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# Development of High Strength GGBS based Self Compacting Concrete by Partial Replacement of Silica Fume in Cement and Granite Powder in Fine Aggregate

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***Abstract: This study focuses on the development of M60 grade Self-Compacting Concrete (SCC) incorporating silica fume (SF) and granite powder (GP) for sustainable and high-performance applications. Silica fume was used as a partial replacement of cement at 2.5%, 5%, 7.5%, and 10% to enhance strength and durability. Fine aggregate was partially replaced with granite powder at 10%, 20%, 30%, and 40% to evaluate its effect on workability and mechanical properties. The fresh properties of SCC were ensured to satisfy standard flowability requirements. Mechanical properties including compressive strength, split tensile strength, and flexural strength were systematically evaluated. The results indicated a significant improvement in strength characteristics with the incorporation of mineral admixtures. The optimum performance was observed at 5% silica fume and 30% granite powder replacement levels. The improved performance is attributed to enhanced particle packing and pozzolanic reactions. This study demonstratesthat the use of silica fume and granite powdercan produce sustainable, high-strength SCC while reducing dependency on natural materials and cement.***
***Keywords: Self-Compacting Concrete (SCC), Silica Fume (SF), Granite Powder (GP).***

## I. INTRODUCTION

In advanced construction and infrastructure systems the extensive utilization of OPC 53 grade cement is recognized as a major contributor to environmental pollution due to significant carbon dioxide ($CO_2$) emissions associated with its production. The cement industry contributes approximately 7% of global $CO_2$ emissions, primarily arising from limestone calcination and high-temperature clinker formation processes. These processes involve substantial fossil fuel consumption and energy-intensive kiln operations exceeding 1400°C, which further intensify the overall carbon footprint. In addition, cement manufacturing requires large-scale extraction of natural raw materials and complex physicochemical transformations, resulting in high embodied energy. Such practices lead to environmental degradation, depletion of natural resources, and adverse impacts on ecological systems and human health, thereby raising serious concerns regarding sustainability. To address these challenges, the incorporation of sustainable and alternative materials in concrete has become essential. Ground Granulated Blast Furnace Slag (GGBS), a by-product of the steel industry, acts as an effective supplementary cementitious material, enhancing long-term strength, durability, and reducing heat of hydration. Silica fume (SF), an ultrafine and highly reactive pozzolanic material, improves the microstructure by reducing porosity and strengthening the interfacial transition zone. Granite powder (GP), generated as a waste material from stone processing industries, can be utilized as a partial replacement for fine aggregate, improving particle packing and reducing reliance on natural river sand. In this study, M60 grade Self-Compacting Concrete (SCC) is developed using GGBS as a primary binder, with partial replacement of cement by silica fume and fine aggregate by granite powder at optimized proportions. The SCC mix ensures high flowability, good passing ability, and resistance to segregation without the need for vibration. The combined use of these materials enhances both fresh and hardened properties, including workability, strength, and durability. The primary objective of this research is to develop a high-strength, eco-friendly concrete with improved performance while minimizing environmental impact.

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## II. REVIEW OF LITERATURE

Shashikant Kumar et at.[1] Studied fresh, mechanical, and durability performance of self-compacting concrete with 40–50% fly ash and 6–8% silica fume as partial cement replacements. The mix showed improved workability, strength, and durability, with enhanced microstructure and reduced permeability. Wenwei Li et al. [2] studied soil stabilization using 1–5% cement and silica fume, which improved strength, compaction, and reduced plasticity. The best results were at 5% mix, showing good durability and performance due to better bonding and pore structure. Rupankar Chakraborti et al. [3] investigated M40 concrete with 20–35% GGBFS and 5–15% silica fume; strength and rheological properties improved due to enhanced pozzolanic reaction and C–S–H gel formation. Higher replacement levels reduced cement consumption and environmental impact while improving durability and microstructural densification. Amandeep Singh et al. [4] reported that replacing 10–25% cement with silica fume improves compressive, tensile, and flexural strength due to enhanced pozzolanic activity and pore refinement. However, replacement beyond 25% reduces workability and performance, confirming silica fume as an effective sustainable SCM. Sravani Japthi et al. [5] studied high-strength SCC with 10–30% GGBFS and 5–15% silica fume as partial cement replacements. The optimized ternary mix 30% GGBFS + 5% silica fume achieved highest strength ~70 MPa with improved durability and microstructure, while excess GGBFS reduced strength.

H. Alperen Bulut Li et al. [6] studied SCC with 5% fly ash, 12.5% silica fume, and 20% GGBFS as partial cement replacements. Silica fume achieved the highest compressive strength 54.2 MPa at 120 days with superior performance and lower radiological risk than fly ash and GGBFS. Abhishek Jain et al. [7] studied granite powder as a partial replacement of natural fine aggregate in fly ash–blended SCC. The study showed improved strength and durability up to 40–50% replacement, with better resistance to chloride, carbonation, and corrosion, while higher content caused slight shrinkage issues. F.A. Mustapha et al. [8] studied SCC with 50% fly ash and 10% silica fume at w/b 0.31, evaluated using slump flow, L-box, and V-funnel tests. The mix achieved high compressive strength ~87 MPa with improved performance, confirming enhanced strength and sustainability of SCC. Abhishek Jain et al. [9] studied granite waste as fine aggregate replacement in fly ash–blended SCC up to 40%. Improved strength, microstructural density, and matrix compactness due to filler effect, with minimal chemical reaction, supporting sustainable use. Abhishek Jain et al. [10] studied SCC using combined granite waste and fly ash to improve fresh and hardened properties. The study showed improved workability, density, and durability, while maintaining strength, providing a sustainable and eco-friendly concrete mix. Abhishek Jain et al. [11] (2019) studied granite cutting waste as fine aggregate replacement in SCC up to 40% to enhance sustainability. The study showed improved strength, durability, and microstructure with maintained workability, while higher replacement reduced performance. O.M. Ofuyatan et al. [12] studied SCC with 5%–15% silica fume and metakaolin as partial cement replacements using 2% superplasticizer. Improved strength and durability, with optimum 15% metakaolin achieving ~49 MPa, while higher replacement reduced strength due to increased water demand.

## III. MATERIALS AND ITS PROPERTIES

The materials used in this experimental investigation for the development of M60 grade Self-Compacting Concrete (SCC) include Ordinary Portland Cement (OPC) 53 grade, Ground Granulated Blast Furnace Slag (GGBS), silica fume, granite powder, fine aggregate, coarse aggregate, water, and superplasticizer JSW Ordinary Portland Cement (OPC) 53 grade was used as the primary binder in this study. It is manufactured by grinding clinker obtained from calcined limestone, clay, and corrective materials, with gypsum added to control setting time. The clinker predominantly contains tricalcium silicate ($C_3S$) and dicalcium silicate ($C_2S$), contributing to early and long-term strength development. The cement was procured from Andhra Pradesh and exhibited a specific gravity of 3.15, indicating suitability for high-strength concrete. It conforms to the requirements of IS 12269:1987. The chemical composition is rich in calcium oxide (CaO) and silicon dioxide ($SiO_2$), essential for hydration reactions. The physical properties comply with relevant Indian Standard specifications, ensuring its applicability in M60 grade SCC. Ground Granulated Blast Furnace Slag (GGBS) is an industrial by-product generated during iron production in blast furnaces operating at high temperatures of around 1500°C. The molten slag formed during this process is rapidly cooled using water quenching, resulting in the formation of glassy granular particles. These granules are subsequently dried and ground into a fine powder to produce GGBS. Owing to its latent hydraulic nature, it is commonly utilized as a supplementary cementitious material in concrete. The GGBS used in this study has a specific gravity of 2.8. The fine aggregate used in this study was natural river sand complying with the grading requirements of IS: 383–2016. The sand was clean and free from harmful impurities such as clay, silt, and organic matter. It satisfied the Zone II grading limits, ensuring proper particle size distribution. The physical properties of the fine aggregate are presented in Table 1. This grading helps in achieving good workability and cohesion in SCC mixes.

Fine aggregate also contributes to improved flowability and filling ability in self-compacting concrete. Crushed angular coarse aggregates of 10 mm nominal size were used in accordance with IS: 383–2016 specifications. The aggregates were clean, hard,

 

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and free from dust, flaky particles, and deleterious materials, ensuring proper interlocking and reduced voids. Their angular shape enhances particle interlock, improving mechanical strength and stability of the concrete matrix. In SCC, well-graded smaller aggregates ensure adequate flowability without segregation, and the properties are presented in Table 2. Silica fume is an ultrafine by-product obtained during the production of silicon or ferrosilicon alloys in electric arc furnaces. It is collected as a fine powder from exhaust gases and processed to achieve high fineness. Silica fume is rich in amorphous silica, which imparts strong pozzolanic reactivity when combined with cement. Its extremely fine particles improve packing density, reduce voids, and enhance the microstructure of concrete. The incorporation of silica fume in SCC improves strength and performance, making it suitable for high-strength and durable concrete applications. Granite powder is a by-product obtained from the cutting and polishing of granite stones in construction industries. It is processed, dried, and sieved to achieve the required fineness for use in concrete. Due to its angular shape and fine particle size, it improves particle packing, reduces voids, and enhances bonding in the mix. It mainly contains silica and alumina, making it suitable as a partial replacement for fine aggregate or as a filler material. The use of granite powder promotes sustainable construction by reducing natural sand consumption and utilizing industrial waste effectively. Sika ViscoCrete-20 HE is a high-range water-reducing admixture based on modified polycarboxylate ether (PCE) technology. It is designed to provide effective dispersion of cement particles, resulting in enhanced flowability and workability required for Self-Compacting Concrete. This admixture improves slump flow, reduces water demand, and enhances the cohesiveness of the mix without causing segregation. It also facilitates the production of high-strength concrete with improved performance. Sika ViscoCrete-20 HE complies with ASTM C494-03, BS 5075, and IS 9103:1999.

Table I. Physical Characteristics of Fine aggregate and Granite Powder

| Property | Fine Aggregate | Granite Powder |
|---|---|---|
| Fineness modulus | 2.867 | 2.85 |
| Zone | II | II |
| Bulk density (Loose) | 1585Kg/$m^3$ | 1450 Kg/$m^3$ |
| Bulk density (Compacted) | 1674 Kg/$m^3$ | 1600Kg/$m^3$ |
| Specific Gravity | 2.68 | 2.78 |

Table II. Physical characteristics of Coarse aggregate

| Property | Coarse aggregate |
|---|---|
| Fineness modulus | 4.20 |
| Specific Gravity | 2.86 |
| Water absorption | 1.0% |
| Crushing value | 13.83% |
| Impact value | 11.3% |
| Elongation index | 20.34% |
| Flakiness index | 16.95% |
| Bulk density (Loose) | 1486 kg/$m^3$ |
| Bulk density (Compacted) | 1674 kg/$m^3$ |

## IV. MIX PROPORTIONS

Mix proportions for M60 grade Self-Compacting Concrete (SCC) were designed as per EFNARC and IS:10262 guidelines. The control mix (M0) consisted of 70% cement and 30% GGBS, along with fine aggregate, coarse aggregate, water, and superplasticizer. Silica fume was used as a partial replacement for cement at 2.5%, 5%, 7.5%, and 10%. In a separate series, fine aggregate was partially replaced with granite powder at 10%, 20%, 30%, and 40%. After determining the optimum replacement levels, a combined mix was prepared for enhanced performance. A constant dosage of 1% Sika ViscoCrete-20 HE was used in all mixes, and the mix details are presented in Table 3.

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Table III Various Mix proportions of SCC

| Mixes Designation | Cement $kg/m^3$ | GGBS $kg/m^3$ | SF $kg/m^3$ | Fine Aggregate $kg/m^3$ | Granite Powder $kg/m^3$ | Coarse aggregate $kg/m^3$ | Water $kg/m^3$ | SP in % |
|---|---|---|---|---|---|---|---|---|
| M0(Reference mix) | 407 | 175 | - | 798 | - | 780 | 179 | 1.2% |
| M1(2.5% of SF) | 400 | 175 | 13 | 798 | - | 780 | 179 | 1.2% |
| M2(5% of SF) | 380 | 175 | 28 | 798 | - | 780 | 179 | 1..2% |
| M3(7.5% of SF) | 362 | 175 | 43 | 798 | - | 780 | 179 | 1.2% |
| M4(10% of SF) | 350 | 175 | 58 | 798 | - | 780 | 179 | 1.2% |
| M5(10% of GP) | 407 | 175 | - | 718 | 75 | 780 | 179 | 1.2% |
| M6(20% of GP) | 407 | 175 | - | 635 | 155 | 780 | 179 | 1.2% |
| M7(30% of GP) | 407 | 175 | - | 535 | 235 | 780 | 179 | 1.2% |
| M8(40%of GP) | 407 | 175 | - | 475 | 315 | 780 | 179 | 1.2% |
| M9(5% of SF+30% of GP) | 380 | 175 | 43 | 535 | 235 | 780 | 179 | 1.2% |

## V. FRESH PROPERTIES

Fresh properties of SCC were evaluated using standard tests, namely Slump Flow, L-Box, and V-Funnel. The obtained values were checked in accordance with EFNARC guidelines. The typical acceptable ranges are: slump flow (550–850 mm), L-Box ratio (0.8–1.0), and V-Funnel time (8–25 seconds) These results are summarized in table 4.

Table IV Fresh properties of various SCC mixes

| Mixes Designation | Slump flow(mm) | L-Box | V-funnel(seconds) |
|---|---|---|---|
| M0 (Reference mix) | 680 | 0.91 | 10 |
| M1(2.5% of SF) | 630 | 0.87 | 11 |
| M2 (5% of SF) | 670 | 0.91 | 8 |
| M3 (7.5% of SF) | 650 | 0.89 | 9 |
| M4 (10% of SF) | 650 | 0.8 | 13 |
| M5 (10% of GP) | 660 | 0.92 | 14 |
| M6 (20% of GP) | 650 | 0.9 | 15 |
| M7 (30% of GP) | 640 | 0.89 | 11 |
| M8 (40% of GP) | 650 | 0.86 | 13 |
| M9(Optimal Mix) (5% of SF +30% of GP30%) | 670 | 0.85 | 14 |

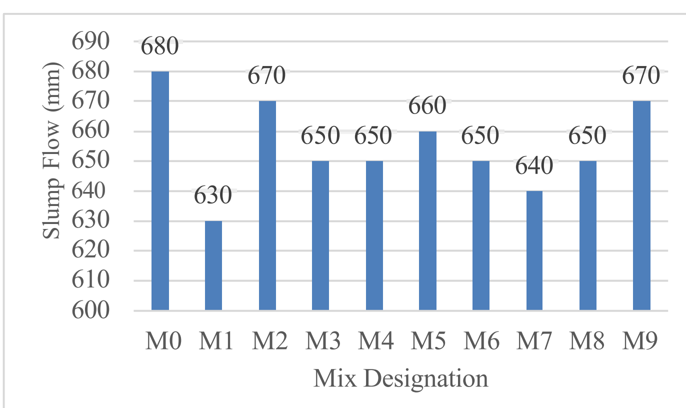


Fig I Graphical representation of Slump flow

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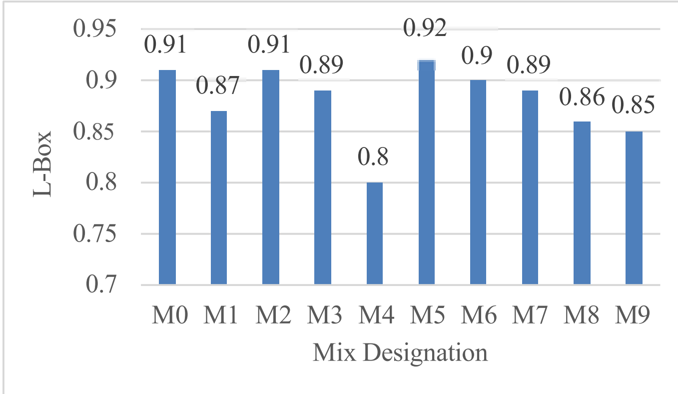


Fig II Graphical representation of L-Box

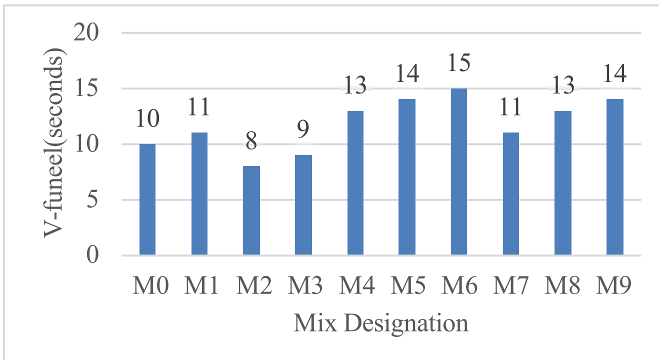


Fig III Graphical representation of V-funnel

## VI. MECHANICAL PROPERTIES

Concrete specimens were prepared to evaluate the mechanical properties of all SCC mixes. Cubes 100 × 100 × 100 mm were cast for compressive strength, cylinders 150 × 300 mm for split tensile strength, and beams 100 × 100 × 500 mm for flexural strength. After 28 days of curing, the specimens were tested, and the results of compressive, split tensile, and flexural strengths for each mix are presented in the table5.

Table5. Mechanical properties of various Mix proportions of SCC

| Mixes Designation | Compressive strength in $N/mm^2$ (28 Days) | Split tensile strength in $N/mm^2$ (28 Days) | Flexural strength test in $N/mm^2$ (28 Days) |
|---|---|---|---|
| M0 (Reference mix) | 68 | 5.02 | 7.01 |
| M1(2.5% of SF) | 60 | 4.2 | 6.09 |
| M2 (5% of SF) | 68.5 | 6.02 | 8.02 |
| M3 (7.5% of SF) | 69 | 4.9 | 7.09 |
| M4 (10% of SF) | 57 | 4.0 | 7 |
| M5 (10% of GP) | 58.03 | 4.5 | 7.2 |
| M6 (20% of GP) | 57.9 | 5.0 | 5.90 |
| M7 (30% of GP) | 67 | 4.8 | 6.01 |
| M8 (40% of GP) | 60 | 4.9 | 7.03 |
| M9(Optimal Mix) (5% of SF +30% of GP30%) | 70 | 6.9 | 8.21 |

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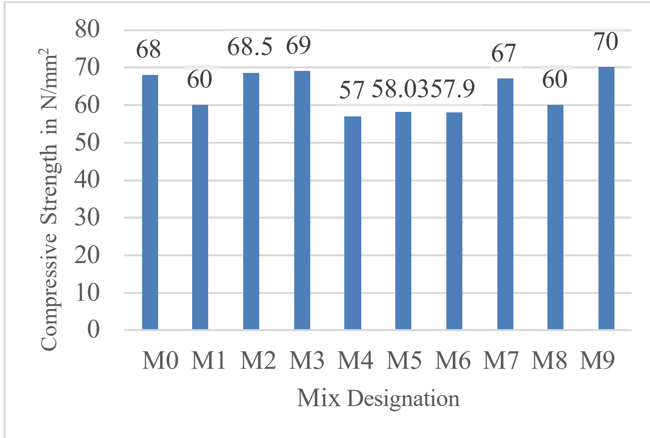


Fig IV Graphical representation of compressive strength

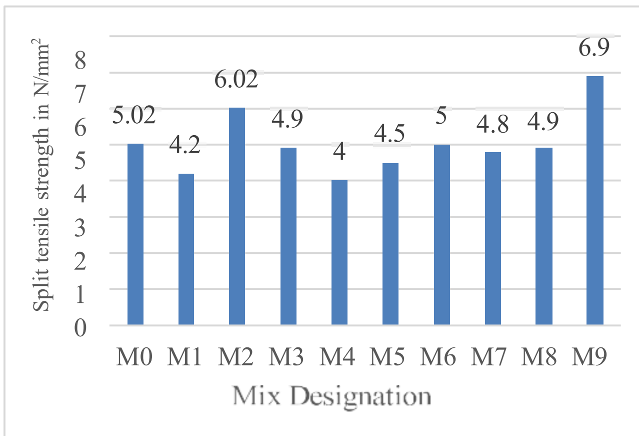


Fig V. Graphical representation of split tensile strength

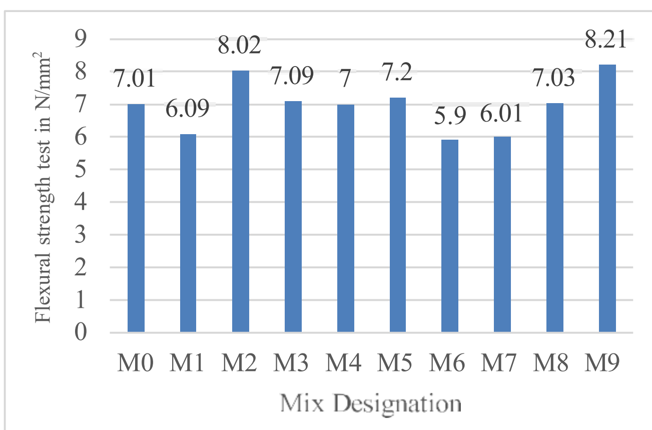


Fig VI. Graphical representation of flexural strength

## VII. CONCLUSIONS

1) Mix M0 (reference SCC mix) established the baseline performance with compressive strength of 68 MPa, split tensile strength of 5.02 MPa, and flexural strength of 7.01 MPa for comparison of all modified SCC mixes.
2) Mix M2 containing 5% silica fume showed improved mechanical performance with compressive strength of 68.5 MPa, split

tensile strength of 6.02 MPa, and flexural strength of 8.02 MPa due to enhanced pozzolanic reaction, refined pore structure, and better particle packing.

*3)* Mix M7 with 30% granite powder achieved satisfactory strength performance with compressive strength of 67 MPa, split tensile strength of 4.8 MPa, and flexural strength of 6.01 MPa owing to filler effect and improved aggregate gradation in the SCC matrix.

*4)* Mix M9 containing combined replacement of 5% silica fume and 30% granite powder exhibited optimum overall performance with maximum compressive strength of 70 MPa, split tensile strength of 6.9 MPa, and flexural strength of 8.21 MPa due to synergistic densification and improved interfacial bonding within the concrete matrix.

*5)* Silica fume replacement improved the fresh and hardened properties up to 5–7.5%, while higher replacement of 10% reduced workability and strength because of excessive fineness, higher water demand, and reduction in effective cementitious content.

*6)* Granite powder replacement enhanced SCC performance up to 30% due to better packing density and filler action, whereas 40% replacement resulted in reduced strength and flowability because of increased fines and reduced cohesiveness.

*7)* All SCC mixes satisfied EFNARC workability requirements and exhibited good filling ability, passing ability, and resistance to segregation. The results confirmed the suitability of the mixes for self-compacting concrete applications.

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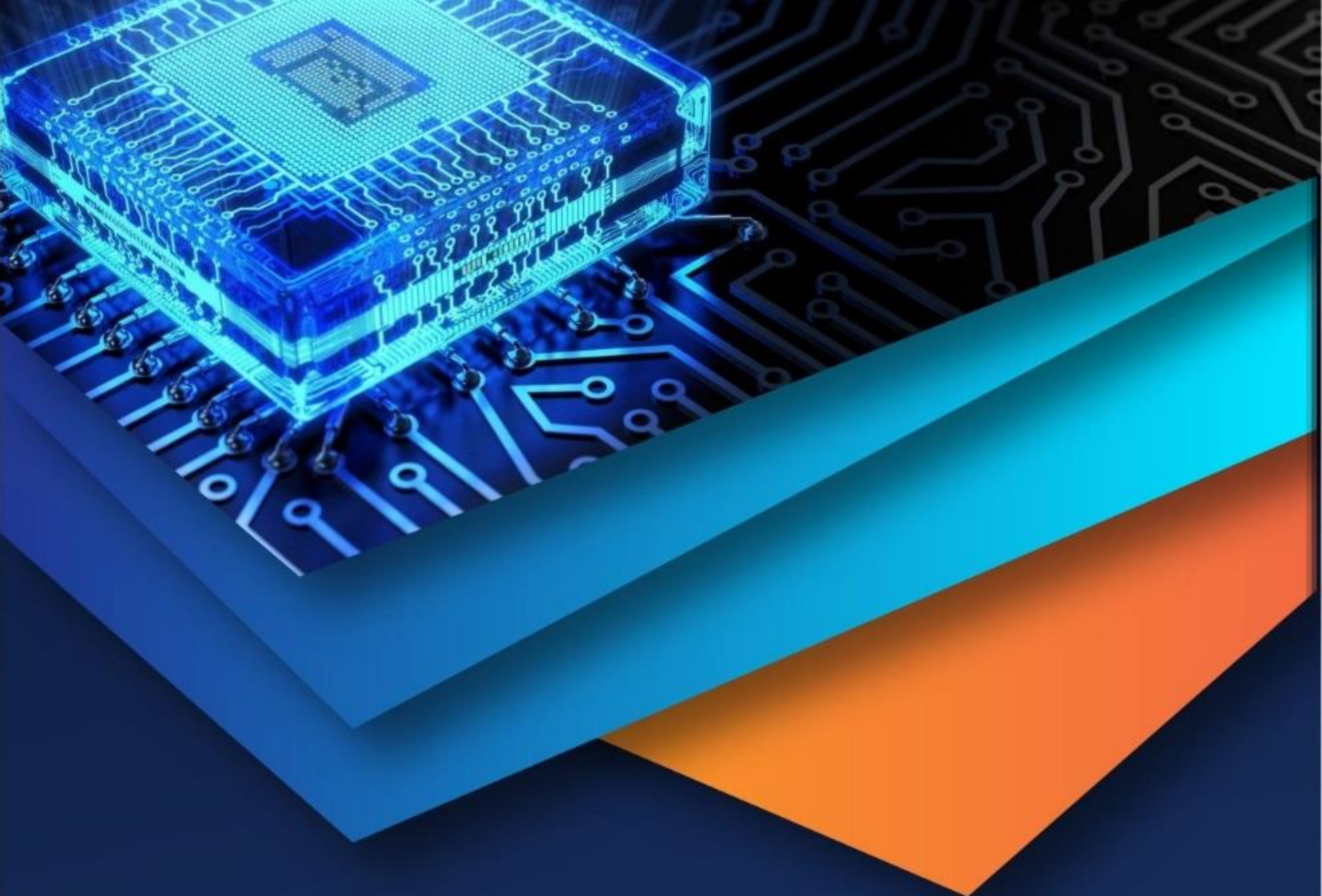


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