Effects of steel fibres on various properties of geopolymer concrete

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ABSTRACT

Geopolymer is a term used to define a category of synthetic alumino-silicate materials with potential use. The geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer concrete significantly reduce the CO2 emission to the atmosphere caused by the cement industries.

Effect of steel fibres on various properties of geopolymer concrete composites (GPCC) having grade M20 has been presented. The study analyses the impact of steel fibres on the compressive, flexural, split-tensile, and durability of hardened GPCC. Geopolymer concrete mixes were prepared using low calcium fly ash and activated by alkaline solutions (NaOH and Na2SiO3) with solution to fly ash ratio of 0.35. Hooked end steel fibres having aspect ratio of 70 with volume fraction of 0.25%, 0.50%, 0.75% and 1% by volume of geopolymer concrete are used. The entire tests were carried out according to test procedures given by the Indian standards wherever applicable. The inclusion of steel fibre showed the excellent improvement in the mechanical properties of fly ash based geopolymer concrete. Test results revealed that fibre reinforced geopolymer concrete possesses superior durability characteristics.

Keyword - *Fly ash, alkaline solution, hooked end steel fibres, Compressive strength, flexure strength, split tensile strength, durability.*

1. INTRODUCTION

Production of Portland cement is increasing due to the increasing demand of construction industries. Therefore the rate of production of carbon dioxide released to atmosphere during production of Portland cement is also increasing.

Now a days, Portland cement (PC) concrete is the most popular and widely used building materials, due to its availability of the raw materials over the world, its ease for preparing and fabricating in all sorts of conceivable shapes. The applications of concrete in the area of infrastructure, habitation, and transportation have greatly prompted the development of civilization, economic progress, and stability and of the quality of life. However, due to the restriction of the manufacturing process and the raw materials, some inherent disadvantages of Portland cement are still difficult to overcome. There are two major drawbacks with respect to sustainability. About 1.5 tons of raw materials is needed in the production of every tone of Portland cement, at the same time about one tone of carbon dioxide (CO_2) is released into the environment during the production. Therefore, the production of PC is extremely resource and energy intensive process. On the other hand, the global warming also can occur because of the greenhouse gases such as carbon dioxide to the atmosphere. A need of present status is, should we build additional cement manufacturing plants or find alternative binder systems to make concrete? On the other scenario huge quantity of fly ash are generated around the globe from thermal power plants and generally used as a filler material in low level areas. Alternative binder system with fly ash to produce concrete eliminating cement is called “Geopolymer Concrete”.

Utilization of concrete as a major construction material is a worldwide phenomenon and the concrete industry is the largest user of natural resources in the world (1). This use of concrete is driving the massive global production of cement, estimated at over 2.8 billion tones according to recent industry data (2). Associated with this is the inevitable carbon dioxide emissions estimated to be responsible for 5 to 7% of the total global production of carbon dioxide (3). Significant increases in cement production have been observed and were anticipated to increase due to the massive increase in infrastructure and industrialization in India, China and South America.

1.1 Geopolymer concrete

The name geopolymer was formed by a French Professor Davidovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules. The geopolymers depend on thermally activated natural materials like Meta kaolinite or industrial byproducts like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These Silicon and Aluminum is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder. Professor B. Vijaya Rangan (2008), Curtin University, Australia, stated that, "the polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon-aluminum minerals that results in a three-dimensional polymeric chain and ring structure…."The ultimate structure of the geopolymer depends largely on the ratio of Si to Al (Si:Al), with the materials most often considered for use in transportation infrastructure typically having an Si:Al between 2 and 3.5 5 &6 . The reaction of Fly Ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

Water is not involved in the chemical reaction of Geopolymer concrete and instead water is expelled during curing and subsequent drying. This is in contrast to the hydration reactions that occur when Portland cement is mixed with water, which produce the primary hydration products calcium silicate hydrate and calcium hydroxide. This difference has a significant impact on the mechanical and chemical properties of the resulting geopolymer concrete, and also renders it more resistant to heat, water ingress, alkali–aggregate reactivity, and other types of chemical attack. In the case of geopolymers made from fly ash, the role of calcium in these systems is very important, because its presence can result in flash setting and therefore must be carefully controlled. The source material is mixed with an activating solution that provides the alkalinity (sodium hydroxide or potassium hydroxide are often used) needed to liberate the Si and Al and possibly with an additional source of silica (sodium silicate is most commonly used). The temperature during curing is very important, and depending upon the source materials and activating solution, heat often must be applied to facilitate polymerization, although some systems have been developed that are designed to be cured at room temperature. The necessity of Geopolymer Concrete, the Constituents, Properties, Applications and Limitations are discussed in detail in this paper.

2. MATERIALS USED AND IT'S PROPERTIES

1. Fly ash

Low calcium fly ash procured from Dirk India Private Limited; Nashik is used in the investigation. Physical properties and chemical composition of fly ash using experimental work along with IS specification are given in Table-1.

Table-1 Physical and chemical properties of fly ash

Part 1			Pozzocrete 63	
Sr No.	**Physical Properties**	**Unit**	**IS Specification**	**Typical Test Result**
1	Fineness – Specific Surface By Blaines Permeability Method	m2/kg	320	439
2.	ROS 500 (25 MIC)	%	Not Specified	17.38
3.	ROS 350 (45 MIC)	%	34	9.76
4	Lime Reactivity (min.)	N/mm^2	4.5	7.08

5.	moisture Content (max)	%	2	0.27	
6.	Autoclave Expansion (Max)	%	0.8	0.028	
7	Compressive Strength At 28 Days	N/mm^2	-	95.41	
	Pozzocrete + Cement Mortar			50.00	94.88%
	Plain Cement Mortar			52.70	
8	Chemical Analysis				
	Test	%	IS specification		
	$SIO_2 + AL_20_3+Fe_2O_3$	%	70 min. by mass	93.13	
	SIO_2	%	-	01.	
	MgO	%	5 max by mass	1.57	
	SO_3	%	3 max. by mass	0.69	
	Na_2O	%	1,5 max by mass	0.57	
9	Total Chloride	%	0.05 max by mas	0.030	

2. Fine Aggregate

Locally available Pravara river sand is used as fine aggregate. The sand is sieved using sieves of size 4.75mm, 2.36mm, 1.18mm,600 micron, 300 micron, 150 micron with slandered IS as per IS 650:1991.

Type- Natural River sand confirm in to grading zone I as per IS 383(20)

F.M = 302.05/100

F.M= 3.02

Water absorption = 3.69%

Water content-Nil

3. Coarse Aggregate

Local aggregates, 20mm and 12.5mm as coarse aggregates and in saturated surface dry condition, are used as per IS 383:1970, IS 2386:1963

Type- Crushed/Angular

Maximum Size= 20mm-12.5mm

Water absorption = 0.87%

4. Steel fibres

Hooked end steel fibres of various aspect ratio 70, 100 and 120 and in various percentage of 0.25, 0.50, 0.75 and 1 is used.

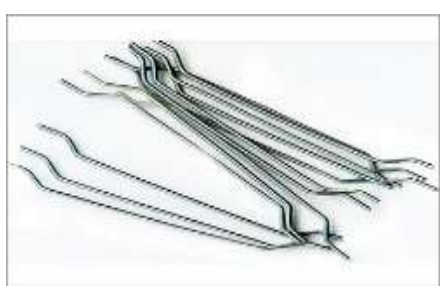


Fig-1 Hooked end steel fibres

Properties of steel fibres:

1. Aspect ratio= 70
2. Length= 35 mm, diameter= 0.5 mm
3. Tensile strength of steel fibres= 1120 MPa.

5. Alkaline solutions

The combination of sodium hydroxide and sodium silicate solution were use for the activation of fly ash. The laboratory grade sodium hydroxide in flake form, with 97.8% purity and three different concentrated laboratory grade sodium silicate solutions were used as an alkaline activator. The chemical composition of sodium hydroxide and sodium silicate use in a present investigation are given in Table-2 & Table-3 respectively.

Table-2 Chemical Composition of Sodium Hydroxide

Chemical composition	Percentage
Purity of NaOH	97.70
Iron as Fe (ppm)	16.5
Chlorides as NaCl (%)	0.045

Table -3 Chemical Composition of Sodium Silicate

Chemical composition	Content
Baume @ 30^0C	56.5 degree
Na_2O%	16.40%
SIO_2 (%)	34.48
Wt ratio	1:2.09

3. METHODOLOGY

The experimental work, mixture proportions, manufacturing and curing of the test specimens are explained in this.

3.1 Types Of Curing, Temperature and Age:

Heat-curing of low-calcium fly ash-based geopolymer concrete is generally recommended. Heat curing substantially assists the chemical reaction that occurs in the geopolymer paste.

Longer curing time improved the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hours of curing time; beyond 24 hours, the gain in strength is only moderate. Therefore, heat curing time need not be more than 24 hours in practical applications. Heat-curing can be achieved by either steam-curing or dry-curing.

Earlier investigation have shown that the effect of age of mortar is not significant after 24 hours. In the present investigation, heating was done in oven at 90^0C for 24 hours, natural curing and tested after duration for 7, 14, 28 days.

3.2 Preparation of Sodium Hydroxide Solution

For the Preparation of one mole solution, flakes of sodium hydroxide weighing 40 gm were added in distilled water so as to make one litre solution where 40 is the molecular weight of NaOH. But it was difficult to prepare exact one – liter solution. Similarly after dissolving the flakes of NaOH, the temperature of solution rise tip to 70 to 80^oC so avoid direct contact of sodium hydroxide solution with skin & eyes. It may cause severe burn.

For preparation of 13 M NaOH solution 520 gms (13x40) of NaOH flakes were added in about 750 ml water and steered the solution and after cooling and add remaining quantity of water so as to make one liter solution. During preparation avoid direct contact of sodium hydroxide solution with skin and eyes. It may cause severe burn.

3.3 Parameters for project

Constant parameters

- Fineness of fly ash
- Alkaline solution to fly ash ratio by mass
- Sodium silicate to sodium hydroxide ratio
- Concentration of NaOH in terms of molarity
- Concentration of Na_2Sio_3
- Type of curing(oven curing
- Curing temperature(90^oC)
- Water to geopolymer binder ratio

Variable parameters

- % of steel fibres

3.4 Mix Design for Geopolymer Binder Ratio 0.35

3.4.1 Basic data required for mix design

- Characteristic strength (M20)= fck=20 MPa
- Fineness of fly ash in terms of specific surface in m^2/kg= 439 m^2/kg
- Workability in terms of flow 25%-50% (Degree of workability= medium)
- Alkali activators (Na_2Sio_3 and NaOH)
- Concentration of NaOH in terms of molarity= 13M
- Concentration of Na_2Sio_3 = 50.32% solid content
- Solution to fly ash ratio by mass = 0.35
- Sodium silicate to sodium hydroxide ratio by mass = 1
  Mix design as per "Mix Design of Fly Ash Based Geopolymer Concrete" by S.V. Patankar [6]

3.5 Casting of specimen

1. Cube moulds of 150 x 150 x 150 mm are used for casting the specimens for compressive strength.
2. Cylindrical moulds of 150 mm diameter and 300 mm long are used for casting the specimens for split tensile strength test.
3. Rectangular beams of size150mm×150mm×700mm were cast for flexure test

3.6 Schedule of casting

Table-4 Schedule of specimen preparation

Vf	l/d	Cubes			Beams	Cylinders	Durability			
		3 days	7 days	28 days	28 days	28 days	HCl	H_2SO_4	$MgSO_4$	Na_2SO_4
0.25%	70	3	3	3	4	3	3	3	3	3
0.50%		3	3	3	4	3	3	3	3	3
0.75%		3	3	3	4	3	3	3	3	3
1%		3	3	3	4	3	3	3	3	3

3.7 Curing of specimen

After one day casting, cubes, beams, and cylinder are demoulded and placed in oven at 90^0C for 24 hours curing. After specified period of natural curing, cubes, beams, cylinder are tested for compressive, flexural, and indirect split tensile test strength for 0.25, 0.50, 0.75 and 1 percentage of steel fibres.

3.8 Test of specimen

3.8.1 Test on Fresh concrete

- **Workability test: Flow table method**
  Reference: IS: 1199 – 1959 – Method of sampling and analysis of concrete.

Procedure:

1. Before commencing test, the table top and inside of the mould is to be wetted and cleaned of all gritty material and the excess water is to be removed with a rubber squeezer.
2. The mould is to be firmly held on the centre of the table and filled with concrete in two layers, each approximately one-half the volume of the mould and rodded with 25 strokes with a tamping rod, in a uniform manner over the cross section of the mould.
3. After the top layer has been rodded, the surface of the concrete is to be struck off with a trowel so that the mould is exactly filled.
4. The mould is then removed from the concrete by a steady upward pull.
5. The table is then raised and dropped from a height of 12.5 mm, 15 times in about 15 seconds.
6. The diameter of the spread concrete is the average of six symmetrically distributed caliper measurements read to the nearest 5 mm.

Flow = [(spread dia -250)/250] × 1000

3.8.2 Test on Hard concrete

- **Compressive Strength-**
  1. The cube will be tested in compressive in accordance with the test procedure given in the Indian standards IS 4031(part 4) 1981 methods of testing for strength of concrete – determination of the compressive strength of concrete specimen.
  2. The compression test on concrete is conducted on cube of specimen of sizes 150mm×150mm×150mm. strength at 3 days, 7 days and 28 days are tested. Compressive strength of cement concrete composite increases as, specimen size is decreases.
- **Flexural Strength Test**
  1. The beams were tested in flexural in accordance with the test procedure given in the Indian standards IS-516-1959, method of testing for strength of concrete- determination pf the flexural strength of concrete specimen.
  2. The standard size of beam specimen of 150mm×150mm×700mm.Over a span of 600mm, if nominal size of aggregate does not exceed 20mm, then 100mm×100mm×500mm specimen is used.
  3. Specimen is loaded at the rate of 4 kN/min for 150mm specimen and 1.8 kN/min for 100mm specimen. Maximum load at failure is noted.
- **Split Tensile Strength**
  1. The cylinder were tested for indirect tensile strength in accordance with the test procedure given in the Indian standards IS – 5816- 1970, method of testing for splitting tensile strength of concrete cylinder.
  2. The load is applied at the rate of 1.2 N/min-2.4 N/min and continuous untiled the specimen fail the maximum load is recorded.

3.8.3 Durability test:

- **Acid Attack on Concrete - (As per ASTM C267)**

  Test Specimen - The present experimental study conducted on concrete specimens of size 150×150×150 mm.

  Preparation of Solution - The specimens are immersed in 5% H2SO4, and HCL solutions respectively for the period of 28 days. The test specimens were immersed in jars filled with 'equal quantities of 5% H2SO4, and HCL (pH = 1). This concentration of acid is representative of that found in sewers that are in the process of deterioration. The pH levels of the acid solutions were monitored at an average interval of 2 days with a portable pH meter. All solutions were replaced with fresh 1 percent solutions if the pH of any solution exceeded a value. All solutions were also replaced prior to immersion of the test specimens after taking measurements. The periodic use of fresh acid solutions along with the use of small test specimens provided an accelerated evaluation of the acid resistance of the concrete mixes.

  Test Measurement - The deterioration of the specimens is estimated by finding out the percentage reduction in weight of the specimen, the reduction in compressive strength of the specimens when they are immersed in chemical solutions.

- **Sulphate Attack on Concrete (As per ASTM C39)**

  Test Specimen - The present experimental study conducted on concrete specimens of size 150×150×150 mm.

  Preparation of Solution - The specimens are immersed in 5% Na2SO4 and MgSO4 solutions respectively for the period of 28 days. The test specimens were immersed in jars filled with 'equal quantities of 5% Na2SO4 and MgSO4.

  Test Measurement - The deterioration of the specimens is estimated by finding out the percentage reduction in weight of the specimen, the reduction in compressive strength of the specimens when they are immersed in chemical solutions.

4. RESULTS

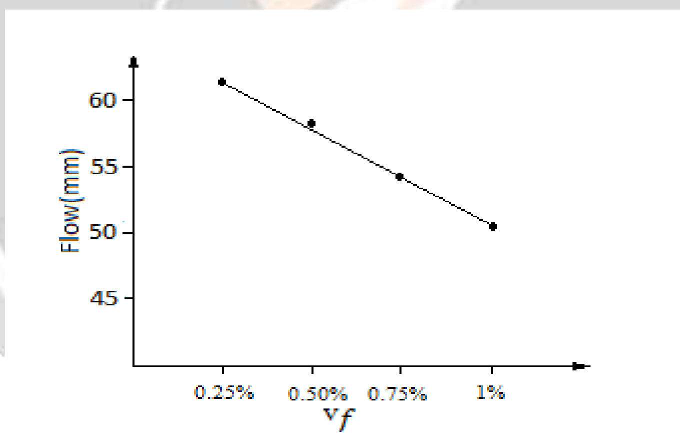
The results and discussion of experimental work carried on effect of various percentage of steel fibres on workability, compressive strength, flexural strength, Split tensile strength and durability of GPC are explained.

4.1 Test for fresh concrete

4.1.1 Flow test for workability:

Table-5 Workability, weight and dry density of GPC [3]

Vf	Flow (mm)	Degree of workability	Weight	Density (kg/m^3)
0.25%	60.40	High	8.30	2460
0.50%	57.33	High	8.36	2479
0.75%	54.13	High	8.45	2505
1%	51.71	High	8.48	2515



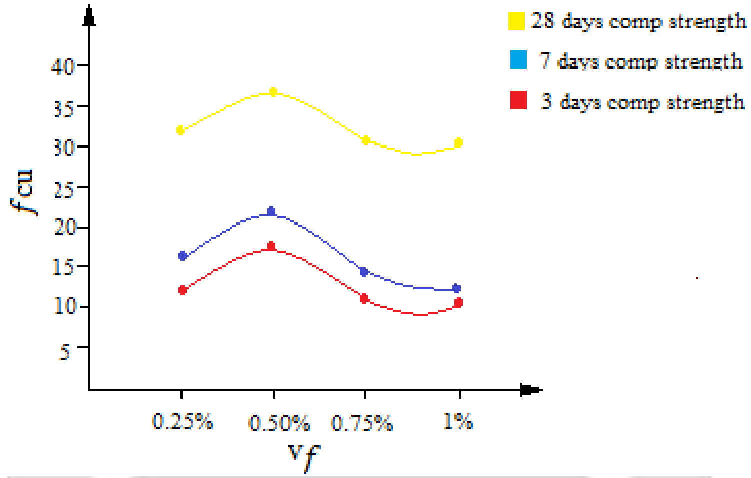
Graph-1 Flow test for workability

4.2 Test for hard concrete

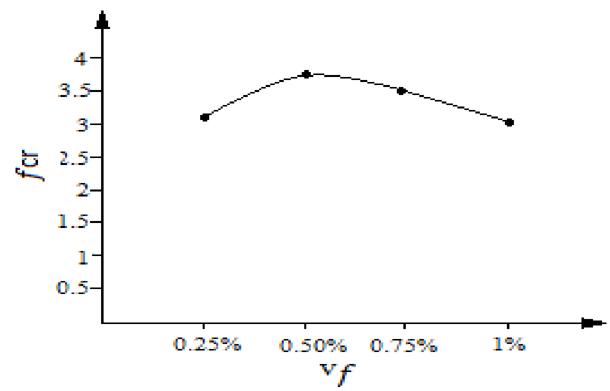
4.2.1 Comparison of compressive strength ($f$cu), flexural strength ($f$cr) and split-tensile strength ($f$cys) for various percentages of steel fibres (Vf).

Table-6 Comparison ($f$cu), ($f$cr) and ($f$cys) for (Vf). [3]

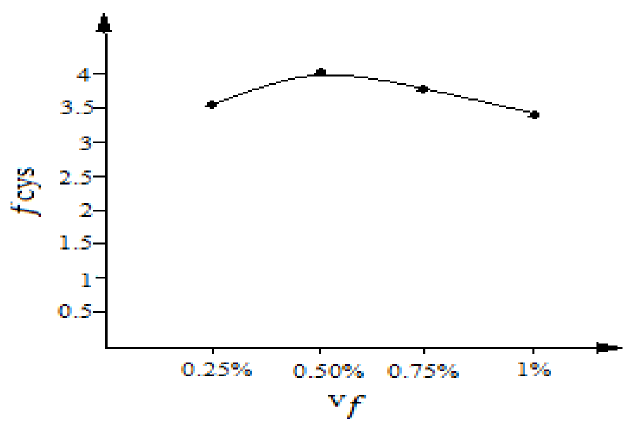
	Strength in MPa				
V_f	$f$cu (3 days)	$f$cu (7 days)	$f$cu (28 days)	$f$cr	$f$cys
0.25%	13.78	15.64	32.05	3.38	3.57
0.50%	19.46	22.26	36.05	3.86	4.07
0.75%	13.12	14.63	31.61	3.57	3.76
1%	11.10	12.21	30.72	3.22	3.4



Graph-2 Variation of compressive strength ($f$cu) with respect to percentage of steel fibres (Vf)



Graph-3 Variation of flexural strength ($f$cr) with respect to percentage of steel fibres (Vf).



Graph-4 Variation of split-tensile strength ($f$cys) with respect to percentage of steel fibres (Vf)

4.3 Durability test results:

4.3.1 Acid Attacks

4.3.1.1 HCl

Table-7 Comparison of compressive strength for HCl attack

V_f	*f*cu	Decrease in *f*cu	% loss in *f*cu	Loss in weight	% loss in weight
0.25%	32.05	32.01	0.124	8.29	0.120
0.50%	36.05	36.03	0.05	8.35	0.119
0.75%	31.61	31.57	0.126	8.44	0.118
1%	30.72	30.65	0.228	8.47	0.118

4.3.1.2 H_2SO_4

Table-8 Comparison of compressive strength for H_2SO_4 attack

V_f	*f*cu	Decrease in *f*cu	% loss in *f*cu	Loss in weight	% loss in weight
0.25%	32.05	31.06	3.1	8.26	0.484
0.50%	36.05	35.05	2.8	8.32	0.480
0.75%	31.61	30.65	3.1	8.42	0.356
1%	30.72	29.65	3.6	8.44	0.473

4.3.2 Sulphate attack

4.3.2.1 $MgSO_4$

Table-9 Comparison of compressive strength for $MgSO_4$ attack

V_f	*f*cu	Decrease in *f*cu	% loss in *f*cu	Loss in weight	% loss in weight
0.25%	32.05	32.03	0.06	8.29	0.120
0.50%	36.05	36.02	0.08	8.35	0.119
0.75%	31.61	31.59	0.06	8.43	0.237
1%	30.72	30.70	0.06	8.47	0.118

4.4.2.2 Na_2SO_4

Table-10 Comparison of compressive strength for Na_2SO_4 attack

V_f	*f*cu	Decrease in *f*cu	% loss in *f*cu	Loss in weight	% loss in weight
0.25%	32.05	32.02	0.09	8.295	0.060
0.50%	36.05	36.04	0.02	8.34	0.239
0.75%	31.61	31.60	0.03	8.435	0.177
1%	30.72	30.69	0.09	8.478	0.023

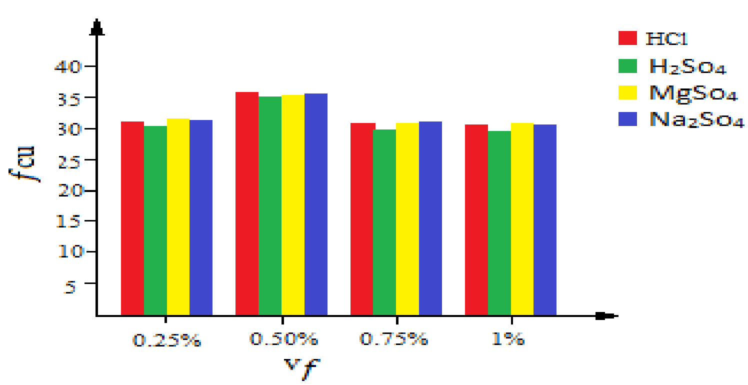


Chart-1 Comparison of Compressive strength for acid and sulphate attack

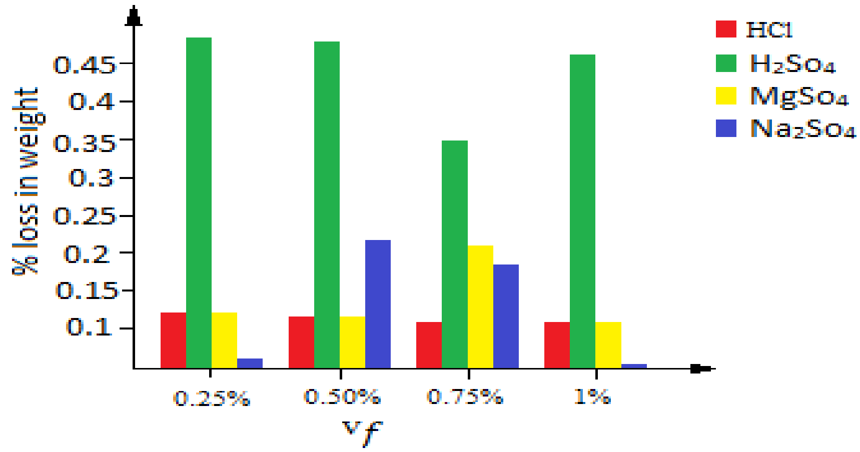


Chart-2 Comparison of weights loss for various acids

5. CONCLUSIONS

1. Workability of geopolymer concrete decrease with increase in percentage of steel fibres.
2. The compressive strength of Steel fibre reinforced geopolymer concrete increase upto 0.50% of steel fibres and then decreases for 0.75% and 1 % of addition of steel fibres due to decrease in workability.
3. The Flexural strength of Steel fibre reinforced geopolymer concrete increase upto 0.50% of steel fibres and then decreases for 0.75% and 1 % of addition of steel fibres due to decrease in workability.
4. The split tensile strength of Steel fibre reinforced geopolymer concrete increase upto 0.50% of steel fibres and then decreases for 0.75% and 1 % of addition of steel fibres due to decrease in workability.
5. The optimum fibre content for the maximum strengths of steel fibres for GPC is 0.50%.
6. H_2SO_4 attack is more severe than HCl due to more loss in compressive strength and weight.
7. Geopolymer concrete is sulphate resisting concrete as loss in compressive strength and weight is very less.
8. The strength of concrete depends on binder mechanism as well as bond mechanism of concrete. Binder mechanism of geopolymer concrete is superior to cement and also ecofriendly but limitations to geopolymer are delay in setting time and high temperature for curing.

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