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Comparative Study on the Strength and Durability Characteristics of M35 Concrete with Partial Replacement of Cement by Mineral Admixtures

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ABSTRACT

The mineral admixtures such as fly ash and ground granulated blast furnace slag (GGBS) are currently being used as supplementary cementitious materials (SCM) to reduce environmental pollution associated with the production of cement and cost of concrete. In the present work, the effect of partial replacement of cement (30 percent) by fly ash / GGBS on the strength and durability properties of commonly used M35 grade concrete made with a water cement ratio of 0.45 and 1.2 percent of CONPLAST SP430 superplasticizer was experimentally determined. The tests conducted were compressive strength test at 3, 7 and 28 days, water absorption, sorptivity, chloride penetration, alkali aggregate reaction, acid attack, sulphate attack at 28 days after curing and X-ray Computed Tomography(X-CT) analysis at 7 and 28 days of curing. The addition of the supplementary cementitious materials such as fly ash, GGBS etc. enhances the strength and durability properties of the concrete. It is observed in the present study that the 28 days compressive strength of concrete mix with GGBS is greater than that of the concrete mix with fly ash by about 10%. For both concrete mixes with fly ash and GGBS, the sorptivity value is initially high and later decreases monotonically as time elapses. From the perspective of sorptivity, there is not much to choose between the two mixes. The concrete mix with GGBS is more resistant to chloride attack than the concrete mix with fly ash mix. There is significant reduction in the compressive strength due to sulphuric acid attack for both the mixes. From this perspective, there is not much to choose between the two concrete mixes. There is significant loss of compressive strength in both the mixes due to the alkali attack. From this point of view, there is not much of a difference between the magnitudes of losses of strength of the two concrete mixes. Concrete with fly ash is more resistant to the alkali attack than the concrete with GGBS.

KEYWORDS: GGBS, Fly ash, Compressive strength, X-CT, Sorptivity, Chloride penetration, Alkali aggregate reaction, Acid attack.

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INTRODUCTION

Concrete is one of the most widely used construction materials in the world. The most expensive ingredient of concrete is cement. Every year, due to production of cement, several million tonnes of CO_2 are being released to the environment causing pollution. In order to overcome the aforesaid adverse effects, supplementary cementitious materials (SCM) such as fly ash, ground granulated blast furnace slag (GGBS) are being utilized as partial replacement of cement[1]. The British Standards Institution defines cement as a hydraulic binder containing finely ground inorganic materials, which form with water a paste that sets and hardens by means of hydration reactions. Particle size plays an important role in ordinary Portland cement (OPC)[1]. The particle size affects the rate of hydration which is responsible for the development of strength in the cement. A smaller particle size means that there is a greater surface area to volume ratio and, therefore, more area is available for water-cement reaction per unit volume. Due to this, most of the OPC particles are smaller than 45 microns, with average particle size of the order of 15 microns. Cement contains many ingredients like oxides of calcium (CaO), silica (SiO_2), aluminium (Al_2O_3), iron (Fe_2O_3), magnesium (MgO) and alkalies like (Na_2O) and K_2O. The main products of hydration of cement are calcium silicate hydrates (C-S-H), calcium hydroxides (CH), and calcium aluminate hydrates (C-A-H)[3]. The changes in the chemistry of binder due to addition of an admixture to cement affects the rate, quantity and quality of hydration products which eventually results in changes in the strength of the cement paste[2]. Cement mortars are porous material with heterogeneous and complex structure, making difficult their characterization. X-Ray computed tomography (X-CT) provides information on shapes of pores, void, distribution, different sizes of pores, moisture moment. The data on total porosity of mortar and distribution of pores in its microstructure allows inferences about the phenomena that affect the mechanical and durability characteristics of the material[4].

SCOPE OF THE PRESENT STUDY

In the present study, cube compressive strength test at 3, 7 and 28 days, water absorption, sorptivity, chloride penetration, alkali aggregate reaction, acid attack, sulphate attack at 28 days after curing period and X-ray Computed Tomography(X-CT) analysis at 7 and 28 days of curing are done to determine the strength and durability characteristics of M35 grade concrete in which 30% of cement is replaced by fly ash/GGBS. The effects of fly ash and GGBS as partial replacement for cement in M35 concrete are compared.

MATERIALS USED IN THE PRESENT WORK

The materials used in the present study are Ordinary Portland Cement of 53 grade conforming to IS 12269:1987, coarse aggregate (Granite stone 20 mm down size), fine aggregate (

river sand), mineral admixtures such as fly ash, GGBS, chemical admixture such as superplasticizer (CONPLAST SP430) and potable water.

Physical Properties of the Materials

Table 1: Physical Properties of the Materials

Property	Cement	Fine Aggregate	Coarse Aggregate	Super-plasticizer
Normal Consistency	28 %	-	-	-
Initial Setting Time	40 min	-	-	-
Final Setting Time	310 min	-	-	-
Specific Gravity	3.11	2.54	2.67	1.2
Water Absorption	-	1.12 %	0.68 %	-

Chemical Properties of the Materials

The chemical composition of the materials used was obtained by using wet chemistry technique. This technique was used for qualitative and quantitative chemical measurement using methods such as gravimetric and volumetric analysis conforming to IS 1147-1985. The testing for chemical composition was carried out at Mineral and Metallurgical Laboratories which is accredited by NABL.

Table 2: Chemical Properties of the Materials

Composition	Cement	Fine Aggregate	Coarse Aggregate	Fly Ash	GGBS
SiO_2	21.98	74.12	75.59	53.09	37.84
Al_2O_3	5.90	14.50	13.22	23.83	18.37
Fe_2O_3	4.60	1.82	2092	11.14	.88
CaO	62.64	2.17	2.58	3.44	37.95
Others	1.66	0.76	0.58	1.34	0.34

Concrete Mix Design

M35 grade of concrete was prepared by using ordinary Portland cement, sand as fine aggregate and crushed granite stones as coarse aggregate (20 mm) etc. The mix design was carried out as per IS: 10262-2009 specifications and the results are given in Table 3.

Table 3: Mix Design Details

Ingredient	Quantity
Cement	350.488 kg/m^3
Fine aggregate	803.962 kg/m^3
Coarse aggregate	1066.90 kg/m^3
Water	157.716 kg/m^3
Mix Proportion C : F.A : C.A	1:2.29: 3.04
W/C	0.45

METHODOLOGY

Compressive Strength Test

The compressive strength test was conducted by using Compression Testing Machine (CTM) of 3000 KN capacity. 150 mm x 150 mm x 150 mm concrete cube specimens were used. Three test specimens were used to obtain one value of compressive strength using standard principles. The cubes were tested at the age of 3, 7, and 28 days.

Sorptivity Test

The performance of concrete cubes subjected to aggressive environments mainly depends on the pore system. Sorptivity can be characterized as the rate of capillary rise of a wetting front (water) through a permeable material (concrete). For this test, cylinders of size 100 mm diameter × 200 mm long were cast using mineral admixture fly ash/GGBS and then cured for 28days. After curing was over, the specimens were cut into 100 mm diameter x 50 mm thick discs as shown in Fig 1. The discs were dried in oven for 100±10°C for 24 hours and then cooled to room temperature. The specimens were drenched in water up to a depth not exceeding 5mm from the bottom of the sample for 180 minutes as shown in Fig 2. The amount of water absorbed in a time period of 30 minutes was measured by weighing the specimen before the time period (Wy) and after the time period of 30 minutes (Wx). Before each weighing, the bottom surface of the disc was wiped with tissue paper. This procedure was repeated for every half an hour and continued up to 3 hours.

Sorptivity is calculated by the formula given below

$$S = \frac{Wx - Wy}{ADT^{1/2}}$$

where

S = Sorptivity (mm)/ (min)$^{1/2}$

Wx = Weight of the disc after 30/60/90/120/150/180 minutes

Wy = Weight of the disc after 0/30/60/90/120/150 minutes

A = surface area of specimen through which water penetrates, mm^2

D = density of water, gm/mm^3;

T = Elapsed time (30 minutes)

The numerator in the above expression represents the increase in the weight of the disc over a period of 30 minutes.

Figure1. Equipment for Slicing of Concrete Cylinders into Discs

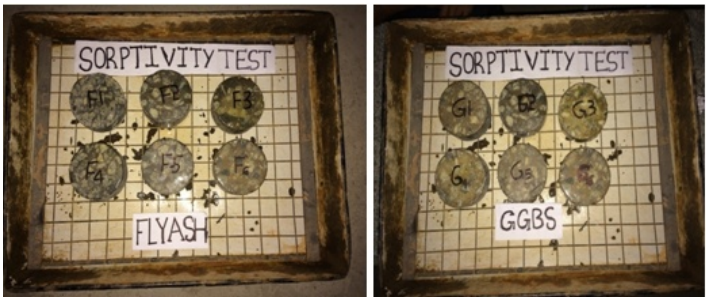


Figure2. Concrete Discs - Sorptivity Test

Chloride Penetration Test

This test is used to find out the chlorine penetration depth in the concrete specimens. In this work, cube specimens of size 100 mm x 100 mm x 100 mm were cast with mineral admixture fly ash/ GGBS. The specimens were removed after 28 days of water curing and then placed in water which contains sodium chloride (NaCl) of 1N. After 28 days of immersion, the specimens were removed and cut into two equal pieces each. Immediately, silver nitrate ($AgNO_3$) of 0.1M was sprayed on those broken pieces. Due to chemical reaction between sodium chloride and silver nitrate a white precipitate was formed on the specimens (vide Fig.3) and the depth of the white precipitate was measured.

Figue3. Typical Cut Concrete Specimens after 28 Days of Immersion

Acid Test

Concrete cubes of size 150 mm × 150 mm × 150 mm with mineral admixture fly ash/GGBS were cast and cured for 28-days. Later all the specimens were kept in sulphuric acid (H_2SO_4) solution for 28 days. A pH value of around 2 was maintained throughout the 28 days of acid curing (vide Fig.4). After 28-days of immersion in the acid solution, the specimens were taken out, washed thoroughly (vide Fig.5) and then tested for compressive strength. The resistance of concrete to acid attack was found by the loss of compressive strength on immersing cubes in sulphuric acid solution.

Figure4. Concrete Specimens under Acid Curing

Figure5. 28 days acid cured concrete specimens

Alkali Aggregate Reaction Test

For alkali attack test, concrete cubes of size 150 mm × 150 mm × 150 mm with mineral admixture fly ash/GGBS were cast and cured for 28-days. Then all the specimens were kept in Sodium Hydroxide (NaOH) solution for 28 days. A pH value of 10.5 was maintained throughout 28 days of alkaline curing. After 28-days of immersion in alkaline solution, the specimens were taken out, washed thoroughly (vide Fig.6) and then tested for compressive strength. The resistance of concrete to alkaline assault was found by the loss of compressive strength due to immersion of cubes in alkaline water.

Figure 6. 28 days Alkaline cured concrete specimens

Porosity Test

Concrete is a heterogeneous material, made up of two different pore systems, gel pores and capillary pores. Gel pores which are inherent in the cement mix are very small and have little to do with the porosity. One of the major concerns in the concrete industry is the passage of extraneous substances via fluids or gasses through the capillary pore systems.

X-ray computed tomography (vide Figs. 7 and 8) is a completely non-destructive means of visualizing the internal structure of any dense, solid object. X-ray micro tomography presents an alternative approach in determining the porosity and pore size distribution in concrete specimens. In this work, due to the high resolution and smaller field of view of the scan, the aggregates were excluded. Hence the porosity values obtained would be higher than the average expected for the concrete bulk.

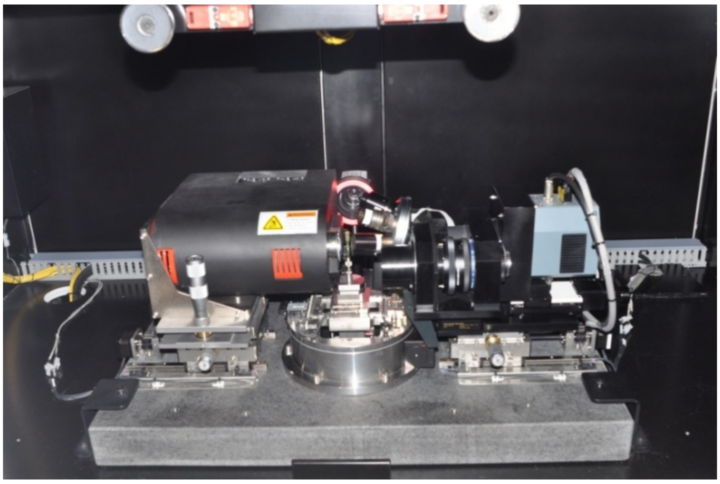


Figure7. X-Ray Computed Tomography Facility at CMTI Lab, Bangalore

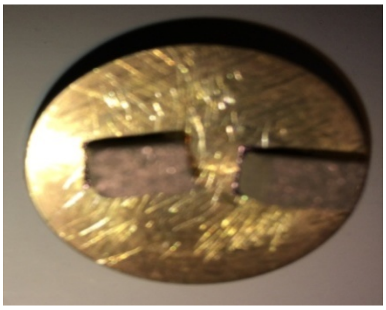


Figure8. Specimen for Porosity Test

TEST RESULTS AND DISCUSSION

General

Tests were carried out to determine the mechanical property such as compressive strength, durability properties such as sorptivity, chloride penetration, acid attack, alkali attack and sulphate attack in this study. The porosity of the concrete with admixture was also determined using X-ray computed tomography.

Compressive Strength Test

The compressive strength tests were carried out on 150mm x 150mm x 150mm size concrete cubes with GGBS/fly ash as admixture at different ages of 3, 7, 28 days. The results are given in Table 4 and Fig.9.

Table 4: Compressive Strength of Concrete Cubes in MPa

Concrete	3 days	7 days	28 days
With fly ash	17.77	22.44	40.14
With GGBS	20.14	26.51	44.14

It is observed that the compressive strength of concrete mix with GGBS is greater than that of the concrete mix with fly ash.

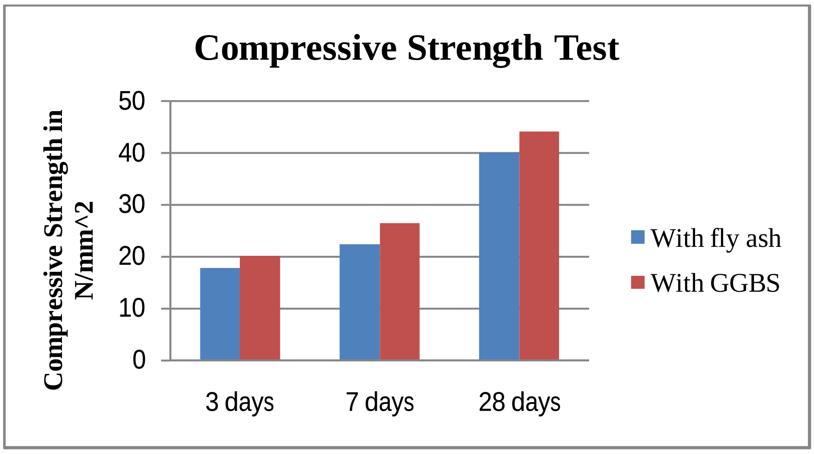


Figure 9. Compressive Strength of Concrete Cubes

The 28 days compressive strength of concrete mix with GGBS is greater than that of the concrete mix with fly ash by about 10%.

Sorptivity Test

The Sorptivity test was carried out after 28 days of water curing on concrete cylinders of size 100 diameter x 200 mm long cast with mineral admixture fly ash/GGBS. The results obtained are shown in Table 5.

Table 5: Sorptivity values

Concrete mix	Sorptivity [mm/(min)$^{1/2}$]					
	30 min	**60 min**	**90 min**	**120 min**	**150 min**	**180 min**
With fly ash	0.1434	0.0301	0.0116	0.0141	0.0106	0.0097
With GGBS	0.1316	0.0273	0.0156	0.0114	0.0104	0.0095

It is observed from Table 5 and Fig.10 that the sorptivity value is initially high for both concrete mixes and decreases monotonically as time elapses (as expected). Sorptivity value shows the rate of water capillary absorption for a mix. From the perspective of sorptivity, there is not much to choose between the two mixes.

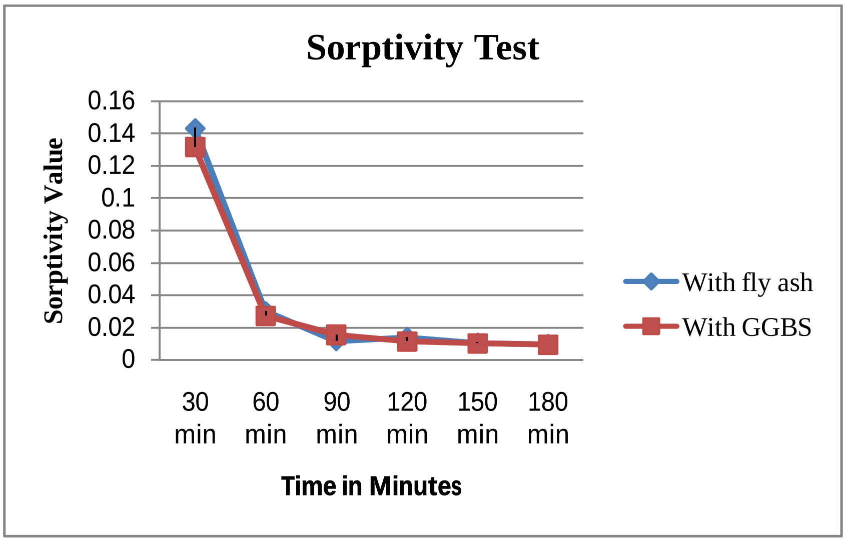


Figure10. Variation of Sorptivity of Concrete

Chloride Penetration Test

The calorimetric chlorination test was carried out on concrete cubes after 28 days curing in 1N sodium chloride solution (NaCl) and the results are given in Table 6 and presented in Fig.11.

Table 6: Chloride Penetration Depth of Concrete Cubes

Concrete Mix	Chloride penetration depth at 28 days
With fly ash	8.50 mm
With GGBS	6.25 mm

It is observed that the mix with GGBS is more resistant to chloride attack than the mix with fly ash mix.

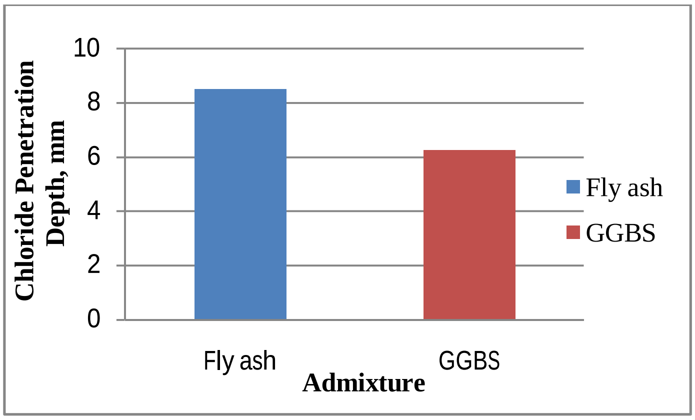


Figure11. Chloride Penetration Depth of Concrete Cubes

Acid Attack Test

Concrete cubes of size 150 mm × 150 mm × 150 mm were cast and cured for 28 days of water curing. Later they were immersed in sulphuric acid (H_2SO_4) solution for 28 days and tested for compressive strength. The results are given in Table 7.

Table 7: Acid Attack Test Results

Concrete Mix	Compressive strength after 28 days of water curing (MPa)	Compressive strength after immersion in H_2SO_4 solution for 28 days (MPa)	% Loss of compressive strength (MPa)
With fly ash	40.14	21.64	46.09
With GGBS	44.14	22.44	49.16

It is observed that there is significant reduction (about 45 to 50% loss) in the compressive strength due to immersion in sulphuric acid for both the mixes. From this perspective, there is not much to choose between the two concrete mixes.

Alkali Aggregate reaction Test

Concrete cubes of size 150 mm × 150 mm × 150 mm were cast and cured for 28 days of water curing; then it was dipped in Sodium hydroxide (NaOH) solution for 28 days. Later it was tested for compressive strength.

Table 8: Alkali aggregate reaction test results

Mix	Compressive strength in water curing (MPa)	Compressive strength in Alkali solution (MPa)	% Loss in compressive strength (MPa)
With fly ash	40.14	29.55	26.40
With GGBS	44.14	31.55	28.52

The results are given in Table 8 and presented in Fig.12.

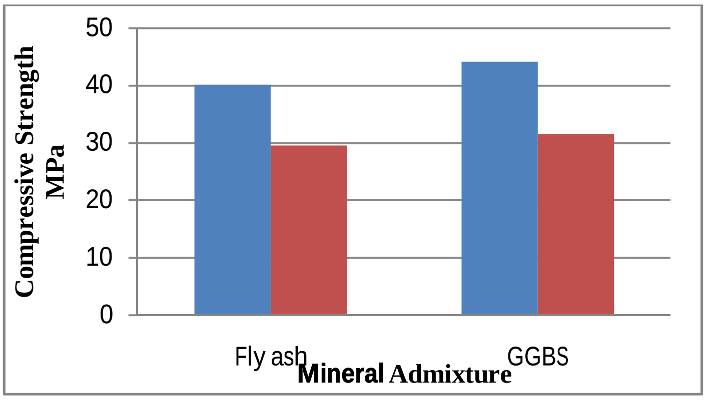


Figure12. Variation in compressive strength due alkali effect

The loss of compressive strength in both the mixes is seen to be significant. There is not much of a difference between the losses of the two concrete mixes.

Porosity Test (X-ray Computed Tomography Test):

The results are given in Table 9 and presented in Fig.13. It is observed that the percentage of voids present in the concrete varies with time. The percentage of voids is more at 7 days when compared with that at 28 days for both the mixes. The percentage of voids of concrete mix with fly ash is less that for concrete mix with GGBS at both 7 and 28 days. It may be because fly ash acts as a filler material and fills more voids when compared with GGBS.

Table 9: X-CT Values on percentage of voids in the Concrete Mixes

Mix	Percentage of Voids (%)	
	7 days	**28days**
With fly ash	20.48	3.66
With GGBS	26.85	9.343

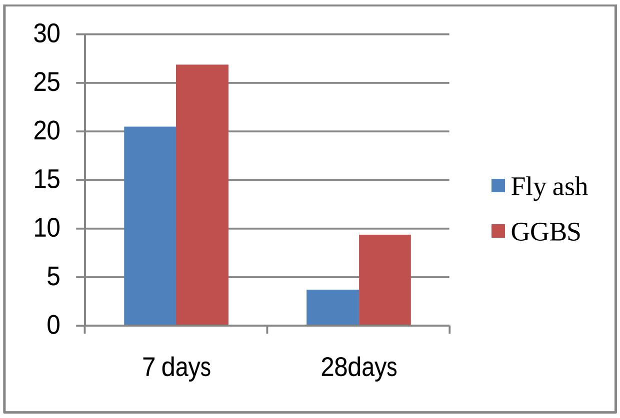
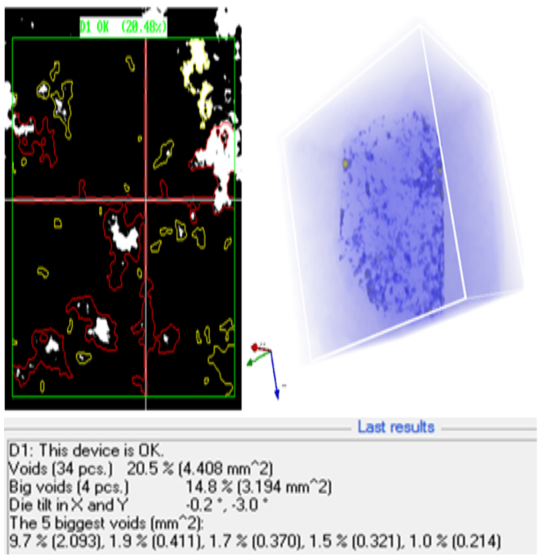
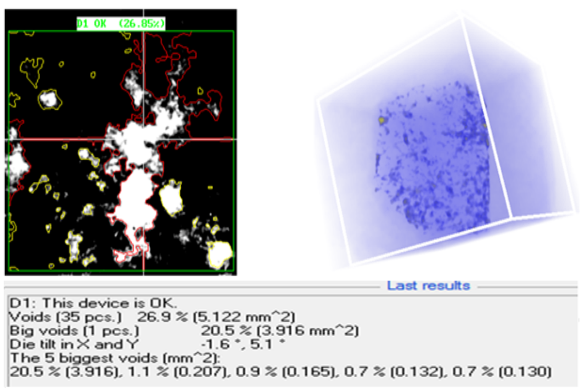


Figure13. X-CT Values on percentage of voids in the Concrete Mixes



Figue14. 2D and 3D view of Concrete with Fly ash at 7 days



Figue15. 2D and 3D view of Concrete with GGBS at 7 days

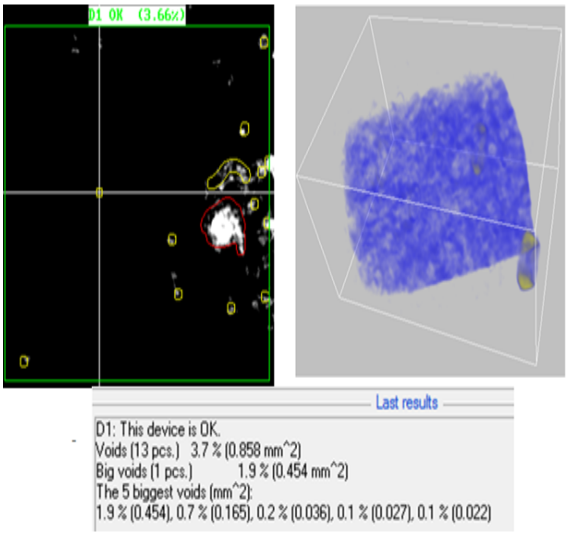


Figure16. 2D and 3D view of Concrete with Fly ash at 28 days

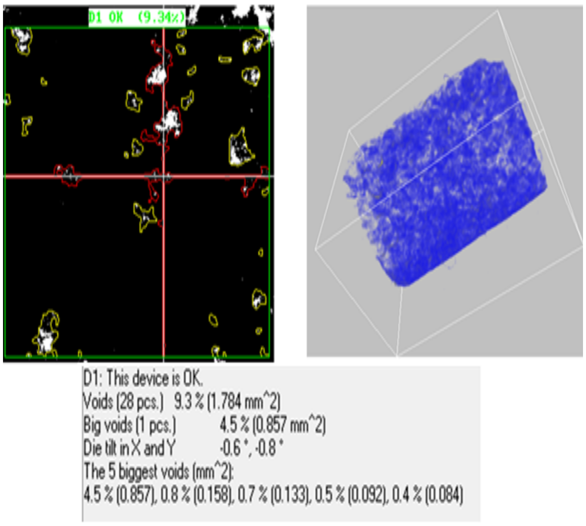


Figure17. 2D and 3D view of Concrete with GGBS at 28 days

Figures 14, 15, 16 and 17 represent the X-ray Computed Tomography images which show the percentages of voids present in the concrete. The percentage of bigger voids present in the specimen is also given. It is also observed that concrete specimen with fly ash has lesser voids at 7 and 28 days when compared to the concrete specimen with GGBS.

CONCLUSIONS

Based on the present work, the following conclusions are made.

- The 28 days compressive strength of concrete mix with GGBS is greater than that of the concrete mix with fly ash by about 10%.
- For both concretes with fly ash and GGBS, the sorptivity value is initially high and later decreases monotonically as time elapses. From the perspective of sorptivity, there is not much to choose between the two mixes.

- The concrete mix with GGBS is more resistant to chloride attack than the concrete mix with fly ash mix.
- There is significant reduction in the compressive strength due to sulphuric acid attack for both the mixes. From this perspective, there is not much to choose between the two concrete mixes.
- There is significant loss of compressive strength in both the mixes due to the alkali attack. There is not much of a difference between the magnitudes of losses of the two concrete mixes. Concrete with fly ash is more resistant to the alkali attack than the concrete with GGBS.
- The percentage of voids present in concrete varies with time. The % of voids in concrete with fly ash is more than that in concrete with GGBS both at 7 and 28 days.

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