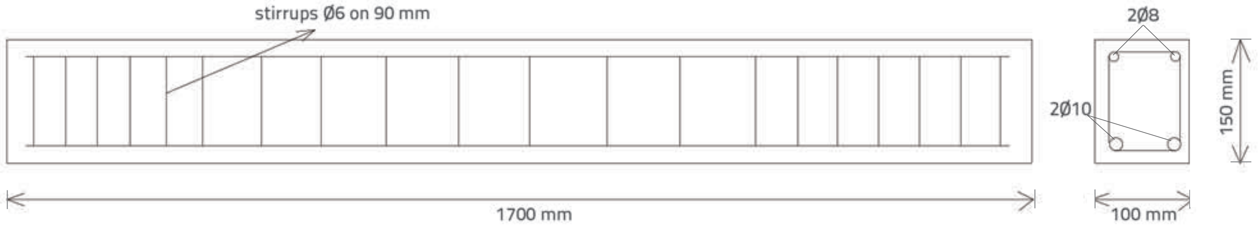

Figure 7. Details of beam reinforcement

Table 7. Flexural strength test results

Specimen of Self Compacting Concrete (SCC)	Ultimate failure load (Pu) [kN]	Ultimate deflection midspan [mm]	First crack load [kN]	Mode of failure
SCC I [0 %]	47,73	19,657	18	Flexure
SCC II [5 %]	48,04	18,847	19	Flexure
SCC III [10 %]	46,66	20,715	15	Flexure
SCC IV [15 %]	40,08	22,125	13	Flexure
SCC V [20 %]	32,89	23,824	12	Flexure

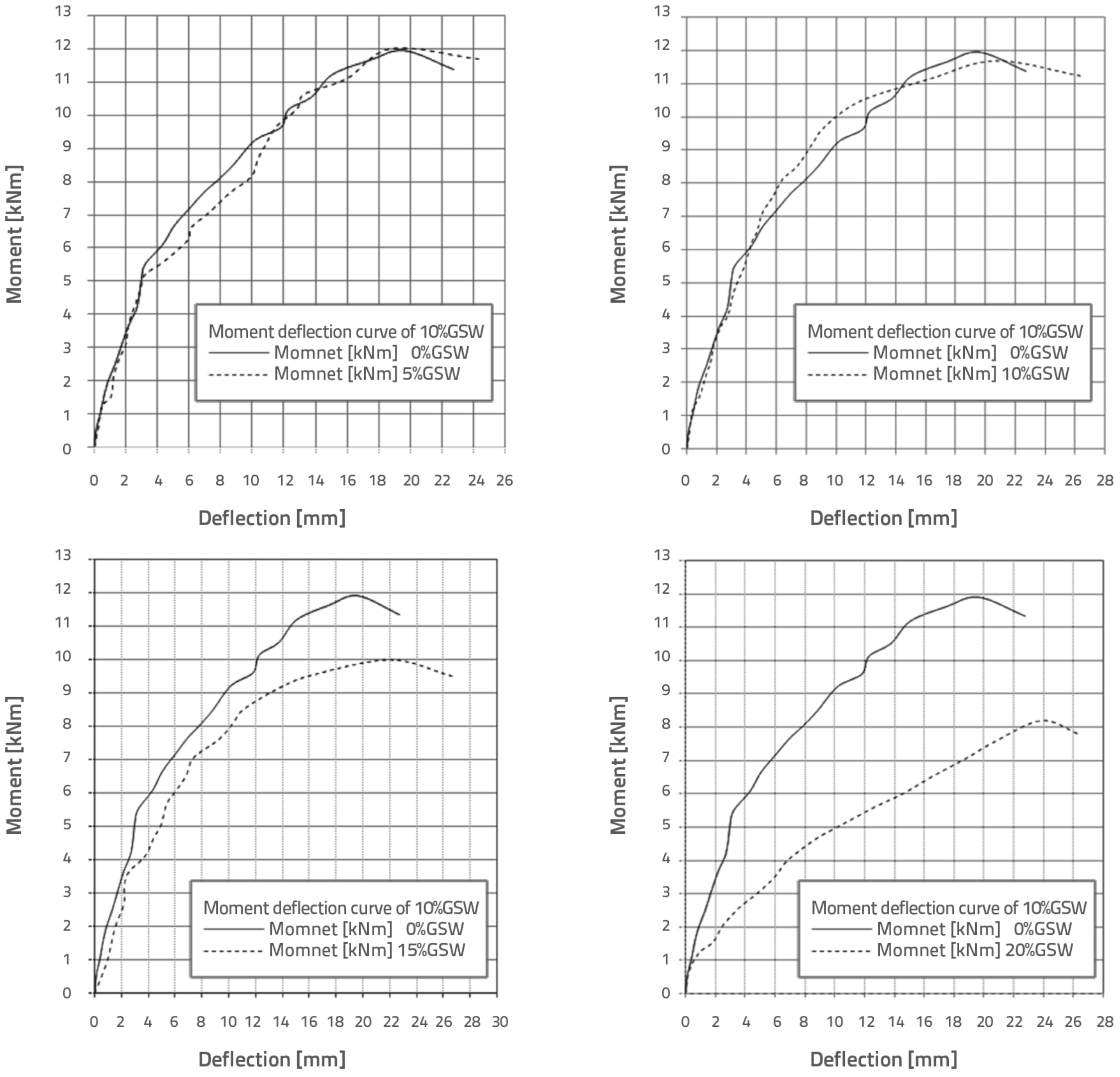

Figure 8. Moment deflection curves of specimens with granite sawing waste (GSW)

Table 7 shows the values of ultimate loads and first crack loads. All the beams showed a structural flexure behavior. All the cracks were vertical in nature and no horizontal cracks were observed, and they formed in the middle flexure region, in which the bending moment is constant which shows that there was a flexure failure. The failure pattern and cracks indicate that there is no bond failure. The steel in the tension region yielded first followed by the crushing of concrete in the compression region, and a typical under reinforced beam failure occurs which did not get affected by the presence of GSW.

After the first crack load, the reinforcement started yielding and more number of cracks had formed in the flexure zone and extended towards the point loads with increment in loads. At the ultimate load, the failure of all reinforced concrete beam occurred with crushing of concrete in compression zone. In the Specimens SCC IV and SCC V more number of cracks formed in flexure zone. It indicates that those do not provide high strength in the flexure zone.

Figure 8 shows the results of moment deflection behavior of reinforced concrete beams with GSW. From the figures, it is obvious that the beams with 5 to 10 % GSW are showing a similar flexural stiffness as in the case of control reinforced concrete beam without GSW. But when the GSW is further increased to 15 %, it tends to reduce the stiffness of the reinforced concrete beam.

The ductility of a structural member is important since it represents the capability to undergo large displacements under specified loading. In this experimental work, the displacement ductility is measured. Before failure occurs it gives sufficient warning. The displacement ductility is the ratio of ultimate displacement and yield displacement. The ductility index of 3 to 5 as given in table 8 have been indicated to be as a measure of good ductility by researchers [25]. The values of ductility index show that better ductility behavior is observed even when the reinforced concrete beams are incorporated with GSW.

Table 8. Moments and ductility ratio

Specimen	Theoretical ultimate moment Mu_{IS} [kNm]	Experimental ultimate moment Mu_{exp} [kNm]	$\frac{M_{Control}}{M_{GSW}}$	Ductility index
SCC I [0 %]	7,10	11,93	-	2,945
SCC II [5 %]	7,20	12,01	1,0067	3,419
SCC III [10 %]	7,25	11,66	0,9773	3,536
SCC IV [15 %]	7,067	10,02	0,8398	3,588
SCC V [20 %]	6,956	8,22	0,6890	3,591

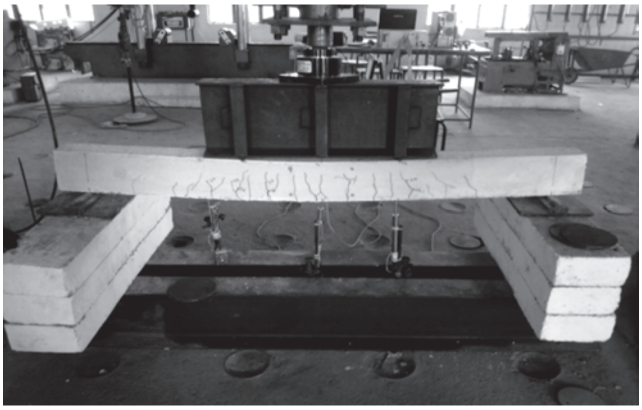

Figure 9. Test setup for reinforced concrete beam

Conclusion

The previously described results show that good deformability in a self compacting concrete mix can be obtained by reducing the water powder ratio. From the XRD results, it is found that the granite particles are more angular with high specific surface. Hence they tend to increase the cohesiveness of the mix but they decrease the workability of mix. Since the fly ash particles are spherical in nature they improve the workability and enhance deformability, and a blend of the above two produces a more workable mix. Since the water powder ratio is constant the flowability is uniform for all mixes.

The GSW (Granite Sawing Waste) is having greater than 25 % of reactive silica hence it can be partly used as a substitute material for cement. The main composition of GSW which are SiO_2, Al_2O_3, CaO and Fe_2O_3 based components along with their tiny particle size ensure their use as a partial replacement material for cement in concrete. When the GSW is used as a replacement material for cement by10 % it increases the strength up to 5.83 %. Conversely upto 15 % of GSW can be used without the loss of compressive strength because of their appropriate particle size distribution and potential pozzolanic activity. The continued hydration and void filling nature of GSW causes the increase in the density of concrete made with GSW at 28 days. The presence of GSW induces small pozzolanic reaction which is the possible reason for increase in the modulus of elasticity initially but at the higher contents, it tends to decrease the elastic modulus.

The reduction in the stiffness of the reinforced concrete beams with GSW content greater than 15 % is due to the decrease in the cement mortar strength. An equivalent flexural performance is observed even when the GSW was added upto 15 %. Hence it is possible to utilize the GSW as a partial replacement material for cement.

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