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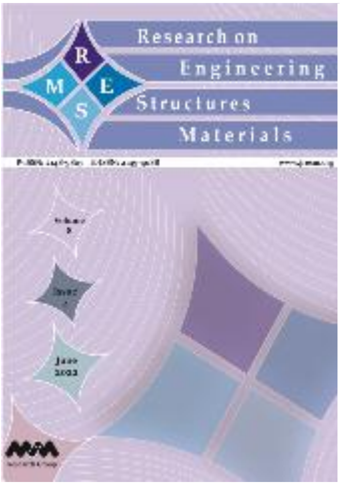

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Deepan Rajendran, Chella Gifta Christopher, Malaiappan Sindhu Muthu

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Technical Note

Self - compacting concrete made with partial replacement of lime stone and quarry dust powder

Deepan Rajendran[a], Chella Gifta Christopher*[b], Malaiappan Sindhu Muthu[c]

Faculty of Civil Engineering, National Engineering College, KR Nagar, Kovilpatti, Tamilnadu, India

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Abstract

Self-compacting concrete is very popular in the field of concrete technology and it plays a significant role while placing the concrete in congested reinforcements. Self-compacting concrete could be produced with high fluidity and good cohesiveness, and it gets compacted by its gravitational force. This paper attempts to understand the influence of filler materials such as lime stone powder and quarry dust as a partial replacement of cement material. Self-compacting concrete was produced by partially replacing the cement by 10%, 20%, 30% Lime stone and Quarry dust powder, and their influence on fresh properties such as passing and filing ability, flowability are examined as per European Federation of National Associations Representing for Concrete (EFNARC) guidelines. Results of fresh and hardened properties exhibited replacement up to 10% lime stone and quarry dust is the optimum level, and other replacement levels produced satisfactory results. Compressive strength, water sorptivity, and density values are marginally affected by the addition of 20% and 30% replacement of these filler materials.

1. Introduction

Concrete is a primary construction material and construction industry has a greater demand for achieving a strong and durable concrete. Cement, aggregates, water, mineral and chemical admixture are the raw materials used in the manufacture of conventional concrete. According to the Cement Industry 2019 report, India is the second largest cement producer in the world and the per capita cement consumption is estimated to be 239kg [1]. Cement manufacturing industries are the major sources of carbon di oxide emission and they produces 310 million tonnes of cement clinkers and they are the major pollutants to the environment [2]. Report says about 12% -15% of total industrial energy emission is contributed by the cement manufacturing industry. It causes a major threat to living hood and endangers the human respiratory systems by producing huge quantity of particulate matters in the production stage. Hence it is necessary to search for an alternative material to replace the cement in the production of concrete in order to save the energy as well as the environment. Nowadays cement is partially replaced with wide variety of supplementary cementitious materials (SCM) and high quality SCM produces strong and durable concrete. However, the extensive use of these SCM's also leads to the depletion of natural resources and hence some initiatives are necessary to identify a suitable substitute for replacing the cement with similar morphological properties [3].

Lime stone and Granite quarries are considerably increasing in number and they produces large amount of Lime stone and Quarry dust in powder form during their crushing process. Handling becomes a challenge for these quarries, because the land filling and disposal of

*Corresponding author: erchellac@gmail.com
[a] orcid.org/0000-0002-2399-3338; [b] orcid.org/0000-0002-4956-9332; [c] orcid.org/0000-0001-7420-8523
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this powder creates serious environmental problems like water, land pollutions and cause determinantal effects to the human health. Both powdered materials are very fine in nature and they contaminate the air during summer and spring seasons [4]. However these finer materials could be successfully utilized as a binder medium to enhance the flowability and viscosity in the production of special concrete like self- compacting concrete (SCC). Self-compacting concrete is a new composite developed in recent years, producing concrete of high fluidity, self compactability, high strength and better serviceability during their exposure conditions. SCC mix designs are different from traditional one in which the rheology of the mortar is adjusted to achieve the concrete with high level of workability. Mineral admixtures and plasticizers are used to achieve the fluidity of concrete and the particle size distribution is the best approach to optimize the fluidity of self-compacting concrete. Inter particle separation combined with particles packing density is the main rheological parameter governing the design of self-compacting concrete. The addition of mineral additives or powders in addition to the cement content is used to achieve the appropriate viscosity of self-compacting characteristics. In SCC, aggregate – cement interface zone is the weakest one and it depends on the fineness of the mineral admixture [4]. Hence the advantages of SCC are numerous and it is described as a most revolutionary material in the construction industry. It offers some economic benefits such as faster construction, reduced man power, good surface finishes, thinner concrete sections, reduced noise level and no vibrations etc. In spite of these merits there are few bottle necks in the application of SCC. Lack of Indian standard codes describing the testing procedures, mix design, high cost, high quality control and need of special form works are few, which may limit the application of self-compacting concrete. Several authors have already explored the behaviour of self-compacting concrete with the incorporation of basalt, granite, marble powders in cement paste, cement mortar and concrete [5 - 7]. Burak Felekoglu produced SCC with quarry lime stone powder as partial replacement of cement reported the substitution of materials reduced the strength when lime stone powder content is increased [8]. Demone et al. analyzed the SCC fresh properties with 16mm and 20mm size coarse aggregates along with the lime stone fillers concluded the robustness of SCC could be improved by the addition of viscous modifying agents [9]. Dehwah summarized relatively better mechanical properties of SCC incorporated with quarry dust powder than its combination with silica fume [10]. Khaleel et al. reported the usage of uncrushed gravel improves the flowability, passing ability, and segregation resistance when compared with crushed gravel [11]. Schankoski et al. concluded the SCC produced with diabase and gneiss quarry powders slightly increased the fresh and hardened properties in comparison with lime stone as filler in concrete production [12]. Self-compacting concrete has become a sustainable development in the field of concrete technology and it could be used in many civil engineering applications [13]. Hence this paper mainly focus on characterizing the self-compacting concrete produced with the incorporation of quarry dust and lime stone powder as a partial replacement of cement. Their impacts on fresh properties and few hardened properties were determined and reported.

2. Experimental Procedure

To understand the behaviour of self-compacting concrete manufactured with the addition of fillers, the following materials were used: Ordinary Portland Cement, Lime stone and Quarry dust powder, Aggregate and Super plasticizers.

2.1. Material and Mixture Proportions

In this experimental study Ordinary Portland Cement 53 grade confirming to IS 12269: 2013 specification was used as an important binder [14]. Physical properties of the cement used in this study are given in Table 1. Cement is replaced with Lime stone powder particles of size less than 0.125 mm and its specific gravity is 2.53. Crushed quarry dust powder smaller than 150µm is also used as a partial replacement material and its specific gravity was measured to be 2.30. Lime stone powder and Crushed quarry dust powder used in this study are shown in Fig. 1 and Fig. 2. Angular shaped aggregates of maximum size 12 mm and specific gravity 2.78 are used as a coarse aggregate. Bulk density and fineness modulus of coarse aggregate are 1486 kg/m3 and 7.48 respectively. Locally available river sand passing through 4.75mm with specific gravity 2.64 confirming to zone II of IS 383: 1970 specifications were used in the study [15]. Bulk density and fineness modulus are measured to be 1720 kg/m3 and 2.85 respectively. CONPLAST SP 430 lignosulphonate based aqueous solution compatible with most of the pozzolanic materials are used as a super plasticizer (SP) in this investigation and its properties are shown in Table 2. Effective dispersion of cement is essential for the production of SCC and electro static dispersion of lateral chains and their linked polymer backbones are capable of producing flowable concrete with reduced water cement ratio.

Eco- friendly SCC mix proportion was done by the detailed mix design procedure suggested by Nan su et al [16].M30 grade concrete is chosen and volume ratio of aggregate is assumed to be in the range of 59% to 68% in this study. Packing factor is an another important parameter in SCC mix design and it is assumed as 1.18 by trial-and-error procedure. Water cement ratio of 0.44 is considered and mixture proportion for the reference concrete is obtained for this testing programme. All the ingredients of concrete are mixed together in a Pan mixer of 40 litres capacity shown in Fig. 3. The details of control mixture are presented in Table 3.

Fig. 1 Lime stone powder

Fig. 2 Quarry dust powder

Table 1. Properties of OPC 53 grade

Properties	Range of values
Specific gravity	3.13
Normal consistency	33%
Initial setting time	105 min
Final setting time	185 min

Table 2. Properties of CONPLAST SP 430

Properties	Range of values
Colour	Colourless
Relative density	1.01± 0.01
pH	8±1

Seven series of mixtures were prepared to examine the fresh properties of SCC made with different proportions of Lime stone (LS) and Quarry dust powder (QD) and their replacement is made on weight basis. Fresh concrete mixture used for SCC testing is shown in Fig. 4. Trial mixtures with various replacement level and their designations are mentioned below.

- Control concrete without any replacement (CC series)
- Cement replaced by 10%, 20% and 30% lime stone powder. (LS series)
- Cement replaced by 10% ,20% and 30% Quarry dust (QD series)

Table 3. Control concrete mixture proportions per cubic meter

Materials	Quantity
Cement	3.13
Fine aggregate	33%
Coarse aggregate	105 min
Water	185 min
Super Plasticizer	4.8% of binder content

2.2. Testing on Fresh properties of Self - Compacting Concrete

The main characteristic of self-compacting concrete is the ability to spread and consolidate by its own weight. Fresh properties are assessed as per the EFNARC guidelines and to measure the filling ability Slump flow, T 500 mm slump flow and V Funnel test were conducted [17]. In order to check the flowing and passing ability L box test is conducted and it is shown in Fig. 5. U box test are done to measure the packing ability of the concrete. The difference in filling height (h2- h1) gives the U box test results. The test set up is shown in Fig. 6. The segregation resistance is measured by V funnel and the test is conducted for 5 minutes time duration. Test set up is shown in Fig. 7. In addition to that fresh state stability is measured by visual examination to ascertain the segregation and bleeding. Fig. 8 shows the slump flow obtained in this experimental programme.

2.3. Hardened Properties of Self-Compacting Concrete

Immediately after the fresh concrete testing, the seven series of specimens were made to understand the influence of filler materials on their hardened properties. Compressive strength test is conducted in a 2000kN capacity compression testing machine as per IS 516 -1959 guidelines on 100mm x 100mm x 100mm size cube specimens after 28, 60, 90, 120 days curing [18]. Dry density values are measured in all the test specimens and their values are compared to observe the influence of limestone and quarry dust in the hardened concrete composites. For each series, three specimens were tested and the average compressive strength and dry density values are considered. Water sorpitivity test also conducted to evaluate the potential durability properties of concrete on hardened stage.

Fig. 3 Pan mixer

Fig. 4 Fresh concrete mix

Fig. 5 L box test

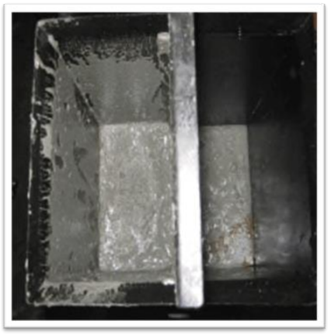

Fig. 6 U box test

Fig. 7 V funnel test

Fig. 8 Slump flow test

3. Results and Discussion

European Federation of National Association Representing for Concrete (EFNARC) has given the typical range of values for ascertaining the flow properties and passing ability of SCC and it is given in Table 4. Tests were conducted as per standard testing procedure and the fresh properties of self-compacting concrete are given in Table 5. The influence of Lime stone filler and quarry dust on compressive strength and water absorption at different curing ages are described in Fig. 9 to Fig. 11.

3.1. Fresh Properties Results of SCC

The influence of lime stone and quarry dust powder on the fresh properties of self – compacting concrete was studied and the results of slump flow, V funnel, L box and U box test are given in Table 5. From the test results, it is observed that the flow properties of 10% lime stone powder was quite high when compared to control concrete and its passing ability as well as the filling ability are increased. The slump flow value is 741mm for CC series and whereas it is 748 mm for LS10 but LS20 and LS 30 shows lower workability than reference concrete. However they are within the EFNARC guidelines mentioned in Table 4, and said to be a self-compacting concrete. Besides it is found that for the same level of replacement with quarry dust powder, the flowability in all the three-replacement found decreased when compared to Lime stone series. Hence the self-compacting concrete designed with lime stone powder is more flowable than SCC produced with quarry dust material. The evidence of flow of mortar and its bleeding characteristics in QD series are observed by its slump flow T500 test . Lime stone powders indicate better shape when compared to quarry dust and the friction between the particles leads to the high flowability characteristics [19]. In V funnel test all the SCC composites satisfies the acceptance criteria of EFNARC specifications. However, in lime stone series the 20% and 30% replacement levels reduced the filling and passing ability which gets altered with the replacement of 30% quarry dust in the fresh composite. L box test results (h2 /h1) are typically in the range of 0.811 – 0.986, which satisfies the SCC acceptance criteria. U box test results corresponding to the difference in height of concrete between the two sections are presented in Table 5. U box results of control concrete is 8 seconds and the passing ability of 10LS series is only 5 seconds and it indicates lime stone powder 10% replacement level increased the passing ability, while the higher replacement shows the opposite trend. U box results of 30QD series are closer to the maximum limit of EFNARC acceptance. This represents the flow is significantly affected by the inclusion of quarry dust powder in SCC concrete.

Table 4. EFNARC guidelines for SCC

Method of testing	Unit	Typical range of values	
		min	max
L-Box Test	-	0.8	1.0
U-Box Test	mm	0	30
V-Funnel Test	sec	6	12
Slump flow test	mm	650	800
J-Ring test	mm	0	10

Table 5. Fresh properties of SCC

Series	Slump flow	T500mm (sec)	Vfunnel (sec)	L box (h2/h1)	U box (mm)
CC	741	1.08	6.83	0.986	8
10LS	748	1.02	6.78	0.994	5
20LS	716	1.24	7.10	0.917	12
30LS	695	1.43	8.64	0.849	18
10QD	720	1.41	7.38	0.884	17
20QD	698	1.67	7.65	0.852	22.5
30QD	672	1.86	11.41	0.811	27

3.2. Compressive Strength of SCC

Fig. 9 shows the variation of compressive strength of cube specimen water cured after 28 days, 60 days, 90 days and 120 days. Compressive strength of cube specimens increases up to 4.38 % with the addition of 10% lime stone powder at 28 days. This lime stone particles act as a nucleation for CH crystals and thereby increase the strength marginally at lower replacement level. The same strength got reduced by up to 12 % particularly in 30LS series [20]. In addition, the strength development does not increase with the increase in curing age in all the test series. Except 30% lime stone replacement all other series produces compressive strength more than 30MPa and maximum value was reported as 34.67 MPa in control concrete and 36.36 MPa in 10% replacement level.

Fig. 10 represents compressive strength results of cubes tested at 28, 60, 90 and 120 days with the partial replacement of cement with quarry dust. The decrease in compressive strength is continuous when the immersion period increases and also the rate of fall increases with the increase in replacement of quarry dust in self-compacting concrete.

When compared to the control concrete at 90 days, the compressive strength of 10 QD, 20 QD and 30 QD series decreases by 5.30%, 7.15% and 27.37% respectively. It implies that the presence of SiO2 phases existing in the quarry dust becomes inactive and pozzolanic activity does not promote any improvement in compressive strength [21].

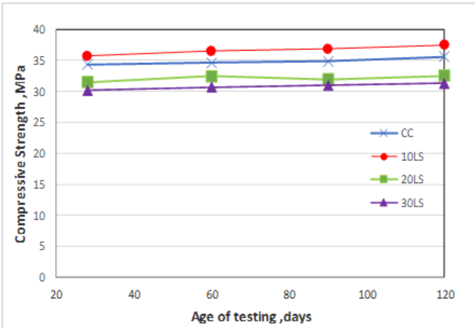

Fig. 9 Compressive strength results of Lime stone series

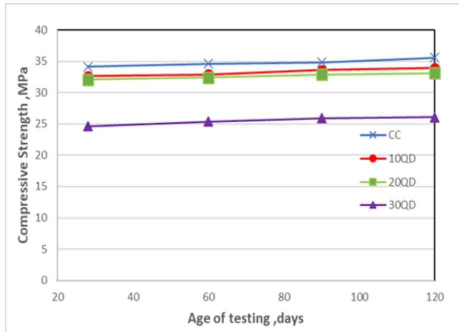

Fig. 10 Compressive strength results of quarry dust series

3.3. Density Values of SCC

Table 6 shows the density variation among control concrete, Lime stone series and Quarry dust series of self-compacting concrete. From the Table 6 it is understood that the density values are not much affected due to inclusion of fillers in the concrete composites. Maximum drop of 2.40 % was observed at 120 days cured specimens and at 30% Lime stone replacement level. This drop is less in Quarry dust replaced series. This is attributed to the dilution effect caused by the addition of crystalline mineral particles which acts as the nucleation sites of heat dissipations and reduces the compressive strength when substitution levels are increased.

Table 6. Density values in kg/m^3

Series	28days	56days	90days	120days
CC	2453	2486	2490	2496
10LS	2453	2480	2486	2490
20LS	2536	2566	2566	2573
30LS	2470	2503	2506	2513
10QD	2493	2520	2516	2523
20QD	2526	2540	2553	2561
30QD	2400	2416	2436	2441

3.4. Water Sorptivity Values of SCC

Sorptivity tests results on lime stone series cube specimens are shown in Fig. 11. Based on the test results it is understood that the changes seems to be negligible in 28 days and 60 days cured specimens. Beyond this age, there is no change in water sorptivity, which implies the reduction in permeation of water as the time goes on increasing in both the filler materials.

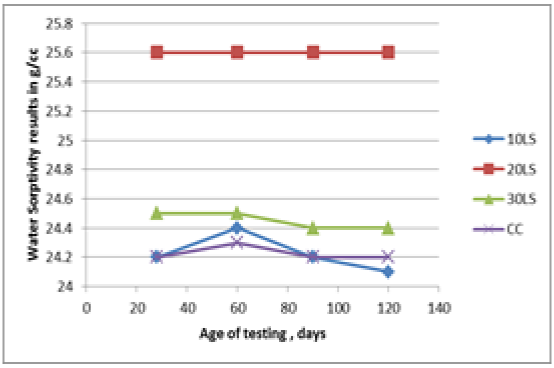

Fig. 11 Water sorpitivity results of Lime stone series

4. Conclusions

Based on the experimental investigation the following conclusions can be made:

- Results indicate the feasibility of producing SCC with the inclusion of lime stone and quarry dust powder as cement replacement materials and their dilution effect enhances the flow properties at all replacement levels, satisfying the values recommended by EFNARC guidelines.
- Fresh properties of self-compacting concrete were found to be good up to 10 % lime stone replacement and beyond that they were slightly affected with the increase in replacement levels. Lime stone powder shows better performance when compared to quarry dust. Lime stone powders are more reactive in the presence of cement rather than they act as fillers. Both can be successfully used in the production of self-compacting concrete.
- Compressive strength of Lime stone 10% replacement level is slightly higher than the control specimens and reduction in density was 1.5 % due to the increased shear when compared with other filler materials. Similarly, the reduction in replacement of 10% quarry dust was 1 % less than control concrete. Sorptivity test results reduced by 1% when compared to control concrete in lime stone series.
- Overall test results indicate the replacement of cement with 10 % lime stone improves the strength and flow properties of self-compacting concrete and also, they reduce the environmental risk of solid waste disposal problems.
- Micro fine lime stone powders fills the coarser voids of cement particles in the concrete and thus increases the density. Loss in mass ratio was found to be negligible in tested specimens and hence they found as appropriate replacement material to produce clean and sustainable products in future.
- Cost effective SCC is feasible with the incorporation of limestone powders as a replacement material.

This study gives some new reasons to use Lime stone powder as fillers and its effect on cement hydration process.

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