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DURABILITY PROPERTIES OF M25 GRADE SELF COMPACTING CONCRETE USING RECYCLED AGGREGATE AND MANUFACTURED SAND

K.Anusree[1], C.Sashidhar[2], J.Guru Jawahar[3]

[1]*PG Scholar in Structural Engineering, JNTUA, Anantapuramu, India,*
anusreeprabhakar102@gmail.com
[2] *Professor, Department of Civil Engineering, JNTUA, Anantapuramu, India*
[3]*Professor, Department of Civil Engineering, AITS, Tirupati, India*

Abstract— Self Compacting Concrete (SCC) is an innovative engineered material for industrial ecology which does not require compaction. SCC likewise alluded as self-consolidating concrete which can flow and consolidate under its own weight. It is sufficiently durable to fill the spaces of any size and shape without segregation and bleeding. Manufactured sand (MSand) and Recycled coarse aggregate (RCA) in M25 grade SCC used in this study have become the focus of interest and received the considerable attention because of environmental benefits. In this research, SCC mixes were prepared using 30% of class F fly ash as cement replacement and with different replacements of sand, MSand, coarse aggregate (CA) and RCA. With addition of super plasticizer, the concrete mix enriches the quality of workability. The present study focussed on fresh and durability properties of SCC. Test methods such as Slump flow, V-funnel and L-box were used to assess the fresh properties of SCC. Durability properties like weight loss, compressive strength loss after acid attack of mixes were studied after 28 and 56 days of immersion of cubes in 3% sulphuric acid (H2SO4) solution after 28 days of curing. The percentage of water absorption and resistance to chloride ion penetration were also studied after 28 and 56 days of curing.

Keywords— SCC, RCA, MSand, fly ash, sand, CA, fresh properties, durability properties

I. INTRODUCTION

Self compacting concrete is highly engineered concrete with higher fluidity without segregation and is capable of filling every corner of formwork under its self weight. Thus SCC eliminates the vibration for the compaction of concrete without affecting its engineering properties. As of the year 2000, SCC used for pre-fabricated products (precast members) and ready mix concrete (cast in situ) in JAPAN, USA and later on INDIA etc. The creation of durable concrete structures requires compaction and skilled labour. Solution for the achievement of durable concrete structures independent of quality construction work is the use of SCC. Present day SCC can be classified as an advanced construction material. The outline and utilization of SCC are presently created by numerous expert associations yet prevalent standard is given by EFNARC (European Federation of National Trade Associations) which is an European organisation concentrated most part on extraordinary development chemicals and solid frameworks (EFNARC 2000). In fresh state, SCC has following three properties; they are filling ability, passing ability and high resistance to segregation. Filling ability (excellent deformability) means flows easily at suitable speed into formwork, passing ability means passes through reinforcements without blocking and high resistance to segregation means the distribution of aggregate particles remains homogeneous in both vertical and horizontal directions. Static segregation is due to gravity which is in vertical direction and Dynamic segregation due to flow which is in horizontal direction [1].

Generally, river sand was used as fine aggregate in constructions. Because of continuous mining of sand from riverbed, it is becoming a scarce material. This led to find a suitable alternative for natural sand which is viable and sustainable. One of the solution is, as a substitute to river sand, Manufactured sand (MSand) has been used. MSand is produced by crushing rocks and stones to size and shape similar to natural sand. In a comparative case the cost of coarse aggregate has increased and accessibility decreased and interest for elective material expanded, in such case RCA gives best option as substitute to CA. RCA are produced from re-processing of mineral waste materials, with the largest source being the construction and demolition waste.

II. EXPERIMENTAL STUDY

In this research work, SCC mixes were prepared using RCA as coarse aggregate and MSand as fine aggregate at different replacement levels. The cement was replaced with 30% of class F fly ash and super plasticizer was used to enhance the workability properties of SCC.

A. Materials

Ordinary Portland cement (OPC) 53 grade was used corresponding to IS: 12269-(1987) [2]. From environment perspective, generation of OPC is not ecological well view point as it takes enormous amount of natural resources and delivers a major amount of greenhouse gases [3]. The physical properties of cement are shown in Table 1.

Table 1: physical properties of cement

Physical properties	**Test result**	**Test method/ Remarks**	**Requirement as per IS 12269 (1987)**
Specific gravity	3.06	IS 4031(1988) – part 11	_
Fineness (m^2/Kg)	311.5	Manufacturer data	Min.225 m^2/kg
Normal consistency	30%	IS 4031 (1988)- part 4	_
Initial setting time (min)	90	IS 4031 (1988)- part 5	Min. 30 min
Final setting time (min)	220	IS 4031 (1988)- part 5	Max. 600 min
Soundness Lechatelier Expansion (mm) Autoclave Expansion (%)	0.8 0.01	Manufacturer data	Max. 10 mm Max. 0.8%
Compressive strength (MPa) 3 days 7 days 28 days	25 39 57	IS 4031 (1988)- part 6	27 MPa 37 MPa 53 MPa

Class F fly ash which is a low calcium fly ash obtained from silos of Rayalaseema Thermal Power Plant (RTPP), Muddanur, Andhra Pradesh was used as an additive according to ASTM C 618 (2003) [4]. As per IS 456 (2000) [5], cement is replaced by 30% of fly ash by weight of cementitious material. Studied revealed that high volumes of fly ash can be used in SCC to attain the desired fresh, mechanical and durability properties of SCC [6]. The chemical and physical properties of class F fly ash are shown in Table 2.

Table 2: chemical and physical properties of class F fly ash

Particulars	Class F fly ash
Chemical composition	
% Silica(SiO_2)	65.6
% Alumina(Al_2O_3)	28.0
% Iron Oxide(Fe_2O_3)	3.0
% Lime(CaO)	1.0
% Magnesia(MgO)	1.0
% Titanium Oxide (TiO_2)	0.5
% Sulphur Trioxide (SO_3)	0.2
Loss on Ignition	0.29
Physical properties	
Specific gravity	**2.13**
Fineness (m^2/Kg)	**360**

To attain superior workability of the fresh concrete, financially accessible SP (BASF Glenium 6100) was utilised. BASF Glenium 6100, an admixture of a new generation based on modified polycarboxylate ether, is used as high range water reducer (HRWR) SP. It is a blended version of both super plasticizer (SP) and viscosity modifying agent. The properties of chemical admixture as obtained from manufacturer are presented in Table 3. A specified quantity of extra water was also used in the preparation of SCC.

Table 3: Properties of chemical admixture

Chemical admixture	Glenium 6100
Main component	Polycarboxylate ether
Specific gravity	1.07
pH	≥6
Solid content (%)	30

Guru Jawahar et al. [7] studied the effect of CA blending on fresh properties of SCC and proposed a typical range of CA content suitable for a particular coarse aggregate blending made with 20 mm and 10 mm size aggregates to obtain successful SCC. In our study crushed granite chips of maximum size 12.5 mm are used for coarse aggregate. Bulk specific gravity in oven dry condition and water absorption of the natural coarse aggregate 12.5 mm are 2.58 and 0.3% respectively. Recycled coarse aggregate used has bulk specific gravity of 2.49 and water absorption of 0.45%. Natural river sand is used as fine aggregate. Bulk specific gravity at oven dry condition and water absorption of the sand are 2.62 and 1% respectively. Manufactured sand has specific gravity and water absorption 2.4 and 1.2%.

B. Mix design

In designing the SCC mix, it is most useful to consider the relative proportions of the key components by volume rather than by mass [8]. Several methods exist for the mix design of SCC. The general purpose mix design method was developed by Okamura and Ozawa [9]. In this study, key proportions of constituents of SCC mixes were obtained by using the SCC mix design tool (JGJ_SCCMixDesign.xls) [10]. Nine mixes of various level of replacements in coarse aggregate and fine aggregate using recycled coarse aggregate and manufactured sand has been listed in Table 4 as shown below.

Table 4: Mix Designations of SCC mixes

Mix type	CA	RCA	Sand	MSand
Mix1	100	0	100	0
Mix2	100	0	75	25
Mix3	100	0	50	50
Mix4	75	25	100	0
Mix5	75	25	75	25
Mix6	75	25	50	50
Mix7	50	50	100	0
Mix8	50	50	75	25
Mix9	50	50	50	50

CA : Coarse aggregate, RCA : Recycled aggregate, MSand : Manufactured sand

Table 5: Mix proportions of constituent materials of SCC mixes

Mix type	Binder Kg/m^3	Cement kg/m^3	Fly ash kg/m^3	Water l/m^3	12mm Kg/m^3 (CA)	12mm kg/m^3 (RCA)	Sand Kg/m^3	MSand Kg/m^3	SP l/m^3
Mix1	501	350.7	150.3	180.36	721.6	0	863.4	0	6.01
Mix2	501	350.7	150.3	180.36	721.6	0	647.55	215.85	6.01
Mix3	501	350.7	150.3	180.36	721.6	0	431.7	431.7	6.01
Mix4	501	350.7	150.3	180.36	541.2	180.4	863.4	0	6.01
Mix5	501	350.7	150.3	180.36	541.2	180.4	647.55	215.85	6.01
Mix6	501	350.7	150.3	180.36	541.2	180.4	431.7	431.7	6.01
Mix7	501	350.7	150.3	180.36	360.8	360.8	863.4	0	6.01
Mix8	501	350.7	150.3	180.36	360.8	360.8	647.55	215.85	6.01
Mix9	501	350.7	150.3	180.36	360.8	360.8	431.7	431.7	6.01

C.Experimental setup

Compressive test has to be performed on cube specimens of size 150 mm x 150 mm x 150 mm with curing period of 28 days in compression testing machine (CTM) as per IS 516 (1991) [11]. Three specimens were casted and tested for each age and each mix.

For durability properties, the tests conducted were

a. Acid attack resistance

b. Rapid chloride permeability test (RCPT)

c. Water absorption

Resistance of concrete specimen of cube size 150 mm x 150 mm x 150 mm against external acid attack was evaluated as per ASTM C 267-01 [12]. Each specimen of concrete was weighed on completion of initial curing period of 28 days. Then the specimens were immersed in 3% sulphuric acid (H_2SO_4) solution. During this test the changes in weight and compressive strength properties of specimens were determined after 28 and 56 days of immersion of specimens in 3% sulphuric acid solution.

Fig 1 Acid attack resistance setup

Rapid Chloride Permeability test (RCPT) was conducted on cylindrical specimens of size 100 mm x 50 mm after 28 and 56 days of curing as per ASTM C1202 [13]. Three test specimens were cast and tested for each age and each mix. RCPT is a two component cell assembly checked for air and watertight. The cathode campartment is filled with 3% NaCl solution and anode compartment is filled with 0.3NaOH solution.Then the concrete specimens were subjected to RCPT by impressing a 60V from a DC power source between the anode and cathode as shown in Figs. 2 and 3. Current is monitored up to 6 hours at an interval of 30 minutes.

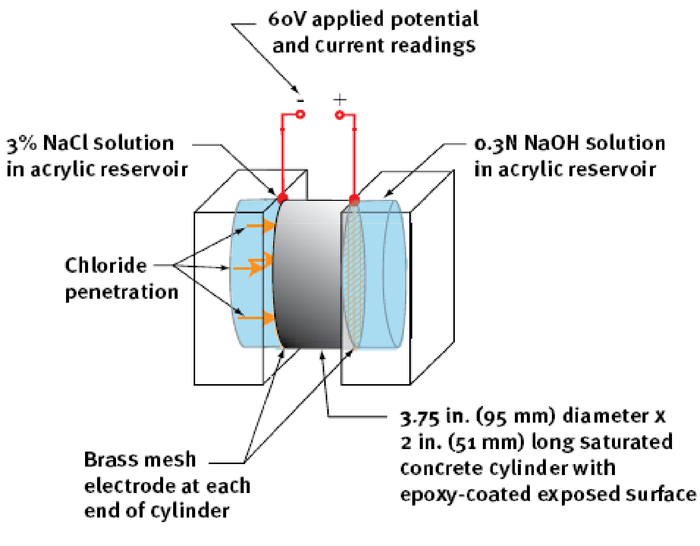

Fig 2 Rapid Chloride Permeability Test Procedure

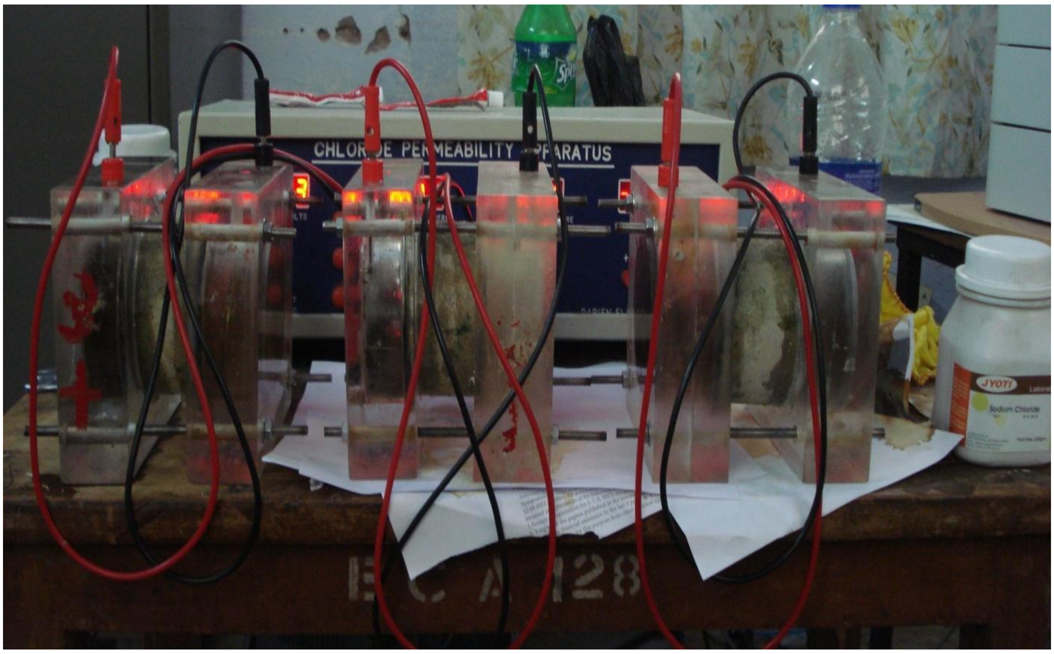

Fig 3 Rapid Chloride Permeability Test Setup

From the current values, the chloride permeability is calculated in terms of coulombs at the end of 6 hours by using the formula.

$$Q = 900\,(I_0 + 2\,I_{30} + 2\,I_{60} + 2\,I_{90} + \ldots\ldots\ldots\ldots + 2\,I_{300} + 2\,I_{330} + 2\,I_{360})$$

The relationship between chloride penetrating rate and the charge passed by coulombs is given in Table 6.

Table 6: Chloride penetrability characteristics as per ASTM C1202

Charge Passed (Coulomb)	Chloride Penetrability
> 4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very Low
<100	Negligible

Water absorption test was conducted on cylindrical specimens of size 100 mm x 50 mm after 28 and 56 days of curing as per ASTM C 642-97 [14]. Three test specimens were cast and tested for each age and each mix. After each curing period, these specimens were oven dried for 24 hours at the temperature of 110^0C and oven dry weight of specimens were measured (W_1). After oven drying, these test specimens were immersed in water and measured the weight of the saturated surface dry specimens at an interval of 12 hours (W_2). This procedure was repeated for not less than 48hours until the two successive readings was same. Water absorption of the tested specimen was calculated as follows:

$$\text{Water absorption (\%)} = [(W_2 - W_1) / W_1] \times 100$$

III. RESULTS AND DISCUSSIONS

A.Fresh properties

Fresh properties such as slump flow, V-funnel and L-box are performed to get the required flow ability to the concrete. The values are shown in Table 7 and follows EFNARC (2002) specifications [8]. According to Bonen and Shah 2005 [15], the key factor for a successful development of SCC is to clearly understand the role of the different constituent material in the mix and their effects on the fresh and hardened properties of SCC.

Table 7: Fresh properties of trial mixes

Mix type	SLUMP FLOW (mm)	V- FUNNEL (SEC)	L-BOX TEST (h2/h1) ratio
MIX1	690	6.2	0.97
MIX2	675	7.3	0.89
MIX3	656	10.4	0.82
MIX4	682	6.6	0.95
MIX5	669	7.9	0.86
MIX6	652	10.9	0.81
MIX7	678	7.1	0.91
MIX8	661	8.4	0.83
MIX9	645	11.1	0.80

A.Mechanical properties

From results, we observe that compressive strength of MIX3 (100% CA - 0% RCA - 50% sand - 50% MSand) is higher i.e. 35.6MPa than other mixes which is due to increase in proportion of MSand because of silica content present in MSand. The use of RCA slightly affects the strength of M25 grade SCC because of residual mortar in RCA have increase in porosity, low specific gravity and high water absorption. After MIX3, MIX6 is showing high compressive strength i.e. 34.3MPa (75% CA - 25% RCA - 50% sand - 50% MSand). Hence we can say that mix with low recycled aggregate and high MSand gives better compressive strength which in our case is MIX3 and after that MIX6 which is gained after 28 days of curing. The test procedures follow IS 516 (1991) [11] specifications.

The compressive after 28 days curing are shown in Table 8.

Table 8: Compressive strength for 28 days

Mix Type	Compressive Strength (MPa) 28 days
Mix 1	32.8
Mix 2	33.2
Mix 3	35.6
Mix 4	31.6
Mix 5	32.4
Mix 6	34.3
Mix 7	30.2
Mix 8	31.8
Mix 9	32.1

B.Durability Properties

In the present investigation, durability properties like weight loss and strength loss after acid attack, resistance to chloride ion penetration and percentage of water absorption have been studied.

1.Performance of SCC before and after acid attack

Compressive strength values for 28 days before acid attack were already shown in Table 8. Weight of the specimens before acid attack is shown in Table 9.

Table 9: Weight (Kgs) of SCC mixes before acid attack

Mix Type	Weight (Kgs) 28 days
Mix 1	7.96
Mix 2	8.14
Mix 3	8.2
Mix 4	7.82
Mix 5	7.94
Mix 6	8.12
Mix 7	7.68
Mix 8	7.74
Mix 9	7.92

From results, it shows that Mix 3 (CA-100, RCA-0, FA-50, MSand-50) has high compressive strength as well as more weight. Since MSand content is more in mix 3 which increases compressive strength and weight. The use of RCA slightly reduces the compressive strength, but the reduction is negligible.

Table 8 and Table 9 shows the initial values of compressive strength and weight before acid attack for 28 days of curing and corresponding loss of compressive strength and weight after acid attack of SCC mixes for 28 days of immersion of specimens in 3% sulphuric acid (H_2SO_4) solution after 28 days of normal curing as shown in Table 10 and Table 11.

Table 10: Compressive strength (MPa) of SCC mixes after 28 days of acid immersion

Mix Type	**Compressive Strength(MPa)**		
	Initial	**After acid**	**% of loss**
Mix 1	32.8	29.9	8.84
Mix 2	33.2	30.8	7.23
Mix 3	35.6	33.4	6.18
Mix 4	31.6	28.4	10.13
Mix 5	32.4	29.3	9.57
Mix 6	34.3	31.4	8.45
Mix 7	30.2	26.6	11.92
Mix 8	31.8	28.5	10.38
Mix 9	32.1	29.1	9.35

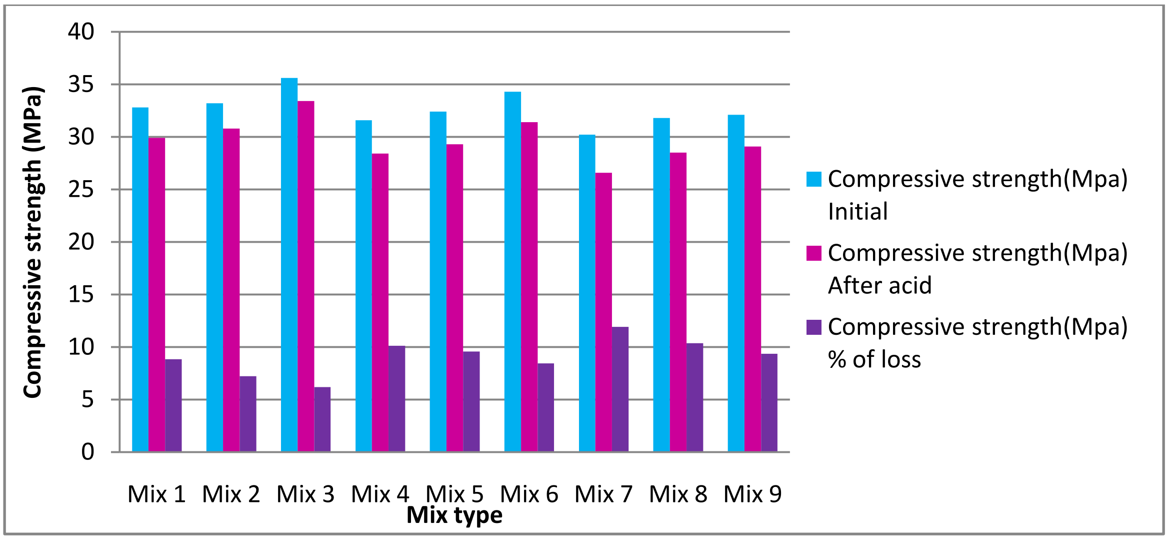

Fig 4 Percentage loss of Compressive strength after 28 days of acid attack

Table 11: Weight (Kgs) of SCC mixes after 28 days of acid immersion

Mix Type	Weight (Kg)		
	Initial	After acid	% of loss
Mix 1	7.96	7.78	2.26
Mix 2	8.14	7.98	1.97
Mix 3	8.2	8.09	1.34
Mix 4	7.82	7.56	3.32
Mix 5	7.94	7.74	2.52
Mix 6	8.12	7.98	1.72
Mix 7	7.68	7.32	4.69
Mix 8	7.74	7.48	3.36
Mix 9	7.92	7.69	2.90

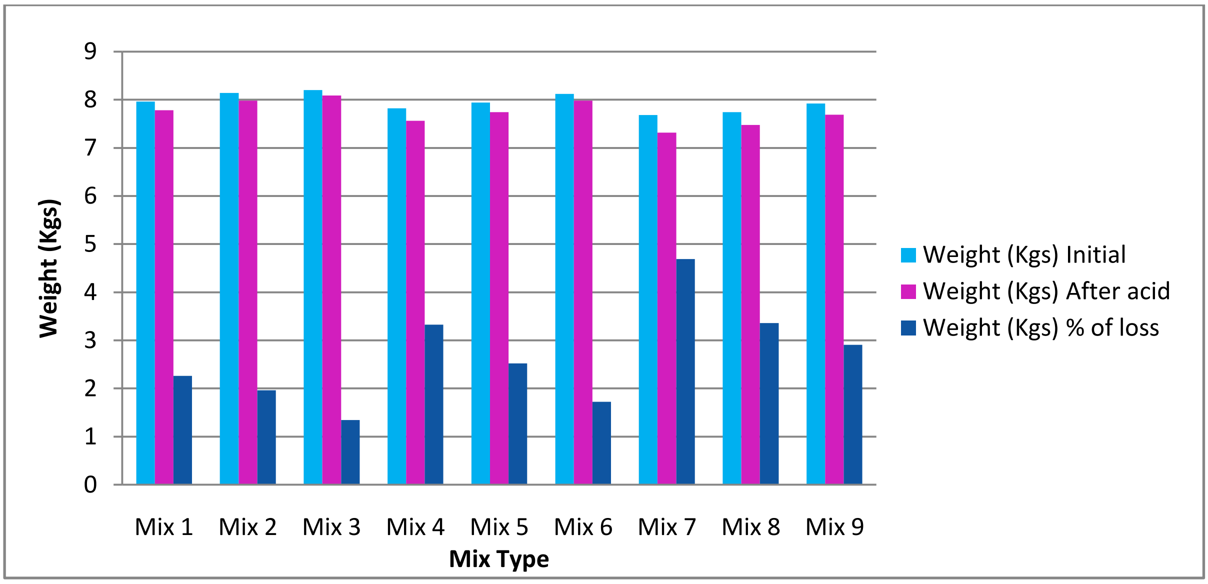

Fig 5 Percentage loss of weight after 28 days of acid attack

Table 12: Compressive strength (MPa) of SCC mixes after 56 days of acid immersion

Mix Type	Compressive strength (MPa)		
	Initial	After acid	% of loss
Mix 1	32.8	27.0	17.68
Mix 2	33.2	28.4	14.46
Mix 3	35.6	31.6	11.24
Mix 4	31.6	25.4	19.62
Mix 5	32.4	27.1	16.36
Mix 6	34.3	29.6	13.70
Mix 7	30.2	24.2	19.87
Mix 8	31.8	26.1	17.92
Mix 9	32.1	27.2	15.26

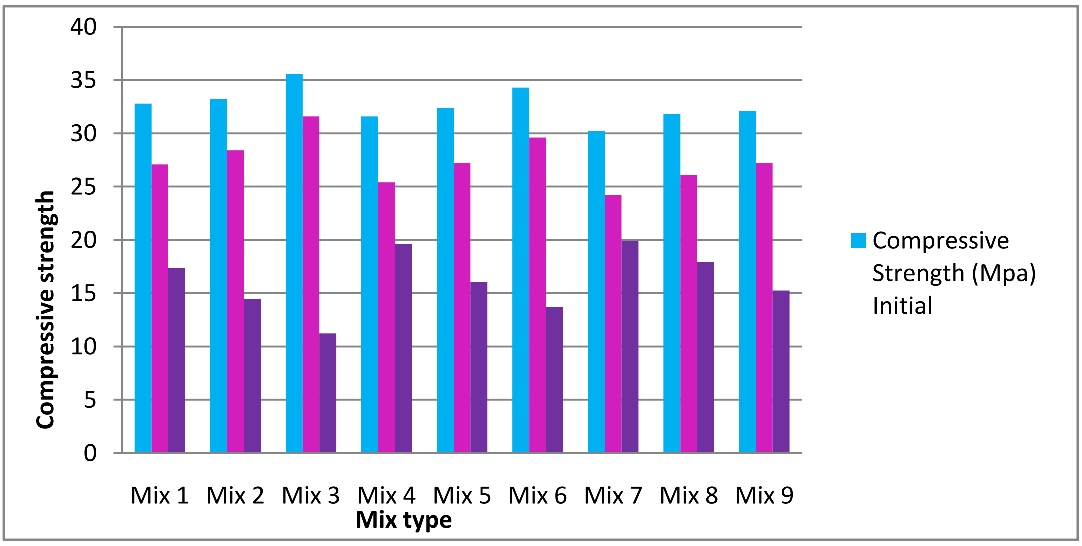

Fig 6 Percentage loss of Compressive strength after 56 days of acid attack

Table 13: Weight (Kgs) of SCC mixes after 56 days of acid immersion

Mix Type	Weight (Kgs)		
	Initial	After acid	% of loss
Mix 1	7.96	7.64	4.02
Mix 2	8.14	7.84	3.69
Mix 3	8.2	7.95	3.05
Mix 4	7.82	7.45	4.73
Mix 5	7.94	7.61	4.16
Mix 6	8.12	7.84	3.45
Mix 7	7.68	7.18	6.51
Mix 8	7.74	7.32	5.43
Mix 9	7.92	7.53	4.92

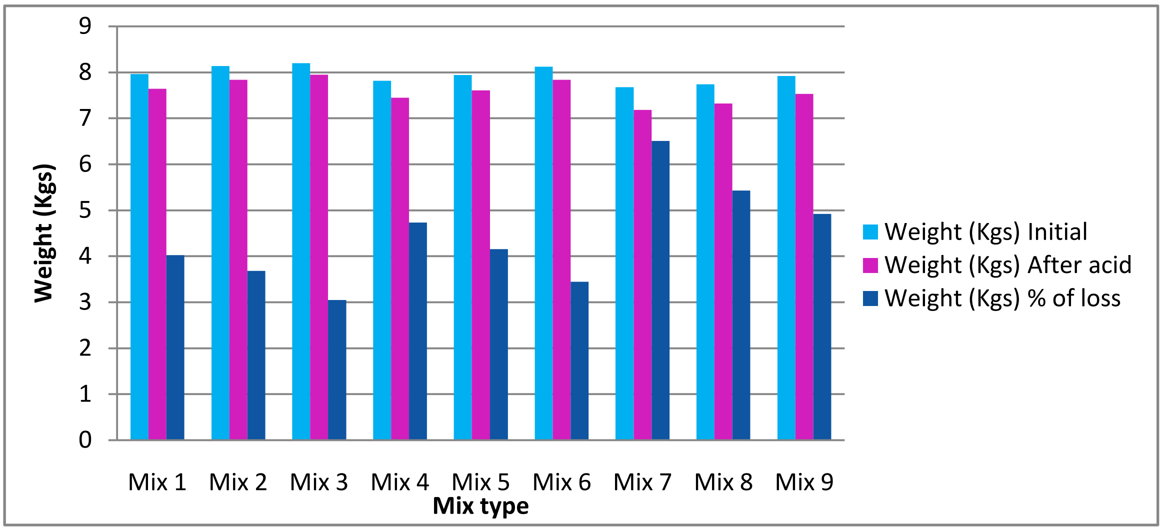

Fig 7 Percentage loss of Weight after 56 days of acid attack

From Table 10 and Table 12, it shows that after 28 and 56 days of acid immersion, the compressive strength decreased, but the decrement is less compared to initial value. From Table 11 and Table 13, it clearly shows that the weight is decreased after 28 and 56 days of acid immersion. The percentage loss of compressive strength and weight is less for mix3 (CA-100, RCA-0, FA-50, MSand-50) since silica content in MSand gives more strength to concrete. The loss of compressive strength and weight is high in mix7 (CA-50, RCA-50, FA-100, MSand-0) when compared to those of other eight mixes. The percentage reduction in weight and compressive strength is decreased with increased replacement of MSand.

It is believed that increased replacement level of MSand is increasing the interlocking property and hence densifying the concrete which refine the pore structure. This improved pore structure and interlocking property is contributed to resist the external sulphuric acid attack. The bonding of SCC paste and aggregate is so strong that tends to increase the mechanical properties.

The increase of RCA replacement decreases the hardened properties due to presence of residual mortar in RCA which is responsible for degradation of mechanical and durability properties. But this degradation is compensating by the increased replacement of MSand which enhances the mechanical and durability properties due to interlocking property. The decrement in properties due to RCA is lower when compared to increment in properties due to MSand replacement.

2.Performance of SCC in resistance to chloride ion penetration

Rapid chloride permeability test (RCPT) is a quick test to measure the rate of penetration of chloride ions in concrete. Rapid chloride permeability of SCC expressed in terms of charge passed in coulombs after 28 and 56 days of curing are shown in Table 14.

Table 14: RCPT values of SCC mixes

Mix Type	Charge passed (Coulombs)		Chloride penetrating rate
	28 days	56 days	
Mix 1	1568	1348	Low
Mix 2	1489	1244	Low
Mix 3	1394	1189	Low
Mix 4	1658	1497	Low
Mix 5	1571	1366	Low
Mix 6	1488	1282	Low
Mix 7	1799	1581	Low
Mix 8	1684	1465	Low
Mix 9	1592	1380	Low

From Table 14, it is observed that M_{25} grade of SCC have attained low penetrating rates at all ages. After 28 and 56 days of curing, penetrating rates of M_{25} grade of SCC were observed as “Low”. This significance in the penetration rates was observed in SCC mainly due to the pozzolanic action, interlocking property of MSand and micro filling of fly ash.

3.Performance of SCC in water absorption

Water absorption of SCC after 28 and 56 days of curing are shown in Table 15. From the Table 15, it is observed that M25 grade of SCC have attained lower percentage of water absorption values at all ages. Significant reduction was observed in the water absorption values of SCC mainly due to continued pozzolanic action of fly ash with the age, micro filling of fly ash and interlocking property of MSand.

Table 15: Percentage of water absorption

Mix Type	**Percentage of water absorption**	
Mix 1	**28 days**	**56 days**
Mix 1	3.04	2.84
Mix 2	2.96	2.79
Mix 3	2.67	2.52
Mix 4	3.09	2.94
Mix 5	3.06	2.89
Mix 6	2.92	2.75
Mix 7	3.18	3.08
Mix 8	3.08	2.91
Mix 9	3.02	2.84

From the above results, it is to be noted that the designed M_{25} grade of SCC was performing enhanced mechanical and durability properties at later ages as compared to early ages. So, the adequate binder cement and 30% replacement level of class F fly ash and 50 % MSand in mix3 (CA100, RCA0, FA50, MSand50) and after this, mix6 (CA75, RCA25, FA50, Msand50) was resulting enhanced fresh, mechanical and durability properties of SCC.

Hence, the mix3 and mix6 can be recommended as normal strength M_{25} grade of SCC for constructions.

IV.**CONCLUSIONS**

1. The durability properties of M 25 grade of SCC were good when compared to regular concrete.
2. M 25 grade of SCC was performing enhanced mechanical and durability properties at later ages as compared to that same grade of regular concrete due to pozzolanic action of class F fly ash.
3. The increase in manufactured sand replacement reduces the fresh properties due to interlocking property of manufactured sand.
4. The increase in replacement level of manufactured sand enhances the mechanical and durability properties of SCC due to filling ability of manufactured sand and its silica content.
5. The increase in replacement level of recycled coarse aggregate has reduced the strength slightly because of ageing effect of aggregates and its effect on fresh properties is negligible.
6. It is concluded that manufactured sand can be partially replaced in the sand to certain extent and in case recycled coarse aggregate increase in percentage causes slight reduction in strength and negligible effect on SCC so they can be used to address the environmental issues.
7. Of all the nine mixes MIX3 and MIX6 is found to be have high durability than other mixes because of manufactured sand , recycled coarse aggregate, sand and natural coarse aggregates.
8. Test results shown that percentage loss of compressive strength and weight is low for MIX3 and after that MIX6.
9. The chloride permeability for all specimens of M_{25} grade SCC have attained " Low " penetrating rates at all ages.
10. The M_{25} grade of SCC have attained lower percentage of water absorption values at all ages, particularly MIX3 showed lower percentage of water absorption due to continued pozzolanic action of fly ash with the age, micro filling of fly ash and interlocking property of MSand.

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