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STRENGTH CHARACTERSTICS OF FIBER REINFORCED GEOPOLYMER CONCRETE FOR RIGID PAVEMENT APPLICATIONS

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Abstract. The present investigation focuses on the design and development of blended fiber reinforced geopolymer concrete for rigid pavement applications. The concrete that is manufactured using alkali activation materials have the potential to replace the OPC as well as the problems that are associated with it. In this investigation, the strength characteristics of GPC for rigid pavement applications are studied and reported. The alkaline initiator solution utilized to activate the GPC binder was NaOH solution of 12Molar concentration, which is mixed in liquid Na2SiO3.The study was divided into two phases and in the first phase of study, the usage of industry residuals like fly ash and GGBS with replacement levels of (50%+50%), (60%+40%) and (40%+60) were used as primary ingredients to prepare GPC of M45 grade and the compressive strength results were noted and in the second phase of study, the strength characteristics of glass fiber reinforced GPC was studied. The test results reported that the prepared GPC is satisfying the strength requirements of rigid pavement applications.

Keywords.Fly ash, GGBS, Alkaline Initiator, Glass Fibers

1. Introduction

The rapid advancements due to globalization around the globe have initiated the living standards of humans with an increment in rate of consumption of natural resources by the humans. This rapid consumption of resources leads to depletion of resources as well as increase in environmental pollution [1]. The industrial waste exhausts from different industries are the major ones among the wastes generated due to industrialization. Trillions of tonnes of these industrial waste exhausts are being generated all around the world, whose dumping is a major problem. These industrial waste exhausts, when disposed in land fills, decrease the productivity of the land. Henceforth, re utilization of these industrial waste exhausts is the one of the alternative solution for this problem[2]. Many researchers have utilized these industrial waste exhausts in the production of concrete and in their related fields. On par with general definition for the term waste, it is any by product or residue that is formed at the end of the process with no usefulness. Now a days, the by products or residues are termed to be unavoidable, instead they are being considered as a symbol of declined resource. Over 1.5 billion tonnes of exhausts are being produced annually throughout the world and only 15% of the generated wastes are being recycled and the majority of wastes are taken to the landfills which are becoming a major cause for contaminations. Despite, with the latest advancements in the waste managing technologies, a sustainable goal of waste management like avoiding and reducing the solid wastes was not achieved. The generation of wastes from the industries have been rapidly growing and it is estimated that this incremental in waste exhausts generation achieves its peak value within few decades unless and until, suitable measures are deployed to handle the wastes [3].Of all these wastes that are being generated,GGBS and fly ash are termed to be two major sources from steel and power plant industries, whose disposal is a typical challenge faced by these industries. The disposal of these wastes in filling the lands is a dangerous activity, since it reduces the soil capacity [4-5].Further; OPC is the major construction material that is being extensively utilized throughout the world. It is an established fact that enormous amounts of green house gases (GHG's) are being generated during the production of OPC. It was also estimated that the production of OPC contributes to 7% of overall pollution. Henceforth, there is a need to find a substitute and alternative material for the conventional OPC which should be eco-friendly and without reducing the quality on par with OPC. The utilization of SCM's in cement concrete which is termed to be blended concretes is one sustainable act in this regard and another alternative is geopolymer concrete or no cement concrete [6-7].The term Geopolymer was coined by Davidovits and it was reported that this concrete has some superior strength characteristics when compared with OPC [8-11].

In this investigation, the design and development of binary blended fiber reinforced GPC for rigid pavement applications is done by taking the above aspects into consideration. The SEM image analysis of binder materials is performed to study the micro structural properties. The optimal dosage of molarity was taken from the literature review and is taken as 12 molar of NaOH [12]. The fresh properties and hardened properties of GPC mortar as well as concrete are studied along with SEM image analysis of binder materials along with GPC concrete.

2.Materials and Methodology

The materials utilized to prepare binary blended Geopolymer concrete are discussed in this section. GGBS with a specific gravity of 2.86, which is procured from Visakhapatnam Steel Plant and FA with a specific gravity of 2.65, which is procured from VTPS, Vijayawada. Table.1 represents the mineral composition of binding materials utilized in current investigation. River sand with stipulations of zone-II and locally available crushed aggregates confirming to the requirements as per IS-383 are utilized. The aggregate material properties are furnished in Table.2. The aggregates utilized in the studyare confirming to the specifications of IS standards i.e., IS:2386-Part 3 (1963).

Table 1: Oxide percentages in binding materials

Binding Material	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	MgO (%)	Fe_2O_3 (%)	Na_2O(%)
Fly Ash-Class F	66.80	1.52	24.50	0.45	4	04
GGBS	39.18	32.82	10.18	8.52	2.02	1.14

Table:2 Aggregate material properties used in the study

Physical Quality	C.A	F.A
G (Specific gravity)	2.67	2.60
Impact value of aggregate	21.4%	-
Crushing value of aggregate	23%	-
Losangeles abrasion resistance	25%	-
% of Water absorption	0.92%	3.96%
Bulk Density a. Dry Loose b. Dry compact	 1499 kg/m^3 1660 kg/m^3	 1440 kg/m^3 1570 kg/m^3
Fineness Modulus	7.25	3.20

The alkaline initiation solution contains solid NaOH in crystalline form with a purity of 98% and liquid Na_2SiO_3 solution and the initiator solution was produced by mixing the alkaline solution containing desired content of NaOH crystals in Na_2SiO_3 and distilled water. The ratio of NaOH to Na_2SiO_3 implemented in the study was 2.5. The alkali consideration of the initiator is a fundamental requirement for imparting the prefunctionary characteristics of binding materials i.e., fly ash and GGBS.

For rigid pavement design and development, flexural strength is the fundamental criteria. As per the specifications of IRC: 15-2011, the min. value of required flexural strength for any rigid pavement is 4.5 MPa, i.e., a concrete grade with min. compressive strength characteristic of above 40 MPa i.e., [M40]. In the present study, M45 grade concrete was chosen and developed by utilizing IS: 10262-2009 code of practice for a slump cone value of 0 to 25 mm[13]. The specified mix design was modified on par with the present literature to prepare

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the Fly ash-GGBS based mix design for binary blended Geopolymer concrete [14] and the quantities are presented in table.3

Table:3 Mix design

Mix	FA+GGBS (50%+50%) (kg/m^3)	Alkaline Solution (Na_2SiO_3 +NaOH) (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	
M45	197.14+197.14	157.72	73.92	20mm----665.28 12mm---- 332.64 6mm ------ 110.88	1108.8

The calculated quantities of binding materials i.e., fly ash & GGBS along with aggregates are mixed in dry condition thoroughly in a mixer. Then the alkaline initiator is mixed.The ingredients are mixed thoroughly until a uniform and homogenous mixture was attained. Standard cube, cylindrical and prism specimens were cast to study the mechanical strength characteristics of binary blended GP concrete. The casted test specimens were kept under ambient curing condition up to the time of testing. The testing procedure of the casted GPC specimens was done based on the specifications of IS code requirements [15]. The SEM image analysis was also performed on the ingredients independently and on blended GPC.The SEM images of used ingredients are furnished in Fig.1 (a,b) & Fig.2.

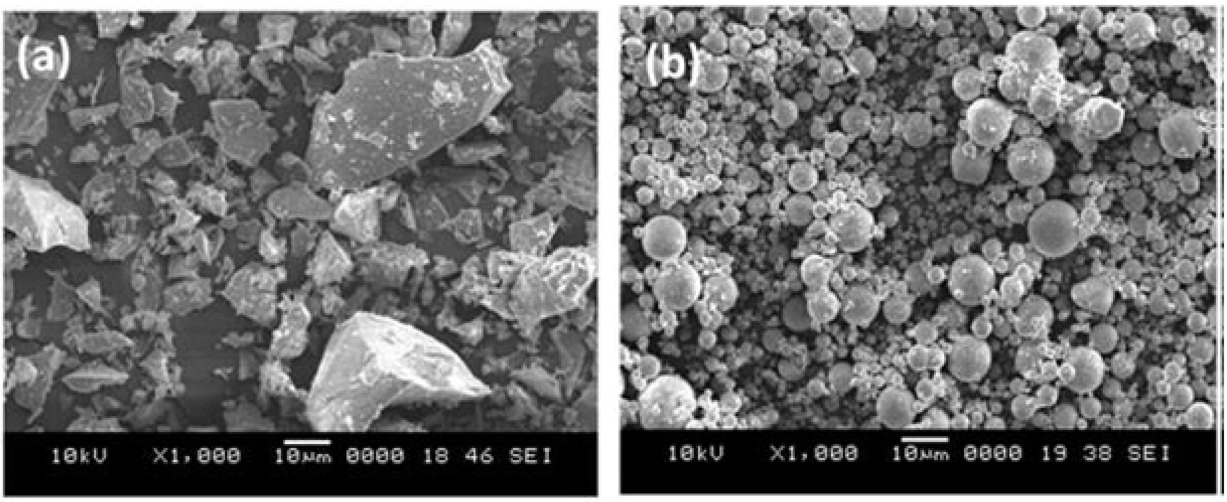

Fig.1 SEM images of (a) GGBS (b) Fly Ash

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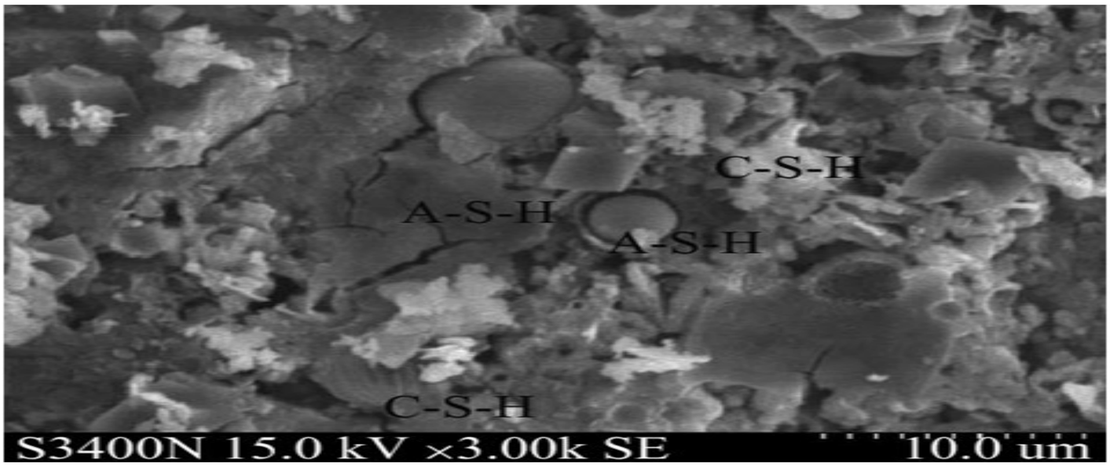

Fig.2 SEM image of binary blended GPC of M45 grade

The SEM images of industrial waste exhausts along with binary blended GPC with (50%+50%) FA and GGBS are furnished in Fig.1(a,b) & 2. The class F-FA particle visual appearance shape is spherical with a smooth surface finish and the range is 1/10th of the max. size of the particle of fly ash. The visual appearance of GGBS particle is straight and rough textured and the size variation ranging from 1 to 10μ. From the above fig., the prepared GPC with the proposed composition formed a condensed structure. With the interaction of GGBS and fly ash, C-S-H and A-S-H gels are formed. GGBS induced an additional calcium content that acted as a further binding agent, which affected the GPC strengthening characteristics. The GPC with proposed composition achieved enhanced strength due to the formation of additional C-S-H and A-S-H gel and a dense micro structural package.

3. Test Results

3.1 Fresh properties, desnity and strength characteristics of GPC

The GPC mix was produced to exhibit workability value of 0-25 mm slump[16]. The cube compression test of the prepared GPC mixes was performed on 100x100x100 mm concrete cube specimens as per the specifications of IS:516[17]. The study was divided into two phases and in the first phase of study, the usage of industry residuals like FA and GGBS with replacement levels of (50%+50%), (60%+40%) and (40%+60) were used as primary ingredients to prepare GPC of M45 grade and the compressive strength results were noted and are furnished in Table 4. In the second phase of study, the optimum mix is selected and the further study was continued. Glass fibers are used to enhance the strength characteristics of GPC.The density of all the GPC mixes was found to be similar to that OPC concrete [18-19]. The test setup of specimens are furnished in Fig.3-5. The test results reported that a maximum 28 days compressive strength was achieved for the replacement level of (50+50%) FA and GGBS in GPC and the obtained test results shown better agreement with the literature[20-21].

Fig.3 Compression test setup of cube

Fig.4 Split tensile test setup

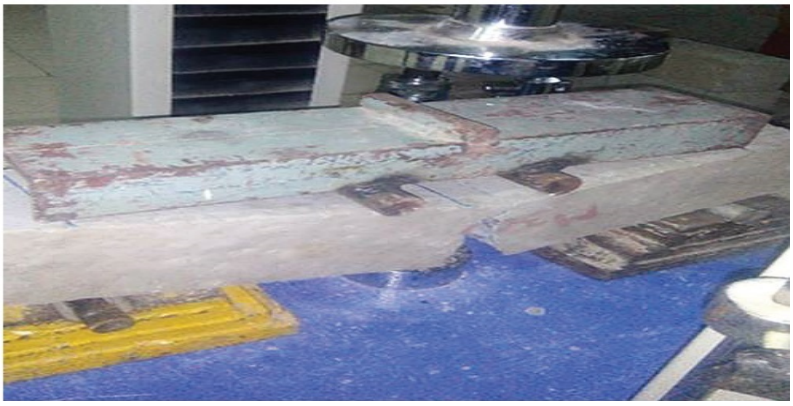

Fig.5 flexural test setup

Table 4: Test results of GPC after 28 days of ambient curing

Mix Designation	% of FA+GGBS	Density of GPC @ 28 days of ambient curing (kg/m^3)	Slump value (mm)	Compressive Strength (MPa)
M-1	(50+50)%	2413	24	53.12
M-2	(60+40)%	2422	20	49.64
M-3	(40+60)%	2402	22	48.53

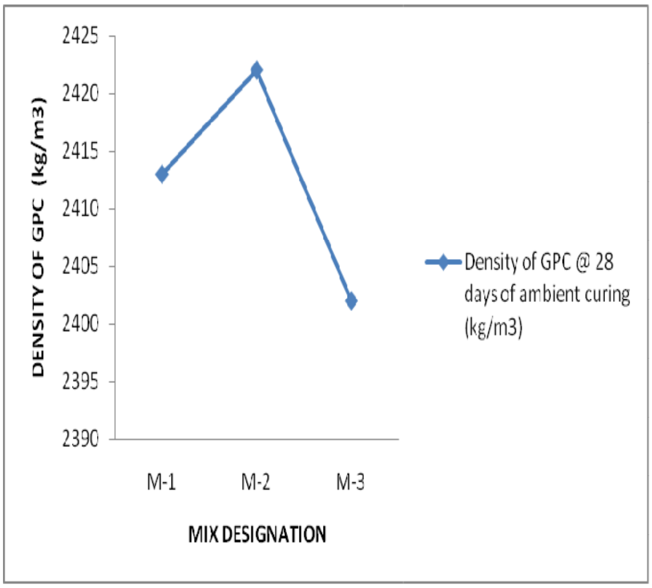

Fig.6 Density of GPC at 28 days of ambient Curing

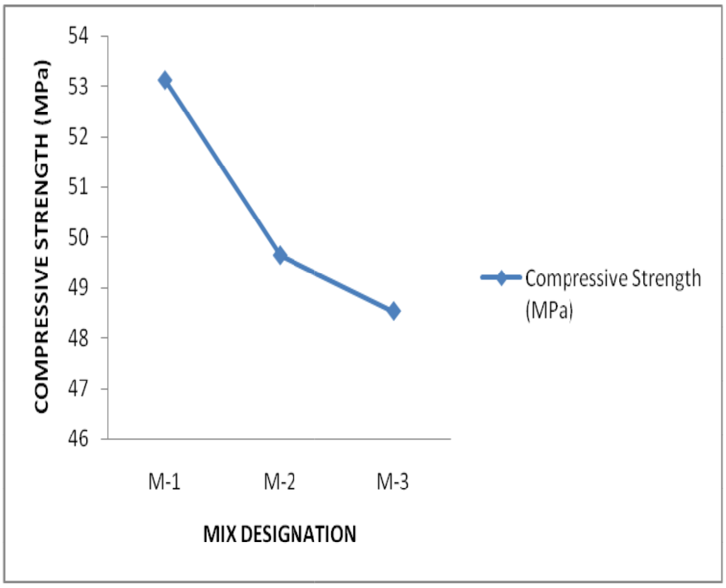

Fig.7 Compressive Strength of GPC at 28 days of ambient curing

From Table.4 and Fig.6,7 it is noticed that with the percentage replacement of GGBS increases, the density of GPC mix also increases and further, the optimum compressive strength is achieved for Mix M-1 and from the test results it is concluded that the test results are in line with literature[20-21]. The mix M-1 is taken as reference mix for the second phase of study and the mechanical strength characteristic of glass fiber reinforced GPC concrete was studied. The test results for II phase of study are furnished in Table.5

Table 5: Mechanical Strength Characteristic of glass fiber reinforced GPC

Mix Designation	% of glass fibers	Slump (mm)	Compressive Strength (MPa)	Split-tensile Strength (MPa)	Flexural Strength (MPa)
M-1	0	24	53.12	4.21	4.61
M-4	0.5	22	53.63	4.35	4.76
M-5	1	18	54.21	4.51	4.95
M-6	1.5	15	56.78	4.79	5.12
M-7	2	10	53.26	4.37	4.89

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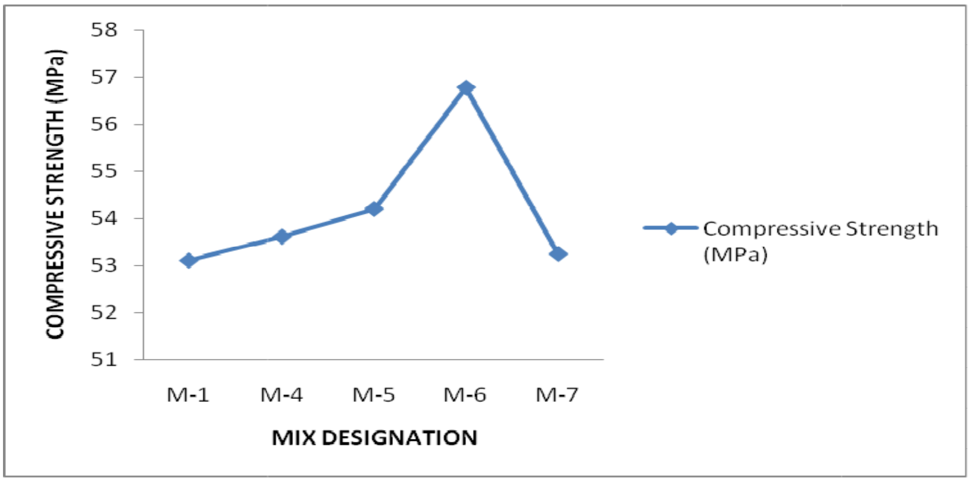

Fig.8 Compressive Strength of glass fiber reinforced GPC at 28 days of ambient curing

From Table 5 and Fig.8, it is noticed that with the inclusion of glass fibers in binary blended geopolymer concrete, the compressive strength is increased and the maximum compressive strength is achieved for Mix M-6 and the percentage increase is found to be 6.89% when compared with mix M-1.

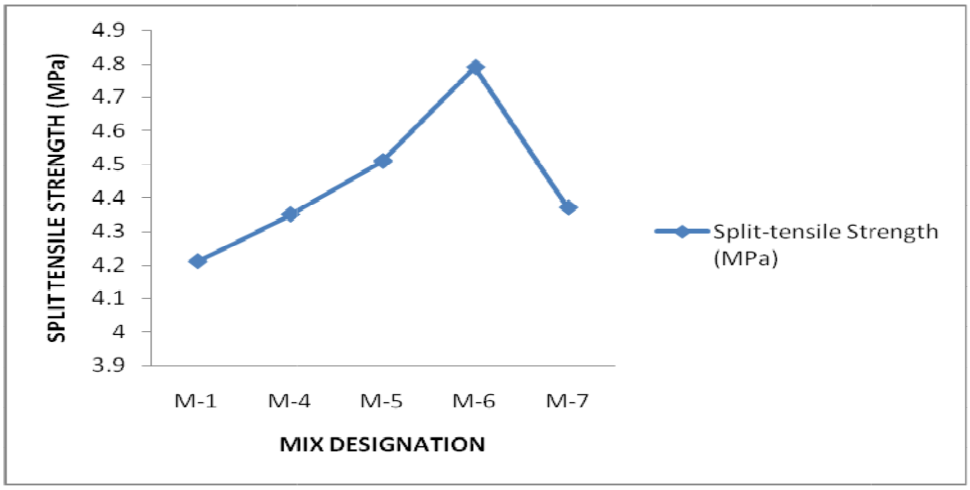

Fig.9 Split-tensile Strength of glass fiber reinforced GPC at 28 days of ambient curing

From Table 5 and Fig.9, it is noticed that with the inclusion of glass fibers in binary blended geopolymer concrete, the split tensile strength is increased and the maximum split tensile strength is achieved for Mix M-6 and the percentage increase is found to be 13.77% when compared with mix M-1.

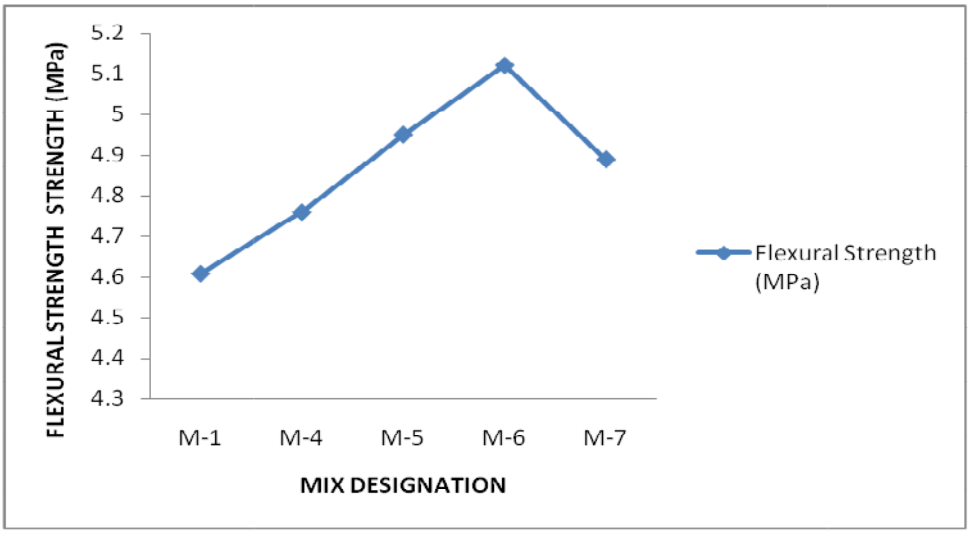

Fig.10 Flexural Strength of glass fiber reinforced GPC after 28 days of ambient curing

From Table 5 and Fig.10, it is noticed that with the inclusion of glass fibers in binary blended geopolymer concrete, the flexural strength is increased and the maximum flexural strength is achieved for Mix M-6 and the percentage increase is found to be 11.06% when compared with mix M-1.

An equation was proposed between flexural and compressive strength of M45 grade geopolymer concrete and the equation was in line with the equation of OPC concrete. Eq.(a) gives the relation between flexural and compressive strength of proposed GPC concrete.

$$f_{cr} = 0.689\ f_{ck}^{0.505} \quad \text{----Eq.(a)}$$

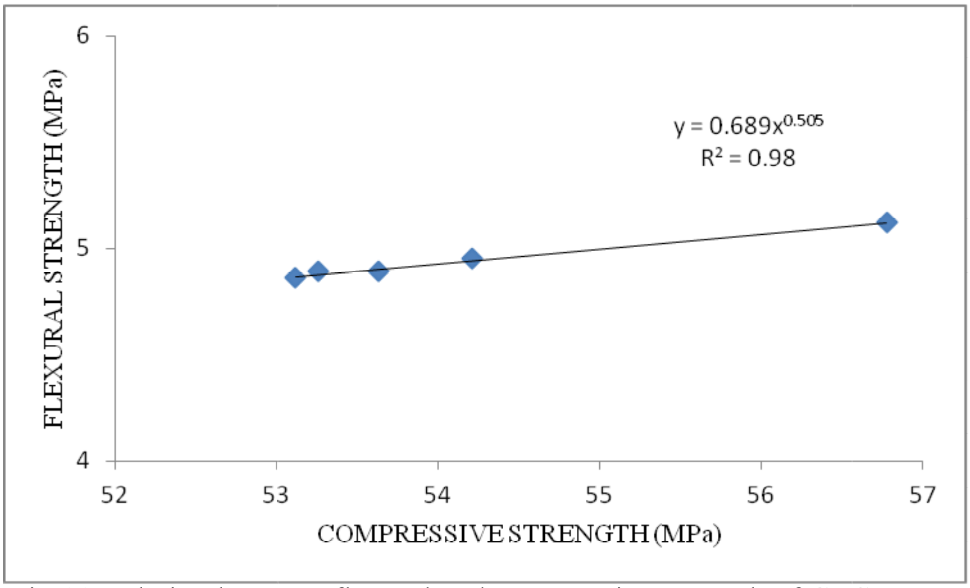

Fig.11 Relation between flexural and compressive strength of GPC concrete

4. Conclusions

The experimental program was performed to attain a quality rigid pavement concrete by utilizing alkaline initiators and also industrial waste exhausts. The aim is to study the use of glass fiber in binary blended geopolymer concrete. In this section, the following conclusions of the experimental program were drawn

1. The density of all the prepared GPC mixes shown the values related to normal OPC concrete and are within the IS codal provisions.
2. The workability range of all cast GPC mixes are in between 0-25 mm
3. The maximum compressive strength was achieved for (50%+50%) of fly ash and GGBS rather than other mixes
4. The maximum mechanical strength characteristic for M45 grade glass fiber binary blended geopolymer concrete was achieved for Mix M-6.
5. The proposed equation for flexural and compressive strength is in line with OPC concrete

REFERENCES

1. A. U. Zaman, "Identification of key assessment indicators of the zero waste management systems", Ecol. Indic. 36 (2014) 682–693. https://doi.org/10.1016/j.ecolind.2013.09.024.
2. A. U. Zaman, A comprehensive study of the environmental and economic benefits of resource recovery from global waste management systems, J. Clean. Prod. 124 (2016) 41– 50. https://doi.org/10.1016/j.jclepro.2016.02.086.
3. D. Hoornweg, P. Bhada-tata, C. Kennedy, Peak Waste When Is It Likely to Occur ?, J. Ind. Ecol. 19 (1) (2014) 1–12. https://doi.org/10.1111/jiec.12165.
4. A. Gholampour, T. Ozbakkaloglu, Performance of sustainable concretes containing very high volume Class-F fly ash and ground granulated blast furnace slag, J. Clean. Prod. 162 (2017) 1407–1417. https://doi.org/10.1016/j.jclepro.2017.06.087.
5. H. Zhao, W. Sun, X. Wu, B. Gao, The properties of the self compacting concrete with fly ash and ground granulated blast furnace slag mineral admixures, J. Clean. Prod. 95 (2015) 66-74. https://doi.org/10.1016/j.jclepro.2015.02.050.
6. M. S. Imbabi, C. Carrigan, S. Mckenna, Trends and developments in green cement and concrete technology, Int. J. Sustain. Built Environ. 1 (2) (2013) 194–216. https://doi.org/10.1016/j.ijsbe.2013.05.001.
7. M. Elchalakani, T. Aly, E. Abu-aisheh, Sustainable Concrete with High Volume GGBFS to Build Masdar City in the UAE, Case Stud, Constr. Mater. 1 (2014) 10–24. https://doi.org/10.1016/j.cscm.2013.11.001.
8. Davidovits, J. (1991). Geopolymers: inorganic polymeric new materials. Journal of Thermal Analysis and calorimetry, 37(8), 1633-1656.
9. Hardjito D, Wallah SE, Sumajouw DMJ, Rangan BV (2004) On the development of fly ash-based geopolymer concrete. ACI Mater J 101(6):467–472

10. Hardjito D, VijayaRangan B (2005) Development and properties of low-calcium fly ash-based geopolymer concrete, Research Report GC 1. Curtin University of Technology, Perth, Australia
11. Kashyap A.M., Rao T.C.S., Rao N.V.R. (2021) Durability Performance of Binary Blended Geopolymer Concrete. In: Abdel Wahab M. (eds) Proceedings of 1st International Conference on Structural Damage Modelling and Assessment. Lecture Notes in Civil Engineering, vol 110. Springer, Singapore. https://doi.org/10.1007/978-981-15-9121-1_15.
12. A.M.N. Kashyap "Prediction Of Setting And Strength Characterstic Of Binary Blended Geopolymer Matrix", i-manager's Journal on Structural Engineering, Vol. 6 l No. 4 l December 2017 - February 2018.
13. Indian Standards, Concrete Mix Proportioning Guidelines. IS:10262-2009. Bureau of Indian Standards, New Delhi, India, 2009, p. 1-11.
14. Kashyap A.M., Rao T.C.S., Rao N.V.R. (2021) Durability Performance of Binary Blended Geopolymer Concrete. In: Abdel Wahab M. (eds) Proceedings of 1st International Conference on Structural Damage Modelling and Assessment. Lecture Notes in Civil Engineering, vol 110. Springer, Singapore. https://doi.org/10.1007/978-981-15-9121-1_15
15. Indian Standards, Indian Standard Methods of Tests- for Strength of Concrete, 1st ed. IS 516-1959. Bureau of Indian Standards, New Delhi, India, 1959.
16. Indian Standards, Methods of sampling and analysis of concrete. IS:1199-1959. Bureau of Indian Standards, New Delhi, India, 1959, p. 1–44. https://doi.org/10.2174/187221013804484881.
17. Indian Standards, Indian Standard Methods of Tests- for Strength of Concrete, 1st ed. IS 516-1959. Bureau of Indian Standards, New Delhi, India, 1959.
18. N. Palankar, A. U. R. Shankar, B. M. Mithun, Investigations on Alkali-Activated Slag / Fly Ash Concrete with steel slag coarse aggregate for pavement structures, Int. J. Pavement Eng. 8436 (10) (2015) 1–13. https://doi.org/10.1080/10298436.2015.1095902.
19. N. Palankar, A. U. Ravi Shankar, B. M. Mithun, Durability studies on eco-friendly concrete mixes incorporating steel slag as coarse aggregates, J. Clean. Prod. 129 (2016) 437–448. https://doi.org/10.1016/j.jclepro.2016.04.033.
20. B. M. Mithun, M. C. Narasimhan, N. Palankar, and A. U. Ravishankar, Flexural Fatigue performance of Alkali Activated Slag Concrete mixes incorporating Copper Slag as Fine Aggregate, SSP-Journal Civ. Eng. 10 (1) (2015) 7–18. https://doi.org/10.1515/sspjce-2015-0001.
21. B. M. Mithun and M. C. Narasimhan, Performance of alkali activated slag concrete mixes incorporating copper slag as fine aggregate, J. Clean. Prod. 112 (2015) 837–844. https://doi.org/10.1016/j.jclepro.2015.06.026.