iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: XII Month of publication: December 2024

DOI: https://doi.org/10.22214/ijraset.2024.66089

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue XII Dec 2024- Available at www.ijraset.com

An Experimental Study on High Strength Geo Polymer Concrete

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Abstract: Geopolymer concrete (GPC), rich in aluminosilicates and activated by alkaline solutions, offers superior durability, thermomechanical properties, and reduced environmental impact compared to conventional concrete. This eco-friendly material uses fly ash, GGBS, and silica fume, with optimized binder ratios like 35:50:15. Ambient curing enhances sustainability by eliminating the need for heat curing. Experimental studies reveal the benefits of incorporating brass-coated steel fibers, with 2.0% achieving optimal mechanical strength. AURAMIX 300 superplasticizer improves workability, while slag content enhances strength and bonding. Though costlier, HS-GPC's lower carbon footprint and high performance make it a sustainable alternative to traditional concrete.
Keywords: Geopolymer concrete, Carbon footprints, Fly ash, GGBS, Silica fume, Brass coated Steel Fibres.

I. INTRODUCTION

The urgent need to conserve natural resources and mitigate environmental degradation has driven efforts to develop sustainable alternatives to traditional construction materials. Ordinary Portland cement (OPC)-based concrete, the most widely used construction material, accounts for over 4 billion tons of annual production, growing at 4% per year. However, OPC production is highly energy-intensive, releasing significant carbon emissions and contributing to global greenhouse gas emissions. Simultaneously, the disposal of industrial by-products like fly ash, GGBS, and red mud poses major environmental challenges, including land usage and ecological harm.

To address these issues, geopolymer concrete has emerged as a sustainable alternative. Utilizing industrial by-products as a complete replacement for Ordinary cement, geopolymer concrete reduces CO2 emissions by up to 80%, making it a critical solution to combat global warming. It is created by activating aluminosilicate-rich materials with alkaline solutions, producing a durable, eco-friendly binder with superior mechanical properties. High strength geopolymer concrete (HSGPC) extends these benefits, achieving exceptional compressive strength and durability, ideal for demanding applications like bridges, high-rises, and precast elements.

HSGPC offers enhanced resistance to chemical attacks, high temperatures, and environmental degradation. By replacing cement with fly ash and GGBS, it significantly reduces the CO2 footprint compared to traditional high-performance concrete (HPC). This innovation delivers higher strength, improved ductility, and exceptional durability. The adoption of HSGPC aligns with global sustainability goals and offers a transformative opportunity for eco-friendly infrastructure. Ongoing research in mix optimization, fiber integration, and advanced production methods is set to further enhance its potential in modern construction.

II. CURRENT TRENDS AND RESEARCH DIRECTIONS

The studies were carried out on the concept of Geopolymer concrete which aiming to replace cement by Supplementary Cementitious Materials (SCM) like Fly ash, GGBS and Silica fume etc., The study by Mohamed Abdellatief, Mohamed Mortagi (2023) explores the use of geopolymer technology to develop ultra-high-performance geopolymer concrete (UHPGC), optimizing its fresh and mechanical properties through response surface methods. The findings highlight an optimized mixture with superior strength, density, and a dense, non-porous microstructure, advancing sustainable concrete solutions [1] .The work done by Parukutty S. Ambily, Chockkalingam Umarani, et al. (2013) develops ambient temperature-cured ultra-high-performance geopolymer concrete (UHPGPC) using industrial by-products like GGBS and silica fume, eliminating Portland cement. The optimized mixtures achieved compressive strengths up to 175 MPa and flexural strengths of 13.5 MPa, offering a sustainable alternative for cast-in-situ applications[2]. In their study of X.Y. Zhang , R. Yu, J.J. Zhang, et al. (2022)developed a low-carbon alkali-activated slag-based ultra-high-performance concrete (A-UHPC) with ultra-low moisture content, achieving a 28-day compressive strength of 118 MPa and reduced CO2 emissions. The optimized A-UHPC aligns with global sustainability goals, offering high performance and low environmental impact [3].

Juntao Dang, Xiaosong Tang et al., (2022) in their work explored adding recycled brick powder to alkali-activated foamed concrete, improving thermal insulation and stability while investigating the effects of activator modulus and Na_2O concentration.

Higher alkalinity enhanced stability, water resistance, and thermal properties, despite some trade-offs in foamability and pore structure [4]. In the year 2019, A. Wetzel, B. Middendorf stated that Portland cement-free, alkali-activated material using GGBS, silica fume, and metakaolin to enhance strength and durability. Achieving UHPC-level compressive strength, the optimized mix features low w/b ratios, improved workability, and reduced porosity through enhanced polymerization [5] [6]. Later Yazan Issa Abu Aisheh, Dawood Sulaiman Atrushi et al.in the year 2022 in their research explored the effects of steel fiber (0–3%) and micro silica (5–25%) on the mechanical properties of ultra-high-performance geopolymer concrete (UHP-GPC). Results reveal that increasing micro silica reduces the need for steel fiber while maintaining strength, with SEM analyses highlighting the underlying micromechanical improvements [7]. In the work of Weena Lokuge, Aaron Wilson et al. (2018) it is mentioned that their study develops a mix design method for Class F fly ash-based geopolymer concrete using the Multivariate Adaptive Regression Spline (MARS) model. The proposed tool achieves targeted compressive strengths (30–55 MPa) and provides a simplified approach for designing geopolymer concrete mixes [8] [9].Later in the year (2018) N.M. Azmee, N. Shafiq researched on Over the past two decades, ultra-high-performance concrete (UHPC) has advanced significantly, offering superior workability, strength, and durability with non-brittle behavior, making it a sustainable material for construction [10]. This paper reviews UHPC's fundamentals, applications, and challenges, promoting its broader adoption despite cost and design limitations.

III. EXPERIMENTAL METHODOLOGY

A. Outline of the Study

The methodology for producing high-strength geopolymer concrete involves using industrial by-products like Fly ash, GGBS, or Silica fume as binders, activated by an alkaline solution of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The concrete mix is created by combining these binders with fine and coarse aggregates, ensuring the correct molarity of the alkaline solution, optimal binder-to-aggregate ratio, and proper curing conditions, often involving heat curing to accelerate Geo polymerization. The focus is on achieving high compressive strength while minimizing environmental impact. Relevant standards such as IS 10262:2019 [11] for mix proportioning, IS 456:2000 [12] for plain and reinforced concrete, and ASTM C618 [13]for Fly ash quality guide the process. This chapter outlines the methodology, experimental program, and mix design details, aligned with the study's objectives.

The present work will be focussing on the performance of Geopolymer concrete tested with various binder content under different binder to solution ratio involving different molarity. Initially the slump cone test is performed to understand the workability and then attempts were made to make a high strength Geopolymer concrete. Firstly 3 varying mixes were made with varying combinations of binder content, binder to solution ratio without any type of fibres involved in it. The fibres used in this study are Brass coated steel fibres. And then the best resulted (higher compressive Strength) mix from the above is considered to make another 3 mixes by adding fibres of 1.5%, 2.0% and 2.5%, then the mechanical properties were tested for the specimens to find out the optimum fibres for the performed experiment on Geopolymer concrete.

B. Materials and Properties

1) *Binder Materials: -*


Fig 1. Fly ash


Fig 2. GGBS


Fig 3. Silica Fume

The binder materials in geopolymer concrete primarily consist of Fly ash and Ground Granulated Blast Furnace Slag (GGBS), which are activated by an alkaline solution. These materials undergo a geo polymerization process, forming a strong and durable matrix as an eco-friendly alternative to traditional cement [14].

Table I. Physical properties of cement and Fly ash, GGBS and Silica fume

S. No	Property	Fly ash	GGBS	Silica Fume
1	Fineness (%)	5	2	5
2	Specific gravity	1.88	2.6	2.22
3	Standard Consistency (%)	37	48	-
4	Initial Setting time (min)	75	13	-
5	Final Setting time (min)	130	16	-

Table II. Chemical compositions of Fly ash, GGBs and Silica fume

Components (%)	Binder contents		
	Fly ash	GGBS	Silica Fume
C	23.29	-	-
C1 H_2o	-	-	0.01
Cao	-	-	0.5
$Si0_2$	3.10	30-50	0.2
Al_2o_3 Feo	36.10	28-38	97
Mgo N2o	25.03	8-24	0.2
So_3	8.66	-	-
Tio_2	1.29	1-18	0.5
K_2o		-	0.2
Fe_2o_3	-	-	0.15
	0.59	-	- 0.5
	0.91	-	0.5
	1.08	-	

2) *Alkaline activated solution:*

The chemical composition of an alkaline activated solution, commonly used in Geopolymer concrete, typically includes a combination of alkali hydroxides and silicates. The main components are:

Table III. Chemical composition of an alkaline activated solution

Components (%)	Solution	
	NaOH	Na_2sio3
H_2	57.48	-
O_2	40	-
Na	2.57	-
$Si0_2$	-	34.35
Na_2o	-	16.37
Ratio of $Na_2o:sio_2$	-	1:209
Total solid%	-	50:68
Water content%	-	49.28

3) Brass coated Steel Fibres:

Brass-coated steel fibers are used to enhance the mechanical properties of concrete, providing increased strength, durability, and resistance to cracking. The physical properties of these fibers include:

Fig 4: Brass coated Steel Fibres

Table IV. Physical properties of Brass coated Micro steel fibres from source

type	Diameter (Df)	length	Aspect ratio	density	Tensile strength	Elastic modulus
Brass coated steel fibres	0.2	13mm	65	0.91g/cm^3	2600mpa	200000mpa

C. Mix Proportions

After numerous trail mixes, the below proportions were extracted to examine the properties of Geopolymer concrete (GPC) with and without fibres. The slump cone test was performed to check the workability and mechanical properties were investigated, and the information about the mix details of High Strength Geopolymer concrete was presented in the below table These proportions were determined after conducting several trial mixes. Mixes M1, M2, and M3 are the control mixes, while mixes M4, M5 and M6 are incorporated with brass coated steel fibres.

Table V. Mix proportions (Kg/m^3)

Material	Mix	M_1	M_2	M_3	M_4	M_5	M_6
Binder	Total binder (Kg/m^3)	500	600	600	500	500	500
	Fly ash (%)	35	35	35	35	35	35
	GGBFS (%)	50	50	50	50	50	50
	Silica (%)	15	15	15	15	15	15
Solution	Sol/binder	0.5	0.6	0.5	0.5	0.5	0.5
	Ratio	1:2.5	1:2.5	1:2.5	1:2.5	1:2.5	1:2.5
	Molarity	14M	14M	16M	14M	14M	14M
	Silica modulus	3.12	3.12	3.12	3.12	3.12	3.12
Aggregates	Fine Aggregate (%)	70	70	70	70	70	70
	Coarse Aggregate (%)	30	30	30	30	30	30

Super plasticizer	2% of solution	2% of solution	2% of solution	2% of solution	2% of solution	2% of solution
Fibres added	0%	0%	0%	1.5%	2.0%	2.5%
Curing	ambient	ambient	ambient	ambient	ambient	ambient

D. Experimental Investigations And Results

Compressive, split tensile, and flexural strength tests were conducted on geopolymer concrete as per IS standards to assess load-bearing, tensile, and bending capacities. Specimens cured for 7 and 28 days provided key data for optimizing the mix design.

1) Slump Cone Test

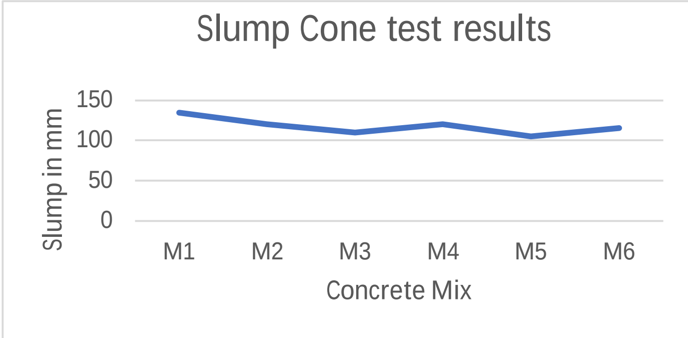
The slump cone test evaluates the workability and flowability of geopolymer concrete by measuring the vertical displacement after cone removal. This test is essential for assessing mix suitability, especially given the variability caused by alkali-activated binders and admixtures.

The slump values of the concrete mixes as shown in table V1 range from 105 mm to 135 mm, reflecting moderate to high workability. Mix M1 exhibits the highest workability at 135 mm, while Mix M5 shows the lowest at 105 mm. The consistent slump range (110–120 mm) in other mixes indicates adequate flowability suitable for general construction, influenced by mix proportions and water-to-binder ratios.

Table VI. Slump values for different mixes

S.no	Concrete mix	Slump in (mm)
1	M1	135
2	M2	120
3	M3	110
4	M4	120
5	M5	105
6	M6	115

Figure 5 Performing Slump Cone Test



Graph 1: Slump cone test results

2) Hardened Properties

Hardened properties of concrete like Compression test, split tensile strength, Flexural Strength are determined to know the mechanical behaviour of the concrete.

a) Compressive Strength Test

The compressive strength of geopolymer concrete, tested on standard cubes per IS 456:2000, is crucial for its structural applications [15]. Influenced by mix design, alkali activators, curing methods, and binder proportions, geopolymer concrete achieves high strength due to its dense matrix and strong aluminosilicate bonds. Its strength and durability make it ideal for eco-friendly structural projects like beams, columns, and pavements.

Table VII and graph 2 shows that the performance of Mixes without Fibres (M1 to M3): M1 shows the highest compressive strength (55.93 MPa at 7 days and 79.79 MPa at 28 days), outperforming M2 and M3, with M3 being the weakest (50.07 MPa at 28 days). Performance of Mixes with Fibres (M4 to M6): Brass-coated steel fibres enhance strength, with M5 achieving the highest values (63.95 MPa at 7 days and 91.36 MPa at 28 days), about 14.5% higher than M1. Optimum Mix: M5 stands out for its superior strength and durability, demonstrating the effectiveness of fibre reinforcement for high-strength applications.

Table VII. Compressive Strength Test values

S. No.	Mix	Compressive Strength (MPa)	
		7 Days	28 Days
1	M1	55.93	79.79
2	M2	39.06	55.8
3	M3	35.04	50.07
4	M4	63.41	86.5
5	M5	63.95	91.36
6	M6	48.24	68.920

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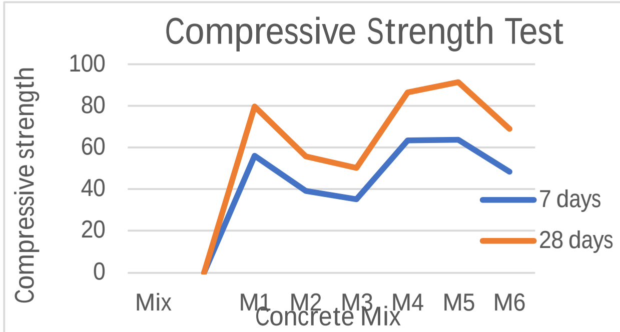
Volume 12 Issue XII Dec 2024- Available at www.ijraset.com



Graph 2: Compressive Strength Test Results

Figure 6. Performing Compressive strength test

b) Split Tensile Test:

The split tensile test measures the tensile strength of geopolymer concrete, assessing its resistance to cracking under indirect tension. Conducted on cylindrical specimens (150 mm × 300 mm) as per IS 5816:1999 [16], a horizontal compressive load splits the cylinder along its vertical axis. Tensile strength is determined from the maximum load at failure.

Table VIII shows the performance of mixes without fibres show M1 as the best performer with a split tensile strength of 3.6 MPa at 28 days, while M2 and M3 achieve lower values, with M2 being the weakest. Fibre-reinforced mixes exhibit significant improvement, with M5 achieving the highest strength of 4.5 MPa at 28 days, 25% higher than M1. Brass-coated steel fibres enhance tensile strength, making M5 the optimum mix for improved resistance to cracking and splitting.\

TableVIII. Split Tensile Strength Test values of different mixes

S. No.	Mix	Split Tensile Strength Strength (MPa)	
		7 Days	28 Days
1	M1	2.4	3.6
2	M2	2.01	2.9
3	M3	2.21	3.19
4	M4	2.6	3.8
5	M5	3.2	4.5
6	M6	3.0	4.3

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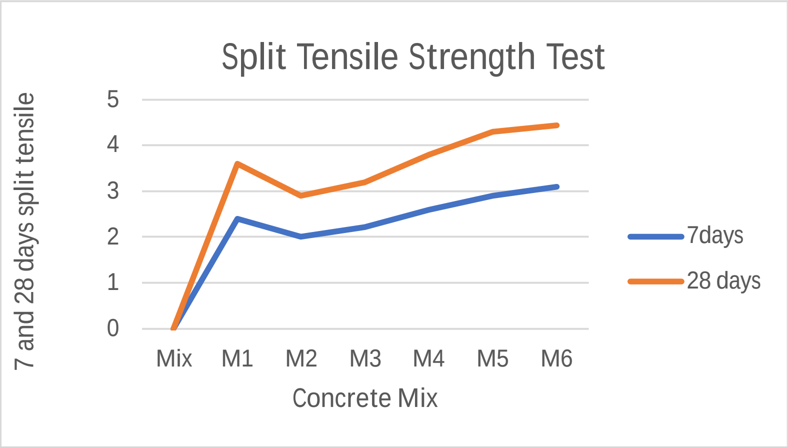
Fig 7. Split Tensile Strength Test



Graph 3: Split Tensile Strength Test Results

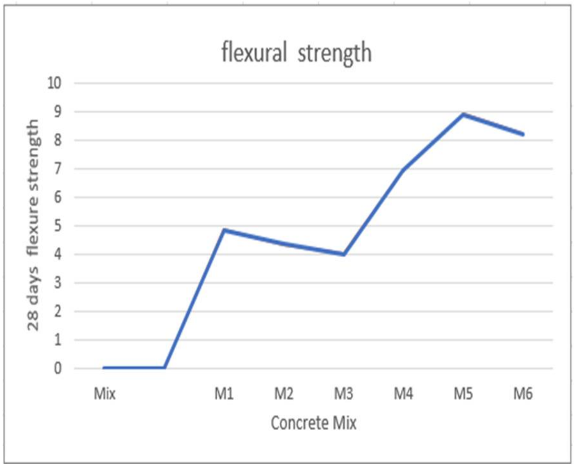
c) Flexural Strength Test:

The flexural strength test evaluates the resistance of geopolymer concrete to bending stresses using beam specimens (150 mm × 150 mm × 700 mm) as per IS 456:2000. The beam is placed on supports, and a load is applied at the centre using a three-point loading system until failure. The maximum load at failure determines the flexural strength, indicating the concrete's ability to withstand cracking or breaking under bending forces.

Table IX and graph 4 represents the performance of mixes Without Fibres (M1 to M3): M1 achieves the highest flexural strength (4.86 MPa at 28 days), outperforming M2 and M3, with M3 being the weakest (4.01 MPa).With Fibres (M4 to M6): Brass-coated steel fibres enhance flexural strength, with M5 reaching 8.9 MPa at 28 days, outperforming M4 (6.96 MPa) and M6.M5's flexural strength is 67% higher than the best non-fibre mix (M1), demonstrating the fibres' significant impact on crack resistance and load distribution

Table IX.Flexural Strength values of different mixes

S. No.	Mix	Flexural Strength (MPa) 28 Days
1	M1	4.86
2	M2	4.35
3	M3	4.01
4	M4	6.96
5	M5	8.9
6	M6	8.22



Graph 4: Flexural strength test results

Fig 8 Flexural Strength values of different mixes

IV. CONCLUSIONS

High-strength geopolymer concrete (HS-GPC) exhibits rapid setting time and strength development compared to nominal concrete. Using locally available 2.36 mm sieved sand and binder materials like fly ash, GGBS, and silica fume creates close bonding, enhancing concrete strength when combined with an alkali-activated solution. Incorporating AURAMIX 300 superplasticizer results in high workability with slump values ranging from 105–135 mm, observed as true slump. Increasing slag content in the binder reduces setting time and workability but improves compressive, split tensile, and flexural strengths when cured at room temperature. Brass-coated micro steel fibers significantly enhance mechanical properties, with the M5 mix (14M molarity) achieving compressive strengths of 63.95 MPa at 7 days and 91.36 MPa at 28 days.

The addition of 2.0% fibers delivers optimal strength across all tests, while 2.5% fibers reduce performance. Though HS-GPC is costlier than cement concrete, it offers superior strength, eco-friendliness, and reduced carbon emissions.

V. FUTURE SCOPE OF WORK

To evaluate the long-term performance of high-strength geopolymer concrete (HS-GPC), tests should be conducted on various grades and mix proportions. Additionally, several tests can be performed to compare the mechanical strength properties of geopolymer binders made from fly ash, GGBS, and silica fume at different levels, such as binder/solution ratio and molarity. While most research has focused on the mechanical properties of ultra-high-strength geopolymer concrete (UHS-GPC), further studies using software for data analysis are also recommended. This experimental study specifically examines brass-coated micro steel fibers at 1.5%, 2.0%, and 2.5%, aiming to identify the optimal fiber percentage for future investigations. Lastly, research into the advantages and challenges of geopolymer concrete can help develop new methods to overcome existing limitations.

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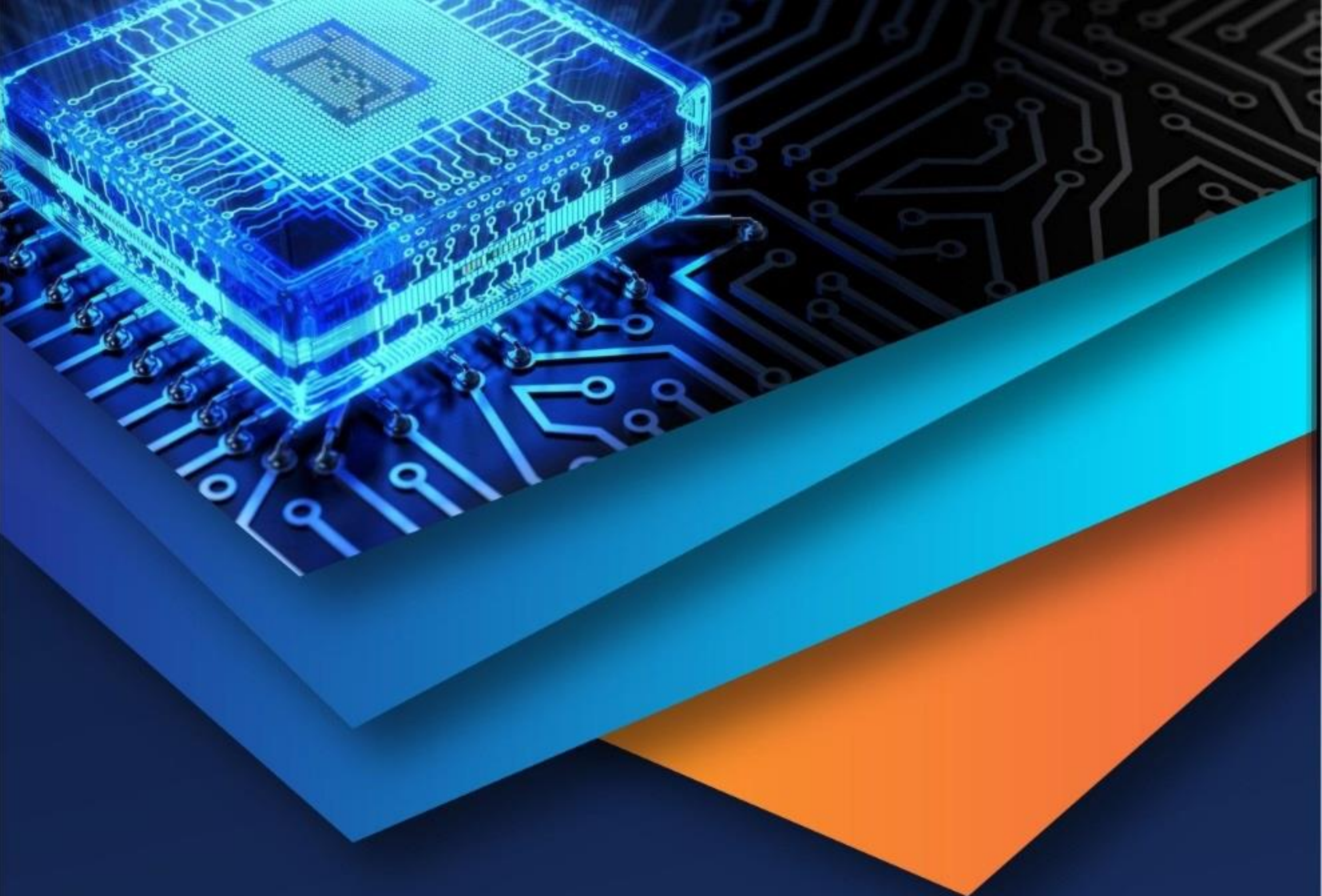

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