An Experimental Investigation on the Mechanical Properties of Geopolymer Concrete Partially Replaced with Recycled Coarse Aggregates.

M.KThangamanibindhu, Research Scholar, St.Peter's University, Chennai

Dr.D.S.Ramachandra Murthy, Vice Chancellor, St.Peter's University, Chennai

ABSTRACT: The large global production of fly ash and rapid advances in geopolymer technology leads to the alternate material for OPC that is Geopolymer concrete (GPC). Geopolymers are showing great potential in future. Recycling aggregate by using it as replacement to new aggregate in concrete could reduce concrete waste and conserve natural sources of aggregates. In this paper, results of the studies carried out on the compressive strength of Geopolymer concrete partially replaced with recycle coarse aggregates have been presented.. A total of 9 mixes were tested, out of which three were conventional concrete mixes and six were GPC mixes having varying combinations of flyash, GGBS and recycled coarse aggregates. The test specimens were of size 100mm x100mm cubes and 100mmx200mm cylinders heat cured at 90°C in an oven and specimens of size 150mmx150mm cubes were cured at ambient temperature conditions. The studies showed that the compressive strength and spilt tensile strength of different mixes were decreased with the increase in the percentage of recycled coarse aggregates.

Keywords: Geopolymer concrete (GPC), Flyash, GGBS, Recycled coarse aggregates,

1. Introduction

Flyash, the finely divided residue that results from the combustion of ground or powdered coal in thermal power station is available abundantly all over the world. Most of the fly ash is disposed as a waste material that covers several hectors of valuable land. Silicon and aluminium are the main constituents of fly ash. In 1978, Joseph Davidovits developed inorganic polymeric materials and coined the term geopolymer. Geopolymer concrete is concrete which does not utilize any Portland cement in its production; the binder of GPC is produced by the reaction of an alkaline liquid with a source material that is rich in silica and alumina. The most common activator is a mixture of water, sodium hydroxide and sodium silicate. Large number of old buildings and other structures were being demolished resulting in generation of demolished concrete used as backfill material and landfills. Utilization of recycled coarse aggregate can be useful for environmental protection and economic benefits. The quality of natural aggregate is based on the physical and chemical properties of source sites, where the recycled coarse aggregate is dependent on contamination of debris sources. Different mixes with partial replacement of recycled coarse aggregates in GPC and OPC were prepared and tested for comparison of strength.

2. Materials

2.1 Cement

Cement Ordinary Portland cement 53 grade conforming to Indian Standard is used for OPC in the present investigation of specific gravity 3.12**.**

2.2 Fly ash

Flyash used in this study was obtained from National Thermal Power Corporation, Ennore and the specific gravity of flyash is 2.14.

2.3 Ground granulated blast furnace slag

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. GGBS is a glassy, granular, non-metallic material consisting essentially of silicates and aluminates of calcium and other bases. The specific gravity of GGBS is 2.9.

2.4 Fine Aggregates

The locally available river sand of zone III was used as fine aggregate in the present investigation.

2.5 Coarse Aggregates

Natural and recycled aggregates were used as the coarse aggregates in the concrete mixtures. Locally available crushed granite of medium size 20mm and 12.5mm was used as the natural coarse aggregate. Recycled aggregates obtained from demolished building of having age 8 years were used

2.6 Alkaline activator

The alkaline activator liquid used was a combination of sodium silicate solutionand sodium hydroxide. An analytical grade sodium hydroxide in Flakes form (NaOH with 98% purity) was used. To avoid effects of unknown contaminants in laboratory tap water, distilled water was used for preparing activating solutions.. The activator solution was prepared at least one day prior to its use in specimen casting**.**

2.7 Water

Distilled Water for GPC and Potable water for normal concrete which are free from chemicals and organic materials were used for the study.

2.8 Super plasticizer- MasterGlenium SKY 8233

PERFORMANCE TEST DATA: Aspect Light brown liquid, Relative Density 1.08 +_ 0.01 at 25°C ,pH >6 ,Chloride ion content < 0.2% .DOSAGE: Optimum dosage of MasterGlenium SKY 8233 should be determined with trial mixes. As a guide, a dosage range of 500 ml to 1500ml per 100kg of cementitious material is normally recommended by manufacturer.

3. DETAILS OF EXPERIMENTS

3.1. Mix design of Geopolymer concrete

For the present study, concentration of sodium hydroxide was taken as 10M and alkaline solution ratio as 2.5 .The various mix proportions are given in Tables-1 and 2 for GPC and normal concrete.

Table -1 : Mix Proportions of Geopolymer Concrete

Material		**Mix-1**	**Mix-2**	**Mix-3**	**Mix -4**	**Mix-5**	**Mix -6**
Coarse aggregates Kg/m^3	20mm	388.2	258.8	-----	388.2	258.8	-----
	12.5mm	905.8	905.8	905.8	905.8	905.8	905.8
	RCA (20mm)	----	129.4	388.2	----	129.4	388.2
Fine aggregates, Kg/m^3		554	554	554	554	554	554
Flyash, Kg/m^3		306	306	306	204	204	204
GGBS, Kg/m^3		102	102	102	204	204	204
SodiumHydroxide, Kg/m^3		41	41	41	41	41	41
SodiumSilicate Solution Kg/m^3		103	103	103	103	103	103
Superplasticizer, lit/m^3		4.89	4.89	4.89	4.89	4.89	4.89
ExtraWater, lit/m^3		22.5	30.5	44.5	22.5	30.5	44.5
Alkaline solution / Flyash (ratio)		0.35	0.35	0.35	0.35	0.35	0.35

Table-2 : Mix Proportions of Cement Concrete

Material		**Mix-7**	**Mix-8**	**Mix-9**
Coarse aggregates Kg/m^3	20mm	379.76	253.18.	------
	12.5mm	859.23	859.23	859.23
	RCA (20mm)	-------	123.52	370.55
Fine aggregates Kg/m^3		781.31	781.31	781.31
Cement Kg/m^3		320.00	320.00	320.00
Water/Cement ratio		0.45	0.45	0.45

3.2. Preparation, Casting and Curing

3.2.1 Geopolymer Concrete

Davidovits (2002) suggested that it is preferable to mix the sodium silicate solution and the sodium hydroxide solution together at least one day before adding the liquid to the solid constituents. Mix sodium hydroxide solution and sodium silicate solution together at least one day prior to adding the liquid to the dry materials. GPC can be manufactured by adopting the conventional technique used in the manufacture of Portland cement concrete. The fly ash and the aggregates were mixed together dry on pan for about 4 minutes. The solution is then added to the dry materials and the mixing continued for another 5 minutes for each mixture with different percentage of RCA. Pan mixer was used for mixing and table vibrator was used for compacting the Cube and cylinder specimens.

Heat curing of GPC is generally recommended, both curing time and curing temperature influence the compressive strength of GPC. After casting the specimens they were kept in rest period for one day and then kept at 90° C for 18 hrs in an oven. The demoulding procedure is similar to that of conventional concrete. The specimens were tested as per IS 516:1959

3.2.2 Cement concrete

All specimens were cast in steel moulds and compacted using Table vibrator. After casting, the specimens were cured in air for a period of 24 hr, and then removed from mould. The specimens were cured in a water tank at 27 ± 1 C until the test ages (7days, 14days and 28 days) were reached

3.2.3 Preparation of Specimens

Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the hardening concrete. Both OPCC and GPC were mixed in a tilting drum mixer machine for about 6-8 minutes. Concrete was placed in the mould in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted using vibrating table. Specimens were demoulded after 24hrs.The OPC cubes were water cured for a period of 7, 14 and 28 days while the GPC cubes and cylinders were cured in oven and ambient temperature, in the laboratory for a period upto 7,14 and 28 days after casting, After the curing period the specimens were tested. Workability of fresh concrete was observed by the Slump test conducted immediately after mixing of each geopolymer concrete. Generally geopolymer concrete mixtures showed sticky and viscous behaviour in fresh state.. Slump was also influenced by the slag content in the mixture and decreased with the increase of slag content. Hence extra water and superplasticiser were added to improve workability of the mixtures.

Fig-1: Specimens in the vibrating table

Fig- 2 :Specimens are placed in the oven for heat curing

Table -3: Details of Specimens

Type of specimen	Type of concrete	Size of specimen	No of specimens	Type of Curing
Cube	Geopolymer Concrete	100mm*100mm*100mm	81	Oven curing
Cube	Geopolymer Concrete	150mm*150mm*150mm	27	Ambient curing
Cylinder	Geopolymer Concrete	100mm*200mm	45	Oven curing
Cube	Cement Concrete	100mm*100mm*100mm	27	Water Curing
Cube	Cement Concrete	150mm*150mm*150mm	09	Water Curing
Cylinder	Cement Concrete	100mm*200mm	09	Water Curing

4. RESULTS AND DISCUSSION

4.1 Compressive strength – oven curing

For the determination of cube compressive strength of concrete Specimens, cubes of size 100×100×100mm were cast and cured at 18 hours at 90°C degrees in oven for geopolymer concrete and water curing for cement concrete. After curing the geopolymer concrete were kept at ambient temperature and specimens were tested in compression testing machine at the age of 7,14 and 28th day. Compressive strength of geopolymer concrete with 10% and 30% replacement of RCA varied with the variation of slag content in the mixture. Strength of concrete mixtures increased from the early age of 7 days and continued to gain strength upto 28 days. The compressive strength of the different mixtures at the ages of 7,14 and 28 days are shown in Fig. -4,5,6 and 7.

The compressive strength (fc) was computed from the fundamental principle as,

fc = load at failure / cross sectional area (Mpa)

Where, P = load at failure (N) and

A = Area of the specimen (mm^2)

. **Fig – 3: Compressive strength testing on Cubes**

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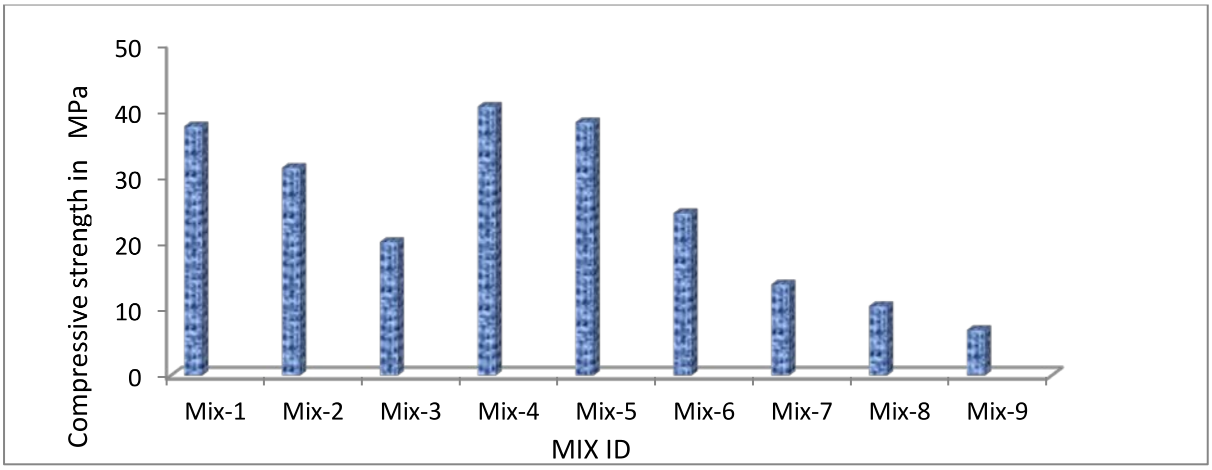

Fig -4: Compressive strength for various mixtures at 7days.

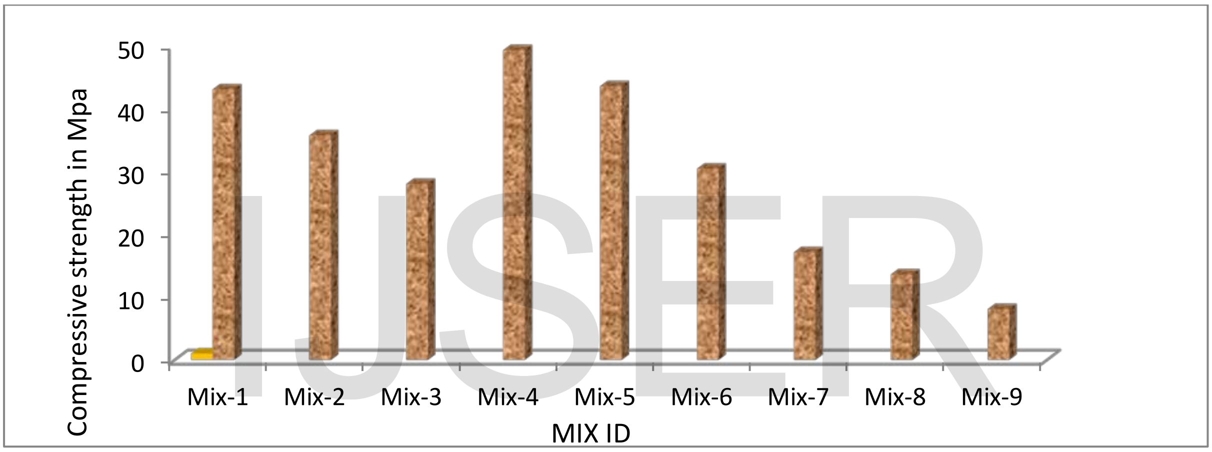

Fig -5 Compressive strength for various mixtures at 14 days.

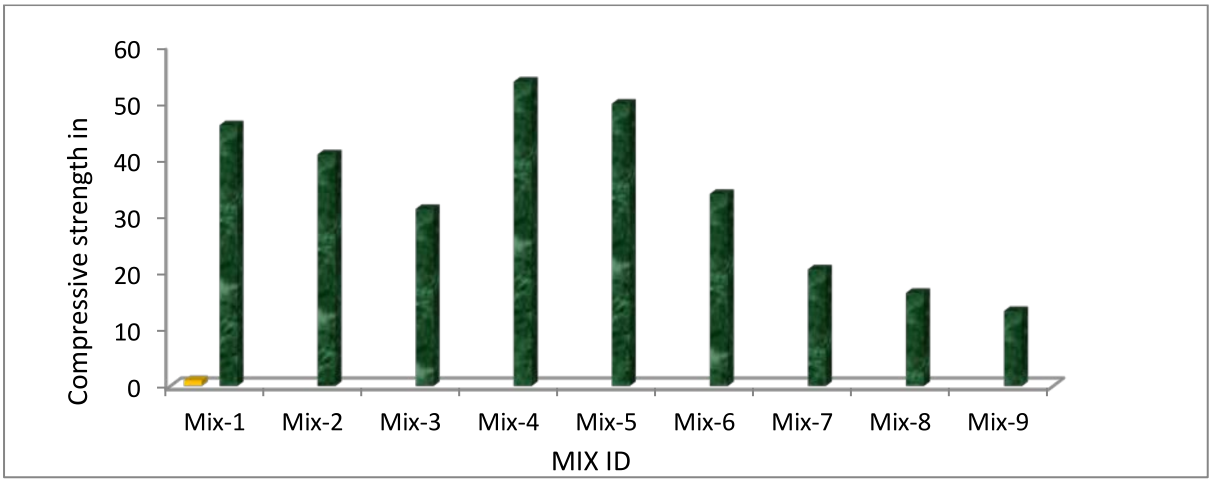

Fig -6 Compressive strength for various mixtures at 28 days

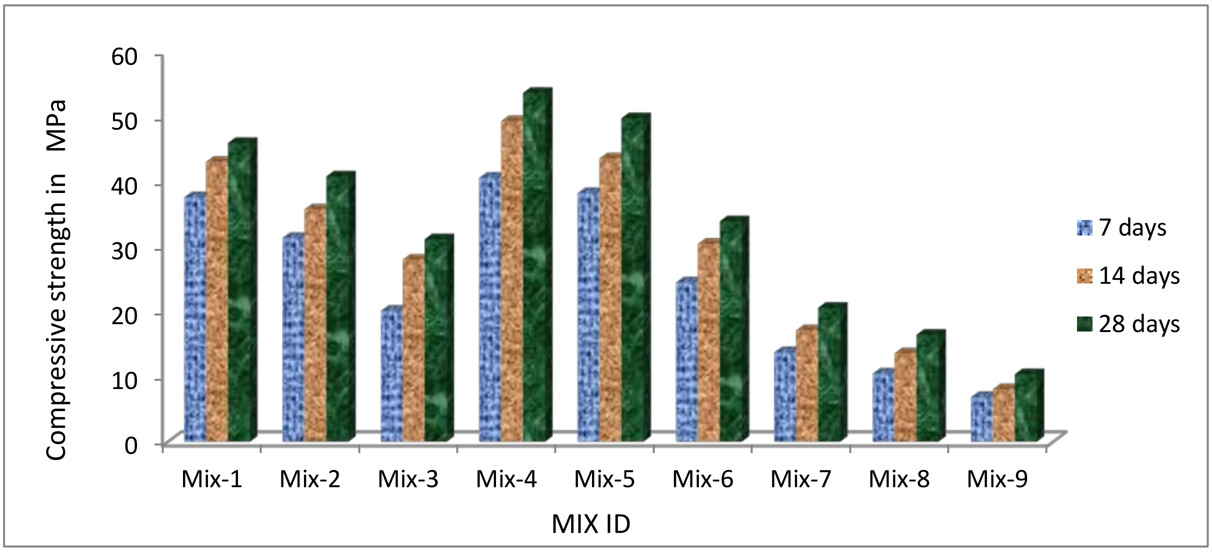

Fig -7: Compressive strength for various mixtures at 7,14 and 28days.

4.2 Spillt tensile strength

For the determination of splitting tensile strength of concrete, cylinder specimens of diameter to length ratio 1:2 was selected. The use of slag as partial replacement of flyash improved the splitting tensile strength of geopolymer concrete and showed decrease in the strength when 10% and 30% RCA used in the mixture. The splitting tensile strength of various mixtures is shown in Fig -9:

Splitting tensile strength (ft) was obtained using the formula,

$$ft = 2P/ \pi DL \qquad (N/mm^2)$$

Where, P = load at failure (N)

D = diameter of specimen (mm),

L = length of specimen (mm)

Fig-8 : Split tensile strength testing on cylinder.

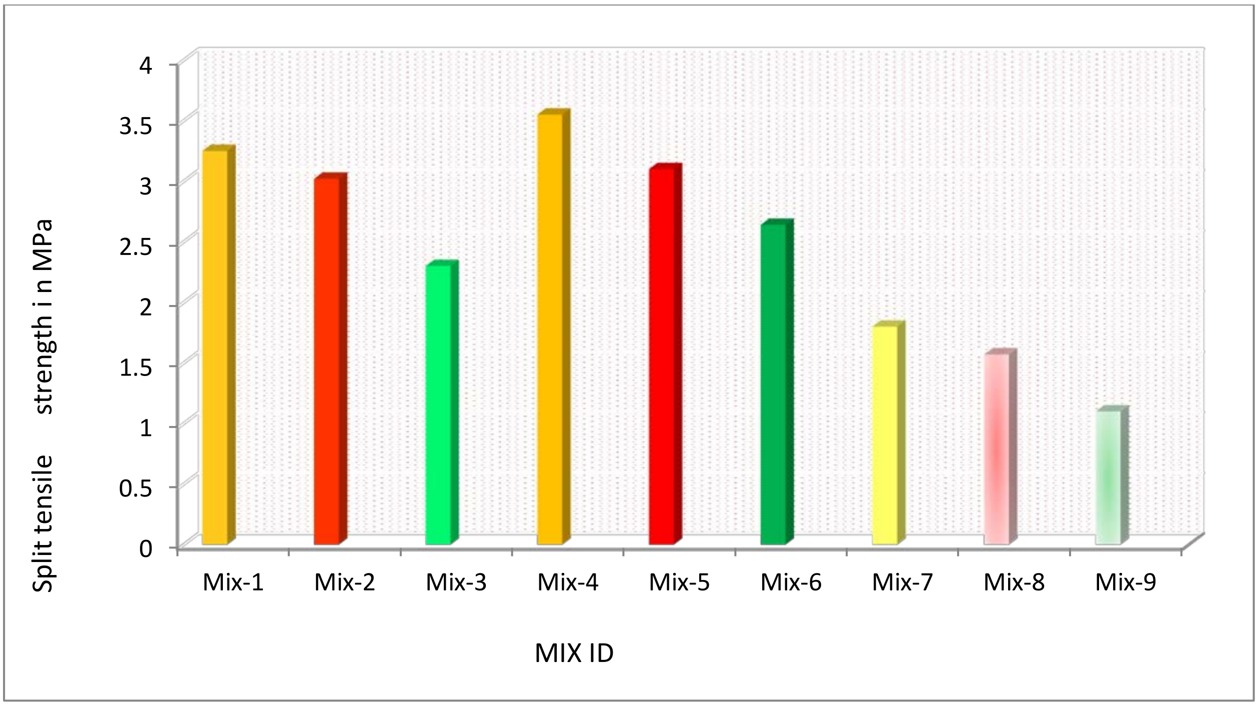

Fig-9: Splitting tensile strength Versus various mixtures at 28days

4.3 Compressive strength- Ambient curing

For the determination of cube compressive strength of concrete. Specimens, cube of size 150×150×150mm. were cast and cured at ambient temperature for 28 days for geopolymer concrete and water curing for cement concrete and specimens were tested in compression testing machine. Compressive strength of geopolymer concrete with 10% and 30% replacement of RCA varied with the variation of slag content in the mixture. The compressive strength of various mixtures is shown in Fig-10 Compressive strength (fc) was computed from the fundamental principle as fc = load at failure / cross sectional area (Mpa) Where, P = load at failure (N)

A = Area of the specimen (mm^2)

Fig -10: Compressive strength testing on Cubes of size 150mmx150mmx150mm

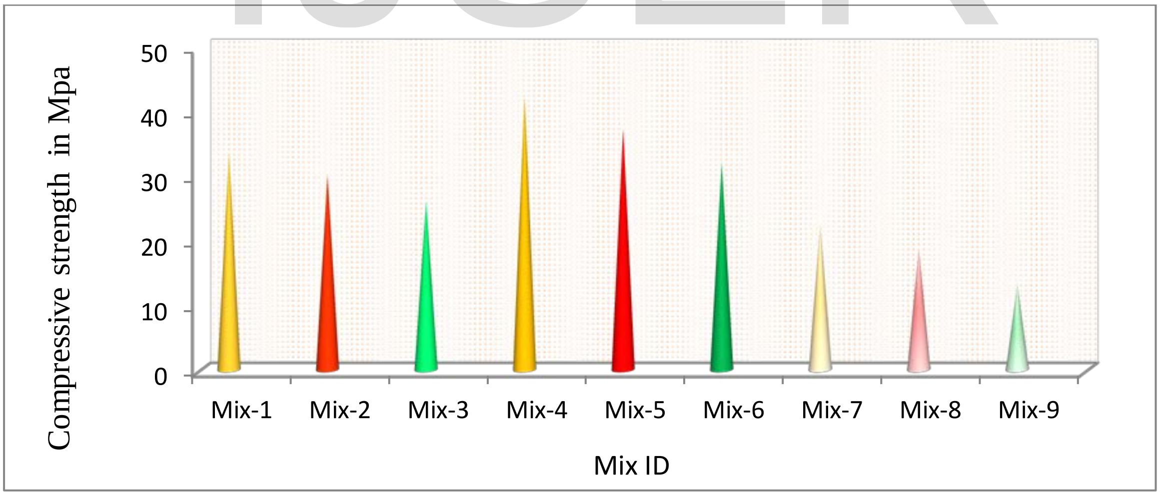

Fig -11: Compressive strength of Ambient cured Geopolymer Concrete and water cured Cement Concrete at the age of 28 days.

4.4 Compressive strength of cubes-oven curing .

Compressive strength of Mix-3 (30% RCA , 25% GGBS and 75% flyash) Shows 32.22% decrease in the strength compared with Mix-1 (0% RCA , 25% GGBS and 75% flyash)

Compressive strength of Mix-6 (30% RCA ,50% GGBS and 50% flyash) Shows 36.83% decrease in the strength compared with Mix-4 (0% RCA , 50% GGBS and 50% flyash)

Compressive strength of Mix-9 (30% RCA and 100% cement) Shows 49.62% decrease in the strength compared with Mix-7 (0% RCA and 100% cement)

4.5 Split tensile strength of cylinders – Oven curing

Split tensile strength of Mix-3 (30% RCA , 25% GGBS and 75% flyash) Shows 29.23% decrease in the strength compared with Mix-1 (0% RCA , 25% GGBS and 75% flyash)

Split tensile strength of Mix-6 (30% RCA ,50% GGBS and 50% flyash) Shows 25.63% decrease in the strength compared with Mix-4 (0% RCA , 50% GGBS and 50% flyash)

Split tensile strength of Mix-9 (30% RCA and 100% cement) Shows 38.89% decrease in the strength compared with Mix-7 (0% RCA and 100% cement)

4.6 Compressive strength of cubes – Ambient curing

Compressive strength of Mix-3 (30% RCA , 25% GGBS and 75% flyash) Shows 22.80% decrease in the strength compared with Mix-1 (0% RCA , 25% GGBS and 75% flyash)

Compressive strength of Mix-6 (30% RCA ,50% GGBS and 50% flyash) Shows 11.96% decrease in the strength compared with Mix-4 (0% RCA , 50% GGBS and 50% flyash)

Compressive strength of Mix-9 (30% RCA and 100% cement) Shows 41.25% decrease in the strength compared with Mix-7 (0% RCA and 100% cement)

5. CONCLUSIONS:

- Conventional methods of mixing, compaction, moulding and demoulding can be adopted for GPC’S, as the GPC does not have any Portland cement, they can be considered as less energy intenstive and GPC utilize the industrial wastes such as fly ash and GGBs for producing the binding system in concrete. Therefore these concretes should be considered as eco-friendly materials.
- Compressive strength of geopolymer concrete increased with the increase of GGBS content.
- Compressive strengths of cement concrete and geopolymer concrete shows decrease in the strength when partially replaced with recycled coarse aggregates.
- Split tensile strength of cement concrete and geopolymer concrete shows decrease in the strength when partially replaced with recycled coarse aggregates.

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Regards

M.K.Thangamanibindhu

Research scholar

St.Peter’s University

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Chennai

Mobile no: 9790742730

mktbindhu@gmail.com.