Strength And Durability Investigations On Self Consolidated Concrete With Pozzolanic Filler And Inert Filler

Ms. Priyanka P. Naik*, Prof. M. R. Vyawahare**

* Department of Civil Engineering, Babasaheb Naik College of Engineering Pusad, Amravati University Pusad-445215, Yavatmal, Maharashtra, India

** Associate Professor of Civil Engineering Department, Babasaheb Naik College of Engineering Pusad, Amravati University, Pusad-445215, Yavatmal, Maharashtra, India

ABSTRACT

Concrete is a versatile widely used construction material. Ever since concrete has been accepted as a material for construction, researchers have been trying to improve its quality and enhance its performance. Recent changes in construction industry demand improved durability of structures. There is a methodological shift in the concrete design from a strength based concept to a performance based design. At present there is a large emphasis on performance aspect of concrete. One such thought has lead to the development of Self Consolidated Concrete (SCC). It is considered as "the most revolutionary development in concrete construction". SCC is a new kind of High Performance Concrete (HPC) with excellent deformability and segregation resistance. It can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process.

The primary aim of this study is to explore the feasibility of using SCC by examining its basic properties and durability characteristics i.e. sorptivity and chloride ion penetration. An extensive literature survey was conducted to explore the present state of knowledge on the durability performance of SCC. However because it usually requires a larger content of binder and chemical admixtures compared to ordinary concrete, its material cost is generally 20-50% higher, which has been major hindrance to a wider implementation of its use. There is growing evidence that incorporating high volumes of mineral admixtures and micro filler as additives in SCC can make it cost effective, however the durability of such need to be proven.

This work consists of: (i) development of suitable mixes of SCC using separately the silica fume and quarry dust as active and inert filler satisfying the requirements of the fresh state. (ii) Casting of concrete samples and testing them for compressive strength, split tensile strength, sorptivity, and chloride permeability test (iii) Comparison of effect of pozzolanic filler and inert filler on strength and durability of self consolidating concrete.

Keyword: Self Consolidated Concrete (SCC), silica fume, quarry dust, strength, durability

1. INTRODUCTION

SCC is a new kind of High Performance Concrete (HPC) which has an excellent deformability and segregation resistance. By name it can be defined as a concrete, which can flow through and fill the gaps of reinforcement and corners of the moulds without any need for external vibration. SCC compacts itself due to its self weight and de-aerates almost completely while flowing in the formwork. SCC can also be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and columns or walls with congested reinforcement. The high flow ability of SCC makes it possible to fill the formwork without vibration. Since its inception, it has been widely used in large construction works or projects in Japan. Recently, this concrete has gained wide use for different applications and structural configurations across the world.

High strength concrete can be produced with normal concrete. But these concretes cannot flow freely by themselves, to pack every corner of moulds and all gaps of reinforcement. High strength concrete based elements require thorough compaction and vibration in the construction process. SCC has more favourable characteristics such as high fluidity, good segregation resistance and distinctive self-compacting ability without any need for external or internal vibration during the placing process. It can be compacted into every corner of formwork purely by means of its own weight without any segregation. Hence, it reduces the risk of honey combing of concrete.

Development of SCC is a very desirable achievement in the construction industry for overcoming the problems associated with cast-in place concrete. It is not affected by the skill of workers, shape and amount 13 of reinforcing bar arrangement of a structure. Due to its high fluidity and resisting power to segregation, it can be pumped over longer distances. It extends the possibility of use of various by products in its manufacturing. The use of SCC not only shortens the construction period but also ensures quality and durability of concrete. It replaces manual compaction of fresh concrete with a modern semi-automatic placing technology.

In present study attempt is made to investigate the effect of pozzolanic filler and inert filler on the strength and durability of self consolidated concrete. The durability of concrete depends on many factors. Those most often considered are cement reactivity with environment, low permeability, diffusion coefficient of species such as sulphate ions and compressive strength. The water absorption is also very important factor effecting durability. The use of mineral additives may provide a way of improving the durability of SCC depending on the type and amount of mineral additive used. In this experiment silica fume was used as pozzolanic filler and quarry dust was used as inert filler.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials

2.1.1 Cement

In this experimental study, Ordinary Portland Cement 53 grade, conforming to IS: 8112-1989 was used. The different laboratory tests were conducted on cement to determine the physical and mechanical properties of the cement used are shown in Table 1.

Table 1: Properties of Cement

Physical Property	Result
Fineness (retained on 90-μm sieve)	5%
Normal Consistency	29%
Vicat initial setting time (minutes)	75 min.
Vicat final setting time (minutes)	482 min.
Specific gravity	3.12
Compressive strength at 7-days	37.33 Mpa
Compressive strength at 28-days	53.64 Mpa

2.1.2 Aggregates

Locally available natural sand with 4.75 mm maximum size confirming to class II- IS 383 was used as fine aggregate, having specific gravity, fineness modulus and unit weight as given in Table 3 and crushed stone with 16mm maximum size having specific gravity, fineness modulus and unit weight as given in Table 3 was used as coarse aggregate. Table 2 gives the physical properties of the coarse and fine aggregates.

Table 2: Physical Properties of Coarse and Fine Aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.5	2.85
Fineness Modulus	2.8	7.44
Surface Texture	Smooth	---
Particle shape	Rounded	Angular

2.1.3 Water

Ordinary potable water available in the laboratory has been used.

2.1.4 Chemical Admixtures

Super plasticizers or high range water reducing admixtures are an essential component of SCC. It is used to provide necessary workability. Glanium B233 (modified P.C. based) was obtained from BASF India Limited, Mumbai.

2.1.5 Quarry Dust

Quarry dust is used as an inert powder. It has been obtained from stone crusher; Quarry dust of specific gravity 2.5 passing through 90µ sieve is used. Chemical composition of Quarry dust is given in table 3.

Table 3: Chemical Composition of Quarry Dust

Sr. No.	Constituents	Quantity (%)
1.	SiO_2	70.74
2.	Al_2O_3	20.67
3.	Fe_2O_3	2.88
4.	TiO_2	0.33
5.	Na_2O	0.11
6.	K_2O	0.19
7.	MgO	1.57
8.	M_2O_2	0.01
9.	CaO	0.2
10.	ZnO	0.01
11.	Pb	625 ppm
12.	Cr	125 ppm
13.	LOI	0.72

2.1.6 Silica Fume

Silica fume imparts very good improvement to rheological, mechanical and chemical properties. It improves the durability of the concrete by reinforcing the microstructure through filler effect and reduces segregation and bleeding. It also helps in achieving high early strength. Silica fume of specific gravity 2.2 is used in this study. Chemical composition of silica fume is given in table 4. Silica fume was obtained form ELKEM materials, Mumbai.

Table 4: Chemical Composition of Silica Fume

Sr. No.	Constituents	Quantity (%)
1.	Sio_2	91.03
2.	Al_2O_3	0.39
3.	Fe_2O_3	2.11
4.	CaO	1.5
5.	LOI	4.05

2.2 Mix Proportion

The mix proportion was done based on the method proposed by Nan-Su et al. [4]. The mix designs were carried out for concrete grades 25, 35, 45. This method was preferred as it has the advantage of considering the strengths of the SCC mix.

The details of mixes are given in table 5. All the ingredients were first mixed in dry condition. Then 70% of calculated amount of water was added to the dry mix and mixed thoroughly. Then 30% of water was mixed with the super plasticizer and added in the mix.

Then the mix was checked for self compacting ability by slump flow test, v-funnel test and L-box test.

Table 5: Mixture proportion for 1m^3 of SCC

Grade of concrete	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Silica Fume (kg/m^3)	Water (kg/m^3)	Water/Binder	Super Plasticizer (kg/m^3)
αS1	315	960	813	215	239	0.45	6.2
αS2	357	960	813	196	223	0.40	6.3
αS3	411	960	813	135	196	0.35	7.29

Grade of concrete	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Crusher dust (kg/m^3)	Water (kg/m^3)	Water/Binder	Super Plasticizer (kg/m^3)
αD1	315	960	813	215	239	0.45	2.558
αD2	357	960	813	196	223	0.40	3.0
αD3	411	960	813	135	196	0.35	3.5

Self Compact ability Tests on SCC Mixes

Various tests were conducted on the trial mixes to check for their acceptance and self compact ability properties. The tests included flow test and V-funnel tests for checking the filling ability and L-box test for passing ability. The mixes were checked for the SCC acceptance criteria given in table no. 6.

Table No. 6 SCC Acceptance Criteria

Method	Properties	Range of values
Slump flow	Filling ability	650-800mm
V-funnel	Viscosity	6-12 sec.
L-box	Passing ability	0.8-1.0

Table 7: SCC Test Results of SCC Mixes

Mix Code	Flow (mm)	V-funnel time (s)	L-box (h2/h1)	Segregation	Remark
αS1	660	8.6	0.90	No	SCC
αS2	680	8.9	0.88	No	SCC
αS3	710	9.4	0.97	No	SCC
αD1	720	8.8	0.95	No	SCC
αD2	705	9.3	0.93	No	SCC
αD3	690	9.5	0.90	No	SCC

The result of the self compact ability tests are tabulated in table 7. All the mixes satisfied the acceptance criteria for self compacting concrete. Hence these mixes were chosen as the successful mixes. The cube specimens of size 150 x 150 x 150 mm were cast for the successful mixes and were tested for the 7-day 28-day compressive strengths. Also cylindrical specimens of size 300mm height and 150mm diameter were cast and tested for 28-days split tensile strength.

3. TEST CONDUCTED

COMPRESSIVE STRENGTH

The compressive loading test on concrete cubes was carried out on a compression testing machine of capacity of 2000KN. For compressive strength test, the specimens used were 150mm x 150mm x 150mm cubes. The strength measurements of concrete specimens were performed at 7 and 28 days. Three specimens tested for each mixture.

SPLIT TENSILE STRENGTH

Cylindrical specimens of size 150mm diameter and 300mm height were used. The test was carried out by placing a cylinder horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. The strength measurements of concrete specimens were performed at 7 and 28 days.

SORPTIVITY

To examine the durability characteristics of SCC, sorptivity was employed. Sorptivity characteristics of SCC for structures located above ground level would be more appropriate; sorptivity coefficient can be determined by following method.

Test Method

Standard 100mm cube specimens were cast. On the following day of casting, the specimens were de-moulded and located in water curing condition for the periods of 28 days.

Water absorption (sorptivity) tests was carried out to determine the sorptivity coefficient of concrete specimens which were preconditioned in oven at 105^0C for 24 hr. and then cooled down within desiccators for 24h to achieve a constant moisture level. Then, four sides of the concrete specimens were sealed by electrical tape to avoid evaporative effect as well as to maintain uniaxial water flow during the test and the opposite faces left open see in fig. 4. Before locating the specimens on water, their initial weight was recorded. One face of specimen was in contact with water, while the water absorption at predefined intervals was noted by taking weight. The specimen was submerged 5mm in water. Procedure was repeated, consecutively at various time intervals 15 min., 30 min., 1 hr, 2 hr, 4 hr, 6 hr, 24 hr, 48 hr and 72 hr until the last reading. Sorptivity coefficient can be calculated by the following expression.

$$S= (Q/A)/\sqrt{t}$$

Where,

S = Sorptivity (cm/$s^{1/2}$)

Q = Vol. of water absorbed in cm^3

A = Surface area in contact with water in cm^2

t = the time (s)

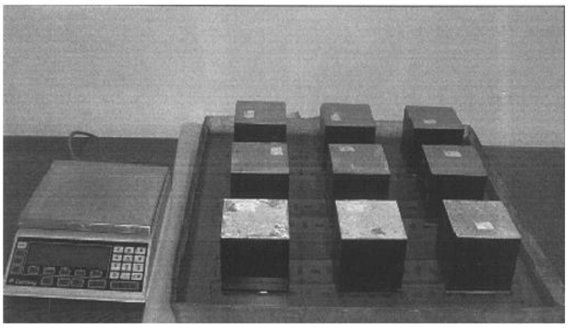

Fig. 1: Experimental Set-up for Water Sorptivity Test

CHLORIDE PERMEABILITY TEST

In chloride permeability test, Concrete blocks were immersed in 3% NaCl solution after period of 28days the specimens were removed from curing tank and their surfaces were cleaned with soft nylon brush to remove weak reaction products.

After a specified duration (28 days) specimens were removed from solution, split and the depth of chloride penetration was determined in one half of the specimen using a colorimetric technique in which silver nitrate solution was used as a colorimetric indicator.

When silver nitrate solution was sprayed on a concrete containing chloride ions, a chemical reaction occurred. The chlorides bind with the silver to produce silver chloride, a whitish substance. In the absence of chlorides, the silver instead bonds with the hydroxides present in the concrete creating a brownish colour. A whitish colour at the border of specimen shows the depth of penetration.

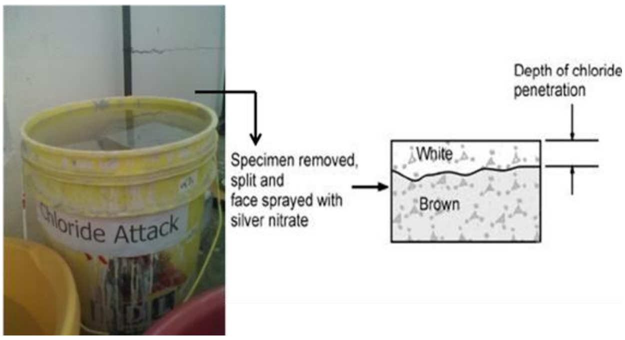

Fig. 2: Chloride Permeability Test

4. RESULT AND DISCUSSION

4.1 STRENGTH PROPERTIES OF SCC MIXES

Compressive Strength of SCC Mixes

Table 8 and fig. no. 3 gives the cube compressive strength of the mixes. It can be seen that strength increases with decreasing Silica Fume and Quarry Dust content. Four standard cubes each for various mixes were tested to determine 7 days and 28 days compressive strength, compressive strength increased with decrease in W/C ratio.

The strength of SCC with silica fume and SCC with quarry dust ranges from **45 MPa** to **62 MPa** and **31 MPa** to **52 MPa** respectively, average compressive strength of SCC having silica fume at 28-days compared to SCC having quarry dust was increased by **25.51%.** Depending upon the mineral admixture, curing condition, the result indicates that the Mineral admixture addition helps in gain of compressive strength than that of Quarry dust. The compressive strength of SCC containing silica fume was greater than that of SCC containing Quarry dust.

Split Tensile Strength

The split tensile strength result shown in table 8 and fig. no. 4. Two standard cylinder specimens each for various mixes were tested to determine 7-days and 28-days split tensile strength. Split tensile strength shows the same trend as compressive strength, increased with decrease in W/C ratio.

Split tensile strength of SCC containing Silica Fume & SCC having quarry dust ranges from **4.3 MPa** to **6.72 MPa** and **3.5 MPa** to **5.29 MPa** respectively. Average split tensile strength of SCC having silica fume at 28-days compared to SCC having quarry dust was increased by **18.06%.**

Silica fume shows the better result in strength properties than quarry dust.

Table 8: Harden Properties

Mix Code	W/C	Compressive Strength (MPa)		Split Tensile Strength (MPa)	
		7 Days	28 Days	7 Days	28 Days
αS1	0.45	27.33	45.11	3.07	4.3
αS2	0.40	32.29	57.11	4.87	5.58
αS3	0.35	44.66	61.12	5.86	6.72
αD1	0.45	22.52	31.5	2.1	3.5
αD2	0.40	29.4	39.9	3.4	4.78
αD3	0.35	37	51.2	4.2	5.29

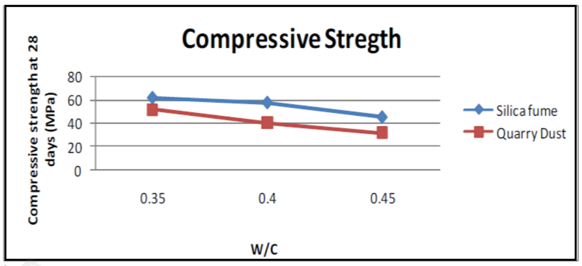

Fig. 3: Result of Compressive strength

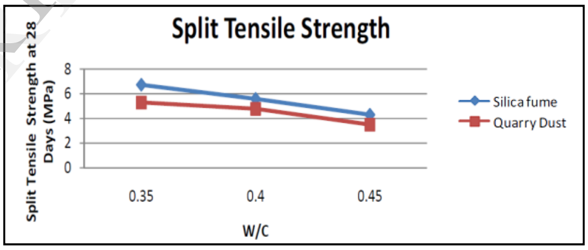

Fig. 4: Result of Split Tensile Strength

4.2 DURABILITY PROPERTIES OF SCC MIXES

Sorptivity

Sorptivity coefficient was determined by means of simple test allowing one face of concrete specimen in contact with water and the mass of water absorbed by capillary suction was measured at predefined intervals.

The result of sorptivity tests are given in table 10 and fig. no.5 on the basis of concrete type. It is indicated that SCC containing Silica Fume gives lower sorptivity values than that of SCC containing dust. There is noticeable difference in the capacity of water absorption by capillary action between SCC made with silica fume and SCC with quarry dust. The highest sorptivity value ($2.2x10^{-3}$)cm/s$^{1/2}$ has been obtained from SCC with quarry dust and lowest sorptivity value ($0.43x10^{-3}$)cm/s$^{1/2}$ obtained from SCC silica fume.

However by using silica fume the sorptivity decreases, as shown in table 9.

It can be suggested, therefore, that using pozzolanic filler such as Silica Fume can enhance the resistivity of SCC against water absorption significantly.

Table 9: Result of sorptivity

Mixes	Sorptivity (cm/s$^{1/2}$)
αS1	0.7×10^{-3}
αS2	0.52×10^{-3}
αS3	0.43×10^{-3}
αD1	2.2×10^{-3}
αD2	1.7×10^{-3}
αD3	0.95×10^{-3}

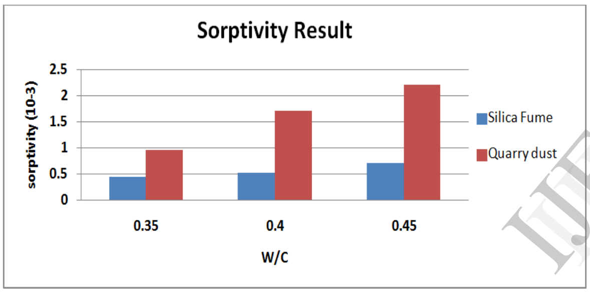

Fig. 5: Result of Sorptivity test

Chloride Permeability Test

It is evident that the pozzolanic admixture creates a more compact concrete. The chloride ion penetration decreases when admixture added because they physically occupy pores in the cement paste by virtue of their particle size.

The depth of chloride penetration is determined in one half of the specimen using a colorimetric technique in which silver nitrate solution is used as a colorimetric indicator. When silver nitrate solution is sprayed on concrete containing chloride ions, a whitish colour at the border of split specimen shows the depth of penetration.

Fig. no.6 and table no.10 shows that SCC made with Quarry Dust shows highest depth of penetration i.e. 1.24 cm and SCC made with silica fume shows lowest depth of penetration i.e. 0.31cm.

Depth of chloride ion penetration of SCC having Quarry Dust compared to SCC containing silica fume was increased by 47.68%, 64.76%, and 72.80% for each grade respectively.

Table 10: Chloride Permeability Test

Mixes	Depth of Penetration (cm)
αS1	0.65
αS2	0.43
αS3	0.31
αD1	1.24
αD2	1.22
αD3	1.14

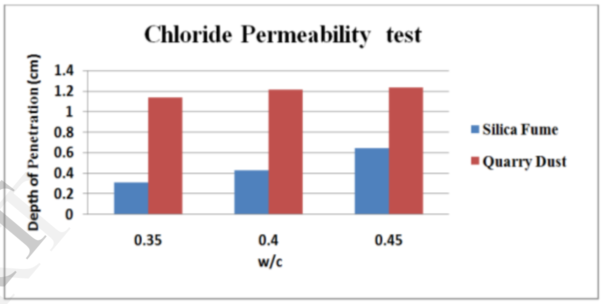

Fig. 6: Result of Chloride permeability test

Conclusion

In the present study of self compacting concrete using pozzolanic filler and inert filler following conclusions were arrived from the experimental investigation. Because of extreme fineness and very high amorphous silicon dioxide content, silica fume is a very reactive pozzolanic material. Hence SCC with silica fume shows the good result in both strength and durability properties.

1. Silica fume was observed to improve the mechanical properties of SCC because of the pozzolanic action of silica fume.
2. Average compressive strength of SCC having silica fume at 28-days compared to SCC having quarry dust was increased by **25.51%.**
3. Average split tensile strength of SCC having silica fume at 28-days compared to SCC having quarry dust was increased by **18.06%.**
4. It has been indicated that SCC having Silica Fume have higher compressive strength and split tensile than those of SCC having inert powder as additional filler i.e. quarry dust. The silica fume has contributed to large extent in development of strength.

5. As the water cement ratio reduces and cements content increases, strength increases in SCC made with silica fume and SCC made with quarry dust.
6. It has been indicated that SCC having Silica Fume has lower soprtivity values in comparison with by SCC containing quarry dust.
7. Proper curing and use of pozzolanic admixture such as Silica Fume as additional powder component enhance the resistivity against sorptivity significantly.
8. The chloride permeability result shows that SCC having silica fume has superior performance in durability properties than SCC having quarry dust.
9. As the water cement ratio reduces strength as well as durability increases in SCC with silica fumes and SCC with quarry dust.
10. Durability of SCC with silica fume is more than that of SCC with quarry dust because of the pozzolanic action of silica fume.

References

[1] The European Guidelines for SCC, May 2005.
[2] Zoran Grdic, Iva Despotovic, Gordana Toplicic Curcic, Properties of Self Compactability Concrete with Different types of Additives, FACTA University, Architecture and Civil Engineering, Vol. 6, 173-177, No. 2, 2008.
[3] Hajime Okamura and Masahiro Ouchi, "Self Compacting Concrete", Journals of Advanced Concrete Technologies, Vol. 1, No. 1 April 2003, pp. 5-15.
[4] Nans, Kung-chung HSU, His Wen Chai, "A Simple Mix Design, Method For Self Compacting Concrete (2001) 1799 – 1807.
[5] Pratibha Aggarwal, Yogeh Aggarwal, S. M. Gupta, R. Siddique, "Properties of Self Compacting Concrete – An Overview" 30th Conference on Our World In Concrete And Structures 23-24 August 2005, Singapore.
[6] G. Kaur, S. P. Singh And S. K. Kaushik, "Reviewing Some Properties of Concrete Containing Mineral Admixtures" Indian Concrete Journal July 2012, 35-49.
[7] Vilas V. Karjinni, Shrishail B. Anandinni and Dada S. Patil, An investigation on the characteristic properties of high performance SCC with mineral admixtures. The Indian Concrete Journal, 2009, 15-19.
[8] M. Rame Gowda, Mattur C. Narasimhan and Karisiddappa, Strength behavior of self-compacting concrete mixes using local materials, The Indian concrete journal, July 2012, 54-60.
[9] C. Selvamony, M. S. Ravikumar, S. U. Kannan and S. Basil Gnanappa, Investigations on self-compacted self-curing concrete using limestone powder and clinkers, APRN journal of engineering and applied sciences, vol. 5, March 2010, 01-06.
[10] A. Navaneethakrishnan, V. M. Shanthi, Experimental study of self-compacting concrete (SCC) using silica fume, International journal of emerging trends in engineering and development, vol. 4, May 2012, 475-482.
[11] S. Bhaskar, Ravindra Gettu, B. H. Bharatkumar and M.Neelamegam, Strength, bond and durability related properties of concretes with mineral admixtures, The Indian concrete journal, February 2012, 09-15.
[12] Kazim Turk, Sinan Caliskan and Salih Yazicioglu, Capillary water absorption of self-compacting concrete under different curing conditions, Indian journal of engineering and materials sciences Vol. 14 October 2007, 365-372.
[13] Talah Aissa, F. Kharchi and R. Chaid, Contribution of natural pozzolana to durability of high performance concrete in chloride environment, The Indian concrete journal June 2011, 39-45.
[14] Md. Safiuddin, J.S. West, and K.A. Soudki, Durability performance of self compacting concrete, Journal of applied sciences and research, 4(12); 1834-1840, 2008, INSInet publication
[15] M.S. Shetty, "Concrete Technology", S. Chand.
[16] www.microsilicachina.com