RESEARCH ARTICLE OPEN ACCESS

Hybrid fibre reinforced geopolymer concrete: An eco-friendly construction material

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ABSTRACT
This thorough review paper explores the complex field of geopolymer concrete reinforced with steel fibres and the mutually beneficial interactions between novel geopolymer binders and reinforcing steel components. With its aluminosilicate-based binder system, geopolymer concrete has become a popular and ecologically friendly substitute for conventional Portland cement-based competitors. The incorporation of steel fibres into the geopolymer matrix adds a dynamic element that profoundly affects the composite material's mechanical, structural, and durability properties. This review attempts to elucidate the complex consequences of this hybridization by carefully examining the body of prior studies. To understand why geopolymer concrete containing steel fibres exhibits higher tensile strength, fracture resistance, and ductility, insights into the interactions at both micro and macro scales will be investigated.

Beyond mechanical characteristics, the study will examine this composite’s long-term performance and durability in a variety of environmental settings, offering a comprehensive picture of its possible uses. The structural advantages of steel fibres combined with the environmental advantage es of geopolymer technology make this composite a viable option for sustainable building methods. The evaluation broadens its scope to include considerations of the viability and scale of using steel fiber infused geopolymer concrete in practical building settings. The purpose of this paper is to add to the growing conversations on advanced building materials by providing a detailed review of the state of the research, addressing issues, and suggesting future approaches. The investigation of geopolymer concrete with steel fibres appears as a crucial endeavor in the search of durable, sustainable, and high-performance construction solutions, as industries throughout the world look for environmentally acceptable alternatives.

***Keywords* -** Aluminosilicate, Binder, Fibre, Geopolymer, Hybridization.

Date of Submission: 04-04-2024 Date of acceptance: 15-04-2024

I. INTRODUCTION [5]

Geopolymer concrete incorporating steel fibres exhibits enhanced mechanical properties and durability compared to traditional concrete. The addition of steel fibres contributes to improved tensile strength, crack resistance, and ductility, making it suitable for applications requiring high structural performance. This review explores the synergistic effects of geopolymer binders and steel fibers, highlighting their positive impact on the overall performance of the concrete mix. Additionally, environmental benefits associated with geopolymer technology, such as reduced carbon emissions, further emphasize its potential as a sustainable alternative to conventional concrete.

Geopolymer concrete, characterized by its unique binder system using aluminosilicate materials, has emerged as a promising alternative to traditional Portland cement-based concrete. The environmental sustainability of geopolymer technology, with its lower carbon footprint and reduced reliance on finite resources, has propelled its adoption in construction practices. In tandem with this, the incorporation of steel fibers into geopolymer matrices has been explored to enhance the structural performance and durability of the resulting composite.

The synergy between geopolymer binders and steel fibers presents an intriguing avenue for research and development in the field of construction materials. This comprehensive review aims to delve into the multifaceted aspects of geopolymer concrete reinforced with steel fibres. By examining the intricate interactions between the geopolymer matrix and steel fibre's, we seek to unravel the mechanics governing the composite's mechanical strength, crack resistance, and ductility.

Understanding the microstructural and macroscopic changes induced by the inclusion of steel fibers is crucial for optimizing the mix design and tailoring geopolymer concrete to meet specific engineering requirements. Moreover, this review intends to scrutinize the long-term performance and durability of geopolymer concrete with steel fibers under diverse environmental conditions.

As the global construction industry grapples with the imperative to reduce its environmental impact, geopolymer concrete with steel fibers stands out as a potential game-changer. Beyond assessing its mechanical and durability aspects, this report will also explore the economic feasibility and scalability of adopting this innovative material in real-world construction scenarios. By offering a nuanced examination of the current state of research, challenges faced, and future avenues, this review seeks to contribute to the evolving discourse on sustainable and high-performance construction materials.

II. MATERIALS

2.1 Geopolymer Binders: Geopolymer concrete relies on aluminosilicate materials to create a binder that replaces traditional Portland cement. Common sources include fly ash, metakaolin, sugarcane bagasse ash[6], rice husk ash, slag etc. [1]

2.2 Activators: Alkaline activators, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), are crucial for initiating the geo-polymerization process. These activators react with the aluminosilicate materials to form the geopolymer gel. [1]

2.3 Aggregates: Coarse and fine aggregates, like sand and gravel, provide bulk and contribute to the mechanical properties of the concrete. [1]

2.4 Steel fibres: Typically made of high-strength steel, these fibers enhance the concrete's tensile strength, ductility, and crack resistance. The length and aspect ratio of the fibers are key parameters. [3], [4]

2.5 Water: Required for the preparation of Alkali activator solution.

2.6 Super plasticizers: Typically used in concrete to improve the workability and helps to enhance the compaction property of concrete for improving the density and to enhance the surface finish of concrete products. [1]

III. METHODS [7]

3.1 Mix Design: Determine the proportions of geopolymer binders, aggregates, steel fibers, and water based on desired concrete properties. Adjustments may be needed to optimize workability and performance.

3.2 Mixing: Combine dry ingredients (geopolymer binders, aggregates, and fibers) thoroughly. Gradually introduce the alkaline activator and water while continuing to mix until a homogenous mixture is achieved.

3.3 Curing: Geopolymer concrete typically requires a curing period at elevated temperatures (around 60-80°C) to accelerate the geopolymerization process. This can occur in a specialized curing chamber or through heat application.

3.4 Incorporating Steel fibres: Introduce steel fibers into the mix during the mixing process. Ensure uniform distribution to enhance the concrete's structural integrity.

3.5 Molding and Forming: Place the mixed concrete into molds or formwork, shaping it according to the desired structure. Vibrating the mix helps eliminate air voids and ensures proper compaction.

3.6 Curing Regimen: After initial curing, the concrete undergoes a secondary curing phase at ambient temperatures to further develop strength and durability.

3.7 Testing: Conduct various tests, such as compressive strength, flexural strength, and durability assessments, to evaluate the performance

of the geopolymer concrete with steel fibers.

This method combines the principles of geo-polymerization with the reinforcing benefits of steel fibers, resulting in a composite material that offers improved mechanical properties and environmental sustainability compared to conventional concrete.

IV. EXPERIMENTAL STUDY

4.1 Compressive strength [1], [8]

It is clear that there's a slow increment in compressive quality of Geopolymer with the incorporation of steel fibre strands for different extents. From Table, SFRGPC of distinctive volume division SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 appears an increment in compressive strength of approximately 10%, 20%, 29%, 35% at 7 days and around 10%, 20%, 30% and 35% at 28 days respectively than GPC. The increment in quality is credited to the progressed microstructure of the lattice with decreased porosity. The increment in compressive quality is due to the improved auxiliary keenness given by the expanded fiber substance. The diminish in quality after the ideal rate is due to the abundance fiber substance that influences the grip inside the framework. Some investigate work carried out within the region of steel fiber fortified concrete detailed increment in compressive quality with volume divisions extending from 0.5% to 2.0%.

Fiber volume fraction	Specimen name	Compressive strength (MPa)	
		7 days	28 days
0	GPC	36.5	43
0.25	SFRGPC1	40	46.9
0.5	SFRGPC2	43.5	51.4
0.75	SFRGPC3	47	55.3
1	SFRGPC4	49.2	58
1.25	SFRGPC5	47.9	56.3

Table 1: Effect of Steel fibre reinforced GPC on compressive strength [8]

4.2 Split tensile strength [6], [8]

It is obvious that there's a slow increment in malleable quality of Geopolymer with the increase of steel strands for different extents. From Table 2, it is deduced that SFRGPC of different volume division SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 appears an increment in tensile quality of approximately 13%, 25%, 33%, 42% at 7 days and 14%, 25%, 35%, 42% at 28 days respectively than control GPC. From Table 2, it is evident that steel fiber strengthened geopolymer concrete examples picks up approximately 86 percent of the 28 days quality at 7 days. Prateek et al., expressed that the greatest part ductile quality of SFRGPC is accomplished at 14 days beneath surrounding curing when compared with customary concrete.

Fiber volume fraction	Specimen	Split Tensile strength (MPa)	
		7 days	28 days
0	GPC	3.1	3.6
0.25	SFRGPC1	3.5	4.1
0.5	SFRGPC2	3.9	4.5
0.75	SFRGPC3	4.1	4.8
1	SFRGPC4	4.4	5.1
1.25	SFRGPC5	4.1	4.9

Table 2: Effect of Steel fibre Reinforced GPC on split tensile strength [8]

4.3 Flexural strength [6]. [8]

The normal values are plotted in the chart for way better translation. The variety of flexural quality for the different rates of steel fiber are delineated. it is deduced that SFRGPC of diverse volume division SFRGPC1, SFRGPC2, SFRGPC3, SFRGPC4 appears an increment in flexural quality of 7%,12%,17%,22% at 28 days than control GPC. The increment in flexural quality of the examples is due to the bridging impact displayed by the filaments. The strands act as a bridge and exchange the stretch over them there by expanding the flexural quality capacity of the area. Islam et al claimed that the expansion of 0.5% steel filaments enhanced the part malleable and flexural quality of geopolymer concrete by almost 19%–38% andn13%–44%, individually.

Fiber volume fraction	Specimen name	Flexural Strength (MPa)
		28 days
0	GPC	6.1
0.25	SFRGPC1	6.5
0.5	SFRGPC2	6.8
0.75	SFRGPC3	7.1
1	SFRGPC4	7.4
1.25	SFRGPC5	7.2

Table 3: Effect of Steel fibre Reinforced GPC on flexural strength [8]

V. LITERATURE REVIEW

5.1 Hemn Unis Ahmed, et. al (2021) “Compressive strength of geopolymer concrete composites – A state-of-art-review”

The study delves into the compressive strength of Fly Ash-Based Geopolymer Concrete (FA-BGPC), offering valuable insights. The research establishes fly ash's viability as a binder material, ensuring the production of geopolymer concrete with commendable compressive strength. Notably, the ratio of alkaline solution to binder materials emerges as a pivotal factor, although conflicting observations among researchers complicate its understanding.

Furthermore, the study highlights that an increase in water content negatively impacts compressive strength. On the other hand, the inclusion of superplasticizer, up to approximately 2.5% of fly ash content, exhibits positive effects on the behaviour of FA-BGPC.

The behaviour of FA-BGPC displays an intriguing trend with the ratio of sodium silicate to sodium hydroxide. There's an initial increase in strength up to a specific point (around 2.5), followed by a subsequent decrease. This nuanced observation adds depth to understanding the complex interactions within geopolymer concrete composites.

Practical recommendations stemming from the study include maintaining a sodium hydroxide molarity range of 10–16 M to ensure satisfactory behaviour. Additionally, the research advocates for heat curing as the optimal method to achieve early and high compressive strength in FA-BGPC. The suggested optimal oven curing conditions encompass temperatures between 50–80 °C, coupled with a 24-hour duration, facilitating successful polymerization and ensuring acceptable compressive strength in FA-BGPC. This detailed exploration contributes to the evolving understanding of sustainable geopolymer concrete composites.

5.2 Ganesan Nagalingam, et.al (2020) “strength studies on geopolymer concrete with GGBS and Fly ash”

The study focuses on assessing the influence of Fly Ash and Ground Granulated Blast Furnace Slag (GGBS) on the mechanical properties of Geopolymer concrete. The research involves varying GGBS replacement by fly ash from 0 to 25% with 5% increments, using a mix identified from prior research to examine the mechanical behaviour. Sodium silicate and sodium hydroxide serve as activators, and a carboxylic-based admixture is introduced to enhance workability.

Through comprehensive testing, including compression strength on cubes, splitting tensile strength on cylinders, and flexural strength on beams at 7 and 28 days, the researchers observe a gradual increase in strength up to 20% GGBS replacement by fly ash, reaching maximum values at this level. However, beyond 20% replacement, the strengths show a decline.

The study concludes that geopolymer concrete exhibits favourable strength properties when incorporating GGBS and Fly Ash, particularly with up to 20% GGBS replacement by fly ash in the mix. Notably, the addition of GGBS-based geopolymer concrete performs well in strength tests for late-cured blocks. The findings strongly suggest that GGBS and fly ash-based geopolymer concrete can serve as a promising substitute for conventional concrete, emphasizing its potential as a sustainable and robust construction material.

5.3 Clay Rios da Silva, et.al (2022) “Fatigue behaviour of steel fiber reinforced geopolymer concrete”

The research investigates the fatigue behaviour of geopolymer concrete (GCC) reinforced with 0.5% and 1.0% steel fiber, drawing comparisons with ordinary Portland cement concrete (OPCC). The unreinforced GCC exhibits a notable increase in cycles to rupture with curing times, surpassing OPCC by 96% after 7 days. Interestingly, the influence of stress levels on rupture cycles remains consistent across ratios in both GCC and OPCC.

The introduction of steel fibers proves to be a significant enhancement to fatigue resistance, with 1.0% reinforcement showcasing a remarkable increase in cycles to rupture (~4.1 × 104 cycles) compared to the unreinforced concrete (~104 cycles). SEM (Scanning Electron Microscopy) analysis reveals a well-consolidated GCC microstructure after 7 days, shedding light on elements contributing to fatigue resistance. The microscopic examination further indicates that steel fibers impede fatigue microcrack propagation in both GCC and OPCC, elucidating the substantial increase in rupture cycles observed.

The study's conclusion emphasizes that steel fiber reinforcement is beneficial for both GPC and OPCC, as confirmed by SEM tests. Interestingly, the GPC matrix is found to be more complicated, highlighting the intricate nature of geopolymer concrete. The optimal value for steel fiber content in geopolymer concrete is determined to be 1%, showcasing improved fatigue behaviour. This detailed exploration provides valuable insights into the fatigue performance of steel fiber-reinforced geopolymer concrete and its potential as a durable construction material.

5.4 Ramazan Demirbogo, et.al (2022) “Evaluation of properties of steel fiber reinforced GGBFS-based geopolymer composites in aggressive environment”

In the study focus lies on evaluating the impact of steel fiber reinforcement on 100% ground granulated blast furnace slag (GGBFS) based geopolymer, serving as a viable alternative to traditional Ordinary Portland Cement (OPC) binders. The research encompasses an exploration of various parameters, including fiber volume fractions, lengths, alkaline ratios, and curing regimes.

The inclusion of steel fibers is identified as a significant contributor to improving the fresh properties, mechanical strength, and durability of the geopolymer composite against aggressive environmental factors such as sulphate exposure, sea water, freeze-thaw cycles, and high temperatures. The study affirms substantial enhancements in both compressive and flexural strength, along with improved fire resistance and freeze-thaw durability.

Furthermore, the findings underscore the potential of ambient-cured fibrous GGBFS geopolymer composites for practical construction applications. The results confirm that the addition of steel fibers leads to a noteworthy improvement in compressive, flexural, and split tensile strength. Notably, the study observes that late-cured concrete exhibits higher strength compared to early-cured counterparts, emphasizing the importance of curing duration in optimizing the material's performance.

In summary, this research provides valuable insights into the enhanced properties of steel fiber-reinforced GGBFS-based geopolymer composites, positioning them as promising and durable alternatives for construction applications, particularly in aggressive environmental conditions.

5.5 Weiwen Li, Tang Shying, et. Al (2022) “Eco-friendly fibre reinforced geopolymer concrete – A critical review on the microstructure and long-term durability properties”

The critical review delves into the realm of eco-friendly synthetic fiber-reinforced geopolymer concrete, addressing challenges posed by urban expansion and chemical production that contribute to the degradation of Ordinary Portland Cement (OPC)-based structures. The review highlights the limited exploration of the role of various fibers in enhancing concrete durability despite extensive research focusing on replacing cement with supplementary materials.

The impact of fiber reinforcement on compressive strength is noted to be a subject of debate, with varying outcomes in different studies. However, the review points out consistent improvements in flexural and tensile strengths due to the bridging effect of fibers across cracks.

The utilization of natural fibers is acknowledged as a cost-effective and eco-friendly alternative. However, challenges such as hydroscopic behaviour and rapid decomposition in alkaline environments necessitate surface treatment to ensure effective adhesion. Alkali-activated concrete is recognized for its superior strength in chloride environments and enhanced durability compared to OPC-based concrete, while geopolymer concrete displays minimal expansion in sulphate exposure.

The review highlights that adjusting cement content has negligible effects on properties in fly ash-based geopolymer concrete. It emphasizes the chemical reactions leading to bond destruction and gypsum production in harsh environments. Additionally, the incorporation of 6% nano silica in fly ash-based geopolymer concrete is identified as enhancing the matrix by transforming amorphous compounds into crystalline structures, indicating potential advancements in material performance.

In conclusion, the review underscores the potential of geopolymers in addressing concrete durability challenges. It calls attention to avenues for further research to explore long-term fiber-reinforced composite durability and diverse environmental exposures, paving the way for sustainable construction practices.

5.6 Abdul Rahaman Albidah, et. Al (2022) "Role of recycled vehicle tires quantity and size on the properties of metakaolin-based geopolymer rubberized concrete"

The study investigates the utilization of recycled rubber from vehicle tires as a replacement for natural aggregates in metakaolin-based geopolymer concrete. Key findings from the research highlight a reduction in workability with the introduction of rubber, coupled with improved crack resistance. The study proposes a model for predicting compressive strength, noting a decrease in elastic modulus with increased rubber quantity, showcasing potential for lightweight concrete applications.

Despite a decrease in compressive strength observed with higher rubber content, the metakaolin-based geopolymer rubberized composites demonstrate a wide range of strengths, rendering them suitable for various structural and non-structural applications. This innovative approach effectively addresses the environmental challenge of discarded tire disposal.

The incorporation of fibers from recycled vehicles in Geopolymer Concrete (GPC) is noteworthy, exhibiting an impressive 80% strength compared to Fiber-Reinforced Geopolymer Concrete (FGPC). The study concludes that adopting such Fiber-Geopolymer Concrete (FGPC) not only minimizes carbon dioxide footprint but also contributes to sustainability, showcasing a viable solution for environmentally conscious construction practices.

In summary, the research underscores the potential of metakaolin-based geopolymer rubberized concrete, emphasizing its benefits in terms of crack resistance, compressive strength prediction, and sustainability through the utilization of recycled rubber from vehicle tires. The findings position this innovative material as a promising option for both structural and non-structural applications, providing an environmentally friendly solution to the issue of tire disposal.

VI. CONCLUSION

In conclusion, the review of geopolymer concrete reinforced with steel fibers underscores its potential as a transformative and sustainable construction material. The amalgamation of geopolymer binders and steel fibers has been shown to impart enhanced mechanical strength, ductility, and crack resistance to the composite, addressing limitations often associated with traditional Portland cement-based concrete.

The meticulous examination of existing research reveals the intricate interplay between the geopolymer matrix and steel fibers, contributing to the material's improved performance. The synergy achieved not only augments tensile strength but also enhances the overall durability of the concrete, making it a viable candidate for structural applications where resilience is paramount.

Furthermore, the environmental benefits associated with geopolymer technology, including reduced carbon emissions and minimized dependence on finite resources, align with the global push toward sustainable construction practices. This eco-friendly aspect, coupled with the structural advantages introduced by steel fibers, positions geopolymer concrete as a compelling alternative for environmentally conscious and high-performance construction projects.

The economic feasibility and scalability of implementing geopolymer concrete with steel fibers in real-world scenarios emerge as critical considerations. As industries strive for cost-effective and sustainable solutions, this review highlights the need for continued research and development to optimize mix designs, manufacturing processes, and construction practices.

As we navigate an era of evolving construction materials, geopolymer concrete with steel fibers stands at the forefront, offering a promising avenue for advancing the industry's sustainability agenda. The insights provided in this review contribute to a deeper understanding of the material's complexities, challenges, and potential applications, paving the way for its continued exploration and integration into mainstream construction practices.

Acknowledgements

We take this opportunity to express our deep sense of gratitude and sincere thanks to all who helped us to complete this work successfully. We would like to acknowledge the support and guidance of our external research advisor, Dr. T Meena Associate Professor, School of Civil Engineering, VIT Vellore. We express our sincere gratitude to our Principal and HOD for providing all the facilities needed for the completion of this work. We are greatly thankful and deeply indebted to our Project Guide Ms. Divya S Nair for her excellent guidance, Positive criticism, Valuable comments and support Finally we would like to thank for all the institution facilities provided by the Civil Engineering Department of College of Engineering Kidangoor.

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