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Investigation on Properties of Self Compacting Concrete with Recycled Aggregate

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***Abstract:** The use of recycled fine aggregates (RFA) obtained from construction and demolition waste offers a sustainable alternative to natural sand in self-compacting concrete (SCC). This study experimentally evaluates the influence of 5% and 10% RFA replacement on the fresh, mechanical, and durability properties of SCC designed for M35 and M45 grades. All mixes satisfied SCC workability requirements with slump flow values between 681 and 718 mm, V-funnel times of 8.1–10.7 s, and L-box ratios above 0.85. Mechanical testing showed negligible strength reduction (~1%) at 5% replacement, while about 6% reduction was observed at 10% replacement after 28 days. Water absorption increased slightly but remained within acceptable limits (<6%). The findings indicate that limited RFA incorporation in SCC is technically feasible and can contribute to sustainable construction without significantly compromising performance.*

***Keywords:** Recycled aggregates, Self-compacting concrete, Fresh properties, Mechanical properties, Durability, Construction waste management, Sustainable concrete.*

I. INTRODUCTION

The construction industry generates large quantities of construction and demolition (C&D) waste, creating environmental and resource management challenges. One practical approach to address this issue is the use of recycled aggregates in concrete production. Among modern concrete types, self-compacting concrete (SCC) has gained significant importance due to its high flowability, ability to consolidate without vibration, and improved placement in congested reinforcement.

Recycled fine aggregates (RFA) derived from C&D waste have shown potential as partial replacements for natural sand; however, their higher water absorption and residual mortar content may influence fresh and hardened concrete properties. Although several studies have examined recycled aggregates in conventional concrete, limited work has focused on their performance in SCC, particularly under Indian material and design conditions.

This study investigates the effect of 5% and 10% RFA replacement on SCC of M35 and M45 grades, with emphasis on fresh properties, strength development, and durability indicators. The objective is to assess the practical feasibility of incorporating RFA in SCC while maintaining acceptable performance levels.

II. MATERIALS AND MIX DESIGN

A. Materials Characterization

1) Cement: Ordinary Portland Cement (OPC) 43-grade conforming to IS 8112:2013 with specific gravity 3.10, fineness 330 m^2/kg, normal consistency 31%, initial setting time 90 minutes, and 28-day compressive strength 43.25 MPa.
2) Fine Aggregates: Natural river sand conforming to Zone II of IS 383:2016 (specific gravity 2.65, fineness modulus 2.75, water absorption 1.01%) and recycled fine aggregates (RFA) from C&D waste processing (specific gravity 2.47, fineness modulus 2.68, water absorption 6.7%, bulk density 1,250 kg/m^3). RFA was processed through crushing, screening, and oven-drying to constant mass.
3) Coarse Aggregates: Crushed granite stone aggregates of 20 mm nominal maximum size conforming to IS 383:2016 (specific gravity 2.74, water absorption 0.49%, aggregate crushing value 21.5%, Los Angeles abrasion value 25.0%).
4) Supplementary Cementitious Materials: Class F fly ash (IS 3812:2013) at 25% replacement and high-reactivity silica fume (9%) with specific gravity 2.20.
5) Admixtures: Polycarboxylate ether-based superplasticizer (IS 9103:1999, specific gravity 1.08, recommended dosage 1.0–1.5% by weight of cementitious material) and potable water (IS 456:2000).

B. Mix Design and Preparation

Six concrete mixtures (Table 1) were designed per IS 10262:2019 with modifications for RFA and SCC requirements. Water content was adjusted for RFA's elevated water absorption (6.7% vs. 1.01%). Mixtures were prepared using a forced-action mixer following a standardized sequence: dry mixing for 3 minutes, superplasticizer addition over 1 minute, and final mixing for 3 minutes to ensure uniformity.

Mixture ID	Grade	RFA %	Cement	Fly Ash	Silica Fume	Water
			(kg/m³)	(kg/m³)	(kg/m³)	(L/m³)
M35-C	M35	0	284	108	39	155
M35-R5	M35	5	284	108	39	158
M35-R10	M35	10	284	108	39	161
M45-C	M45	0	324	123	44	162
M45-R5	M45	5	324	123	44	165
M45-R10	M45	10	324	123	44	168

Table 1: Concrete mixture composition for six mixes (kg/m³)

III. EXPERIMENTAL PROGRAM AND TESTING METHODS

Fresh property tests were conducted per IS 1199 Part 6:2018: Slump Flow Test (measures filling ability; SF1: 550–650 mm, SF2: 660–750 mm, SF3: 760–850 mm); V-Funnel Test (evaluates viscosity; VF1: 6–12 s); L-Box Test (assesses passing ability; $H_2/H_1 \geq 0.85$ for H2 classification).

Hardened properties were tested at 7 and 28 days: Compressive Strength (IS 516:1959, 150 mm cubes at 14 MPa/min); Split Tensile Strength (IS 5816:1999, 100 mm diameter × 200 mm cylinders); Flexural Strength (IS 516:1959, four-point loading on 100 × 100 × 500 mm prisms); Water Absorption (IS 3812:2013, 50 mm cubes oven-dried at 105°C to constant mass, immersed 24 h at 27°C).

IV. RESULTS AND ANALYSIS

A. Fresh Properties

All six concrete mixtures satisfied SCC self-compacting specifications per IS 1199 Part 6:2018.

Mixture ID	Slump Flow (mm)	Classification	Remarks
M35-C	718	SF2	Excellent flowability
M35-R5	710	SF2	Marginal reduction
M35-R10	698	SF2	Within acceptable range
M45-C	702	SF2	Excellent flowability
M45-R5	692	SF2	Marginal reduction
M45-R10	681	SF2	Within acceptable range

Table 2: Slump Flow Test Results

1) Slump Flow: All mixes achieved SF2 classification (660–750 mm). Control mixes exhibited excellent flowability (M35-C: 718 mm, M45-C: 702 mm). RFA incorporation resulted in marginal reductions ranging from 12–37 mm, attributable to RFA's higher water absorption and angular particle morphology. The maximum decrease (M35-C: 718 mm → M35-R10: 698 mm, 2.8% reduction) remained well above the SF2 minimum of 660 mm, confirming maintained filling ability and self-placement capability.

Mixture ID	V-Funnel Time (s)	Classification	Segregation Assessment
M35-C	8.5	VF1	Excellent resistance
M35-R5	9.2	VF1	Within range
M35-R10	10.1	VF1	Within range
M45-C	8.1	VF1	Excellent resistance
M45-R5	9.0	VF1	Within range
M45-R10	10.7	VF1	Within range

Table 3: V-Funnel Test Results

2) V-Funnel Test: All mixes satisfied VF1 classification (6–12 seconds), confirming excellent segregation resistance and viscosity control. Control mixes exhibited rapid discharge (M35-C: 8.5 s, M45-C: 8.1 s), indicating low viscosity. RFA incorporation increased discharge times marginally; maximum values (M35-R10: 10.1 s, M45-R10: 10.7 s) remained comfortably within VF1 specification. The 1.6–2.6 second increase (16–29% relative) from control to 10% RFA reflects enhanced inter-particle friction from RFA's residual mortar coating, which improves segregation resistance and material cohesion—a beneficial durability aspect.

Mixture ID	H_2 (mm)	H_2/H_1 Ratio	Passing Ability
M35-C	182	0.91	Excellent
M35-R5	178	0.89	Excellent
M35-R10	170	0.85	Satisfactory
M45-C	184	0.92	Excellent
M45-R5	178	0.89	Excellent
M45-R10	170	0.85	Satisfactory

Table 4: L-Box Test Results

3) L-Box Test: All mixes achieved $H_2/H_1 \geq 0.85$, confirming excellent passing ability through reinforcement per IS 1199 Part 6:2018. Control specimens achieved ratios of 0.91–0.92, indicating superior reinforcement penetration without blockage. RFA incorporation at 5% resulted in $H_2/H_1 = 0.89$, representing negligible degradation. At 10% RFA replacement, ratios decreased to exactly 0.85, the critical H2 minimum threshold, demonstrating that SCC maintains minimum acceptable passing ability, confirming successful flow through congested reinforcement without segregation or blockage even at maximum tested RFA content.

B. *Mechanical Properties at 28 Days*

Mixture ID	7-Day (MPa)	28-Day (MPa)	vs. Target	vs. Control	Status
M35-C	36.52	45.06	+4.2%	Reference	Excellent
M35-R5	36.18	44.67	+3.3%	99.1%	Negligible loss
M35-R10	25.92	42.33	-2.1%	93.9%	Acceptable
M45-C	44.78	57.85	+8.6%	Reference	Excellent
M45-R5	34.41	56.77	+6.6%	98.1%	Negligible loss
M45-R10	33.14	54.38	+2.1%	93.9%	Acceptable

Table 5: Compressive Strength Results (7 and 28 days)

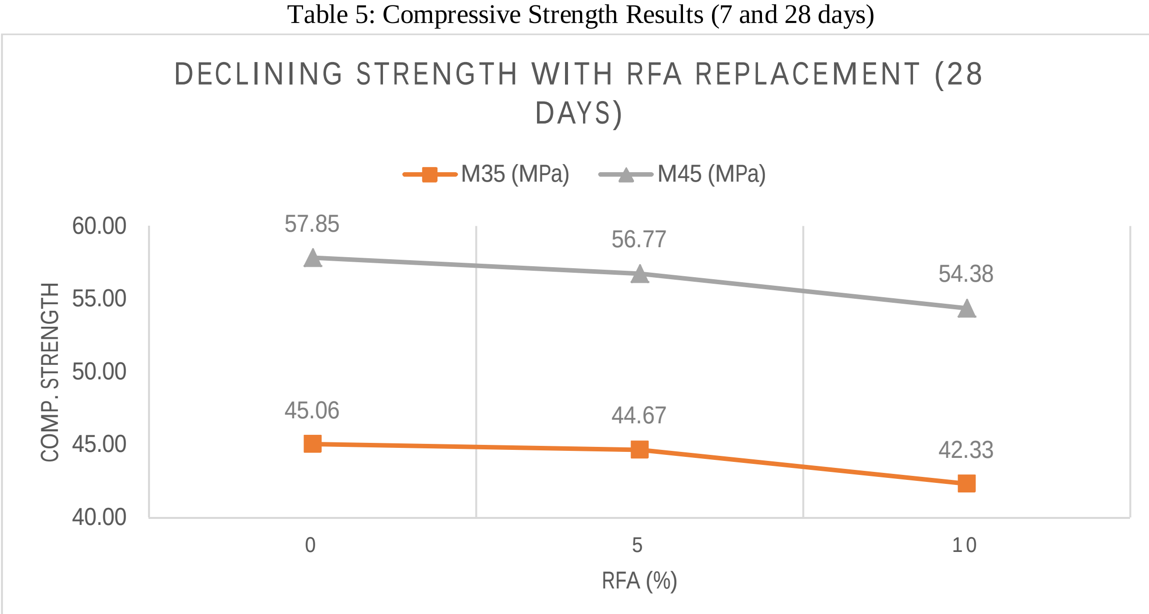

Figure 1: Compressive Strength at 28 Days vs RFA Replacement Level

Mixture ID	Tensile Strength (MPa)	vs. Control	Ratio (T/C)
M35-C	3.244	Reference	0.0720
M35-R5	3.217	99.2%	0.0720
M35-R10	3.047	93.9%	0.0720
M45-C	4.165	Reference	0.0719
M45-R5	4.088	98.2%	0.0720
M45-R10	3.915	93.9%	0.0719

Table 6: Split Tensile Strength Results (28 days)

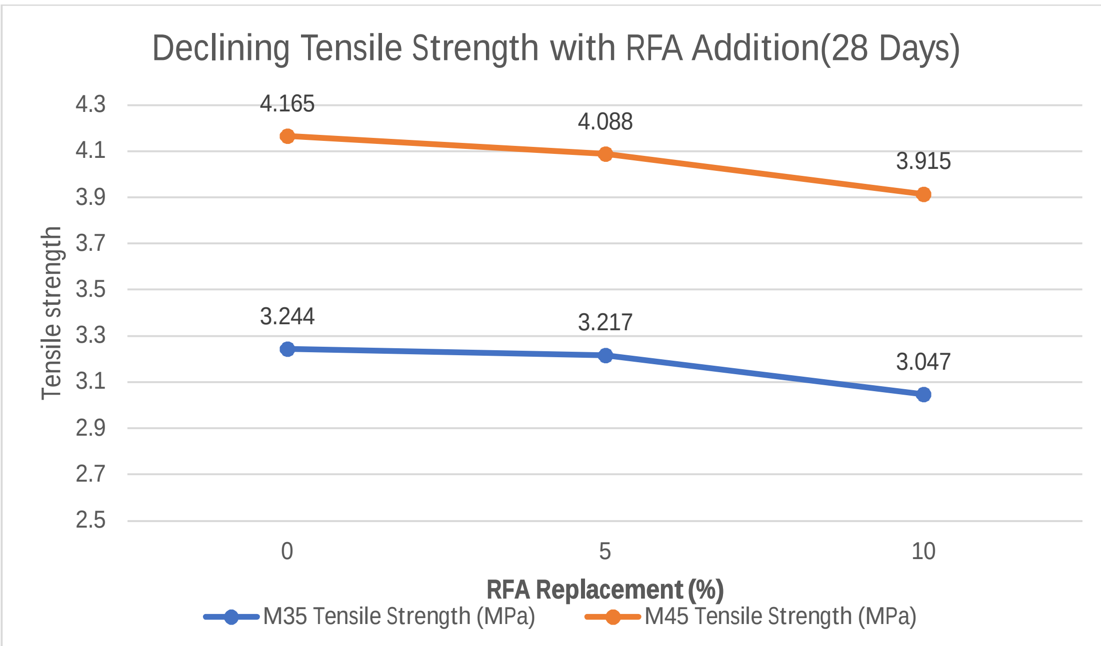

Figure 2: Split Tensile Strength at 28 Days vs RFA Replacement LeveTable 5: Compressive Strength Results (7 and 28 days)

Mixture ID	Flexural Strength (MPa)	vs. Control	Ratio (F/C)
M35-C	4.957	Reference	0.1100
M35-R5	4.914	99.1%	0.1101
M35-R10	4.656	93.9%	0.1101
M45-C	6.364	Reference	0.1100
M45-R5	6.245	98.1%	0.1100
M45-R10	6.073	95.1%	0.1118

Table 7: Flexural Strength Results (28 days)

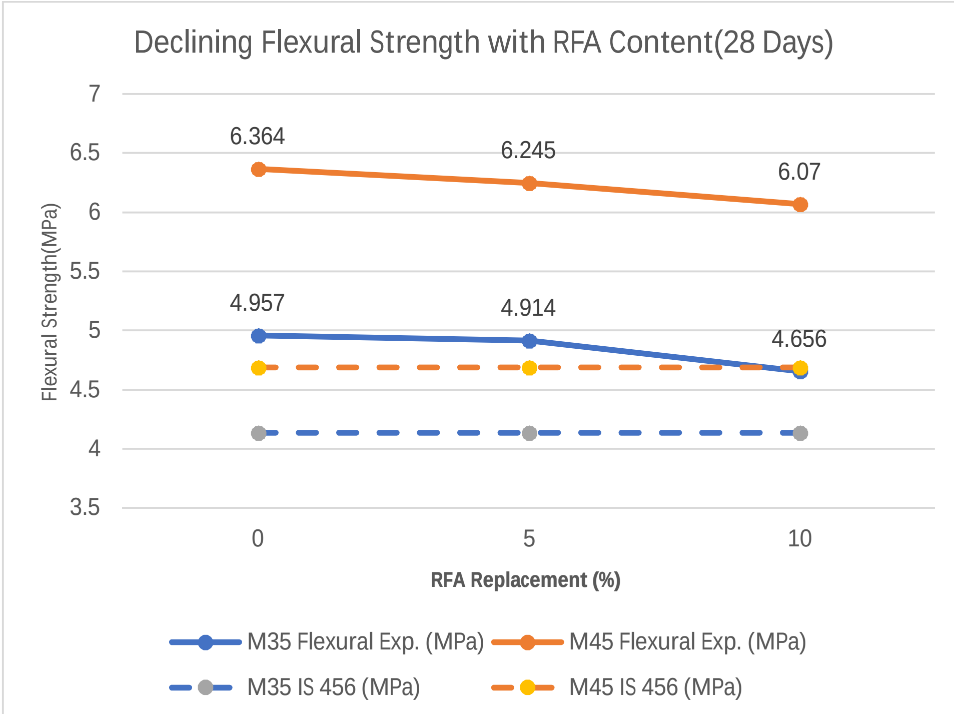

Figure 3: Flexural Strength vs RFA Replacement Level (28 days)

The mechanical behavior of SCC with recycled fine aggregates was assessed through compressive, split tensile, and flexural strength tests at 28 days. All three strength parameters followed a similar trend as the RFA content increased. At 5% replacement, the differences compared with control mixes were very small and practically insignificant, suggesting that limited use of recycled fines does not noticeably affect the load-carrying capacity or cracking resistance of SCC. When the replacement level was increased to 10%, a modest reduction in strength was observed across all tests, generally in the range of about 5–7%. This reduction is most likely associated with the higher porosity of recycled aggregates and the residual mortar attached to their surfaces, which can slightly weaken the bond within the concrete matrix. Despite this, the proportional relationship between compressive, tensile, and flexural strengths remained fairly consistent, indicating that the overall mechanical response and failure characteristics of SCC were not fundamentally altered. These results suggest that low levels of RFA can be used without major performance concerns, while somewhat higher replacements may still be acceptable depending on the structural requirements and exposure conditions.

C. Durability Assessment: Water Absorption

Mixture ID	Water Absorption (%)	Permeable Pore Volume	Quality Grade
M35-C	2.4	10.2	Excellent
M35-R5	3.1	12.6	Good
M35-R10	4.0	15.1	Fair
M45-C	2.1	9.2	Excellent
M45-R5	2.9	11.8	Good
M45-R10	3.6	14.2	Fair

Table 8: Water Absorption Test Results (28 days per IS 3812:2013)

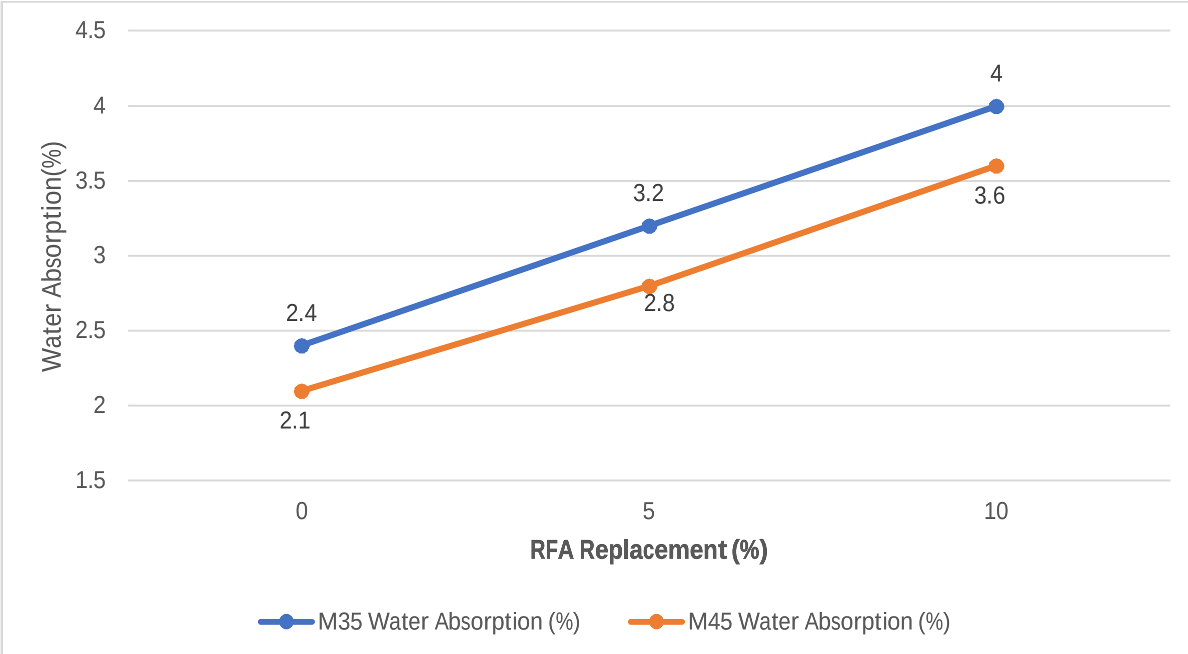

Figure 4: Water Absorption vs RFA Replacement Level

Water absorption increased progressively with RFA content, reflecting the higher porosity and residual mortar associated with recycled aggregates. However, all values remained well below the commonly accepted limit of 6%, suggesting that durability performance is still satisfactory for normal exposure conditions. The observed trend highlights the need for careful mix design and moisture control when higher RFA contents are considered, particularly in aggressive environmental conditions.

V. OBSERVATIONS

1) All mixes maintained self-compacting characteristics after adjusting water content for RFA absorption, confirming compatibility of recycled fines with SCC technology.
2) Mechanical strength reductions were minor at 5% replacement and moderate at 10%, showing a predictable relationship between RFA content and strength performance.
3) Tensile and flexural strengths followed similar trends to compressive strength, indicating no significant change in failure mechanism.
4) Durability indicators such as water absorption increased with RFA content but remained within acceptable limits for most practical applications.
5) Higher-grade concrete (M45) exhibited slightly better resistance to performance reduction, suggesting that increased binder content helps offset RFA limitations.

VI. CONCLUSIONS

This study demonstrates that recycled fine aggregates from construction and demolition waste can be successfully incorporated in self-compacting concrete at limited replacement levels. Fresh concrete properties remained within SCC acceptance criteria for all mixes tested. Mechanical strength reductions were negligible at 5% replacement and moderate at 10%, while durability indicators showed manageable increases in water absorption. Overall, the results suggest that partial replacement of natural sand by recycled fines can be adopted in SCC without significant compromise in performance, offering a practical pathway toward more sustainable concrete production. Further studies on long-term durability and higher replacement levels are recommended to expand application potential.

A. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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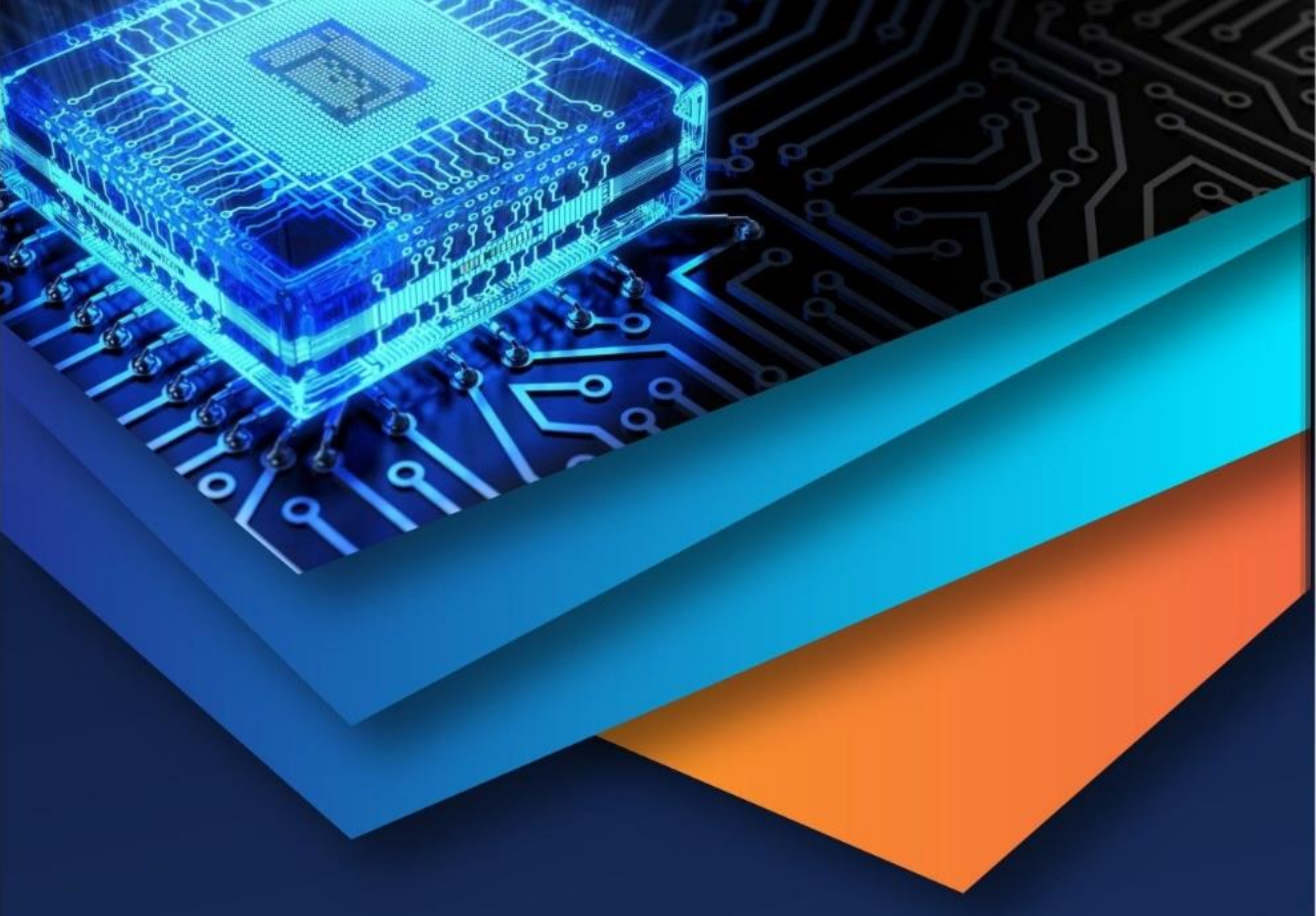

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