A Study on Enhancing the Properties of Geopolymer Concrete with Hybrid Fibers

Mahesh Chandra Shah
Department of Civil Engineering, Graphic Era Hill University, Dehradun, Uttarakhand, India 248002

Article Info
Page Number: 1136-1146
Publication Issue:
Vol. 70 No. 2 (2021)

Article History
Article Received: 18 October 2021
Revised: 20 November 2021
Accepted: 22 December 2021

Abstract: As the manufacture of one ton of Portland cement releases about one ton of CO2 into the atmosphere, and since burning lime stone releases CO2 directly, the cement industry is responsible for around 7% of global CO2 emissions. In the calcination process, the calcium carbonate in limestone is transformed into calcium oxide and carbon dioxide. This step alone is responsible for half of the cement industry's carbon footprint. The use of fossil fuels to heat the kiln results in indirect emissions. When these fuels are used, they contribute to the release of more carbon dioxide. Human activities release greenhouse gases like CO2 into the atmosphere, leading to global warming. In terms of greenhouse gases, carbon dioxide is responsible for around 65% of the warming effect. Geopolymer concrete reinforced with hybrid fibers is the subject of this work.

Keywords: geopolymer concrete, global warming, global warming, fuels.

1. Introduction

The urgent necessity to choose a replacement to cement that gives security and strength to buildings while also keeping the environment pollution free arises from cement's status as a significant source of global warming. With the advent of geopolymer technology, any material rich in alumina and silica may be used to completely replace cement in the production of concrete. Other materials beyond cement that may be used to make geopolymer concrete include rice husk ash, fly ash, and GGBS. Meanwhile, the disposal problem of fly ash and its copious supply are serious concerns. Fly ash is a byproduct of thermal power stations that use coal as a fuel source. It's typically been seen as a waste substance, and getting rid of it has caused a lot of environmental and ecological issues. [1]

Economic and social progress is impossible in underdeveloped nations like India without first generating electricity. As a result, fly ash output has gone up. In terms of environmental impact, the cement sector is responsible for about 7% of worldwide CO2 emissions. Clinker usage may be lowered and greenhouse gas emissions reduced if fly-ash were used instead. In terms of the bottom line, switching to fly ash from cement results in lower manufacturing costs and a higher-quality end product. [2-3]

The high cost of both manufacturing and delivering cement puts a strain on any cement company's capacity to turn a profit. Fly ash might be used as a component in raw-meal in clinker manufacturing thanks to the increased awareness and laws on environmental concerns in the cement industry. Cement is crystalline and hardens slowly, whereas fly ash cools

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

quickly and becomes amorphous, or glassy. Fly ash also has a lower CaO percentage than Portland cement.[4-5]

When it comes to electricity, using fly ash in the cement manufacturing process may reduce consumption by roughly 8 to 10 percent. There has been a plateau in the share of PPC in the country's cement manufacturing. Particles in fly ash are usually between ten and one hundred microns in size, making them silt. These micro-sized glass balls make new concrete easier to shape and move around. Fly ash's fineness is the single most critical factor in determining its pozzolanic reactivity. Different portions of fly ashes have distinct characteristics. It is generally agreed that a fly ash's impact on mortar strength is the result of a multiplicative influence of its size fractions. Using fly ash into concrete as a cement replacement material or as an additive in cement has various advantages from a financial, technical, and environmental standpoint. Different size fractions of fly ashes have varying qualities depending on the burning temperature, the kind of coal used, and other considerations.[6-7]

The building sector is showing a lot of interest in geopolymer technology, which is a concrete technique that uses sustainable materials. Studies of this topic date back to the pyramid era. In 1978, Professor Davidovits J. invented the term "Geo-polymer" after discovering that the polymerization process occurs during a very rapid chemical reaction under alkaline environment on Si-Al rocks, yielding a 3D polymeric chain or ring structure comprised of Si-O-Al-O links. [8]

If you dissolve materials with reactive alumina and silica, and maybe even another silica source , in alkaline-activating solutions (you'll get geopolymer, which are three-dimensional networks of aluminosilicate molecules. Polymerization of the Si-O-Al-O link is the key principle underlying this geopolymer, which forms when Al-Si source materials like fly ash or rice husk are combined with an alkaline activating solution (NaOH or KOH solution with Na2SiO3 or K2SiO3). The geopolymer may have the chemical formula -Si-O-Al-O- or -Si-O-Al-O-Si-O- or even more complicatedly, -SiO-Al-O-Si-O-SiO-.[9]

Fly ash from coal-fired power plants is a good source of low-calciummaterial for making geopolymer concrete. The majority of the world's supply of fly ash is low calcium fly ash, which is produced when anthracite or bituminous coal is burned. Because of its lower CO2 equivalent emission, GeoPolymer Concrete (GPC) may be used in place of OPC concrete. The use of GPC helps cut down on harmful CO2 emissions. As it turns out, there are several situations in which GPC just cannot replace OPC concrete. Taking into account the facts that GPC may acquire the same strength as regular concrete, it can be utilized instead of regular concrete.[10]

2. Material and Methods

In order to meet the standards set by the I. S., research and experimentation are being conducted to determine the optimal proportion of hybrid fibers. The current process consists of three distinct phases. In the preliminary research phase, unreinforced geopolymer concrete is used. Here, the NaOH molarity is changed from 8 to 10, 12, or 13 moles. Furthermore, 1, 1.5, and 2 ratios of sodium silicate to sodium hydroxide are examined. In the next phase of

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

the study, geopolymer concrete is improved by including steel crimped fibers with aspect ratios of around 60. Geopolymer concrete may have both polypropylene and basalt fibers. Hybridization of fibers is performed in the third phase of study. Three steel fibers with aspect ratios of 60 were hybridized with Polypropylene fibers independently. Moreover, basalt fibers and steel fibers with an aspect ratio of 60 are hybridized and incorporated into geopolymer concrete.

Mix Design for Geopolymer Concrete:

Table 1: Planning Geopolymer Concrete Mixtures

Molarity	**Na_2SiO_3 / NaOH**	**Fly Ash kg/m³**	**Fine Aggregate kg/m³**	**Coarse Aggregate kg/m³**	**NaOH kg/m³**	**Na_2SiO_3 kg/m³**	**Additional Water kg/m³**
8	1	420	672.63	1277.04	73.5	73.5	18.33
	1.5	420	671.47	1274.84	58.8	88.2	21.69
	2	420	670.70	1273.37	49	98	23.93
10	1	420	671.50	1274.88	73.5	73.5	21.61
	1.5	420	670.567	1273.108	58.8	88.2	24.325
	2	420	669.95	1271.94	49	98	26.118
12	1	420	670.43	1272.86	73.5	73.5	24.71
	1.5	420	669.71	1271.486	58.8	88.2	26.80
	2	420	669.24	1270.58	49	98	28.181
13	1	420	669.80	1271.64	73.5	73.5	26.55
	1.5	420	669.21	1270.52	58.8	88.2	28.27
	2	420	668.81	1269.77	49	98	29.41

Use of Hybrid Fibers

Fiber hybridization between steel and polypropylene or steel and basalt is used in the current study. Here, Polypropylene is combined with crimped steel fibers to create a hybrid with an aspect ratio of 60.

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

Table 2: Geopolymer concrete's fiber percentage of hybridization

Hybridization	**Steel %**	**Polypropylene % or Basalt %**
Steel Fibers with Aspect Ratio 60 and Basalt		
SB - 1	0.8	0.2
SB - 2	0.6	0.4
SB - 3	0.4	0.6
SB - 4	0.2	0.8
Steel Fibers with Aspect Ratio 60 and Polypropylene		
SP I - 1	0.8	0.2
SP I - 2	0.6	0.4
SP I - 3	0.4	0.6
SP I - 4	0.2	0.8

Non Destructive Testing:

Hybrid fibers in geopolymer concrete are subjected to non-destructive testing. After 28 days, samples are subjected to an ultrasonic pulse velocity test and a rebound hammer test in the current study.

3. Results

- **Plain GPC's Compressive Strength Changes with Molarity and Na2SiO3/NaOH Ratio:**

Here we investigate the effects of changing the sodium silicate to sodium hydroxide ratio and the molarity of sodium hydroxide on the compressive strength of plain geopolymer concrete. Eight, ten, twelve, thirteen, fourteen, sixteen, and twenty-four mol of sodium hydroxide are all possible. There are three different ratios of sodium silicate to sodium hydroxide: 1, 1.5, and 2.

Cubes are used to measure the compressive strength of materials. The strength of concrete is a measurement of its resistance to compression under load. The table below illustrate the

Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183
results obtained for 1, 1.5, and 2 sodium silicate to sodium hydroxide ratios at an 8 molar NaOH concentration.

Table 3: NaOH 8 M Compressive Strength of a Cube Specimen

Na_2SiO_3 / NaOH	Compressive Strength (MPa)		
	3 Days	7 Days	28 Days
1	19.55	25.92	32.29
1.5	21.77	30.36	35.4
2	25.47	33.77	38.95

It has also been shown that a 2:1 sodium silicate to sodium hydroxide ratio yields the highest compressive strength.

Higher ratios of sodium silicate to sodium hydroxide result in unworkably sticky mixtures, hence they are avoided.

The 8 molar NaOH concentration is adjusted to a 10 molar NaOH concentration. The second mixture is adjusted to include 10 molar NaOH. Table summarizes the outcomes for 1, 1.5, and 2 sodium silicate to sodium hydroxide ratios at a 10 M NaOH concentration.

Table 4: A cube specimen's compressive strength at 10 M NaOH

Na_2SiO_3 / NaOH	Compressive Strength (MPa)		
	3 Days	7 Days	28 Days
1	22.81	29.33	35.7
1.5	24.9	33.77	38.81
2	28.59	35.99	43.1

The compressive strength of the concrete rises from 8 to 10 M by increasing the sodium hydroxide content. Cube specimen's compressive strength in 12 M NaOH:

Compressive strength data on cube specimens is acquired for 1, 1.5, and 2 sodium silicate to sodium hydroxide ratios and 12 Molar NaOH concentration. The data is shown in Table.

Table 5: NaOH 12 molar concentration cube specimen compressive strength

Na_2SiO_3 / NaOH	Compressive Strength (MPa)		
	3 Days	7 Days	28 Days
1	25.92	33.62	38.21
1.5	27.7	36.73	41.77
2	31.54	38.07	47.18

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

It is observed that compressive strength of 12 Molar NaOH concentration is achieved maximum for ratio of Na_2SiO_3 / NaOH of 2. Also, for ratio of 1, the 28 days compressive strength achieved is approximately equal to target mean strength of conventional concrete of M30 grade. As, ratio of Na_2SiO_3 / NaOH increases compressive strength is increases. Compressive strength obtained is more than 8 Molar and 10 Molar NaOH concentration.

3 days increase in strength of geopolymer concrete for 12 Molar NaOH concentration is observed 12 %, 10.10 % and 9.35 % for sodium silicate to sodium hydroxide ratio of 1, 1.5 and 2, respectively as compared to 10 Molar NaOH concentration.

Similarly, 7 days increase in strength is achieved as 12.76 %, 8.05 % and 5.46 % for sodium silicate to sodium hydroxide ratio of 1, 1.5 and 2 respectively, as compared to 10 Molar NaOH concentration.

Table displays the outcomes for 1, 1.5, and 2 sodium silicate to sodium hydroxide ratios at a 13 Molar NaOH concentration. The failure of cube specimens at a 12 Molar NaOH concentration is brittle, and a modest increase in strength is seen. In order to achieve a 13 Molar NaOH concentration, cube specimens are cast.

Table 6: NaOH 13 M Compressive Strength of a Cube Specimen

Na_2SiO_3 / NaOH	Compressive Strength (MPa)		
	3 Days	7 Days	28 Days
1	27.99	35.4	40.2
1.5	30.07	38.21	44.29
2	33.77	42.51	49.33

Nevertheless, brittle failure is seen during testing, even at the highest Compressive strength reached at 13 Molar NaOH concentration and also for ratio of sodium silicate to sodium hydroxide as. When alumina and silica are leached off by high NaOH concentrations, the compressive strength attained in this case is greater than that produced with a 12 Molar NaOH concentration.

- **The Effect of Hybrid Fibers on the Compressive Strength of Geopolymer Concrete:**

The geopolymer concrete is taken to its third and final stage of development with the addition of two distinct kinds of fibers. Steel fibers are quite rigid, whereas polypropylene fibers are somewhat flexible. Another contrast in materials is the hardness of steel and the pliability of basalt. Hybridization, as proposed by Bentur and Mindess , offers a method in which the initial fracture stress and ultimate strength are both increased thanks to a single kind of fiber that is both stronger and stiffer. Toughness and strain capacity in the post-cracking zone are enhanced by the use of a second, more flexible and ductile kind of fiber. Provide a hybrid reinforcement, they say, with one kind of fiber being smaller to bridge micro fractures.

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

Moreover, crack expansion may be controlled. The second kind of fiber is much bigger, and it can stop the spread of macro fractures.

GPC Hybrid Fibers' Compressive Strength, SP I:

SP I is the primary kind of mixture. The geopolymer concrete is reinforced with two different kinds of fibers: crimped steel fibers with an aspect ratio of 60 and polypropylene fibers. Table shows the composition of the four different blends used in the hybridization process.

Table 7:Geopolymer Concrete with Hybrid Fibers: Compressive Strength at the SP I Level

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SP I -1	60	0.8	0.2	49.33	55.1	58.21
2	SP I-2	60	0.6	0.4	42.96	46.22	50.21
3	SP I -3	60	0.4	0.6	31.4	35.55	39.1
4	SP I-4	60	0.2	0.8	26.81	29.62	32.28

There was localized fiber flocculation and a low workable mix for the fourth type. Nevertheless, a lag was seen in the failure of the cube specimen during testing. There was no brittle failure seen across all four mixture types, even after a few minutes of the dial gauge not moving. The first kind of steel-polypropylene hybrid displays a cohesive mix, whereas the other varieties all show non-cohesive mixes. Fly ash and supplementary water are required for the fourth kind of mix to be workable.

GPC Hybrid Fibers' Compressive Strength, SP II:

The second kind of geopolymer concrete mix, designated SP II, includes crimped steel fibers with an aspect ratio of 70 in addition to polypropylene fibers. In this case, we consider hybridization while preparing four distinct blends (Table). Table displays the results of testing the compressive strength of various mixtures.

Table 8: Geopolymer Concrete with Hybrid Fibers: Compressive Strength at the SP II Level

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SP II -1	70	0.8	0.2	48.14	54.07	56.88
2	SP II-2	70	0.6	0.4	38.96	44.29	47.7

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ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

3	SP II -3	70	0.4	0.6	32.14	35.88	38.51
4	SP II-4	70	0.2	0.8	24.88	27.55	30.36

The SP II -3 and SP II -4 mixtures show evidence of fiber flocculation. As a consequence, the honeycomb structure of the specimens was detected, and the material's compressive strength was diminished. In addition, 5% more fly ash is needed to combat this element.

GPC Hybrid Fibers' Compressive Strength, SP III:

Table displays the results of compressive strength tests conducted on SPIII type mixtures.

Here, longer strands and shorter polypropylene fibers are intertwined.

Table 9: Geopolymer Concrete with Hybrid Fibers: Compressive Strength at the SP III Level

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SP III -1	100	0.8	0.2	47.55	51.25	54.22
2	SP III-2	100	0.6	0.4	36.77	42.36	46.96
3	SP III -3	100	0.4	0.6	31.257	34.21	37.18
4	SP III-4	100	0.2	0.8	22.21	25.47	29.47

The compressive strength decreases for many different mixtures. Compressive strength is another area where SP I and SP II hybridization excel above SP III hybridization. Flocculation of fibers at one location was detected due to the lengthy length of Crimped steel fibers with an aspect ratio of 100 when combined with polypropylene fibers (SP III). Uneven fiber distribution makes the mixture less manageable. Compressive strength of geopolymers decreases as a result.

GPC Hybrid Fibers' Compressive Strength, SP:

SB refers to a hybrid material consisting of Basalt Fibers and Crimped Steel Fibers with an aspect ratio of 60. Table displays the results for compressive strength for the SB type.

Table 10: Polymer Concrete with Hybrid Fibers: Compressive Strength at the SP

Sr. No.	Notation	Aspect Ratio	Steel %	Basalt %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SB 1	60	0.8	0.2	51.35	56.73	59.25
2	SB 2	60	0.6	0.4	43.85	47.88	53.03
3	SB 3	60	0.4	0.6	33.47	38.36	41

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

4	SB 4	60	0.2	0.8	27.99	29.32	34.51

Table displays the compressive strength of cube specimens made using hybrid fibers like Crimped Steel Fiber (60) and Basalt. SB I kind of blend yields the highest compressive strength. Steel basalt hybridization displays a cohesive mix with increased compressive strength as compared to steel polypropylene hybridization. The 59.25 MPa attained compressive strength is more than that of any other combination.

The Effect of Hybrid Fibers on the Tensile Strength of Geopolymer Concrete:

As shown in Table, there are four distinct hybridization methods (SP I, SP II, SP III, and SB). The geopolymer concrete used here has a sodium silicate to sodium hydroxide ratio of 2, and a NaOH content of 13 Molar. The ratio of alkaline solution to fly ash is fixed at 0.45 for all blends.

Geopolymer concrete's split tensile strength for SP Table displays several types of mixtures. Four different mixtures are made for each hybridization type, as shown in Table.

Table 11: Comparison of Steel (60) & Polypropylene (PP) Hybrid Fibers for Tensile Strength in GPC

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Split Tensile Strength in MPa
1	SP I -1	60	0.8	0.2	9.23
2	SP I-2	60	0.6	0.4	6.972
3	SP I -3	60	0.4	0.2	5.478
4	SP I-4	60	0.2	0.8	4.256

Shows that the first kind of combination had the highest split tensile strength, at 9.23 MPa. The split tensile strength is highest for the SP I kind of mix (0.8% crimped steel + 0.2% polypropylene), and it decreases for the other three types of mixes owing to the decreased workability of geopolymer concrete. Split tensile strength decreased as a result of decreased flow capacity.

For SB type mixtures, Table takes into account hybridization of fibers for crimped steel fibers with an aspect ratio of 60 and basalt fibers. Table displays the results of split tensile strength tests conducted on SB mix types.

Table 12: GPC's hybrid fibers, made from Steel (60) and Basalt, exhibit a split tensile strength.

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Split Tensile Strength in MPa
1	SB 1	60	0.8	0.2	9.024

2	SB 2	60	0.6	0.4	7.16
3	SB 3	60	0.4	0.2	5.24
4	SB 4	60	0.2	0.8	3.83

Shows that the split tensile strength is greatest for the first kind of mix SB 1 , and decreases for the other three types of mixes. Yet, the mix was manageable in comparison to SP mixes, and the attained strength was similar to that of SP I and SP II mixes.

Geopolymer Concrete Nondestructive Testing using a Rebound Hammer and Hybrid Fibers

The Table displays the outcomes of the NDT performed on GPC with hybrid fibers utilizing the Rebound Hammer for SP I, SP II, SP III, and SB..

Table 13: For SP I, Rebound Hammer performs NDT on GPC with hybrid fibers

Sr. No.	Type	Aspect Ratio of Steel	% Steel	% Polypropylene	Compressive Strength in MPa
1	SP I-1	60	0.8	0.2	59
2	SP I-2	60	0.6	0.4	52.73
3	SP I-3	60	0.4	0.6	41.26
4	SP I-4	60	0.2	0.8	32.56

The compressive strength of geopolymers measured with a rebound hammer for SP I mixes is shown. As the first kind of mix was workable and fibers were found to have good bonding with concrete, it was determined that this mix had the highest compressive strength. The strength is toned down significantly for the second blend type. Compressive strength was also decreased since the third and fourth types of mix were less workable and lacked cohesiveness.

Table 14: Rebound Hammer's hybrid fiber nondestructive testing of GPC for SB

Sr. No.	Type	Aspect Ratio of Steel	% Steel	% Polypropylene	Compressive Strength in MPa
1	SB 1	60	0.8	0.2	61.24
2	SB 2	60	0.6	0.4	54.31
3	SB 3	60	0.4	0.6	42.16
4	SB 4	60	0.2	0.8	33.55

ISSN: 2094-0343
DOI: https://doi.org/10.17762/msea.v70i2.2183

Demonstrates that the first kind of mix incorporating steel basalt achieves the highest compressive strength . Since the hybridization mixture was cohesive, steel basalt fibers had superior compressive strength over steel polypropylene fibers. Moreover, specimens with steel basalt hybridization had polished surfaces.

4. Conclusion

The results reveal that the split tensile strength of geopolymer concrete decreases as the percentage of polypropylene fibers and basalt fibers in the material grows beyond 0.2% by mass; hence the strongest geopolymer concrete is the first kind of mix in every combination. Cube specimens of geopolymer concrete reinforced with hybrid fibers are subjected to a rebound hammer test. Tests using a Rebound Hammer show somewhat better performance than those with a Concrete Testing Machine. The results show that SB mixes are superior to SP I, SP II, and SP III. The highest compressive strength was found in the first kind of mixtures across all four hybridization types. As compared to SP I, SP II, and SP III mixes, SB mixes are superior. The highest compressive strength was found in the first kind of mixtures across all four hybridization types. Steel basalt hybridization is less efficient (SP III-1) than hybridization with longer fibers. Every day, progress in infrastructure takes the lead. As a consequence, a lot more land has to be used for building. From the perspective of lowering carbon dioxide emissions, finding alternatives to cement is essential if humanity is to rein in global warming. In the future, GGBS may be used to make geopolymer concrete in lieu of cement. Geopolymer concrete, in which cement is partially replaced by lime, allows for curing temperatures to be kept below 60 degrees Celsius.

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