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Durability Evaluation of Industrial by Products in Low Strength Self Compacting Concrete

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Abstract— ***Self compacting concrete (SCC) is a breakthrough in concrete technology, especially because of its ease of placement without the need to use external dynamic forces in the form of vibrations. This research paper focused on the effect of industrial by products like GGBS and crusher rejected fines (CRF) in Self Compacting Concrete on its durability aspect. Partial replacement of cement in SCC with cheap available industrial by-product could produce environmentally durable concrete. In this experimental program, SCC is produced by replacing partially cement to GGBS from 40% to 70% and 50% CRF to river sand. The curing period of the specimens are extended upto 180 days and the durability tests like Sorptivity, Water penetration and Rapid chloride penetration are conducted for 90 and 180 days curing period. The flow-ability property of self compacting concrete mixes increases with the increase in GGBS replacement level. The experimental results reveal that SCC with GGBS and CRF performance is better in durability aspects.***

Index Terms— **Sorptivity, Crusher Rejected Fines (CRF), Rapid Chloride Test, Self Compacting Concrete (SCC), Permeability.**

I. INTRODUCTION

Global warming is a major problem for today's and future development and hence shifting towards sustainable cement replacement materials are the attractive option to obtain green concrete. To achieve reasonable concrete cost and as well as the environmental conservation, Wastes and by-products can be introduced into self compacting concrete to conserve natural resources and as well as to reduce the cost of SCC. The service life of a structure is determined largely by its durability properties and existing environmental conditions.

Based on the experimental report by Santosh Kumar Karri, et al., concluded that the effect of acid on concrete decreases with the increase of percentage of GGBS. At 40% replacement of GGBS the resistance power of concrete is more. H.J.H. Brorouwers et al., analyzed which combinations of three sands, gravel, SP and slag blended cement result in the lowest powder (cement, limestone powder) content and the paste lines of the powders are used to derive a linear relation between the deformation coefficient and the product of Blaine value and particle density. R.Vasusmitha et al. concludes that Chloride ion penetration depends on chloride binding capacity of the constituent materials. Denser microstructure of HSSCC contribute for a lower plastic settlement, higher bond between steel and concrete matrix, lower permeability to oxygen and lower chloride diffusion coefficient and higher tensile.

II. MATERIALS USED IN DEVELOPMENT OF SCC

Table I - The Physical Properties of the Materials Used in SCC Mixture

S.NO	Material	Properties
1.	Crushed granite stone	Maximum size : 12.5mm Specific gravity : 2.72 Bulk density : 1500 Fineness modulus : 5.49 Water absorption : 0.5%
2.	Cement	Specific gravity : 3.15 Fineness :4%
S.NO	**Material**	**Properties**

3.	River sand	Specific gravity : 2.6 Density : 1633.33kg/m3 Fineness modulus : 3.84 Water absorption : 1.32% Grading Zone : zone III
4.	Crusher rejected fines	Specific gravity : 2.55 Bulk density : 1743.33 Fineness modulus : 3.9 Water absorption : 2.31% Grading Zone : zone III
5.	Ground granulated blast furnace slag	Specific gravity : 2.58 Fineness : 8%
6.	Water	P_H value : 7
7.	Super plasticizer	Master Glenium sky BASF B233

III. MIX PROPORTION AND TEST METHODS FOR EVALUATING THE FRESH PROPERTIES OF SCC

In the present research the mix design was based on Okamura and Ozawa method, which is a simple and rational method. In this method, the coarse aggregate and fine aggregate contents are fixed and self - compatibility is to be achieved by adjusting the water/powder ratio and super plasticizer dosage. T. Hajime Okamura et al. (2003) established the rational mix-design methods proportioning coarse aggregate and mortar as 50% and 40% respectively of the total aggregate volume. The required water/powder ratio and admixture ratio is determined by conducting a number of trial batches until we reach the SCC properties by the test. The flow ability properties of SCC mixes were obtained conducting the slump flow test, v- funnel test and L box test. The results of the fresh properties are summarized in TABLE I. Cubes and cylinders were casted and de-molded next day and cured for upto 180 days.

Table II - SCC Mix Proportions by its Weight of Materials

S .No	Material	Mix Designation					
		SCC0	SCC40	SCC50	SCC60	SCC70	SCC80
1.	Cement Kg/m^3	400	240	200	160	120	80
2.	GGBS Kg/m^3	0	160	200	240	280	320
3.	River sand Kg/m^3	874	441	441	441	441	441
4.	CRF Kg/m^3	0	424	424	424	424	424
5.	Coarse aggregate Kg/m^3	921	922	922	922	922	922
6.	Water liters	210	218	220	221	222	223
7.	Super plasticizer	1.5%	1.54%	1.47%	1.45%	1.45%	1.45%

Table III – Fresh Properties of SCC Mixes

Mix Designation		Slump Test		V - Funnel Test		L - Box Test
		Slump (mm)	T50 Time (sec)	Time for Discharge (sec)	T5 Time (sec)	H2/H1
SCC0	Control Mix	610	3.89	16	21	0.52
SCC40	GGBS - 40% CRF - 50 %	650	3.8	13	19	0.66

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SCC50	GGBS - 50% CRF - 50 %	663	3.5	9	12	0.71
SCC60	GGBS - 60% CRF - 50 %	685	3.	6	8	0.85
SCC70	GGBS - 70% CRF - 50 %	663	3.5	9	12	0.71

IV. SORPTIVITY TEST

Sorptivity testing was performed in accordance with ASTM C 1585-04. Sorptivity is a function of the increased mass of a specimen resulting from absorption of water, relative to the time that one surface is exposed to water. The absorption, I, is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. For the purpose of this test, the temperature dependence of the density of water is neglected and a value of 0.001 g/mm^3 is used. The units of I are mm.

$$I = mt/(a * d) \quad (1)$$

Where I = the absorption,
mt = the change in specimen mass in grams, at the time t.

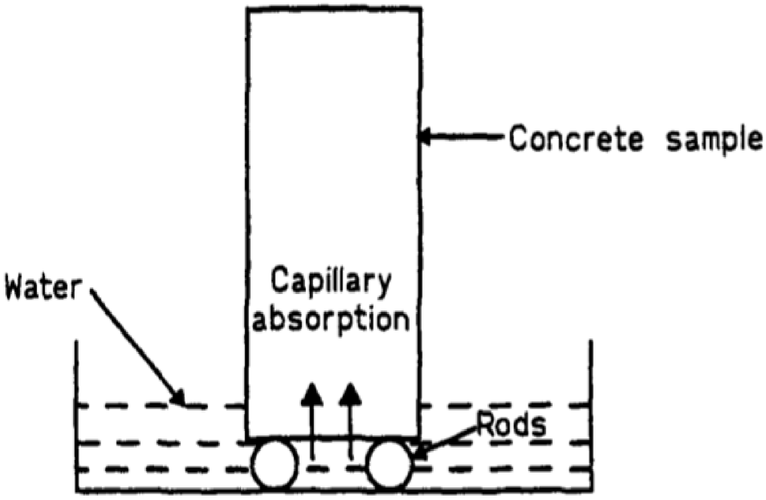
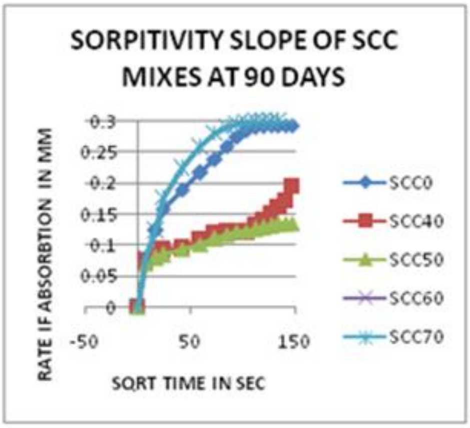


Fig 1.Schematic Arrangement of the Sorptivity Test
Source: (Claisse 1997)



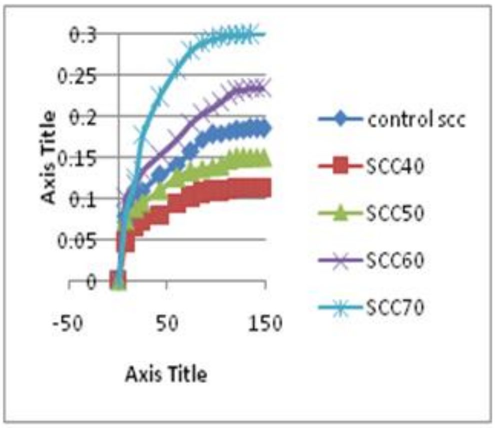


Fig 2(a).Initial and secondary absorption curve at 90 days curing.
Fig 2(b).Initial and secondary absorption curve at 90 days curing 180 days curing.

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Table IV – Sorptivity Values and Respective Equations of SCC Mixes with GGBS and CRF

Curing Days	Mix Designation	Sorptivity ($mm/s^{0.5}$)	Sorptivity Equation	R^2	S
90 days water curing	SCC0	0.003363	0.0054-0.000016√time	0.73	0.0019913
	SCC40	0.00183	0.0050-0.000067√time	0.84	0.0020181
	SCC50	0.002157	0.004522-.000049√time	0.65	0.0018765
	SCC60	0.00409	0.0059-0.000014√time	0.63	0.0022064
	SCC70	0.00426	0.05176+0.002734√time	0.93	0.0188315
180 days water curing	SCC0	0.002624	0.04151+0.002415√time	0.93	0.014915
	SCC40	0.001741	0.02570+0.001544√time	0.92	0.0095538
	SCC50	0.002117	-0.0119+0.005356√time	0.96	0.194958
	SCC60	0.003446	0.05176+0.002734√time	0.92	0.0188315
	SCC70	0.003567	0.0059-0.000014√time	0.89	0.0022064

V. PREDICTION IN CHLORIDE PENETRATION IN SCC

Rapid chloride permeability test (RCPT) has been developed as a quick test able to measure the rate of transport of chloride ions in concrete. This test was conducted as per ASTM C 1202-94.Chloride ingress is the major form of environmental attack in reinforced concrete which causes early deterioration of the structure due to corrosion of re-bars. The concrete cylindrical specimens - 50 mm thick, are first prepared by coating the dry side surface with a special sealer and then vacuum conditioning it for 22 hrs. as per the ASTM Codal procedure. The saturated specimens are then mounted in the Plexiglas cells, the sealant applied and the reservoirs filled with NaCl & NaOH solutions respectively. The cell terminals are then connected to the Power supply unit through cables provided – one for each channel and the test started. The passing current magnitude depends on the ions passing through the pores of the concrete specimen (including chloride ions), which in turn depend on the permeability of concrete. The current is recorded manually from the digital readouts of the power supply unit - every ½ hr., for 6 hrs. The recorded values of specimen diameter and current are fed into the accompanying spreadsheet software to get the final RCPT value.

The total charge Q passed in 6 hours is calculated as per the formula:

$$Q = 900 \times (I0 + 2 \times I30 + 2 \times I60 + 2 \times I120 \ldots\ldots + I360) \qquad (2)$$

The value is adjusted for specimen diameters other than 95 mm. This charge in coulombs is an indication of the Cl-Ion penetrability as listed below.

Table V – Results of Co-Efficient Of Chloride Migration in SCC Specimens

SCC Mixes	Charge Passed (coulombs) - 90 Days	Chloride Ion Penetrability	Charge Passed (coulombs) - 180 Days	Chloride Ion Penetrability	REFERENCE CHART
SCC0	2633	Moderate	1585	Low	**>4000 - High** **2000-4000 - Moderate** **1000-2000 - Low** **100-1000 - Very low**
SCC40	2014	Moderate	804.8	Very low	
SCC50	1410.4	Low	764	Very low	
SCC60	1367.60	Low	659	Very low	
SCC70	1276	Low	592.17	Very low	

VI. WATER PERMEABILITY TEST

In depth of penetration method, no discharge was obtained even after a period of 100hrs. K was calculated by using depth of penetration method. When durability of concrete is considered then permeability becomes the main culprit in deterioration. Water seeps to reinforcement through capillary tubes and cracks which results to exposed reinforcement for corrosion. Water penetration test is one the important criteria to determine durability of concrete.

Water permeability test determines the true resistance of concrete against the penetration of water under hydrostatic pressure. The cubes are subjected to 0.5Mpa of hydrostatic pressure over a period of three days and

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depth are measured and summarized in table. The smaller the depth of penetration results in a higher resistance of water pressure i.e. pressure given from 5kg/cm^2 upto 15kg/cm^2.
The Coefficient of permeability (k) is calculated by IS 3085-1965

$$K = D2p/2TH \quad (3)$$

by valenta referred in Neville 1981

Where D- depth of penetration method,
P-Porosity of concrete measured as fraction,
T- Time in sec,
H- Pressure head = 100m

Porosity is calculated with the mix ratio of the SCC mix, w/c ratio and the physical properties of the SCC mix ingredients. The formula derived by Neville and brooke (2008).

$$P = \frac{[(w/c)-(0.17h)+(a/c)]}{0.317+(1/Sfa)(Af/c)+(1/Sca)(Aca/c)+(w/c)+(a/c)} \quad (4)$$

Where w/c- water Cement ratio
h - Degree of hydration 68% for 0.5 w/c
a - Volume of entrapped air
S- Specific gravity of cement
Sfa - Specific gravity of fine aggregate
Sca - Specific gravity of coarse aggregate,
Af, Aca, Ac - Proportions of fine aggregate, coarse aggregate and cement.

Table VI – Penetration Depth and Permeability of SCC Mixes

Mix Designation	90 Days Curing		180 Days Curing	
	Average Penetration Depth (mm)	Permeability	Average Penetration Depth (mm)	Permeability
SCC0	8	1.164 X10^{-13}	6	0.655 X10^{-13}
SCC40	11	2.202 X10^{-13}	7	0.8918X10^{-13}
SCC50	10	1.8 X10^{-13}	7	0.8918X10^{-13}
SCC60	9	1.474 X10^{-13}	6	0.655 X10^{-13}
SCC70	8	1.164 X10^{-13}	5	0.4549 X10^{-13}

VII. RESULTS

A. Influence of GGBS and CRF on the Sorptivity Co-Efficient in SCC Mixes

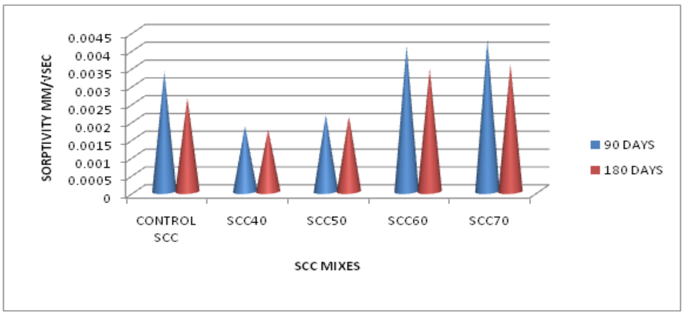

Fig 4. Results of Capillary Absorption of Water through Concrete Surfaces

The results confirm that the SCC40 and the SCC50 mixes had lower sorptivity values than of the control SCC mix. The increase in percentage of GGBS increases the sorptivity by 50%. Sorptivity is less in 180 days than the 90 days value. Such results would reveal that the nearer surface of the SCC specimens is denser and more resistant to ingress of any fluid in the SCC mixes than the control SCC mix.

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B. Influence of GGBS and CRF on the Chloride Penetration of SCC Mixes

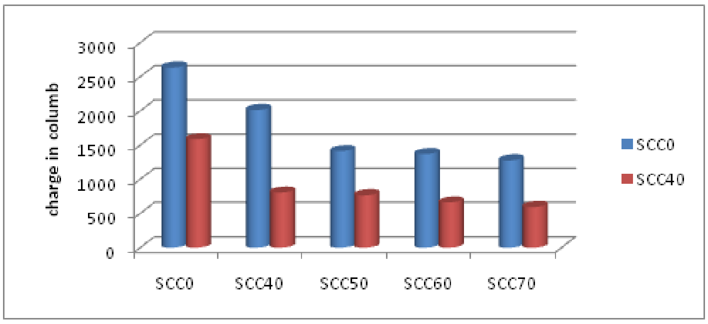

Fig 5. RCPT Values of SCC Mixes for Different Age of Concrete

The rcpt values are analyzed and the results reveal that the performance of GGBS and CRF increased with regard to durability. Chloride permeability of SCC with GGBS & CRF shows less permeability and falls in the very low range when compared with control SCC.

C. Influence of GGBS and CRF on the Permeability of SCC Mixes

For control SCC, the Co-efficient of permeability for 90 days and 180 days curing are 1.164 $X10^{-13}$m/sec and 0.655 $X10^{-13}$ m/sec respectively. The permeability of concrete decreases with the increase in age of concrete in all SCC mixtures.

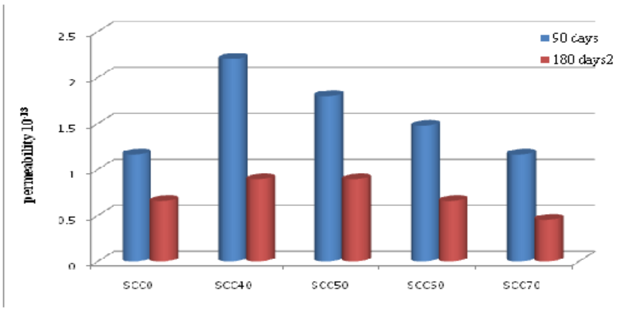

Fig 6. Permeability Values of SCC Mixes for Different Age of Concrete.

VIII. CONCLUSION

Influence of GGBS and CRF on the Sorptivity Co-Efficient, Permeability and the Chloride Penetration of SCC Mixes observed from the experimental results shows the characteristics values of the SCC. It also shows the durability of the SCC mixes and also proves its efficiency and productive usage.

From the results obtained we can also observe that the age of SCC is directly proportional to the sorptivity values, the values prove that the sorptivity decreases as the curing period of concrete increases.

Also, in the experimentation the slag based Self Compacting concrete sets more slowly than the control mix made with ordinary Portland cement. Use of GGBS significantly reduces the risk of reinforcement corrosion provides higher resistance to chloride ingress. And also the flow-ability property of self compacting concrete mixes increases with the increase in GGBS replacement level.

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