International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

Development of Alkaline Activated High Strength Concrete using Fly Ash - Ground Granulated Blast Furnace Slag - Metakaolin as Binders and Manufacturing Sand as Fine Aggregate

S.Dhavamani Doss, S.Thirugnanasambandam, P.Murthi, K.Poongodi

Abstract: Structures built with normal concrete are fading out from the construction industry due to the development of high strength concrete. The massive structures such as sky scrapers, bridges, tunnels, nuclear plants, underground structures need high strength concrete to withstand the high intensity vertical, horizontal and moving loads etc. The development of high strength alkaline activated concrete will reduce the usage of cement in construction community. Lesser the utilisation of cement will lessen the high emission of carbon dioxide gas into the atmosphere. In this study, high strength concrete using alumina and silica rich materials are made with a mix ratio of 1:1.31:2.22. The water to cement ratio for high strength cement concrete and the alkaline solution to binder ratio for alkaline activated concrete are kept as 0.35. Low calcium fly ash, Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin are used as binders and Manufacturing Sand is used as fine aggregate to made high strength alkaline activated concrete. The high strength alkaline activated concrete tests results are better than the high strength cement concrete.

Key Words: Alkaline activated concrete, Fly ash, Ground Granulated blast furnace slag, High strength concrete, Manufacturing sand, Metakaolin.

I. INTRODUCTION

Nowadays most of the structures are opt to build with higher number of stories to accommodate the vertical space.

Due to the drastic increase in the population all around the world, there is a shortage of horizontal space for the occupancies. In developed countries, the high-rise structures are built as a result of pride and innovations in the development of infrastructure industry. An important aspect of high-rise building is strength. Appropriate strength is essential for a high rise building to withstand several kinds of loads due earthquake, wind, drifting and etc. Based on strength, concrete is classified into normal, standard and high strength concrete. The concrete with characteristic strength up to 20 MPa is known as normal concrete.

Revised Manuscript Received on February 28, 2020.
***** Correspondence Author
S.Dhavamani Doss*, Research Scholar, Structural Engineering Department, Annamalai University, Annamalainagar, India.
S.**Thirugnanasambandam,** Professor, Structural Engineering Department, Annamalai University, Annamalainagar, India.
P.Murthi, Centre for Construction Methods and Materials, Department of Civil Engineering, S R Engineering College, Warangal, India. E.mail:dr.murthi@srecwarangal.ac.in.
K.Poongodi, Centre for Construction Methods and Materials, Department of Civil Engineering, S R Engineering College, Warangal, India.

The concrete with characteristic strength between 20 MPA to 45 MPa is known as standard concrete and the concrete with characteristic strength of 50 MPa and above is known as high strength concrete [1].

In olden days (1950), it was believed that the concrete with 30 MPa is high strength concrete. Later in the 1960, concrete with MPa 40 – 60 MPa is said to be high strength concrete. After 1980, high strength concrete is progressed beyond 100 MPa [2]. However, the concrete with compressive strength of 50 to 100 MPa is still considered as high strength concrete [3]. The production of High Strength Cement Concrete (HSCC) requires raw materials such as cement as binder, river sand as fine aggregate and blue metal as coarse aggregate. The cement is produced by calcination of clay and natural limestone at a very higher temperature. During this process a very higher percentage of carbon dioxide is emitted into the atmosphere. These carbon dioxides emitted from the cement production causes severe air pollution and global warming. Climate change is a serious concern as a consequence of global warming [4] [5].

River sand is a natural source material, which is formed due to the weathering of rocks. This is a very long process and it consumes lot of time. Now, the demand for river sand is very high in construction due to its unavailability. On further utilisation of river sand will cause disintegration of river sand. To reduce the use of river sand, Manufacturing Sand (M-Sand) is used as a replacement for fine aggregate. The high strength alkaline activated concrete is produced by using alumina – silica rich resource material as a binder with filler materials such as fine and coarse aggregate. In alkaline activated concrete Portland cement is fully replaced by materials such as fly ash, Ground Granulated Blast Furnace Slag (GGBS), Metakaolin, rice husk ash and etc. Production of alkaline activated concrete is capable of reducing the use of cement. Since the use of concrete will increase in future, the need of binder will also increase so the use of cement will rapidly increase. To reduce the climate change and global warming, the seven percentage of total carbon dioxide emission from the cement industries [5] should be reduced by replacing cement concrete by alkaline activated concrete.

II. HIGH STRENGTH CONCRETE (HSC)

The achievement of high strength concrete is greatly influenced by Super Plasticizer (SP), mineral admixture, size and shape of coarse aggregate and water to binder ratio. Lesser the ratio of water to binder, higher strength will be achieved. When water to binder ratio is decreased, the workability of high strength concrete will be affected. To achieve good workability proper SP should be used.

This will enhance the HSC mix to achieve strength up to 75 MPa with a water to binder ratio of 0.4. To achieve HSC with compressive strength from 75 to 100 MPa, the water cement ratio must be reduced to 0.25 to 0.30 with addition of SP, mineral admixture and small cubic or rounded shaped coarse aggregates should be used. Silica fume is recommended with high percentage of SP for getting HSC with compressive strength more than 100 MPa. The water to binder ratio is limited to 0.22 to 0.25 [3]. In this study high strength concrete with cement and alkaline activated binder are developed.

A. High Strength Cement Concrete (HSCC)

In HSCC, the part of cement is very important. The amount of binder will greatly influence the strength of the HSCC. Higher amount of cementitious materials will increase the strength of concrete.

At the same time too much of cement content will creates shrinkage cracks in the concrete due to a very higher heat of hydration process. The cement content for HSCC should be in the range 415 to 650 kg/m^3 [6]. All kinds of cements such as Ordinary Portland cement (OPC), sulphate resisting cement, blended cement (partial replacement of cement with fly ash, GGBS, Metakaolin and other pozzolanic materials.

The application of early high strength cement will cause micro pores in the HSCC [7]. The coarse aggregate used in HSCC should be in the size of 10 to 17 mm without flakiness and irregular shapes [6]. Fine aggregate with higher fineness modulus will be optimum for HSCC [7]. The quality of materials should be strictly maintained to get good quality HSCC [8].

B. High Strength Alkaline Activated Concrete (HSAAC)

In HSAAC, alkaline solution is playing a major role and the strength of the HSAAC is depends upon it. The strength of the HSAAC will change with the change in alkaline solution such as molar concentrations, Na_2SiO_3 to NaOH ratio, alkaline solution to binder ratio and etc. The alkaline activated concrete was invented by Dr. Joseph Davidovits, a French scientist in 1978 [9], [10], [11]. In HSAAC, the alumina – silica rich materials are used as binder material. These materials are not readily reacting with water to obtain sufficient bond strength.

So, to activate the binding capability of binders, alkaline solution is added to the binder materials. Hence, it is known as alkaline activated concrete. Alkaline activation process is a three-dimensional polymeric reaction, in which the hardening of alkaline activated concrete is achieved through polycondensation process.

During this process, heat is required to enhance the hardening process. To achieve hardening of HSAAC in ambient temperature, GGBS is added with the fly ash. The alkaline activated concrete is heat resistant and achieve high early strength [11]. In alkaline activation process, polymeric bonds are produced due to the chemical reaction between alumina silicates oxide and alkali poly silicates [12].

III. MATERIAL PROPERTIES

The materials selection process plays an vital role in both HSCC and HSAAC. Inferior materials will affect the strength of concrete mixes. So raw materials for HSCC and HSAAC should be properly collected.

A. HSSC Binder

OPC and Silica fume are used as binder material for HSCC. 53 grade OPC is partially replaced by silica fume to achieve high strength of concrete. The presence of silica fume will not only enhance the strength property but also enhance the workability and durability properties of HSCC [13]. The percentage of silica fume as a partial replacement of OPC is optimum at 10% [14], [15]. Silica fume is in the form of glass obtained as a by-product during the production of ferrosilicon alloys and silicon. It is very small and highly reactive material, which will react with calcium hydroxide and convert it into strong calcium di-silicate hydrate gel. 90% of OPC and 10% of silica fume is used as binder material for making HSCC. Figure 1 and 2 show the OPC and silica fume used as a binder material for HSCC. The specific gravity of OPC and silica fume are 3.15 and 2.25 respectively.

B. HSAAC Binder

Low calcium fly ash (Class F type), GGBS and Metakaolin are used as binder materials for HSAAC. In these three binding materials fly ash and GGBS are obtained as a by-product from thermal power pants and steel industries respectively. Metakaolin is obtained by calcination of kaolin clay at temperature between 500º C to 800º C. Proper care should be taken during the process of calcination of kaolin clay [16]. To obtain good quality of Metakaolin, the kaolin clay should properly roast without over burning. Over burning of kaolin clay will converted to non-reactive mullite [17]. The specific gravity of fly ash, GGBS and Metakaolin are 2.15, 2.62, 2.56 respectively. Fly ash, GGBS and Metakaolin are silica - alumina rich materials and are suitable as binders for HSAAC. Figures 3 to 5 show the binder materials used for HSAAC.

C. Fine Aggregate

Usually river sand is used as fine aggregate for making concrete. In this study, M-Sand is used as a replacement for river sand. M-Sand. M-Sand is obtained from crushing and grinding of granite stones. The advantageous of M-Sand production using modern equipment is, the size and shape of the M-Sand can be controllable. Cubical and well graded M-Sand can be produced using modern crusher. To achieve good quality of M-Sand with economically less price, VSI crusher should be used [18]. M-Sand will enhance the quality of HSCC and HSAAC, since it is well graded and free from impurities such clay, chlorides and etc. The specific gravity of M-Sand is 2.70 with a fineness modulus of 2.91. M-Sand chosen for this study confirming Zone II of IS 383-1970 [19]. Figure 6 shows the M-Sand used as fine aggregate for HSCC and HSAAC.

D. Coarse Aggregate

For HSC concrete, the quality of coarse aggregate is very important.

The coarse aggregate used for making HSCC and HSAAC is crushed granite stone or blue metal. The size of the coarse aggregate is restricted to 10 to 12.5 mm. The specific gravity of crushed granite stone is 2.70 with a fineness modulus of 6.52. Crushed granite stone aggregate is purchased from locally available market and it is confirming IS 2386-1963: IV and V [20], [21].

Figure 7 shows the crushed stone aggregate used as coarse aggregate for making HSSC and HSAAC.

Fig. 1 Ordinary Portland cement

Fig. 2 Silica Fume

Fig. 3 Fly Ash

Fig. 4 GGBS

Fig. 5 Metakaolin

E. Alkaline Solution

Alkaline solution or activator solution is a mixture of sodium or potassium silicate solution and sodium hydroxide or potassium hydroxide solution. In this study sodium based alkaline solution is prepared. The vital role of alkaline solution is to activate the binding capability of binder materials. The ratio of sodium silicate solution to sodium hydroxide solution is kept as 2.5. The molarity of the alkaline solution is kept as 16 M. The strength of alkaline activated concrete is greatly influenced by the concentration of the solution [22]. To achieve HSAAC, alkaline solution with higher concentration is prepared. Figure 8 to 9 shows the alkaline solution used for mixing HSAAC. The alkaline solution should be prepared 24 hours prior to casting of HAAAC.

F. Water

Potable water is used for mixing of HSCC mixes. Water should be free from chemicals such as chloride, sulphate and etc.

G. Super Plasticizer (SP)

For making HSC, the role of SP is very significant. HSC is achieved by lowering the solution to binder ratio. With lower ratio 0.35 it is difficult to achieve workability. So, the use of proper water reducing SP compulsory for HSSC and HSAAC. The specific gravity of SP is 1.08 and it is modified Ligno Sulphonate (MLS) based SP with pH value of 6 and the colour of the SP is dark brown and the SP chosen is confirming to IS 2645-2003 and IS: 9103 – 1999.

IV. MIX PROPORTIONING OF HSCC AND HSAAC

High strength concrete for characteristic strength of 60 MPa is arrived with a mix ratio of 1: 1.31: 2.22 for both HSCC and HSAAC mixes. The water to binder ratio for HSCC and alkaline solution to binder ratio for HSAAC is kept as 0.35. The Table 1 shows the mix proportions of HSCC and HSAAC. Totally five HSC mix proportions are arrived namely High Strength Cement Concrete (HSCC), High Strength Alkaline Activated Concrete with zero percent Metakaolin (HSAAC0), High Strength Alkaline Activated Concrete with 60 % GGBS, 35% fly ash and 5 % Metakaolin (HSAAC5), High Strength Alkaline Activated Concrete with 60% GGBS, 25 % fly ash and 15% Metakaolin (HSAAC15) and High Strength Alkaline Activated Concrete with 60% GGBS, 15 % fly ash and 25% Metakaolin (HSAAC25). Table 2 shows the percentage of binder and filler materials in the mix proportions of HSSC and HSAAC.

Fig. 6 M-Sand

Fig. 7 Crushed Granite Stone Aggregate

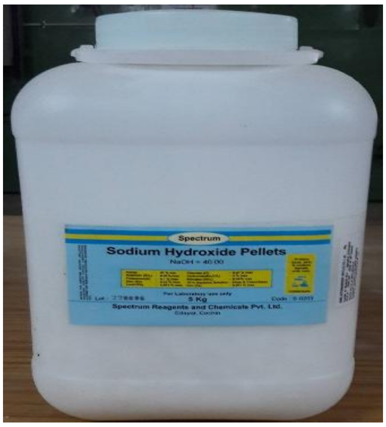

Fig. 8 Sodium Hydroxide

Fig. 9 Sodium Silicate

A. Casting and Curing of HSCC and HSAAC

Casting of HSCC, OPC and silica fume are completely mixed. Then M-Sand is mixed with binders until uniform mixing is obtained. After that coarse aggregate is mixed with the dry mortar for 2 to 3 minutes. Then 70 % percentage of water is added to the dry mixture and mixed for 2 minutes and finally, in remaining 30% water add SP and stir well to achieve uniform dispersion of SP in water. Then the SP with water is mixed with the wet concrete matrix for 3 minutes. After completion of mixing of HSCC, the fresh HSCC is poured into the cube steel mould of area 10000^2. The HSCC in cube moulds are kept 24 hours in room temperature and then de-moulded. The de-moulded HSCC concrete cubes are immersed in water for curing for 28 days. Casting of HSAAC, GGBS, fly ash and Metakaolin are thoroughly mixed. Then M-Sand is added to the binder and allowed for dry mixing. Then coarse aggregate is added to the dry mortar mix and mixed for 2 to 3 minutes. Then alkaline solution is added to the dry concrete matrix followed by SP and the mixing is continued for 2 minutes. After mixing the HSAAC is poured into cube steel moulds of area 10000 mm^2. After 24 hours the HSAAC cubes are de-moulded and kept in ambient temperature for 7 days. Figure 10 shows the mixing of HSCC and HSAAC and Figure 11 shows the cast HSCC and HSAAC cubes.

Table 1 Mix Proportioning of HSSC and HSAAC

Materials	High Strength Cement Concrete HSSC (kg/m^3)	High Strength Alkaline Activated Concrete (HSAAC) (kg/m^3)
Binder	500	530
M-Sand	655	694.30
Blue metal	1110	1176.6
Water	175	-----
Alkaline Solution	-----	185.50
Super Plasticizer	5.0	7.95

Table 2 Mix Proportioning of HSSC and HSAAC

HSC Materials	HSCC (%)	HSAAC0 (%)	HSAAC5 (%)	HSAAC15 (%)	HSAAC25 (%)
OPC	90	---	---	---	---
Silica fume	10	---	---	---	---
GGBS	---	60	60	60	60
Fly ash	---	40	35	25	15
Metakaolin	---	---	5	15	25
M-Sand	100	100	100	100	100
Blue metal	100	100	100	100	100
Water	100	---	---	---	---
Alkaline Solution	---	100	100	100	100
Super Plasticizer	1	1.5	1.5	1.5	1.5

Fig. 10 Mixing of HSCC & HSAAC

Fig. 11 Cast HSCC and HSAAC Cubes

V. EXPERIMENTAL INVESTIGATION

A. Compression Strength Test on HSCC and HSAAC

The HSCC cubes are tested for compressive strength after 7, 14 and 28 days using 200-ton capacity compression testing machine. The HSAAC cubes are tested for compressive strength after 7 days. The cubes are placed in the compression testing machine and the uniaxial compression loading is gradually applied on the HSSC and HSAAC cubes until failure occurs. The ultimate compressive loads are noted and from this the compressive strength of cubes are arrived. Figure 12 shows the compressive strength test setup of HSC cubes. The compressive strength test results are given in Table 3.

B. Durability Test on HSCC and HSAAC

Durability of a concrete is a main concern, since deterioration high strength concrete is easily possible to chemical attacks. The concrete is durable material until it is exposed into an aggressive environment [18].

In past decades the strength aspect of concrete only taken into account. Durability is not a concern but now, strength alone is not sufficient to determine the quality of concrete. Strength and durability properties of concrete must consider together to determine the quality of concrete. In this study durability property of HSCC and HSAAC cubes are tested by immersing them in aggressive environment such as sulphate attack and acid attack.

C. Acid Resistant Test

The concrete when exposed to severe acid attack, deterioration of concrete will rapidly increase. The HSCC and HSAAC cubes are immersed in 5 % concentration hydrochloric acid [23] as shown in Figure 13. The concentration of solution is checked and maintained regularly for 56 days. After 56 days immersion of HSCC and HSAAC cubes in hydrochloric acid solution they are tested under uniaxial compression strength test. The test results are given Table 4. The surface of the HSCC damaged higher than the surface of HSAAC.

Fig. 12 Compressive Strength Test Setup of HSC cubes

Table 3 Compressive Strength Test Results of HSCC and HSAAC cubes

Type of specimen	Curing Type	Area of Specimen	Curing period	Average Compressive Strength (MPa)		
				7 days	14 days	28 days
HSCC	Water curing	10000	28	47.99	54.47	69.52
HSAAC0	Ambient curing	10000	7	79.55	---	---
HSAAC5	Ambient curing	10000	7	77.85	---	---
HSAAC15	Ambient curing	10000	7	75.75	---	---
HSAAC25	Ambient curing	10000	7	72.65	---	---

D. Sulphate Resistant Test

The concrete is exposed to sulphate attack through soil. Almost all the soil contains sulphate in the form potassium sulphate, magnesium sulphate, sodium sulphate and calcium sulphate. The solid sulphate is not effectively because damage in concrete compared to sulphate in solution form [18]. They penetrate through pores and cause volume change in concrete.

The HSCC and HSACC cubes are immersed in 5 % concentration sodium sulphate solution [23] as shown in Figure 14. The concentration of solution is checked and maintained regularly for 56 days. After 56 days immersion of HSCC and HSAAC cubes in sodium sulphate solution, they are tested under uniaxial compression strength test. The test results are given Table 5.

Fig. 13 Acid Resistant Test

Fig. 14 Sulphate Resistant Test

Table 4 Compressive Strength Test Results of HSCC and HSAAC Cubes after Acid Resistant Test

Type of specimen	Acid solution	Area of Specimen	Exposure Period	Average Compressive Strength (MPa)	Loss of compressive Strength (%)
HSCC	Hydrochloric acid	10000	56	56.83	18.25
HSAAC0	Hydrochloric acid	10000	56	71.40	10.25
HSAAC5	Hydrochloric acid	10000	56	69.01	11.35
HSAAC15	Hydrochloric acid	10000	56	66.18	12.64
HSAAC25	Hydrochloric acid	10000	56	62.73	13.66

Table 5 Compressive Strength Test Results of HSCC and HSAAC Cubes after Sulphate Resistant Test

Type of specimen	Acid solution	Area of Specimen	Exposure Period	Average Compressive Strength (MPa)	Loss of compressive Strength (%)
HSCC	Sodium Sulphate	10000	56	61.69	11.26
HSAAC0	Sodium Sulphate	10000	56	77.50	2.58
HSAAC5	Sodium Sulphate	10000	56	75.62	2.86
HSAAC15	Sodium Sulphate	10000	56	73.30	3.23
HSAAC25	Sodium Sulphate	10000	56	70.05	3.58

VI. RESULT AND DISCUSSIONS

The HSAAC shows a higher compressive strength than HSCC. There is a slight decrease in the compressive strength of HSAAC with the increase of Metakaolin percentage in the mix. The percentage of binders in the HSAAC mixes for HSAAC0, HSAAC5, HSAAC15, HSAAC25 are GGBS (60%): FA (40%): MK (0%), GGBS (60%): FA (35%): MK (5%), GGBS (60%): FA (25%): MK (15%), GGBS (60%): FA (15%): MK (25%) respectively. The HSCC and HSAAC mixes are proportioned for obtaining high strength concrete with characteristic strength M60 grade.

All the mixes achieved M60 grade. HSAAC0 mix achieved higher compressive strength (79.88 MPa) compared to HSCC, HSAAC5, HSAAC15 and HSAAC25. HSCC mix achieved lower compressive strength (69.52 MPa) compared to all other HSAAC mixes. The compressive strength of HSAAC5, HSAAC15 and HSAAC25 are 77.85, 75.75 and 72.65 respectively. The durability test results for acid resistant test and sulphate resistant test results conveys that the HSAAC cubes exhibits higher resistant than HSCC cubes. The percentage loss in compressive strength of HSSC due acid attack and sulphate attack are 18.25% and 11.26% respectively. The percentage loss in compressive strength of HSAAC due to acid and sulphate attack are lesser than HSCC. The higher compressive strength and higher resistant of HSSAC to chemical attacks are due to the presence of alkaline activated binding materials which makes a strong transition zone by enhancing bond between binders and filler materials in the concrete matrix. The higher concentration of alkaline solution in the HSSAC enhance the binding property and makes a stronger transition zone. The percentage loss in compressive strength due to chemical attack in HSCC is higher than HSAAC because of the presence of calcium hydroxide and other hydrated products in HSCC. The acids are also capable of affecting C-S-H in cement concrete. The sulphates and acids presence in the environment will enter the concrete and causes disintegration to the concrete by means of volume change, expansion and disruption. In HSCC, the sulphates enter the concrete matrix through pores and reacts with Calcium Aluminate Hydrate (C-A-H) to form calcium sulphoaluminate within the framework of hydrated cement paste. This will increase the volume up to 227 % results in gradual deterioration of concrete takes place [18]. In HSAAC, the hardening process is a polymerisation process forming three-dimensional cross-linked Si-O-Al bonds. This will enhance the bond strength and decrease the voids in concrete. The strength and durability properties of HSCC and HSAAC before and after sulphate and acid resistant tests are found and shown in Figures 15 to 20.

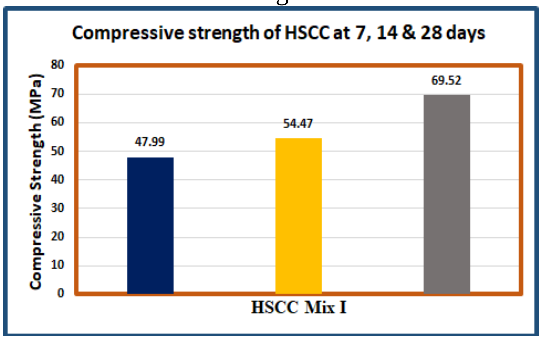

Fig. 15 Compressive Strength of HSCC at 7, 14 & 28 days

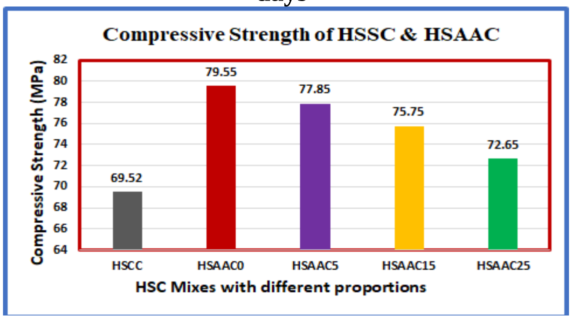

Fig. 16 Comparison of Compressive Strength of HSCC & HSAAC

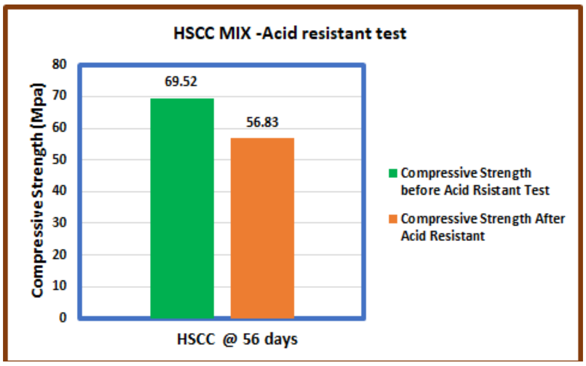

Fig. 17 Comparison of Compressive Strength of HSCC before and after Acid Resistant Test

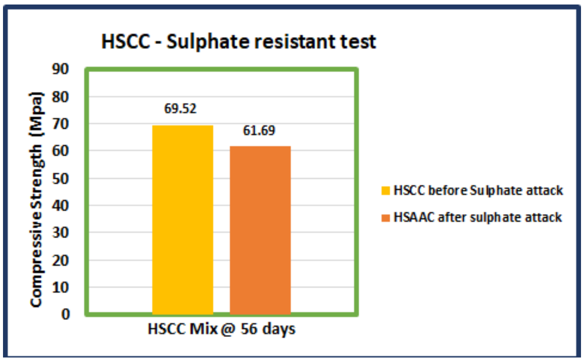

Fig. 18 Comparison of Compressive Strength of HSCC before and after Sulphate Resistant Test

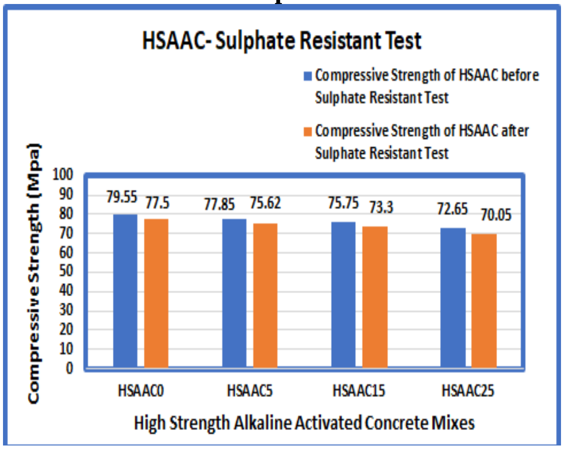

Fig. 19 Comparison of Compressive Strength of HSCC before and after Sulphate Resistant Test

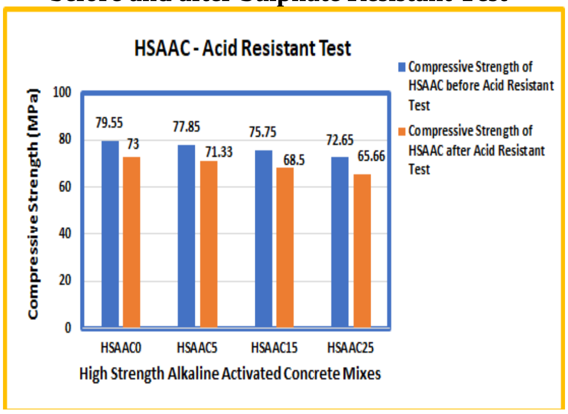

Fig. 20 Comparison of Compressive Strength of HSCC before and after Acid Resistant Test

VII. CONCLUSIONS

The strength and durability aspects of high strength concrete is observed by conducting compressive strength test and chemical resistant tests. Different types of high strength concretes are made such as HSCC with OPC and silica fume as binder, HSAAC with GGBS, fly ash and Metakaolin with different percentages as binder. M-Sand and crushed granite stone are used as fine and coarse aggregate for all types of HSC respectively. The compressive strength of HSCC, HSAAC0, HSAAC5, HSAAC15, HSAAC25 are 69.52, 79.55, 77.85, 75.75 and 72.65 MPa respectively. The increase in the percentage of Metakaolin affects the compressive strength of HSAAC and there is a slight reduction in compressive strength. The presence of silica fume and M-Sand in HSCC attributed to higher compressive strength. Silica fume react with hydrated calcium hydroxide to for additional C-S-H gel. It will enhance the bond strength of transition zone of HSCC. The presence of silica-alumina rich materials and alkaline solution in HSAAC enhance the binding of the concrete and achieves early high strength under ambient curing temperature at 7 days. The higher compression strength of all HSC mixes is also influenced by presence of M-Sand. The M-Sand is well graded and it improves the packing between the binder and filler materials in concrete matrix. Good packing of aggregates will also contribute to improvement in compressive strength. The percentage of loss in compressive strength of HSCC, HSAAC0, HSAAC5, HSAAC15, HSAAC25 due to acid attack are 18.25, 10.25, 11.35, 12.64 and 13.66 percentages respectively. The percentage of loss in compressive strength of HSCC, HSAAC0, HSAAC5, HSAAC15, HSAAC25 due to sulphate attack are 11.26, 2.58, 2.86, 3.23 and 3.58 percentages respectively. There are no major differences in the loss percentages of compressive strength of HSAAC. It is observed that the HSAAC with higher percentage of GGBS and fly ash shows higher compressive strength.

REFERENCES

1. Mohammad Abdur Rashid and Mohammad Abdul Mansur, Considerations in producing high strength concrete, Journal of Civil Engineering (IEB), 37(1) (2009) 53-63
2. P.Murthi, K.Poongodi, P.O.Awoyera, R.Gobinath, R.Saravanan (2019), "Enhancing the strength properties of High-performance concrete using Ternary blended cement: OPC, Nano-silica, Bagasse ash", Silicon, doi: org/10.1007/s12633-019-00324-0.
3. Wu. D, Sofi. M and Mendis. P, High strength concrete for sustainable construction, International Conference on Sustainable Built Environment (ICSBE-2010), Kandy, 13-14 December 2010, PP. 434-442
4. S.Thirugnanasambandam and C.Antony Jeyasehar (2019), Ambient cured geo-polymer concrete products. Lecture noes in civil engineering. 25, pp. 811-828.
5. McCaffrey R (2002) Climate Change and the Cement Industry. Global Cement and Lime Magazine (Environmental Special Issue): 15-19. Available at www.propus.com/gcl2002.
6. A.Sivakrishna, V.Ranga Rao (2019) Strength prediction of Geo-polymer concrete using Fuzzy, International Journal of Recent Technology and Engineering, Vol.7, No.6. pp.668-671.
7. Standard CP 5(BC2:2008), BCA Sustainable Construction Series-3, The education and research arm of the Building and Construction Authority, Singapore 2008. ISBN 978-981-05-9753-5, Website: www.bca.gov.sg/academy, pp.3-104
8. Carrasquillo, R. L. (1985), "Production of High Strength Pastes, Mortars, and Concrete," Very High Strength Cement-Based Materials, Materials Research Society Symposia Proceedings, Vol. 42, pp.151-168.
9. Davidovits J. Chemistry of Geopolymeric Systems, Terminology, Geo-polymer '99 International Conference; 1999 June 30 to July 2, 1999; France; 1999. p. 9-40.
10. Davidovits J, Properties of Geo-polymer Cements, First International Conference on Alkaline Cements and Concretes; 1994; Kiev, Ukraine, 1994: SRIBM, Kiev State Technical University; 1994. p. 131-149.
11. P. Duxson, A. Fernández-Jiménez, J. L. Provis, G. C. Lukey, A. Palomo, and J. S. J. van Deventer, 2007, Journal of materials science, vol. 42, pp. 2917-2933.
12. J. Davidovits, Geopolymers and geopolymeric materials, Journal of Thermal Analysis, vol. 35, pp. 429–441, 1989.
13. T.Ravikumar, A.Sivakrishna, Design and Testing of fly-ash based geo-polymer concrete, International Journal of Civil Engineering and Technology, Vol.8, No.5, 2017, pp.480-491
14. Behnood, A., and Ziaria, H, "Effects of silica fume addition and water to cement ratio on the properties of high-strength concrete after exposure to high temperatures" Cement and Concrete Composites 30(2), 2007, pp. 106-112.
15. Ting, E.S.K., Patnaikuni, I., Pendyala, R.S. and Johanson, H.A., "Effectiveness of Silica Fumes available in Australia to Enhance the strength of Very High Strength Concrete", International conference on The Concrete Future, Kuala Lumpur 1992.
16. Patrick N. Lemougna, Kai-tuo Wang, Qing Tang, U. Chinje Melo, Xue-min Cui, Recent developments on inorganic polymers synthesis and applications, Ceramics International 42 (2016) 15142–15159.
17. Palanisamy Murthi, Paul Awoyera, Palanisamy Selvaraj, Devi Dharsana & Ravindran Gobinath (2008), "Using silica mineral waste as aggregate in a green high strength concrete: workability, strength, failure mode, and morphology assessment" Australian Journal of Civil Engineering, pp. 1-8, DOI: 10.1080 /14488353.2018. 1472539.
18. A.Sivakrishna, V.Ranga Rao (2019) Strength prediction of Geo-polymer concrete using ANN, International Journal of Recent Technology and Engineering, Vol.7, No.6. pp.661-667.
19. IS 383: 2016, Coarse and fine aggregates for concrete - specifications. Third revision. Bureau of Indian standards, New Delhi, India.
20. IS 2386: 1963, Methods of test for aggregates for concrete. Part IV Mechanical Properties. Bureau of Indian standards, New Delhi, India.
21. IS 2386: 1963, Methods of test for aggregates for concrete, Part V Soundness. Bureau of Indian standards, New Delhi, India.
22. Subhash V. Patankar, Yuwaraj M. Ghugal and Sanjay S. Jamkar, Effects of concentration of sodium hydroxide and degree of heat curing on fly ash – based geopolymer concrete.
23. B. Vijaya Rangan,, "Geo-polymer concrete for environmental protection", The Indian Concrete Journal, Special Issue-Future concrete, pp. 41-59, April 2014.

AUTHORS PROFILE

Mr. S.Dhavamani Doss, is a research scholar in the department of civil and structural engineering at Annamalai University. He completed his undergraduate and postgraduate degree in civil and structural engineering at Annamalai University during 20011 and 2013 respectively. His area of interest is geopolymer concrete, behavior of concrete members.

Dr.S.Thirugnanasambantham, working as Professor in Department of Civil and Structural Engineering, Annamalai University. He has more than 30 years of academic experience. He has published more than 90 papers in conferences and journals. Currently, guiding 4 Ph.D research scholars and he is member of doctoral committee member of various universities. His area of interest is Geo-polymer concrete, repair and rehabilitation of structures.

Dr.P.Murthi, working as Professor in Department of Civil Engineering at S R Engineering College, Warangal, Telangana State. He has published more than 50 research papers in indexed journals and conferences. He has 32 years of teaching experience including 12 years of research experience. He guided 5 Ph.Ds and currently 1 Ph.D scholar pursuing Ph.D under his supervision.

Dr.K.Poongodi, working as Professor in Department of Civil Engineering at S R Engineering College, Warangal, Telangana State. She has published more than 10 research papers in indexed journals and conferences. She has 14 years of teaching experience including 6 years research experience.