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Research Article

Sustainable Development of Geopolymer Concrete Using Fly Ash and Coir Fibre Reinforcement: An Experimental Study

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ABSTRACT

Geopolymer concrete is a cutting-edge, eco-friendly substitute for conventional Portland cement (OPC) concrete that may reduce carbon emissions while simultaneously recycling materials from farms and factories. The purpose of this experimental research is to examine the feasibility of incorporating fly ash and coir fiber, two byproducts of thermal power plants, into geopolymer concrete (GPC) in order to promote sustainable development. Geopolymerization starts with aluminosilicate fly ash and then adds reinforcement, coir fiber, to boost the mix's flexural and tensile strengths. Both the soft and hardened forms are tested for several properties, including workability, compressive strength, tensile strength, resistance to chemicals, and water absorption. Coir fiber reinforcing improves GPC's fracture resistance, ductility, and energy absorption capacity, in contrast to the common brittleness of geopolymeric binders. The combination of fly ash and coir fiber has two positive effects on sustainable construction: increasing recycling rates and decreasing use of non-renewable materials. In line with sustainable building practices and the concept of the circular economy, the findings indicate that geopolymer concrete enhanced with coir fiber is an excellent choice for environmentally friendly infrastructure, particularly in regions abundant in fly ash and coconut husk.

Keywords: Geopolymer concrete, Fly ash, Coir fibre, Sustainable development, Mechanical properties.

Introduction

In terms of usage, concrete is second only to water as the most used building material globally. Because of its adaptability, resilience, and longevity, it has become an essential component of contemporary infrastructure projects, contributing to its widespread acclaim. The main ingredient in traditional concrete, OPC, is known to release a significant amount of carbon dioxide into the atmosphere during its manufacturing. The calcination of limestone and the high energy requirement of cement manufacture are the main causes of the estimated 7-8% of global CO_2 emissions caused by the cement industry. In response to this worrisome effect on the environment, scientists and engineers have developed geopolymer concrete (GPC) as a sustainable substitute for OPC. An inorganic polymeric substance called geopolymer concrete is made by activating aluminosilicate-rich materials like fly ash, slag, or metakaolin with solutions of alkali. Green plastic composites (GPC) are far less harmful to the environment than their OPC counterparts since they do not need the calcination of limestone in their manufacturing. Because of its cheap cost, availability, and pozzolanic reactivity, fly ash—a byproduct of coal-fired power plants—is especially appealing as a predecessor. By incorporating fly ash into geopolymer concrete, we can reduce the amount of industrial waste that ends up in landfills, which in turn helps with cleaner energy production and more environmentally friendly waste management. As a result of its minimal carbon footprint and high efficiency, GPC has attracted interest from throughout the world in this area.

Geopolymer concrete has several benefits, but it also has some downsides that make it not suitable for everything. Its fragility in the face of tensile and flexural stresses is a major drawback. The compressive strength of GPC is exceptional, but its impact and fracture resistance are below average. Because of this, studies on geopolymer composites that mix natural and synthetic fibers to increase their ductility, toughness, and energy absorption capacity have been on the rise. Because of its abundance, reusability, affordability, and desirable mechanical properties, coir fiber—made from coconut husks—has attracted special attention among natural fibers. Reinforcing concrete using lignocellulosic coir fiber is an excellent idea because of the material's resilience to salt and humidity as well as its pliability and high toughness. Coir fiber is more in line with sustainable building aims than synthetic fibers since it is renewable, biodegradable, and has lower production energy intensity. Coir fiber, when mixed with GPC, may bridge microcracks, slow the spread of fractures, and increase the load-carrying ability once cracks have formed. For uses that call for increased resilience and longevity, coir-reinforced geopolymer concrete is a great option.

As a part of a larger shift toward circular economy concepts, GPC with fly ash and coir fiber improves mechanical performance. Waste reduction, resource optimization, and value creation from byproducts are the tenets of the circular economy. In this scenario, the energy sector's fly ash and the agriculture sector's coconut husk are transformed into building materials with additional value, which helps to lessen environmental impacts and creates economic possibilities. SDGs of the United Nations, especially those concerning responsible consumerism and climate action, are supported by this method. The inclusion of fibers in GPC often enhances flexural and split tensile strengths, according to experimental research. However, in order to prevent problems like poor workability or fiber aggregation, the ideal dose of fiber must be precisely calculated. When compared to synthetic fibers, coir's intermediate tensile strength and coarse surface roughness make it ideal for bonding with geopolymer matrices. Its inherent energy-absorbing properties also make it a good material for impact-resistant buildings. Problems including water absorption propensity, long-term durability, and fiber quality fluctuation need methodical research.

The purpose of this experimental investigation is to create and describe geopolymer concrete that is based on fly ash and reinforced with coir fiber. The workability, compressive strength, split tensile strength, flexural behavior, and durability under chemical and environmental exposures are some of the fresh and hardened qualities that the study intends to evaluate. In order to find a happy medium between sustainability, strength, and durability, this research analyzes the performance of fiber-reinforced GPC and hopes to provide practical recommendations for optimising mix composition, fiber content, and curing conditions. Carbon emission reduction, non-renewable resource minimization, and the promotion of locally accessible materials are three of the most pressing issues confronting the construction industry today. Fly ash and coir fiber, when combined in geopolymer concrete, provide a solution to all three. Sustainable building techniques will benefit from this study's findings, and engineers, academics, and legislators working to create environmentally friendly and robust infrastructure for the future will find the study's conclusions very useful.

Literature Review

Verma, Manvendra et al., (2022) Using a multitude of chemical reactions and compositions to establish a robust bond, geopolymer concrete (GPC) emerges as a groundbreaking new substance in the construction industry. The combination is bound together by the pozzolanic components, which are industrial waste products with a high silica and alumina concentration. These materials include fly ash, GGBFS, and rice husk ash. Geopolymer concrete has several advantages over traditional concrete, including being inexpensive, lasting a long time, thermally stable, simple to work with, eco-friendly, and cement-free. GPC reduces carbon footprints by making use of industrial solid waste, including slag, fly ash, and ash from rice husks. About one metric ton of carbon dioxide emissions were produced throughout the cement manufacturing process, which contributed to environmental damage and accelerated global warming as a result of the increasing production of greenhouse gases. In an effort to construct in an eco-friendly way, GPC seeks for binding characteristics that are comparable to cement yet use less of it. Consequently, geopolymer concrete provides an alternate to Portland cement concrete, which may have substantial monetary worth and aid in the long-term development of India's construction industries. Reviewing the relevant literature, we find that geopolymer concrete outperforms Portland cement concrete in terms of physical, mechanical, and long-term durability. Protect yourself against acid, sul-phate, and salt assaults using geopolymer concrete. Bridges, skyscrapers, highways, tunnels, dams, and hydraulic structures are just a few of the many construction-related uses for geopolymer concrete, which is renowned for its outstanding performance. According to the assessment, sustainable development is the result of adopting geopolymers in India's building industry. This is due to the fact that these materials assist society monetarily and provide employment opportunities, while simultaneously decreasing emissions of carbon dioxide and improving the use of natural resources and waste materials. Additionally, they are more cost-effective when constructing long-lasting infrastructure.

Singh, Arunaditya. (2020) when it comes to building materials, concrete is unrivaled in its dependability, adaptability, and longevity. Concrete, second only in use to water, requires substantial amounts of Portland cement. The manufacturing of ordinary Portland cement is the second leading cause of atmospheric carbon dioxide pollution. An innovative and environmentally sustainable substitute for traditional Portland cement concrete, geopolymer concrete offers a number of advantages over its predecessor. The need for Portland cement will be reduced if geopolymer becomes more widely used. Materials used to make geopolymer concrete include fly ash, ground-up bricks (GGBS), and activators that are alkaline. Improved compressive, tensile, and acid resistance is all benefits of geopolymer concrete reinforced with PET fibers. The percentage of fly-ash and GGBS in this investigation is 50/50. There are two key reasons why PET fiber (which makes up 0.25 and 0.5% of the cube's weight) is so popular: first, it's very flexible, which means it's less likely to shatter. Another issue is the massive amount of plastic bottles, which are a major source of PET fiber, that are being dumped into the seas and on land. Because of this, the aquatic life suffers, and the ecology becomes unbalanced. The curing process for geopolymer concrete including PET fiber is done at room temperature. Afterwards, the cubes undergo compression and split tensile exams.

Saral, J et al., (2018) Environmental contamination has emerged as the foremost global concern in recent times. Everyone knows that making one metric ton of cement releases 0.8 tons of carbon dioxide into the air. On the other hand, fly ash is an undesirable byproduct of the flue gasses released by thermal power plants as a result of burning pulverized coal. Fly ash is now being dumped in landfills in large quantities since it is not being used effectively. Because of this problem, researchers have been trying to find a new binder that would limit the need of OPC. By substituting 40% copper slag and glass fiber for sand, geopolymer concrete's mechanical properties were improved, and the material's strength was evaluated in this study. The main component for binding was fly ash. This study investigates the effects of heat curing eopolymer concrete composites in a hot air oven at 60˚C for 24 hours on their water absorption, compressive strength, and split tensile strength. The glass fiber volume fractions that were added to the mixture were 0.5%, 1%, 1.5 %, and 2.0 %. Within this section, we illustrate the relationship between the volume percentage of fibers and the compressive and split tensile strengths of geopolymer concrete. Both the fiber-and non-fiber varieties of geopolymeric concrete outperform their non-fiber equivalents, as shown here.

Hassan, Amer. (2018). The performance of Geopolymer concrete based on fly ash was tested experimentally, and the findings are presented in this research. Gravel, pebbles, sand, water, and an alkaline liquid are the main ingredients of geopolymer concrete. Sodium hydroxide and sodium silicate make up the alkaline liquid. After about 5 minutes of mixing, the sodium hydroxide particles and water formed an alkaline liquid solution. The next step was to combine the sodium silicate and sodium hydroxide solutions. The day before the mixing day, this liquid was made. Insect ash Based Geopolymer concrete has the ability to supplant OPC concrete in several uses, including precast units, and is better for the environment. Both the amount of greenhouse gases emitted and the expense of disposing of industrial waste may be mitigated via the usage of geopolymer technology.

NarasimhaSwamy, P.A.N.V.L. et al., (2017) Coir fiber's durability behavior is tested in geopolymer concrete that is based on fly ash. The coir fiber is treated with a rubber latex solution before being used in geopolymer concrete. An assortment of percentages, including 0%, 0.75%, 1.5%, 2.25%, and 3%, are applied to a 25mm length of Coir fiber. The geopolymerization technique made use of a solution containing both sodium silicate and sodium hydroxide. Use a ratio of 0.45 for the binding agent to fly ash. You may utilize molarities of 10M and 12M. Reinforced with coir fiber, which helps to withstand microcracks. In cases when resistance to microcracks is necessary, this may be useful.

Srinivasan, Kumar et al., (2015) The strength parameters are affected by the fly ash content; as the fly ash content rises, the compressive, split, tensile, and flexure strengths all go up, but if the content goes up even higher, they go down. A flyash level of 27% in 130 liters of water was determined to be ideal. Steel fiber added to geopolymer concrete reduced compressive strength by a small amount while increasing split tensile strength and flexure capacity by a large margin. The beams' ultimate load capacity and cracking moment capacity both rose as the fiber percentage increased, which is consistent with what one would anticipate from regular Portland cement concrete. Aspect ratios of 75 and fiber fractions between 0.6% and 1% significantly affect flexure strength increases of up to 11.5%.

Methodology

Preparation of Alkaline Activator Solution

For molarity mixes of 10M, this study looks at how geopolymer concrete performs in tests for compressive strength, flexural strength, and split tensile. The use of antacid activators that included a mixture of sodium hydroxide and sodium silicate facilitated geopolymerization. A ten-molar solution of sodium hydroxide (10 M) was prepared by dissolving 400 g (10 x 40) of the salt in distilled water until it reached a volume of one liter. The final concentration of NaOH will change depending on the combined arrangement, as well as molarity, M.

Materials utilized as a part of the present examination

For the purpose of strengthening Geo Polymer concrete blends, the following materials are used as fiber reinforcement: elegance-F fly ash, coarse total, fine aggregate, sodium hydroxide association, sodium silicate association, latex elastic, coir fiber, and converting quotes of 0, 0.75, 1.5, 2.25, and 3. For this test, the starting liquid is a combination of sodium hydroxide (97%) and sodium silicate (Na_2O-13.72%, SiO_2-34.16%, and H_2O-47.2%). OPC isn't necessarily used in these mixes to any significant extent.

Treatment of coir fibre

The coir fiber is separated from the coir pith and other unwanted substances. After that, it undergoes synthetic chemical treatments after being sliced to a varied length of 2.5 cm. After 48 hours, the sodium hydroxide solution is absorbed by the coir fibers. We removed the fiber, rinsed it again with water, and dried it well. A latex compound is made by mixing standard elastic latex with a sodium hydroxide solution, water, and a percentage of 70%. In order to achieve homogeneity, the latex compound and the left answer were discarded. After about fifteen minutes of submersion, the coir fiber is removed from the liquid and allowed to dry. In the lab, a slate blender will be used to dry the aggregates and fly powder for the third and final motion. The addition of coir fiber and alkaline solutions came later.

Instruction of Geopolymer Concrete Specimens

To get the desired alkalinity in the basic activator solution, sodium hydroxide was mixed with sodium silicate one day before adding the solid. To begin, combine the fine totals, fly ash, and coarse totals in a level dish blender without water for three minutes. Wet mixing was performed for four minutes after adding basic activator arrangement to the waterless blend that had been previously mixed. Coir fiber was then added to the mixture. For compressive quality, 30 pieces measuring 150 mm x 150 mm x 150 mm were thrown. For split rigidity, 30 chambers measuring 150 mm crosswise over and 300 mm stature were tossed. For flexural quality, 30 shafts measuring 1000 mm x 150 mm x 150 mm were tossed. The coir fiber rates varied between 0, 0.75, 1.5, 2.25, and 3. The examination examples are tossed using criteria cast iron molds. Engine lubricant was placed across the inside surfaces of the molds before throwing. Layers of geopolymer cement were added to the molds after they had been blended using a level skillet blender machine. Using a table vibrator, we compacted each cement layer.

Curing of Geopolymer Concrete Specimens

Because the geopolymer solid does not set quickly at room temperature, unlike regular cement, the samples were left in molds for one day before being demoulded because of this. The time it takes to go from finishing the test samples to starting the treatment at a higher temperature is what the word "relax period" describes. In order to completely install a geopolymer solid example without leaving a nail sway on the cement surface, at least three days are required. Thirty solid forms, thirty barrels, and thirty pillars were maintained under an encompassing environment for curative purposes at room temperature toward the end of the one-day relaxation period that each sample was provided.

Tests On Geopolymer Concrete

Compressive strength

A material or structure's compressive energy is its breaking point under the influence of hundreds of stresses that cause them to shrink. It may be one-of-a-kind by combining strategic strength with twisting in a challenging gadget. Some compounds degrade at their compressive strength limit, while others bind indefinitely, hence a particular computed disfigurement may be defined as the maximum compressive stress. One input attribute for form delineation is compressive electricity. Typically, compressive strength is evaluated using a comprehensive testing engine that ranges from small desk-top systems to ones with a limit of more than 53 MN.

Split tensile strength

Tensile testing, sometimes known as stress testing, is an important part of resource discipline that involves putting a model through its paces under controlled pressure in anticipation of failure. Typically, the grades given at the beginning of the test are used to choose a substance for a request, for quality control purposes, and to predict how a substance would react to different kinds of services. Great tensile strength, maximum persistence, and reduction in the province are properties that may be precisely determined by a tensile test. You may also specify the following parameters on these dimensions: Young's modulus, Poisson's ratio, yield strength, and tension hardness. The unthinking type of isotropic materials is often obtained by uniaxial tensile testing. Biaxial tensile testing is crucial for isotropic materials like blended fabrics and resources.

Flexural strength

One property of substances is their flexural strength, which is sometimes called modulus of rupture, coil strength, or split energy. This is the stress in a material just before it breaks in a flexure test. Most often, engineers will use the oblique bowing test, which involves bending a sample with an inside or rectangular pass section until it cracks or becomes acquiescent using a three-point flexural check

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system. At the point of a crack, the flexural pressure stands in for the primary anxiety professional in the fabric. It's purposeful in terms of stress, as this example shows.

Observations And Results

In Tables 1-3, you can see the outcomes of every combination.

Table 1: Coir Fibre Effect on Strength (N/mm²)

Molarity	% of Coir Fibre	7 Days	14 Days	28 Days
10	0.00	5.10	5.40	12.20
10	0.75	6.80	7.20	13.80
10	1.50	7.40	7.60	15.30
10	2.25	8.30	9.30	15.80
10	3.00	6.50	6.70	13.80

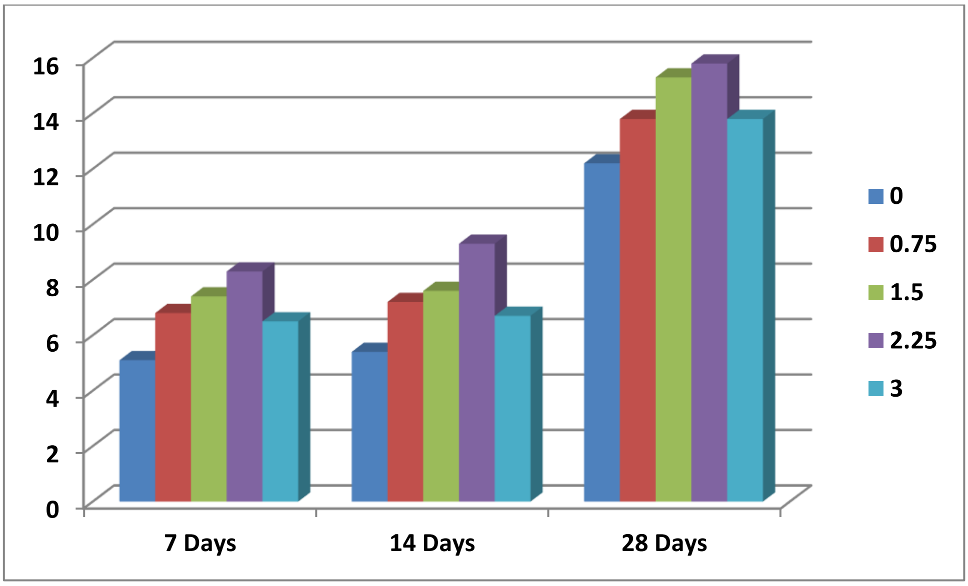

Figure 1: Coir Fibre Effect on Strength (N/mm²)

See how the amount of coir fibers affects the strength development of geopolymer concrete at various curing ages from the compressive strength findings shown in Table 1. By day 7, the concrete with no fiber content had reached baseline strength of 5.10 N/mm², and by day 28, it had increased moderately to 12.20 N/mm². There is a clear increase in compressive strength once coir fiber is added. The 28-day strength reached 13.80 N/mm² at 0.75% fiber content, and reached a high of 15.30 N/mm² at 1.50% fiber content, indicating continued improvement. Modest fiber inclusion improves matrix bonding, fracture resistance, and load distribution; 2.25% fiber addition produced the best results, with peak strength of 15.80 N/mm² at 28 days. The strength decreased to 13.80 N/mm² at 3% fiber concentration, indicating that an overabundance of fibers might reduce compressive strength due to poor workability, weak fiber dispersion, and void formation. The predicted pattern of increased strength with curing age was found across all blends, with the most significant increases between 7 and 28 days. The findings show that there is an ideal dose of fibers beyond which mechanical characteristics degrade.

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Table 2: Coir Fibre Effect on Split Tensile Strength (N/mm^2)

Molarity	% of Coir Fibre	7 Days	14 Days	28 Days
10	0.00	0.09	0.15	0.70
10	0.75	0.12	0.18	0.90
10	1.50	0.20	0.28	1.10
10	2.25	0.45	0.65	1.80
10	3.00	0.25	0.35	1.50

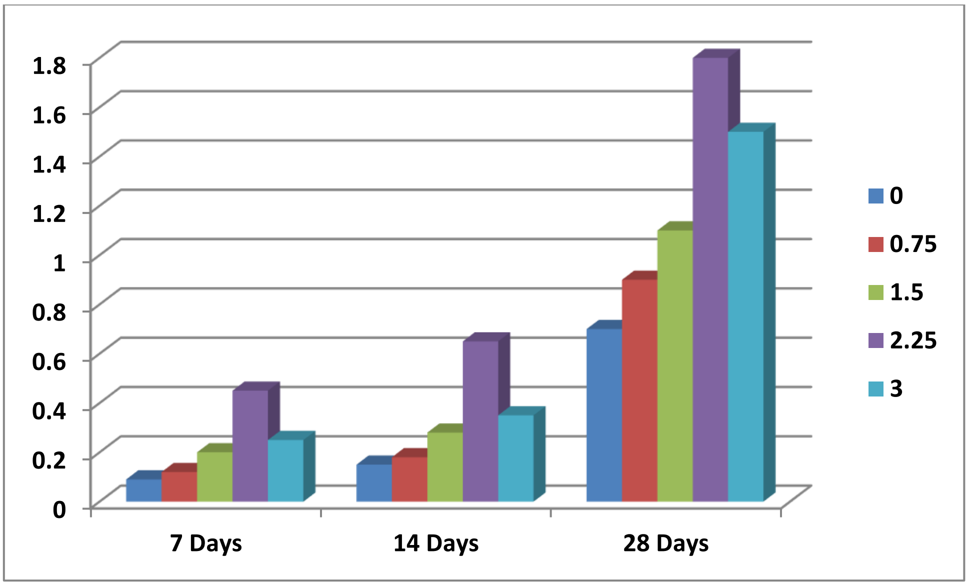

Figure 2: Coir Fibre Effect on Split Tensile Strength (N/mm^2)

Table 2 shows the split tensile strength values, which show how coir fiber improves the tensile behavior of geopolymer concrete. The concrete's tensile strength was just 0.70 N/mm^2 after 28 days when there was no fiber content. The tensile strength showed a steady improvement when coir fiber was added, suggesting greater fracture resistance and fiber bridging action. At 0.75% fiber, the strength rose somewhat to 0.90 N/mm^2, while at 1.50% fiber, there was a more noticeable improvement, reaching 1.10 N/mm^2 after 28 days. The optimal fiber dosage for stress transmission and fracture arresting inside the matrix was found to be 2.25 percent fiber content, which resulted in the greatest tensile performance at 28 days, reaching 1.80 N/mm^2. The detrimental impact of fiber agglomeration and poor workability at higher doses was shown when the fiber content was raised to 3.00%, leading to a decrease to 1.50 N/mm^2. Mixes with a moderate to high fiber concentration show the biggest increase in strength from 7 to 28 days, although the effect is stable across all fiber percentages. Incorporating coir fiber into a mixture greatly enhances its tensile strength; the optimal dose was determined to be 2.25%.

Table 3: Effect of Coir Fibre on Flexural Strength (N/mm^2)

Molarity	% of Coir Fibre	7 Days	14 Days	28 Days
10	0.00	0.19	0.25	0.35
10	0.75	0.58	0.70	0.85

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10	1.50	0.88	1.00	1.15
10	2.25	1.20	1.50	1.85
10	3.00	1.00	1.20	1.55

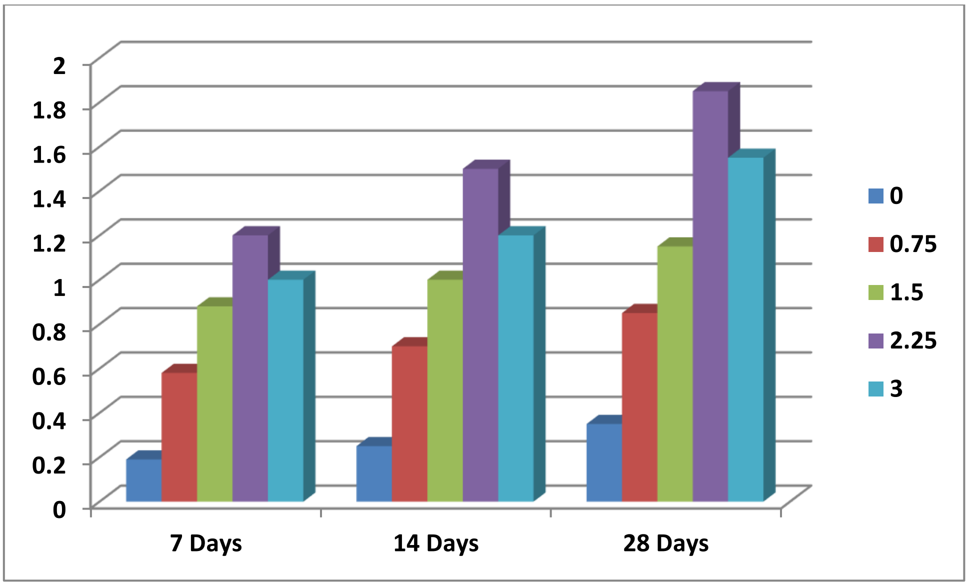

Figure 3: Effect of Coir Fibre on Flexural Strength (N/mm²)

Table 3 shows that adding coir fiber to geopolymer concrete significantly increases its load-carrying and crack-resisting capability in terms of flexural strength. There was very little resistance to bending forces at 28 days when the flexural strength was just 0.35 N/mm^2 due to the absence of fiber. Flexural strength increased by a factor of two with the addition of 0.75 percent fiber, to 0.85 N/mm^2; after 28 days, it reached 1.15 N/mm^2, a further improvement with 1.50% fiber. The flexural strength reached its highest at 1.85 N/mm^2 at a fiber content of 2.25%, demonstrating the fiber's significance in enhancing post-cracking behavior, increasing ductility, and bridging fractures. The strength decreased to 1.55 N/mm^2 at 3.00% fiber content, which is still greater than the control mix but indicates that adding too much fiber lowers workability, causes fiber clumping and incorrect dispersion, and weakens the matrix-fibre link. Strength increases with curing time in all mixtures, which is indicative of the geopolymer binder matrix's ongoing growth, according to the data. In conclusion, the research proves that coir fiber greatly improves flexural strength, with 2.25% fiber content being determined as the sweet spot for optimal performance.

Conclusion

This experimental investigation emphasizes the possibility of geopolymer concrete made of fly ash and reinforced with coir fiber as a greener substitute for traditional Portland cement concrete. The findings show that geopolymer concrete's tensile, flexural, and crack-resistance qualities are much improved by adding coir fiber, which solves one of the material's intrinsic weaknesses—brittleness. Using fly ash as the main binder not only makes better use of industrial waste, but it also lowers the material's carbon impact. Fly ash and coir fiber work together to provide a product that is both eco-friendly and efficient with resources; this makes it a good fit with sustainable development and the circular economy. In addition to improving the strength and durability of the concrete, the research shows that coir-reinforced geopolymer concrete may boost local economy, especially in areas where coconuts are grown in plenty and thermal power is generated. This method helps create greener infrastructure by repurposing agricultural and industrial waste into building materials instead of sending them to landfills. All things considered, geopolymer concrete reinforced with coir fiber is a practical and environmentally friendly option for green building. It shows potential for solving the current world's infrastructure demand and environmental sustainability problems with more optimization and widespread use.

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