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Sustainable Development of Glass Fiber Reinforced Concrete Using Palm Oil Ash as Supplementary Cementious Material

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Abstract: The growing demand for sustainable construction materials has encouraged the exploration of industrial and agricultural by-products as supplementary cementitious materials in concrete. This study investigates the sustainable development of glass fiber reinforced concrete (GFRC) incorporating palm oil fuel ash (POFA) as a partial cement replacement. Glass fibers were added at a constant dosage of 1% by volume to enhance tensile strength and crack resistance, while POFA was utilized at replacement levels of 5%, 10%, 15%, 20%, and 25%. The experimental program evaluated the fresh and hardened properties of the mixes, including workability, compressive strength, split tensile strength, and flexural strength at different curing periods. Results indicate that the inclusion of POFA enhances the sustainability of concrete production by reducing cement consumption and utilizing agricultural waste. Optimum performance was observed at moderate replacement levels, where the combined effect of POFA and glass fibers improved strength, durability, and environmental benefits.
Keywords: Compressive strength, Split tensile strength, Flexural strength, glass fiber, palm oil ash.

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its versatility, durability, and ease of production. However, its large-scale use poses significant environmental concerns, primarily because cement production is energy-intensive and a major contributor to global carbon dioxide emissions. In order to promote sustainable construction practices, researchers and engineers are increasingly focused on incorporating alternative materials and innovative techniques that can reduce the environmental footprint of concrete without compromising its performance. Among various strategies, the use of supplementary cementitious materials (SCMs) derived from industrial and agricultural wastes has gained considerable attention. Palm oil fuel ash (POFA), a by-product generated from burning palm oil residues in power plants, is rich in silica and possesses pozzolanic properties. By partially replacing cement with POFA, not only is the consumption of natural resources minimized, but waste disposal issues are also addressed, contributing to sustainable development.

At the same time, enhancing the mechanical performance of concrete remains a crucial objective. The addition of fibers, particularly glass fibers, has been found to significantly improve concrete's tensile and flexural strength while reducing crack propagation. Glass fiber reinforced concrete (GFRC) combines the benefits of higher strength, better ductility, and improved durability, making it suitable for modern construction needs.

This study aims to develop sustainable glass fiber reinforced concrete by incorporating 0.75% glass fibers along with varying percentages of POFA (5%, 10%, 15%, 20%, and 25%) as a partial replacement of cement. The experimental investigation focuses on evaluating fresh and hardened properties of the mixes, such as workability, compressive strength, tensile strength, and flexural performance. The outcomes are expected to highlight the optimum level of POFA replacement that balances mechanical properties, durability, and environmental benefits, thereby promoting eco-friendly concrete technology.

II. OBJECTIVES

The objectives of the study are

1) To investigate the effect of incorporating 1% glass fibers on the workability and mechanical properties of concrete.
2) To evaluate the performance of palm oil fuel ash (POFA) as a supplementary cementitious material at replacement levels of 5%, 10%, 15%, 20%, and 25%.
3) To assess the influence of POFA and glass fibers on the workability, compressive strength, split tensile strength, and flexural strength of concrete.

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III. MATERIALS AND PROPERTIES

A. Cement

Ordinary Portland Cement (OPC) of 53 Grade was used as the primary binding material in the present study. This grade of cement is known for its high early strength and superior compressive strength, making it suitable for structural applications requiring higher durability and load-bearing capacity.

Table 1: Properties of Cement

S.No.	Properties	Typical values
1	Specific gravity	3.15
2	Normal consistency	27.5%
3	Initial setting time	80 min
4	Final setting time	180 min
5	Fineness	8%
6	Density	1440 kg/m³

B. Fine Aggregate

As the fine aggregate, natural river sand was utilized. It was sieved and tested for grading, specific gravity, and fineness modulus. Reducing segregation in the mix, increasing workability, and filling voids are all made possible by fine aggregate.

Table 2: Properties of Fine Aggregate

S. No.	Properties	Typical values
1	Specific gravity	2.51
2	Fineness modulus	2.9
3	Bulk density	1563 Kg/m³
4	Water absorption	1%

C. Coarse Aggregate

The coarse aggregate was crushed angular stone. To achieve good interlocking and strength qualities in the hardened concrete, the aggregates were cleaned, surface-dried. Crushed stones of size below 25mm are used.

Table 3: Properties of Coarse Aggregate

S.No.	Properties	Typical values
1	Specific gravity	2.54
2	Fineness modulus	5.51
3	Density	1500 kg/m³
4	Water absorption	1.1%
5	Aggregate size	25 to 10 mm

D. AR Glass Fiber

Glass fiber enhances concrete by improving tensile, flexural, and impact strength while controlling microcracks. it is light white in color and have a diameter of 6-18mm. In this project 6,12mm glass fibers are used. It is locally available from Tina enterprises, Delhi.

Fig 1: Glass fibers

Table 4: Properties of Glass fiber

Property	Value
Type	Glass Fiber
Length (mm)	12
Equivalent Diameter (mm)	0.015
Aspect Ratio	800
Density (g/cm³)	2.7
Young's Modulus (GPa)	70
Tensile Strength (MPa)	2500
Elongation at Break (%)	4.2
Moisture Absorption (%)	< 0.1
Softening Point (°C)	1020

E. Palm oil Ash

Palm Oil Fuel Ash (POFA) is used as partial replacement for cement. It is a byproduct of burning palm oil husks and shells in biomass power plants. It is a fine, grey powder. It is locally available from Patanjali private limited Pedhapuram**.**

Fig 2: Palm Oil Fuel Ash

Table 5: Properties of palm oil ash

Sl. No.	Physical Property	Value
1	Specific gravity	1.19
2	Colour	Grey
3	Bulk density	1598 kg/m^3

F. Water

Water is fundamental ingredient in concrete which is used for both mixing and curing. Water used in concrete should be clean and free impurities. Water available in the laboratory is used.

G. Admixture

Conplast SP430 is a high-range water-reducing superplasticizer commonly used to improve the workability of concrete without increasing the water content. It helps produce highly workable or flowing concrete, making placement easier in congested reinforcement. The admixture also enhances strength and durability by reducing the water–cement ratio while maintaining good consistency. It is widely used in high-performance, pumped, and precast concrete applications.

H. MIX DESIGN

M30 Grade is adopted for this project. It is done as per IS 10262-2019. Here is the mix ratio.

Table 6: Mix quantities

Cement (Kg/m³)	Fine aggregate (Kg/m³)	Coarse aggregate (Kg/m³)	Water (L/m³)
412	625	1096	177.3
1	1.51	2.65	0.43

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IV. EXPERIMENTAL INVESTIGATION

A. *Tests Conducted On Fresh Concrete*

1) Workability Test

A slump cone test was executed to examine the workability of the concrete with different ratios of processed Palm oil ash, which was used as a partial replacement for cement in the concrete production.

B. *Tests On Hardened Concrete*

1) Compressive Strength Test

Compressive strength is the ability of concrete to withstand loads without crushing. It is determined by testing concrete cubes of size 150*150*150mm under UTM.

$$\text{compressive strength fc} = \frac{Load}{Area}$$

2) Split Tensile Strength Test

Split tensile strength shows how well concrete can resist cracking when a tensile force acts on it. It is also done under UTM by testing cylinders specimens of size length 300mm and diameter 150mm.

$$\text{split tensile strength} = \frac{2P}{\pi LD}$$

Where, P = Load, L = Length of the cylinder, D = Diameter of the cylinder.

3) Flexural Strength Test

The flexural test measures how well concrete can resist bending or cracking when a load is applied at the center of a beam. It is done under double point loading of beam specimen size 700*150*150mm.

$$\text{Flexural strength} = \frac{PL}{BD^2}$$

Where, P = Load., L = Length of the beam, B = Width of the beam, D = Depth of the beam.

V. RESULTS AND DISCUSSIONS

A. *Slump Cone Test*

M1 = Conventional concrete, M2 = 1% glass fiber 5% palm oil ash, M3 = 1% glass fiber 10% palm oil ash
M4 = 1% glass fiber 15% palm oil ash, M5 = 1% glass fiber 20% palm oil ash, M6 = 1% glass fiber 25% palm oil ash.

Table 7: Slump Values

Mix ID	Percentage replacement		Slump (mm)
	GF (%)	POFA (%)	
M1	0	0	102
M2	1	5	80
M3		10	75
M4		15	78
M5		20	67
M6		25	56

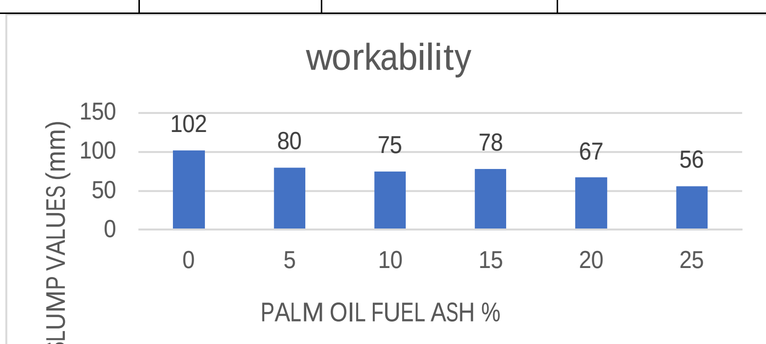

Fig 3: workability of concrete

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The slump test results show that workability decreases when glass fiber and higher percentages of POFA are added. The control mix (M1) had the highest slump of 102 mm, while mixes with glass fiber and increasing POFA showed a steady reduction, reaching 56 mm at 25% POFA. This drop is mainly because fibers limit flow and POFA absorbs more water, making the mix stiffer.

1) Compressive Strength Test Optimum Value Of Glass Fiber

Table 8: Optimum of glass fiber

Mix ID	% of Glass fiber	28days Compressive strength (N/mm²)
G1	0.75	38.75
G2	1	40.12
G3	1.5	37.83

The compressive strength results indicate a clear influence of glass fiber content on concrete performance. The mix containing 0.75% glass fiber (G1) achieved a strength of 38.75 N/mm², showing an improvement over the conventional mix. An optimum value was observed at 1% glass fiber (G2), which recorded the highest strength of 40.12 N/mm², attributed to better crack bridging and enhanced matrix integrity. However, increasing the fiber content to 1.5% (G3) resulted in a reduced strength of 37.83 N/mm², likely due to fiber agglomeration and decreased workability, which hinder proper compaction. Overall, the results suggest that 1% glass fiber provides the maximum benefit for compressive strength development.

2) Compressive Strength Test GF And POFA Concrete

Table9: Compressive strength test results for GF+POFA concrete

Mix ID	Percentage replacement		Compressive strength (N/mm²)	
	Glass fiber (%)	Palm oil fuel ash (%)	7 days	28 days
M1	0	0	34.62	39.83
M2	1	5	32.7	38.52
M3		10	33.9	40.12
M4		15	35.46	42.96
M5		20	34.20	41.02
M6		25	30.24	36.6

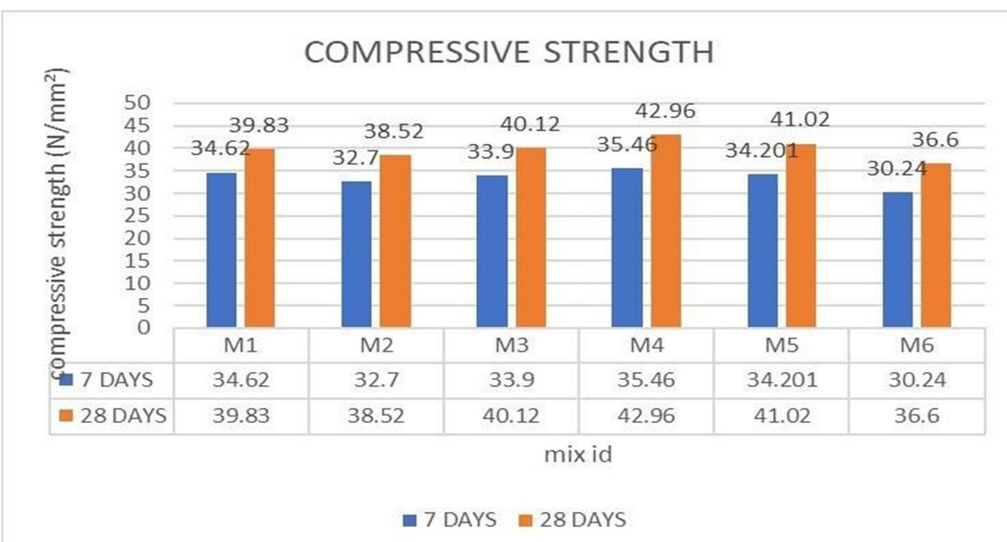

Fig 4:- Compressive strength for 7 and 28 days

Fig 5: Cube specimens

Fig 6: Compression test for cube specimens

The compressive strength results show that incorporating 1% glass fiber with varying POFA replacement levels influences both early and later age strengths. Compared with the control mix (M1), mixes M3, M4, and M5 exhibit improved 28-day strength, with M4 (15% POFA) achieving the highest value of 42.96 N/mm², indicating an optimum replacement level. Strength decreases when POFA content reaches 25% (M6), showing that excessive POFA reduces overall performance. Overall, moderate POFA replacement enhances concrete strength, while higher levels lead to a reduction.

B. Split Tensile Strength

Table 10: - split tensile strength results for GF+POFA concrete

Mix ID	Percentage replacement		Split tensile strength (N/mm²)	
	Glass fiber (%)	Palm oil fuel ash (%)	7 days	28 days
M1	0	0	2.01	2.3
M2	1	5	2.52	3.08
M3		10	2.63	3.12
M4		15	2.78	3.24
M5		20	2.73	3.16
M6		25	2.63	3.12

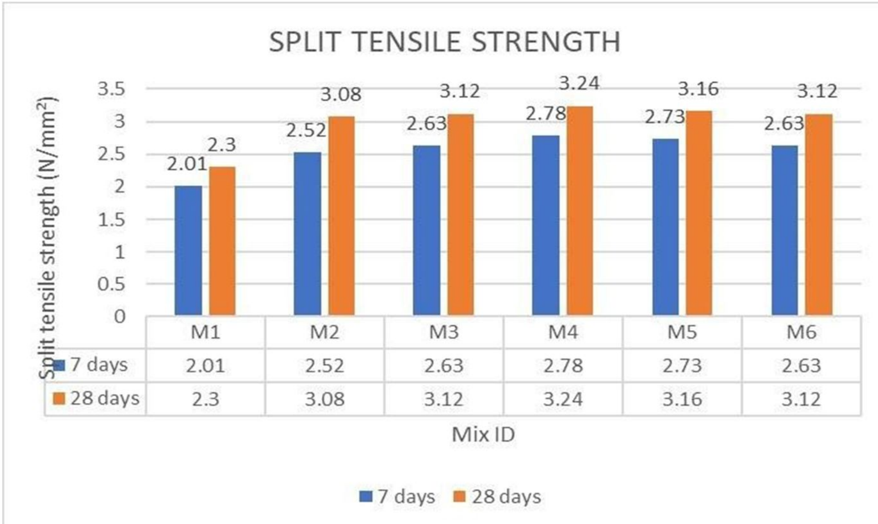

Fig 7:- Split Strength for 7 and 28 days

Fig 8: Cylinder specimens

Fig 9: Testing of Cylinder Specimens

The split tensile strength values indicate that adding 1% glass fiber along with POFA enhances both 7-day and 28-day strengths compared to the control mix (M1). The strength gradually increases from M2 to M4, with M4 (15% POFA) reaching the highest tensile strength of 2.78 N/mm² at 7 days and 3.24 N/mm² at 28 days. Beyond this level, mixes M5 and M6 show a slight decline, suggesting that 15% POFA is the optimum replacement for improving tensile performance. Overall, moderate POFA content improves the fiber–matrix bonding and contributes to better tensile behavior.

C. Flexural Strength

Table11: Flexural strength results for GF+POFA concrete

Mix ID	Percentage replacement		Flexural strength (N/mm²)	
	Glass fiber (%)	Palm oil fuel ash (%)	7 days	28 days
M1	0	0	4.148	4.6
M2	1	5	5.02	5.72
M3		10	5.59	5.85
M4		15	5.67	6.25
M5		20	5.59	6.11
M6		25	5.18	5.94

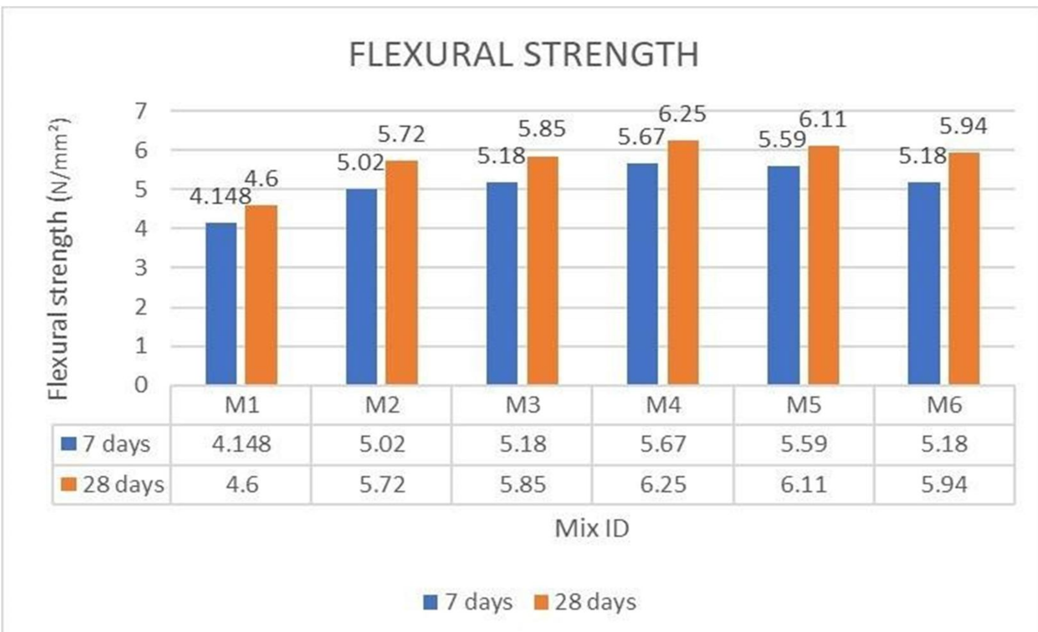

Fig 10:- Flexural Strength for 7 and 28 days

The flexural strength results show a consistent improvement when 1% glass fiber is combined with POFA as a partial cement replacement. All modified mixes (M2–M6) outperform the control mix (M1) at both 7 and 28 days. The flexural strength increases steadily up to 15% POFA (M4), which records the highest values—5.67 N/mm² at 7 days and 6.25 N/mm² at 28 days—indicating the optimum replacement level. Beyond 15% POFA, mixes M5 and M6 show a slight reduction, though still higher than the control. Overall, moderate POFA addition enhances fiber interaction and matrix stiffness, resulting in better flexural performance.

Fig 11: Testing of Beams

VI. CONCLUSIONS

This study examined how concrete behaves when Palm Oil Fuel Ash (POFA) is used as a partial cement replacement along with a constant 1% Alkali-Resistant (AR) glass fiber. The results provide a clear understanding of how this combination influences strength development and overall performance.

1) The reduction in slump with increasing POFA indicates a steady decline in workability, which is expected given the finer particle size of POFA and the presence of fibers. Even with this reduction, the mixes retained workable consistency suitable for normal construction practices.
2) Across all mechanical tests, the mixes containing POFA and glass fiber consistently outperformed the control concrete. The compressive strength increased up to a POFA replacement of 15 %, where the mix achieved its highest strength at 42.96 MPa. This improvement can be linked to the pozzolanic reaction of POFA, which contributes to better matrix densification, combined with the crack-arresting ability of the glass fibers.
3) A similar pattern appeared in the split tensile and flexural strengths. The 15 % POFA mix again recorded the highest values, showing its effectiveness in enhancing tensile resistance and improving the concrete’s behavior under bending. The presence of AR glass fiber played a major role in limiting crack initiation and spreading, which resulted in greater ductility and improved post-cracking response.
4) Beyond 15 % POFA, all mechanical strengths began to decline, suggesting that excessive ash content disrupts the balance of cementitious compounds and leads to weaker bonding. This confirms that POFA must be used within an optimal range to achieve tangible benefits in performance.
5) Overall, the results demonstrate that combining 15 % POFA with 1 percent AR glass fiber provides a well-optimized, high-performing, and more sustainable concrete mix. This approach not only improves key strength parameters but also utilizes an agricultural waste material, thereby contributing to resource efficiency and reduced cement consumption. The enhanced tensile and flexural behavior further suggests that this modified concrete is suitable for applications where crack resistance, ductility, and long-term durability are critical.

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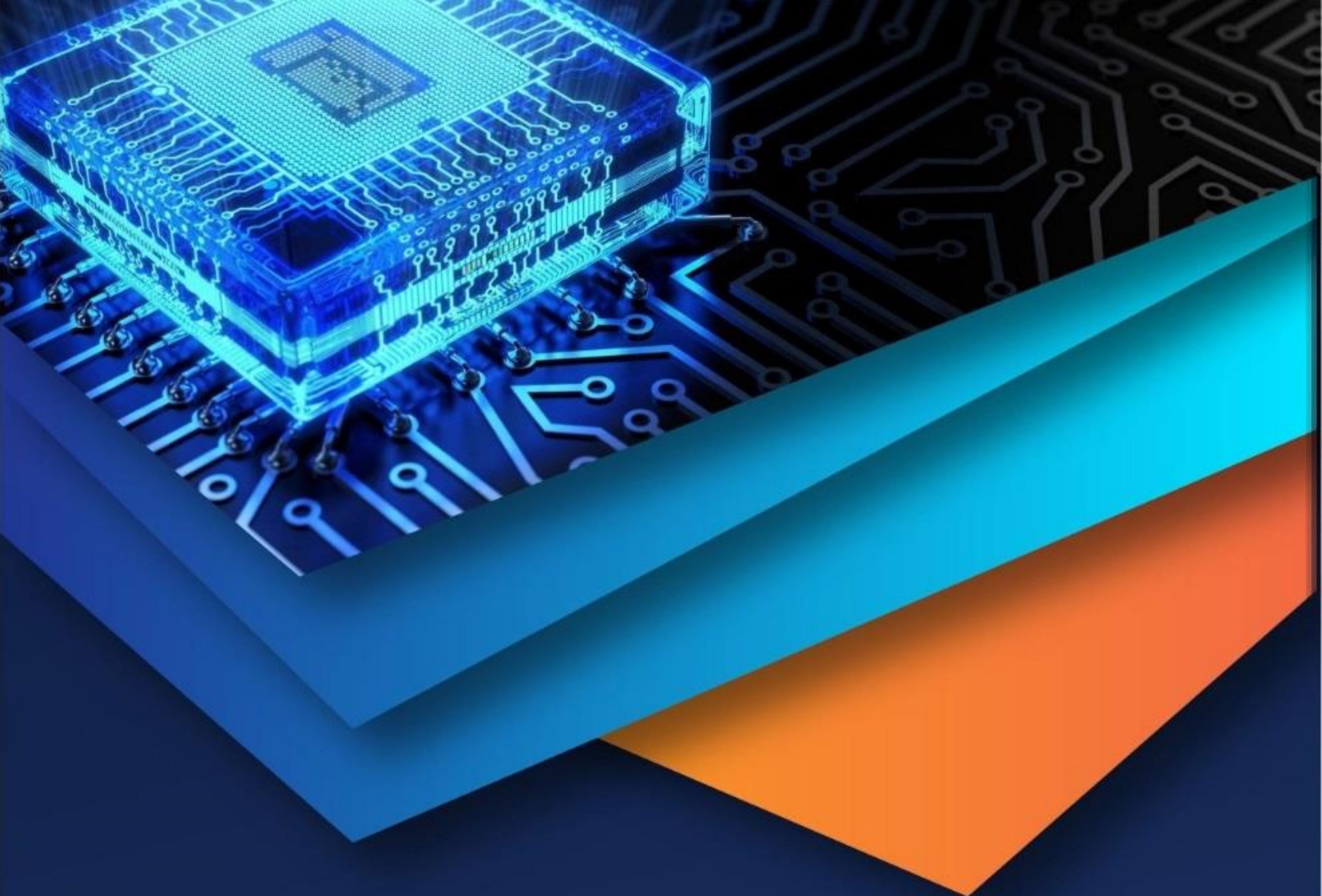

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