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CHARACTERISTIC EVALUATION OF GEOPOLYMER CONCRETE BY USING STEEL FIBERS

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Abstract

Recent advancements in the research for OPC-free cement have highlighted the need to develop alternative binding agents that are environmentally conscious. One promising alternative is geopolymer, which typically consists of fly ash, sodium silicate, and sodium or potassium hydroxide (NaOH or KOH). As many coal-based power plants in India are transitioning towards cleaner energy production, the availability of fly ash might decrease in the future. This situation has led to increased production of Ordinary Portland cement and heightened demand for natural river sand in the construction industry. Unfortunately, the production of cement contributes to CO_2 emissions, and the availability of river sand has become scarcer and costlier due to unauthorized sand mining. This research aims to identify environmentally friendly substitutes for both cement and river sand. The current study involves experimental investigations into fly ash-based geopolymer cement, focusing on evaluating its properties and strength characteristics, including the incorporation of steel fibers. The characteristic evaluation of geopolymer concrete by using steel fibers involves a comprehensive assessment of mechanical properties, durability, and other relevant factors. The goal is to determine how steel fibers enhance the performance of geopolymer concrete. 0.2 %, 0.4 %, 0.6%, 0.8 %, and 1 % steel fibers were added. Optimum average compressive strength of the concrete was found to be 51.26 % for addition of 0.8% steel fibers.

Keywords: Geopolymer concrete, Steel fibers,

1. Introduction

Concrete is a widely used construction material, with Portland cement being a primary ingredient in its production [1]. The demand for concrete has been increasing steadily over time. However, cement production is energy-intensive and contributes to CO_2 emissions, a major factor in global warming. Global warming is a significant environmental concern caused by greenhouse gas emissions, particularly CO_2 [2]. The cement industry is responsible for about 6% of all CO_2 emissions due to the CO_2 emitted during cement production [3]. To address the environmental impact, efforts have been made to replace or partially replace Portland cement in concrete production. Geopolymer, an inorganic alumino-silicate material, has emerged as a promising alternative [4]. It offers similar strength, appearance, and properties to traditional cement, but with lower greenhouse gas emissions. Geopolymer cement is produced through the activation of materials rich in Si and Al, such as fly ash, slag, rice husk, and clays. Geopolymers have good mechanical properties, fire resistance, and acid resistance. The use of geopolymer helps reduce CO2 emissions associated with cement production. Fly ash, a byproduct of thermal power plants, is commonly used in geopolymer production. It contains SiO_2 and Al_2O_3, which are essential components for geopolymerization. Fly ash is divided into Class F (low-calcium) and Class C (high-calcium), with both types being explored for geopolymer cement production [5-6]. The Government of India, have initiated programs to increase the utilization of fly ash in various applications, including concrete production. Fly

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ash reacts with calcium hydroxide during hydration to form a binding C-S-H gel, making it suitable for partial replacement of ordinary Portland cement (OPC) in concrete. While fly ash can replace a significant portion of OPC in concrete, complete replacement has been an ongoing research area. Fly ash's content of SiO_2 and Al2O3 makes it useful for developing special cement, which is an area of ongoing exploration [7].

High-calcium fly ash, typically containing 12-25% calcium oxide, has been investigated for its potential use in geopolymer production. Research has shown that geopolymer paste and mortar produced from high-calcium fly ash exhibit good strength and durability [8-10]. The exploration of geopolymer and increased utilization of fly ash are aimed at reducing CO_2 emissions associated with cement production and addressing the environmental impact of construction materials [11-15]. Geopolymer concrete is made using several key materials. Fine aggregate: Small-sized particles that fill the gaps between larger aggregates. Larger particles that provide strength and stability to the concrete. Materials like fly ash, silica fume, slag, etc., rich in alumino-silicates that react with alkaline activators to form the geopolymer binder. A solution that triggers the reaction between pozzolanic materials and helps in forming the geopolymer binder. Various materials can be used as a source of alumino-silicates pozzolanic powder in GPC production. Fly ash is a commonly used material due to its availability, but alternatives like silica fume, slag, rice-husk ash, and red mud can also be considered.

The durability of GPC refers to its ability to withstand weathering, chemical attacks, abrasion, and other deterioration processes. While strength is important, durability ensures that the concrete can maintain its structural integrity and performance over time, even in challenging conditions. Durability of GPC is assessed through various tests that measure its resistance to different types of deterioration: The ability of the concrete to resist the penetration of water and other liquids. The capacity to withstand wear and tear caused by friction or rubbing. The resistance to damage caused by repeated freezing and thawing cycles. The ability to endure high temperatures without significant loss of strength or structural integrity. Resistance to degradation caused by sulfate-containing compounds. The ability to maintain strength and mass over time. The durability of GPC can be affected by various factors, including: Type of pozzolanic material used. Composition and properties of the alkaline activator solution. Curing temperature and duration. Molarity of the alkaline solution used. Properties of the aggregates utilized. The performance of GPC in different exposure conditions can vary over the short and long term. Different combinations of materials and curing conditions can impact how well GPC maintains its durability characteristics over time.

II. Materials

The dry fly ash, specifically Pozzo Crete 63, is being used as a base material in your experimental work. Depending on the context of your experiment, the pozzolanic properties of the fly ash could be utilized to enhance the properties of a cementitious mixture, like concrete. It's commonly used as a supplementary cementitious material to improve strength, durability, and other engineering properties of construction materials. An experimental work that involves using low calcium, Class F dry fly ash as a base material. This fly ash, named "Pozzo Crete 63," is a high-efficiency Class F pozzolanic material. Pozzo Crete 63 is obtained through the selection and processing of fly ashes generated from the combustion of pulverized coal in power stations. The purpose of using this material in your experiment could be related to its pozzolanic properties. Fly ash is a fine powder that is a byproduct of burning pulverized coal in electric power generating plants. It's typically categorized into two main classes: Class F and Class C. Class F fly ash is obtained from burning coal with a low calcium content and is known for its pozzolanic properties, meaning it can react with lime to form cementitious compounds. This makes it suitable for use in concrete and other construction materials. Pozzo Crete 63 is a specific brand or trade name for a high-efficiency

Class F pozzolanic material. It's produced by selecting and processing fly ashes resulting from the combustion of pulverized coal in power stations. The "63" might refer to a specific grade, specification, or quality control parameter of this pozzolanic material. Chemical composition of Pozzo Crete 63 as obtained from dirk India Private Limited.

Table 1 General Information

Properties	Specifications
Colour	Light grey
Bulk Weight	Approx. 0.90 metric ton per cubic meter
Specific density	Approx. 2.30 metric ton per cubic meter
Size	90% < 45 micron
Particle shape	Spherical
Package	30 kg paper bags, 1 metric ton big-bags and bulk tankers

Steel Fibers: Size of the fibers in SFRC varies between 0.25 mm to 1 mm in diameter & from 12mm to 60mm in length, and the fiber content ranges from 0.3 to 2.5 percent by volume. Steel fibers used in SFRC are Straight, Hooked, Crimped, Paddled, and Enlarged ends.A combination of sodium silicate solution and sodium hydroxide solution was used as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions. The sodium hydroxide solids were either technical grade in flakes form (3 mm) with a specific gravity of 2.130, 97 % purity. The sodium hydroxide (NaOH) solution was be prepared by dissolving either the flakes or the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molarity M. For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8M concentration. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 10M: 314 grams, 12M: 361grams, 14M: 404 grams, and 16M: 444 grams. Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution and water is the major component. The chemical composition of the sodium silicate solution was Na_2O=14.05- 16.05%, SiO_2=32.14-34.01% and water =50.93-52.92% by mass. The other characteristics of the sodium silicate solution were specific gravity=1.53 g/cc and viscosity at 20°C=400 cp. The ratio of sodium silicate to sodium hydroxide is kept 2, 2.5, 3.

Methodology

Water holds paramount importance in both geopolymer concrete and conventional concrete. In geopolymer concrete, water serves to enhance workability and permeability, allowing for proper solidification through the evaporation of liquids during the curing process at elevated temperatures. The concentration of sodium hydroxide and sodium silicate influences the flow characteristics of concrete; higher concentrations reduce flow while simultaneously promoting compressive strength in geopolymer concrete. Adjusting the workability of concrete can be achieved by adding superplasticizer or extra water. However, the introduction of superplasticizer to enhance workability by more than 4% adversely impacts the strength of geopolymer concrete. In this regard, the addition of extra water results in greater strength compared to the use of superplasticizer. Strength refers to a material's ability to withstand external forces or loads without deformation or failure. The mechanical strength of a chosen engineering material is a crucial criterion for it to effectively endure varying mechanical forces. Toughness, on the other hand, pertains to a material's capacity to absorb energy and deform plastically without fracturing. It is quantified by the energy absorbed per unit volume (measured in Joules per cubic meter). The toughness value is derived from the material's stress-strain behavior. An ideal tough material exhibits both significant strength and ductility. Materials that possess high strength but limited ductility lack sufficient toughness, just as materials with ample ductility but low strength are also insufficiently tough. Thus, true toughness necessitates the ability to withstand high stress and strain. Hardness signifies a material's resistance to permanent shape alteration due to external stress. Several measures of hardness exist, including Scratch Hardness, Indentation Hardness, and Rebound Hardness. Scratch Hardness evaluates a material's resistance to surface scratches from external forces. Indentation Hardness gauges a material's resistance to dents caused by external pointed objects. Rebound Hardness, also known as dynamic hardness, is determined by the bounce height of a diamond-tipped hammer dropped onto a material from a fixed height. Hardenability refers to a material's capacity to attain hardness through heat treatment processes. It's quantified by the depth to which the material achieves hardness. Brittleness signifies how prone a material is to fracturing under the influence of force or load. Brittle materials exhibit minimal energy absorption and fracture without significant strain. Brittleness and ductility are opposing traits in materials. Temperature also impacts a material's brittleness; some normally ductile metals become brittle at low temperatures.

Results and Discussion

Compressive strength refers to the ability of a material to withstand axial loads or forces that tend to squeeze or crush the material. It is usually tested by applying a compressive load to a standard specimen until the specimen fails or fractures. Compressive strength is an essential property for materials like concrete, where the ability to withstand compression is crucial in supporting structural loads. Compressive strength is often reported in units of pressure, such as megapascals (MPa) or pounds per square inch (psi). Split tensile strength, also known as indirect tensile strength, is a measure of a material's ability to resist tensile (pulling) forces. This property is particularly relevant for brittle materials like concrete. In a split tensile strength test, a cylindrical or prismatic specimen is subjected to a diametrical compressive load, causing the specimen to split along the applied load. Flexural strength, also known as modulus of rupture, measures a material's ability to resist bending or flexural stresses. This property is crucial for materials used in beams, slabs, and other structural components subjected to bending loads. A flexural strength test involves applying a load to the center of a beam-shaped specimen until it breaks or develops visible cracks. The maximum load that the specimen can withstand before failure is used to calculate the flexural strength. The specimen weight and compressive strength are mentioned in table 2.

Table 2. Specimen weight in gram for Na_2Sio_3/NaOH=1.0

%volume of steel Fibers in G.S	($SiO2/Na_20$) =2.0	($SiO2/Na_20$) =2.5
0.0	8.12	8.40
0.0	8.52	8.56
0.0	8.48	8.50
0.1	8.50	8.60
0.1	9.10	8.90
0.1	8.80	8.50
0.2	7.90	9.10
0.2	8.20	8.90
0.2	8.40	8.80

0.3	8.56	8.48
0.3	8.40	8.50
0.3	8.90	8.70
0.4	8.70	8.90
0.4	8.52	8.80
0.4	8.48	8.78
0.5	8.70	8.54
0.5	9.0	8.85
0.5	8.90	8.50

Table 3. 7- Day Compressive strength specimen weight in gram for Na2Sio3/NaOH=2.0

% Volume of steel Fiber	Crushing load($x10^3$) N	Compressive strength (n/mm^2)	Avg comp strength ($n/m M^2$)
0.0	760.00	33.78	34.22
0.0	770.00	34.22	
0.0	780.00	34.67	
0.2	840.00	37.33	36.59
0.2	820.00	36.44	
0.2	810.00	36.00	
0.4	820.00	36.44	37.18
0.4	840.00	37.33	
0.4	850.00	37.78	
0.6	910.00	40.44	41.18
0.6	920.00	40.88	
0.6	950.00	42.22	
0.8	850.00	37.78	38.96
0.8	900.00	40.00	
0.8	880.00	39.11	
1.0	860.00	38.22	37.78

Table 4. 28-day Compressive strength specimen weight in gram forNa_2Sio_3/NaOH=2.0

% Volume of steel Fiber	Crushing load($x10^3$) N	Compressive strength (n/mm^2)	Avg comp strength ($n/m M^2$)
0.0	1090.00	48.44	48.44
0.0	1080.00	48.00	
0.0	1100.00	48.89	
0.2	1100.00	48.89	48.30
0.2	1070.00	47.56	
0.2	1090.00	48.44	
0.4	1090.00	48.44	48.74
0.4	1080.00	48.00	

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0.4	1120.00	49.78	
0.6	1130.00	50.22	51.26
0.6	1150.00	51.11	
0.6	1180.00	52.44	
0.8	1160.00	51.56	50.67
0.8	1120.00	49.78	
0.8	1140.00	50.67	
1.0	1120.00	49.78	48.59

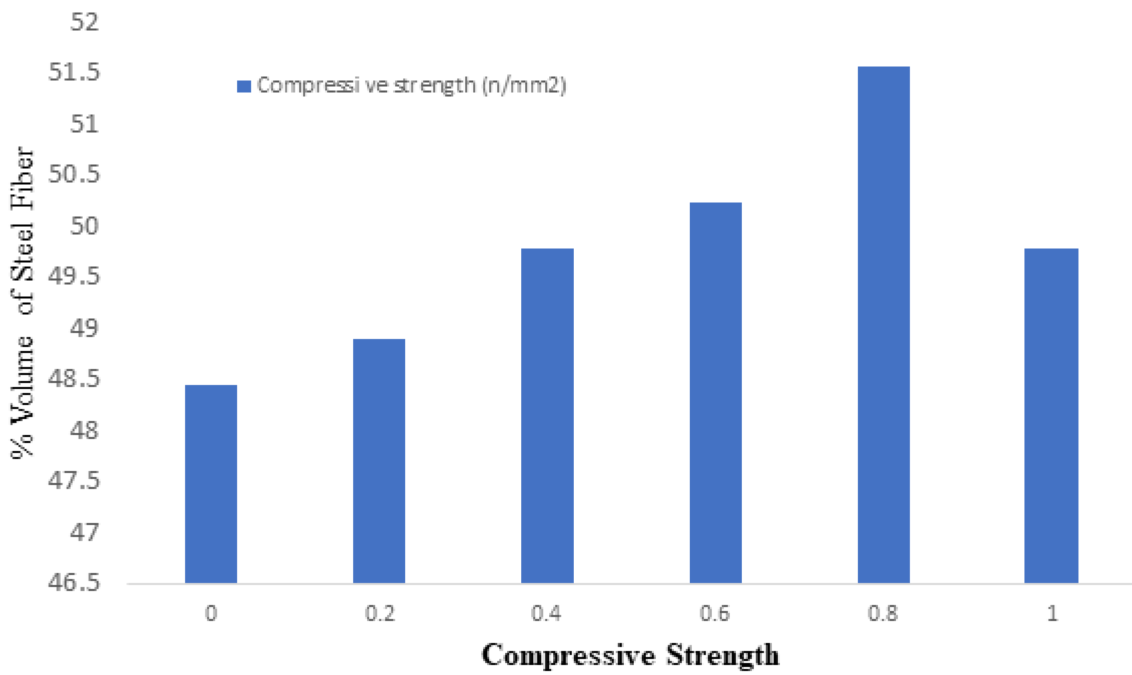

Fig. 1. Compresive strength of Concrete enhnaced by adding steel fibers

Split tensile strength, also known as indirect tensile strength or Brazilian tensile strength, is a mechanical property of concrete that measures its resistance to tensile stress. It is determined by subjecting a cylindrical or disk-shaped concrete specimen to diametral compression, causing the specimen to fail in tension along a plane perpendicular to the applied load. This property is particularly relevant for assessing the performance of concrete under indirect tensile loading conditions. Split tensile strength testing provides valuable information about a concrete mix's ability to withstand tensile forces. When evaluating geopolymer concrete with steel fibers, this test helps assess the effectiveness of the fibers in enhancing the concrete's resistance to cracking and improving its overall mechanical behavior.

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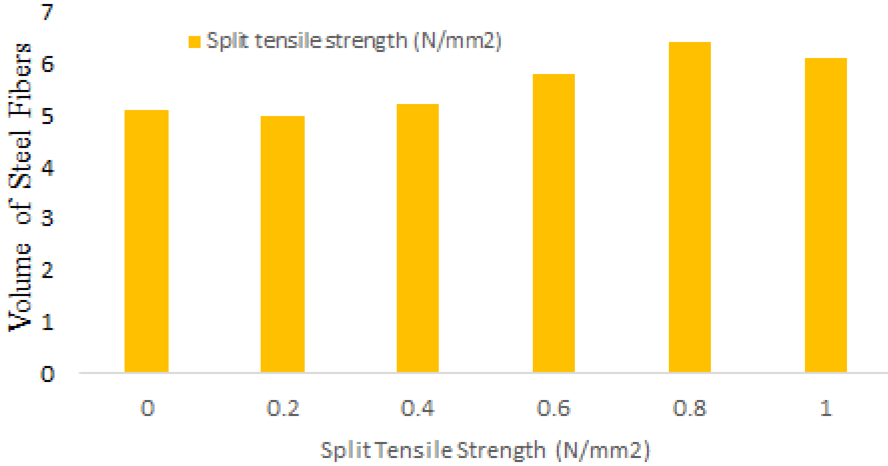

Fig. 2. Split Tensile strength of Concrete enhnaced by adding steel fibers

Flexural strength, also known as modulus of rupture, is a measure of a material's ability to resist bending or flexural stresses. In the context of concrete, it reflects the material's capacity to withstand applied loads that cause bending. Geopolymer concrete with steel fibers can exhibit improved flexural strength compared to traditional concrete due to the reinforcing effects of the fibers. Flexural strength testing provides insight into the concrete's ability to withstand bending and structural loads. It helps assess the impact of steel fibers on the concrete's resistance to cracking and its overall flexural behavior, which is crucial for applications like beams, slabs, and other structural elements subjected to bending forces.

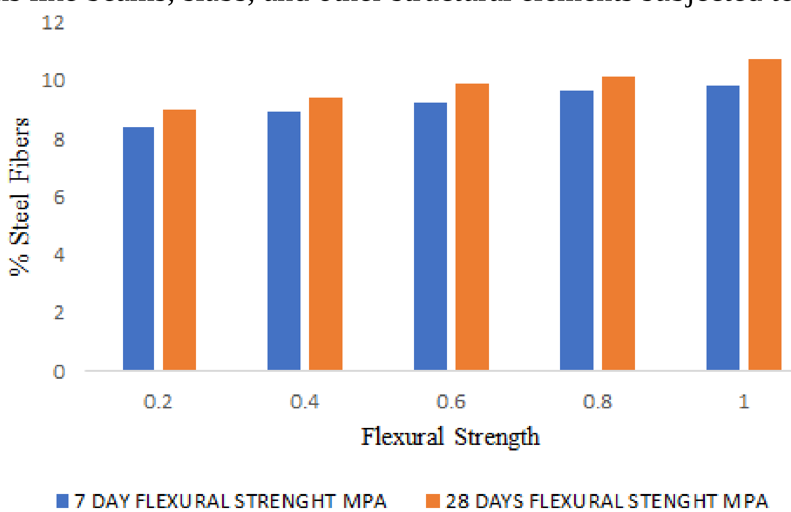

Fig. 3. Flextural strength of Concrete enhnaced by adding steel fibers

Conclusion:

Based on the results obtained from the experimental investigations, the following conclusions can be drawn:

1. Use of Silica and Alumina-rich Fly Ash: The study utilized fly ash that is rich in silica and alumina to create geopolymer concrete. This process involves using sodium hydroxide and sodium silicate chemicals. The geopolymer concrete can be prepared through conventional mixing techniques, but extra care is required during handling and mixing due to the involvement of chemicals.
2. Replacement of Cement with Industrial Waste: In geopolymer concrete, traditional cement was entirely substituted with industrial waste, specifically fly ash. Since geopolymer concrete utilizes

industrial waste as its binding material, it is considered an eco-friendly material, as it contributes to waste reduction and minimizes environmental impact.

3. Environmental Benefits: Geopolymer concrete not only reduces greenhouse gas emissions compared to traditional concrete but also addresses the issue of industrial waste disposal costs. This highlights the potential environmental benefits of using geopolymer concrete in construction projects. Additionally, the average density of geopolymer concrete is similar to that of ordinary Portland cement-based concrete.
4. Compressive Strength Enhancement: The addition of steel fibers to geopolymer concrete resulted in increased compressive strength compared to plain geopolymer concrete. The maximum compressive strength was achieved when incorporating 0.6% volume of steel fibers in geopolymer concrete, with a specific Na_2O/SiO_2 ratio of 0.20.
5. Split Tensile Strength Improvement: Similar to compressive strength, the introduction of steel fibers in geopolymer concrete led to enhanced split tensile strength compared to plain geopolymer concrete. The optimal split tensile strength was observed when including 0.6% volume of steel fibers in geopolymer concrete.
6. Optimal Fiber Content: The study determined that the ideal fiber content for achieving maximum values of various strength properties in geopolymer concrete was 0.6% by volume. This specific volume of steel fibers contributed to improved compressive and split tensile strength.

In summary, the experimental results suggest that using silica and alumina-rich fly ash to create geopolymer concrete with steel fiber reinforcement can lead to improved mechanical properties. This eco-friendly alternative not only addresses environmental concerns associated with traditional concrete but also utilizes industrial waste effectively. The findings provide insights into the optimal parameters for achieving enhanced strength characteristics in geopolymer concrete.

Conflict of Interest

No conflict of interest

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References

1. Bhavik kumar, B. Patel, Jayesh kumar Pitroda.: A Review of Geo Polymer Concrete by Using Various Industrial Waste Materials. International Journal of Constructive Research in Civil Engineering. 3(4): 121-131(2017).
2. Leandro B.de Oliveira Afonso R.G.de Azevedo Markssuel T.Marvil Elaine C.Pereira Roman Fediuk Carlos Mauricio Vieira: Durability of geopolymers with industrial waste. Case Studies in Construction Materials. 16: e00839 (2022).
3. Mohammadhosseini, H., Yatim, J.M: Evaluation of the Effective Mechanical Properties of Concrete Composites Using Industrial Waste Carpet Fiber. INAE Lett 2:1–12 (2017). https://doi.org/10.1007/s41403-017-0016-x.
4. Lenin Sundar, Sherine Raj: Study on Characteristics of Geopolymer Concrete with E-Waste. Journal of Mechanical and Civil Engineering. 14(3):21-27 (2017).
5. Fatheali A. Shilar,Sharanabasava V. Ganachari,Veerabhadragouda B. Patil, Kottakkaran Sooppy Nisar, Abdel-Haleem Abdel-Aty. S. Yahia: Evaluation of the Effect of Granite Waste Powder by Varying the Molarity of Activator on the Mechanical Properties of Ground Granulated Blast-Furnace Slag-Based Geopolymer Concrete. Polymers. 14 (2): 306 (2022). https://doi.org/10.3390/polym14020306.
6. Ramamohana Reddy Bellum, Karthikeyan Muniraj, Sri Rama Chand Madduru: Characteristic

Evaluation of Geopolymer Concretefor the Development of Road Network: Sustainable Infrastructure. Innovative Infrastructure Solutions. 5:91(2020). https://doi.org/10.1007/s41062-020-00344-5.

7. Murtaza Joya, Shalika Mehta: A Review on Effect of Glass Fiber on Fly Ash based Geopolymer Concrete using Recycled Aggregates. International Research Journal of Engineering and Technology. 7(12):736-739(2020).
8. Manvendra Verma, Nirendra Dev, Ibadur Rahman, Mayank Nigam, Mohd. Ahmed, Javed Mallick: Geopolymer Concrete: A Material for Sustainable Development in Indian Construction Industries-Review. Crystals. 14(5): 868 (2022). 10.3390/polym14050868.
9. Natarajan KS, Yacinth SIB, Veerasamy K: Strength and durability characteristics of steel fiber-reinforced geopolymer concrete with addition of waste materials. Environmental Science and Pollution Research (2022). https://doi.org/10.1007/s11356-022-22360-x
10. Balamurali Kanagaraj, Tattukolla Kiran, Anand N., Khalifa Al Jabri, Justin S: Development and strength assessment of eco-friendly geopolymer concrete made with natural and recycled aggregates. Construction Innovation (2022). https://doi.org/10.1108/CI-08-2021-0157.
11. N. Ganesana, R. Sahana, and P. V. Indira: Effect of hybrid fibers on tension stiffening of reinforced geopolymer concrete. Advances in Concrete Construction. 5(1):75-86 (2017). https://doi.org/10.12989/acc.2017.5.1.75.
12. Chevula Surendar, K.Anand Goud, Shruthi Kaviti: Behavior of Geopolymer Concrete by using Steel Fibers. International Journal of Innovative Technology and Exploring Engineering. 9(4): 2422-2429 (2020).
13. Tung T. Tran, Thong M. Pham, Hong Hao: Effect of hybrid fibers on shear behaviour of geopolymer concrete beams reinforced by basalt fiber reinforced polymer (BFRP) bars without stirrups. Composite Structures. 243:112236 (2020).
14. Chithambar Ganesh A, Sowmiya K and Muthukannan M: Investigation on the effect of steel fibers in geopolymer concrete. IOP Conf. Series: Materials Science and Engineering 872 (2020) 012156 (2020). IOP Publishing. doi:10.1088/1757-899X/872/1/012156.
15. Umesh Raut, Shalini Prabu: Strength of geopolymer concrete reinforced with basalt Fiber. International Research Journal of Engineering and Technology. 6(4): 3811-3817 (2019).
16. Purwanto, Ay Lie Han1, Nuroji, and Januarti Jaya Ekaputri: The influence of molarity variations to the mechanical behavior of geopolymer concrete. MATEC Web of Conferences 195, 01010 (2018). https://doi.org/10.1051/matecconf/201819501010.