International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.5., Issue.5, 2017
Sept-Oct

RESEARCH ARTICLE

ISSN: 2321-7758

AN EXPERIMENTAL INVESTIGATION ON BOND STRENGTH OF GEO POLYMER CONCRETE

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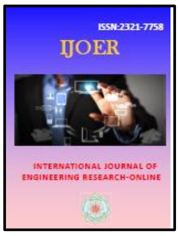

ABSTRACT

The major problem that the world is facing today is the environmental pollution. In the construction industry mainly the production of ordinary Portland cement (OPC) will cause the emission of pollutants which results in environmental pollution. The production of one ton of Portland cement emits approximately 850kg of CO2 into the atmosphere. An effort in this regard is the replacement of Portland cement with materials of biological origin or by-product materials such as FLYASH, GGBFS etc. The silicon present in GGBFS and FLYASH is activated with an alkaline liquid which is a combination of Sodium Silicate and Sodium Hydroxide solutions to form Alkaline activated paste that binds other unreached materials. In this work the influence of Fly ash and GGBFS on the strength of geo-polymer concrete activated by using 8M alkaline solutions for fluid to binder ratio of 0.46, 0.445 and 0.43 are studied. Tests were carried out on 150mmX150mmX150mm cubes.

In the present work, the strength characteristics of Geopolymer Concrete using fly ash and GGBS in Compression and as well as Bond were studied. To study the BOND STRENGTH of concrete by using pullout test method (IS 2770-part1), by 16mm diameter Mild and HYSD steel bars were used.

1. INTRODUCTION

Among all the industries, construction industry consumes the foremost raw materials, as well as each the renewable and non-renewable resource. Investigation shows that concrete is that the largest volume industrial product on earth (apart from the treated water) with a production of regarding one ton of concrete per capita factory-made per annum. Throughout the assembly of concrete, immense quantities of aggregates and cement are consumed per annum. However, the qualified natural aggregates for concrete production are being depleted, and also the manufacture of cement is very energy overwhelming and emits gas carbon dioxide. The cement producing currently ranks because the seventh most energy intensive industry within the US and up to seven-member of worldwide CO_2 are produced by the industry of ordinary Portland cement The emission of carbon dioxide throughout the assembly of ordinary Portland cement is tremendous as a result of the assembly of 1 ton of Portland cement emits close to one ton of CO_2 into the atmosphere

The geo polymer technology shows goodly promise for application in concrete industry as an alternative binder to the Portland cement In terms of worldwide warming, the alkaline geo polymer concrete considerably cut back the carbon dioxide emission to the atmosphere caused by the cement industries Davidovits (1988; 1994) projected that associate degree alkaline liquid can be used to react with the silicon (Si) and aluminium (Al) in a very source material of earth science origin or in by product materials like fly ash and GGBS to produce binders. As a result of the method chemical change chemical action} that takes place during this case could be a polymerization process, he coined the term alkaline Activated to represent these binders.

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The geo polymer concrete has 2 limitations like the delay in setting time and also the necessity of heat curing to achieve strength. These 2 limitations of geo polymer concrete mix was eliminated by replacing 100 percent of fly ash by OPC on mass basis with alkaline liquids resulted in geo polymer Concrete Composite (GPC mix)

The present work is aimed toward the study on the compressive strength, split tensile strength, bond strength characteristics of geo polymer using fly ash and GGBS that are producing at close temperature conditions while not water curing.

1.1: WHAT IS WRONG WITH CEMENT CONCRETE?

- Many concrete structures deteriorate when twenty years.
- Cement production releases high amounts of CO_2 in to the atmosphere (1tonne of cement production releases 1tonne of CO_2) (0.55tonnes of CO_2 is free because of chemical action and zero.4tonnes of CO_2 is free because of combustion of carbon fuel) therefore contributively to seven-member of world CO_2 emissions.
- Cement is one amongst the foremost energy intensive material.
- Cement is factory-made from natural resources.

1.2: MAKING OF CEMENT:

Cement is created by heating limestone (calcium carbonate) with little quantities of alternative materials (such as clay) to 1450 °C in a very kiln, in a very method referred to as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to create calcium oxide, or quicklime, which is then blended with the other materials that are included within the mix. The ensuing hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to form 'Ordinary Portland Cement', (often referred to as OPC). Cements also are available in different grades in market like 41, 43. 51, 53 etc.

1.3: HOW TO REDUCE THE USE OF CEMENT?

- 1. Partially replace the use of cement in concrete.
  Example: High volume fly ash and GGBFS concrete.
- 2. Develop alternate materials.
  Example: Geo polymer concrete.

1.4:GEO POLYMER CONCRETE:

'Geo Polymer Concretes' (GPC) are Inorganic polymer composites, which are prospective concretes with the potential to form a substantial part of an environmentally sustainable construction by replacing/supplementing the conventional concretes. GPC have high strength, with good resistance to chloride penetration, acid attack, etc. These are ordinarily formed by alkali activation of industrial alumina silicate waste materials like fly ash and GGBS, and have a very small Greenhouse footprint in comparison to traditional concretes. It is a mixture of binder (aluminium silicate material), fine aggregate, coarse aggregate and alkaline resolution. Water reducing agent within the form of super-plasticizer can be added for workability. And also, further water can be added for increased workability. Hardened cementations paste made from AL-SI rich

- Materials and alkaline solution
- Combines waste product into useful product
- Setting mechanism depends on polymerization

1.5: GEOPOLYMERS (OR) ALKALINE ACTIVATED POLYMERS:

- Geopolymers are inorganic polymers.
- Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials. Geopolymers can be classified into two major groups: pure inorganic geopolymers and organic containing geopolymers, synthetic analogues of naturally occurring macro molecules.
- An alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or bi-product materials to produce binders. Here, the chemical reaction that takes place is a polymerisation process. The microstructure of geopolymer material is amorphous instead of crystalline. The polymerisation process involve a

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substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows (Daviovits 1999):

$$M_n [-(SiO_2)_z-AlO_2]_n.wH_2O$$

Where: M= the alkaline element or cation such as potassium, sodium or calcium; the symbol – indicates the presence of bond, n is the degree of poly condensation or polymerisation; z is 1, 2, 3, or higher up to 32.

The chemical reaction may comprise the following steps:

1. Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
2. Transportation or orientation or condensation of precursor ions into monomers.
3. Setting or polycondensation/polymerisation of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately.

1.5.1:MICROSTRUCTURE OF THE ALKALINE ACTIVATED WILL BE AS SHOWN BELOW:

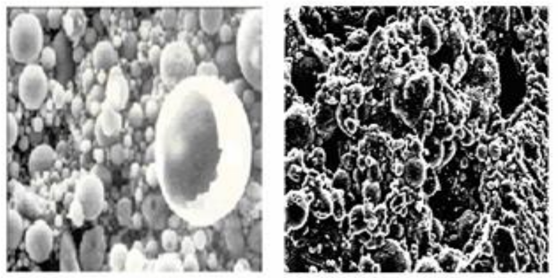

Fig 1: Micro Structure

1.5.2 GEO POLYMER CONCRETE CAN TAKE ONE OF THE THREE BASIC FORMS:

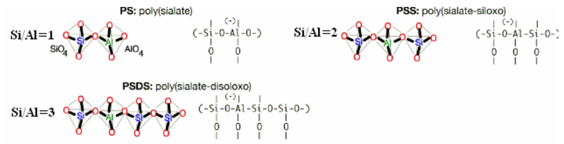

FIG 2: Basic Forms

- Poly (sialate), which has [-Si-O-Al-O-] as the repeating unit.
- Poly (sialate-siloxo), which has [-Si-O-Al-O-Si-O-] as the repeating unit.
- Poly (sialate-disiloxo), which has [Si-O-Al-O-Si-O-Si-O-] as the repeating unit.
- Sialate is an abbreviation of silicon-Oxo-aluminate.
- Water is released during the chemical reaction. The expelled water leaves behind discontinuous Nano pores in the matrix, which provides benefits (resistant to heat, water ingress, alkali–aggregate reactivity, and other types of chemical attack.) to the performance of geopolymers. Therefore, water in a geopolymer mixture plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement mixture during the hydration process.

1.6 SCOPE OF WORK: The study contributes to the development of environmental friendly binders in concrete. The study utilized fly ash and GGBFS because the base materials for creating Geo polymer concrete. As way as possible the technology used for manufacture of OPC paste were used. The concrete property studied is that the compressive strength in relation with the percentage of (GGBFS) constituents used in the alkaline resolution. The tests strategies those were accessible for the ordinary concrete was accustomed predict the result.

2. LITERARTURE REVIEW

Rama Seshu Doguparti [4] in this paper they gave brief discussion about the experimental investigation on the bond strength of geo polymer concrete. The bond strength of geo polymer concrete cubes of grade M35 reinforced with 16 mm thermo mechanically treated (TMT) rod is analyzed. In this investigation they totally prepared 5 cubes in those 5 cubes 3 for finding strength of geo polymer concrete and remaining 2 for bond strength using 16 mm dia bars. Bond strength is determined at age of 7days.The results indicate that the bond performance of reinforced geo polymer concrete is good compare to conventional concrete and it proves it is good for construction.

IS 2770(PART-1)-1967[2] This standard (Part I) covers the method for the comparison of the bond resistance of different types of reinforcing bars with concrete by means of a pull-out test. By using this code book we can find bond strength of various concrete mixes with various bars like mild steel and HYSD etc..,

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B.V. Vijay Rangan[1], Curtin University ,Bentley, Engineering. In this paper they gave brief explanation about geo polymer concrete mixes that means amount of fly ash percentage and sodium hydroxide and sodium silicate percentages. By many investigations on geo polymer concrete finally one mix proportion gave good results based on all proportions that mix proportions briefly discuss in this paper.

Joseph Davidovits[3] Many observers of ancient design are stricken by the large distinction in quality between original structures and more modern repairs. Recent studies have tried to work out why ancient mortars and concretes are such a lot a lot of durable than their modern counterparts. several of those materials are found to be geopolymeric concrete that has been replicated and should encourage be an applicable concrete for several modern purposes.

3.MATERIALS USED:

1.FLY ASH: Class F fly ash is designated in ASTM C 618 and originates from anthracite and bituminous coals. It consists mainly of alumina and silica and has a higher LOI than Class C fly ash. Class F fly ash also has a lower calcium content than Class C fly ash.

Table 1:showing ASTM Requirements of Fly ash

Property	ASTM C618 Requirements, %
SiO_2 plus Al_2O_3 plus Fe_2O_3, min	70
SO_3, max	5
Moisture content, max	3
Loss on Ignition, max	6

Fig. 3: FLY ASH

2.GGBFS: The blast furnace scoria may be a bi-product of the iron producing industry. Iron ore, coke and limestone are fed into the furnace and also the resulting molten scoria floats above the molten iron at a temperature of about 1500°C to 1600°C. The liquid slag has a composition of about half-hour to four-hundredth SiO2 and about 400th CaO, that is near the chemical composition of Portland cement. After the molten iron is tapped off, the remaining liquid slag that consists of mainly siliceous and aluminous residue (Higgins 2000) that is thought as ground granulated blast furnace slag (GGBFS).

Fig 4: GGBFS

3. ALKALINE SOLUTION

- The most common alkaline liquid used in Geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.
- The Sodium Hydroxide (with a molecular weight of 40) will be in flakes and pellet form with about 98% purity. These pellets are mixed with distilled water to obtain the sodium hydroxide solution of required molarity.The concentration of sodium hydroxide solution can vary in the range between 8 Molar and 16 Molar; however, 8 Molar solution is adequate for most applications.
- Addition of sodium metasilicate in water gives sodium metasilicate solution.
- Sodium silicate solution is available in market in the name of 'A50' solution.
- Both the solutions are mixed together to get the alkaline solution and put aside for 24hrs before the usage.

Fig 5: Alkaline Solutions

4.AGGREGATES:

4.1 FINE AGGREGATE:

River sand confirming to ZONE-II has been used as fine aggregate.The specific gravity and water absorption of sand according to IS 2386(part-III,1963)600 microns passing fine aggregate is used in this investigation for preparing of Geo polymer concrete.

Fig 6: Fine Aggregate

By experimental investigation.

1.specific gravity = 2.4

2.fineness modulus = 3.38

3.The bulk density of aggregate=1519.4kg/m^3

4.2 COARSE AGGREGATES:

Three different sizes of coarse aggregates are used in this investigation for preparation geo polymer concrete.

- Passing From 20mm Sieve And Retained On 16mm Sieve.
- Passing From 12mm Sieve And Retained On 10mm Sieve.
- Passed From 6mm Sieve And Retained On 2.36mm sieve.

Fig 7:Coarse Aggregate

The properties of coarse aggregate are as follows

1.Specific gravity of coarse aggregate = 2.875

2.The bulk density of coarse aggregates = 1409.4kg/m^3

5. MIX PROPORTION: An example of calculating the required quantities of different materials for a considered proportion is given below:

Dimension of the cube= 150mm= 150×10^{-3}m.

Volume of the cube= $(0.150)^3$= $3.375\times10^{-3}m^3$

- Total amount of concrete required for 3 cubes = 28kgs.
- Total (binder + fluid) = 23% of total = 6.21kg.
- Only binder = 71.24% of (fluid + binder)= 4.43kg,
- Fluid content = 28.66% of (fluid + binder)= 1.779kg.
- Total aggregate = 77% of total = 21.79kg.
- Fine aggregate = 30% of total aggregate = 6.537kg.
- Total coarse aggregate=70% of total aggregate=15.253kg.(21.173% of 20mm +28.29% of 12mm+50.54% of 6mm)
- The adopted fluid to binder ratios are: 0.46, 0.445, 0.43..

For 6 Cubes

- The weight of binder for 6 cubes =8.86Kg.
- Weight of aggregate (sand) for 6 cubes = 13.074Kg
- Weight of coarse aggregate for 6 cubes =30.506Kg.
- Weight of fluid = 0.46×8.86 = 4.0756Kg, 0.445×8.86 = 3.94Kg and 0.43*8.86=3.81kg.respectively.
- The binder in this research is a mixture of GGBFS and Fly Ash.
- The weights of these two materials are also calculated proportionately.
- For example if the binder contains 100% GGBFS and 0% fly ash then the amount of GGBFS is 4.43Kg and the amount of fly ash is 0Kg.
- For binder contains 75% GGBS and 25% fly ash then the amount of GGBS is 3.33 and the amount of fly ash is 1.1kg.
- For binder contains 50% GGBS and 50% fly ash then the amount of GGBS is 2.215 and the amount of fly ash is 2.215kg.

6. TESTS CONDUCTED:

6.1 WORKABILITY TEST: These tests were conducted before casting the concrete cubes. Many methods are used to find workability in this case Slump cone were conducted.

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Fig 8:Workability Test

Table 2: Workability Test

Mix(%)	Change in fluid content (%)
100% Flyash	40
25% GGBS + 75% Flyash	41.5
50% GGBS + 50% Flyash	43
75% GGBS + 25% Flyash	44.5
100% GGBS	46

6.2 COMPRESSIVE STRENGTH TEST

Fig 9: CTM

The cube specimens prepared were allowed to self curing under ambient conditions and the compressive strength was found out for 3, 7 and 14 days. The cubes were tested in compression testing machine. Three cubes were tested at a time and the results presented here is the mean of the three values.

6.3 BOND STRENGTH TEST: The mechanics of bond stresses ensure the reinforcement is solidly anchored to the surrounding concrete. Analysis and design of the reinforced concrete composite members are based on the assumption that no slippage will occur in the interface of steel and concrete. Bond stress is the shear stress at the reinforcing bar – concrete interface which by transferring load between the reinforcing bar and the surrounding concrete, modifies the steel stresses. This bond stress enables the two materials to form a composite member. The efficiency of a reinforced concrete structural member is based on the adequate composite action between the steel and concrete.

Fig 10: Preparation of cubes for bond

6.3.1SLIP OF BARS:

During slip the bar comes out of the cube as shown in figure:11 which will occur in case of MILD steel bars.

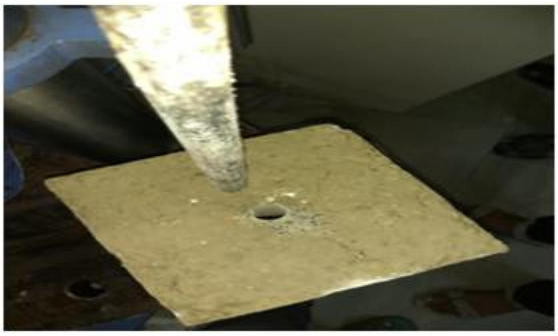

Fig: 11 Slipping of bar

6.3.4 YIELDING OF BARS: In yielding of bars the may broken during testing without slipping as shown In figure 12 which will occur in case of HYSD bars.

Fig:12 Yielding of Bar

6.3.5CRACKS/CRUSHING OF CONCRETE: The cracks were also may develop in cubes during testing in UTM as shown in figure:13 which will occur in case of HYSD bars.

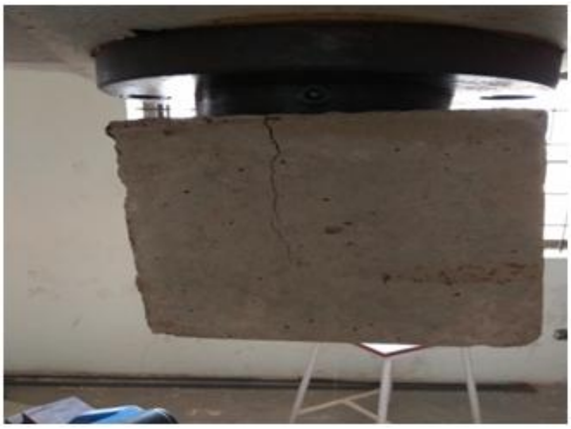

Fig 13: Cracks

6.4 SPLIT TENSILE STRENGTH TEST:

- In Split Tensile Strength Test we prepare the geo polymer concrete as we done before.
- Prepare the cylindrical moulds and apply the grease on it.
- Place the concrete in the moulds and vibrate it.
- After vibration we place the cylinders for 24 Hours in room temperature.
- Then stripping the cubes after 24 hours.
- Place the cylinders for ambient curing after stripping.
- Then the cylinders were tested.

Fig 14: Split Tensile Strength test

7. TEST RESULTS:

TABLE 3: Results of compressive strength

MIX	Compressive Strength (Mpa)			
	3 days	7 days	14 days	28 days
100% FLYASH	22.8	39.55	42.6	43
75% FLYASH	34.8	40.15	43.2	43.76
50% FLYASH	40.59	43.4	48.5	49.14
25% FLYASH	45.23	47.3	49.64	52.1
0% FLYASH	50.68	52.61	54.1	54.34

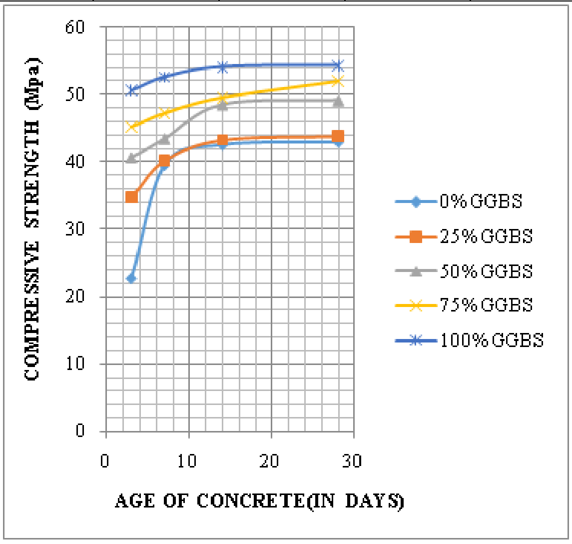

Fig 15: GRAPH B/W COMPRESSIVE STRENGTH AND AGE

TABLE 4: Results of Split Tensile Strength

MIX	Split Tensile Strength (Mpa)			
	3 days	7 days	14 days	28 days
100% FLYASH	4.19	5.31	6.57	7.68
75% FLYASH	5.309	6.57	7.47	8.53
50% FLYASH	6.57	7.64	8.53	9.55
25% FLYASH	7.49	8.7	9.55	10.47
0% FLYASH	8.55	9.55	10.47	11.1

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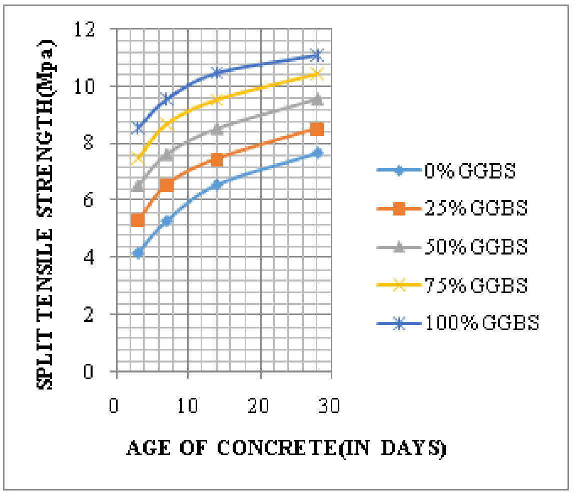

Fig 16: GRAPH B/W SPLIT TENSILE STRENGTH AND AGE

TABLE 5: Results of Bond strength for MILD STEEL.

S. No.	Ultimate Bond Strength(Mpa)			
	For Mild Steel			
	3 days	7 days	14 days	28 days
0% GGBS	6.89	9.3	11.01	12.202
25% GGBS	7.82	10.01	11.936	13.5
50% GGBS	7.95	10.61	12.334	13.9
75% GGBS	8.5	10.87	12.59	14.45
100% GGBS	8.88	11.27	12.99	14.7

TABLE 6: Results of Bond strength for HYSD STEEL.

S. No.	Ultimate Bond Strength(Mpa)			
	For HYSD at 2.5 mm Slip			
	3 days	7 days	14 days	28 days
0% GGBS	11.17	11.27	11.49	11.66
25% GGBS	8.74	10.11	11.42	11.93
50% GGBS	11.495	11.939	11.945	11.95
75% GGBS	11.938	11.943	11.95	11.956
100% GGBS	11.938	11.948	11.956	11.97

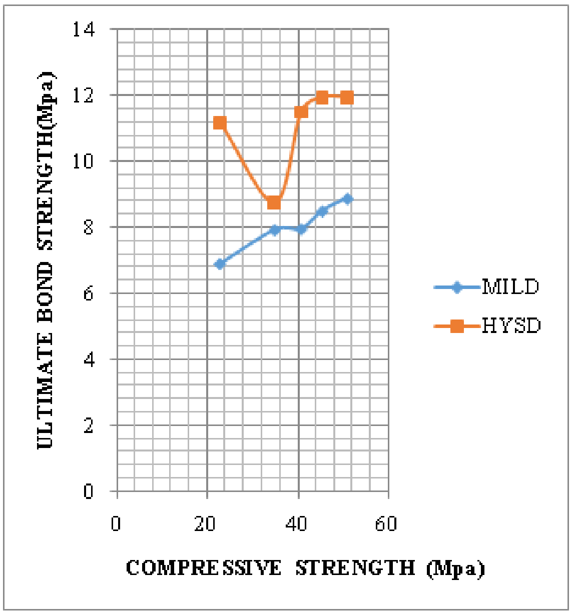

Fig 17: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND COMPRESSIVE STRENGTH FOR 3 DAYS

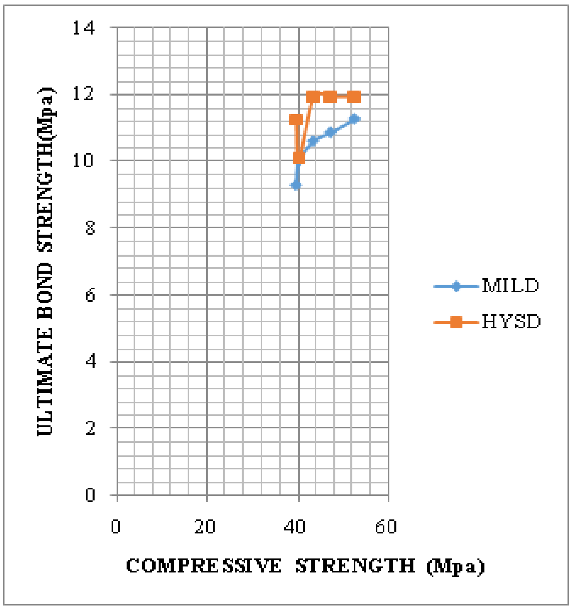

Fig 18: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND COMPRESSIVE STRENGTH FOR 7 DAYS

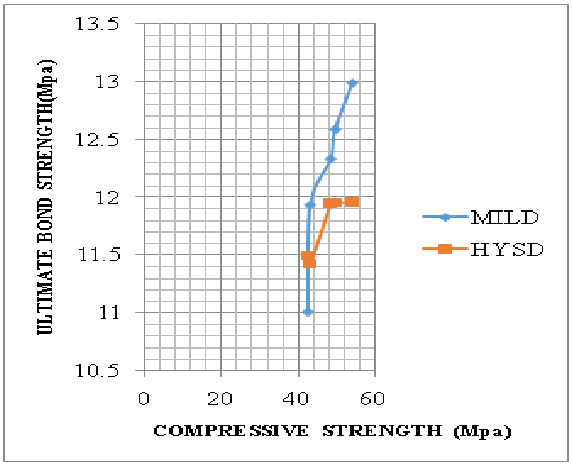

Fig 19: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND COMPRESSIVE STRENGTH FOR 14 DAYS

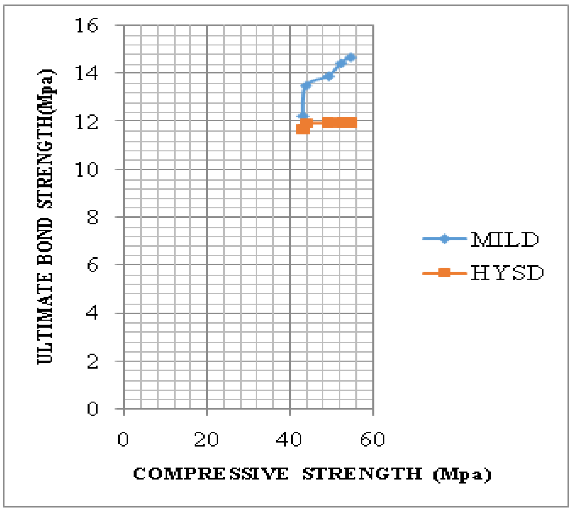

Fig 20: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND COMPRESSIVE STRENGTH FOR 28 DAYS

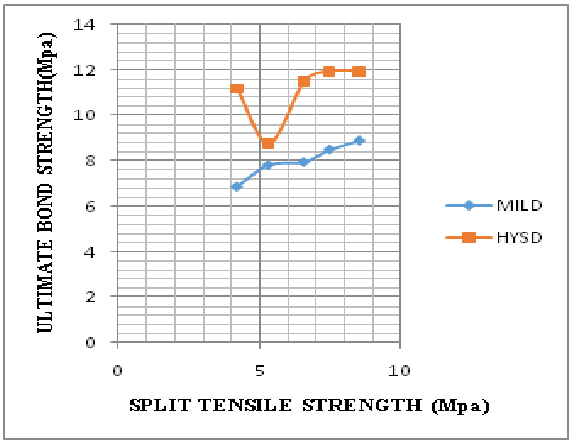

Fig 21: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND SPLIT TENSILE STRENGTH FOR 3 DAYS

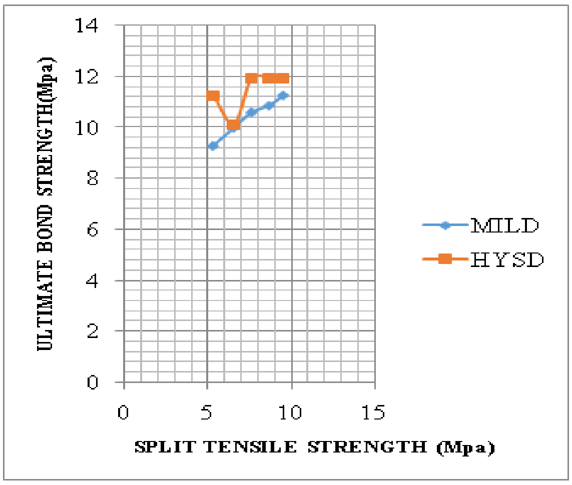

Fig 22: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND SPLIT TENSILE STRENGTH FOR 7 DAYS

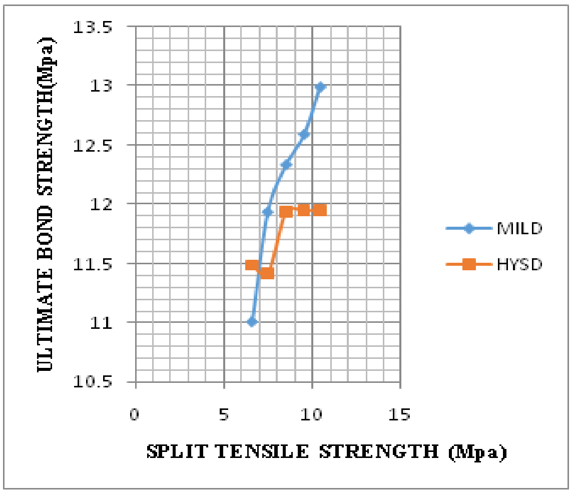

Fig 23: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND SPLIT TENSILE STRENGTH FOR 14 DAYS

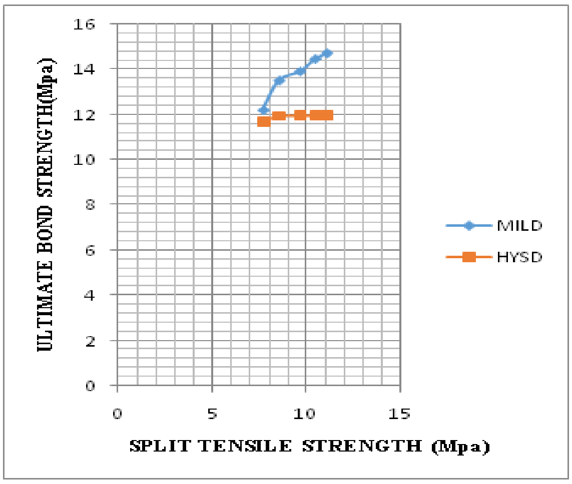

Fig 24: GRAPH B/W BOND STRENGTH OF MILD STEEL, HYSD AND SPLIT TENSILE STRENGTH FOR 28 DAYS

8. CONCLUSIONS:

1. High early age strength can be achieved with GPC made with GGBFS. For the tested based on previous investigations, 60% to 90% of the target strength is achieved in 3 days.
2. As no cement is used, the GPC can be recognized as eco-friendly because, cement production leads to emission of CO_2.
3. The workability of GPC is poor when compared to ordinary cement concrete. However, increase in workability can be achieved by using super plasticizer.
4. For same f/b ratio the workability of (50% GGBFS+ 50% FLY ASH) concrete is found to be better than other two. Hence f/b ratio shall be increased with increase in the GGBFS content.
5. For 100% GGBS the compressive strength increases by 7.77% at 7 days and 16.01% at 14 days when compared to 3 days strength
6. For (75% GGBS+25% FLY ASH) concrete the compressive strength increases by 9.44% at 7 days and 19.75% 14 days. When compared to 3 days strength
7. For (50% GGBS+50% FLY ASH) concrete the compressive strength increases by 6.89% at 7days and 19.4% at 14 days when compared to 3 days strength
8. Compressive strength decreases with increase in Fly Ash content.
9. For 100% GGBFS the three days compressive strength is found to be much higher than the other two.
10. For 100% GGBS the split tensile strength increases by 11.69% at 7 days and 22.45% at 14 days when compared to 3 days strength
11. For (75% GGBS+25% FLY ASH) concrete the split tensile strength increases by 16.15% at 7 days and 27.50% at 14 days when compared to 3 days strength
12. For (50% GGBS+50% FLY ASH) concrete the split tensile strength increases by 16.28% at 7 days and 29.83% at 14 days when compared to 3 days strength
13. Split tensile strength decrees with increase in Fly Ash content.
14. Pull out of bars is possible in case of mild steel used for bond strength test.
15. Yielding of bars takes place in case of HYSD steel used for bond strength test.
16. The ultimate bond strength between GPC and MILD STEEL decreases with increase in Fly Ash content.
17. The bond strength between GPC and MILD STEEL decreases with increase in Fly Ash content.

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