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Effect on Properties of Geopolymer Concrete after Addition of GGBS & Glass Powder

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ABSTRACT

The present study aims at adopting ambient curing for developing geopolymer concrete so as to make this concrete feasible for mass applications. Keeping up with ambient curing the addition of GGBS in percentages of 15%, 20%,25% & Glass Powder in percentages of 5%,10%,15% has been done so as to bypass the need for carrying out oven curing. In addition to this the study aims at gauging the effect of different molarities i.e 4M, 8M &12M on the mixes prepared& in turn deciding the optimum molar concentration for preparation of the mixes. To develop this geopolymer concrete according to our objectives some of the past literature has been reviewed to understand its reaction mechanism and accordingly select the proportion of materials for carrying out experimental work. To study the effectiveness of ambient curing over oven curing a total of 150 no samples have been prepared out of which 15 no comprise the control mix. The mix proportions of the geopolymer concrete samples prepared in this study have been adopted on a trial and error basis due to non availability of IS codes for design mix.

1. Introduction

With growing concern over environmental problems related to global warming, there have been many efforts in the construction field to reduce CO2 emissions. On observation it has been found that about one ton of CO2 is emitted for every ton of cement produced & this accounts for approximately 5–7% of global anthropogenic CO2 emissions . The key causes of high CO2 emissions arising from OPC manufacture have been attributed to (i) calcination of limestone, one of the key ingredients, which leads to formation and release of CO2 (ii) high energy consumption during manufacturing, including heating raw materials within a rotating kiln at temperatures greater than 1400ºC [1].

Alternative cements to OPC have been proposed to reduce greenhouse gas emissions such as blended cements, in which OPC has been partly substituted by supplementary cementitious materials (SCCs), to be used as binder for concrete. Common SCCs include fly ash, a fine waste residue that is collected from the emissions liberated by coal burning power stations, and ground granulated blast furnace slag, a waste by-product from steelmaking. Flower and Sanjayan(2007) have shown that blended cements reduce CO2 emissions by 13–22%, although this estimate can vary depending on local conditions at the source of raw materials, binder quantity and amount of OPC replacement, type of manufacturing facilities, climate, energy sources, and transportation distances.

To carry out a complete overhaul of the OPC from construction activities an alternative cementitious binder, termed ''geopolymer'', comprising of an alkali-activated fly ash, has been considered as a substitute for OPC. This new class of material known as Geopolymer was developed in 1978 by a French scientist Joseph Davidovits. He defined geopolymer as a family of amorphous alkali or alkali-silicate activated aluminosilicate binders of composition $M_2O{\cdot}mAl_2O_3{\cdot}nSiO_2$, usually with $m \approx 1$ and $2 \le n \le 6$ (M usually is Na or K). He defined that this process of geopolymerisation involved a chemical reaction between various alumino-silicate oxides with silicates under highly alkaline conditions, yielding polymeric Si – O – Al – O bonds [2].

Turner & Collins (2013) carried out a comparative study of the carbon footprint of OPC & geopolymer concrete with the help of term defined as CO_2-e emitted (kg CO_2-e/kg). They defined this term as the amount of energy utilized in activities necessary to construct 1m^3 of concrete& the calculation of CO_2-e was based on the collective contributions of CO_2, CH_4, NO_2, and synthetic gases evolved during each activity, taking into account the energy content of the fuel, the global warming gas types produced, and the respective gas global warming potential (GWP), when the fuel is fully combusted. A comparison of the carbon footprint of OPC & geopolymer concrete is shown in Fig. 1 [3].

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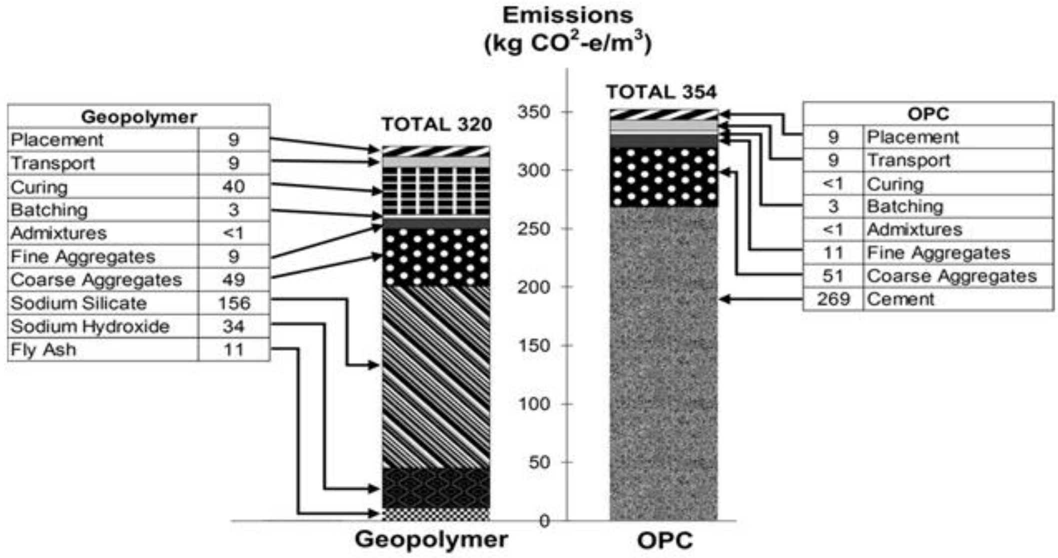

Fig. 1: Summary of CO_2-e for Grade 40 Concrete Mixtures with OPC and Geopolymer Binders [4]

As shown in the Fig. 1, the carbon emissions involved in the formation of geopolymer concrete are approximately 9% lesser than that of OPC cement concrete. So considering this in mind a proposition was prepared to carry out paper work after removal of oven curing, sodium silicate & cement i.e major contributors to CO_2-ewithout compromising too much on the strength & durability front. This led to use of pozzolanic materials like flyash, glass powder and alccofine (GGBS) in varying proportions so that the desired strength & a comparatively lesser carbon footprint of the concrete can be achieved.

2. Literature review

Geopolymer was introduced to the world in the late 1970s. It was developed in 1978 by a French scientist Joseph Davidovits. The use of the material increased during the 1980s and 1990s for non structural applications. During this period, geopolymer became recognized for high thermal stability and good acid resistance. Keeping up with the pace it has been used for a no of non structural applications but on structural front it is largely confined to lab scale. Of late usage of geopolymer concrete for construction of building has been reported in Australia [5].

This section presents a review of literature highlighting the work done by various researchers with regards to the mechanical properties of GPC. The mechanical properties which have been primarily reviewed in the research papers are compressive strength, flexural strength & split tensile strength. To have a clear overview of our proposed work research papers using similar kind of materials & under similar testing condition have been mainly reviewed [6].

For the review of the papers presented all the details such as materials used, mix proportion, casting procedure, results & their discussion have been thoroughly presented. All the papers presented in the literature review have been discussed chronologically thereby indicating the advancement in the material up till date [7].

Furthermore, the significant developments regarding performance and applications of GPC that have taken place in the recent past have also been studied. Some of the papers covered in the literature review are Shayan & Xu (2004),Wongpa et al. (2010), Aleem & Arumairaj (2012),Naidu et al. (2012), Lee & Lee (2013), Deb et al. (2014),Gao et al. (2015), Kamali & Ghahremaninezhad (2015),Nazari et al. (2015), Thomas & Peethamparan (2015) & Mithanthaya & Rao (2015) respectively [8].

All the necessary information in the form of source of materials, mix proportions adopted, properties studied and their results in the form of graphs & tables have been incorporated in this literature review [9].

The coarse and fine glass particles were used as replacement for the corresponding size ranges of natural aggregate materials, whereas the GLP was used as a pozzolanic material, i.e., the same application as for fly ash. The natural materials used in this work were nonreactive, natural, victorian concrete sand and a crushed basalt coarse aggregate. A reactive greywacke coarse aggregate from NSW was used to assess the effectiveness of GLP in suppressing ASR expansion [10].

Glass, due to its silica-rich nature and amorphous structure, is susceptible to chemical attack under the high alkali conditions provided by the hydrated cement phase in the concrete. This chemical attack on glass leads to production of extensive formation of ASR gel, which is expansive and could cause premature cracking in the concrete, if appropriate precautions are not put in place in the formulation of the concrete mix.

Based on the criteria given in Australian Codes, it was found that use of up to 30% glass in the concrete may not cause deleterious effects, particularly if the alkali content of the concrete was low (below 3-kg Na2O equivalent per cubic meter). At higher alkali contents of concrete, further expansion may occur. In addition to the glass content of mortar bars, the particle size also had an effect on the

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expansion. Therefore, it was concluded that the magnitude of expansion would depend on the interaction of glass content, particle size and alkali content of the concrete. These results showed that glass could react and produce ASR gel and that once the particle size was sufficiently reduced, it could act as a pozzolanic material [11].

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As far as utilisation as fine and coarse aggregates was concerned, trial mixes were undertaken with the view of establishing how much fine and coarse glass could be used in concrete mixtures that would be suitable for some structural applications and for concrete pavements. The trials aimed at producing concrete appropriate as Vic Roads 32-MPa strength grade. This mixture contained a binder of 255-kg/m^3 cement and 85-kg/m^3 fly ash. The coarse aggregate and sand contents were 1080 and 780 kg/m^3, respectively. After a number of trials & adjusting the properties of fresh and hardened concrete, the following concrete mixture formulations were found to be satisfactory, as detailed in table 1 [15].

Table 1: Concrete Mixes for 25 MPa Concrete (Air entrained)

Mix no.	Binder(%)		Glass content(%)		w/b	Slump (mm)	Air(%)	Strength (MPa)		Super plasticiser
	Cement	Flyash	Coarse	Fine				7 days	28 days	
1	75	25	50	50	0.46	60	1	28.6	39.9	Yes
2	75	25	50	50	0.52	80	2	25.3	35.0	No

In the use of glass as pozzolanic material, replacement was done with cement & mortar cubes having aggregate/cement ratio of 2.25 & water/cement ratio of 0.47 were prepared. In the case of cement replacement, the reduction in the 28-day strength increased with the level of cement replacement and for samples containing up to 30% replacement it was concluded that reduction in the strength occurred mainly because in such short periods the pozzolanic effects were not fully operational. In addition to this, replacement of aggregates was also done with GLP & mortar cubes were prepared. On testing mortar cubes at 28 days it was found that the effect of replacement of aggregates by GLP was more pronounced as compared to the replacement of cement by GLP [16].

On studying about the long term strength development characteristics it was observed from the tests that the replacement of cement and aggregates by GLP was beneficial for strengths obtained at longer ages & it was probably due to improvement in the particle packing as well as the pozzolanic reaction becoming fully operational at longer ages. The result for this observation is shown by Fig. 2.

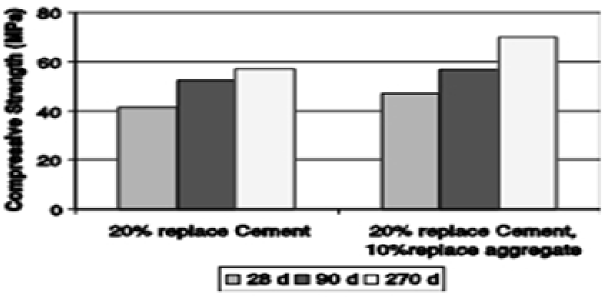

Fig. 2: Strength Development of Reactive Aggregate with Additional GLP.

3. Materials and design methodology

The present section deals with the material properties and the mix proportion adopted for the development of GeopolymerConcrete specimens. In order to achieve the objectives of the present study, an experiment was performed to determine the compressive strength, flexural strength& split tensile strength of the geopolymer concrete specimens made by using flyash, glass powder and GGBS along with the NaOH solution as alkaline activator.

The properties of various materials used for making GPC concrete mixes were determined in laboratory as per relevant IS codes of practice. The materials used in the present experimental study undertaken for the development of GPC were flyash, coarse aggregates, fine aggregates, and NaOH solution, in addition to glass powder and alccofine(GGBS) in varying proportions. The importance of study of the various properties of material is used to check the acceptance of materials with the codal provision requirements and to enable an engineer to design a concrete mix for a particular strength. The description of various materials along with their investigated properties which were used in this study are detailed in the following sub-sections [17]:

4. Flyash

Flyash may be defined as an aluminosilicate source which represents the majority component of geopolymer concrete quantity wise and has the least unit cost of all the cementing materials used in the mix.Flyash plays the important role of reducing brittleness in geopolymer concrete to a considerable extent so that it can withstand more tensile stress without addition of reinforcing steel. The fly ash particles are dominantly spherical in shape and range in diameter from 1 to 200 μm. Some of the fly ash particles are even hollow shaped. It contains both crystalline phases like quartz, mullite, hematite, etc. and also amorphous phases.

Fly ash, as the solid by-product of the combustion of coal, is generally extracted from the combustion flue gases emanating from coal-fired power plant through the process of electrostatic precipitation.The Flyash used in the paper work was procured from a coal based thermal power plant located in Nalash village near Rajpura town in Patiala district of Punjab. The plant consists of 2x700 MW units & is being operated by Larsen & Toubro. The flyash procured was Class F flyash&photograph of it is shown in Fig. 3.

Fig. 3: Actual Photograph of Flyash

According to ASTM C 618-93 flyash is classified into 3 categories namely Class N, Class F &Class C depending upon the source from which it is produced. In this Class N flyash is obtained from natural sources &consists of raw or calcined natural pozzolans such as laterite shale, Class F flyash produced from burning anthracite & Class C flyash produced from burning lignite or sub-bituminous coal. The specification for the flyash of any type is given by the IS 3812: 2013.The physical properties & chemical properties of the flyash are presented in Table 2 & Table 3. respectively.

Table 2: Physical Properties of Flyash. (Provided by Supplier).

Characteristics	Value
Blaine fineness	265 m^2/Kg
Specific Gravity	2.35
Particle Size	8 to 14 µm

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Table 3: Chemical Properties of Flyash.(Provided by Supplier)

S.N.O	Tests	Result(%)	Requirements in % (As per IS:3812:2013)
1	$SiO_2+Al_2O_3+Fe_2O_3$, % by mass	92.78	70(Min)
2	Silicon dioxide as SiO_2, %by mass	62.55	35(Min)
3	Magnesium Oxide as MgO, % by mass	0.13	5(Max)
4	Total Sulphur as SO_3, % by mass	0.22	3(Max)
5	Available Alkali as Na_2O % by mass	0.20	1.5(Max)
6	Total Chlorides as Cl,% bymass	0.024	0.05(Max)
7	Loss on Ignition,% by mass	0.52	5(Max)

Glass Powder

Glass powder may be defined as primarily a silicate source which provides the necessary cations to be acted upon by alkaline activator thereby leading to creation of additional cementing by products. Its main use in the geopolymer concrete is associated with strength gain at longer ages & improvement of durability properties of the resulting geopolymer concrete.

They may also be defined as non-crystalline silicates containing other oxides. In glass powder silicon atoms together with other elements (e.g. Al, Zr, B) readily form bridging bonds with oxygen atoms to provide the highly cross-linked glass network.

The Glass powder used in the study belonged to the family of post consumer glass. Scraps of Glass pieces were collected & were ground by manual means to obtain glass powder passing through 600 micron IS sieve.The photograph of the glass powder used in the paper work is shown in Fig.3.2& its properties presented in Table 3.3 respectively.

There are mainly three types of glass powders that can be used for formation of geopolymer concrete: Post industrial by-product derived from waste glass fiber, Post industrial by-product obtained from recycling of glass & Post consumer glass powder obtained by grounding scraps of the glass pieces obtained from human consumption.

5. Results and discussion

In this section results obtained from various tests conducted on the geopolymer concrete specimens are presented and discussed to study the effect of addition of GGBS in percentages of 15%,20%,25% & Glass Powder in percentages of 5%,10%,15% on the compressive strength, flexural strength & split tensile strength of geopolymer concrete specimens. To make this study two dimensional molar concentration of NaOH i.e 4M, 8M & 12M as a variable has also been considered and its effect on compressive strength, flexural strength & split tensile strength has been studied. The compressive strength and flexural strength tests on the specimens have been performed after 7 and 28 days of curing whereas split tensile strength of the specimens has been checked for 28 days only. To get a better idea of the split tensile strength of geopolymer concrete specimens a comparison of the measured split tensile strength with the split tensile strength predicted as per various equations and codal provisions has been done.

To study the effect of these variables on the mechanical properties various graphs and bar charts showing the relative strength in different samples have been drawn. In addition to this to know about the effectiveness of ambient curing over oven curing a comparison of mechanical properties of blended mixes with the control mix has been done. A comparative study of various blended mixes with control mix has also been done with the help of SEM-EDS tests conducted on the specimens at the age of 28 days curing. For all the results obtained a discussion on the trend developed in the properties has been done & reasons for these trends have also been assigned on the basis of reaction mechanism & SEM-EDS test conducted on the specimens.

6. Compressive strength

Compressive strength is the most common property used to describe a concrete. Since other properties of concrete often correlate well with the compressive strength, it is used as an indicator of the other mechanical properties. The results of the compressive strength tests of geopolymer concrete samples are given in Table 4. respectively. These are the mean values of the results obtained from three identical specimens.

Table 4: Compressive Strength Results of Geopolymer Concrete Samples

	Ingredients							Strength	
	Flyash	GGBS	Glass Powder	CA (20mm)	CA (10 mm)	FA	NaOH	7 days	28 days
Units	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(MPa)	(MPa)
Designation									
Control	450	-	-	720	480	575	70.00	7.37	15.11
M1-4M	315	112.5	22.5	720	480	575	23.33	20.44	26.64
M2-4M	315	90	45	720	480	575	23.33	17.28	23.91
M3-4M	315	67.5	67.5	720	480	575	23.33	15.33	21.95

M1-8M	315	112.5	22.5	720	480	575	46.66	14.93	23.33
M2-8M	315	90	45	720	480	575	46.66	12.05	20.35
M3-8M	315	67.5	67.5	720	480	575	46.66	11.11	18.13
M1-12M	315	112.5	22.5	720	480	575	70.00	12.53	20.66
M2-12M	315	90	45	720	480	575	70.00	15.64	23.06
M3-12M	315	67.5	67.5	720	480	575	70.00	10.40	17.42

For the control mix containing only flyash as binder & activated using 12M NaOH solution the compressive strength at 7 days has been found to be 7.37MPa and at 28 days has been found to be 15.11MParespectively. The control mix studied over here has been subjected to 48 hours oven curing at60ºC & followed subsequently by ambient curing upto the age of testing.

In the 12 M category the mix M1-12M (containing 70% Flyash, 25% GGBS and 5 % Glass powder) & activated using 12 M NaOH solution was found to have flexural strength of1.87MPa after 7 days and 1.83MPa after 28 days respectively. In the mix M2-12M as the percentage of GGBS decreased by 5% & that of glass powder increased by 5% the flexural strength increased by 15.51% at 7 days and 27.87% at 28 days respectively. In the mix M3-12M as the percentage of GGBS further decreased by 5% & that of glass powder increased by 5% the flexural strength decreased by 8.33% at 7 days and 19.23% at 28 days respectively.

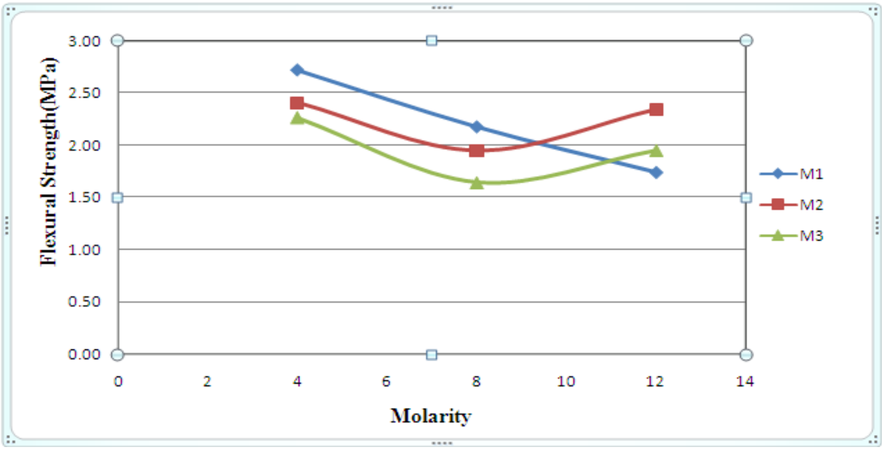

Fig 4: Effect of Concentration of NaOH on 7 day Flexural Strength

Fig.4. shows theeffect of concentration of NaOH on the 7 day flexural strength of different mixes. It can be seen from Fig.4, that themaximum flexural strength is achieved for 4M category samples as compared to 8M & 12 M category samples. It may be noted that this pattern of flexural strength observed is similar to the pattern observed in compressive strength & the reason for it has already been discussed in the compressive strength section.

Furthermore, it is to be observed from this figure that no control mix result has been shown on this figure on account of breaking of control mix specimen while demoulding. The reason for breaking of this specimen at the time of demoulding is due to inadequate gain of strength upto the age of demoulding on account of low reactivity of flyash at ambient conditions. Another factor that aided this breaking of the sample was the higher self weight of the sample used for checking flexural strength as compared to cubes used for checking compressive strength.

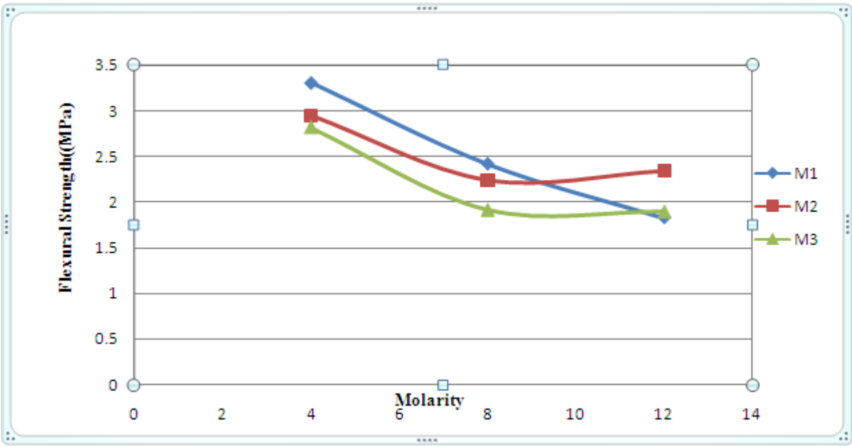

Fig 5: Effect of Concentration of NaOH on 28 day Flexural Strength

Fig 5 shows the effect of concentration of NaOH on the 28 day flexural strength of different mixes. On seeing Fig.5, it may be noted that in the 12M category there is one abrupt variation that is the strength of M2-12M is highest in this category & doesn't follow the general trend observed for the other categories in this graph. The reason for this variation has already been discussed in the compressive strength section.

Furthermore, it can be seen from the fig 5 that as the percentage of GGBS decreases from M1 to M3 so is the decrease in flexural strength except 12M category. The possible reason for this is the same as observed for compressive strength.

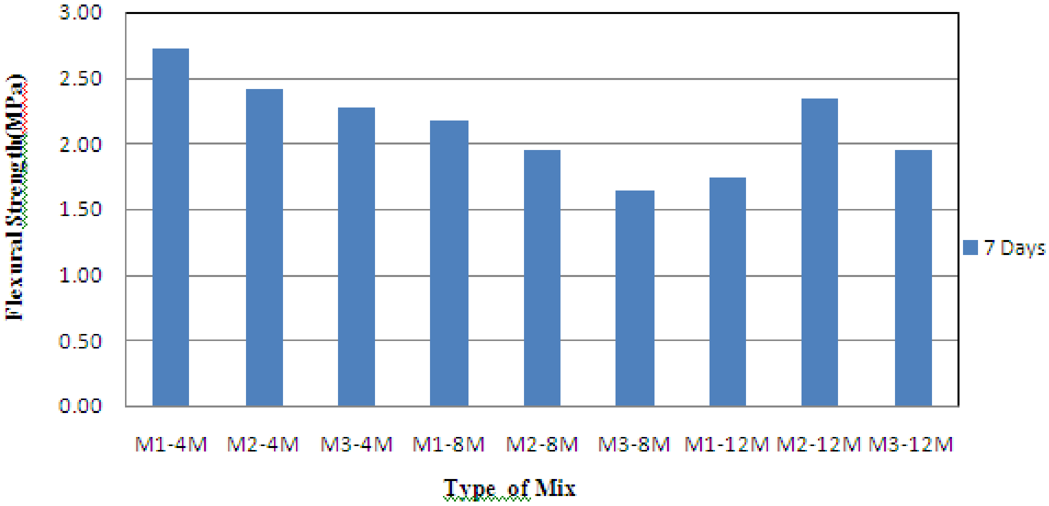

Fig 6: Flexural Strength Variation for Different Mixes of Geopolymer Concrete at 7 days

7. Conclusions

The present section deals with the conclusions drawn from the results obtained after testing the geopolymer concrete specimens for compressive, flexural & split tensile strength respectively. The conclusions presented in this section have been given property wise & have been finalized on the basis of experimental results along with SEM & EDS tests. To explore further on the paper work undertaken some gaps have been identified and they have been included under the heading scope for further work. Based upon the results discussed in the previous section, following are the major conclusions for the properties studied :

- From the view point of strength M-1mix containing 70% Flyash, 25% GGBS &5% GP works out to be the optimum mix for preparation of geopolymer concrete samples.
- The observance of abrupt variation regarding increase of strength in M2-12M mix indicates that only addition of GGBS is not the sole criteria for increase of strength.
- The optimum molarity of NaOH solution for achieving the highest strength of GPC mixes at 7 as well as 28 days curing works out to be 4M as per the molar concentrations considered.
- An average increase of about 30% in the compressive strength has been observed for a period of 7 to 28 days thereby indicating gain of strength similar to OPC Concrete.

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