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SELF COMPACTION HIGH PERFORMANCE GREEN CONCRETE FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

Self Compacting Concrete (SCC) as the name implies that the concrete requiring a very little or no vibration to fill the form homogeneously. SCC is defined by two primary properties: Ability to flow or deform under its own weight and the ability to remain homogeneous while doing so. A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has environmental impact due to high consumption of energy and other resources. One important issue is the use of environmental-friendly concrete ("green concrete") to enable worldwide infrastructure growth without affecting the environment [1]. The potential environmental benefit to society of being able to build with green concrete is huge. Suitable environmental cost of producing concrete into the current price by adjusting the price of environment resources to elevate concrete's price, which will be helpful for protection of the environment and will promote the advancement of concrete technology. The problems of sustainable development should be considered on the society-economy-technology level. Fresh properties and basic strength characteristics, such as compressive strength, splitting tensile strength, with crusher rock and marble slurry dusts are the main focuses in this research.

INTRODUCTION

Conventional concrete aggregate consists of sand (fine aggregate) and various sizes and shapes of gravel or stones. However, there is a growing interest in substituting alternative aggregate materials. Even though aggregate typically accounts for 70% to 80% of the concrete volume, it is commonly thought of as inert filler having little effect on the finished concrete properties. However, research has shown that aggregate in fact plays a substantial role in determining workability, strength, dimensional stability, and durability of the concrete. The demand of natural sand is quite high in developing countries owing to rapid infrastructural growth. Quarry dust and marble sludge are dumped in the nearby land and the natural fertility of the soil is spoiled. To avoid the pollution and reuse the waste material, the present study is carried out.

Concrete and the environment

There is an increasing concern now that the choice of construction materials must also be governed by ecological considerations. In the beginning of the 20th

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Century, the world population was 1.5 billion; by the end of the 20th Century it had risen to 6 billion. Considering that it took 10,000 years after of the last ice age for the population to rise to the 1.5 billion mark, the rate of growth from 1.5 to 6 billion people. In the beginning of the 20th Century, approximately eleven percent of the people lived in cities; in the year 2001 nearly three of the six billion inhabitants live in and around the cities (Jochen and Wicht, 2000).

Future demand for concrete

Ordinary concrete, typically, contains about 12 percent cement, 8 percent mixing water, and 80 percent aggregate by mass. This means that, in addition to 1.5 billion tonnes of cement, the concrete industry is consuming annually 9 billion tonnes of sand and rock together with one billion tonne of mixing water. The 11.5 billion tonnes-a-year concrete industry is thus the largest user of natural resources in the world. The demand for concrete is expected to grow to approximately 18 billion tons (16 billion tonnes) a year by 2050 (Claus Pade, 2005).

Self-compacting concrete

Self Compacting Concrete (SCC) has been developed to ensure adequate compaction and facilitate placement of concrete in structures with congested reinforcement and in restricted areas. Concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction. It is also referred as self-leveling concrete, super workable concrete, self-consolidating concrete, highly flowable concrete, non-vibrating concrete, etc.

Self-compacting high performance concrete

The prototype of SCC was first completed in 1988 using materials already on the market. The prototype performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties and was named "High Performance Concrete." Since then, the term high performance concrete has been used around the world to refer to high durability concrete. Therefore, Okamura[4] has changed the term for the proposed concrete to "Self-Compacting High Performance Concrete" (SCHPC) and was defined as follows at the three stages of concrete:

(1) Fresh : Self – Compactable.
(2) Early age : avoidance of initial defects.
(3) After hardening : Protection against external factors.

SCHPC can be described as a high performance material which flows under its own weight without requiring vibrators to achieve consolidation by complete filling of formworks even when access is hindered by narrow gaps between reinforcement bars (Zhu *et al.* 2001).

Self compacting high performance green concrete

A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has environmental impact due to high consumption of energy and other resources. One important issue is the use of environmental-friendly concrete (green concrete) to enable worldwide infrastructure growth without affecting the environment.

Green concrete has nothing to do with color. It is a concept of thinking environment into concrete considering every aspect from raw materials manufacture over mixture design to structural design, construction, and service life. Green concrete is very often allso cheap to produce, because, for example, waste products are used as a partial substitute for cement, charges for the disposal of waste are avoided, energy consumption in production is lower, and durability is greater.

Sustainable development of concrete industry

During the last few decades, society has become aware of the problems associated with land filling of residual products, and limits, restrictions and taxes have been imposed. Disposal of wastes has become a major problem in metropolitan areas in India especially the disposal of Crusher Rock Dust (CRD) generated from stone crusher industry and Marble Slurry Powder (MSP) generated from the stone processing Industry in the country. For sustainable development of this industry, technological developments are urgently required to cope up with the ever increasing CRD and MSP problem by way of development and promotion of technologies for the utilization of these wastes. At present, the disposal solution employed is land filling. However, the volume of CRD and MSP to be disposed of remains considerably high and become less feasible in recent years as environmental concerns have lead to rapidly increasing costs. Therefore, the civil engineers have been challenged to convert these industrial wastes, in general, to useful building and construction materials. Utilization of these wastes for construction shall not only solve waste problems, but also provide a new resource for construction purposes. The usage of SCHPC is rapidly growing all over the world, however, there is a need to decrease the material cost, develop globally agreed upon test methods, and a gain a deeper understanding of SCHPC technology. It may be possible to use residual products from other industries in the concrete production while still maintaining a high concrete quality. As several residual products have properties suited for concrete production, there is a large poelevential to increase material recycling by investigating the possible use of these for concrete production. One way to reduce the material cost of SCC is through adequate mix proportioning and the addition of supplementary powder materials, such as CRD and MSP in concrete mix. This also alleviates these wastes disposal problem. When assessing the environmental compatibility of concrete it is essential to consider all life cycle phases and not only the environmental impacts associated with the production and use of the material itself. Even a small reduction of the environmental impact per tonne of concrete will result in large environmental benefits because of the vast amount of concrete produced today. The potential environmental benefit to society of being able to build with green concrete is huge. It is realistic to assume that technology can be developed which can halve the CO2 emission related to concrete production. Concrete with reduced environmental impact, the so-called green concrete, has been produced in Denmark for some years (Glavind and Munch-Petersen, 2000).

Scope of study

Strength is one of the most important properties of concrete since the first consideration in structural design is that the structural elements must be capable of carrying the imposed loads. Furthermore, strength characteristic is also vital because it is related to several other important properties which are more difficult to measure directly. According to this matter, fresh properties and development of compressive strength, splitting tensile strength are studied.

EXPERIMENTAL PROGRAM MATERIALS

Cement

Ordinary Portland cement (OPC) of 43 grade having a specific surface of 412.92 m^2/kg and conforming to IS: 8112-1989 was used. The cement was kept in an air-tight container and stored in the humidity-controlled room to prevent cement from being exposed to moisture. The chemical composition of river sand, crusher rock dust and marble sludge and cement were given in Table 1.

Sand

The sand used in this study was natural sand conforming to Zone II with specific gravity 2.68, fineness modulus as 3.42. This material is dried at room temperature for 24 hours to control the water content in the concrete. The maximum size of fine aggregate was taken to be 4.75 mm. The testing of sand was done as per Indian Standard Specifications IS: 383 –1970 . Table 2 represents the combined grading of CA and F.A (River sand, CRD and MSP).

Marble Sludge Powder (MSP)

MSP was obtained in wet form directly taken from deposits of Marble factories. Wet MSP must be dried before the sample preparation. MSP contains several Marble types and Marble particles. Hence, waste Marble sludge was sieved from 1mm sieve. The high content of CaO confirmed that the original stones were Marble and limestone. The sludge was also tested to identify the absence of organic matter, thus confirming that it could be used in concrete mixtures.

Crusher Rock Dust (CRD)

The CRD used in the investigation was obtained from Madurai district crusher industry. The specific grav-

Table 1. Chemical composition

Sample	Fe_2O_3 % wt.	MnO. % wt.	Na_2O % wt.	MgO % wt.	K_2O % wt.	Al_2O_3 % wt.	CaO % wt.	SiO_2 % wt.	Test Method
River Sand	1.75	nil	1.17	0.85	1.15	11.25	3.11	82.45	IS:
Crusher rock dust	5.22	0.07	1.50	1.33	5.34	14.63	1.28	75.25	4032-
Marble Sludge Characteristics	11.99	0.08	2.08	8.74	2.33	4.45	1.58	64.86	1968[7]
Portland cement	0.55	0.85	0.85	2.15	0.85	5.50	63.50	21.50	

ity of the CRD is 2.72 and bulk density is1820 kg/m3.

Course aggregate

The type of coarse aggregate used is angular aggregates with rough surfaces from crushed natural rock stone aggregate of nominal size of 20 mm was used. Coarse aggregate Specific gravity is 2.74; bulk density is 1636 kg/m3.

Water

In this study, normal tap water available in the concrete laboratory was used. Water conforming to the requirements of water for concreting and curing as per IS: 456-2000.

Super Plasticizer

Commercially available Super plasticizer Conplast SP430A1 from Fosroc Chemicals (India) Ltd., Bangalore was used to produce high workability in concrete and reduce the water cement ratio. The Specific gravity of the Conplast SP430A1 is 1.18 to 1.20 at 20° C.

Mix design and preparation of specimen

For selecting a suitable mix using local marginal aggregates, 288 trial mixes were considered by varying the mix parameters, such as quantity of MSP, superplasticizer (SP), Water/Powder ratio and fine aggregate/coarse aggregate ratio (FA/CA). Two hundred and seventy trial mixes were prepared by varying the SP ratio, fine to coarse aggregate ratio, MSP content and Water Powder ratio for three different contents of M20, M30 and M40 grades to select a suitable mix. Five levels of MSP 0%, 5% 10% 15% and 20%, three levels of the SP 0%, 0.5% and 1.0% on weight of total powder content, two levels of fine to coarse aggregate ratio: 1 and 1.1 (by mass), and three levels of water powder ratio 0.80, 1.0 and 1.2 (by volume) by keeping cement content constant and three different grades of M20, M30 and M40 were used for preparing and testing of these two hundred and seventy trial

Table 2. Combined Grading of CA and F.A (River sand, CRD and MSP)

Sieve Size	Total percent retaining			
	Course Aggregate	River Sand	Crusher Dust	Marble Sludge
40 mm	0	0	0	0
20 mm	65.5	0	0	0
10 mm	88.0	0	0	0
4.75 mm	100	0	0	0
2.36 mm	100	5.5	14.6	4
1.18 mm	100	44.3	47.3	9.18
600 μ	100	45.72	65.0	16.15
300 μ	100	85	78	23.84
150 μ	100	97	87	37.19
< 150 μ	100	100	100	100

Table 3. Selected Mix proportion for SCC test

MIX	Cement in Kg	MSP in Kg	River Sand	CRD in kg	CA in Kg	Water in Litre	Super plasticizer in Litre	W/P or eW/C ratio	Grade of Concrete
NCRS3	383.2	0	577	0	1199	191.6	3.83	W/C=0.50	M20
NCCRD3	383.2	0	0	537	1253	191.6	3.83	W/C=0.50	
SCHPGC 76	383.2	0	0	940	850	266.1	3.83	W/P=1.0	
SCHPGC79	383.2	141	0	799	850	364.0	5.24	W/P=1.0	
NCRS6	511	0	497	0	1159	191.6	5.11	W/C=0.375	M30
NCCRD6	511	0	0	448	1208	191.6	5.11	W/C=0.375	
SCHPGC 161	511	0	0	828	828	354.9	5.11	W/P=1.0	
SCHPGC 164	511	124	0	704	828	441.0	6.41	W/P=1.0	
NCRS9	618	0	371	0	1200	185.4	6.18	W/C=0.30	M40
NCCRD9	618	0	0	324	1249	185.4	6.18	W/C=0.30	
SCHPGC 251	618	0	0	787	786	429.2	6.18	W/P=1.0	
SCHPGC 254	618	117	0	670	786	510.4	7.35	W/P=1.0	

mixes. Based on the test results, some of the trial concrete mixes tested are found to be suitable for SCC flow properties and producing high-strength SCHPGC and presented in the Table 3.1. The concrete was mixed using a tilting-type laboratory mixer and was poured into the moulds in layers. Compaction of concrete was done using a table vibrator. The specimens were cured under water along with moulds after 24 hour of casting. After 28 days of curing, permeability tests were conducted.

Fresh Properties

Slump flow test

For each mix, slump flow, J-ring test, U- Box, L-box and V-funnel test were carried out. It is the most commonly used test and gives a good assessment of filling ability. At first, the inside of slump cone and the smooth leveled surface of floor on which the slump cone is to be placed are moistened. The slump cone is held down firmly. The cone is then filled with concrete. No tamping is done. Any surplus concrete is removed from around the base of the concrete. After this, the cone is raised vertically and the concrete is allowed to flow out freely. The diameter of the concrete in two perpendicular directions is measured. The average of the two measured diameters is calculated. This is the slump flow in mm. The higher the slump flow value, the greater its ability to fill formwork under its own weight. As per EFNARC, (2002) guide, the range is from 650 mm to 800 mm.

J-ring test

The J-ring test is based on a J-ring developed in Japan (in fact, J-ring means Japanese ring) and is to be carried out together with the slump flow test. This involves the slump cone being placed inside a 300 mm diameter steel ring attached to vertical reinforcing bars at appropriate spacing (the J-ring itself. The J-rings used by different researchers are basically similar except for the clear spacing between the steel bars, which varies from 30 to 122 mm. The J-ring test is an improvement upon the Slump Flow test on its own as it aims to also assess the passing ability of the fresh mix.

L - box test method

It assesses filling and passing ability of SCC. The vertical section is filled with concrete, and then gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the heights 'H1' and 'H2' are measured. Closer to unity value of ratio 'H2/H1' indicates better flow of concrete (Zhu *et al.* 2001).

U-box test

This test is used to measure the filling ability of SCC. In their test, a specially designed U-box, comprising of a storing compartment, a filling compartment and an opening between the two compartments, is employed for the U-box test.

V-funnel test

The test measures flowability and segregation resistance of concrete. At first, the test assembly is set firmly on the ground and the inside surfaces are moistened. The trap door is closed and a bucket is placed underneath. Then the apparatus is completely filled with concrete without compacting. After filling the concrete, the trap door is opened and the time for the discharge is recorded. This is taken to be when light is seen from above through the funnel.

Mechanical Properties

Mechanical properties such as compressive strength and split tensile strength are evaluated. Compressive strength and split tensile strength test were conducted for SCHPGC, NCRS and NCCRD.

Compressive Strength Test

Compressive strength test usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. The compression test is an important concrete test to determine the strength development of the concrete specimens. Compressive strength tests were performed on the cube specimens at the ages of 7, 28 and 90 days.

Splitting Tensile Strength

The indirect method of applying tension in the form of splitting was conducted to evaluate the effect of MSP and CRD on tensile properties of concrete. The split tensile strength is a more reliable technique to evaluate tensile strength of concrete (lower coefficient of variation) compared to other methods. The split tensile strength of 150 mm diameter and 300 mm high concrete cylindrical specimens was determined to assess the effect of CRD and MSP on the tensile properties of the concrete.

RESULTS AND DISCUSSION

A total of 288 trial concrete mixes have been produced and tested for their workability, filling ability, passing ability and strength using the slump flow test, J-ring test, U-box test, V- funnel test, sieve segregation test and cube compression test to study the combined effects of the W/P ratio, MSP and CRD fine aggregate proportions on the performance of SCHPGC.

70 concrete mixes out of 270 mixes were able to achieve a slump flow of above 650 mm. 28-day cube compressive strength of highest value may be regarded as SCHPGC. However, their filling ability, passing ability and segregation stability varied and not all are qualified as SCHPGC. The J-ring, V-funnel, U-box and sieve segregation tests were employed to assess the performance of the concrete mixes.

The J-ring test allowed the passing ability through bars of 30mm spacing to be evaluated. It also allowed the blockage of aggregate particles owing to low passing ability and paste-aggregate separation owing to low segregation stability to be observed directly. However, the J-ring test results are not considered as good measures of passing ability and segregation stability because of their low sensitivity and low reproducibility.

The U-box and sieve segregation tests provided much better measures of filling ability, passing ability and segregation stability. They revealed very clearly how the passing ability and segregation stability varied with the W/P ratio and the aggregate proportions. Overall, the results of J-ring, U-box and sieve segregation tests showed that the cohesiveness and FA/CA ratio, percentage of SP, MSP and CRD content are the major factors affecting the performance of SCHPGC. The effects of the MSP content are more significant than the amount of CRD in the fine aggregate content.

Taking the acceptance criteria of SCC as slump flow $\geq$ 650 mm, reduction in slump flow owing to the presence of the J-ring $\leq$100 mm, U-box filling height $\geq$ 300 mm, V-funnel time 6 - 12 seconds and segregation index $\leq$ 20 %, mixes SCHPGC 79, SCHPGC 164 and SCHPGC 254 may be accepted as SCHPGC. For a given SCHPGC satisfying all the performance requirements for SCC, a slight change in the mix design parameters would lead to non-compliance of some of the performance requirements for SCC. Therefore, the performance of SCHPGC is very sensitive to any changes in the mix design parameters.

Compression Test

The SCHPGC79, NCCRD6 and NCCRD9 achieved highest 7 days compressive strength of 18.15 N/mm^2, 25.15 N/mm^2 and 34.10 N/mm^2 for M20, M30 and M40 grade of concrete respectively. The SCHPGC79, SCHPGC164 and SCHPGC254 achieved highest 28 days compressive strength of 26.85 N/mm^2, 37.25 N/mm^2 and 49.60 N/mm^2 for M20, M30 and M40 grade of concrete respectively. Similarly, the SCHPGC79, SCHPGC164 and SCHPGC254 achieved highest 90 days compressive strength of 33.15 N/mm2, 45.35 N/mm^2, and 55.42 N/mm^2 for M20, M30 and M40 grade of concrete respectively. The test results of 7 days, 28 days and 90 days compressive strength are given in Table 6.

NCCRD achieves higher initial compressive strength for M30 and M40 grade. Later on SCHPGC achieves higher compressive strength at 28 days and 90 days for all grade of concrete. It represents, the MSP presents in the concrete react slowly with hydration of cement and improves the strength of concrete.

Table 6. Compressive and Split Tensile Strength

Grade of Concrete	Sample	Compressive Strength in N/mm^2			Split Tensile Strength in N/mm^2		
		7 days	28 days	90 days	7 days	28 days	90 days
M20	NCRS3	16.5	24.6	29.45	2.38	3	3.62
	NCCRD3	17.87	25.85	32.62	2.95	3.15	3.88
	SCHPGC76	17.35	23.56	30.85	2.42	2.85	3.15
	SCHPGC79	18.15	26.85	33.15	2.92	3.35	4.05
M30	NCRS6	23.12	34.75	42.25	2.72	3.74	4.07
	NCCRD6	25.15	37	44.12	2.95	3.82	4.25
	SCHPGC161	23.85	37.25	45.35	2.65	3.15	4.38
	SCHPGC164	24.33	38.5	46.55	3.02	4.05	4.47
M40	NCRS9	32.52	45.78	52.26	3.12	3.93	4.85
	NCCRD9	34.1	49.21	54.15	3.35	4.02	5.12
	SCHPGC251	30.85	46.25	51.22	3.32	3.85	4.95
	SCHPGC254	36.21	49.6	55.42	3.55	4.15	5.25

Moreover, MSP reduce the pore structure of concrete results improve the strength of concrete.

Split Tensile Strength Test

The NCCRD3, NCCRD6 and SCHPGC254 achieved highest 7 days split tensile strength of 2.95 N/mm^2, 2.95 N/mm^2, and 3.55 N/mm^2 for M20, M30 and M40 grade of concrete respectively. The SCHPGC79, SCHPGC164 and SCHPGC254 achieved highest 28 days split tensile strength of 3.35 N/mm^2, 4.05 N/mm^2 and 4.15 N/mm^2 for M20, M30 and M40 grade of concrete respectively. Similarly, the SCHPGC79, SCHPGC164 and SCHPGC254 achieved highest 90 days split tensile strength of 4.05 N/mm^2, 4.47 N/mm^2, and 5.25 N/mm^2 for M20, M30 and M40 grade of concrete respectively. The test results of 7 days, 28 days and 90 days split tensile strength are given in Table 6.

NCCRD achieves higher initial split tensile strength for M20 and M30 grade. Later on SCHPGC achieves higher split tensile strength at 28 days and 90 days for all grade of concrete. When comparing the SCHPGC and NCCRD with NCRS there is much improvement in split tensile strength value. Comparing the SCHPGC with NCCRD, there is only very little strength improvement. The crusher rock particles have greater rough surface than river sand. The rough surface improves the bond strength. Hence, a SCHPGC and NCCRD concrete specimen gives greater strength. MSP have very smooth surface. Hence, MSP presents in the SCHPGC did not improve the bond strength.

CONCLUSION

All the experimental data show that it is possible to use both the wastes in the manufacturing of SCHPGC. Furthermore, in many cases the addition of the wastes improves the physical and mechanical properties. These results are of great importance because this kind of innovative concrete requires large amounts of fine particles. Due to its high fineness of the Marble sludge it provided to be very effective in assuring very good cohesiveness of concrete. From the above study, it is concluded that the Crusher dust and Marble sludge may be used as a replacement material for fine aggregate. Fresh properties of the Selected SCHPGC mixes were compared with the recommended range given by EFNARC, "Specifications and Guidelines for Self-Compacting Concrete," EFNARC, UK. The test results are satisfied the recommended range.

- The chemical compositions of Crusher dust and Marble sludge such as Fe_2O_3, MnO, Na_2O, MgO, K_2O, Al_2O_3, CaO, and SiO_2 are comparable with that of cement.
- SCHPGC Mix (15% MSP and 85% CRD with FA/CA ratio (1.1) gives an excellent result in strength aspect and quality aspect.
- Test results show that these industrial wastes are capable of improving hardened concrete performance.
- SCHPGC mix enhancing fresh concrete behaviour and can be used in architectural concrete mixtures containing white cement.

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