Nat. Volatiles & Essent. Oils, 2021; 8(4): 3114-3124

Sustainable Medium Strength Geopolymer with Fly Ash and GGBS as Source Materials

Prashant Sunagar[1*], T Geetha Kumari[2], Jyothilakshmi R[3], Mahesh Kumar C L[4], Shwetha K G[4] and Sumalatha J[5], Naveen G M[6]

[1, 2&5]Department of Civil Engineering, M S Ramaiah Institute of Technology, Bangalore, India

[3]Department of Mechanical Engineering, M S Ramaiah Institute of Technology, Bangalore, India

[4]Department of Civil Engineering, Nitte Meenakshi Institute of Technology, Yelahanka, Bengaluru, India

[6]Department of Civil Engineering, Government Engineering college, Chamarajanagara, India

*Corresponding author. Email: prashant.sjce@gmail.com

Abstract

The properties of cement in the world are second only to water. As the interest and demand for concrete as a raw material increases, Portland cement also sparked further interest. Concrete production is expected to increase from 1.5 billion in 1995 to 2.2 billion in 2010 (3% increase in annual production). In 1 ton of cement production, 1 ton of CO_2 is released into the atmosphere. Among ozone depleting substances due to unnatural climate change, the contribution of carbon dioxide to global warming is about 65%. In addition, cement is the building material that requires the most energy. Immunity to OPCs has been shown in studies because many structures are particularly damaged and begin to decline naturally after 20 and 30 years. Efforts should be made to develop eco-friendly construction materials to reduce greenhouse gas emissions.

KEYWORD: Compressive strength, tensile strength, load deflection under flexure, durability

Introduction

The global use and demand of concrete as a construction material is very high, about 1.5 billion tons of cement in 1995 and 2.2 billion tons of cement was manufactured (increasing about 3% annually). For every one tonne cement production about one tonne CO_2 is generated which contributes 65% to global warming (Dharek et al., 2018). Even though the use of cement is so extensive due to its properties and many efforts are being made to reduce its content by substituting it with by-product materials to reduce its effect on global warming. The development of geopolymer concrete in which by-products like fly ash, GGBS, rice husk ash, silica fume etc., is used as powder content and silicon and calcium as a main content are activated in the blast furnace slag. Calcium silicate hydrate gel is produced as a main binder in hydration process. The strength of Geopolymer concrete was studied by Jamkar et al., 2013, Vora and Dave, 2013, Shaikh and Vimonsatit, 2015, Reddy et al., 2016 and Dao et al., 2019, Dharek et al., 2020) The durability studies on Geopolymer concrete were also conducted by many researchers (Law et al., 2015; Ganesan et al., 2015; Luhar et al., 2019; Cheema et al., 2009; Kabir et al., 2019).

The properties of geopolymer concrete were studied by several researchers (Xie et al., 2019; Li et al., 2019; Jena and Panjgrahi, 2029; Amran et al., 2020; Noushini et al., 2020; Shahmansouri et al, 2020; Amran et al., 2021; Moghaddam et al., 2021; Dharek et al., 2020; Shahmansouri et al., 2021). In this paper, geopolymer concrete with binder content as fly ash (ASTM Class F) is used. This paste binds fine aggregate and coarse aggregate and other materials to form concrete (Sumalatha et al., 2020). The alkaline liquid which is the combination of NaOH and Na2SiO$_3$ react with silicon and aluminium present in fly ash to produce paste content. Guohao Fang et.al studied mechanical properties and workability parameters of AAFS concrete cured at ambient temperature was measured to aquire the ideal blend for production application. The outcomes exhibited that with rise in slag content and NaOH solution molarity compressive strength of concrete was improved but both workability and setting time of concrete got decreased. Mohammad Soleymani Ashtiani et.al focused on the usage of the locally available materials, a high-strength SCC mix of a 100 MPa was designed and it was discovered that with an equal w/b ratio, concrete develops higher compressive strength. Pradip Nath et.al trial mixes with different GPC corresponding geopolymer mortar mixtures were designed with ground GGBS as admixture in order to improve the premature age properties. From results the difference between the slag content, the ratio of Na2SiO3, NaOH and the total alkaline activator solution was compared. Marios Soutsos et.al mainly aimed to study the strength development of fly ash based mortar with variation in activator dosage and curing procedure and adding on to this the microstructure of the reacted mortar and strength development of concrete with partial substitution with GGBS was determined.

Methodology

This chapter presents gives details about the methodology use in the production of ASTM Class F fly-ash based geopolymer concrete and normal concrete. There are many trial and error processes involved in the development of GPC made from fly ash. The main objective is to examine the important parameters that affect the dose of the mixture. When possible, follow current practices used in the manufacture and testing of regular Portland cement. The aim of this section is to promote the use of GPC over ordinary concrete in the construction industry to get the benefits of new material.

Following parameters is used to produce M40 grade fly ash-based GPC:

- SiO_2 to (Al_2O_3) ratio by mass of the fly ash in the variety of 2.0 to 3.5.
- Molarity of 8 to 14 M for NaOH.
- Na_2SiO_3 to NaOH liquid ratio by mass.
- Curing temperature at 60^0 C from 24 to 72 hours.

Table 1: Mıx Proportıons For M40 Grade GPC & NC

Materials	GPC M40	NC M40
Cement (kg / m^3)	-	434.2
Fly ash (kg / m^3)	382	-
GGBS (kg / m^3)	42	-
Silica Fume (kg / m^3)	-	-
Coarse Aggregate (kg / m^3)	1295	1050
Fine Sand (kg / m^3)	555	700.8
NaOH Solution 8 mol (kg / m^3)	36	-
Na_2SiO_3 solution (kg / m^3)	90	-
Water (lit / m^3)	16.96	150
Superplasticizer (%)	3	2.5

Materials

Fly ash and GGBS

Fly ash is utilized for the combination of geopolymeric binder. Fly ash of Class F (ASTM) got from Raichur Thermal Power Station. Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the steel industry. SEM analysis of fly ash and GGBS are shown in the figure 1 and 2.

Figure 1: SEM analysis of fly ash

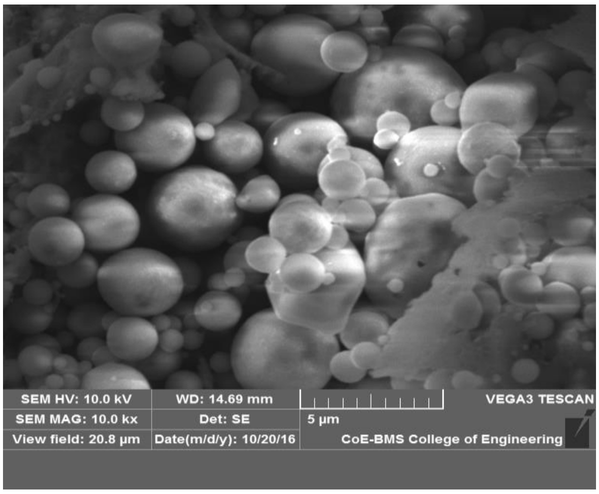
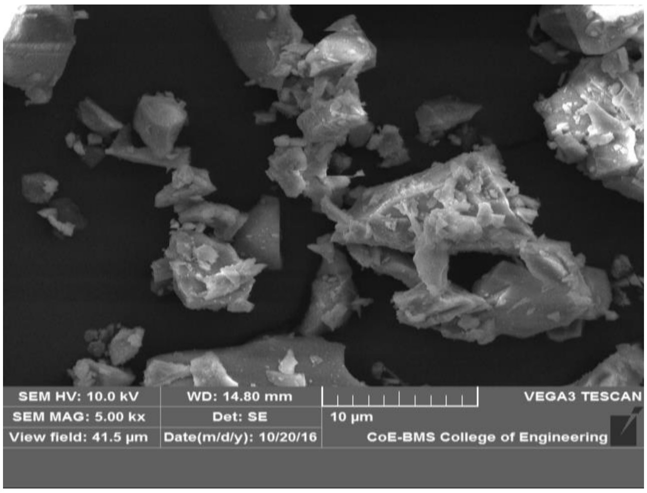


Figure 2: SEM analyses of GGBS



Alkaline Liquids

Na_2SiO_3 and NaOH solutions were used for activating fly ash. 8, 12 and 14 Molar was prepared by blending the pellets of weight 320, 480 and 560gm with water. NaOH particles are mixed with water to form a NaOH solution. Water changes liable on the concentration of the solution articulated in moles (M). For example, 8M contains 8x40 = 320 g NaOH particles per liter of solution (here the number of 8 moles and the molecular weight of 40 NaOH). Prepared to mix Na2SiO3 and NaOH 24 hours before use. Superplasticizer is used to increase workability of concrete. Conplast 430 is used as superplasticizer with is replaced by about 3% by mass of binder. Potable drinking water was used. ACC Birla super 53 cement was used for the experimental work. coarse aggregate of 12.5mm down size and fine aggregate of 4.75mm down size were used.

Strength and Durability properties

Various strength parameters like compressive, flexural, and split tensile strength, durability properties like acid resistance test, sulphate resistance test, and sea water resistance test were also carried out.

For Strength studies

Six cubical moulds of size 100 mm for compressive strength test, six cylindrical moulds of size 150mm diameter and 300mm height for split tensile strength and six prisms of size 75x75x450 mm for flexural strength test were used to prepare specimen of GPC and same of normal concrete.

For Durability studies

Six cubical moulds of size 100 mm each for acid test, sulphate attack test and sea water resistance test, six cylindrical moulds of size 100x200 mm for corrosion test were used to prepare specimen of GPC and same of normal concrete.

Sample Preparation for Strength Propertıes

Compressive strength

The standard cube of 150mm size confirming to IS 10086-1982 was used. The GPC and NC specimens were subjected to compression test at 7, 14 and 28 days of curing and tested using CTM machine.

Split tensile strength

This test conducted using standard cylindrical mould of size 150 mm diameter and 300 mm confirming to IS 10086-1982.The GPC and NC cylindrical specimens were tested for 28 days strength after casting. The split tensile strength (indirect test) was determined as per IS: 5816-1999

Flexural strength

In this test beam mould of size 75x75x450 mm confirming to IS 10086-1982 is used. Test is carried out at the curing age of 28 days using a flexural strength testing machine of 500KN capacity. Beam is subjected to a two-point moulding test confirming to IS: 516-1959.

Durabılıty Tests on Concrete

Acid resistance test

The standard size of 100mm cube specimen is used to conduct acid resistance test at the age of 28 days curing. Weight of specimen is measured in water which is diluted with 2N i.e., 10% by weight of hydrochloric acid for 6weeks. The specimen was subjected to alternate wetting and drying for every 2days, then surface of the specimen was cleaned regularly for a week once the cube is taken out of acid. After this procedure the loss of weight and its compressive strength is measured.

Sea water resistance test

The standard size of of 100 mm cube specimen is used to conduct sea water resistance test at the age of 28 days curing. The sample is engrossed in water with 5% by weight of NaCl for 6weeks. The specimen was subjected to alternate wetting and drying for every 2days, then surface of the specimen was cleaned regularly for a week once the cube is taken out of salt water. After this procedure the loss of weight and its compressive strength is measured.

Sulphate resistance test

The standard size of 150 mm cube specimen is used to conduct sulphate resistance test at the age of 28days curing. The sample is immersed in water with 5% by weight of $MgSO_4$ for 6weeks. The specimen was subjected to alternate wetting and drying for every 2days, then surface of the specimen was cleaned regularly for a week once the cube is taken out of salt water. After this procedure the loss of weight and its compressive strength is measured.

Corrosion test

The difference in electric potential through reinforcement in concrete set up electrochemical cell. At reinforcement interface 1 part becomes anode and the other turn out to be cathode which is coupled by an electrolyte in hardened cement paste in the form of pore water.

Results

Table 2 Trial mixes

Materials	**Mass, Kg/m^3**			
	M 1	**M 2**	**M 3**	**M 4**
Al/Fa	**0.3**	**0.35**	**0.4**	**0.45**
CA	1290	1290	1290	1290
FA	544	544	544	544
Class F, Fly ash	382	366	355	342
GGBS	46	44	41	38
Na_2SiO_3 soln	88	99	109	118
NaOH soln	37	43	46	50
SP	3%	3%	3%	3%
water	3%	3%	3%	3%
Cube strength	40.2	44.2	49.2	50.2

Fig 3: Strength variation with respect to ratio of alkaline liquid to binders

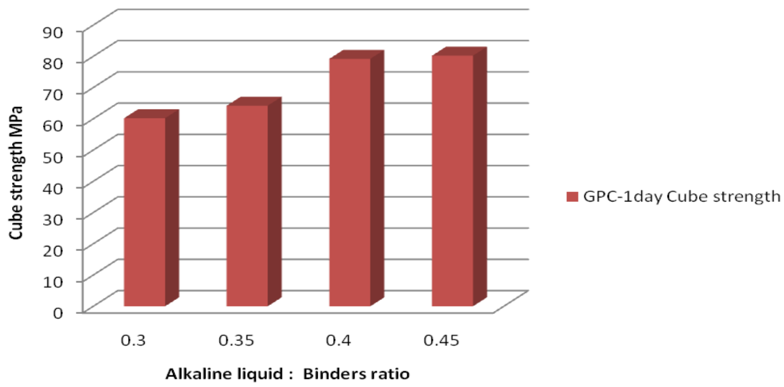


Fig 4: Effect of molarity

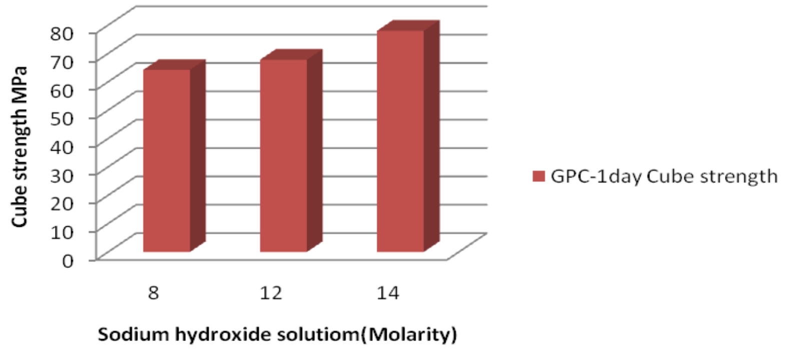


Fig 5: Effect of water content and curing time on strength

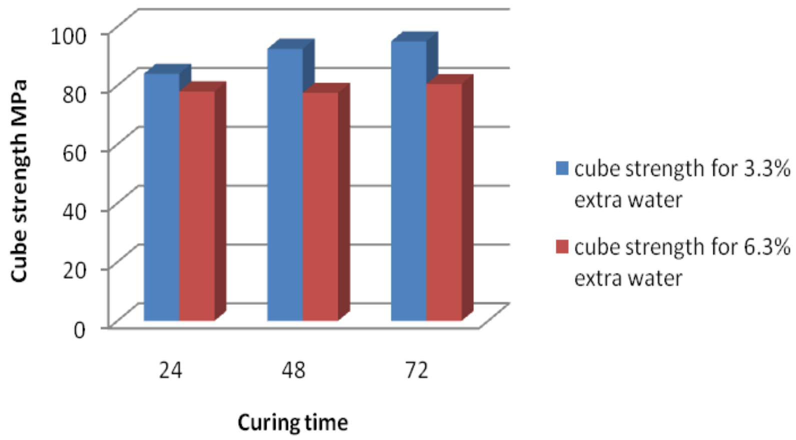
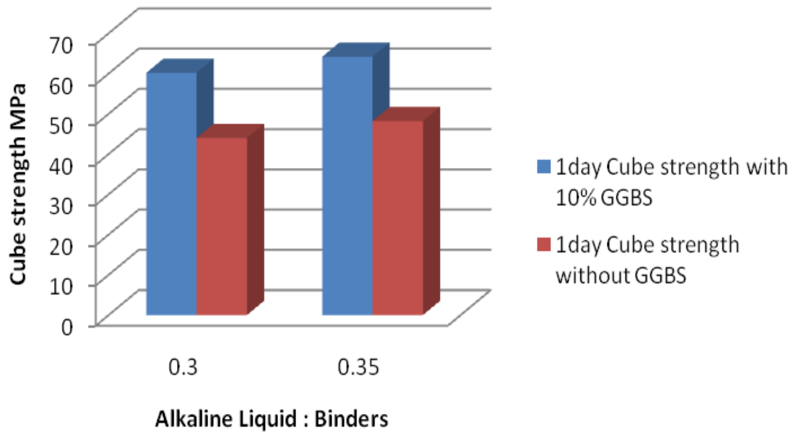


Fig 6: Effect of GGBS on strength

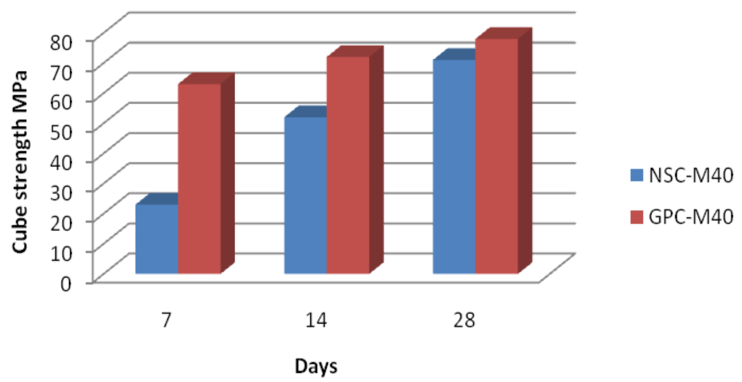


Comparıson Of Strength Propertıes Between M40 GPC and NC

Compressive strength

Compression test is conducted at 7 and 28 days as per 1S:516 using cubes of size 100 x 100 x 100mm and the average results of three samples obtained for M40 grade concrete both GPC and NC and their comparisons are shown in figure 7.

Fig 7: Compressive strength of NSC and GPC



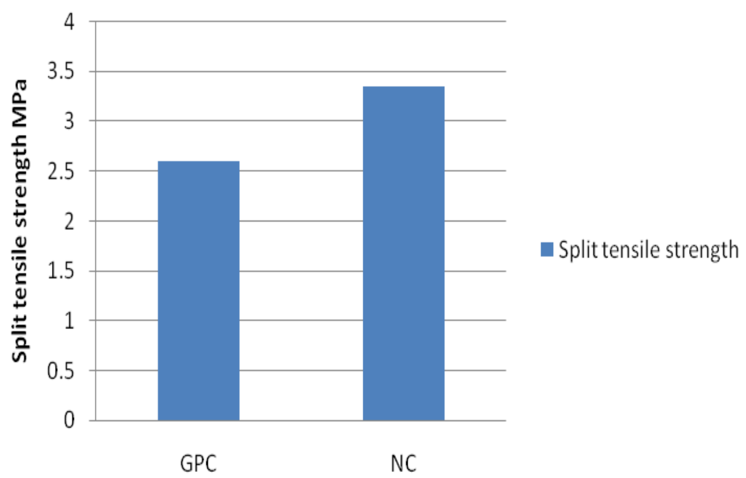
Split Tensile Strength

Tensile strength is important for slabs which are designed based on flexural strength, are subjected to tensile stresses. For this test 100mm x 200mm cylinders are cast and tested at 28 days in a CTM machine and the test results are presented in table 3 with figure 8 .

Table 3 Split tensile strength values for GPC and NC

Tensile load (N)	Splitting tensile strength (MPa)	
	GPC	NC
100000	3.18	3.82
70000	2.23	3.50
70000	2.23	2.86
90000	2.86	3.18
80000	2.55	3.18
80000	2.55	3.50
Average split tensile strength	2.6	3.34

Fig 8 : Split tensile strength values of GPC and NC



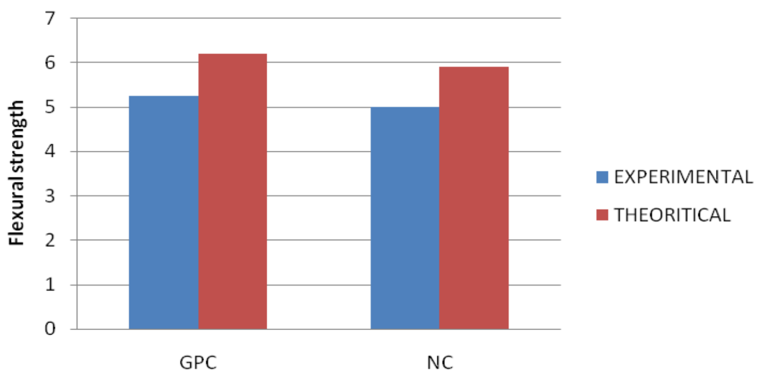
Flexural Strength

For this test 100mm x 100mm x 500mm prisms are cast and tested at 28 days using UTM in two-point loading arrangements. Mechanical dial gauge reading gives the central deflection at an interval of 100kg loading. M40 grade concrete the flexural strength results of both GPC and NC are tabulated in the table 4 with figure 9.

Table 4 Flexural strength values for GPC and NC

Mix no	Flexural strength (MPa)	
	GPC	**NC**
1	5.792	5.148
2	5.792	4.826
3	5.792	5.470
4	5.792	4.504
5	5.792	4.826
6	5.792	5.148
Average flexural strength	5.256	4.98

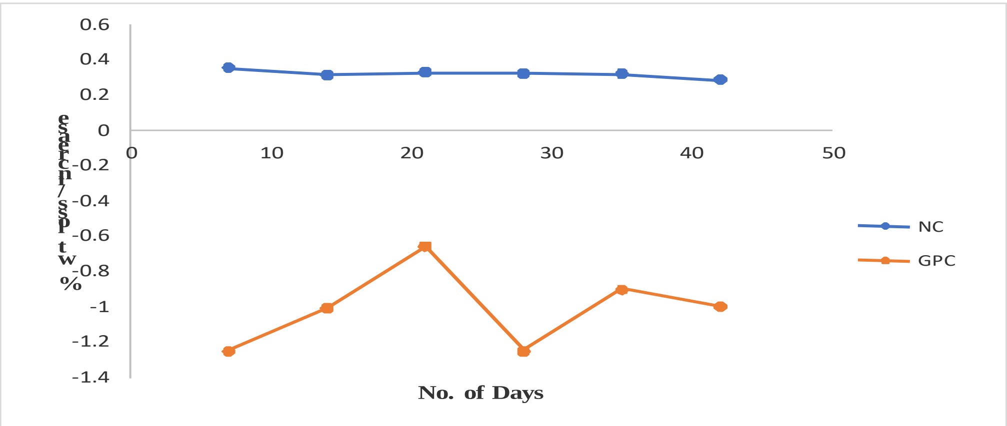
Fig 9: Flexural strength values of GPC and NC



Comparıson of Durabılıty Propertıes Between M40 GPC and NC

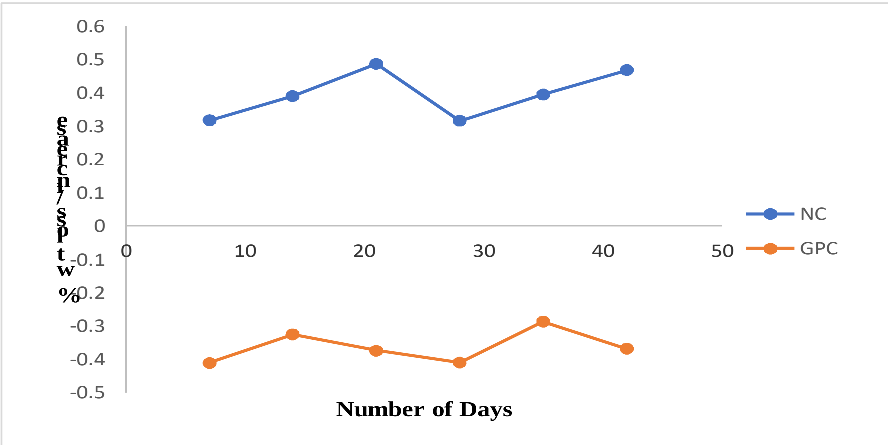
Acıd Test (2N HCl -10% by Weight)

Figure 10: Acid test values for GPC and NC



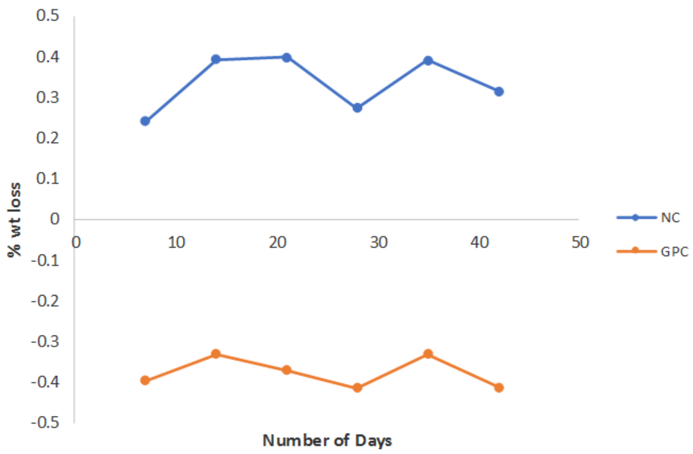
Sulphate Resistance Test ($MgSO_4$ - 5% by Wt)

Figure 11: Sulphate resistance test values for GPC and NC



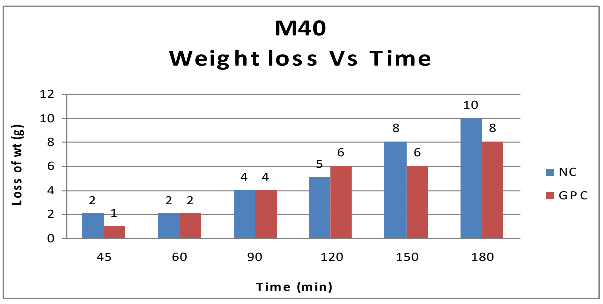
Sea Water Resistance Test (NaCl - 5% by Wt)

Figure 12: Sea water resistance test values for GPC and NC



Corrosion Test Results

Figure 13: Corrosion test values for GPC and NC



Conclusıons

GPC is around 58% more than OPC in 7 days.. Tensile strength of GPC is 22% a lesser amount of than NC. There was an increase in weight loss in both geopolymer and normal concrete. It has also been observed that Compressive strength decreases with respect to time. It has also been observed that Compressive strength decreases with respect to time in normal concrete and no much affect of sulphate attack on compressive strength on GPC. It has been observed that there was a gradual increase in weight loss in normal concrete and geopolymer specimens. It has also been observed that effect of sea water on compressive strength of GPC is not very much. With similar compressive strength, the GPC has the better resistance of steel bar corrosion than that of the conventional concrete. Fly ash-based GPC has exceptional compressive strength, making it ideal for structured applications._Heat-cured low CFS based GPC displays exceptional resistance to sulphate attack and respectable resistance to acid attack than normal concrete. It is more environmental friendly and has the potential to replace OPC in various applications such as pre-cast units. To conclude, the properties of GPC has proven to be more satisfactory than normal conventional concrete.

References

Amran, M., Debbarma, S., & Ozbakkaloglu, T. (2021). Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties. *Construction and Building Materials*, *270*, 121857.

Amran, Y. M., Alyousef, R., Alabduljabbar, H., & El-Zeadani, M. (2020). Clean production and properties of geopolymer concrete; A review. *journal of cleaner production*, *251*, 119679.

Cheema, D., Lloyd, N., & Rangan, B. V. (2009). Durability of geopolymer concrete box culverts-A green alternative. In *Proceedings of 34th Conference on Our World in Concrete and Structures* (pp. 85-92). CI Premier Pty Ltd.

Dao, D. V., Ly, H. B., Trinh, S. H., Le, T. T., & Pham, B. T. (2019). Artificial intelligence approaches for prediction of compressive strength of geopolymer concrete. *Materials*, *12*(6), 983.

Dharek M.S. et al. (2021) Experimental Investigations on Strength Performance of the Brick Produced by Blending Demolished Waste with Pozzolanic Materials. In: Biswas S., Metya S., Kumar S., Samui P. (eds) Advances in Sustainable Construction Materials. Lecture Notes in Civil Engineering, vol 124. Springer, Singapore. https://doi.org/10.1007/978-981-33-4590-4_54

Dharek M.S., Sreekeshava K.S., Vengala J., Pramod K., Sunagar P., Shivaprakash M.V. (2022) Experimental Investigations on Utilization of Bagasse Ash in Adobe Bricks. In: Nandagiri L., Narasimhan M.C., Marathe S., Dinesh S. (eds) Sustainability Trends and Challenges in Civil Engineering. Lecture Notes in Civil Engineering, vol 162. Springer, Singapore. https://doi.org/10.1007/978-981-16-2826-9_31

Dharek M.S., Sunagar P., Harish K., Sreekeshava K.S., Naveen S.U., Bhanutej (2020) Performance of Self-flowing Concrete Incorporated with Alumina Silicates Subjected to Elevated Temperature. In: Subramaniam K., Khan M. (eds) Advances in Structural Engineering. Lecture Notes in Civil Engineering, vol 74. Springer, Singapore. https://doi.org/10.1007/978-981-15-4079-0_10

Dharek, M. S., Sunagar, P., Bhanu Tej, K. V., & Naveen, S. U. (2018). Fresh and Hardened Properties of Self-consolidating Concrete Incorporating Alumina Silicates. In Lecture Notes in Civil Engineering (pp. 697–706). Springer Singapore. https://doi.org/10.1007/978-981-13-3317-0_62

Fang, G., Ho, W. K., Tu, W., & Zhang, M. (2018). Workability and mechanical properties of alkali-activated fly ash-slag concrete cured at ambient temperature. *Construction and Building Materials*, *172*, 476-487.

Ganesan, N., Abraham, R., & Raj, S. D. (2015). Durability characteristics of steel fibre reinforced geopolymer concrete. *Construction and Building Materials*, *93*, 471-476.

Jamkar, S. S., Ghugal, Y. M., & Patankar, S. V. (2013). Effect of fly ash fineness on workability and compressive strength of geopolymer concrete. *The Indian Concrete Journal*, *87*(4), 57-61.

Jena, S., & Panigrahi, R. (2019). Performance assessment of geopolymer concrete with partial replacement of ferrochrome slag as coarse aggregate. *Construction and Building Materials*, *220*, 525-537.

Kabir, S. A., Alengaram, U. J., Jumaat, M. Z., Yusoff, S., Sharmin, A., & Bashar, I. I. (2017). Performance evaluation and some durability characteristics of environmental friendly palm oil clinker based geopolymer concrete. *Journal of cleaner production*, *161*, 477-492.

Law, D. W., Adam, A. A., Molyneaux, T. K., Patnaikuni, I., & Wardhono, A. (2015). Long term durability properties of class F fly ash geopolymer concrete. *Materials and Structures*, *48*(3), 721-731.

Luhar, S., Chaudhary, S., & Luhar, I. (2019). Development of rubberized geopolymer concrete: Strength and durability studies. *Construction and Building Materials*, *204*, 740-753.

Moghaddam, S. C., Madandoust, R., Jamshidi, M., & Nikbin, I. M. (2021). Mechanical properties of fly ash-based geopolymer concrete with crumb rubber and steel fiber under ambient and sulfuric acid conditions. *Construction and Building Materials*, *281*, 122571.

Nath, P., & Sarker, P. K. (2014). Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition. *Construction and Building materials*, *66*, 163-171.

Noushini, A., Castel, A., Aldred, J., & Rawal, A. (2020). Chloride diffusion resistance and chloride binding capacity of fly ash-based geopolymer concrete. *Cement and Concrete Composites*, *105*, 103290.

Reddy, M. S., Dinakar, P., & Rao, B. H. (2016). A review of the influence of source material's oxide composition on the compressive strength of geopolymer concrete. *Microporous and Mesoporous Materials*, *234*, 12-23.

Shahmansouri, A. A., Bengar, H. A., & Ghanbari, S. (2020). Compressive strength prediction of eco-efficient GGBS-based geopolymer concrete using GEP method. *Journal of Building Engineering*, *31*, 101326.

Shahmansouri, A. A., Nematzadeh, M., & Behnood, A. (2021). Mechanical properties of GGBFS-based geopolymer concrete incorporating natural zeolite and silica fume with an optimum design using response surface method. *Journal of Building Engineering*, *36*, 102138.

Shaikh, F. U. A., & Vimonsatit, V. (2015). Compressive strength of fly-ash-based geopolymer concrete at elevated temperatures. *Fire and materials*, *39*(2), 174-188.

Sumalatha J, Manish S Dharek, Niranjan G.H., Prashant Sunagar and Abhishek Kumar Chaurasiya, Development of Sustainable Building Blocks with Tyre Waste, Flyash and Lime. International Journal of Civil Engineering and Technology, 11(5), 2020, pp. 93-104.

Vora, P. R., & Dave, U. V. (2013). Parametric studies on compressive strength of geopolymer concrete. *Procedia Engineering*, *51*, 210-219.

Xie, J., Wang, J., Rao, R., Wang, C., & Fang, C. (2019). Effects of combined usage of GGBS and fly ash on workability and mechanical properties of alkali activated geopolymer concrete with recycled aggregate. *Composites Part B: Engineering*, *164*, 179-190.