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Optimization of Concrete Mix Design: The Role of Hemp Fiber, Pumice Pozzolana and Micro Silica in Enhancing Strength and Workability

Mr. Deepak Kumar[1], Mr. Sourabh Lalotra[2]
[1]MTech. Student, Sri Sai Group of institutes Badhani, Pathankot, India
[2]Assistant Professor, Sri Sai Group of Institutes, Badhani, Pathankot, India

Abstract: ***This study explores the synergistic effects of hemp fibre, pumice pozzolana, and micro silica on Hemp Fiber Reinforced Concrete (HFRC) to enhance its mechanical properties and durability in harsh environments. The research aimed to assess the impact of hemp fibre on compressive, tensile, and flexural strength; evaluate the role of pumice pozzolana in improving concrete durability; and optimize the combined use of these materials for superior performance.***

For the mix design, a water–cement ratio of 0.42 was adopted. The main ingredients used in the concrete mix include coarse aggregate, fine aggregate, cement (OPC-53), Pumice pozzolana, Hemp fibre and micro silica. Tests were conducted to investigate adhesive properties, bond characteristics within the matrix, compressive strength, Tensile strength and flexural strength. For compressive strength testing, concrete cubes of dimensions 150 × 150 × 150 mm were cast. For flexural strength determination, concrete beams of size 700 × 150 × 150 mm were prepared. For split tensile strength testing, concrete cylinders measuring 300 mm in height and 150 mm in diameter were cast. A slump test was also carried out to determine the workability of the concrete mix. The specimens were tested at 7 and 28 days for compressive strength, flexural strength, and split tensile strength.

Keywords: Concrete, Pozzolana, Hemp Fiber, Micro Silica.

I. INTRODUCTION

*C*oncrete is the most widely used construction material worldwide due to its versatility, strength, and durability. However, despite its significant advantages, traditional concrete faces several challenges, particularly in terms of strength, workability, sustainability, and environmental impact. Over the years, research has focused on optimizing concrete designs to address these issues. One promising avenue for enhancing concrete performance involves incorporating supplementary materials like fibers, pozzolanic materials, and micro-sized additives. The incorporation of hemp fibers, pumice pozzolana, and micro silica in concrete mix design has gained significant attention due to their ability to improve the mechanical properties and workability of concrete while also contributing to sustainability.

II. LITERATURE REVIEW

1) Wang et al. (2014)|: Wang et al. explored the incorporation of hemp fibers into concrete and found that hemp fiber reinforced concrete (HFRC) improved the flexural strength and tensile strength of concrete. Their study demonstrated that the optimal content of hemp fibers ranged from 1.0% to 2.0% by volume. At these levels, hemp fibers effectively prevented crack propagation, thereby improving the ductility and impact resistance of concrete. They also noted that beyond 2.0% fiber content, the concrete's workability decreased, and the mix became more difficult to handle.
2) Moradinasab et al. (2019): Moradinasab and colleagues investigated the influence of hemp fiber length and dosage on the mechanical properties of concrete. Their study concluded that shorter fibers (10 mm to 15 mm) showed better dispersion in the concrete matrix and improved the composite's flexural and compressive strength. The researchers found that hemp fibers also enhanced the energy absorption capacity of concrete, making it more suitable for use in areas subjected to dynamic loads.
3) Beddar et al. (2016): Beddar et al. studied the durability aspects of hemp fiber reinforced concrete (HFRC) in aggressive environments. They found that the addition of hemp fiber enhanced the water retention properties of concrete, reducing shrinkage cracking and improving the material's resistance to freeze-thaw cycles. Their work demonstrated that hemp fibers not only enhanced the mechanical properties but also contributed to the long-term durability of the material.

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4) Perez et al. (2017): Perez and his team focused on the sustainability aspect of hemp fiber in concrete. They reviewed the environmental benefits of using hemp fibers, highlighting their renewable nature and biodegradability. The incorporation of hemp fibers was found to reduce the carbon footprint of concrete by replacing synthetic fibers or traditional reinforcing materials. Their study also highlighted that hemp-based concrete could serve as an energy-efficient building material.

III. MATERIAL USED

1) Hemp Fiber

Hemp fiber is a natural reinforcement material obtained from the Cannabis sativa plant. It is widely used in various industries, including construction, due to its high strength-to-weight ratio and sustainability. Hemp fibers are generally light, biodegradable, and have excellent mechanical properties. The fibers are known for their ability to improve concrete's tensile strength, flexural strength, and durability.

Fig 1 Hemp Fiber

2) Pumice Pozzolana

Pumice pozzolana is a volcanic ash with pozzolanic properties, meaning it reacts with calcium hydroxide in cement to form additional calcium silicate hydrate (C-S-H) gel, improving the concrete’s strength and durability. It is a fine, light-gray powder, often used as a replacement for a portion of cement in concrete to reduce environmental impact and improve performance.

Fig 2. Pumice Pozzolana

3) Micro silica (Silica Fume)

Micro silica, also known as silica fume, is a byproduct from the production of silicon metal and ferrosilicon alloys. It consists of extremely fine particles that are highly reactive and used to improve concrete's mechanical properties and durability.

Fig 3. Micro silica

4) Ordinary Portland Cement (OPC)

The source of cement typically comes from local cement manufactures. For a project involving M45 grade concrete, standard cement such as Ordinary cement used. The fineness of cement is greater than $225m^2/Kg$. Higher fineness means faster hydration and early gain strength is generally grey in colour. And maybe off white it depends upon the raw material. The initial setting time is a minimum of 30 minutes, ensuring adequate time for mixing and placing. The final setting time is generally within 10 hours, allowing the concrete enough time for mixing placing and finishing before concrete get hardens.

Fig 4.- Ordinary Portland Cement 53

5) Coarse Aggregate

Coarse aggregate was collected from a Crusher & quarry as per requirement in testing work. The specific gravity of coarse aggregates lies between 2.6 and 2.9, higher density means aggregate is denser and harder. The crushing strength is high; it should be passed from Impact value test. The water absorption should be less than 2%, to avoid affecting the water cement ratio. Bulk density varies from 1400 to 1600 kg/m³, depending on the grading and compaction. Soundness of aggregate is to be good. It is preserving concrete from weathering and chemical attacks.

Fig. 5- Coarse Aggregate

6) Fine Aggregate (FA)

Fine aggregate was taken from crusher as required amount in testing work. The specific gravity of fine aggregates ranges from 2.6 to 2.7, indicating moderate density. The fineness modulus lies between 2.3 and 3.2, showing that the sand is well graded. Water absorption is generally below 3%, depending on the moisture condition and surface texture. The Loose bulk density is typically in the range of 1400Kg/m^3–1600 kg/m³, while compacted bulk density is higher 1600kg/m^3 -1800kg/m^3.The colour and texture are uniform, free from clay, silt, or organic impurities. Fine sand should not contain reactive forms of silica. Higher amount of silica increases strength and stability. Moderate amount of Al_2O_3 in fine sand supports early strength of concrete. Low clay and Silt are not suitable in excessive amounts, reducing workability and strength.

Fig.6 - Fine Aggregate

IV. MIX PROPORTIONS

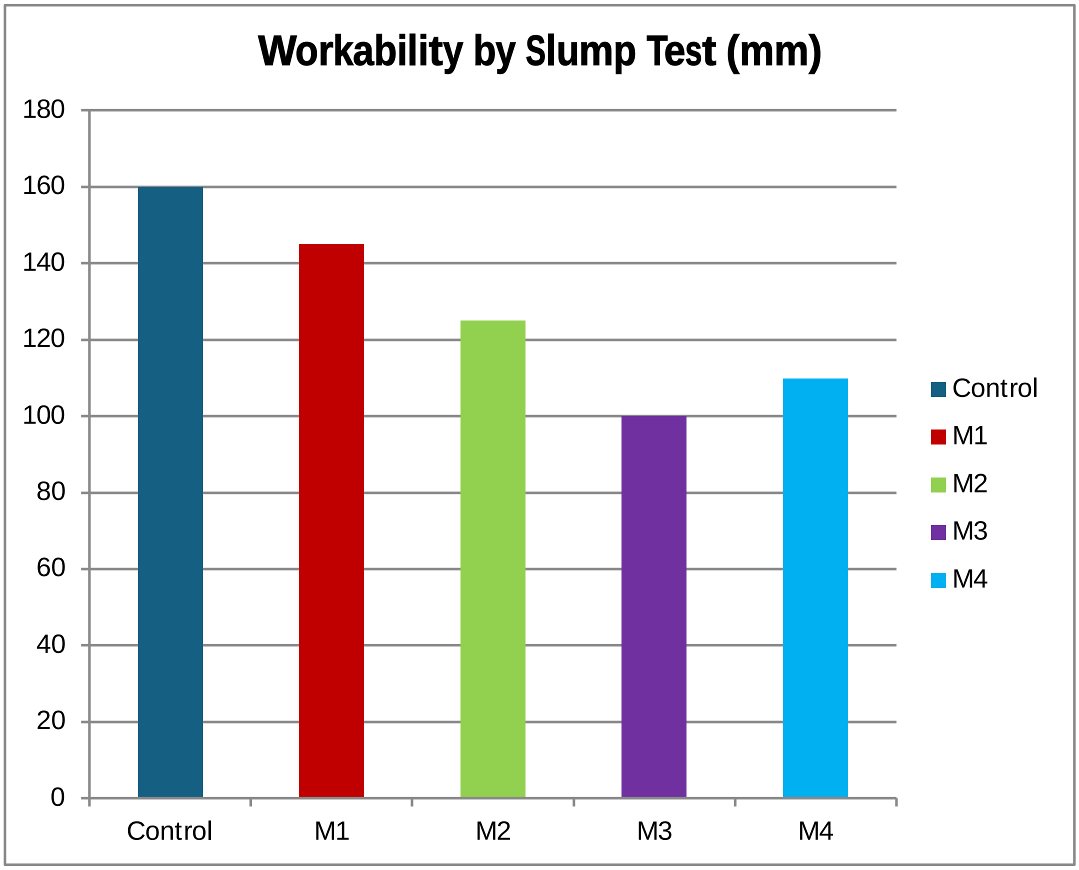
The Experiment have five mixes- Control (M0) without adding any replacement. M1 having 12% (PP),5%(MS) and 0.5% (HF).M2 with 16% PP,5% MS and 1% HF.M3 with 18% PP,6%MS,1.5%HF.M4 with 20% PP,5.5%MS and 2% HF

V. TESTING PROCEDURES

Test Include Slump Test for workability, Compressive strength, Flexural Strength, Tensile Strength.

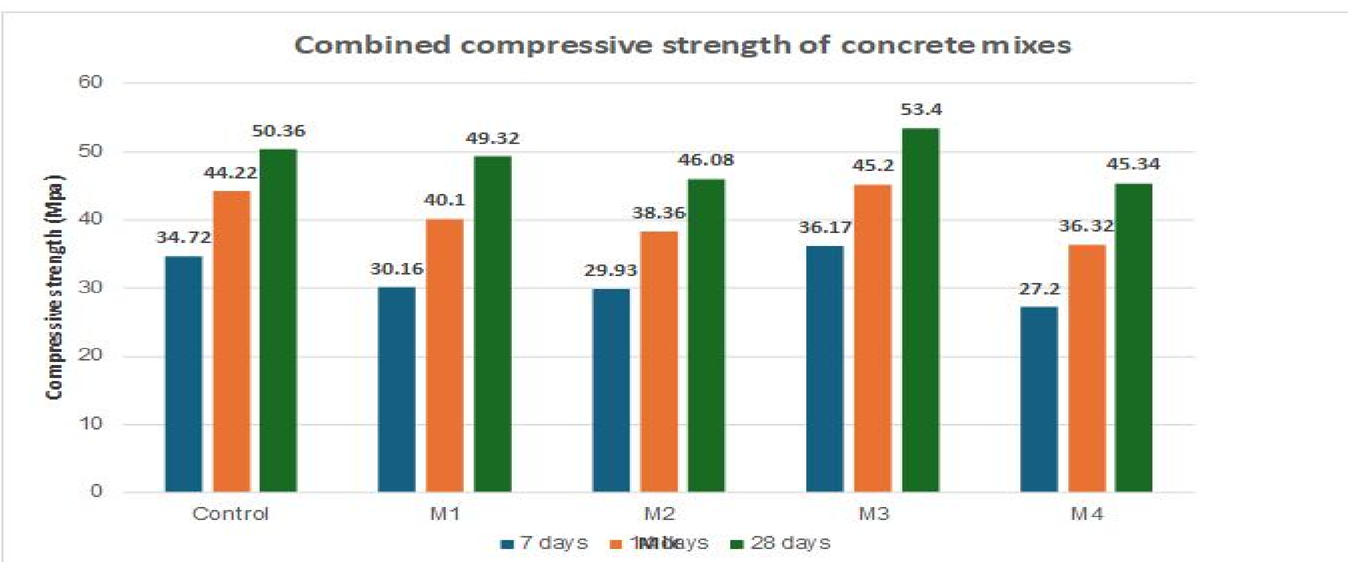
VI. RESULTS

A. Workability



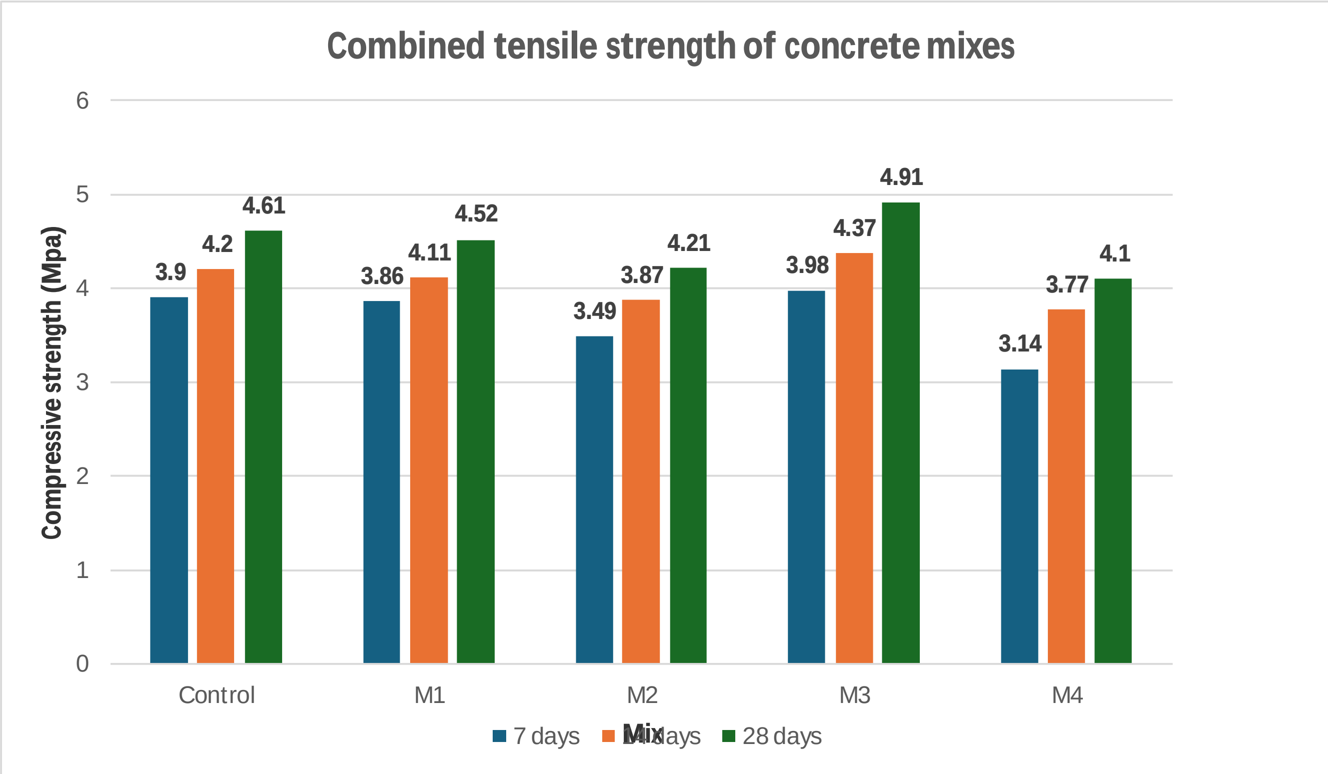
Workability, represented by slump values, clearly shows a decline in value with the increase in PP, MS, and HF content.

VII. COMPRESSIVE STRENGTH



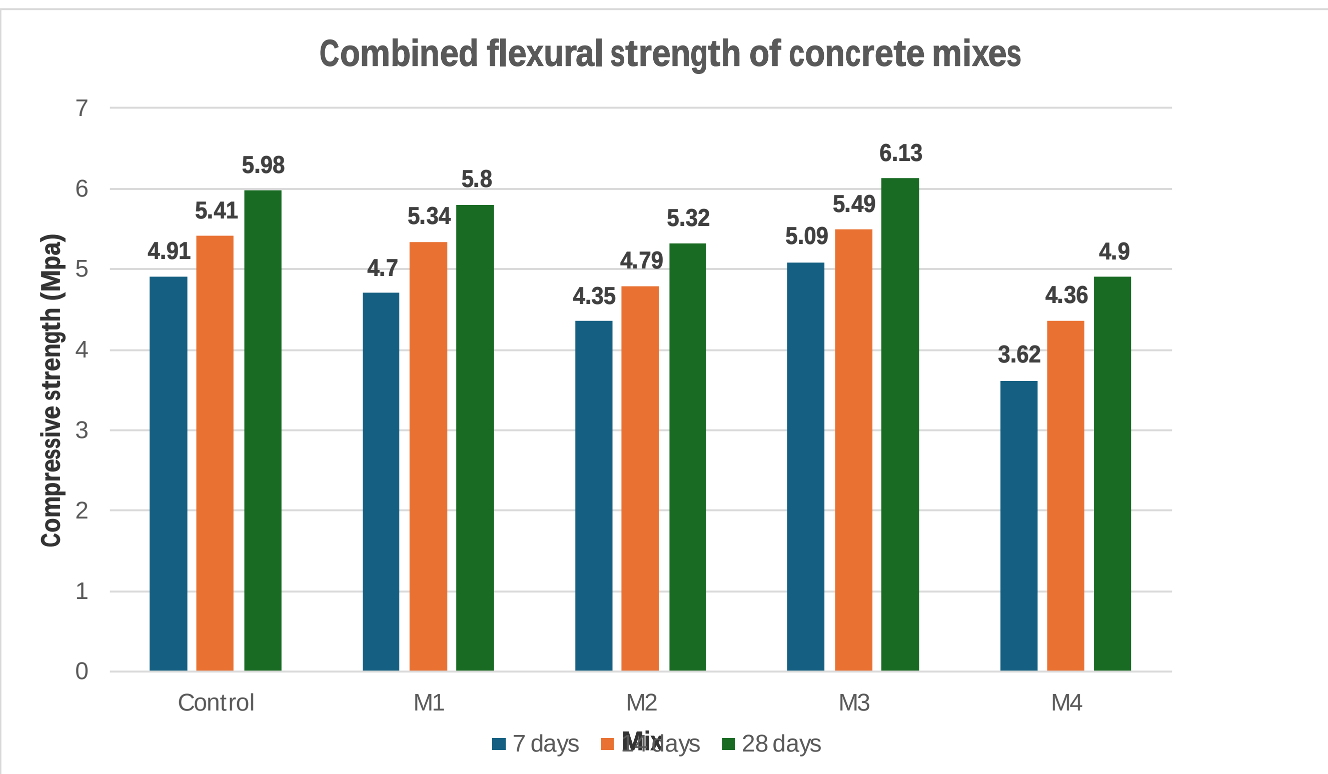
Here is the combined graph showing the compressive strength of HFRC for all three curing periods (7, 14, and 28 days) across the different mixes (M1, M2, M3 and M4).

VIII. TENSILE STRENGTH



The combined graph brings together the tensile strength data for the three mixes (M1, M2, M3and M4) at 7, 14, and 28 days into one consolidated visualization

IX. FLEXURAL STRENGTH



X. CONCLUSION

The results of this study demonstrate that the synergistic effect of Hemp Fiber, Pumice Pozzolana, and Micro silica significantly improves both the mechanical properties and durability of Hemp Fiber Reinforced Concrete (HFRC). The mechanical strength of HFRC was enhanced by the addition of Hemp Fiber, which improved tensile strength and flexural strength, making it suitable for structural applications. Pumice Pozzolana improved compressive strength and durability, reducing the permeability and increasing the chemical resistance of concrete. The combination of these materials with Micro silica further optimized the Fiber-matrix bonding, providing a more dense and stronger concrete mix.

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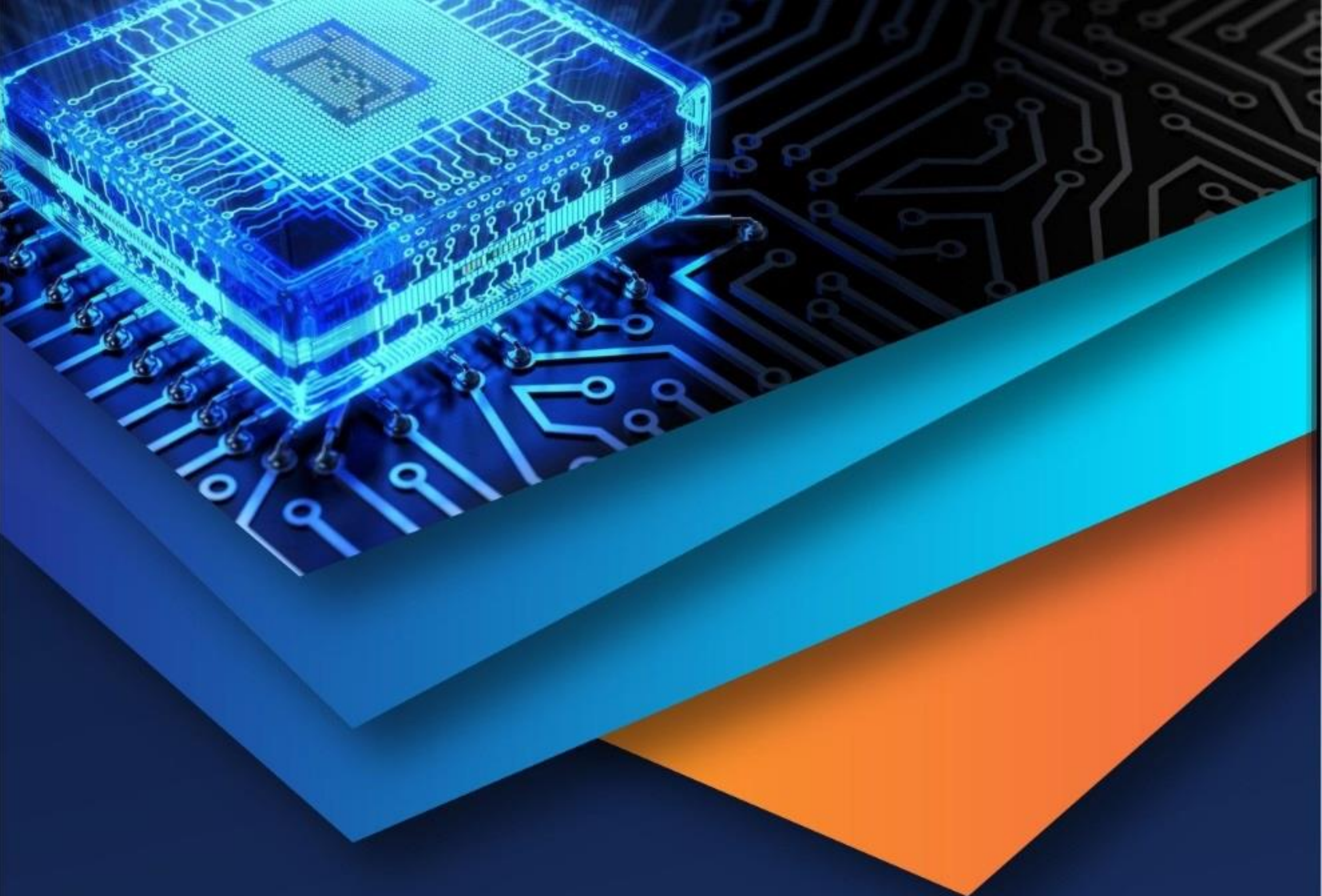

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