International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 5 (2019), pp. 636-641

Self compacting concrete containing large volumes of Class C flyash and processed slag sand for carbon foot print mitigation

C. P. Ramesh[1], M.E, H.P. Vageesh[2], M.Tech, T. Raghavendra[3], PhD, M.ASCE, B. C. Udayashankar[4], PhD and A. Shashishankar[5], PhD

[1]*Research Scholar, Department of Civil Engineering, SET- JAIN University, Bengaluru, Karnataka, India, cp.ramesh@jainuniversity.ac.in*

[2]*Assistant Professor, Department of Civil Engineering, R. V. College of Engineering, Bengaluru, Visvesvaraya Technological University, Karnataka, India, vageeshhp@rvce.edu.in*

[3]*Associate Professor, Department of Civil Engineering, R. V. College of Engineering, Bengaluru, Visvesvaraya Technological University, Karnataka, India, raghavendrat@rvce.edu.in,*

[4]*Professor, Department of Civil Engineering, R. V. College of Engineering, Bengaluru, Visvesvaraya Technological University, Karnataka, India, udayashankar@rvce.edu.in*

[5]*Professor and Head, Department of Civil Engineering, AMC Engineering College, Bengaluru, Visvesvaraya Technological University, Karnataka, India*

Abstract

Self compacting concrete (SCC) is a concrete which flow by its own weight and fills up congested reinforcement without the influence of external vibration, it was first developed in Japan in early 80's. From last two decades it has become consent to use SCC due to the rapid growth of urbanization and due to lack of space for storing construction materials. As the population rate is increasing day by day and thereby causing depletion of natural recourses which are affecting the environment severely and also necessitating the use of sustainable materials. Many researchers illustrated the utilization of alternates to natural aggregates such as quarry dust, crushed stone aggregates, construction and demolition waste, copper slag, crushed sand from different mineralogical sources, marble and granite waste aggregates, etc., for sustainability. Various studies proved that these alternatives can be used as partial replacement of natural river sand in SCC. Fly ash a byproduct from thermal power plants having pozzolonic properties is highly suggested as cement replacement material for eco friendly constructions. This present investigation is carried out on novel SCC and according to European Federation of National Associations Representing for Concrete (EFNARC) guidelines; by complete replacement of fine aggregates with Processed Slag Sand (PSS) and partial replacement of Binder with Class C fly ash i.e. 40 percent of total binder which is termed as SCC 64 (60:40). The results obtained concerning flow, strength, durability, water permeability and rapid chloride ion penetration; for SCC 64 is very much favorable in comparison with SCC CM, for green initiative.

Keywords: SCC; PSS sand; Class C Fly ash

I. INTRODUCTION

SCC (Self compacting concrete) was brought forth in 1980's at Japan. It is an advanced concrete which flows under its self weight and doesn't require external vibration to attain compaction, it is used for construction for high rise structures with heavy and congested reinforcement where achieving compaction is a major concern.

One of the key importance of this work is to find out the durability aspects of SCC mixes. The durability parameters were enhanced by the utilization of marginal materials such as class C fly ash in SCC73 (Vageesh H P et.al 2018) likewise ISP slag as replacement for natural sand, even for small ratios (Zofia Szweda et.al 2017). Similar behavior was observed in the enhancement of durability; chloride migration, electrical resistivity, and carbonation by incorporation of fly ash (FA) and limestone filler (LF) as partial substitution for cement through SEM image analysis (Pedro Raposeiro da Silva and Jorge de Brito 2016). The key interest of this proposed effort is to design an appropriate mix proportion for SCC with incorporating marginal materials and to develop suitable design mix. Due to the incorporation of high volume in fly ash content 0-35%, the Slump Flow and flexural strength values were increased where as the compressive strength and modulus of elasticity values decreased (Khaled Omar Mohamed Oraibi et.al 2015). A similar values for Modulus of elasticity was reported for SCC and Vibrated concrete based on the data collected and compared with the predicted from the formulations and existing models developed (from Euro code 2 and the Model Code) (BartCraeye et.al 2014). By the replacement level at 0 to 50%, Recycled asphalt pavement (RAP) and supplementary cementitious materials (SCM's) reduced the ultimate strength, and also compressive strength Development rate at 3, 14, and 28 days however they satisfied the fresh properties of SCC, mixes possessing moderately high percentages of SCMs and RAP showed satisfactory compressive strength (Enad Mahmoud et.al 2013). By the incorporation of waste mineral Admixtures, limestone powder (LP), basalt powder (BP) and marble powder (MP) as partial replacement of Portland cement improved the economic feasibility of SCC but reduced the Elastic and dynamic modulus of SCC mixes (Mucteba Uysal and Kemalettin Yilmaz 2011). Concrete mixes with different replacement levels of metakaolin (MK) and limestone filler (LF) were remained sound and maintained their original pore structure

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after different exposure periods which are examined for rapid chloride permeability (RCPT), water sorptivity, water porosity, rapid freezing and thawing and also with sulphuric acid solutions with concentrations of 3%, 5% and 7%, with the mutual action of LF into MK concretes exhibit good resistance against sulphuric acid attack. The water absorption, water porosity of concrete with MK and LF was better than the nominal mix; RCPT results in the mixture have significantly higher permeability than other concrete mixture. (Seyed Mahmoodreza Joorabchian 2010)

In this present experimental work it was planned to study the behavior of novel SCC mixes both at fresh and hardened state, containing, alternate fine aggregate such as Processed Slag Sand (PSS) in complete replacement to natural fine aggregate material and 40 percent of class C fly ash is replaced to the total weight of binder. Compressive strength at 7, 28, 56 and 90 day's age, split tensile strength and flexure at 28 and 56 day's age; was investigated. The stress-strain characteristics, effect of water-powder ratio on Properties of SCC mixes and durability (water permeability and rapid chloride ion penetration are not evaluated in literature (Vageesh H P et.al 2018)) were investigated. With larger benefits, till date SCC technology was not implemented in IS Codes, so for mix design purpose Japanese method was used by following EFNARC (European Federation of Natural Association Representing for Concrete) guidelines, later a desired mix was proposed on basis of workability property in its fresh state, compressive strength and durability requirements

II. MATERIALS AND METHODS

II.I Materials

For determining the chemical and physical properties of SCC ingredients. Bureau of Indian Standards (IS) procedures were followed, the following are the properties of materials used in SCC

II.I.I Binders

1. Cement (C): 53 grade; Specific gravity=3.15

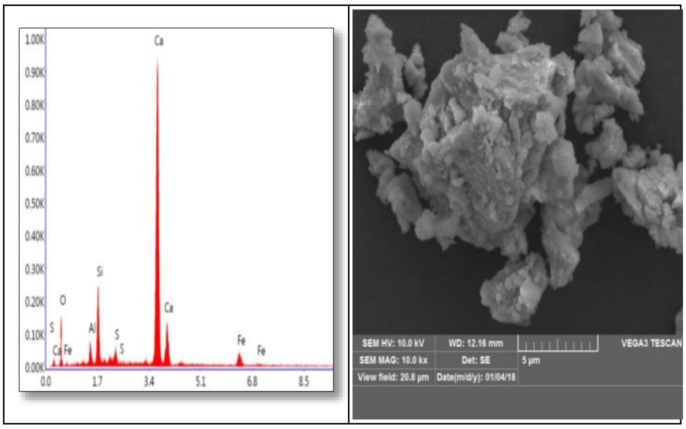

Fig. 1. SEM-EDS Analysis for Cement (Vageesh H P et.al 2018)

2. Class-C fly ash : Specific gravity = 2.12

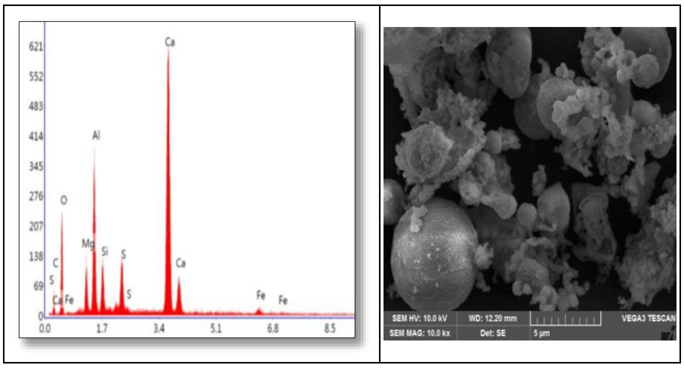

Fig. 2. SEM-EDS Analysis for Class C Fly ash (Vageesh H P et.al 2018)

II.I.II Super-**plasticizer**

1. Master Glenium Sky 8233: Specific gravity = 1.08

II.I.III Fine Aggregate

1. A) Processed Slag Sand (PSS): Specific gravity = 2.53

   B) Water absorption for (PSS) = 0.3%

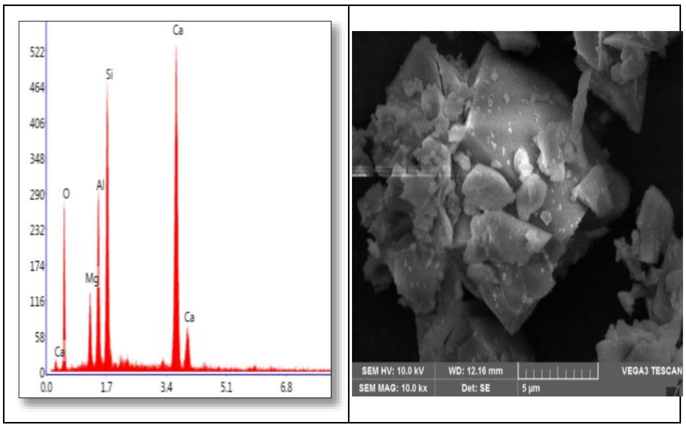

Fig. 3. SEM-EDS Analysis for Processed Slag Sand (Vageesh H P et.al 2018)

2. M-sand: Specific gravity = 2.63

II.I.IV Coarse aggregate

1. A) Crushed granite stones of 12.5 mm down size; Specific gravity = 2.67

   B) Water absorption = 0.8%

II.I.V *Water*

1. Potable water of pH 7

II.II Methodology

Japanese method of mix design:

The Japanese method mix design procedure as indicated in literature is adopted. (Jagadish Vengela and R.V. Ranganath 2004).

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Vageesh H P et.al, and C.P Ramesh et.al, (2018 and 2019) adopted Japanese method. In this method ultimate super plasticizer dosage is arrived at using Marsh cone apparatus in which all other parameters such as fine aggregates, coarse aggregates water-powder ratio are constant. Trial mixes are prepared for SCC 64 and thereby the flow parameters such as slump flow, V-Funnel, U-Box and J- Ring are ensured to be conforming to EFNARC guidelines.

Fine aggregates materials are entirely replaced by Processed Slag Sand (PSS) and Binder was partly replaced with Class C fly ash in varying percentage 40% by the weight of cement i.e. (60:40) is considered and named as SCC 64. And controlled mix is named as SCC CM. to attain the desired mix ratio numerous trails were carried out, all SCC mix confirmed and achieved workability property. Standard cylindrical specimens of size 150 mm diameters and height 300mm were cast to assess compressive strength, splitting tensile strength and Young's modulus. 500mm x 100mm x 100mm sized standard Beams were cast to calculate flexure strength. Standard cubes of size 150mm x 150mm were considered to asses durability aspects such as acid attack test, alkaline attack test and water permeability, for rapid chloride penetration (RCPT) Standard cylindrical specimens of size 100mm diameter and 50 mm height were cast. Water permeability assessment was conducted according to German Standard DIN 1048 on concrete specimens of size 150x150x150 mm, at an age of 28 days, by passing water under pressure of 500 kPa (5 bar) for 72 hours duration. RCPT was assessed in accordance with ASTM C 1202, the overall charge passed in Coulombs was determined.

Both the SCC mixes satisfies the workability requirements given by EFNARC, for SCC CM slump flow was 725mm where as for SCC 64 is 700 mm, interms of V-Funnel both the SCC mixes was arrived at 10 Seconds, in L-Box the height ratio for both the mixes was 0.8, and difference in height in U-Box was found to be 18mm and 0mm respectively.

III. RESULTS AND DISCUSSION

III.I Compressive Strength

As mentioned in literature (Vageesh H P et.al 2018) "Compressive Strength indicates the resistance to permanent deformation of normal and modified self-compacting mixtures". Compressive strength was evaluated at 7, 28, 56 and 90 day's age. It has been noted that at the age of 7 days the SCC 64 mixes obtained lesser relative strength of about 42% when compared to 7 days strength of SCC CM, which is around 92% of SCC CM 28 days strength (with cement content of 434.3 kg/m^3) and similar observation was made by literature (R. Saleh Ahari et al. 2015) and (C.P.Ramesh et al. 2019) wherein around 89% of their control mix was obtained at 7 days age (with cement content of 454.5 kg/m^3). It may be observed in (**Figure 12)**, the formation and presence of ettringites, indicating the onset of secondary reaction involving fly ash. hence due to pozzolonic action of fly ash (refer **Figure 10 and 11** (Vageesh H P et.al, and C.P Ramesh et.al, 2018 and 2019) and in **Figure 12**), the compressive strengths at later ages (28, 56 and 90 days) was improved and finally reached values almost equal to SCC CM mixes **(Figure 4)**

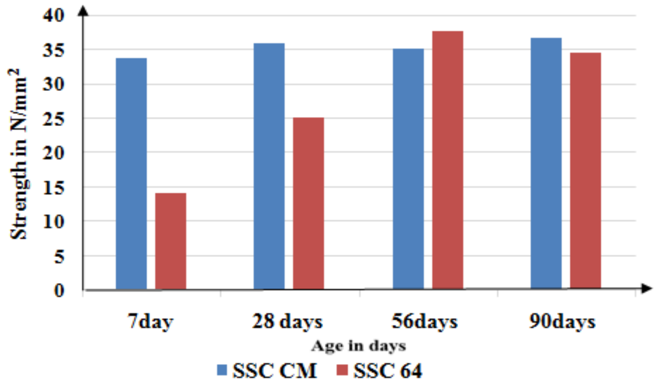

Fig. 4. 7, 28, 56 and 90days compressive strength of SCC CM and SCC 64 mixes

III.II Tensile strength

The split tensile strength value is affected by percentage of fly ash (Vageesh H P et.al 2018). As observed in (**Figure 5),** SCC CM mixes resulted in comparatively more split tensile strength values of about +26% and +22.35% when compared with SCC 64, at the age of 28 and 56 days, respectively.

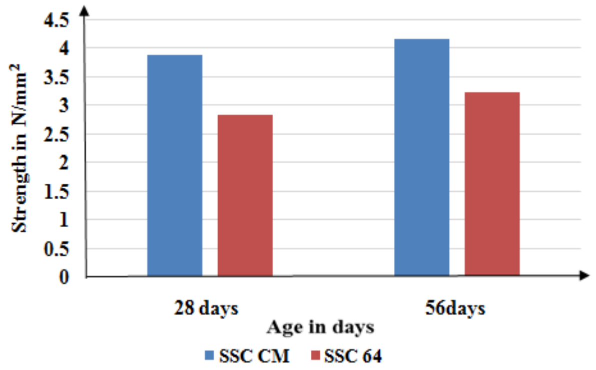

Fig. 5. 28 and 56 days Split tensile strength of SCC CM and SCC 64 mixes

III.III Flexural Strength

It may be observed in (Figure 6), SCC CM mixes resulted in flexural strength value of about +36% when compared with SCC 64 at the age of 28 and 56 days respectively same thing was mentioned in the literature (C.P.Ramesh et al. 2019).

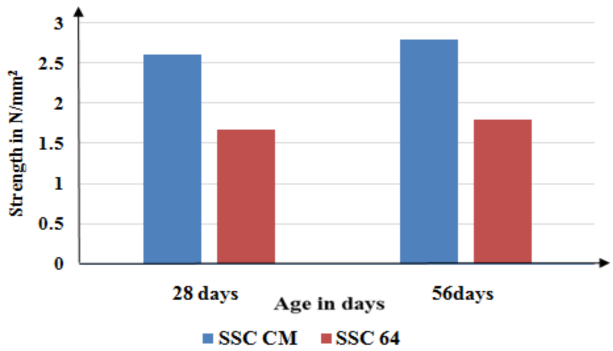

Fig. 6. 28 and 56 days Flexural strength of SCC CM and SCC 64 mixes

III.IV The modulus of elasticity (MOE)

The highest value of modulus of elasticity was found for SCC CM (36GPa) when compared to SCC 64 (2.7Gpa) same was observed in literature (Vageesh H P et.al 2018 and C.P Ramesh et.al 2019) as shown in (**Figure 7 and 8)**

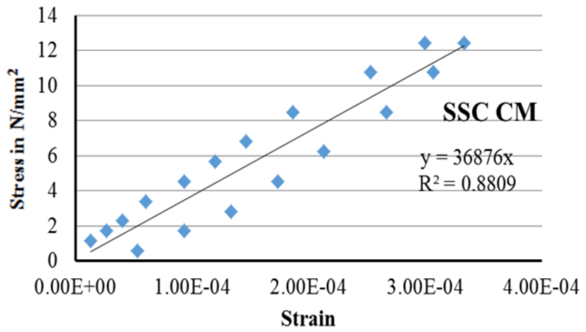

Fig. 7. 28 days Modulus of Elasticity of SCC CM (Vageesh H P et.al 2018)

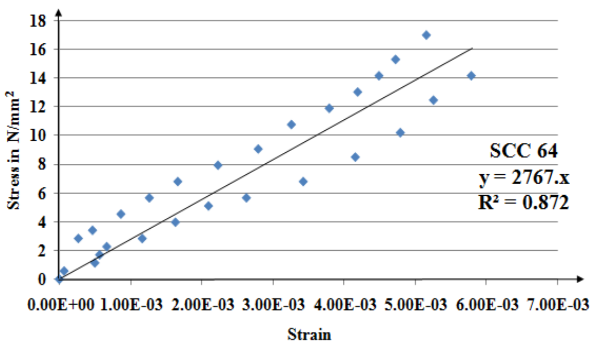

Fig. 8. 28 days Modulus of Elasticity of SCC 64

III.V Durability

III. V. I Acid and Alkali attack Tests

Durability tests for acid and alkali resistance was carried out as per literature (Vageesh H P et.al 2018) and the performance of the concrete specimens were evaluated after immersion into the 10% sulphuric acid solutions and 10% of 1N NaOH solution. The weight and dimension of the concrete samples was monitored weekly throughout the entire testing period and was recorded (refer **Table 1 and 2**); the compressive strength of specimens was evaluated and compared **(Table 3)** at the age of 28 days in acid / alkali exposure (refer **Figure 9 to 13**). Acid exposure of SCC CM mix resulted in huge difference with respect to weight loss and compressive strength, of about 18% and 54%, respectively; when compared with acid exposure results for weight and strength of SCC 64 mix (Seyed Mahmoodreza Joorabchian 2010).Whereas the alkaline exposure resulted in no considerable loss of weight and compressive strength for SCC CM mix when compared with SCC 64 mix. This indicates that replacement of cement as a binder by high volumes of fly ash will result in high acid exposure resistant SCC as mentioned by (C.P.Ramesh et.al, 2019).

Table 1. Comparison of change in weight and dimensions of 10% Acid Cured SCC Specimen at the age of 56 days

SCC mix	Original weight for 10% Acid in Kg	Change in weight for 10% Acid in Kg	Original dimension for 10% Acid in mm	Change in dimension for 10% Acid in Mm
SCC CM	8.18	6.64	150 X 150	141 X 142
SCC 64	8.59	7.59	150 X 150	146 X 145

Table 2. Comparison of change in weight and dimensions of 1N 10% Alkaline Cured SCC Specimen at the age of 56 days

SCC mix	Original weight for 1N 10% Alkaline in Kg	Change in weight for 1N 10% Alkaline in Kg	Original dimension for 1N 10% Alkaline in mm	Change in dimension for 1N 10% Alkaline in Mm
SCC CM	8.255	8.32	150 X 150	150 X 150
SCC 64	8.26	8.3	150 X 150	149 X 150

Table 3. Compressive strength Comparison of Acid and Alkaline Cured SCC Specimen at the age of 56 days

SCC mix	10% Acid cured strength (MPa)	1Normal 10% Alkali cured strength (MPa)
SSC CM	9.57	35.88
SSC 64	20.35	34.02

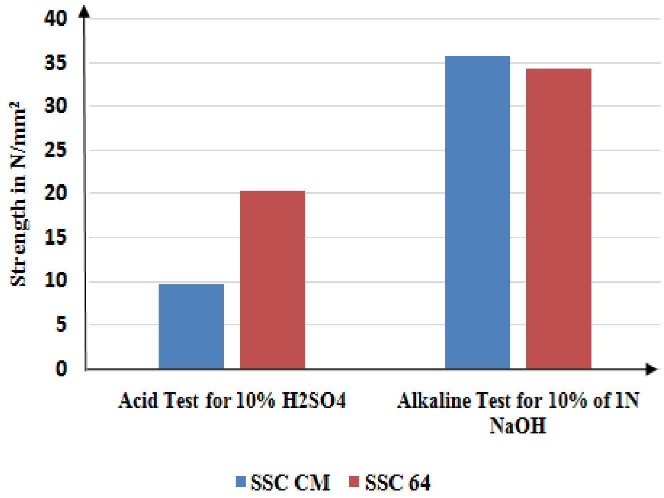

Fig. 9. 56 days Compressive strength of Acid and Alkaline Cured SCC Specimens

III.V.II Water Permeability

Water permeability test results in terms of depth of penetration for all the mixes are tabulated in **Table 4**. German Standard DIN 1048 specified method was followed for evaluating water permeability of SCC CM, SCC 64 and SCC 73. Water permeability test for SCC 73 mix was earlier not evaluated in literature (Vageesh H P et.al 2018). It has been noted that all the SCC mixes satisfy the guidelines up to the replacement level of 40% for binder with class C fly ash similar observation was made in literature (L.A. Pereira-de-Oliveira et. al. 2014)

Table 4. Water permeability results for SCC CM, SCC 64 and SCC 73 mixes at the age of 28 days

SCC mix	Test Results	Requirements as per DIN 1048
SSC CM	22.5	Maximum 25 mm
SSC 73	23	
SCC 64	23	

III.V.III Rapid chloride ion permeability

The RCPT tests were performed on SCC CM, SCC 64 and SCC 73 mixes at the age of 28 days and the results obtained are reported as an average of three tested specimens. RCPT test SCC 73 mix was earlier not evaluated in literature (Vageesh H P et.al 2018). Charge passed in Coulombs for all the mixes are tabulated in (**Table 5).** The twenty-eight day total charged passed for SCC CM mixes are 2974 coulombs, and is more for SCC 73 mixes 3493 coulombs which falls under moderate range of permeability as per ASTM C 1202, whereas SCC 64 mixes resulted in higher value of RCPT (around 4468 Coulombs) due to the presence of higher volumes of fly ash (refer **Figure 10 to 12**), of about 40 percent of total binder content and similar results are reported in literatures of (C.P. Ramesh et.al, 2019 and Saleh Ahari et al. 2015)

Table 5. Rapid chloride ion permeability results for SCC CM, SCC 64 and SCC 73 mixes at the age of 28 days

SCC mix	Total charge passed (Coulombs)	Requirements as per ASTM C 1202
SSC CM	2974	**Moderate**
SSC 73	3493	
SCC 64	4468	**High**

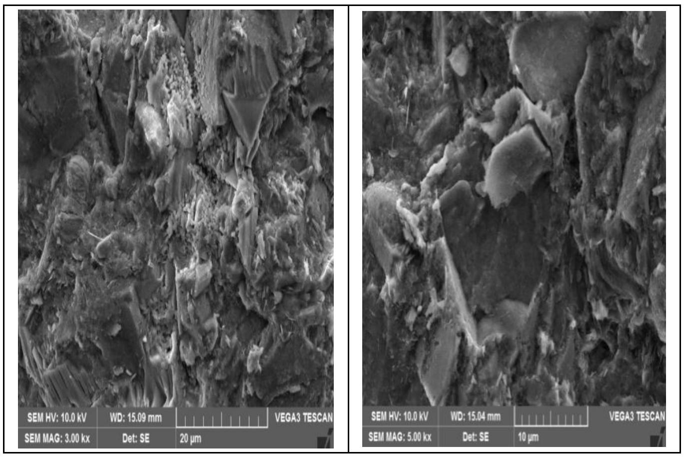

Fig. 10. SEM image for SCC CM @ 28 Days (Vageesh H P et.al 2018)

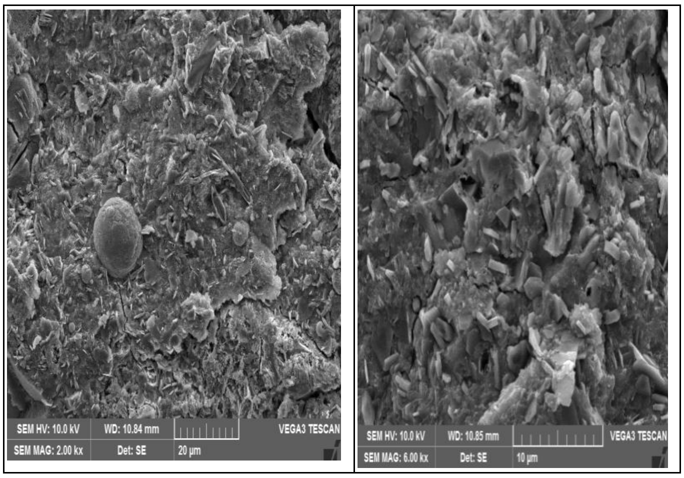

Fig. 11. SEM image for SCC 73 @ 28 Days (Vageesh H P et.al 2018)

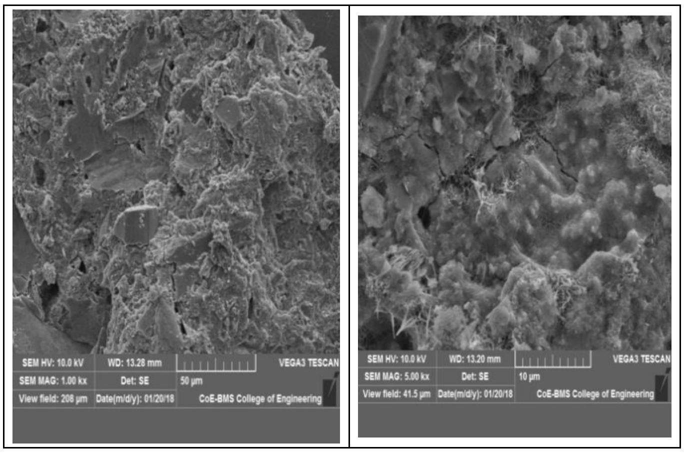

Fig. 12. SEM image for SCC 64 @ 28 Days

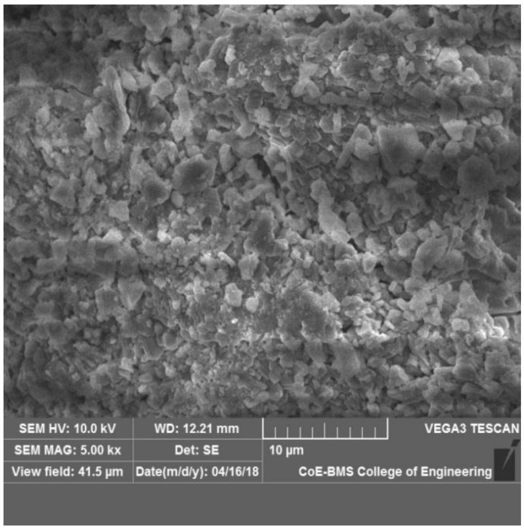

Fig. 13. SEM image for SCC 64 @ 56 Days (After acid exposure)

IV. CONCLUSIONS

The following conclusions were drawn based on the experimental results obtained for self compacting concrete mixes containing industrial byproducts.

1) At 7 days age, SCC 64 mix gained very less compressive strength compared to SCC CM this trend was also observed by (R. Saleh Ahari et al. 2015 and C.P.Ramesh et al. 2019) and at later ages (28, 56 and 90 days), due to the pozzolonic action of Class C fly ash, the compressive strength of SCC 64 was increased and found to be similar to SCC CM.

2) Tensile strength values of SCC 64 resulted in lesser values and similarly for flexural strength (Vageesh H. P. et.al 2018 and C.P.Ramesh et.al 2019) in comparison with SCC CM at 28 days and 56 days, respectively this may be due to increase in the volume of fly ash at 40% of total cement content .

3) Young's modulus of SCC 64 mixes were relatively less in comparison with SCC CM mixes due to the incorporation of mineral admixtures, and the same was observed in literatures of (Mucteba Uysal et al., Vageesh H. P. et al., 2018 and C.P.Ramesh et al., 2019)

4) Alkaline exposure resulted in negligible weight loss and acid exposure resulted in significant weight loss for SCC CM mix when compared with SCC 64 mixes, due to the action of sulphuric acid (Seyed Mahmoodreza Joorabchian et al., 2010, Vageesh H. P. et al., 2018 and C.P. Ramesh et al., 2019).

5) SCC 64 mixes resulted in relatively better and adequate compressive strength values when compared to SCC CM after exposure to acid and alkaline environment same observations made in literature (Vageesh H. P. et al., 2018 and C.P. Ramesh et.al, 2019)

6) Incorporation of larger volume of Class C Fly ash was durable in terms of permeability values. The water penetration depths was within acceptable range as specified in DIN 1048 and the same trend was noted by (L.A. Pereira-de-Oliveira et. al. 2014 Vageesh H. P. et al., 2018 and C.P. Ramesh et.al, 2019)

7) Incorporation of Processed Slag Sand resulted in relatively higher chloride permeability for SCC 64 mixes showed then compared with other two mixes SCC CM, SCC 73; and lesser than SCC 55, and this trend was also recorded by (R. Saleh Ahari et al, 2015, Vageesh H. P. et al., 2018 and C.P. Ramesh et.al, 2019)

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