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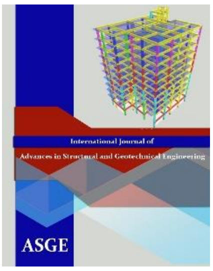

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Mechanical Properties of Fiber Reinforced Geopolymer Based Materials

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ABSTRACT

Geopolymer concrete (GPC) is considered the most promising eco-friendly material alternative to Portland Concrete (PC) and an opportunity to utilize by-products in concret manufacturing. One key driver in geopolymer development is the desire to reduce greenhouse gas emissions from the production of Portland cement products. Geopolymers exhibit good mechanical propertieps, durability and thermal resistance. Due to the relatively low tensile strength of GPC fibers may be added to overcome this deficiency.This paper presents an experimental investigation for the parameters affecting the properties of the geopolymer based materials. The investigated parameters affecting of of the geopolymer mortar (GPM) included age of mortar at the time of testing (7 days and 28 days), concentration of morlar (8 M, 10M, 12M and 14M) , ratios of activator to binder (0.5,0.55,0.6), ratios of Sodium Silicate to Sodium Hydroxide Solution by mass (1:1, 1.5:1, 2:1 and 2.5:1), Curing time (48 and 96hrs) and rest period (RP) (24 and 48hrs). More over this study is directed to investigate the influence of adding different fiber types (steel and polypropylene) as well as different fiber contents (0, .5, 1, and 1.5 %) to GPC mixes on the mechanical properties. The investigated properties included compressive, splitting tensile and flexural strengths. Based on the test results, it was observed that the fibers reinforced geopolymer concrete (FRGPC) have relatively higher strength than geopolymer concrete (GPC) and was shown that using 1.5% steel fibers showed the most improvement in the mechanical properties. The percentages of enhancements were 23.06%, 85.23% and 55.66% for compressive, splitting and flexural strengths over the (GPC) mix with out fibers, respectively.

Keywords: Geopolymer mortar, Compressive strength, flexural strength , steel fiber, polypropylene fiber, mechanical properties.

INTRODUCTION

Demand for concrete as construction material is on the increase and so is the production of cement.The production of one ton of cement liberates about one ton of CO2 to atmosphere (Roy,1999) [1]. In order to address environmental effects associated with Portland cement, there is need to develop alternative binders to make concrete. The development and application of high volume fly ash concrete, which parameters such as concentration of sodium hydroxide, the ratio of sodium silicate to sodium hydroxide, the rest period, external water content in the mixture, dosage of superplasticiser, the curing method, curing period, and ratio of alkaline liquid to fly ash (Prakash et al, 2013) [5].

The ratio of tensile strength to compressive strength is significantly low. Therefore, the addition of fibers has already been introduced in GPC to improve the ductility of the matrix. The main purpose of the fiber is to control cracking and to increase the fracture toughness of the brittle matrix through bridging action during both micro and macro cracking of the matrix. Debonding, sliding and pulling-out of the fibers are the local mechanisms that control the bridging action. (Dias et al., 2005 [6]; Reis, 2007) [7]. Incorporation of polypropylene fibers (PF) is claimed to enhance concrete's performance due to the high impact resistance; increased strain to failure; a fine cracked free finish; more water permeable resistant and consequent improved durability (Yao et al., 2003) [8]. The inclusion of steel fibers (SF) to conventional reinforced concrete improves the cracking strength and restricts the cracks‟ growth and consequently smaller cracks width (Richardson et al., 2006) [9].

(Yeol Choi et al.,2005) [10] investigated the relationship between the splitting tensile strength and compressive strength of glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC). Test results indicated that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by approximately 20–50%, and the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of its compressive strength. Based on this investigation, a simple 0.5 power relationship between the splitting tensile strength and the compressive strength was derived for estimating the tensile strength of GFRC and PFRC .

(Vijai et al.,2011) [11]. studied the effect of inclusion of steel fibers on the properties of GPC. Steel fibers were added to the mix in the volume fractions of 0.25%, 0.5%, 0.75% volume of concete. The investigation is designed to evaluate the mechanical properties of steel fibre reinforced GPC consisting of 90% Fly ash, 10% Cement and alkaline liquids. They found that replacing 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength, split tensile strength and flexural strength by 73%, 128% and 17% respectively with reference to GPC mix. Addition of steel fibers in GPC enhanced its mechanical properties. Addition of 0.25%volume fraction of steel fibers resulted in an enhanced compressive strength, split tensile strength and flexural strength by 11%, 1% and 3% respectively with reference to GPC mix. For addition of 0.5% volume fraction of steel fibers the compressive strength, split tensile strength and flexural strength is increased by13%,18% and 34% respectively with reference to GPC mix. Similarly addition of 0.75% volume fraction of steel fibers resulted in an enhanced compressive strength, split tensile strength and flexural strength by 24%, 24% and 44% respectively with reference to GPC mix.

This research aims to investigate the properties of fiber reinforced geopolymer based materials with different fiber types and contents.

EXPERIMENTAL PROGRAM

To achieve the objectives of this research twenty-five mortar mixes and eight of fibers reinforced geopolymer mixes were designed to study the effect of various parameters affecting the mechanical properties of geopolymer mortar and concrete.

Material

Locally available materials were used for making fiber reinforced geopolymer concrete (FRGPC) mixes. These materials included low-calcium fly ash as source materials, aggregates, alkaline liquids, water, steel fiber, polypropylene fiber and superplasticizer.

Fly Ash

Low calcium class F from Sika Egypt with specific gravity 2.25 was used as the binder to produce mortar and concrete. Chemical compositions of the fly ash used were analyzed and the results are given in **Table 1**.

Table 1:Chemical composition of FA

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	LOI
(%)	60.25	28.57	4.99	1.19	0.24	0.04	0.01	1.08	2.31	0.52	0.55

Aggregates

Fine aggregates (sand) is the natural siliceous sand that satisfies the requirements of ECP 203-2007. It is clean and nearly free from impurities with a specific gravity of 2.55 and passed through sieve of size 4.75 mm is suitable to be used in casting GPC and GPM mixes.
The coarse aggregate used was dolomite with maximum nominal size of 10 mm and specific gravity of 2.67. It was screened and washed to remove all the organic and inorganic compounds. It was used in a saturated surface dry condition before using in GPC, to avoid neither water absorption from activator solution or nor contributed more water to the mixes, and was complied with the limits of ECP 203-2007 [12].

Alkaline Liquid (AL)

A combination of sodium hydroxide (NH) solution and sodium silicate (NS) solution was used as alkaline activator for geopolymerization. Sodium hydroxide (NH) in flakes form with 98-99 % purity purchased from local chemical supplier was used and sodium silicate solution (Na_2O = 14.7%, SiO_2 = 29.4% and water = 55.9% by mass) was used as alkaline liquid. Sodium hydroxide solution is prepared by dissolving the flakes in water. Tap water available in the laboratory was used to prepare NH solution.

Water

Potable water is generally considered as being acceptable. It was used for preparation of NH solution and for extra water added to enhance workability of mixes

Superplasticizer (SP)

Aqueous solution of modified polycarboxylates in the form of a clear liquid and having a density of approximately 1.08 kg /liter at room temperature, with a Trade name of "SikaViscoCrete-3425" supplied by Sika company Egypt, was used a superplasticizer (SP) to improve the workability of all geopolymer concrete mixes. It meets the requirements for SP according to ASTM C 494 Types G and F.

Fibers

Hooked-end steel fibers (SF) and polypropylene fibers mesh (PF) were used in this study for preparing GPC mixes. The properties of the used fibers are presented in **Table 2** as per supplier.

Table 2: Properties of the used fibers (as per supplier)

Type	Diameter (mm)	Length (mm)	Aspect ratio	Density (kg/m3)	Elastic modulus (MPa)	Tensile strength (MPa)
Steel fibers	0.5	35	70	7850	$2x10^5$	1100
Polypropylene fibers	0.02	15	750	900	3500	550

Primary study for producing GPM and GPC
Mix proportions

A total number of 25 mixtures of GPM were investigatedphase (I). Each mix had constant fly ash to sand weight ratio of 0.5 and cured at 65°C. Different mixes with different proportions were made to produce GPM with optimum design. The measured properties were the compressive strength and flexural strength. The flow test was performed according to ASTM C1437. The mix proportions for each mix are tabulated in **Table 3**.

The mix proportions of GPC mixtures which was used in this phase(II) are listed in **Table 4.** Atotal number of 8 GPC mixtures were designed with aconstant amount of the alkaline solution (AL) as 57% of the total binder. The ratio of NS to NH was maintained at 2.0 in all mixtures. Extra water and SP were added to all GPC mixtures by 2% and 3%,respectively by mass of total binder.

Table3: Mix proportions of geopolymer mortar mixtures for phase (I) (on weight basis)

Mix No	Mix ID	Molar	NS:NH	AL:FA	Curing(hrs)
1	**M8S1**	8	1:1	0.5	48
2	**M8S1.5**	8	1.5:1	0.5	48
3	**M8S2**	8	2:1	0.5	48
4	**M8S2.5**	8	2.5:1	0.5	48
5	**M10S1**	10	1:1	0.5	48
6	**M10S1.5**	10	1.5:1	0.5	48
7	**M10S2**	10	2:1	0.5	48
8	**M10S2.5**	10	2.5:1	0.5	48
9	**M10S2A.55**	10	2:1	0.55	48
10	**M10S2A.6**	10	2:1	0.6	48
11	**M12S1***	12	1:1	0.5	-
12	**M12S1.5***	12	1.5:1	0.5	-
13	**M12S2**	12	2:1	0.5	48
14	**M12S2.5**	12	2.5:1	0.5	48
15	**M12S2A.55**	12	2:1	0.55	96
16	**M12S2A.55Q10****	12	2:1	0.55	96
17	**M12S2A.57R.P24**	12	2:1	0.57	96
18	**M12S2A.57R.P48**	12	2:1	0.57	96
19	**M14S1***	14	1:1	0.5	-
20	**M14S1.5***	14	1.5:1	0.5	-
21	**M14S2**	14	2:1	0.5	48
22	**M14S2.5**	4	2.5:1	0.5	48
23	**M14S2A.55**	14	2:1	0.55	48
24	**M14S2A.6**	14	2:1	0.6	48
25	**M14S2.5C96**	14	2.5:1	.5	96

**: Replacement of FA by 10% quartz
Mixes with (*) were not cast due to fast setting in the mixer

Table 4: Geopolymer mixes proportions for phase (II), kg/m^3

Mix No	Mix ID	FA	S	CA	NH	NS	W	SP	F
1	GPC-12	450	562.79	918.23	85.5	171	9	13.5	-
2	GPCSF 0.5%-12	450	557.72	909.97	85.8	171	9	13.5	39.1
3	GPC	450	557.72	909.97	85.5	171	9	13.5	78.1

	SF1%-12								
4	GPCSF 1.5%-12	450	557.21	909.97	85.5	17	9	13.5	117.2
5	GPCPPF 0.5%-12	450	557.72	909.97	85.8	171	9	13.5	4.5
6	GPCPPF 1%-12	450	557.72	909.97	85.8	171	9	13.5	9.00
7	GPCSF 1%-10	450	557.72	909.97	85.8	171	9	13.5	78.1
8	GPCSF 1%-14	450	557.72	909.97	85.8	171	9	13.5	78.1

M: molar
FA : Fly Ash
W: Extra Water
S: sand
F: Fiber
NH: NaO H Solution
NS : Na_2SiO_3 Solution
CA: Coarse Aggregate
SP: Super Plasticizer

Preparation of specimens

The steel moulds were cleaned and oiled to allow smooth stripping. The mold faces and the base plate were wiped with a cloth as necessary to remove any excess release agent and achieve a thin, even coating on the interior surfaces for GPM and GPC.

Mixing of GP Mixes

The NH solution was prepared one day before mixing process. ALwas prepared by mixing the NH and NS solutions together and was left in room temperature (23±2 °C, 55% RH) to cool down prior to mixing with the solids. For making GPM specimens of various test series, FA and AL in desired proportion were first mixed together in Hobart mixer (5 liters capacity) for five minutes. The sand was then slowly added and mixed for another five minutes. The fresh mortar mix had good consistency and glossy appearance. The fresh geopolymer mortar mixes was then cast in 40 mmx40 mmx160 mm steel molds and vibrated on vibration table to remove any entrapped air.

For making GPC specimens the solid constituents of the GPC mix (FA, S and CA) were dry mixed in a rotating drum mixer with fixed blades (100 liter capacity) for about three minutes. After the dry mixing, AS and extra water along with SP were added to the dry mix to make the mix wet until it gains homogeneous state. For FRGPC mixes, fibers were gradually added to the wet mix to ensure that the fibers were uniformly distributed in the mixture to make a homogenous fibrous composite and the mixing continued for another 5 minutes. After thorough mixing, the fresh concrete was tested for slump and immediately poured in molds for the preparation of samples for testing hardened concrete properties. The cubes of size (100 mm x 100 mm x 100 mm) for compressive strength, cylinders (100 mm diameter and 200 mm height) for splitting tensile, prisms (100 mm x 100 mm x 500 mm) for flexural strength were used.

The GP mixes were placed in the molds in three equal layers of equal thickness and each layer was vibrated for two minutes on vibration table until the mixes were thoroughly compacted and the slurry appeared on the top surface of the specimens. Then the top surface was leveled using a smooth trowel after compaction. The specimens were then covered in order to prevent loss of moisture.

Curing

After casting the specimens, they were kept in a rest period for 24 hours in the laboratory ambient conditions at (23±2 °C, 55% RH). At the end of the rest period, specimens were placed inside the heat curing chamber and were cured at 65 °C for 48 hours for GPM and 96 °C for GPC. The test specimens were then left in the laboratory at ambient temperature (23±2 °C, 55% RH) until the day of testing at 7, 28 days for GPM and GPC mixes.

Results and discussions
phase (I) geopolymer mortar
Factors affecting GPM compressive strength
Effect of concentration of NH

The effect of concentration of NH solution in terms of molarity (8, 10, 12, 14) for NS to NH ratios of 2 and 2.5 on the compressive strength of GPM can be observed by comparing results of mixes M8S2, M10S2, M12S2 and M14S2 for NS to NH ratio of 2 and also mixes M8S2.5, M10S2.5, M12S2.5, M14S2.5 and M14S2.5 for NS to NH ratio of 2.5.
The results show that the compressive strength of GPM specimens at 7 and 28 days increases with increasing in the concentration of NH in GPC mix as presented in **Figure 1**. For mixtures with a maintained ratio of NS: NH as 2, the compressive strength after 28 days of mixture M8S2 was 32.4 MPa, whereas mixtures M10S2, M12S2 and M14S2 were 33.4, 46.7 and 50.3 MPa respectively; the increases were by 3.09%, 44.14% and 55.25% compared to M8S2 mix. For mixtures with a maintained ratio of NS: NH as 2.5, the compressive strength after 28 days of mixture M8S2 was 18.5 MPa, whereas mixtures M10S2, M12S2 and M14S2 were 32.63,42.9 and 47.5 MPa respectively, the increases were by 76.38%, 131.89% and 156.76% compared to mix M8S2.

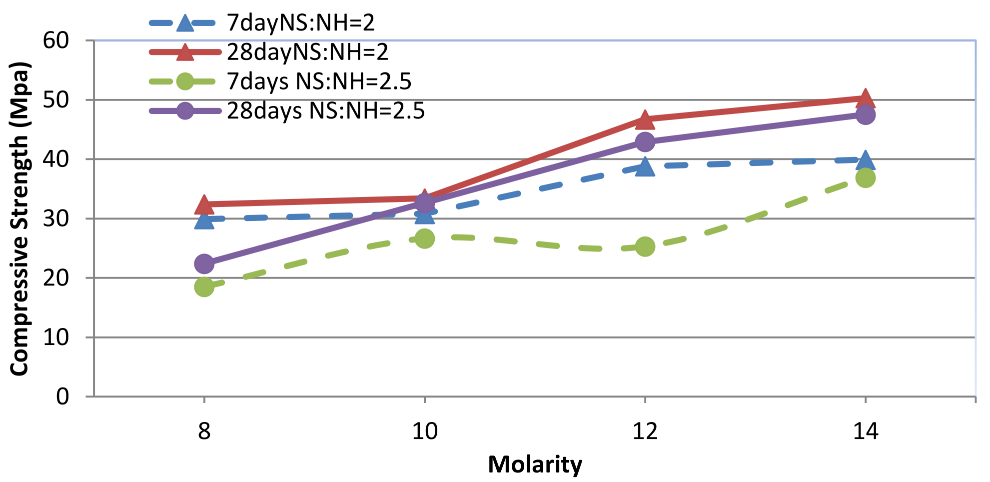

Figure1: Effect of concentration of sodium hydroxide solution

Effect of ratio of activator to fly ash

The results demonstrate that the compressive strength values decrease with increasing in the AS to FA ratio as shown in **Figure 2**. At 28 days, the decreases in compressive strength were about 8.98% and 14.67% for mixtures M10S2A.55 and M10S2A.6 compared to mix M10S2A.5. For mixtures M14S2A.55 and M14S2A.6 the decreases in the compressive strengths at 28 days were by 11.73% and 18.69% respectively, when compared to mix M14S2A.5.

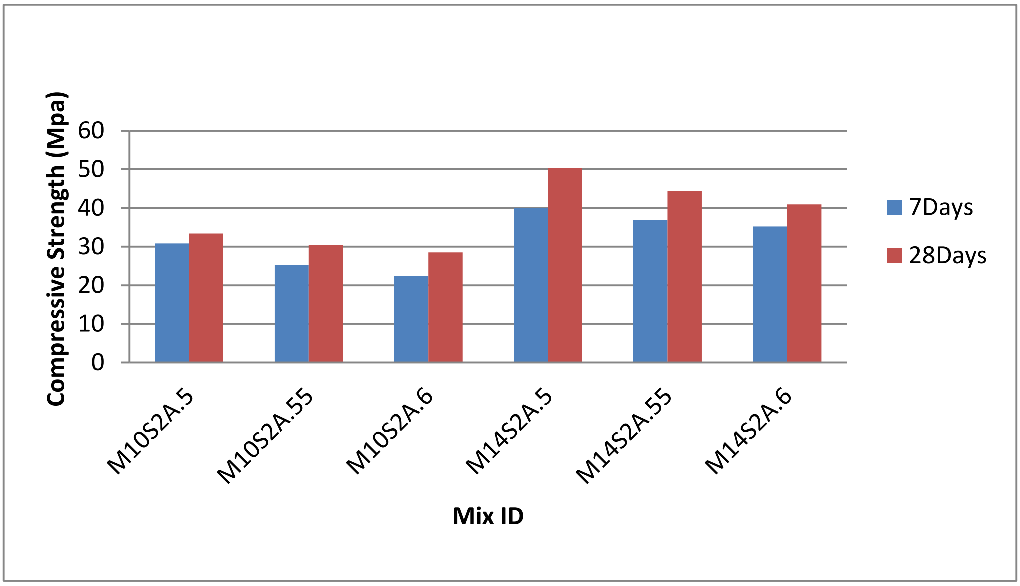

Figure 2: Effect of ratio of activator to fly ash

Effect of varying ratios of Sodium Silicate to Sodium Hydroxide Solution

For molar 8 the results demonstrate that the compressive strength values decrease with increasing in NS to NH solution ratio at 28 days as shown in **Figure 3**. At the increase of NS to NH solution ratio from 1:1 to 2.5:1. the decrease in compressive strength was about 8.3% ,6.9% and 35.6% for mixtures M8S1.5, M8S2 and M8S2.5 compared to mix M8S1.

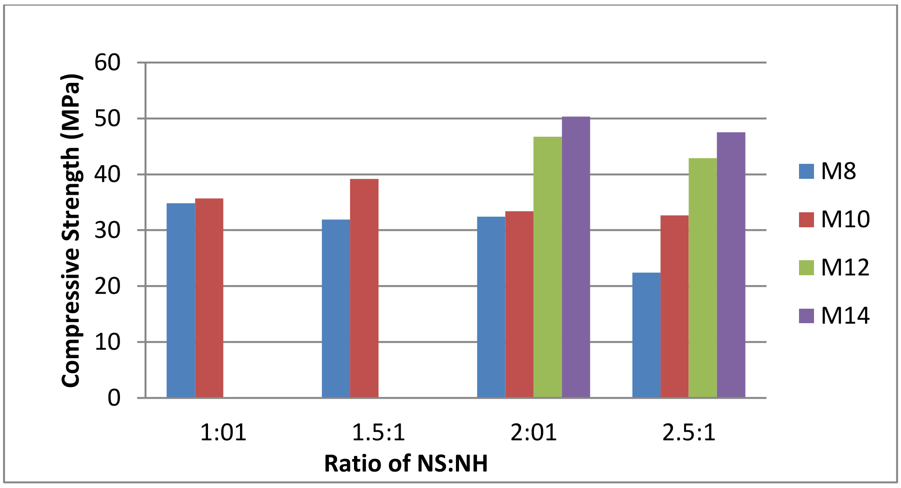

Figure 3: Effect of varying ratio of Sodium Silicate to sodium hydroxide solution

Effect of varying the curing Times

The results demonstrate that the compressive strength increased with increase in duration of curing as shown **Figure 4.** The increase in the curing time from 48 to 96 hours increased the compressive strength from 39.9 to 45.4 MPa at 7days for mixtures M14S2 and M14S2C96. At 28 days the compressive strength increased from 50.3 to 56.2 MPa 28 days. The increase in compressive strength were about 13.8% and 17.1% at 7 and 28 days for mixes respectively.

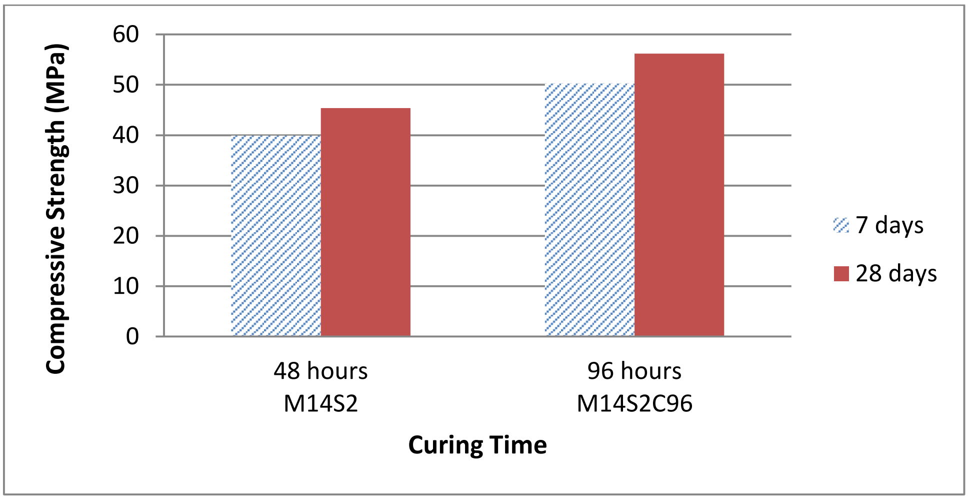

Figure 4 : Effect of varying the curing time

Effect of varying the rest period

The test results shown in **Figure 5** demonstrate that the compressive strength of geopolymer mortar increased with the increase in the rest period from 24h to 48h.The compressive strength increased from 34.8 to 39.8 at 7days and 44.6 to 48.3 at 28 days for mixture M12S2A.57RP24h and M12S2A.57 RP48h respectively. After 7 days the compressive strength increased by 14.36% and 8.29% at 28 days respectively.

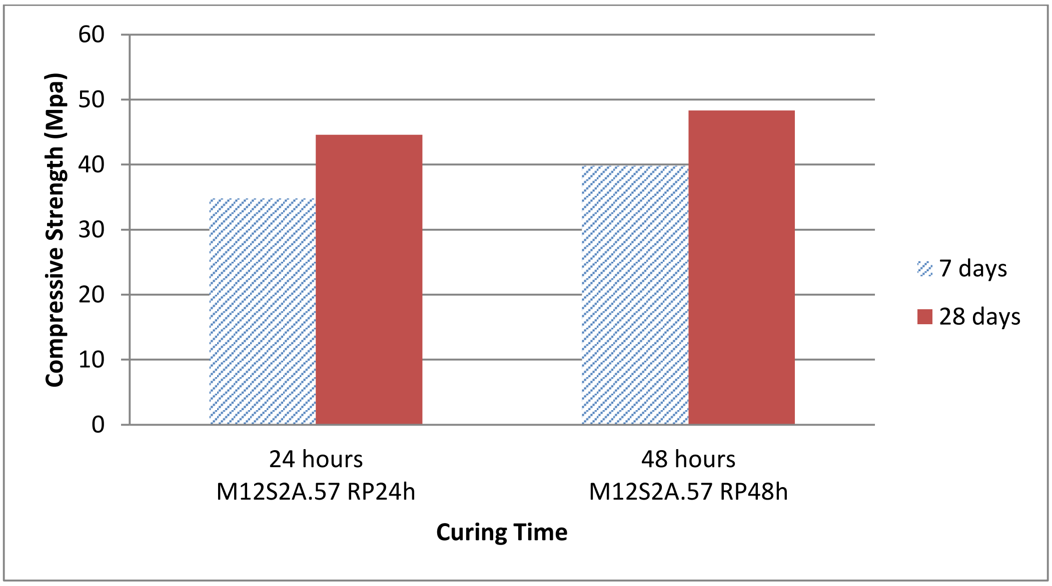

Figure 5: Effect of varying the rest period

Factors affecting flexural strength of GPM
Effect of Concentration of NH

The effect of concentration of NH solution in terms of molarity for NS to NH ratios of 2 and 2.5 on the flexural strength of GPM can be observed by comparing results of mixes M8S2, M10S2, M12S2 and M14S2 and for NS to NH ratio of 2 and also mixes M8S2.5, M10S2.5, M12S2.5, M14S2.5 and M14S2.5 for NS to NH ratio of 2.5. The flexural strength was measured at 7 and 28 days as shown in **Figure 6**.

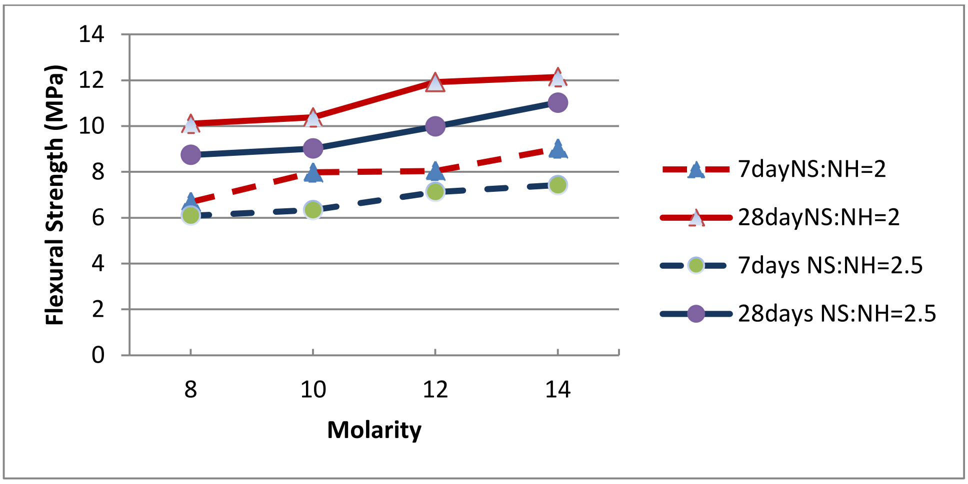

Figure 6: Effect of concentration of sodium hydroxide solution

The results show that the flexural strength of GPC specimens at 7 and 28 days increases with increasing in the concentration of NH in GPC mix as presented in **Figure 6**. For mixtures with a maintained ratio of NS:NH as 2, the flexural strength after 28 days of mixture M8S2 was 10.1 MPa, whereas mixtures M10S2, M12S2 and M14S2 were 10.38, 11.92 and 12.14 MPa respectively; the increases were by 2.77%, 18.01% and 20.19% compared to M8S2 mix. For mixtures with a maintained ratio of NS: NH as 2.5, the flexural strength after 28 days of mixture M8S2 was 8.74 MPa, whereas mixtures M10S2, M12S2 and M14S2 were 9.02,9.98 and 11.02 MPa respectively, the increases were by 3.20%, 14.19% and 26.09% compared to mix M8S2.

Effect of ratio of activator to fly ash

The results demonstrate that the flexural strength values decrease with increasing in the AS to FA ratio as shown in **Figure 7**. At 28 days the decreases in flexural strength were about 16.18% and 22.73% for mixtures M10S2A.55and M10S22A.6 compared to M10S2 mix. For mixtures M14S2A.55 and M14S2A.6 the decreases in the flexural strengths at 28 days were by 14% and 26.77% for mixes respectively, when compared to mix M14S2A0.5.

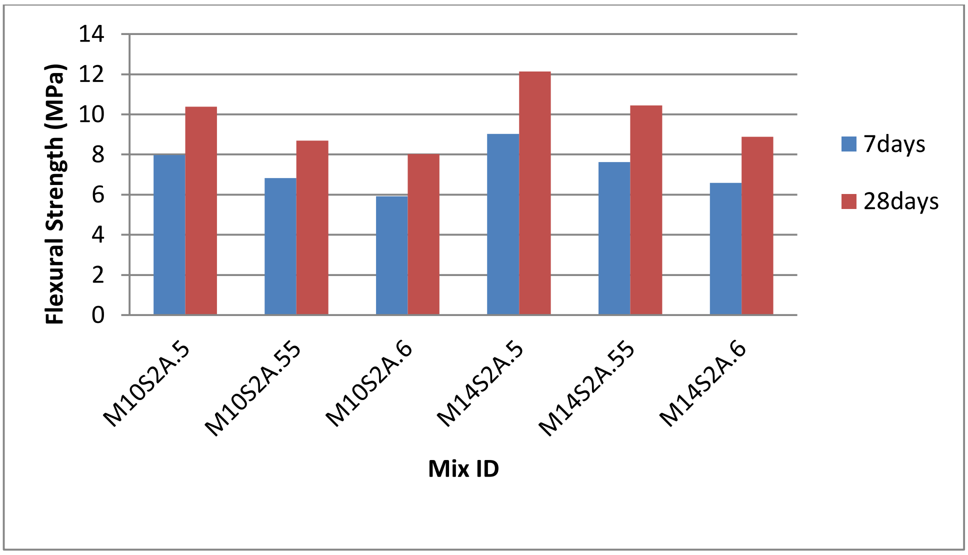

Figure7: Effect of ratio of activator to fly ash

Effect of varying ratio of sodium silicate to sodium hydroxide solution

The results demonstrate that the flexural strength values decrease with increasing in NS to NH solution ratio at 7and 28 days as shown in **Figure 8**. At the increase of NS to NH solution ratio from 2:1 to 2.5:1 for molar 12 for mixtures M12S2 and M12S2.5.

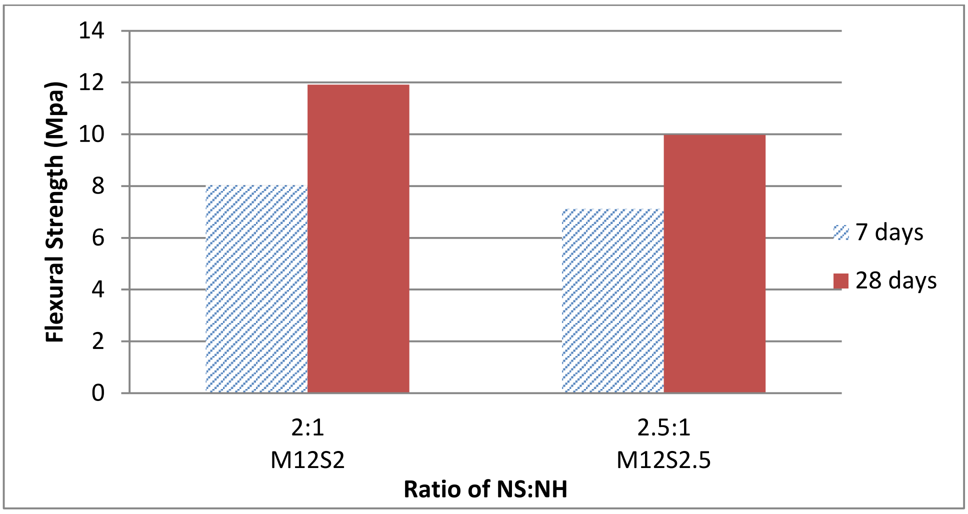

Figure 8: Effect of varying ratio of sodium silicate to Sodium hydroxide solution

Effect of varying the curing time

The results demonstrate that the flexural strength increased with increase in duration of curing as shown **Figure 9**. The increase in the curing time from 48 to 96 hours increased the flexural strength from 9.02 to 9.61 MPa at 7 days for mixtures M14S2 and M14S2C96. At 28 days the flexural strength increased from 12.14 to 13.39 MPa 28 days. The increase in flexural strength was about 6.54% at 7days and 10.29% at 28 days .

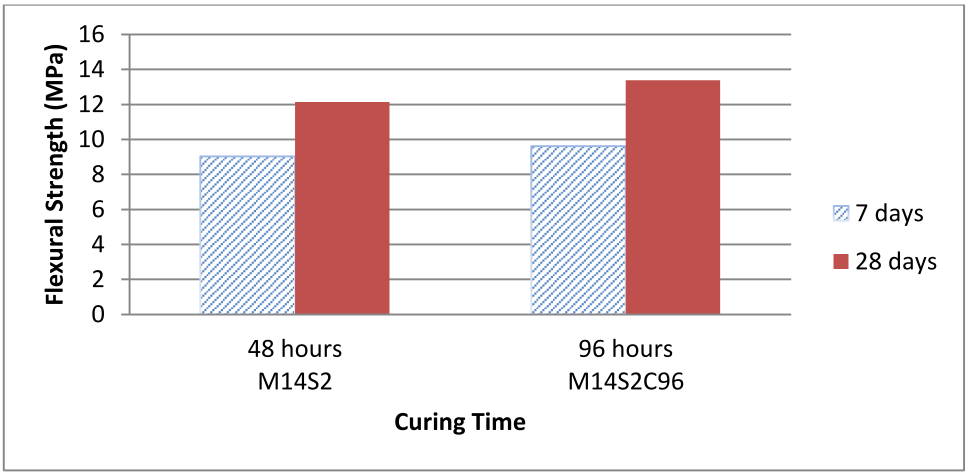

Figure 9 : Effect of varying the curing time

Effect of varying the rest period

The test results shown in **Figure 10** demonstrate that the flexural strength of GPM increased with the increase in the rest period.The flexural strength increased from 6.93 to 7.25 at 7days and 8.58 to 9.47 at 28 days for mixtures M12S2A.57 and M12S2A.57 RP48. the increase in flexural strength was about 4.61% and 10.37% for 7 and 28 days respectively.

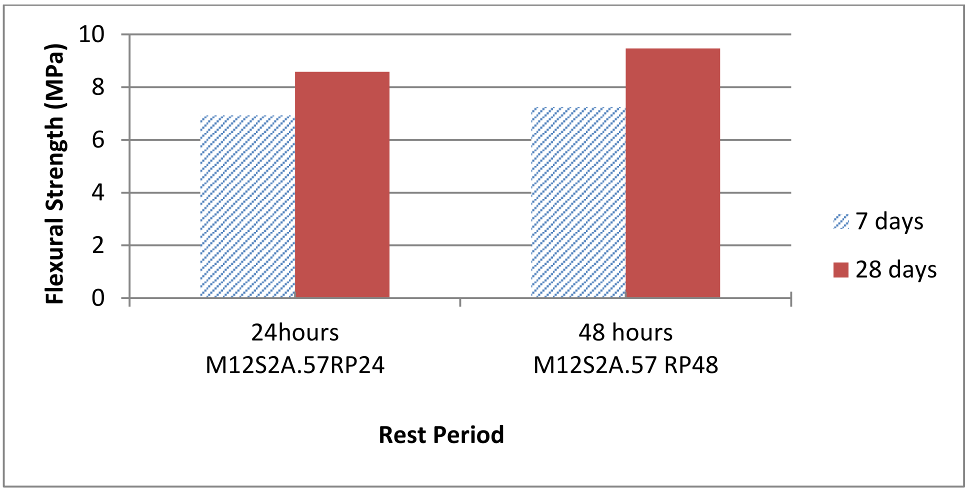

Figure 10: Effect of varying the rest period

phase (II) geopolymer concrete
Compressive strength of GPC Mixes

The average compressive strength of GPC mixes after 28 days with and without fibers heat cured at 65 °C for 96 hours is given in **Table 5** and plotted in **Figure 11**. The results showed that increasing of SF volume fraction resulted in an increase in the compressive strength up to 23..05% compared to mix GPC-12 (control mix). The influence of the used fiber type was investigated through mixes GPC .5%S-12 , GPC 1%S-12, GPC.5%P-12 and GPC1%P-12. The compressive strength values were 29.8, 30.67, 28.4 and 27.48 MPa for the mentioned mixes, respectively. It can be seen that 1% volume fraction of SF showed the highest compressive strength. Generally, it can be noticed that increasing of SF volume fraction enhanced noticeably the compressive strength. Moreover, using of PF reduced slightly the compressive strength up to 4.59% compared to GPC-12.

The effect of using different molar(10 ,12,14) at fixed ratio of steel fibers on the compressive strength can be observed by comparing results of mixes GPC1%S-10, GPC1%S-12 and GPC1%-14. The results show that the compressive strength at 28 days increases with increasing the molar. the compressive strength after 28 days of mixture were 29.65, 30.67 and 35.18MPa ,respectively.

Table 5: Mechanical properties of GPC mixes at 28 days

Mix ID	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
GPC-12	27.19	2.98	4.15
GPC.5%S-12	29.80	3.64	4.65
GPC1%S-12	30.67	5.14	5.28
GPC1.5%S-12	33.46	5.52	6.46
GPC.5%P-12	28.44	3.06	4.58
GPC1%P-12	27.48	3.14	4.51
GPC1%S-10	29.65	5.20	5.87
GPC1%S-14	35.18	6.71	6.86

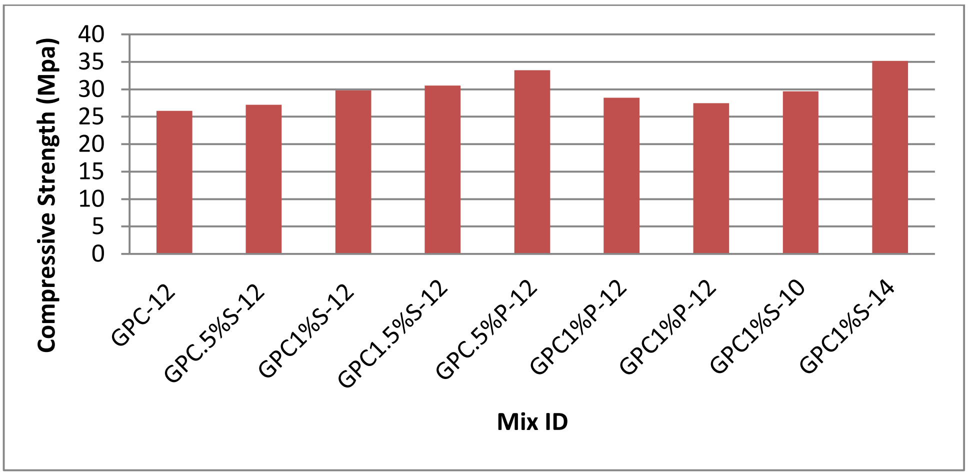

Figure 11: Compressive strength of GPC mixes at 28 days

Splitting Tensile Strength

The average splitting tensile strength of GPC mixes after 28 days with and without fibers is given in **Table 5** and shown in **Figure 12**. The addition of SF in the GPC mix at volume fractions of 1% and 1.5% increased the splitting tensile strength. The values of splitting tensile strength were 5.14, 5.52 and 3.95 MPa for GPC1%S-12, GPC1.5%S-12 and GPC-12. Hence, the increase in volume fraction of SF, by 1% and 1.5%, led to significant enhancements by 70% and 85%, respectively when compared to control mix GPC-12. The splitting tensile strength values were 3.64, 5.14, 3.06 and 3.14 MPa for GPC.5%S-12, GPC1%S-12, GPC.5%P-12 and GPC1%P-12, respectively. The results of the splitting tensile strength showed increases by 22.14%, 72.48% ,2.68% and 16%, respectively for the previously mentioned mixes. Therefore, among the used fiber types 1% SF showed the best improvement in splitting tensile strength followed by 1% PF. Based on these results, the mix containing 1.5% SF had the highest splitting tensile strength among the other mixes compared to mix GPC.

The effect of using different molar(10 ,12,14) at fixed ratio of steel fibers on the splitting tensile strength can be observed by comparing results of mixes GPC1%S-10, GPC1%S-12 and GPC1%-14. The results show that the splitting tensile strength at 28 days increases with increasing the molar. the splitting tensile strength after 28 days of mixture were 5.20, 5.14 and 6.71 MPa ,respectively.

Flexural Strength

The average flexural strength of GPC mixes after 28 days with and without fibers is tabulated in **Table 5** and plotted in **Figure12**. The results showed that increasing of SF volume fraction resulted in an increase in the flexural strength. The values of the flexural strength were 5.28, 6.46 and 4.15 MPa for GPC1%S-12, GPC1.5%S-12 and GPC, respectively. The addition of 1% SF and 1.5% SF to GPC mix enhanced the flexural strength by 27.22% and 55.66% over mix GPC. The flexural strength values types were 4.65, 5.28,4.58 and 4.51 MPa for for GPC.5%S-12, GPC 1%S-12, GPC.5%P-12 and GPC1%P-12, respectively. The addition of .5% SF and 1% SF enhanced the flexural strength by 12.04% and 27.22% compared to mix GPC. On the contrary, the addition of .5% PFand 1%PF decreased the flexural strength by 10.36% and 8.67% with respect to GPC mix. Generally, it can be noticed that increasing of steel fiber volume fraction enhanced the flexural strength. On the contrary, using of PF reduced slightly the flexural strength compared to mix GPC.

The effect of using different molar(10 ,12,14) at fixed ratio of steel fibers on the flexural strength can be observed by comparing results of mixes GPC1%S-10, GPC1%S-12 and GPC1%-14. The results show that the flexural strength at 28 days increases with increasing the molar. the flexural strength after 28 days of mixture were 5.28, 5.87 and 6.86 MPa ,respectively.

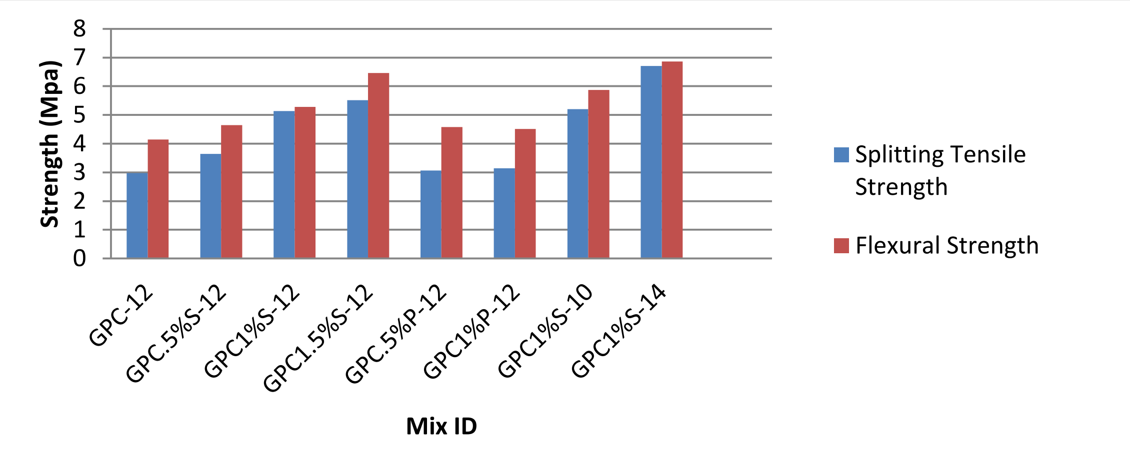

Figure 12: Splitting tensile and flexural strengths of GPC mixes at 28 days

CONCLUSIONS

The following concluding remarks have been made on basis of the work conducted:

- The compressive strength of the geopolymer mortar mixes increased with increase of concentration in terms of molarities of sodium hydroxide. The highest compressive strength achieved at M14 as 50.3 MPa at 28 days.
- The sodium silicate to sodium hydroxide ratio by mass equal to 2 has resulted in the higher compressive strength as compared to the ratio of 2.5 for the geopolymer mortar mixes. The highest compressive strength achieved at M14 as 50 MPa at 28 days.
- The compressive strength of the geopolymer mortar increased with the increase in the curing time. The highest compressive strength achieved at M14 as 56.2 MPa at 28 days.
- Using steel and polypropylene fibers enhanced the mechanical properties of GPC mix. The results showed that the addition of steel fibers by 1 and 1.5% volume fraction, the compressive strength was increased by 12.79 and 23.06%, respectively. Also, the flexural strength was increased by 27.23 and 55.66%, respectively. while addition of .5 and1% polypropylene fibers enhanced only the splitting tensile by 2.68 and 5.36%%, respectively and increased slightly both of compressive and flexural properties..

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