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Evaluating the Performance of Hybrid Fiber Reinforced Concrete Incorporating Polyvinyl Alcohol (PVA), Banana Fiber and Sisal Fiber

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Abstract: ***Concrete is one of the most widely used construction materials due to its high compressive strength, durability, availability, and versatility. However, conventional concrete is relatively weak in tension and is susceptible to cracking and brittle failure. The incorporation of fibers into concrete is an effective approach for improving its crack resistance and mechanical performance. The present study investigates the performance of Hybrid Fiber Reinforced Concrete incorporating Polyvinyl Alcohol (PVA) solution, banana fiber, and sisal fiber. In the present investigation, M25 grade concrete was used as the base concrete. Polyvinyl Alcohol powder was dissolved in water and incorporated into the concrete at a constant dosage of 2.5% by weight of cement. Banana fiber and sisal fiber were incorporated at different volume fractions of 0%, 0.25%, 0.50%, and 0.75%. A total of ten concrete mixtures, designated as M0 to M9, were prepared to investigate the individual and combined effects of banana and sisal fibers. The experimental programme included the slump test, compressive strength, split tensile strength, flexural strength, water absorption. Overall, the study demonstrates the potential of PVA-banana-sisal hybrid fiber reinforced concrete as a promising alternative for improving the mechanical performance of M25 concrete. The use of banana and sisal fibers also provides an opportunity to utilize renewable natural materials in cement-based construction. Further investigations are recommended to evaluate long-term durability, microstructural characteristics, shrinkage and creep behaviour, economic feasibility, and structural-scale applications of the developed hybrid concrete.***

Keywords: Hybrid Fiber Reinforced Concrete, Polyvinyl Alcohol, PVA Solution, Banana Fiber, Sisal Fiber, M25 Concrete, Compressive Strength, Split Tensile Strength.

I. INTRODUCTION

Concrete is the most extensively used construction material across the world because of its versatility, high compressive strength, durability, and economic viability. It serves as the fundamental material for modern infrastructure, including residential buildings, commercial structures, bridges, highways, dams, tunnels, and industrial installations. With the rapid expansion of urban areas and infrastructure projects, the demand for concrete with superior mechanical performance, enhanced durability, and improved long-term serviceability has increased considerably. Although conventional concrete performs well in compression, it has relatively low tensile strength and exhibits brittle failure characteristics. Consequently, the formation and growth of micro-cracks under mechanical loading, shrinkage, thermal variations, and environmental exposure remain major issues that affect the structural integrity and durability of reinforced concrete members. In recent years, the combination of Polyvinyl Alcohol (PVA) fibers with other reinforcing fibers such as steel or polypropylene fibers has emerged as a promising approach for producing high-performance concrete. PVA fibers improve crack control and strain-hardening behavior, while steel fibers contribute to higher flexural strength, greater energy absorption, and improved structural toughness. The hybrid system therefore provides a balanced combination of strength, ductility, durability, and serviceability. The present investigation was carried out to evaluate the mechanical and durability performance of hybrid fiber reinforced concrete (HFRC) incorporating Polyvinyl Alcohol (PVA) and steel fiber. The addition of two different types of fibers in concrete provides a synergistic effect by controlling micro-cracks and macro-cracks, thereby improving the overall structural performance. While PVA fibers enhance crack resistance and ductility at the micro level, steel fibers contribute significantly to load-carrying capacity, toughness, and post-cracking behavior. The experimental programme was planned to investigate the influence of hybrid fibers on the fresh and hardened properties of M25 grade concrete. A conventional concrete mix without fibers was prepared as the control mix, whereas hybrid fiber reinforced concrete mixes containing different fiber dosages were produced for comparison. The total fiber contents considered in this investigation were 0.25% 0.50% and 0.75% by volume of concrete.

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- Materials Used Ordinary Portland Cement (OPC) 53 Grade
- Fine Aggregate (Natural River Sand)
- Coarse Aggregate
- Potable Water
- Polyvinyl Alcohol (PVA)
- Super plasticizer (if required)

Table: - Chemical composition of cement

Contents	%
CaO	60-65
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.5-4
Alkalis	0.5-1.3
SO_3	1-2

Table: - Physical and Mechanical Properties of used banana fiber

S.no	Properties	Value
1	Tensile Strength	529 to 914 MPa
2	Density	1.25 to 1.5 g/cm³),
3	Elongation	3% to 6.5%
4	Appearance	Fine, smooth texture with a natural off-white to yellowish-brown color and a gleaming look.
5	Diameter	20 to 30 microns (or 0.080 to 0.250 mm

II. POLYVINYL ALCOHOL (PVA)

Polyvinyl Alcohol (PVA) is a high-performance synthetic fiber widely used in cementitious composites due to its excellent tensile strength, high elastic modulus, and superior bonding characteristics with the cement matrix. The hydrophilic nature of PVA fibers enables strong adhesion between the fiber surface and hydrated cement paste, resulting in effective crack bridging and improved resistance to crack propagation.

Figure :- PVA Powder / Granules

A. Physical Properties

- Solubility: Dissolves in water. Partially hydrolyzed types dissolve in cold water; fully hydrolyzed types need warm water. It does not dissolve in most organic oils or solvents.
- Appearance: Odorless and tasteless powder, flakes, or pellets.
- Density: Solid density ranges from 1.27 to 1.31 g/cm³.
- Melting Point: Around 180°C to 190°C for partial grades, and up to 230°C for fully hydrolyzed types

B. Mechanical and Barrier Properties

- Strength: High tensile strength and flexibility when dry.
- Gas Barrier: Exceptional blocker against oxygen and aromas.
- Chemical Resistance: Good resistance to oils, greases, and petroleum-based solvents.
- Humidity Effect: Water acts as a plasticizer. High humidity reduces tensile strength while increasing stretchiness.

C. Chemical and Environmental Properties

- Stability: Stable at room temperature, but starts to change color or decompose if heated above 200°C.
- Safety: Non-toxic and biocompatible, making it safe for skin contact, eye drops, and medical uses.
- Biodegradability: Breaks down slowly in water and soil via specific microorganisms

Image of Compression testing machine and Cube moulds

Figure: - Mixing of materials & Casting of specimen

Final Experimental Matrix

Mix ID	PVA (% by wt. of cement)	Banana Fiber (% by volume)	Sisal Fiber (% by volume)
M0	0.0	0.00	0.00
M1	2.5	0.25	0.00
M2	2.5	0.50	0.00
M3	2.5	0.75	0.00
M4	2.5	0.00	0.25
M5	2.5	0.00	0.50
M6	2.5	0.00	0.75
M7	2.5	0.25	0.25
M8	2.5	0.50	0.50
M9	2.5	0.75	0.75

Table: - Compressive Strength at 7 Days

Mix ID	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
M0	18.5	18.2	18.7	18.47
M1	17.5	17.2	17.8	17.50
M2	17.2	17.8	17.9	17.63
M3	17.6	17.3	17.7	17.53
M4	18.1	18.5	18.2	18.27
M5	18.5	18.7	18.4	18.53
M6	18.8	18.3	18.4	18.50
M7	19.2	19.8	19.9	19.63
M8	19.8	20.2	20.4	20.13
M9	19.1	19.5	19.1	19.23

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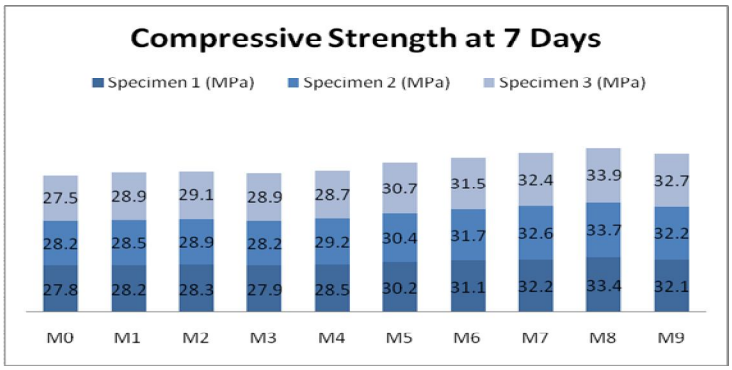


[1] Discussion

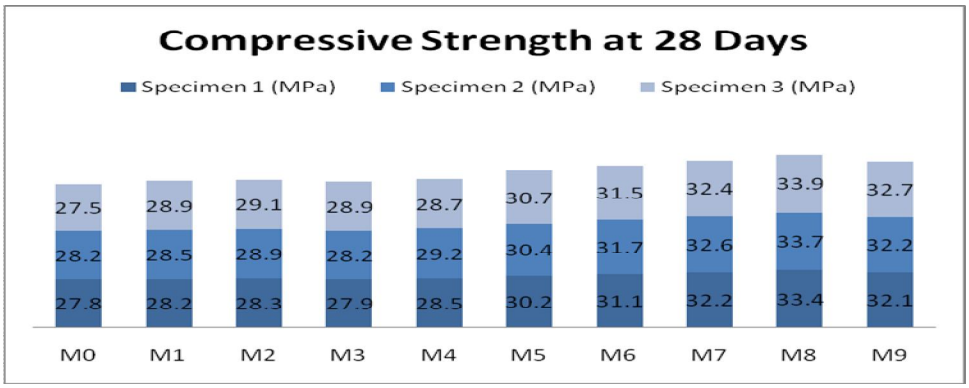
The compressive strength results of the M8 concrete mix at 7 days are presented in the table. Three cube specimens of M8 recorded compressive strengths of 19.8 MPa, 20.2 MPa, and 20.4 MPa, respectively. The average compressive strength was found to be 20.13 MPa.

The M8 mix consisted of 2.5% Polyvinyl Alcohol (PVA), 0.50% banana fiber, and 0.50% sisal fiber. The average strength of 20.13 MPa indicates that the incorporation of PVA, banana fiber, and sisal fiber provided a positive contribution to the early-age compressive strength of concrete. The presence of natural fibers helps to control the initiation and propagation of micro-cracks within the concrete matrix, while PVA contributes to better cohesion of the cementitious matrix.

The small variation among the three individual specimens indicates reasonably consistent test results. The maximum strength of 20.4 MPa was obtained from the third specimen, while the minimum strength of 19.8 MPa was obtained from the first specimen. The difference between the highest and lowest values is relatively small, indicating good uniformity of the prepared specimens.

Table:- Compressive Strength at 28 Days

Mix ID	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
M0	27.8	28.2	27.5	27.83
M1	28.2	28.5	28.9	28.53
M2	28.3	28.9	29.1	28.77
M3	27.9	28.2	28.9	28.33
M4	28.5	29.2	28.7	28.80
M5	30.2	30.4	30.7	30.43
M6	31.1	31.7	31.5	31.43
M7	32.2	32.6	32.4	32.40
M8	**33.4**	**33.7**	**33.9**	**33.67**
M9	32.1	32.2	32.7	32.33



[2] Discussion

The incorporation of fibers is expected to influence compressive strength through several mechanisms. PVA can improve the cohesion of the cementitious matrix, while banana and sisal fibers can help control the development and propagation of microcracks. The 28-day compressive strength results of the concrete mixes M0 to M9 are presented in the table. The average compressive strength of the different mixes ranged from 27.83 MPa to 33.67 MPa. The reference mix M0 recorded an average compressive strength of 27.83 MPa, whereas the highest average compressive strength was obtained for M8, with a value of 33.67 MPa.

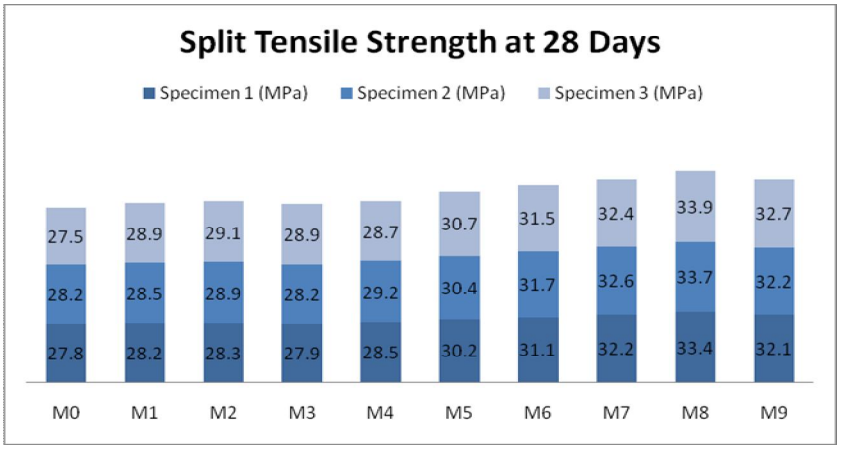
The individual compressive strength values of M8 were 33.4 MPa, 33.7 MPa, and 33.9 MPa, giving an average value of 33.67 MPa. The relatively small variation among the three specimens indicates good consistency of the test results. Compared with the reference mix M0, the 28-day compressive strength of M8 increased from 27.83 MPa to 33.67 MPa, representing an improvement of approximately 20.98%.

The increase in compressive strength of the modified mixes can be attributed to the combined effect of Polyvinyl Alcohol (PVA), banana fiber, and sisal fiber. The fibers can help control the development and propagation of micro-cracks within the concrete matrix. The PVA solution may also contribute to improved matrix cohesion and interaction between the cementitious materials and fibers. The combined presence of banana and sisal fibers provides a fiber-bridging effect, which helps to restrain crack development under applied compressive loading.

A progressive improvement in compressive strength can be observed from M5 to M8. Mix M5 achieved an average strength of 30.43 MPa, M6 achieved 31.43 MPa, M7 achieved 32.40 MPa, and M8 achieved the maximum value of 33.67 MPa. However, M9 showed a slight reduction in strength to 32.33 MPa. This indicates that increasing the fiber content beyond the optimum level does not necessarily result in further improvement in compressive strength. Higher fiber content may affect workability, fiber dispersion, and compaction, which can influence the overall strength of concrete.

Table :- Split Tensile Strength at 28 Days

Mix ID	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
M0	2.65	2.70	2.90	2.75
M1	3.10	2.80	2.80	2.90
M2	3.05	3.01	2.95	3.00
M3	2.80	2.85	2.90	2.85
M4	3.08	3.20	3.00	3.09
M5	2.98	2.85	3.05	2.96
M6	3.80	3.90	3.75	3.82
M7	3.95	3.80	3.65	3.80
M8	**4.05**	**3.95**	**4.10**	**4.03**
M9	3.80	3.75	3.80	3.78



[3] Discussion

The incorporation of banana and sisal fibers is expected to have a more pronounced influence on tensile-related properties than on compressive strength. The fibers can act as crack-bridging elements and resist the propagation of cracks generated under tensile loading.

The split tensile strength test was conducted at 28 days to evaluate the tensile behaviour and crack-resistance characteristics of the different concrete mixes. The results show that the average split tensile strength of the investigated mixes varied from 2.75 MPa to 4.03 MPa.

The reference mix M0 recorded an average split tensile strength of 2.75 MPa, based on the three individual specimen values of 2.65 MPa, 2.70 MPa, and 2.90 MPa. With the incorporation of banana fiber and sisal fiber along with PVA, an overall improvement in split tensile strength was observed in several modified mixes.

The average split tensile strength of M1, M2, and M3 was 2.90 MPa, 3.00 MPa, and 2.85 MPa, respectively. These results indicate that the addition of banana fiber initially improved the tensile strength, with M2 showing better performance than M1 and M3. However, the reduction observed in M3 suggests that a higher banana fiber content does not necessarily provide further improvement, possibly due to difficulties in maintaining uniform fiber dispersion and workability.

For the sisal fiber mixes, M4, M5, and M6 achieved average split tensile strengths of 3.09 MPa, 2.96 MPa, and 3.82 MPa, respectively. Among these mixes, M6 exhibited a significant increase in split tensile strength. This improvement indicates the beneficial contribution of sisal fibers in resisting tensile cracking and bridging cracks within the concrete matrix.

The hybrid fiber mixes showed comparatively higher split tensile strength. Mix M7 achieved an average value of 3.80 MPa, while M8 recorded the highest average split tensile strength of 4.03 MPa. The individual specimen values of M8 were 4.05 MPa, 3.95 MPa, and 4.10 MPa, demonstrating good consistency among the tested specimens. Compared with the reference mix M0, the split tensile strength of M8 increased from 2.75 MPa to 4.03 MPa, representing an improvement of approximately 46.67%.

The improvement in split tensile strength can be attributed mainly to the fiber-bridging and crack-control mechanisms provided by banana and sisal fibers. When tensile cracks initiate in the concrete matrix, the fibers can bridge the developing cracks and transfer tensile stresses across the cracked region. The combined use of two different natural fibers may provide a more effective crack-control mechanism than the use of a single fiber type. The PVA solution may further contribute to matrix cohesion and interaction between the fibers and cementitious matrix.

Mix M9, containing the higher combined fiber content, recorded an average split tensile strength of 3.78 MPa, which was lower than M8. This reduction indicates that an excessive amount of fiber may adversely affect the uniform distribution and compaction of concrete. Therefore, the results suggest that there is an optimum fiber content beyond which the tensile performance may decrease.

Overall, M8, containing 2.5% PVA, 0.50% banana fiber, and 0.50% sisal fiber, demonstrated the highest 28-day split tensile strength among the investigated mixes. The result confirms that an appropriate hybrid combination of banana and sisal fibers can significantly improve the tensile performance of M25 concrete. The improvement from 2.75 MPa for M0 to 4.03 MPa for M8 demonstrates the effectiveness of the hybrid fiber system in enhancing resistance to tensile cracking.

III. CONCLUSIONS

The present experimental investigation was carried out to evaluate the performance of hybrid fiber reinforced concrete incorporating Polyvinyl Alcohol (PVA) solution, banana fiber, and sisal fiber. M25 grade concrete was used as the base concrete. PVA powder was dissolved in water and incorporated into the concrete at a constant dosage of 2.5% by weight of cement. Banana and sisal fibers were incorporated at different volume fractions ranging from 0% to 0.75%.

A. Conclusion Based on 7-Day Compressive Strength

The 7-day compressive strength results show that the reference PVA-modified mixture M0 achieved an average compressive strength of approximately 18.47 MPa.

The hybrid mixtures exhibited different responses depending on the proportion of banana and sisal fibers.

The highest 7-day compressive strength was obtained for M8, with an average value of M7 and M9 were approximately 19.63 MPa and 19.23 MPa, respectively.

This indicates that the incorporation of banana and sisal fibers at an appropriate combination can contribute to improved early-age compressive strength. However, the results also indicate that simply increasing the fiber content does not necessarily result in a continuous increase in strength.

B. Conclusion Based on 28-Day Compressive Strength

The 28-day compressive strength results demonstrate a clear improvement in the performance of the hybrid fiber reinforced concrete mixtures.

The average compressive strength of M0 was: 27.83 MPa and 27.83 MPa

The strength increased progressively for several fiber combinations, with M8 providing the highest 28-day compressive strength.

For M8: Average Compressive Strength=33.4+33.7+33.93Average Compressive Strength = 33.67 MPa Thus, M8 showed a substantial improvement compared with M0.

The percentage increase in compressive strength of M8 relative to M0 is: 20.98 %

Therefore, the M8 mixture demonstrated approximately 21% higher 28-day compressive strength than the M0 mixture.

The improvement can be attributed to the combined action of PVA, banana fiber, and sisal fiber, which can improve matrix integrity and restrict the development and propagation of microcracks.

C. Conclusion Based on 28-Day Split Tensile Strength

The split tensile strength results indicate a considerable improvement with the incorporation of banana and sisal fibers.

The average split tensile strength of M0 was: 2.65+2.70+2.903=2.75

The highest split tensile strength was obtained for M8: 4.05+3.95+4.103 = 4.03

The percentage improvement compared with M0 is $4.03-2.752.75\times100$ =46.67%

Thus, M8 exhibited approximately 46.7% higher 28-day split tensile strength than M0.

This significant improvement indicates the effectiveness of the hybrid fiber system in resisting tensile cracking. Banana and sisal fibers can act as crack-bridging elements and transfer tensile stresses across developing cracks.

IV. ACKNOWLEDGMENT

Overall Performance of the Hybrid Fiber System

The experimental results demonstrate that the combined incorporation of PVA solution, banana fiber, and sisal fiber can improve the mechanical performance of M25 concrete.

Among the investigated mixtures, M8, containing:

- PVA = 2.5% by weight of cement
- Banana fiber = 0.50% by volume
- Sisal fiber = 0.50% by volume

provided the best overall performance based on the available compressive and split tensile strength results.

Table:-The average values obtained for M8 were

Property	M0	M8	Improvement
7-day compressive strength	18.47 MPa	20.13 MPa	8.99%
28-day compressive strength	27.83 MPa	33.67 MPa	20.98%
28-day split tensile strength	2.75 MPa	4.03 MPa	46.67%

The results indicate that the improvement is more pronounced in **tensile behaviour** than in compressive strength.

This can be attributed to the crack-bridging mechanism provided by the natural fibers. The combined fiber system helps restrict crack opening and propagation, thereby improving the tensile resistance of the concrete.

V. FINAL CONCLUSION

The present investigation demonstrates that the incorporation of Polyvinyl Alcohol solution, banana fiber, and sisal fiber can significantly modify the performance of M25 concrete. The experimental results indicate that an appropriate combination of natural fibers is essential for achieving improved mechanical performance.

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Among the investigated mixtures, M8 containing 2.5% PVA, 0.50% banana fiber, and 0.50% sisal fiber exhibited the best performance in terms of the measured compressive and split tensile strengths. The 28-day compressive strength increased from 27.83 MPa for M0 to 33.67 MPa for M8, representing an improvement of approximately 20.98%. Similarly, the 28-day split tensile strength increased from 2.75 MPa to 4.03 MPa, corresponding to an improvement of approximately 46.67%.

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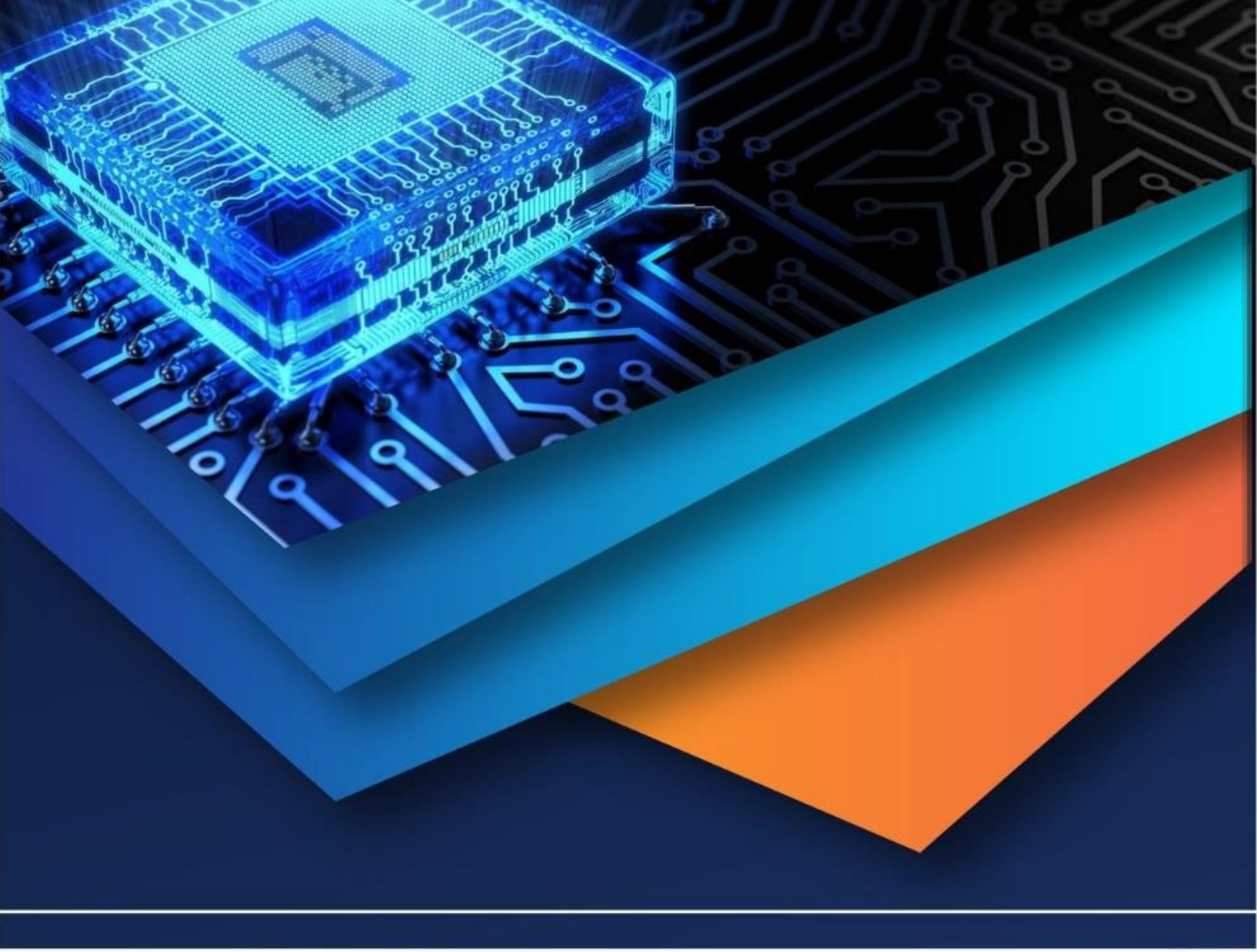

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