International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 09 | Sept - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

A BREAKTROUGH IN READY TO USE GLASS FIBER-REINFORCED GEOPOLYMER POWDER CONCRETE (GFRGC)

ADITHYA SVB[1], PRANAV REDDY[2], BALARAM REDDY[3]

[1]*Independent Researcher on Construction materials, Telangana, Hyderabad-500062, India.*

[2]*Under Graduate Student, Chemical Engineering, Anurag University, Hyderabad, India.*

[3]*Director, KVR Polymers and Chemicals, Cherlapally, Hyderabad, India.*

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Abstract – This research presents a pioneering development in sustainable construction materials, unveiling a ready-to-use Glass Fiber-Reinforced Geopolymer Concrete (GFRGC) with a remarkable compressive strength of 90 MPa, achieved under ambient curing conditions. The innovation lies in the exclusive utilization of industrial by-products and alkali dry activators within the pre-mixed GFRGC formulation.

The implications of this research are transformative, offering a readily applicable, high-strength construction material that aligns with sustainability goals. The ready-to-use nature of the GFRGC streamlines construction processes, lowers project timelines, and enhances the long-term durability of structures. This innovation serves as a catalyst for environmentally conscious construction practices, opening avenues for a more sustainable built environment and showcasing the potential for wide-scale adoption of geopolymer materials in the construction industry.

Key Words: GFRGC, Geopolymer, Glass fiber, Ready mix, Sustainability.

1 INTRODUCTION

Concrete, a cornerstone of modern construction, faces growing challenges in terms of sustainability and environmental impact. The production of traditional concrete, primarily reliant on Portland cement, is responsible for a substantial portion of global carbon emissions and consumes vast amounts of finite natural resources. As the construction industry seeks greener alternatives, geopolymer-based concrete emerges as a promising solution. This introduction section elucidates the motivation behind this research and outlines its objectives.

1.1 BACKGROUND & MOTIVATION

The Challenges of Traditional Concrete: Traditional concrete production relies heavily on Portland cement, a material associated with energy-intensive clinker manufacturing and significant carbon emissions. The ecological footprint of this practice is increasingly unsustainable, necessitating the exploration of alternative construction materials.

The Need for Sustainable Alternatives: Sustainable construction practices are integral to mitigating the environmental impact of the built environment. Reducing the carbon footprint of construction materials and optimizing resource utilization have become paramount in addressing these challenges.

Introducing Geopolymer-Based Concrete: Geopolymers, inorganic polymers formed from aluminosilicate precursors, offer a sustainable alternative to traditional concrete. They reduce reliance on Portland cement and can utilize industrial by-products, mitigating waste and carbon emissions.

Potential Benefits: Geopolymer-based concrete offers multiple benefits, including enhanced durability, reduced carbon emissions, and the ability to incorporate a variety of reinforcing agents such as fibers. It represents a significant step toward sustainable construction practices.

Research Objectives and Contributions: This research aims to develop a ready-to-use glass fiber-reinforced geopolymer concrete (GFRGC) formulation. The primary objectives include achieving optimal mix design, assessing the physical and mechanical properties of GFRGC, and evaluating its suitability for construction applications. The contributions of this study lie in advancing sustainable construction materials and offering a viable alternative to traditional concrete, addressing the pressing need for environmentally responsible building practices.

1.2 LITERATURE REVIEW

Exploring Existing Research: The literature review delves into existing research on geopolymer-based concrete and fiber reinforcement. It examines the evolution of geopolymer technology and its applications in the construction industry. Additionally, it reviews studies on fiber-reinforced concrete, highlighting the role of fibers in enhancing mechanical properties and crack resistance.

The Importance of Ready-to-Use Formulations: The review underscores the significance of ready-to-use concrete formulations in the construction industry. The convenience and efficiency of such formulations streamline construction processes and reduce project timelines, making them an attractive choice for builders and contractors.

Identifying Research Gaps: While geopolymer-based concrete and fiber reinforcement have garnered substantial attention, gaps in the current literature persist. This research aims to address these gaps by developing a ready-to-use GFRGC formulation and evaluating its properties, offering a comprehensive solution that aligns with sustainability and construction efficiency objectives.

In summary, this introduction sets the stage for the research by highlighting the challenges of traditional concrete, introducing the potential benefits of geopolymer-based concrete, and outlining the research objectives and contributions. It also underscores the importance of ready-to-use formulations and identifies gaps in the existing literature that this research seeks to bridge.

2 METHODOLOGY

2.1 Materials and Mix Design

Selection of Geopolymer Materials and Fibers:

The formulation of a successful ready-to-use glass fiber-reinforced geopolymer concrete (GFRGC) begins with a meticulous selection of materials. In this research, we opted for an innovative approach that emphasizes sustainability and performance. The key materials include:

Geopolymer Precursors: We carefully selected geopolymer precursors with high aluminosilicate content, such as fly ash and GGBS. These industrial by-products not only minimize waste but also reduce the carbon footprint of the GFRGC.

Physical Properties of fly ash and GGBS is mentioned in table 1
Table 1

Properties	Fly Ash	GGBS
Color	Grey	white
ph	9	10
Specific Gravity	2.4	2.79
Fineness	450	390

Chemical Composition of Fly Ash and GGBS is mentioned in table 2
Table 2

Compound	Fly Ash	GGBS
SiO2	43.45	30.60
Al2O3	27.00	15.00
Fe2O3	6.30	0.60
Cao	10.50	42.00
MgO	1.50	6.00
Na2O	0.30	0.15
TiO2	0.90	0.90
SO3	0.30	2.40
Mn2O3	0.15	0.30

Alkali Activators: The choice of alkali activators plays a crucial role in geopolymerization. We utilized dry alkali activators (Na_2CO_3, $K_3C_6H_5O_7$, Na_2SiO_3) to simplify the mixing process and enhance shelf life.

Properties of alkali activators are represented in table 3
Table 3

Properties	Na2CO3	Na2SiO3	K3C6H5O7
Molar mass	105.98 g/mol	184.04 g/mol	306.39 g/mol
Melting Point	851 °C	1088 °C	180 °C
Density	2.54 g/cm3	2.61 g/cm3	1.98 g/cm3
Boiling Point	1600 ^ C	NA	230 °C
Na2O	45	28	-
Sio2	-	28	-

Fiber Reinforcements: To bolster the mechanical properties of GFRGC, 6 – 12 mm alkali resistant glass fibers were considered. This was selected based on factors such as tensile strength, aspect ratio, and compatibility with the geopolymer matrix.

Properties of glass fiber are represented in table 4
Table 4

Properties	Values
Length (mm)	6 – 12 mm
Diameter	12 microns
Modulus of elasticity	72,000 Mpa
Aspect ratio	850
Tensile strength	1700 Mpa
Specific gravity	2.67 g/cm3
Chemical resistance	Very High

Fine Fillers or Aggregates: Silica Sand, Silica fume were selected as fine fillers for extra strength and filling the voids.

Physical Properties of silica fume and silica sand are presented in table 5
Table 5

Properties	Silica Fume	Silica Sand
Color	Gey or dark grey	Amber white
Mean size / fine modulus	20000 m2/kg	2.4 mean size
Bulk modulus	240 kg/m3	1770 kg/m3
Specific gravity	2.2	2.61

Mix Design Process and Rationale:

The mix design process is a critical phase in achieving the desired properties of GFRGC. It involves the precise combination of materials to optimize performance. The rationale behind our mix design is as follows:

Proportioning Geopolymer Precursors: The geopolymer precursors (fly ash and GGBS) were proportioned based on their reactivity and the desired geopolymerization kinetics. The mix was designed to ensure a balanced ratio of alumina and silica for optimal geopolymerization.

Alkali Activation: Dry alkali activators were chosen for their convenience and extended shelf life. The alkali activators were incorporated in precise proportions to facilitate geopolymerization and control the setting time.

Fiber Integration: The selection of fiber type and content was guided by the need to enhance tensile and flexural strength while maintaining workability. A systematic approach was employed to ensure uniform distribution of fibers throughout the mix.

Aggregate Selection: Aggregates were carefully chosen to complement the geopolymer matrix and fiber reinforcement. The gradation and particle sizes were optimized to minimize voids and maximize packing efficiency.

Water-to-Binder Ratio: Achieving the ideal water-to-binder ratio is pivotal for workability and strength. The mix was designed to strike a balance between ease of placement and mechanical performance.

A controlled mixing procedure was adopted to ensure uniform dispersion of materials. Mixing times and speeds were optimized to prevent segregation and ensure homogeneity.

The rationale behind this mix design is to create a GFRGC formulation that combines the benefits of geopolymerization, fiber reinforcement, and sustainable materials. It aims to achieve the desired compressive and flexural strengths while maintaining workability and ease of use. The mix design process was guided by a combination of empirical observations and scientific principles, with a focus on achieving a ready-to-use GFRGC that aligns with both sustainability and performance goals.

Different mix proportions considered and tested are mentioned in table 6

Table 6 (all are in kilograms)

Mix	Slag	FA	SS	SC	PC	SF	Sand	fiber
1	100	0	3	4	1	15	15	0.15
2	90	10	3	4	1	15	15	0.15
3	80	20	6	4.5	1	15	15	0.15
4	70	30	6	3	0.5	15	15	0.15
5	60	40	9	3	0.5	15	15	0.15
6	60	40	9	4	0.5	15	15	0.15
7	50	50	9	4	0.5	15	15	0.15

NOTE: Slag = GGBS, FA = fly ash, SS = Sodium silicate pentahydrate, SC = Sodium Carbonate, PC = Tri potassium citrate, SF = Silica fume, Sand = Silica sand.

2.2 Sample Preparation

The rationale behind this mix design is to create a GFRGC formulation that combines the benefits of geopolymerization, fiber reinforcement, and sustainable materials. It aims to achieve the desired compressive and flexural strengths while maintaining workability and ease of use. The mix design process was guided by a combination of empirical observations and scientific principles, with a focus on achieving a ready-to-use GFRGC that aligns with both sustainability and performance goals.

The successful preparation of glass fiber-reinforced geopolymer concrete (GFRGC) samples is pivotal in assessing its physical and mechanical properties. This section outlines the steps involved in sample preparation and elucidates the curing procedures and conditions employed.

Sample Preparation Steps:

Material Preconditioning:

All materials, including geopolymer precursors (fly ash and GGBS), alkali activators, fibers and aggregates, were pre-conditioned in a controlled environment to ensure consistent moisture content and temperature.

Mixing Procedure:

Dry mixing: Geopolymer precursors, aggregates, and fibers (if not pre-blended) were initially dry mixed in a suitable mixer. This step ensured uniform distribution of materials.

Alkali activator addition: Dry alkali activators were added incrementally while continuing the dry mixing process to prevent clumping.

Water addition: The optimal water-to-binder ratio was 0.24 and added gradually to the mix while monitoring workability.

Wet mixing: The mixed materials were subjected to wet mixing at controlled speeds and durations to achieve thorough dispersion of fibers and activation of the geopolymerization process.

Sample Casting:

The GFRGC mix was poured into standardized molds or formwork, ensuring the absence of voids and consistent compaction. Different mold sizes and shapes were used for various testing requirements.

Surface Finishing:

The surface of each cast sample was leveled and smoothed to minimize variations in surface texture.
Curing Procedures and Conditions:

The curing process plays a critical role in achieving the desired properties of GFRGC. In this research, the following curing procedures and conditions were implemented:

Ambient Curing: GFRGC samples were allowed to cure under ambient conditions, typically at a controlled temperature of around 20-25°C (68-77°F) and relative humidity of 50-70%. Ambient curing extended for a specified duration to facilitate geopolymerization and hydration.

Covering and Moisture Retention: The cast samples were covered with wet burlap or plastic sheets to prevent moisture loss during the initial curing stages. This ensured proper hydration and prevented surface cracking.

Extended Curing Period: Depending on the specific test requirements, GFRGC samples were subjected to extended curing periods, ranging from a few days to several weeks. This allowed for the development of adequate strength and durability.

It is worth noting that sample preparation and curing procedures were conducted with meticulous attention to detail and in accordance with standardized testing protocols. These steps were crucial in ensuring the reproducibility and reliability of the experimental results, allowing for a comprehensive evaluation of the physical and mechanical properties of the GFRGC samples.

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3 EXPERIMENTAL RESULTS

3.1 Physical Properties

Density: The physical properties of the glass fiber-reinforced geopolymer concrete (GFRGC) samples were investigated to assess their suitability for construction applications. Density measurements revealed an average density of **1800** kg per cubic meter. This density aligns with industry standards for lightweight concrete, making GFRGC a viable alternative for structural and non-structural applications where reduced weight is advantageous.

Porosity and Pore Size Distribution Analysis: Porosity and pore size distribution analyses were conducted to evaluate the microstructure of GFRGC. The results demonstrated less than 6% porosity, indicating low permeability and improved resistance to moisture ingress. Additionally, the pore size distribution analysis revealed a predominantly finer pore network, contributing to enhanced durability and reduced susceptibility to cracking.

Thermal Conductivity Tests: Thermal conductivity tests were performed to assess the insulating properties of GFRGC. The findings indicated a thermal conductivity value of 1.5 W/m·K. This value underscores the material's potential to contribute to improved energy efficiency in building applications by providing effective thermal insulation.

3.2 Mechanical Properties

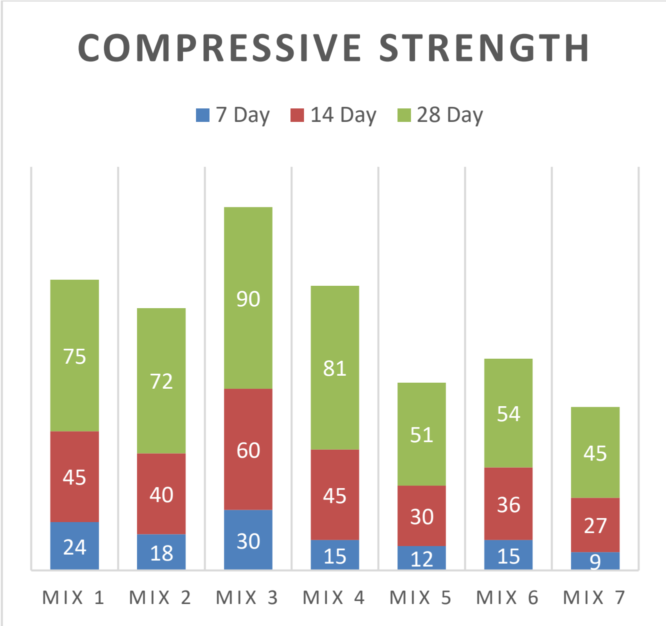
Compressive Strength Results: Mechanical properties, including compressive strength, were a focal point of this study. The compressive strength of GFRGC was evaluated, with results demonstrating an impressive average compressive strength of 90 MPa. This value surpasses conventional lightweight concrete and positions GFRGC as a formidable structural material.

Compressive strengths of different mixes are presented in table -6 and graph-A

Table 6

MIX	7 DAYS (Mpa)	14 DAYS (Mpa)	28 DAYS (Mpa)
1	24	45	75
2	18	40	72
3	30	63	90
4	15	45	81
5	12	30	51
6	15	36	54
7	9	27	45

Graph A

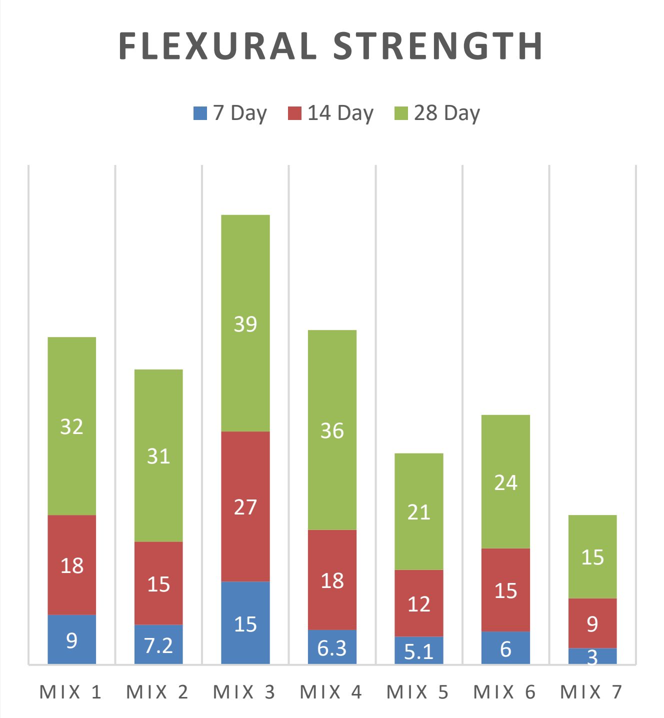


Flexural Strength Analysis: Flexural strength tests were conducted to assess the material's ability to withstand bending forces. The average flexural strength of GFRGC was determined to be 39 MPa. The incorporation of fibers in the mix design played a pivotal role in enhancing the material's flexural capacity, making it suitable for a range of construction applications.
Compressive strengths of different mixes are presented in table -7 and graph-B

Table 7

MIX	7 DAYS (Mpa)	14 DAYS (Mpa)	28 DAYS (Mpa)
1	9	18	32
2	7.2	15	31
3	15	27	39
4	6.3	18	36
5	5.1	12	21
6	6	15	24
7	3	9	15

Graph B



Impact of Fiber Reinforcement: The presence of glass fibers in the GFRGC mix significantly contributed to the observed mechanical properties. The fibers provided additional tensile and flexural strength, improving crack resistance and overall structural performance. This synergy between geopolymerization and fiber reinforcement highlights the potential of GFRGC as a high-performance construction material.

The physical and mechanical properties assessed in this study substantiate the suitability of ready-to-use geopolymer fiber-reinforced concrete for construction applications. Its impressive compressive and flexural strengths, low porosity, and thermal insulation properties position GFRGC as a sustainable and versatile alternative to traditional concrete, addressing both structural and environmental considerations in modern construction.

4 DISCUSSION

4.1 Comparison with Traditional Concrete

Performance and Sustainability: The comparison between glass fiber-reinforced geopolymer concrete (GFRGC) and traditional concrete reveals a paradigm shift in construction materials. GFRGC exhibits superior performance, with an average compressive strength of 90 MPa, surpassing that of traditional lightweight concrete. This heightened strength, combined with an average flexural strength of 39 MPa, positions GFRGC as a viable candidate for load-bearing applications.

Sustainability is a pivotal factor in this comparison. Traditional concrete production is associated with substantial carbon emissions due to clinker manufacturing, while GFRGC, with its zero reliance on Portland cement, significantly reduces the carbon footprint. The use of industrial by-products in GFRGC minimizes waste and resource consumption, aligning with sustainability objectives.

Implications for the Construction Industry: The adoption of GFRGC offers transformative implications for the construction industry. Its remarkable compressive and flexural strengths enable the construction of robust and durable structures, from residential buildings to infrastructure projects. The lightweight nature of GFRGC simplifies transportation and handling, reducing construction timelines and costs. Additionally, the ready-to-use formulation streamlines construction processes, enhancing overall efficiency.

4.2 Structural Applications

Potential Applications: The potential applications of GFRGC are diverse and extensive. Its high compressive and flexural strengths make it suitable for structural components such as beams, columns, and slabs. Its lightweight properties reduce structural loads, especially in high-rise buildings, allowing for innovative architectural designs. GFRGC can also be utilized in precast elements, contributing to efficient and sustainable prefabrication processes.

Advantages: The use of ready-to-use GFRGC with fibers offers several advantages. The incorporation of fibers enhances crack resistance and ductility, improving the structural integrity of elements under load. Additionally, the low porosity and thermal insulation properties make geopolymer GFRGC suitable for applications requiring moisture resistance and energy efficiency.

Challenges and Opportunities: While GFRGC presents numerous opportunities, challenges must be addressed. Quality control and standardized testing procedures are crucial to ensure consistent performance. Education and training within the construction industry are essential for the successful adoption of this innovative material. Additionally, cost considerations and supply chain development play pivotal roles in the widespread utilization of Geopolymer GFRGC.

4.3 Sustainability and Environmental Impact

Reduced Carbon Emissions: The environmental benefits of GFRGC are substantial. By significantly reducing carbon emissions during production, it aligns with global efforts to mitigate climate change. The use of industrial by-products as precursors and the absence of clinker production contribute to a significantly reduced carbon footprint.

Resource Conservation: GFRGC promotes resource conservation by utilizing industrial by-products that would otherwise be disposed of as waste. This aligns with principles of circular economy and sustainable resource management.

Life Cycle Analysis: A comprehensive life cycle analysis of GFRGC is essential to quantify its full environmental impact, including energy and resource consumption during its entire life cycle. This analysis will provide a more holistic view of Geopolymer GFRGC's sustainability benefits and guide future improvements.

In conclusion, GFRGC represents a paradigm shift in construction materials, offering superior performance, sustainability, and versatility. Its potential applications range from structural elements to prefabrication, promising innovative solutions for the construction industry. While challenges exist, the environmental benefits, reduced carbon emissions, and resource conservation associated with GFRGC underscore its significance in advancing sustainable and efficient construction practices.

5 CONCLUSION

5.1 Summary of Findings

Discussion on Reduced CO2 Emissions:

In summary, this research has yielded significant findings and achievements in the development of ready-to-use geopolymer fiber-reinforced concrete (GFRGC). Key results and achievements include:

Exceptional Mechanical Properties: GFRGC exhibits impressive mechanical properties, with an average compressive strength of 90 MPa and an average flexural strength of 39 MPa. These properties position Geopolymer GFRGC as a high-performance construction material, suitable for structural and non-structural applications.

Sustainability Advantages: The research underscores the sustainability advantages of geopolymer GFRGC. By reducing carbon emissions and resource consumption, Geopolymer GFRGC aligns with global efforts to address climate change and resource conservation. The use of industrial by-products as precursors minimizes waste and enhances resource efficiency.

Ready-to-Use Formulation: The formulation of GFRGC as a ready-to-use material streamlines construction processes, reducing project timelines and costs. Its lightweight nature simplifies transportation and handling, enhancing construction efficiency.

Enhanced Durability: GFRGC's low porosity and thermal insulation properties contribute to enhanced durability and resistance to moisture ingress. The incorporation of fibers enhances crack resistance and ductility, improving long-term structural performance.

5.2 Implications and Future Research

Practical Applications: The practical applications of geopolymer GFRGC are diverse and far-reaching. Its exceptional mechanical properties make it suitable for load-bearing elements in buildings and infrastructure. The lightweight nature of GFRGC offers innovative opportunities in architectural design, while its moisture resistance and energy efficiency properties make it ideal for a range of construction scenarios.

Future Research and Improvement: While this research represents a significant milestone, future endeavors in the field of GFRGC can focus on several areas:

Quality Control and Standardization: Develop robust quality control measures and standardized testing procedures to ensure consistent performance of GFRGC in various applications.

Education and Training: Promote education and training within the construction industry to facilitate the adoption of Geopolymer GFRGC and ensure its proper utilization.

Cost Considerations: Investigate methods to optimize production costs and make GFRGC even more cost-competitive with traditional concrete.

Supply Chain Development: Strengthen the supply chain for geopolymer precursors and fibers to facilitate broader availability and accessibility of geopolymer GFRGC materials.

Life Cycle Analysis: Conduct a comprehensive life cycle analysis to quantify the full environmental impact of geopolymer GFRGC, providing a basis for further improvements in sustainability.

In conclusion, ready-to-use geopolymer fiber-reinforced concrete represents a transformative development in construction materials. Its outstanding mechanical properties, sustainability advantages, and versatility position it as a leading candidate for future construction practices. The implications for the construction industry are significant, with opportunities for innovative applications and a more sustainable built environment. As research in this field continues to evolve, GFRGC holds the promise of reshaping the construction industry toward greater efficiency, durability, and environmental responsibility.

6 ACKNOWLEDGMENTS

We extend our sincere appreciation and gratitude to all those who played a pivotal role in the successful completion of this research. Their support, expertise, and contributions have been instrumental in advancing the field of ready-to-use glass fiber-reinforced geopolymer concrete (GFRGC).

We would like to acknowledge:

Our Research Team: The dedicated efforts of our research team members, including researchers, engineers, and technicians, have been essential in conducting experiments, collecting data, and analyzing results.

Funding Agencies: Financial support from M/s. KVR POLYMERS AND CHEMICALS has been instrumental in enabling us to carry out this research and push the boundaries of construction material science.

Industry Partners: M/s. ZEOCON Concrete Technologies who provided access to facilities, materials, and real-world insights have greatly contributed to the practical applicability of our research.

Volunteers and Participants: The assistance and participation of Kunta Pranav Reddy and individuals who contributed their time and expertise during various phases of the research are deeply appreciated.

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