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ORIGINAL PAPER

A Study on High Strength Geopolymer Concrete with Alumina-Silica Materials Using Manufacturing Sand

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Abstract
High strength concrete is an essential need for construction industry since the importance of the structures are of a deep concern. Concrete is said to be high strength concrete (HSC) when the compressive strength exceeds 55 N/mm^2. Due to the vast infrastructure development around the world, the need for high strength concrete is increasing day by day. Nowadays, in the construction industry the environmental conditions, types of structures, availability of materials and effect of greenhouse gases in the past were not as same as today. The structures built today have to face a lot of challenges to withstand the hysterias effects. Nowadays the infrastructure development increased by constructing innovative structures in the aspects of size and shape. Presently the architects are keen in constructing lean structures to increase the aesthetic looks of the structure. For the construction of such innovative structures, high strength concrete is essential. On the other hand, the availability of the materials for cement concrete and the emission of carbon dioxide to atmosphere due to the production of cement are the serious issues emerging in the construction industries creating major problems regarding environmental safety conditions. This study is mainly concentrated to produce high strength concrete with sustainable materials without cement to find a solution to the above problems. This is achieved by using geopolymer concrete with alumina-silica materials, made up of fly ash, Ground Granulated Blast Furnace Slag (GGBS), Manufacturing Sand (M Sand), crushed stone aggregate and alkaline solution. In this study high strength geopolymer concrete with and without Manufacturing Sand is considered for research and the results obtained are compared with high strength cement concrete with and without Manufacturing Sand. In this study river sand is completely replaced with M Sand. The use of Manufacturing Sand in the concrete contributes to the strength due to its better gradation.

Keywords Alkaline solution · Alumina-silica · Compressive strength · Fly ash · Geopolymer concrete · GGBS · High strength · M sand

1 Introduction

The impact of concrete in the planet earth is tremendous. After the arrival of concrete in the construction field, many unimaginable thoughts became imaginable. The type of dwellings shifted from traditional to modern concepts. Now one step higher, the concrete with high strength came into role around a decade. The concrete is a hardened material used in the construction all around the globe. The amount of usage of concrete is second next to water and is estimated to increase in future [1]. The concrete is said to be High Strength Concrete (HSC) when its compressive strength was 25 MPa during the mid of twentieth century. In 1980 it was 50 MPa. Now around two decades back it is increasing according to the specified projects [2]. The concrete with compressive strength of 40–60 MPa is quiet considered as HSC [3]. Generally the concrete exhibits 55 MPa or higher, and fall under the banner of HSC [4]. The HSC can be produced using all kind of cementitious materials except high early strength cements. Since hydration temperature is quickly increased in concrete using high early strength cement, micro cracks occur due to higher cementitious content [5]. HSC has a high demand and in future the need of HSC will increase due to the infrastructure development. For making HSC, Portland cement is inevitable and need of Portland cement will increase. This will be of main

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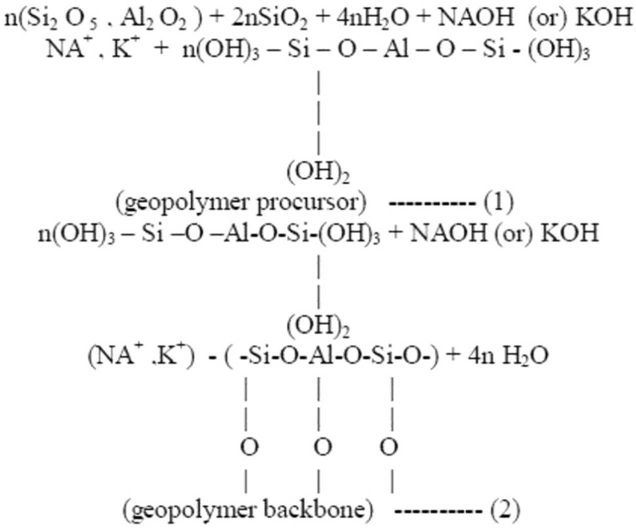

Fig. 1 Polymerisation reaction

concern since most of the carbon dioxide emission is triggered from the production of cement [6, 7]. The production cement also accumulates elevated amount of natural limestone and energy. The production of HSC also need aggregates other than cement as filler materials. River sand is most commonly used as fine aggregate. At current scenario, the availability of river sand is almost in end line. This will kindle the serious issues to the ecosystem. So the need of sustainable materials to produce HSC is adequate to solve the problems blooming due to production of conventional concrete. The main objective of this study is to produce HSC without cement and river sand. Cement and river sand are completely replaced by fly ash/ Ground Granulated Blast Furnace Slag (GGBS) and M Sand. Sustainable concrete with sustainable materials will reduce the igniting problems such as high carbon emission, degradation of natural resource materials nad high energy utilisation. Such a sustainable concrete can be produced using fly ash, GGBS, calcined kaolin with alkaline solution [8, 9].

Fig. 2 Ordinary Portland

Fig. 3 Silica Fume cement

The concrete produced using these materials is known as geopolymer concrete. The geopolymer concrete with calcined source materials possess higher compared to non calcined source materials [10].

2 Geopolymer Concrete

Geopolymer technology was invented and named by a French scientist Dr. Joseph Davidovits in 1978. [11, 12]. The geopolymer binders are the suitable replacement for ordinary Portland cement binders, since the geopolymer binders are far superior in bond strength, early high strength, thermal resistant etc., [13]. Geopolymer reaction is an exothermic reaction consisting of dissolution, orientation and polycondensation [11, 12]. The geopolymerisation is a chemical reaction between aluminosilicates oxide and alkali poly silicate resulting in formation of polymeric bonds [14]. In geopolymer concrete, cement is replaced by silica and aluminium source materials. The strength of the geopolymer is based on the type of source materials used as finder and the molar concentration of the alkaline solution. The geopolymer concrete achieves

Fig. 4 Fly ash

Fig. 5 GGBS

greater strength at an early age. Geopolymer technology is suitable for HSC. The HSC made by geopolymer technology may be called as High Strength Geopolymer Concrete (HSGC). The polymerisation reaction is shown in Fig. 1.

3 High Strength Concrete (HSC)

3.1 Fundamental Requirements for HSC

For making a HSC, there should not be any compromise over quality of the materials, production and execution process [5]. The selection of aggregate plays an essential role in HSC. Crushed aggregate with size of 10–17 mm is optimum for HSC [5]. The fine aggregate with higher fineness modulus may be used [15]. The aggregate should be durable and compatible with the binder. HSC should be highly workable. Suitable super plasticisers should be adopted for obtaining high workability with proper care in adding dosage of super plasticisers. To reduce the shrinkage cracks in HSC, one or more supplementary alumina-silica materials such as fly ash, GGBS, silica fume can be used with cement. The water cement ratio or alkaline solution source material ratio is an important factor which greatly influenced the strength of HSC. Lower the ratio will give additional strength to the HSC [15].

Fig. 6 River Sand

Fig. 7 M Sand

3.2 Applications of HSC

HSC has lot of advantages over normal strength concrete. The application of HSC is wide. HSC is used to build higher buildings, long span bridges, heavy duty industrial floors, foundations for marine structures, reserviours and parking garages. HSC is also used to minimise the size of the columns in tall buildings. HSC is used in the place the high early strength is needed [15].

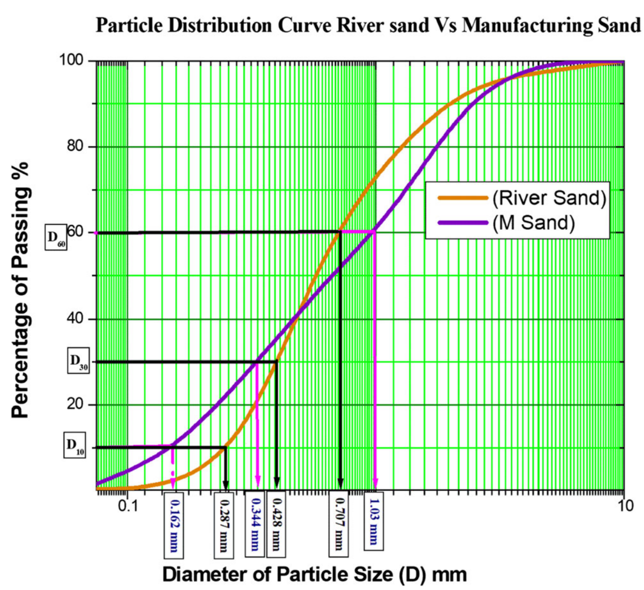

Fig. 8 Particle distribution curve for river sand and M Sand

Fig. 9 Coarse Aggregate (20 mm)

4 Materials

The selection of materials for HSC is based on their availability near the site location. It will make the fresh concrete more workable and good finishing of the concrete [15]. There is no need of special materials for producing HSC but great care should be taken in quality control [16].

4.1 Cementitious Material

Ordinary OPC is used for conventional HSC and Fly ash/GGBS are used for geopolymer HSC. HSC concrete proportioning will accumulate higher cementitious material content. In high strength concrete, the amount of cement is consumed in between 415 to 615 kg/m^3 [15]. In this study high strength

Fig. 10 Coarse Aggregate (10 mm)

Fig. 11 Constituents of Alkaline Solution

concrete with OPC and fly ash/GGBS is tried for developing HSC. 80% of cement and 20% of silica fume are used for making High Strength Cement Concrete (HSCC). Silica fume is a very fine non crystalline by-product obtained from the production of ferrosilicon alloys in smelters. The process of production of silica fume requires an electric arc furnace [17]. The specific gravity of silica fume is 2.2. Silica fume is added with OPC to enhance the strength of HSCC. 50% of fly ash and 50% of GGBS are used for making HSGC. OPC 53 grade cement was chosen for making HSCC. The specific gravity of cement is 3.15. Fly ash is obtained from Mettur power plant. Fly ash is obtained as a result of coal burning to produce electricity. Abundant quantity of fly ash is available in India. The specific gravity of fly ash is 2.1. GGBS is obtained as a by-product during the manufacturing of steel. It is obtained by quenching process. The specific gravity of GGBS is 2.65. GGBS is added in the HSGC to improve the early strength and the binding property. Figures 2, 3, 4, and 5 show the cementitious material used for making HSCC and HSGC.

4.2 Fine Aggregate

Fine aggregates used for making HSCC and HSGC are same. Locally available river is mostly used for making all type of concrete. The availability of natural river sand is inadequate now. The need for fine aggregate will increase till the need of concrete is essential for developing the infrastructure. In this study, HSC concrete is tried with river sand and with M Sand. The M Sand has various advantages than river sand. M Sand is manufactured in industries. This will enhance the properties of M Sand whereas river sand is formed by the weathering of parental rocks. The quality of river sand is not controllable. The shape of the river sand is also irregular. The quality control for M Sand is decided in industries. The shape of M sand is cubical with good gradation. In river sand clay impurities are unavoidable but in M Sand there are no clay impurities. 100% of river sand and M Sand are used for both HSCC and HSGC. The specific gravity of river sand is 2.6 and the

Table 1 Materials for casting specimens

SI. No	Specimen type	Binder	Fine aggregate	Coarse aggregate	Water/Alkaline solution	Super-Plasticer
1	HSCC1	Cement/Silica fume	River Sand	Crushed Granite Stone	Water	MLS based
2	HSCC2	Cement/Silica fume	Manufacturing Sand	Crushed Granite Stone	Water	MLS based
3	HSGC1	Fly ash/GGBS	River Sand	Crushed Granite Stone	Alkaline Solution	MLS based
4	HSGC2	Fly ash/GGBS	Manufacturing Sand	Crushed Granite Stone	Alkaline Solution	MLS based

specific gravity of M sand is 2.70 confirming zone II as specified in IS: 383–1970. The fineness modulus of river sand is 3 and the fineness modulus of M Sand is 2.85. Figures 6 and 7 show the fine aggregates used for making HSC. The particle distribution curve for river sand and M Sand are plotted using data obtained from sieve analysis test and it is shown in Fig. 8. The uniformity coefficient (Cu) and the coefficient of gradation Cc of river sand are 2.46 and 0.93 respectively. This indicates that, it is uniformly graded and the particle sizes are in similar range. The uniformity coefficient (Cu) and the coefficient of gradation Cc of M Sand are 6.35 and 0.710 which indicates that, it is well graded and the particle sizes are in different ranges. The uniformity coefficient of sand is greater than 4, then it is said to be well graded and the value lesser than 4 is said to be uniformly graded.

4.3 Coarse Aggregate

Crushed granite stones with low angular and cubical shape are chosen as coarse aggregate. 20 mm − 10 mm size aggregate in the ratio of 60:40 is used respectively. The specific gravity of crushed stone is 2.70 and the fineness modulus is 6.85. Rounded and elongated aggregate were removed since they may lead to bond failure in HSC. The chosen coarse aggregate confirming IS: 2386–1963 part IV and V. Figs. 9 and 10 show the coarse aggregate used in this study. The coarse aggregate was in saturation condition while mixing.

4.4 Alkaline Solution for HSGC

Alkaline solution is used to mix the High Strength Geopolymer Concrete (HSGC) instead of water. The alkaline solution is formed by mixing sodium hydroxide solution and sodium silicate solution or potassium hydroxide solution and potassium silicate solution. In this study, sodium based materials are chosen for economic and availability purposes. The ratio of alkaline solution to binder material is chosen as 2.5. The molarity of the alkaline solution is 16 M. The main objective of alkaline solution is to activate the bonding capacity of the binder material with the aggregates. The alkaline solution is prepared by mixing sodium hydroxide pellets with required amount of water. Then after 30–40 min the sodium hydroxide solution was mixed with sodium silicate solution. The activator solution should be prepared 24 h prior to casting of specimens. Figure 11 shows the materials used for prepare alkaline solution.

4.5 Water for HSCC

Potable water is used for mixing High Strength Cement Concrete (HSCC) and the water should be free from chemicals and organic materials. Distilled water can also be used for mixing concrete. In this study, potable water free from chemicals especially from chloride, sulphate etc. used the optimum water cement ratio for HSC is 0.30–0.35 [5]. In this

Table 2 Mix proportions percentage of materials for casting specimens

SI.No	Types of specimens	Binder materials (%)				Fine aggregate (%)		Coarse aggregate (%)	Solution (%)		SP (%)
		Cement	Silica fume	Fly ash	GGBS	River sand	Manufacturing sand		Water	Alkaline solution	
1	HSCC1	80	20	–	–	100	–	100	100	–	1.5
2	HSCC2	80	20	–	–	–	100	100	100	–	1.5
3	HSGC1	–	–	50	50	100	–	100	–	100	1.5
4	HSGC2	–	–	50	50	–	100	100	–	100	1.5

Table 3 mix proportions of materials for HSCC and HSGC concrete

SI.No	Types of specimens	Binder materials (kg/m^3)				Fine aggregate(kg/m^3)		Coarse aggregate (kg/m^3)	Solution (kg/m^3)		SP (kg/m^3)
		Cement	Silica fume	Fly ash	GGBS	River sand	M Sand		Water	Alkaline solution	
1	HSCC1	384	96	–	–	681.72	–	1155.06	160	–	7.20
2	HSCC2	384	96	–	–	–	681.72	1155.06	160	–	7.20
3	HSGC1	–	–	248.45	248.45	705.59	–	1197.52	–	163.98	7.45
4	HSGC2	–	–	248.45	248.45	–	705.59	1197.52	–	163.98	7.45

study, the water cement ratio was chosen as 0.33. The total water content used was 160 kg/m^3.

4.6 Super-Plasticer (SP)

For making HSC, SP is mandatory to increase the workability with low water content. Generally, naphthalene based, Poly Carboxylic Ether (PCE) and Modified Ligno Sulphonate (MLS) SP are available in the market. In this study based on several experiment MLS based SP, a dark brown liquid was chosen. The specific gravity of the SP is 1.08 at 25 °C with pH value of greater than 6. It is confirming IS: 2645–2003 and IS: 9103–1999 and it is available in 20 kg, 100 kg and 200 kg in the market. The optimum percentage of SP chosen was 1.5 based on experiments to achieve workability.

5 Experiments

The casting of High Strength Cement Concrete (HSCC) and High Strength Geopolymer Concrete (HSGC) are similar except the solution used for mixing. For HSCC with river sand and M Sand, water was used for mixing. For HSGC with river sand and Manufacturing Sand (M Sand), alkaline solution was used for mixing. The binder materials and the filler materials were mixed for 2–3 min for obtaining a uniform dry mix. Then for HSCC, water was added and for HSGC, alkaline solution was added. Then the mix was mixed for 2 min, resulting in formation of fresh concrete. Tables 1 and 2 show the types of specimens, mix proportions and % of materials for casting specimens. The mix proportions of binders, filler materials and solution (water and alkaline solution) for making HSCC and HSGC concrete are given in Table 3. The water-cement ratio of HSCC was taken as 0.33 and the alkaline solution to binder ratio for HSGC was chosen as 0.33.

In this study, the High Strength Concrete (HSC) is designed for a mix ratio of 1:1.42:2.41 for both HSCC and HSGC. The difference between the HSCC and HSGC is the type of materials used. In HGSC 15% of extra water is used with 1.5% SP for achieving workability. The fresh concrete is poured into cube moulds of 100 × 100 × 100 mm size. Proper compaction was done to ensure the absence of honey comb in the specimens. The concrete were demoulded from the moulds and cured. The High Strength Cement Concrete with river sand (HSCC1) and High strength Cement Concrete with M Sand (HSCC2) specimens were cured under water curing for 28 days. High Strength Geopolymer Concrete with river sand (HSGC1) and High Strength Geopolymer Concrete with M Sand (HSGC2) specimens were curing under ambient temperature for 24 hours. Figures 12, 13, 14, and 15 show the casting process and testing of HSC specimens. The cube specimens were tested under incremental compression load using 200 t

Fig. 12 Mixing of HSC

Fig. 13 Fresh HSC

Fig. 14 Casting of HSC specimens

capacity compression testing machine available in our laboratory that was bought from Perfect Techonologies, an ISO 9001-2008 certified manufacturer. Totally 36 cube specimens were cast and for one sample three specimens were tested and average compressive strength was determined. Four types of mixes with different combination of materials were cast. For each mixes, three samples (9 specimens) were tested and average compressive strengths were found and tabulated in Table 4. Totally, 12 samples (36 specimens) were tested for determining the compressive strength of HSC concrete. The change in compressive strength for the four specimens is mainly due to the type of materials used in it. HSCC2 shows higher compressive strength than HSCC1 due to the presence of M sand, which has better gradation than river sand. HSGC2 has higher compressive strength than all other specimens due to of the presence of geopolymer materials and M sand.

Fig. 15 Testing of HSC specimen

6 Durability Properties on High Strength Concrete (HSC)

The high strength concrete specimens were exposed chemical environment to study their durability properties. The specimens were tested for sulphate attack, acid attack, sea water absorption test. The test specimens were immersed in chemical environment for 28 and 56 days. The specimens were immersed on the 3rd day after casting specimens. The specimens were cleaned, washed and surface dried for testing the compressive strength of specimen.

6.1 Sulphate Attack Test

All the specimens were immersed in the sodium sulpahate solution with 5% [18] concentration as shown in Fig. 16. The solution was stirred and replaced regularly to maintain the concentration of the solution. The specimens were tested at 28 and 56 days. The findings indicates, that the HSGC1 and HSGC2 are excellent in sulphate resistance compared to HSCC1 and HSCC2. The surface of the specimens were not damaged and no kind of spalling were found in HSGC1 and HSGC2. The average compressive strength of all the specimens after sulphate attack is given in Table 5. There is no significant reduction in the compressive strength observed in HSGC1 and HSGC2 but there is a slight change in compressive strength for HSCC1 and HSCC2.

6.2 Acid Resistant Test

All the specimens were immersed in the hydrochloric acid (HCL) with 5% concentration is shown in Fig. 17. The solution was stirred and replaced regularly to maintain the concentration of the solution. The specimens were tested at 28 and 56 days. After the tested period, the surface of all the specimens were damaged due to acid attack. There is a degradation of compressive strength found in all the specimens. But, the HSGC1 and HSGC2 has better resistance to acid attack when compared to HDCC1 and HSCC2. The average compressive strength of all the specimens after sulphate attack is given in Table 6. There is no significant reduction observed in the compressive strength of HSGC1 and HSGC2 but there is a slight change in compressive strength of HSCC1 and HSCC2.

7 Results and Discussions

In this research, four varieties of high strength concrete using different combination of materials were studied. Among the four types, two types of high strength concrete were prepared by using Ordinary Portland Cement as binder with river and Manufacturing Sand. The other two kinds were cast by using Alumina-Silica materials as binder with river sand and

Table 4 Compressive strength of hsc specimens

SI.NO	Type of specimens (mm)	Area of specimen (mm^2)	Method of curing	Weight of specimens (Kg)	Number of days under curing	Ultimate load (KN)	Compressive strength (N/mm^2)		Average compressive strength (N/mm^2)
1	HSCC1	10,000	Water	2.514	28	677.2	677.2	66.50	66.50
				2.493		665.0	66.50		
				2.619		652.8	65.28		
			Water	2.624	28	667.9	66.79	67.60	
				2.562		672.9	67.29		
				2.644		687.2	68.72		
			Water	2.589	28	662.3	66.23	65.40	
				2.601		657.9	65.79		
				2.623		641.8	64.18		
2	HSSC2	10,000	Water	2.456	28	662.6	66.26	67.50	68.43
				2.485		689.9	68.99		
				2.524		672.5	67.25		
			Water	2.627	28	683.5	68.35	68.50	
				2.654		685.6	68.56		
				2.592		685.9	68.59		
			Water	2.533	28	695.3	69.53	69.30	
				2.543		691.1	69.11		
				2.503		692.6	69.26		
3	HSGC1	10,000	Ambient	2.491	03	685.0	68.50	68.90	68.90
				2.462		682.5	68.25		
				2.502		699.5	69.95		
			Ambient	2.252	03	6923.3	69.23	69.40	
				2.456		693.6	69.36		
				2.436		696.1	69.61		
			Ambient	2.532	03	685.0	68.50	68.40	
				2.548		682.4	68.24		
				2.436		684.6	68.46		
4	HSGC2	10,000	Ambient	2.578	03	726.8	72.68	72.80	71.46
				2.596		727.5	72.75		
				2.846		72.97	72.97		
			Ambient	2.353	03	713.5	71.35	71.80	
				2.459		715.6	71.56		
				2.555		724.9	72.49		
			Ambient	2.620	03	723.5	72.35	72.50	
				2.562		726.6	72.56		
				2.528		725.9	72.59		

* HSCC1 High Strength Cement Concrete with river sand; *HSCC2* High Strength Cement Concrete with M sand; *HSGC1* High Strength Geopolymer Concrete with River Sand; *HSGC2* High Strength Concrete with M Sand

Fig. 16 Sulphate attack test

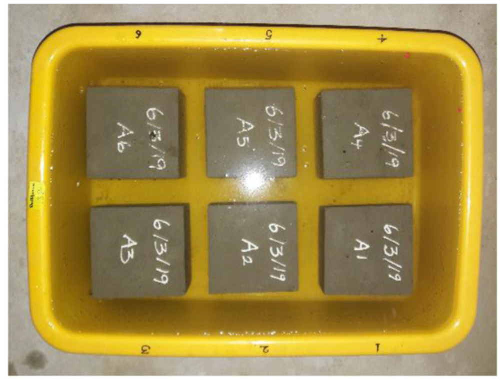

Fig. 17 Acid resistant test

manufacturing sand. The high strength concrete cubes were tested under compression and durability aspects. The addition of alumina – silica binder in high strength geopolymer concrete reacts with alkaline solution to make a 3D cross linked polymer chain which is increase the strength of high strength of geopolymer concrete. The addition of manufacturing sand to the high strength concrete ensures the perfect particle packing since, the particle distribution curve shows that the manufacturing sand was well graded and the river sand was uniformly graded. This has happened because of the manufacturing of river sand is a natural process where no control over production of sand is possible. But the manufacturing of M sand is fully controllable and the proper gradation can be achieved. Overall, all the high strength concrete with cement and geopolymer achieved more than 60 MPa. The compressive strength of all the four types of concrete is shown in Figs. 18, 19, 20, 21, 22, 23, and 24. The average compressive strength of all specimens immersed in sulphate and acid is shown in Figs. 25 and 26.

The high strength geopolymer concrete with river and manufacturing sand exhibits good resistant to sulphate attack than high strength cement concrete. There is no major changes compression strength in the high strength geopolymer concrete against sulphate. The degradation of compressive strength is observed in the high strength cement concrete and high strength geopolymer concrete.

8 Conclusions

1. This research work is based on high strength concrete with Ordinary Portland cement and Geopolymer (Alumina – Silica) material as binder. In addition to this, for two kinds of concrete, river sand and with well graded manufacturing sand. The compressive strength of the high strength concrete was greatly influenced by the binders and M Sand. Addition of M Sand in high strength cement concrete (HSCC2) increases the compressive strength by 2.82% compared to HSCC1. The addition of M sand in high strength geopolymer concrete (HSG2) increases the compressive strength by 3.60% compared to HSGC1. This small amount of change in compressive strength is attributed to the well graded grain size of M Sand. The addition of alumina – silica (geopolymer) binder in high strength concrete shows an improvement in the early compressive strength, where the high strength cement concrete needs 28 days to achieve the required strength. The early strength of geopolymer concrete at ambient conditions is mainly achieved due the presence of Ground Granulated Blast Furnace Slag (GGBS). For geopolymer reaction, heat is used as a catalyst to increase the quick hardening. When GGBS and fly ash are combined with the alkaline solution, quick hardening is achieved. The hardening of high strength geopolymer concrete is mostly influenced by the percentage of GGBS. At the same time, increasing the percentage of GGBS will decrease the workability of concrete. In this study,

Table 5 Compressive strength of HSC after sulphate attack

S.No	Type of specimen	Average compressive strength before sulphate attack @ 3 days N/mm^2	Average compressive strength before sulphate attack @ 56 days N/mm^2	Percentage reduction in compressive strength (%)
1	HSCC1	66.50	59.41	10.66
2	HSCC2	68.43	61.27	10.46
3	HSGC1	68.90	66.14	4.01
4	HSGC2	71.46	68.60	4.00

Table 6 Compressive strength of HSC after acid attack

S.No	Type of specimen	Average compressive strength before sulphate attack N/mm^2 @ 3 days	Average compressive strength before sulphate attack @ 56 days N/mm^2	Percentage reduction in compressive strength (%)
1	HSCC1	66.50	55.75	16.17
2	HSCC2	68.43	58.62	14.34
3	HSGC1	68.90	62.42	9.41
4	HSGC2	71.46	64.90	9.18

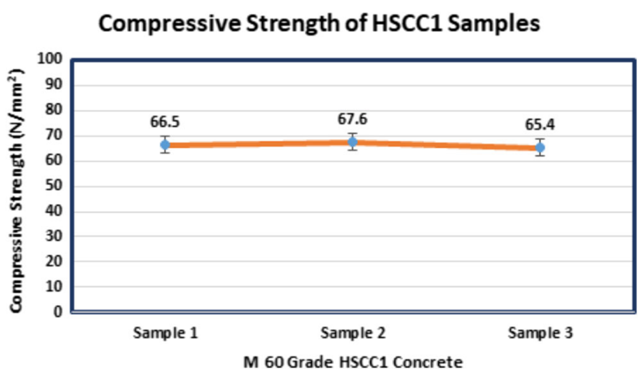

Fig. 18 28 Days Compressive Strength of HSCC1

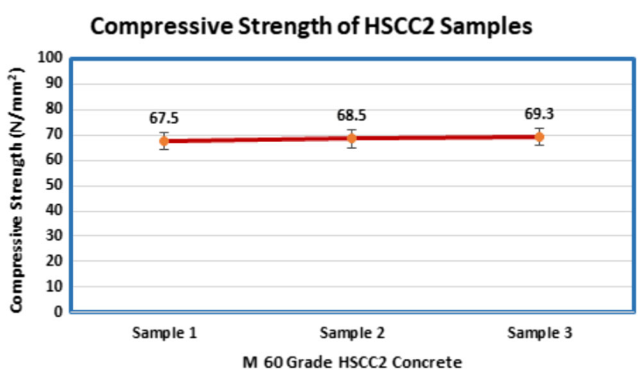

Fig. 19 28 Days Compressive Strength of HSCC2

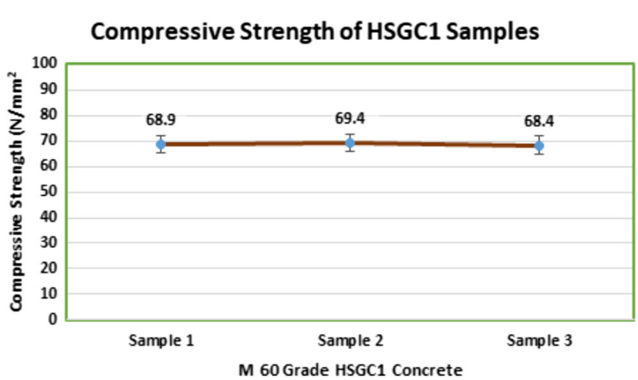

Fig. 20 03 Days Compressive Strength of HSGC1

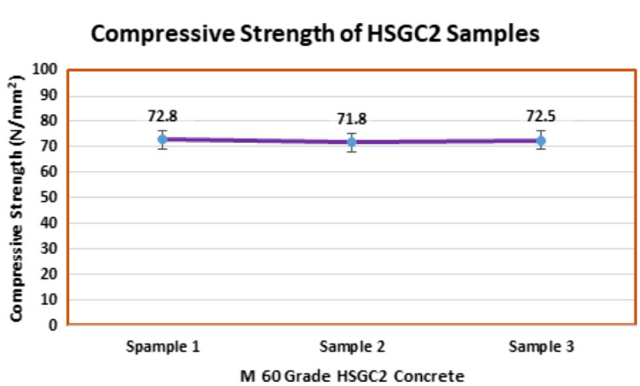

Fig. 21 03 Days Compressive Strength of HSGC2

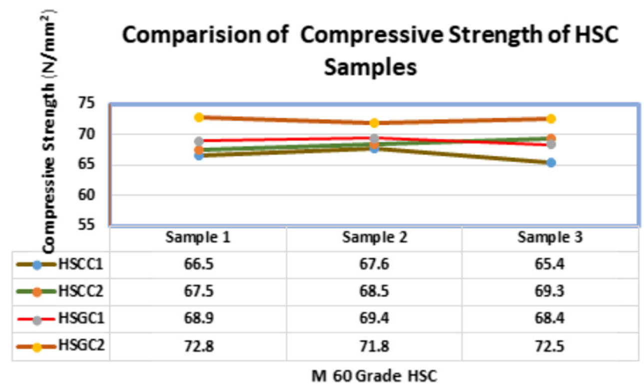

Fig. 22 Compressive Strength Comparison of HSC Specimens (Graph)

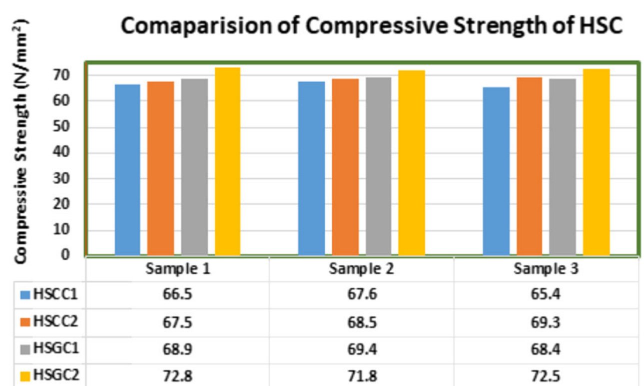

Fig. 23 Comparisons of Compressive Strength of HSC Specimens (Bar Chart)

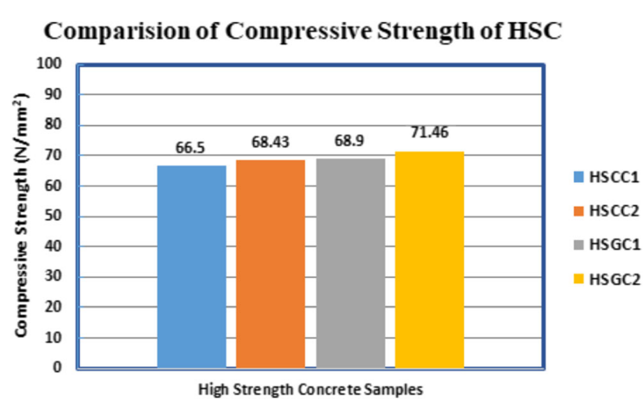

Fig. 24 Comparisons of Average Compressive Strength of HSC Specimens

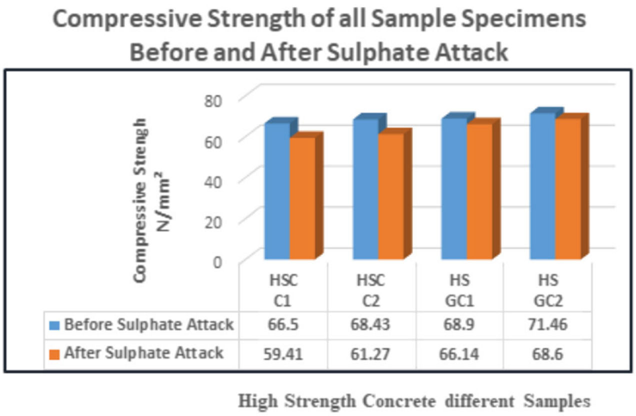

Fig. 25 Average Compressive strength before and after Sulphate attack

50% of binder was replaced by GGBS and another 50% of binder was replaced by low calcium fly ash.

The excellent resistance of high strength geopolymer concrete against sulphate attack is attributed due to the low calcium fly ash. In the case of high strength cement concrete, the resistance is low when compared to high strength geopolymer concrete. In HSCC, the presence of high calcium content will lead to the formation of gypsum or ettringite. This will make the HSCC, less resistant to sulphate. In geopolymer with low calcium fly ash, the formation of ettringite is impossible and this makes the HSGC unsusceptible to sulphate attack. The reduction of compressive strength of high strength geopolymer concrete is around 4% which is insignificant but in the case of high strength cement concrete it is around 10%. This increase in reduction in compressive strength is due to the presence of high calcium in Ordinary Portland Cement. The performance of high strength geopolymer concrete is better than high strength cement concrete against acid attack (5% HCL) but the compressive strengths of the HSCC and HSGC are degraded. The reduction in compressive strength of HSCC is around 16% and HSGC is around 9%. Both HSSC and HSGC were affected by acid attack but damage is lesser in HSGC due to presence of fly ash and GGBS, which are very smaller in particle size. This contributes to reduction of pores in inter transition zone.

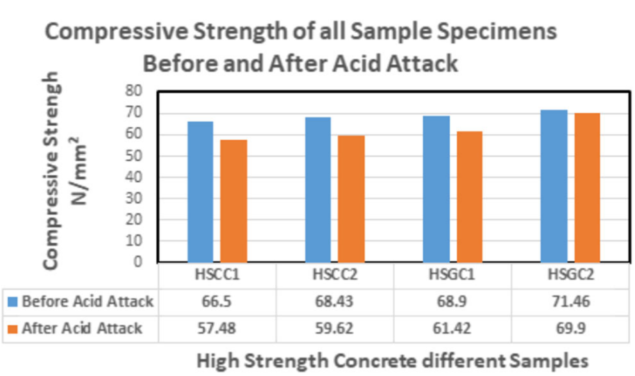

Fig. 26 Average Compressive strength before and after Acid attack

The average 28 day compressive Strength of High Strength Cement Concrete with River Sand (HSCC1) is 66.50 N/mm^2 and with M Sand (HSCC2) is 68.43 N/mm^2. The average compressive Strength of High Strength Geopolymer Concrete with River Sand (HSGC1) is 68.90 N/mm^2 and with M Sand (HSGC2) is 71.46 N/mm^2. The water curing is completely eliminated in high strength geopolymer concrete. The utilisation of geopolymer technology in construction field will enhance the production of ecofriendly and sustainable concrete.

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