E-ISSN 2581 – 7957
P-ISSN 2277 – 3916

CVR Journal of Science and Technology, Volume 23, December 2022
DOI: 10.32377/cvrjst2302

Strength and Durability Studies on Lightweight Self-Compacting Concrete Partially Replacing Coarse Aggregate with Sintered Fly Ash Aggregate

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Abstract: **This paper investigates the strength and durability studies on lightweight self-compacting concrete partially replacing coarse aggregate with sintered fly ash aggregate, with different grades of concrete. (M20, M30 and M40). In this study, the rational mix design procedure for self-compacting concrete is used. The present study consists of two phases. In the first phase, SCC mixes for different grades are developed without using lightweight aggregates. The second phase of the study introduces lightweight aggregates (i.e Sintered fly ash aggregates) varying in sizes from 8mm-12mm partially replacing coarse aggregate in self-compacting concrete. Compressive strength, split tensile strength and flexural strength and durability studies were conducted. The test results indicate significant improvement in the strength properties of self-compacting concrete by the inclusion of sintered fly ash aggregates as a partial replacement for natural aggregates.**

Index Terms: **Self-compacting concrete, Sintered fly ash aggregates, Lightweight Concrete, Lightweight self-compacting concrete, Durability.**

I. INTRODUCTION

Self-compacting concrete is defined as Concrete which can flow under its self-weight and fill the formwork in completely, even in the presence of dense reinforcement, without using any vibration actions, maintaining homogeneity [1-5]. It was first developed in Japan, to overcome the problems caused by a lack of complete and uniform compaction through vibrators. Self-compacting concrete is not affected by the shape and quantum of reinforcing bars or the enactment of a structure. Due to its high property of flowing, it is easily a changeable quality and resistant to segregation [6].

Usually, chemical admixtures such as hi-range water reducers (Super Plasticizer) and Viscosity Modifying Agents, which change the rheological properties of concrete are used. Mineral admixtures are used as an extra fine material besides cement [7-10]t. In this study cement content was partially replaced with mineral admixture, i.e., fly ash. Admixtures improve the flowing and strength and durability properties of concrete [11-18].

Significance of study:

India produces approximately 120 million tons of fly ash annually; this fly ash is coming from thermal power plants as a by-product and the main challenge faced by the thermal plants is the safe disposal of this fly ash. In the construction industry, we use large-scale usage of concrete. In the making of concrete, we use natural aggregates as the ingredients in the form of coarse aggregates, which leads to natural imbalance and depletion of natural sources of rocks and hills. To overcome this problem, the best solution is to use the various engineering by-products in the manner of sustainable development. From this point of view, the idea of sintered fly ash aggregates comes in. Using these sintered fly ash aggregates produces the concrete lightweight which makes the concrete economical and lightweight.

The usage of lightweight aggregate i.e, sintered fly ash aggregates in self-compacting concrete gives lightweight self-compacting concrete which produces both benefits of lightweight which reduces the weight of concrete in comparison with conventional concrete and the benefits of self-compacting concrete.

II. LITERATURE REVIEW

Anitha J, Pradeepa S, Lalit Soni, Rakshit KB (2016)

Studied that superplasticizers are the most important admixtures enhancing concrete performance. The development of new superplasticizers during the last decades has determined the most important progress in the field of concrete structures in terms of higher strength, long durability, lower shrinkage and safer placement, particularly in elements with very congested reinforcement. The progress from sulphonated polymer to polycarboxylate has resulted in higher water reduction at given workability and lower slump loss. More recently poly-functional superplasticizers have been developed which are able to completely keep the initial slump for at least 1 hr. without any retarding effect on the early strength. Moreover, multi-purpose and poly-functional superplasticizers have been

Received on 09-08-2021, Revised on 18-10-2022, Accepted on 30-10-2022.

invented which are able to reduce drying shrinkage. The recent progress of superplasticizers was examined in this paper.

Megha H Patel1, Nandan H Dawda (2017)

The development of self-compacting concrete started in Japan in the middle of 1980s with an aim to reduce durability problems in complicated and densely reinforced concrete structures due to lack of skilled labour and poor communication between the designer and the construction engineer. The concept of Self-compacting concrete (SCC) was proposed for the first time by Prof. Hajime Okamura (1997), but the prototype was first developed in 1988 in Japan by Professor Ozawa (1989) at the University of Tokyo. The last few decades is considered to be the era of self-compacting concrete and thousands of research has been carried out. In India, the development of concrete possessing self-compacting properties is still very much in its initial stages. Over the past couple of years, few attempts have been made, still the cost of production of such concrete is a challenging issue for the present concrete engineers. Hence, in the present paper, an attempt is made to understand the effect of various types of mineral and chemical admixture (Rice husk ash, Metakaolin) on the properties of SCC concrete with the cost-by-benefit analysis for the same. It is basically an attempt to sum up the effect of various ingredients on concrete.

Manu S. Nadesan, P. Dinakar (2021)

In this paper, the authors explained how lightweight aggregate concrete differs from normal concrete and the various properties of sintered fly ash aggregates. Fly ash is a waste material which generates twin problems of discarding as well as environmental degradation, due to its nature of causing air and water pollution on a large scale. Nearly145 coal-based thermal power stations in India are producing over 184 million tons of fly ash per year out of which only 56% was utilized effectively and the remaining is still a concern to the community. Therefore, the manufacture of sintered fly ash lightweight aggregate is an appropriate step to utilize a large quantity of fly ash in concrete. However, the non-existence of worthwhile technology to produce sintered fly-ash lightweight aggregates and the absence of a market has deterred Indian entrepreneurs from producing sintered fly-ash aggregate. Recently a couple of industry players in India have focused their attention on the development of sintered fly ash lightweight aggregates commercially on a large scale from the fly ash obtained from their captive power plants. As such, there is no Indian standard available for lightweight aggregates. More recently, pilot studies by the authors have established that this material displays substantial potential for use in structural concrete. The lightweight aggregates manufactured with fly ash are light due to the presence of air voids and these voids are responsible for their absorbency. This absorbency plays a significant role in the mix design and also in the performance of the concrete. The absorption caused by the lightweight aggregate is mainly responsible for the difficulty during the production of lightweight aggregate concrete (LWAC) in practical situations. Porous lightweight aggregates have become highly sensitive as the w/c ratio varies. The moisture content during the mixing stage state is a major concern for LWAC. The North American approach is to use the LWA in a saturated state; contrary to this, the Norwegian approach prefers dry LWA having a moisture content of less than 8%. The problems associated with the variation in the moisture content with pre-soaked LWA can be nullified using dry LWA and the reduction in fresh mix density is an added advantage in this procedure. By considering the cost of production and the improved durability properties it was suggested to use the aggregates in the dry state. Also, there is no appreciable difference in the workability and compressive strength between the concrete using air-dried and pre-soaked aggregates if the water absorption is compensated by additional water during mixing. The mix design of SLWAC is more complex than that of normal concrete as more design parameters such as absorbed water during the mixing of concrete and proportioning of different aggregate sizes etc. are needed to be determined. Taking this into account, a simplified design method is required to produce SLWAC made with natural sand. Presently due to the lack of proper mix design procedures, the developed concrete is poor in structural performance and therefore the use of sintered fly ash lightweight aggregates has been limited to non-structural elements. Till now no reliable study has been made to determine the water absorbed by the porous aggregate during concrete mixing. In the earlier methods, the absorbed water was determined by completely immersing the aggregates in water for a specified time. Also, combined aggregate grading is missing from all the available methods. The main objective of this paper is to suggest a simple and reliable mix design method to the community to bridge the existing gap. Consequently, this study examines the development of LWAC and evaluates the performance of these concretes through proper experimental investigations. The outcome of these investigations on fly ash lightweight aggregate specifies that one can suppose not only the environmental protection through recycling of waste resources but also the reduction in dead load and enhancement of some of the matured concrete properties.

III. RAW MATERIAL

A.Cement

The majority of concrete is mostly made of cement. In this experiment, common Portland cement (53 Grade per IS: 8114-1978) [19] was used.

B. Aggregate

For this study, aggregate that complies with IS: 383-1970 [20] (coarse and fine aggregate) was employed. We employed angular coarse aggregate with a size range of 10 mm to 8 mm and fine aggregate passing through 4.75 mm. In SCC, coarse aggregate content is typically the bare minimum.

C. Fly Ash

In this study, FA was added as a mineral additive. Fly ash is nothing more than the byproduct of burning powdered coal. Fly ash proves the use of IS: 3812 [20].

D. *Super plasticisers*

In this study, CONPLAST SP430, a tool for enhancing concrete workability, is utilized.

E. *Water*

The most crucial component of concrete is water, which aids in tying together the cement and particles.

F. *Sintered fly ash aggregates*

The different size fractions of sintered fly ash aggregates (2–4 mm fraction, 4–8 mm fraction and 8–12 mm fraction) were taken as coarse aggregates

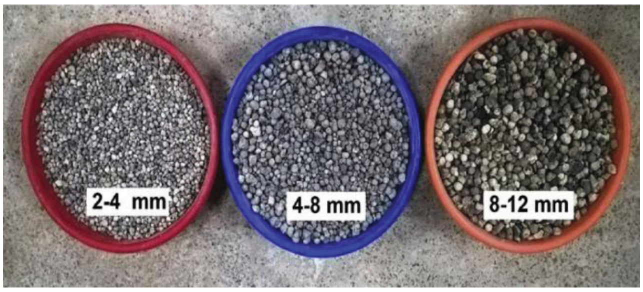


Figure 1. Sintered fly ash aggregates.

TABLE I.
PHYSICAL PROPERTIES OF SINTERED FLY ASH AGGREGATES.

Property	Cement	Fine Aggregate	SFA Coarse Aggregate 8-12 mm	Coarse Aggregate 10-12 mm
Consistency	32%	-	-	-
Initial setting time (Minutes)	60	-	-	-
Specific gravity	3.15	. 2.52	1.764	2.66

IV. TESTS AND METHODOLOGY

Slump Flow Test and $T_{50\ cm}$ Test:

Self-consolidating concrete should have the following properties in its fresh state: flowability, filling ability, and segregation resistance ability [21-23]. The suggestions made in EFNARC (2005) were used in this study to evaluate the qualities of LWASCC in its fresh form. The fresh LWASCC's slump-flow, time to attain 500 mm of slump-flow, and passing ability (confined flowability) utilizing L-box (H2/H1) were all assessed immediately after mixing. After 60 minutes (slump-flow and T500) and 80 minutes, the tests were repeated (L-box). The degree of mixture segregation was evaluated using the visual stability index (VSI). Following the slump-flood test, the concrete mixture is visually inspected by looking at how the coarse aggregate is distributed throughout the concrete mass, how the mortar fraction is distributed, particularly around the perimeter, and how the concrete is bleeding. There are four stability classes, each of which is assessed by a visual inspection (ACI 237R-07:2007) Gołaszewski & Szwabowski, 2011) [24].

The slump flow test is used to find the free flow of the self-compacting concrete without obstructions. $T_{50\ cm}$ is also an indication of SCC flow. A lower time means greater flow ability. The research suggested a time of 2-5 seconds for general civil engineering applications [25].
Slump flow Apparatus

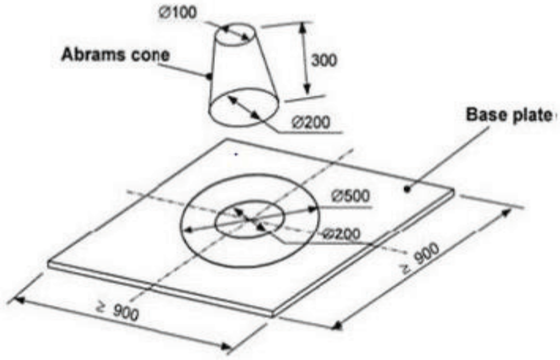


Figure 2. Slump Flow Test

V-Funnel Test

- This V-Funnel apparatus is used to find the viscosity of self-compacting concrete.
- In this test the time required to empty a V-Funnel is observed. shorter flow time indicates a greater flow ability
- Test conducted in our laboratory, the time of emptying the V-funnel is 8-seconds.

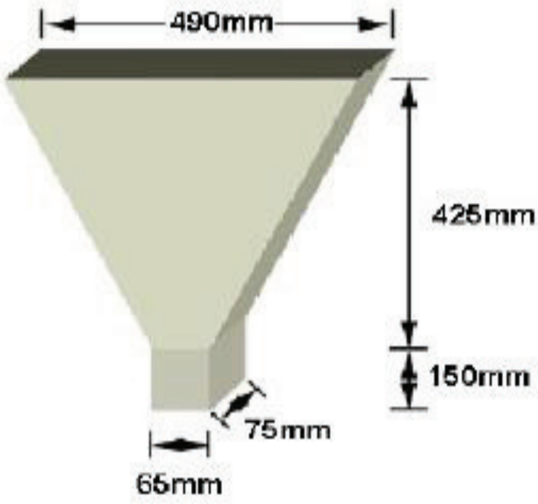


Figure 3. V-Funnel Apparatus

L-Box Test

This method used a test apparatus consisting of a vertical section and a horizontal through into which the concrete is allowed to flow when the releasing of the trap door from the vertical section passes through reinforcing bars.

The time that takes the concrete to flow into the horizontal section is measured. And we have to take the heights of both ends of the apparatus values (H1 & H2). The L-Box test gives an indication of the filling ability and passing ability of the SCC [26-30].

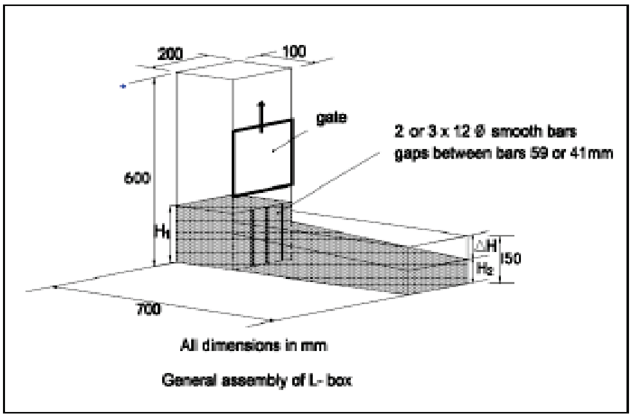


Figure 4. L-Box Apparatus

V. RESULTS AND DISCUSSION

TABLE II.
FRESH AND HARDENED PROPERTIES OF SCC

Grade of Concrete	Fresh properties			Hardened Properties Comp.Strength(N/mm²)	
	T50cm (2-5) sec	V-Funnel (6-12) sec	L-Box (0.8-1)	7 Days	28 Days
M20	4	7	0.88	15.10	24.52
M30	5	8	0.89	23.47	35.16
M40	5	9	0.89	28.88	46.33

TABLE III.
COMPRESSIVE STRENGTH OF SINTERED FLY ASH AGGREGATES SCC.

Grade of Concrete	Percentage Replacement (%)	Hardened Properties Comp.Strength(N/mm²)	
		7Days	28Days
M20	10	14.76	26.92
	20	15.52	25.36
	30	16.66	26.10
	40	15.93	25.52
M30	10	22.8	35.99
	20	23.4	34.65
	30	24.4	34.41
	40	22.9	33.46
M40	10	26.66	44.23
	20	26.85	44.98
	30	28.87	46.52
	40	26.23	45.23

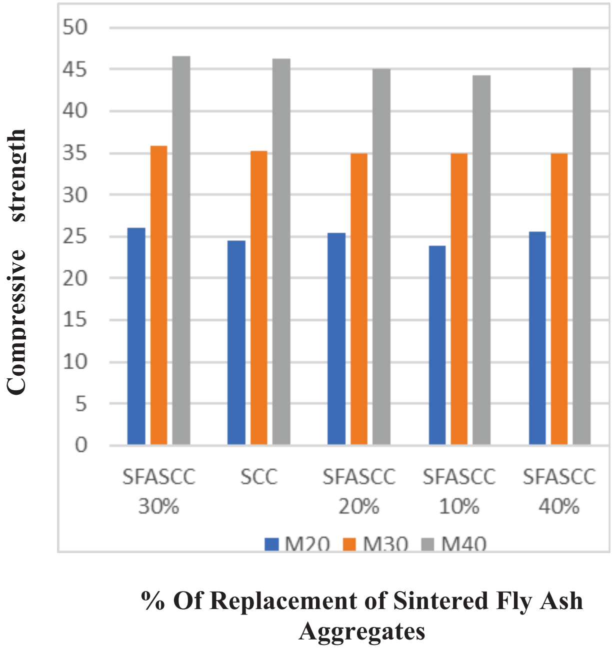
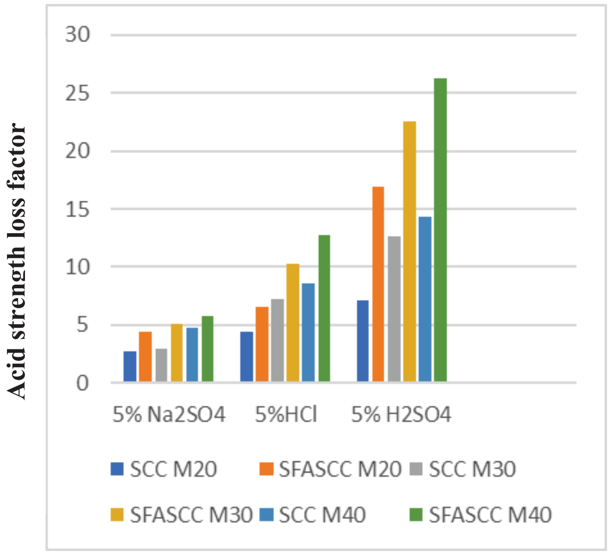


Figure 5. Variation of Compressive Strengths for SCC and SFASCC for 28 days

In this study, more compressive strength was obtained at 30% replacement of coarse aggregate by Sintered fly ash aggregates i.e., 6%, 2% and 1% for M20, M30 and M40 grades respectively at 28days.

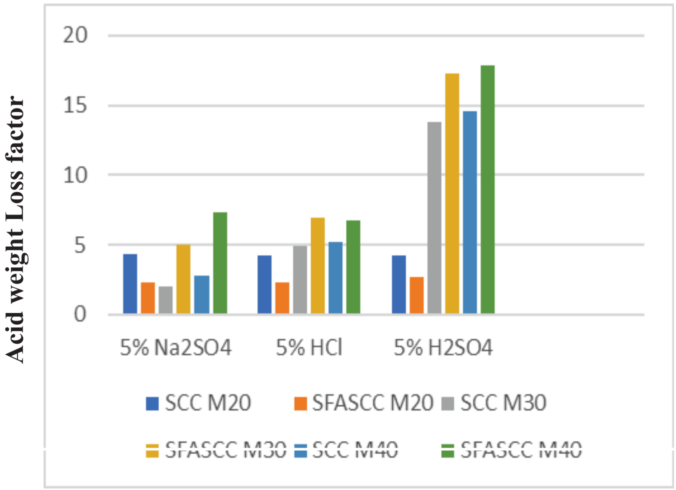
Studies on the durability of SCC and SFASCC

- In the first and second phase investigations were carried out to develop different SCC mixes of different grades of concrete i.e., M20, M30 and M40 using fly ash and chemical admixtures, and to study its fresh and hardened properties.
- In the Investigations at 30% replacement, we got good results. so a durability test was done on 30% replacement sintered fly ash aggregate cube specimens.
- In this investigation the cube specimens were immersed in the chemicals of 5% concentration of Na_2SO_4, HCl and H_2SO_4 solutions in the lab. For the period of 28days and 56days.
- After 28days and 56days the cube specimens were tested.
- In this test results the cube specimens which are immersed in H_2SO_4 are more affected in compressive strength, Weight loss and also in the Dimensions of specimens. Compared with Na_2SO_4, HCl Solutions.
- The Acid Strength Loss Factor, Acid Attacking Factor, Acid Weight Loss Factor and Acid Durability Loss Factor are observed more in the H_2SO_4 solution at 28days and 56days of age.



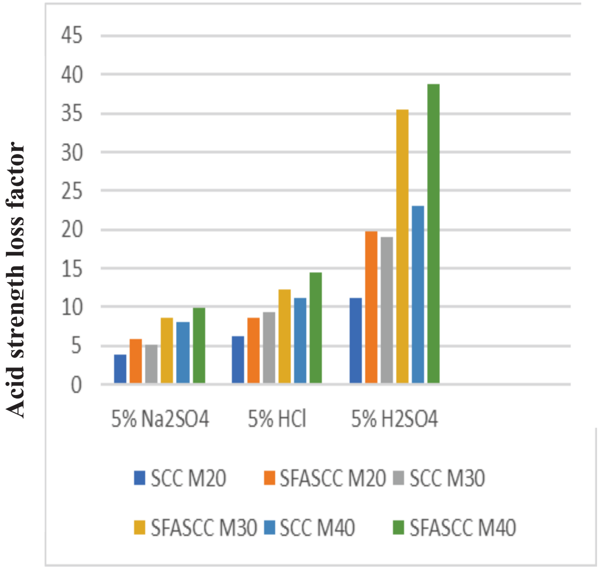
Type of acid with various grades of concrete at 28days

Figure 6. Acid Strength Loss Factors (ASLF) for SCC and SFASCC at 28 Days



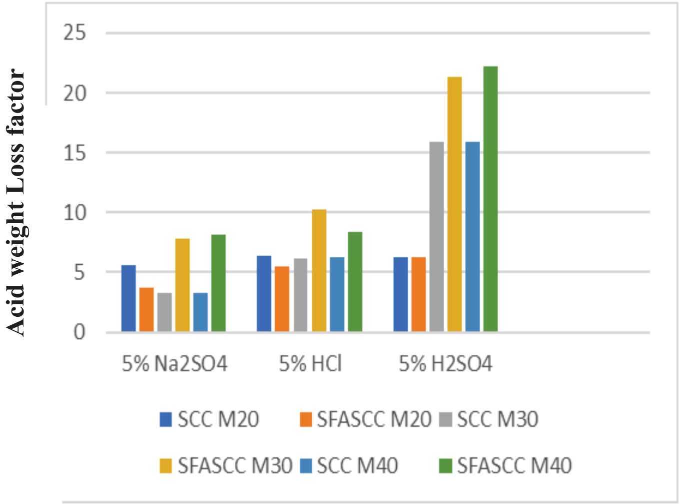
Type of acid with various grades of concrete at 28days

Figure 8. Acid weight loss factors (AWLF) for SCC and SFASCC at 28 days of immersion



Type of acid with various grades of concrete at 56days

Figure 7. Acid Strength Loss Factors (ASLF) for SCC and SFASCC at 56 Days



Type of acid with various grades of concrete at 56days

Figuren 9. Acid weight loss factors (AWLF) for SCC and SFASCC at 56 days of immersion

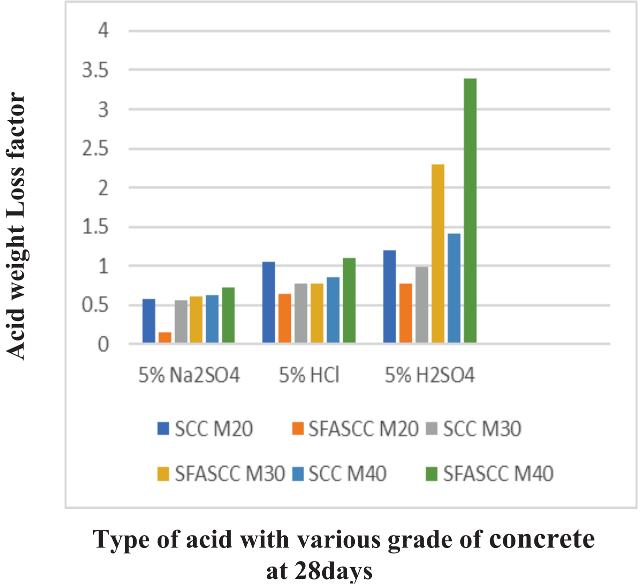


Figure 10. Acid Attack Factors (AAF) on diagonal length in % loss @28days

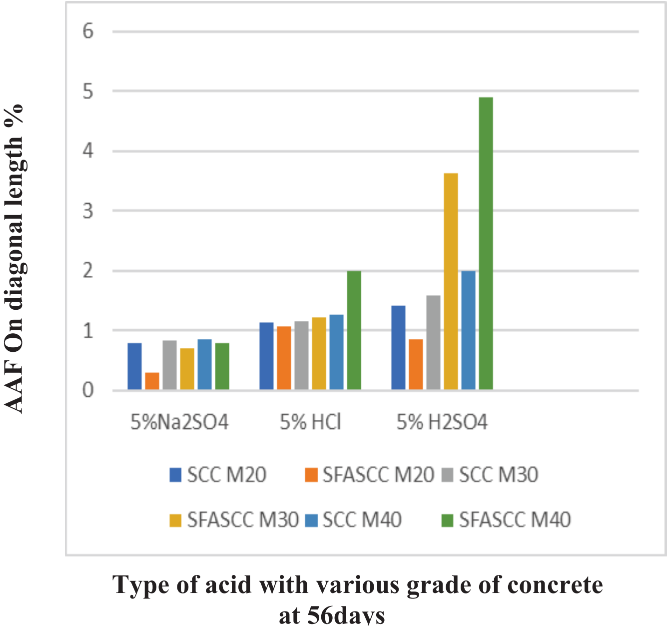


Figure 11. Acid Attack Factors on diagonal length in % loss @56days

VI. CONCLUSIONS

Based on the experimental work conducted on SCC mixes of different grades (M20, M30, M40) the following conclusions are made regarding the properties and behaviour of concrete on partial replacing Coarse aggregate by using Sintered fly ash aggregates and aim to study the strength and durability properties. The following specific conclusions are drawn from this experimental study:

1. Disposal of fly ash in structural landfills can hence be minimized thereby reducing air pollution and unhygienic environmental conditions in particular locations.
2. In this study, more compressive strength was obtained at 30% replacement of coarse aggregate by Sintered fly ash aggregates i.e, 6%,2% and 1% for M20, M30 and M40 grades respectively at 28days.
3. Split tensile and flexural strength increases with an increase in the percentage of Sintered fly ash aggregates and thereafter it decreases. In the Investigations at 30% replacement, we got good results. so a durability test was done on 30% replacement.
4. The percentage loss of compressive strength, weight, diagonal shape and dimensions of Cube specimens are more affected by 5 % H_2So_4 solution at the age of 28days, and 56days. when compared to HCL and Na_2SO_4. So, the durability of concrete is more affected by H_2SO_4.
5. By the investigation it is observed that In the H_2SO_4 solution the strength loss is 11%,23%, and 24% more compared with the HCL solution and 14%,27%, and 28% more compared with the Na_2SO_4 Solution for M20, M30 and M40 respectively.
6. The weight loss in H_2SO_4 Solution is 3%,13%,14% more compared with Na_2SO_4 Solution and 1%,11%,14% more compared with HCL solution for M20, M30 and M40 respectively.
7. The percentage dimension change in H_2SO_4 Solution is 0.7%,6%,7% more compared with Na_2SO_4 Solution and 0.3%,5%,6% more compared with HCL solution for M20, M30 and M40 respectively.
8. Use of Sintered fly ash aggregates in concrete reduces the disposal problems of by-products (fly ash) which is produced by thermal power plants.
9. Sintered fly ash aggregate concrete density achieved is 1705kg/m^3 and whereas conventional aggregate self-compacting concrete density is 2400kg/m^3 reduces the self-weight of the concrete in various structural elements thereby reducing the load on foundations and can reduce in cross-sectional dimensions of structural elements.

REFERENCES

[1] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955.

[2] Ouchi M. and Okamura H. “Effect of Super Plasticizer on Self-Compact ability of Fresh Concrete Journal of the Transportation Research Board 1997 pp37-40.

[3] Gao Peiwei, Deng Min and Feng Naiqui: “The Influence of SP and Superfine Mineral Powder on the Flexibility, Strength and Durability of HPC. Cement and Concrete Research. 2000, Vol.31, pp703-706.

[4] Raghuprasad P. S. et. al. “Comparative Study on Different types of Blended Cement with Different Grade O.P.C Concrete – An Experimental Approach”, ICACC-2004. Proceedings of International Conference on Advances in Concrete and Construction. 16-18 December 2004, Hyderabad, Vol.II, pp637- 646.

[5] Nan Su, Kung-Chung Hsu, His-Wen Chai “A Simple Mix Design Method for Self-Compacting Concrete” Journal of Cement and Concrete Research 31(2001) pp 1799-1807.

[6] Seshadri Sekhar.T, Sravana. P and Srinivasa Rao. P, “Some Studies on the Permeability Behaviour of Self-Compacting Concrete” AKG Journal of Technology, Vol.1, No.2.(2005

[7] S Venkateswara Rao, M V Seshagiri Rao, D Ramaseshu, P Rathish Kumar "A Rational Mix Design Procedure for Self-Compacting Concrete" 2010.

[8] Naik et al, Rafat Siddique, Yogesh Aggarwal, Pratibha Aggarwal, ElHadj Kadri, Rachid Bennacer, "Strength, durability, and micro-structural properties of concrete made with Foundry Sand (FS)'', Construction and Building Materials,2011, Vol. 25, pp. 1916–1925.

[9] AndEnad Mahmoud, Ahmed Ibrahim, Hassan El-Chabib, and Varun Chowdary Patibandla "Self-Consolidating Concrete Incorporating High Volume of Fly Ash, Slag" International Journal of Concrete Structures and Materials Vol.7, No.2, pp.155–163, June 2013.

[10] Arvind Kumar, Dilip Kumar "Use of Sintered Fly Ash Aggregates as Coarse Aggregate in Concrete" SSRG International Journal of Civil Engineering (SSRG-IJCE)– volume1issue4 September 2014.

[11] M.K Dipti Kanta Rout, Rinkan Rohit Jena "Investigation on the Development of Light Weight Concrete with Sintered Fly Ash Aggregate and Activated Fly Ash in Blended Cement" International Journal of Engineering Research & Technology Vol. 4 Issue 04, April-2015.

[12] Pankaj Dhemla, B L Swami and Prakash Somani "Experimental Investigation of Light Weight Concrete Using Sintered Fly Ash Aggregates" ICSEEGT 2021.

[13] Manu S. Nadesan, P. Dinakar "Mix design and properties of fly ash waste lightweight aggregates in structural lightweight concrete"

[14] Dr.M.Vijaya Sekhar Reddy, Dr. M.C. Nataraja, K.Sindhu ,V.Harani and K.Madhuralalasa "Performance of Light Weight Concrete using Fly Ash Pellets as Coarse Aggregate Replacement" International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 9, Number 2 (2016).

[15] S.Renuka, S. Viveka "Study of strength characteristics of fly ash aggregates in lightweight concrete" International Journal of Engineering Research and Technology.

[16] Durga, C. S. S., Ruben, N., Chand, M. S. R., & Venkatesh, C. (2019, December). Evaluation of mechanical parameters of bacterial concrete. In *Annales de Chimie-Science des Matériaux* (Vol. 43, No. 6, pp. 395-399).

[17] Anirudh, M., Rekha, K. S., Venkatesh, C., & Nerella, R. (2021). Characterization of red mud-based cement mortar; mechanical and microstructure studies. *Materials Today: Proceedings*, *43*, 1587-1591.

[18] Bellum, R. R., Venkatesh, C., & Madduru, S. R. C. (2021). Influence of red mud on performance enhancement of fly ash-based geopolymer concrete. *Innovative Infrastructure Solutions*, *6*(4), 1-9.

[19] Venkatesh, C., Sri Rama Chand, M., Ruben, N., & Sonali Sri Durga, C. (2021). Strength Characteristics of Red Mud and Silica Fume Based Concrete. In *Smart Technologies for Sustainable Development* (pp. 387-393). Springer, Singapore.

[20] Bellum, R. R., Al Khazaleh, M., Pilla, R. K., Choudhary, S., & Venkatesh, C. (2022). Effect of slag on strength, durability and microstructural characteristics of fly ash-based geopolymer concrete. *Journal of Building Pathology and Rehabilitation*, *7*(1), 1-15.

[21] Venkatesh, C., Ruben, N., & Chand, M. S. R. (2020). Red mud as an additive in concrete: comprehensive characterization. *Journal of the Korean Ceramic Society*, *57*(3), 281-289.

[22] Venkatesh, C., Chand, M. S. R., & Nerella, R. (2019, April). A state-of-the-art on red mud as a substitutional cementitious material. In *Annales de Chimie: Science des Materiaux* (Vol. 43, No. 2, pp. 99-106).

[23] Venkatesh, C., Nerella, R., & Chand, M. S. R. (2020). Comparison of mechanical and durability properties of treated and untreated red mud concrete. *Materials Today: Proceedings*, *27*, 284-287.

[24] Venkatesh, C., Nerella, R., & Chand, M. S. R. (2020). Experimental investigation of strength, durability, and microstructure of red-mud concrete. *Journal of the Korean Ceramic Society*, *57*(2), 167-174.

[25] Venkatesh, C., Nerella, R., & Chand, M. S. R. (2021). Role of red mud as a cementing material in concrete: A comprehensive study on durability behaviour. *Innovative Infrastructure Solutions*, *6*(1), 1-14.

[26] Ruben, N., Venkatesh, C., Durga, C. S. S., & Chand, M. S. R. (2021). A comprehensive study on the performance of glass fibres-based concrete. *Innovative Infrastructure Solutions*, *6*(2), 1-11.

[27] Ramanjaneyulu, N., Srigiri, K., & Rao, M. S. (2018). Strength and durability studies on lightweight self-compacting concrete with LECA as partial replacement of coarse aggregate. *CVR Journal of Science and Technology*, *15*, 1-9.

[28] Ramanjaneyulu, N., Rao, M. S., & Desai, V. B. (2019, March). Behavior of Self-Compacting Concrete Partial Replacement of Coarse Aggregate with Pumice Lightweight Aggregate. In *International Conference on Advances in Civil Engineering (ICACE-2019)* (Vol. 21, p. 23).

[29] . Ramanjaneyulu, N., Seshagiri Rao, M V & Bhaskar Desai.,V.Comprehensive Study on Fresh and Hardened Behaviour of Sintered Fly Ash Aggregate based Lightweight Self-Consolidating Concrete in the IJSRD (International Journal of Scientific Research and Development) | Vol. 9, Issue 8, 2021 | ISSN (online): 2321-0613

[30] T. Vijay Kumar, Ramanjaneyulu, N., Flexural Behavior of Self-compacting Concrete Beams Partially replacing Conventional aggregate with Pumice Aggregate CVR Journal of Science and Technology, Volume 22, June 2022