Optimizing Fiber-Reinforced Geopolymer Concrete for Sustainable Infrastructure

1) D.Varun Kumar, Assistant Professor, Geetanjali College of Engineering and Technology.

ABSTRACT:
Global Warming is one of the major threats to our ecosystem. Among all the greenhouses gases leading to global warming, carbon dioxide is of maximum percentage. Researchers are analysing and finding ways to reduce the emission of carbon dioxide into the environment. And even the infrastructure development is growing worldwide, so the demand for cement increases as it is the basic ingredient in concrete. Geopolymer concrete includes source material containing silicon and aluminium of geological origin or in by-product materials like fly ash, blast furnace slag etc., alkaline liquid which is commonly made by combining Sodium Hydroxide and Sodium Silicate solutions, coarse aggregate and fine aggregate. Even while curing it does not require any water hence it saves considerably large amount of water. The study is focused on the performance of fly ash and slag based geopolymer concrete with the addition of steel fiber & the effect of steel fiber on the properties of geopolymer concrete. The work is carried out by taking 60% fly ash and 40% GGBS as a replacement to cement and a combination of sodium silicate solution and 14M sodium hydroxide solution were used. In this study two types of steel fibers are used i.e., crimped steel fibers and hooked end steel fibers with an aspect ratio of 60, length of 30mm and diameter of 0.5mm. The two steel fibers were taken by varying percentages such as 0.5%, 1.0%, 1.5% and 2.0% by weight of concrete. A total of 96 cubes of 150mm X 150mm X 150mm were tested for compressive strength for 3, 7, 21 and 28days and the results are analyzed.

1.0 INTRODUCTION

Concrete is the most common construction material used in building industry. Cement is a basic component of concrete used for building and civil engineering construction. The production of cement involves the consumption of large quantities of raw materials, energy, and also results in the release of a significant amount of solid waste materials and green house gaseous emissions. The emissions from cement plants which cause greatest concern and which need to be dealt with are dust, carbon dioxide CO_2, nitrogen oxides (NO_x) and Sulphur dioxide (SO_2). Manufacturing of one ton of cement generates about one ton of CO_2. 4 to 5% of the global CO_2 emissions are caused by cement production. Nowadays, there is a big concern about the development of alternative materials to Portland cement. Therefore, efforts are made to develop the other form of cementitious materials for production of concrete. Producing cement uses a great deal of energy, so finding a waste product that can substitute for cement makes good environmental sense. Replacing energy-consuming Portland cement with recyclable materials and minerals offers two distinct benefits to the environment. It significantly reduces the amount of CO_2 released into the atmosphere and it minimizes massive landfill disposal. Waste materials that contain silica and alumina were applied to replace some portion of cement in concrete. Fly ash, Rice husk ash, silica fume and ground granulated blast furnace slag are some of the examples of cement replacement materials that are commonly used. However, these materials can only replace up to certain percentages of portion of cement in concrete. High volume fly ash concrete has been developed that utilized fly ash to replace cement up to 60% without reducing concrete performance. Percentage replacement of cement above 60% would not provide any improvement to the concrete performance, therefore new binder material that could fully replace cement portion in concrete is necessary to create superior and more environmentally friendly concrete. In 1978, Professor Joseph

Davidovits introduced the development of mineral binders with an amorphous structure, named geo polymers. Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term ‘Geo polymer’ to represent these binders

Problem Description

As the demand for cement is increasing the demand for Portland cement also increases as it is the basic ingredient in concrete and to produce cement it releases huge amount of CO_2 so there is a need for an alternative eco-friendly material which can replace Portland cement and one such materials is geopolymer concrete. Cement industry is responsible for about 7% of total CO_2 emission. Production of 1 tonne of Portland Cement emits approximately 1 tonne of CO_2 into the atmosphere. And also, the use of by-products minimizes the dumping issues. Geopolymer technology has the potential to reduce the emission of CO_2 into the atmosphere caused by cement industries.

Objectives

1. To develop an alternative binder to replace cement.
2. To obtain a mix proportion for fiber reinforced geopolymer concrete.
3. To determine the optimum percentage of steel fibers in concrete to achieve maximum strength.
4. To study the effect of fibers on compressive strength of geopolymer concrete.

2.0 LITERATURE REVIEW

An attempt has been made for an excessive literature study related to mechanical and durability characteristics of geo polymer concrete and fiber reinforced geo polymer concrete.Pallavietal.**[1]**presentedexperimentalstudyongeopolymerconcretewithdifferentalkaline liquidto fly ashratios at differentcuring temperatures. Higherconcentration of sodium hydroxide solution results in higher compressive strength. Asthecuring temperatureincreases the compressive strength also increases.E. Rabiaa et al. **[2]** studied on the impact of steel fibers and nanomaterialson the mechanical properties of geopolymer concrete. The results concluded that byusingoptimumpercentageofsteelfibersandnanomaterialsshowedsignificantimprovementin themechanicalproperties of geopolymer concrete.Peng Zhang et al. **[3]** presented experimental investigation on bond stressof steel bars in reinforced geopolymer concrete. The results showed that the bondstrengthof GPC was approximately 21%higherthan that ofreinforced OPC.YiweiLiuetal.**[4]**investigatedonthedevelopmentofultra-highperformancegeopolymerconcreteandinfluenceofsteelfibersonmechanicalproperties. Adding steel fibers reduced flowability and increased compressive strengthandultimate flexural strength.Debabrata Dutta et al. **[5]** reported about the mechanical, durability andmicrostructural properties of fly ash based geopolymer concrete blended with silicafume and borax. The results showed are better than that of conventional fly ash basedgeopolymerconcrete.AmerHassan**[6]**presentedontheperformanceofflyashbasedgeopolymer concrete. The behaviour of fresh concrete and hardened concrete werereported. IncreaseinactivatorratioshowedincrementinstrengthparametersofGPC.Sandeepetal.**[7]**studiedonthedevelopmentofalternativebindingmaterial and addition of lime powder in geopolymer concrete. The use of lime powdergavebetterresultswithoutheatcuring.Additionof15%oraboveaffectedtheworkabilityand compressive strength of geopolymerconcrete

3.0 ExperimentalWork

ThisIn their experimental study tomaterialsused,mixdesigncalculation,testsonaggregate and the methodology followed for producing and curing the specimens arediscussed. In order to develop the fly ash and slag based geopolymer concrete withaddition of steel fibers the mix is designed considering the past research works. Thefocus of the study is to obtained an optimum mix proportion for the fiber reinforcedgeopolymerconcrete byusingthedraftIndianstandard guidelines.

MaterialsUsed

FlyAsh:

Fly ash is a by-product obtained as a result of coal burning to produce electricity. Asthere is abundant quantity of fly ash available this is chosen as one of the sourcematerials. In the present experimental work, Class C fly ash obtained from GlobalReady Mix Concrete Plant, Rampally, Hyderabad was used, it is shown in fig

Fig. 3.1: Fly Ash

Table:PhysicalPropertiesofFlyAsh

SpecificGravity	2.11
Fineness	410m^2/kg
Residueon 45μsieve	1.6%

Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag is a by-product obtained as a result of iron manufacturing. It has the property of enhancing strength of the concrete when replaced as a binding material. GGBS used in this experimental work was also obtained from Global Ready Mix Concrete Plant, Rampally, Hyderabad, is shown in fig

Fig: GGBS

Table:PhysicalPropertiesofGGBS

SpecificGravity	2.86
Fineness	365m^2/kg
Residueon 45μsieve	2.7%

Steel Fibers

Two types of steel fibers are used in the experimental work, hooked end steel fiber and crimped steel fiber. The hooked end steel fibers are obtained from Prism Ready Mix Concrete Plant, Nacharam, Hyderabad and crimped steel fibers from Vruksha Composites, Tenali, shown in fig

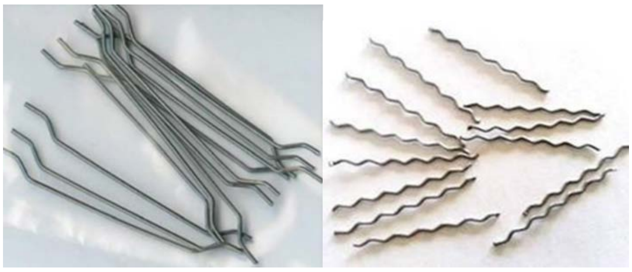

Figure: Hooked End Steel Fibers,Crimped Steel Fibers

Sieve Analysis of Coarse Aggregate

Sieve analysis of coarse aggregate is done as per IS: 2386(part-I)-1963, The observations are presented below in table 3.6 and the gradation curve for coarse aggregate is shown in figThe fineness modulus of coarse aggregate is found to be 6.95. The coarse aggregate passing through 12.5mm sieve and retaining on 10mm sieve was used in the experimental work

Table: Sieve Analysis Results of Coarse Aggregate

ISSieveSize	WeightRetained(%)	CumulativeWeightRetained(%)	CumulativeWeight Passing(%)
40mm	0	0	100
20mm	3.1	3.1	96.9
10mm	89.1	92.2	7.8
4.75mm	7.6	99.8	0.2

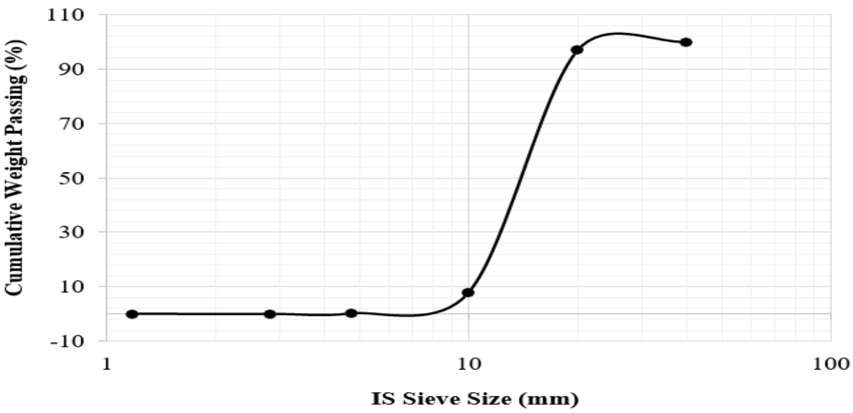

Figure: Gradation Curve of Coarse Aggregate

Table:Results ofSpecificGravity&WaterAbsorptionof CA

Details	TestNumber		
	1	2	MeanValue
Weightofsaturatedaggregatesuspendedin waterwiththebasket,W_1(g)	1942	1942	1942
Weightofbasketsuspendedinwater,W_2(g)	695.5	695.5	695.5
Weightof saturatedsurface dryaggregate in air,W_3(g)	2004	2005	2004.5
Weightofovendriedaggregate,W_4(g)	2000	1998	1999
Specificgravityof aggregate=$\frac{W_4}{W_3-(W_1-W_2)}$	2.64	2.63	2.637
Waterabsorption(%)=$\frac{(W_4-W_3)*100}{W_4}$	0.20	0.35	0.275

Table:SieveAnalysisResults ofFineAggregate

ISSieveSize	WeightRetained(%)	CumulativeWeightRetained(%)	CumulativeWeight Passing(%)
4.75mm	0	0	100
2.36mm	6.3	6.3	93.7
1.18mm	23.8	30.1	69.9
600μ	24.3	54.4	45.6
300μ	30.9	85.3	14.7
150μ	13.6	98.9	1.1

Mix Design Calculation

As there is no proper mix design procedure before, the researchers followed similar mix design as that of OPC. In this experimental work we have followed the mix design procedure as per ICS 91.100 'Draft Indian Standard Guidelines for Geopolymeric Concrete for Precast Products' and designed M30 grade concrete mix and the quantities of materials for casting 96 cubes of 150mm X 150mm X 150mm is presented in table

Mix design of M30 grade with Fly Ash: GGBS = 60 : 40 for 1m^3 concrete mix.

Selection of target strength

Target strength = (fck+10) or (fck*1.4), whichever is less. Target strength = (30+10) = 40MPa or (30*1.4) = 42MPa

Therefore, Target Strength = 40MPa

Preparation of Test Specimens

The sodium hydroxide pellets of 99% purity are dissolved in water to prepare 14M NaOH solution. For preparing 14M NaOH solution, 560g of NaOH flakes are dissolved in 1litre of water, The required quantity of NaOH and Na_2Si0_3 solutions are measured, as shown in fig.

Figure: a)**Preparation of NaOH, b) Sodium Silicate Solution, c) Alkaline Liquid**

Casting & Curing of Specimens

For casting cubes of fiber reinforced geopolymer concrete, initially the dry ingredients i.e., fly ash, ggbs, fine aggregate, coarse aggregate and steel fibers are weighed,Then the fresh concrete mix was placed into the moulds of 150mm X 150mm X 150mm, as shown in fig.

Figure: Casted Specimens

4.0 RESULTS AND DISCUSSIONS

In this chapter the experimental results are presented. The results of slump test and compressive strength test are analyzed and discussed. The comparison between the compressive strength test results of crimped steel fiber reinforced geopolymer concrete cubes and hooked end steel fiber reinforced geopolymer concrete cubes is also discussed.Fiber reinforced geopolymer concrete showed medium workability. The compressive strength of GPC is enhanced by incorporation of steel fibers. This improvement is due to the capability of steel fiber to delay and postpone the propagation of crack. Maximum compressive strength was observed at 1.5% of steel fiber in both the concrete types. Compressive strength of hooked end steel fiber reinforced geopolymer concrete showed higher strength compared to crimped steel fiber. The maximum compressive strength of both the types of steel fibers is above 55MPa therefore, it can be concluded that the development of high strength fiber reinforced geopolymer concrete was successful.

Workability:

The results of the slump test are presented in table The slump value for geopolymer concrete mix with addition of 2% of binder content of superplasticizer is found to be 100mm and by addition of different percentage of steel fibers the workability is found to be in the range of 50mm to 80mm. Therefore, with addition of steel fibers the concrete mix showed medium workability.

Table: Slump Value for Varying Percentage of Steel Fiber

PercentageofSteelFiber	SlumpValue
0.0%	100mm
0.5%	76mm

1.0%	68mm
1.5%	59mm
2.0%	53mm

Compressive Strength:

The compressive strength test is performed at 3, 7, 21 and 28days. The result of each mix is the mean value of the compressive strength of three test specimens. The results of compressive strength of crimped steel fiber reinforced geopolymer concrete cubes and hooked end steel fiber reinforced geopolymer concrete cubes is presented in tableThe compressive strength at 1.5% of steel fibers showed higher compressive strength in both the types of steel fiber compared to other percentages of steel fibers and addition of steel fiber beyond 1.5% resulted in decreases in compressive strength.

Table: Compressive Strength of CSF Concrete Cubes

PercentageofS teelFibers	**CompressiveStrengthinMPa**			
	3days	**7days**	**21days**	**28days**
0.5%	31.03	38.00	45.78	50.22
1.0%	31.11	39.10	49.33	51.55
1.5%	33.55	41.56	51.56	54.67
2.0%	30.88	40.44	50.22	52.00

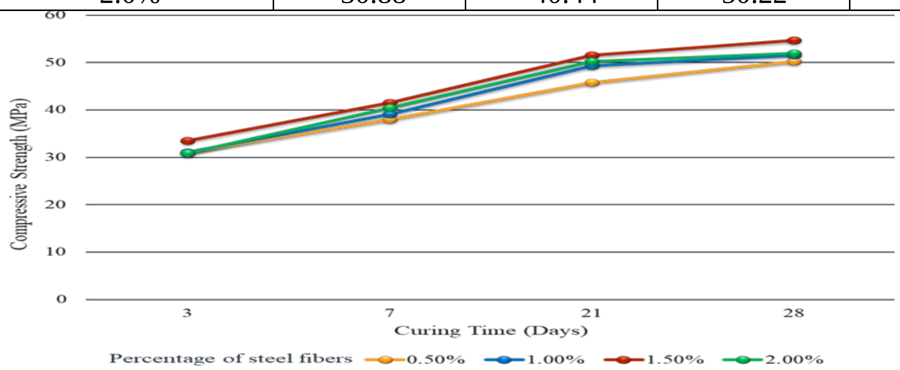

Figure: Compressive Strength of CSF Concrete Cubes

Table: Compressive Strength of HSF Concrete Cubes

Percentage of Steel Fibers	Compressive Strength in MPa			
	3 days	7 days	21 days	28 days
0.5%	22.89	34.67	44.00	44.89
1.0%	24.67	40.44	47.11	48.89
1.5%	31.56	49.33	53.78	56.44
2.0%	29.56	41.78	48.89	51.56

Comparison of Compressive Strength Between CSF & HSF Concrete

The results of crimped steel fiber reinforced geopolymer concrete cubes and hooked end steel fiber reinforced geopolymer concrete cubes at 1.5% addition of steel fibers The graph representing the comparison of results The compressive strength of hooked end steel fiber reinforced geopolymer concrete is higher compared to crimped steel fiber reinforced geopolymer concrete. The hooked end steel fibers handled the existence of microcracks present in the concrete in a better way compared to crimped steel fiber because of cracks' micro dimension. Therefore, the hooked end steel fibers showed its impact on the compressive strength by enhancing the efficiency of bridging microcracks.

Table:CompressiveStrengthofCSF &HSFConcreteCubes

PercentageofSteelFibers	CompressiveStrengthinMPa			
	3days	7days	21days	28days
1.5%CSF	33.55	41.56	51.56	54.67
1.5%HSF	31.56	49.33	53.78	56.44

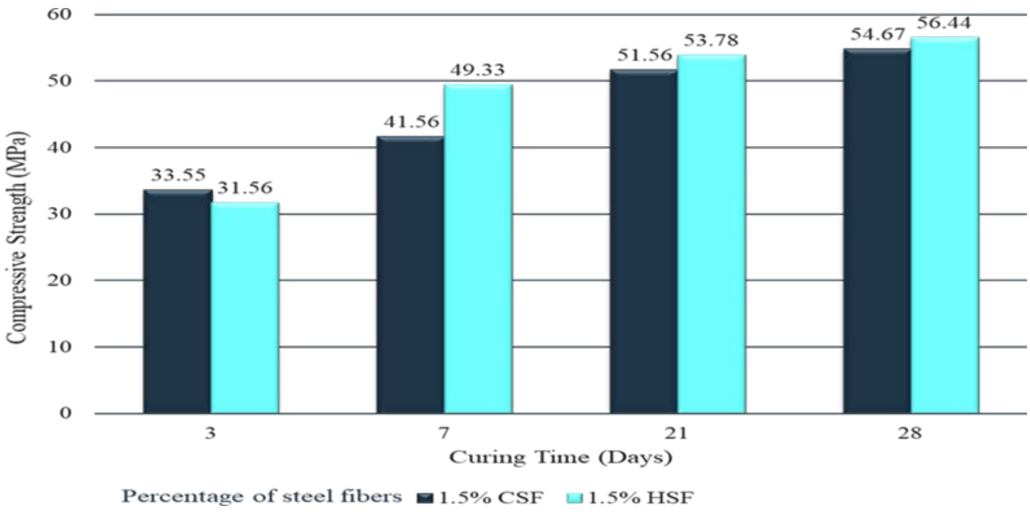

Figure: Compressive strength of CSF & HSF Concrete Cubes

Discussions

Fiber reinforced geopolymer concrete showed medium workability. The compressive strength of GPC is enhanced by incorporation of steel fibers. This improvement is due to the capability of steel fiber to delay and postpone the propagation of crack. Maximum compressive strength was observed at 1.5% of steel fiber in both the concrete types. Compressive strength of hooked end steel fiber reinforced geopolymer concrete showed higher strength compared to crimped steel fiber. The maximum compressive strength of both the types of steel fibers is above 55MPa therefore, it can be concluded that the development of high strength fiber reinforced geopolymer concrete was successful

CONCLUSION:

Geopolymer concrete is more Environmentally friendly and has the potential to replacethe ordinary Portland cement concrete. In terms of reducing the global warming, thegeopolymer technology could reduce the CO_2emission to the atmosphere caused bycement.Itdoesnotonlycontributetothereductionofgreenhousegasemissionbutalsoreduces the disposal cost of industrial waste and it saves considerably large amount ofwater also, as it does not require water for curing. Studies revealed that geopolymer ishighlyflexiblematerialatahighertemperatureandallowsthematerialtoaccommodatelargestrains withoutfracturingandgainsstrengthwhenexposedtofireandgeopolymerconcretepossesses excellentmechanical and durabilityproperties.

The development of high strength fiber reinforced geopolymer concrete and theeffectofsteelfibersarestudied.Basedontheresultsobtainedthefollowingconclusionsaredrawn:

- The compressive strength of GPC was enhanced by the incorporation of steelfibersinto thegeopolymer concrete mixture.
- Thecompressivestrengthincreasesbyaddingtwotypesofsteelfibersindividually in GPC mix up to optimum percentage of steel fibers and thendecrementin compressivestrength wasobserved.
- The maximum compressive strength of the two types of concrete was found at1.5% of steel fiber content and on further increase in steel fiber content, thecompressivestrength decreased.
- The improvement in compressive strength of FRGPC was due to the capabilityoffibers to delayandpostpone thepropagationof crack.
- Compressivestrengthofhookedendsteelfiberreinforcedgeopolymerconcreteshowedhigherstrengthcompared tocrimped steelfiber.
- Thehookedendsteelfibershandledtheexistenceofmicrocrackspresentintheconcretein a better wayduetothecracks’ microdimension.
- The hooked end steel fibers showed its impact on the compressive strength byenhancingtheefficiencyofbridgingmicrocracksandimprovedthecompressivestrength.

Future Scope:

- Theothermechanicalpropertiesofhighstrengthfiberreinforcedgeopolymerconcrete areto be studied,i.e.,flexural strength and splittensilestrength.
- Thedurabilitypropertiesofthehighstrengthfiberreinforcedgeopolymerconcreteshould also be studied.
- Indepthstudyontheeffectof steelfibers andthefactorsaffecting the strengthoftheconcrete.

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