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To Investigate and Optimize Concrete Properties Using Volcanic Ash, Nano Silica with Addition of Cotton Fiber

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Abstract: Cotton Fiber Reinforced Concrete (CFRC) has emerged as a promising sustainable construction material, incorporating natural fibres to enhance concrete's mechanical properties. However, to further improve its performance, it is essential to explore innovative additives. Nano Silica (NS) and Volcanic Ash (VA) are two such materials that have demonstrated potential in enhancing concrete's properties, especially in terms of strength and durability. This study investigates the synergistic effects of NS and VA on the mechanical properties and durability of CFRC, with a focus on its performance under various curing conditions. The primary objective of this study was to assess the effects of incorporating NS and VA in CFRC on its compressive strength, tensile strength, flexural strength, and durability. The durability tests focused on sulphate resistance, chloride ingress, and water permeability. The results showed a significant improvement in the compressive strength, tensile strength, and flexural strength of CFRC with the incorporation of NS and VA, especially in Mix M3. Mix M3 also showed superior durability, with the highest resistance to sulphate attack, chloride ingress, and water permeability. SEM and XRD analyses revealed a dense microstructure and enhanced hydration due to the NS and VA combination. This study confirmed that the synergistic incorporation of NS and VA significantly enhances the mechanical properties and durability of CFRC. Mix M3 (2.5% NS, 12% VA,1% CF) demonstrated the optimal performance, suggesting it as a high-performance material for structural applications in harsh environments.

Keywords: Concrete, Volcanic Ash, Cotton Fiber, Nano Silica

I. INTRODUCTION

Concrete is one of the most widely used construction materials globally, primarily due to its durability, versatility, and relatively low cost. However, the environmental impact associated with traditional concrete production is substantial. The extraction of raw materials like sand, gravel, and cement, along with the carbon emissions from cement production, contribute to environmental degradation. According to the Global Cement and Concrete Association (GCCA, 2019), cement production alone accounts for approximately 8% of global carbon dioxide emissions. In response to these environmental concerns, the construction industry has turned towards sustainable alternatives and practices to reduce the ecological footprint of concrete.

II. LITERATURE REVIEW

Xie et al. (2016) investigated the specific role of nano silica in concrete and its ability to improve both early and long-term strength development. Their findings highlighted that nano silica particles fill the micro voids in the cement matrix and help refine the pore structure, thus leading to better durability characteristics such as reduced water permeability and enhanced resistance to sulphate attacks. The synergy between NS and the cement matrix also results in improved fibre-matrix bonding, which is essential for fibre-reinforced composites. Monteiro and Sant (2017) reviewed the historical and modern applications of volcanic ash in concrete. They discussed how volcanic ash reacts with calcium hydroxide to form additional C-S-H gel, improving the overall strength and durability of concrete. VA also reduces the heat of hydration, making it particularly useful for large-scale concrete applications, such as in dams and large structures where temperature control is critical. Zhang and Li (2008) conducted a comprehensive review on the application of nano silica in concrete. Their study found that NS, due to its high surface area and reactivity, significantly improves the mechanical properties and durability of concrete. The addition of nano silica enhances the density of the cement matrix, resulting in increased compressive strength, reduced porosity, and improved resistance to chemical attacks. NS also reacts with calcium hydroxide (CH) to form additional calcium silicate hydrate (C-S-H), which enhances the bonding between particles and fibres, thus contributing to better overall performance.

III. MATERIAL USED

A. Cotton Fiber

Cotton Fibers are naturally occurring Fibers extracted from the cotton plant's seed. The physical properties of cotton Fibers that are important for their incorporation into concrete. Typically, between 20 to 50 mm, though it can vary depending on the source and preparation method. Around 10–20 microns, which allows for the effective bonding within the cement matrix. Cotton Fibers have a relatively low density, around 1.5 g/cm³, which contributes to the reduction in the overall weight of the concrete. The surface area of cotton Fibers is relatively large, which helps in bonding with the cement matrix. Cotton Fibers primarily consist of cellulose, which is a polysaccharide.

Fig.1 Cotton Fiber

B. Nano Silica

Nano silica is a form of silica that has been processed to a nanometer scale (typically <100 nm), which significantly affects its properties. Nano silica has an average particle size of around 10 to 20 nm, providing a very high surface area to volume ratio (BET surface area between 200-300 m²/g).It typically appears as a fine white powder with a very light and dry texture. The density of nano silica is typically around 2.2 to 2.5 g/cm³, which is slightly higher than that of cotton fibers but much lower than traditional concrete aggregates. The particles are often spherical or irregular in shape, depending on the production method. Nano silica is composed almost entirely of silicon dioxide (SiO_2), which is highly reactive with calcium hydroxide in the concrete matrix.

Fig.2 Nano Silica

C. Volcanic Ash

Volcanic ash is a fine powder produced by the eruption of volcanoes. Volcanic ash consists of fine particles, typically smaller than 100 microns. Its particle size is critical for its pozzolanic activity when mixed with cement. The colour of volcanic ash varies from light grey to dark brown depending on the mineral content. However, in concrete, it generally appears as a light grey powder. The density of volcanic ash ranges from 2.2 to 2.8 g/cm³. This density is like that of traditional cement and aggregates. The ash particles tend to be highly porous, which is important for its pozzolanic reaction and its ability to react with calcium hydroxide in the concrete matrix.

Fig.3 Volcanic Ash

Volcanic ash appears as a fine, powdery substance, often gray or slightly brown. Above is an image of volcanic ash that is ready to be incorporated into concrete. Volcanic ash is known for its pozzolanic properties, which make it a valuable supplementary cementitious material (SCM). Volcanic ash typically contains 40-60% silica (SiO_2), which is responsible for its pozzolanic reactivity when combined with calcium hydroxide in concrete.

D. Cement (OPC)

The source of cement typically comes from local cement manufactures. For a project involving M45 grade concrete, standard cement such as Ordinary Portland cement is used. The grade of cement refers to minimum compressive strength 43 MPa which is achieved after 28 days of curing. In this project we will take Design mix of M45.The specific gravity of OPC ranges between 3.10 and 3.15.and its density is determined by Le Chatelier apparatus. The fineness of cement is greater than 225m^3/Kg. Higher fineness means faster hydration and early gain strength. Cement is generally grey in colour. And maybe off white it depends upon the raw material.

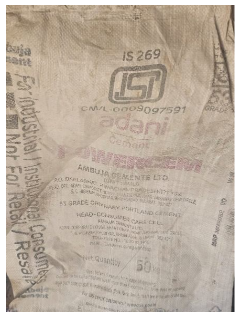


Fig.4 Cement

E. 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/m^3, depending on the grading and compaction. Soundness of aggregate is to be good. It is preserving concrete from weathering and chemical attacks. Coarse aggregates consist mainly of granite, basalt and limestone. They contain minor amounts of alumina, iron oxide, and magnesium oxide. Sulphate and chloride contents are very low, reducing the risk of steel corrosion. Chemically stable, hard aggregates provide better long-term strength.

Fig.5 Coarse Aggregate

F. 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/m^3, 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.

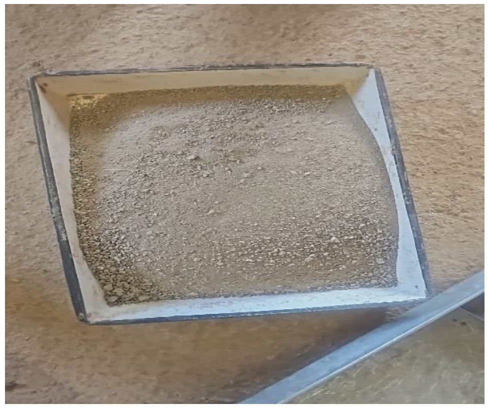


Fig.6 Fine Aggregate

IV. MIX PROPORTIONS

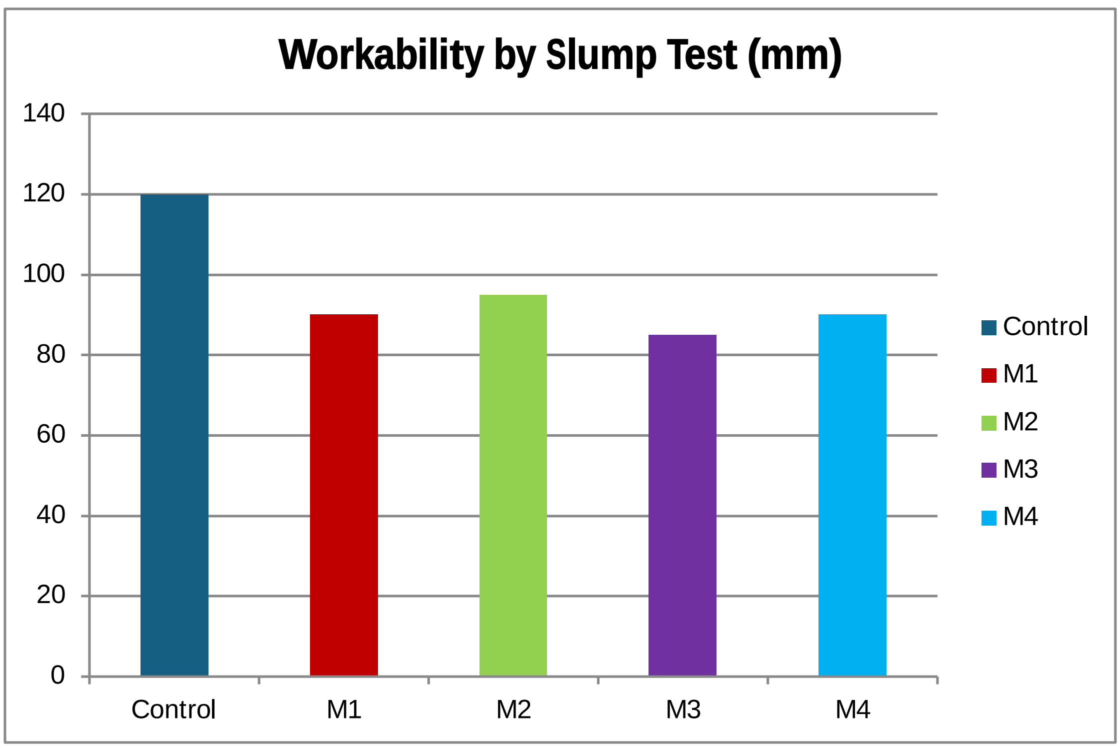
The Experiment have five mixes- Control (M0) without adding any replacement. M1 having 10% (VA),2%(NS) and 0.5% (CF).M2 with 15% VA,3% NS and 0.8% CF.M3 with 12% VA,2.5%NS,1%CF.M4 with 9% VA,3%NS and 0.3% CF

V. TESTING PROCEDURES

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

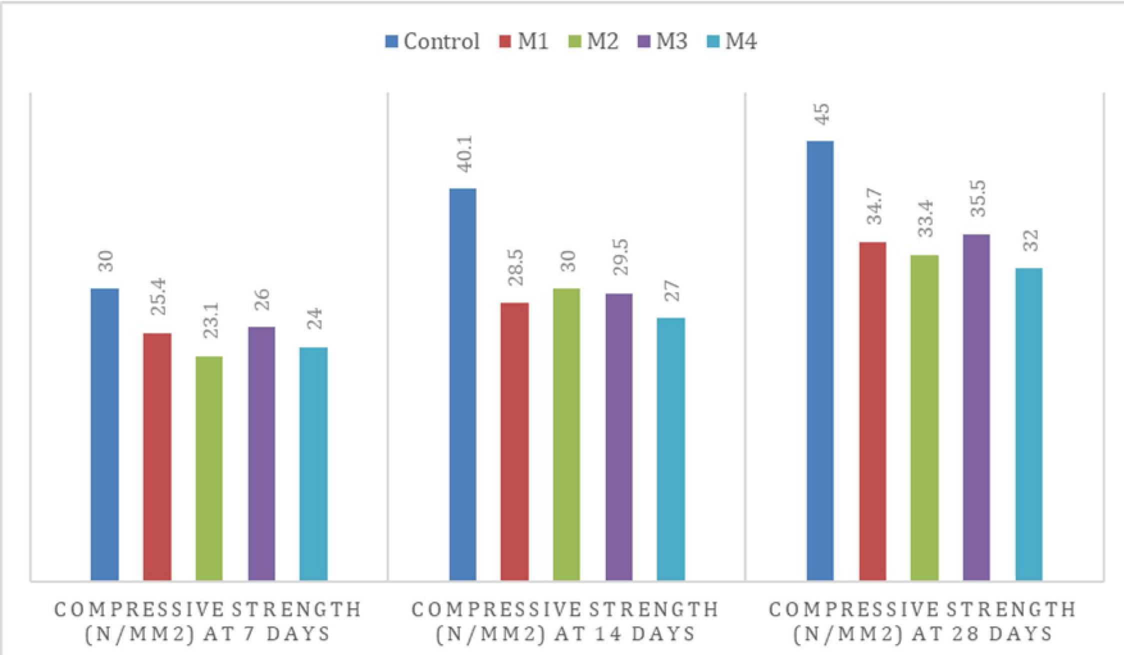
VI. RESULTS

A. *Workability*



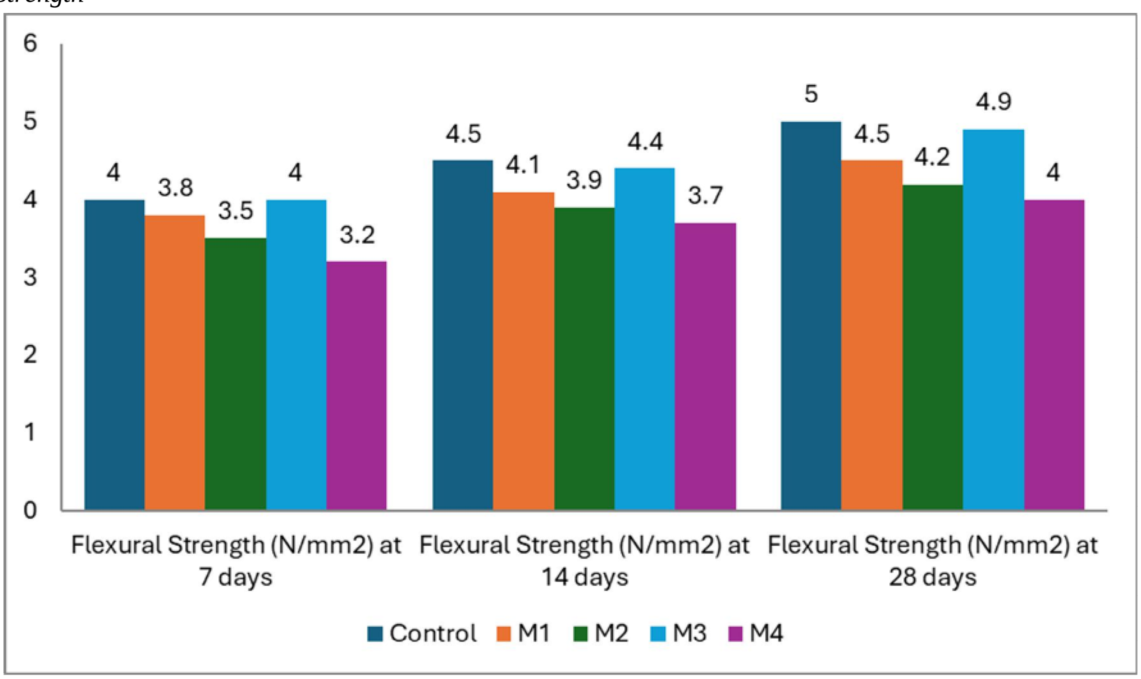
Workability, represented by slump values, clearly shows a decline in value with the increase in VA, NS, and CF content.

B. Compressive Strength



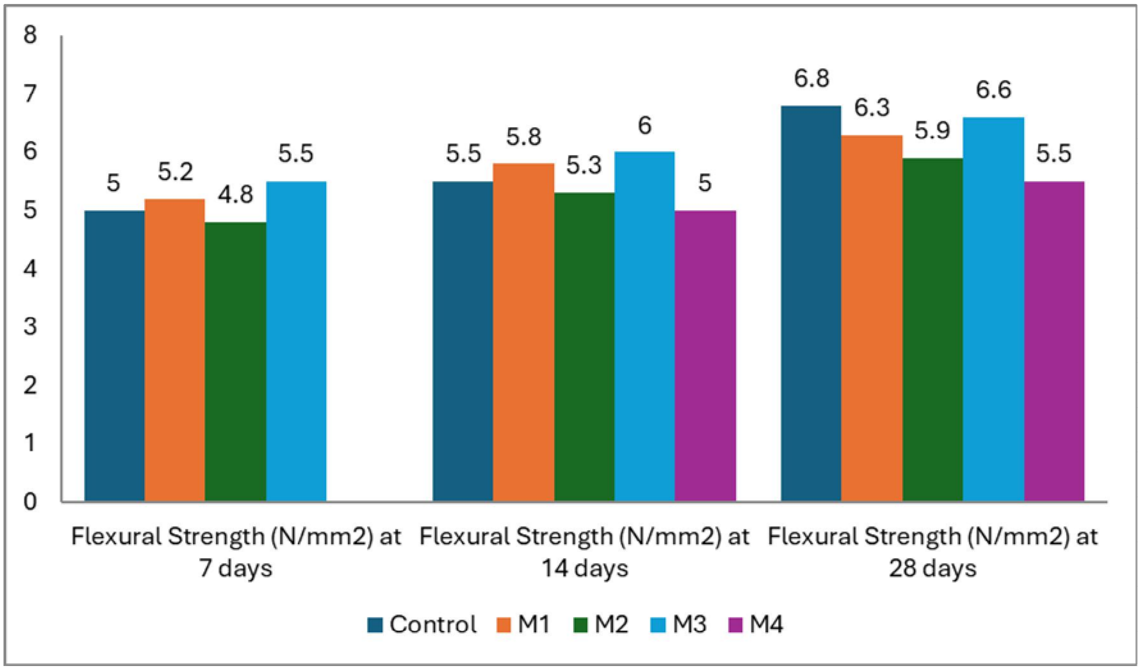
Here is the combined graph showing the compressive strength of CFRC for all three curing periods (7, 14, and 28 days) across the different mixes (M1, M2, M3 and M4). The bars represent the strength for each curing period, making it easy to compare performance at each stage for each mix.

C. 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.

D. Flexural Strength



The combined graph shows the flexural strength of the three mixes (M1, M2, and M3) at 7, 14, and 28 days. The graph clearly shows that M3 consistently outperforms M1 and M2 across all curing periods, with the highest flexural strength at each stage

VII. CONCLUSION

This study successfully demonstrated the synergistic effect of Nano Silica (NS) and Volcanic Ash (VA) in enhancing the mechanical properties and durability of Cotton Fiber Reinforced Concrete (CFRC). The results showed significant improvements in compressive strength, tensile strength, flexural strength, and resistance to chemical attacks. The optimized mix (M3), containing 2.5% NS and 12% VA, exhibited the best overall performance and is recommended for use in high-strength and durable concrete applications. This research contributes to the sustainable development of construction materials and offers a cost-effective and environmentally friendly solution for the construction industry.

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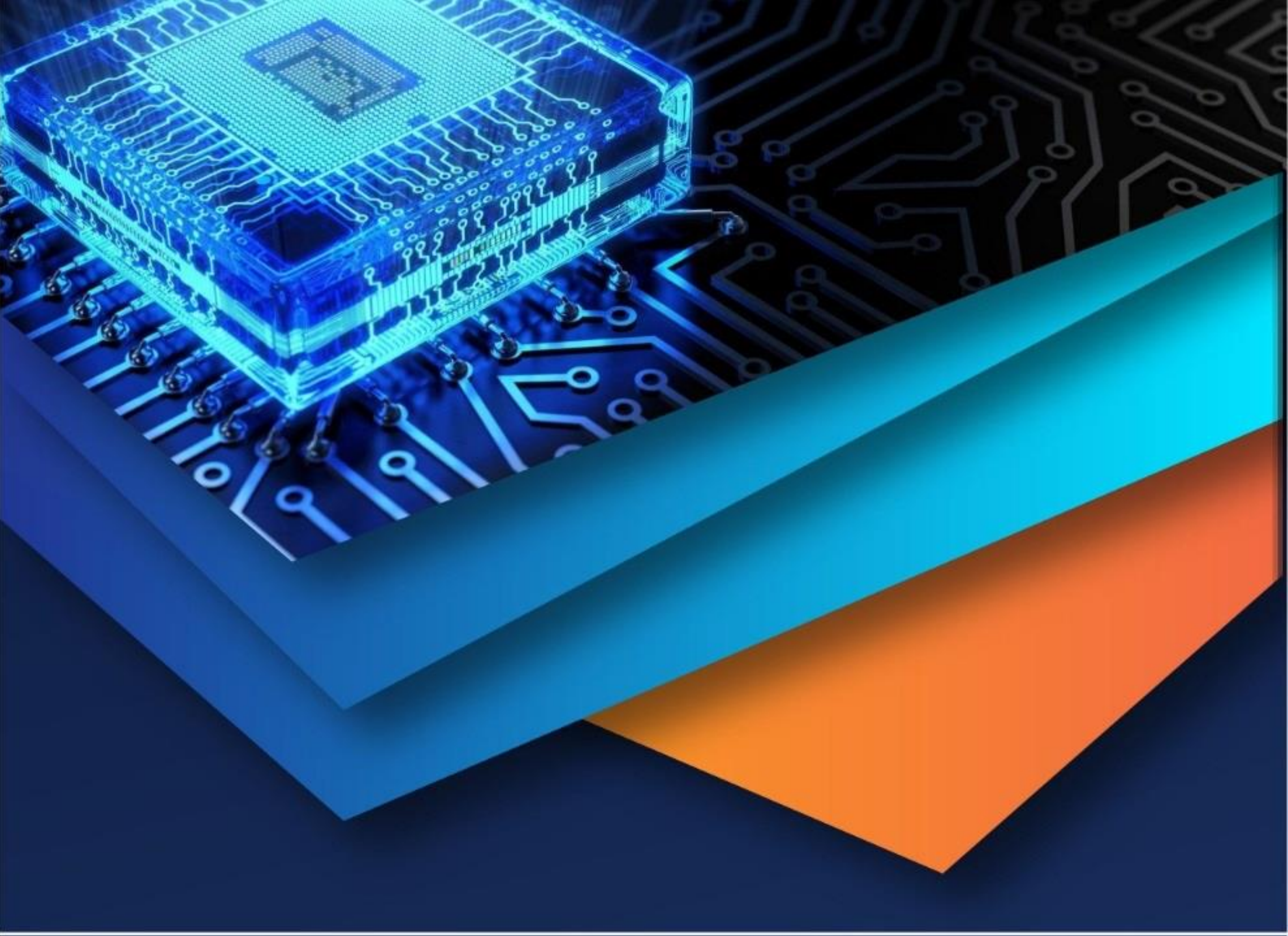

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