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Optimization of Steel Fibre Content for Enhancing Strength, Toughness, and Durability of High-Performance M50 Concrete

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Abstract: ***Concrete is one of the most widely used construction materials; however, its low tensile strength and susceptibility to cracking can affect the long-term performance of structures. The use of steel fibres in concrete is an effective method to improve its mechanical and durability properties. This study presents an experimental investigation on the strength and durability characteristics of M50 grade concrete incorporating steel fibres in different proportions.***
Steel fibres were added at varying percentages by volume of concrete, and the performance of the mixes was evaluated through a series of laboratory tests. Fresh concrete properties were assessed using the slump test, while hardened concrete properties were determined through compressive strength, split tensile strength, and flexural strength tests. Durability performance was evaluated using water absorption and chemical resistance tests.
The experimental results indicated that the inclusion of steel fibres significantly enhanced the tensile and flexural strength of M50 concrete, while also providing moderate improvement in compressive strength. The fibres helped control crack propagation and improved the overall toughness of the concrete. Durability tests showed reduced water absorption and better resistance to aggressive environmental conditions compared to conventional concrete. Among the different fibre contents investigated, the optimum performance was achieved at approximately 1.5% steel fibre content.
The study concludes that steel fibre-reinforced M50 concrete offers improved strength, crack resistance, and durability, making it suitable for high-performance structural applications such as pavements, industrial floors, bridges, and high-rise buildings.
Keywords: M50 Concrete, Steel Fibres, Compressive Strength, Split Tensile Strength, Flexural Strength, Durability.

I. INTRODUCTION

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and ease of production. However, conventional concrete exhibits low tensile strength, brittle behavior, and poor resistance to crack propagation, which can adversely affect the performance and service life of structures. To overcome these limitations, various types of fibres have been incorporated into concrete to improve its mechanical and durability properties.

Among the different fibre types, steel fibres are widely used because of their high tensile strength, modulus of elasticity, and ability to bridge cracks within the concrete matrix. The inclusion of steel fibres helps in controlling crack development, enhancing ductility, improving energy absorption capacity, and increasing resistance to impact and fatigue loading. As a result, Steel Fibre Reinforced Concrete (SFRC) has gained significant attention for applications such as industrial floors, pavements, bridges, tunnels, and high-rise structures. M50 grade concrete is classified as high-strength concrete and is commonly used in modern infrastructure projects where superior strength and durability are required. Although M50 concrete provides high compressive strength, it remains susceptible to brittle failure and crack formation under tensile and flexural stresses. The incorporation of steel fibres can effectively enhance its post-cracking behavior and overall structural performance. Several researchers have reported improvements in compressive strength, split tensile strength, flexural strength, and durability properties with the addition of steel fibres. However, the degree of improvement depends on factors such as fibre content, aspect ratio, fibre geometry, and mix composition. Therefore, it is essential to evaluate the optimum fibre dosage for achieving enhanced performance without significantly affecting workability.

The present study investigates the effect of steel fibre incorporation on the strength and durability characteristics of M50 grade concrete. Experimental tests were conducted to evaluate compressive strength, split tensile strength, flexural strength, and durability properties of concrete mixes containing different percentages of steel fibres. The results provide valuable insights into the suitability of steel fibre reinforced M50 concrete for high-performance structural applications.

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II. LITERATURE REVIEW

The application of steel fibres in concrete has gained significant attention in recent decades due to their ability to improve the mechanical properties and durability performance of concrete structures. Researchers have extensively investigated the influence of steel fibres on compressive strength, tensile strength, flexural strength, crack resistance, toughness, and long-term durability. The existing literature can be broadly categorized into mechanical strength enhancement, durability performance, crack control and toughness characteristics, fibre dosage optimization, and high-strength concrete applications.

Mechanical strength improvement is one of the most extensively studied aspects of Steel Fibre Reinforced Concrete (SFRC). Song and Hwang (2004) reported that the incorporation of steel fibres significantly enhanced the split tensile and flexural strengths of high-strength concrete due to the crack-bridging mechanism provided by the fibres. Khaloo and Kim (2010) observed that steel fibre addition increased compressive strength by approximately 5–15% while substantially improving tensile and flexural performance. Similarly, Singh and Sharma (2017) investigated M50 grade concrete reinforced with steel fibres and found improvements of 20–35% in split tensile strength and 15–30% in flexural strength compared to conventional concrete. These studies demonstrate that steel fibres contribute significantly to the load-carrying capacity and structural performance of concrete.

Durability enhancement is another important area of research in steel fibre reinforced concrete. Yazici et al. (2014) evaluated the permeability characteristics of SFRC and reported reduced water absorption and chloride penetration due to improved crack control. Sahmaran et al. (2015) found that steel fibres enhanced resistance against sulphate and acid attacks by limiting crack widths and restricting the ingress of aggressive chemicals. Kumar et al. (2019) further confirmed that steel fibre reinforced concrete exhibited lower permeability and improved durability under harsh environmental conditions. These findings indicate that steel fibres can significantly improve the service life and long-term performance of concrete structures.

Crack control and toughness improvement have been identified as major benefits of steel fibre incorporation. Banthia and Gupta (2006) investigated the impact resistance and energy absorption characteristics of fibre reinforced concrete and concluded that steel fibres effectively delayed crack propagation and enhanced post-cracking behavior. ACI Committee 544 (2009) reported that steel fibres improve ductility, toughness, fatigue resistance, and resistance to shrinkage cracking in concrete structures. Rao and Seshu (2013) observed that the presence of steel fibres delayed crack initiation and increased the energy absorption capacity of concrete, thereby improving structural reliability under dynamic and repeated loading conditions.

Several researchers have focused on determining the optimum fibre content required for achieving maximum performance. Afroughsabet and Ozbakkaloglu (2015) reported that steel fibre contents ranging from 1.0% to 1.5% by volume provided the most effective balance between strength enhancement and workability. Patel and Desai (2018) reached similar conclusions while studying hooked-end steel fibres in high-strength concrete, recommending fibre dosages of 1–1.5% for structural applications. Sharma et al. (2021) also found that M50 concrete containing 1.5% steel fibres exhibited superior compressive, tensile, and flexural strength compared to other fibre percentages. These studies suggest that excessive fibre content may reduce workability without providing proportional strength gains.

The use of steel fibres in high-strength concrete has emerged as a promising solution for modern infrastructure projects. Prakash and Rao (2020) investigated the flexural behavior of steel fibre reinforced M50 concrete beams and reported significant improvements in stiffness, load-carrying capacity, and crack resistance. Reddy and Kumar (2022) evaluated the durability performance of high-strength steel fibre reinforced concrete under chloride and sulphate exposure and observed enhanced resistance to chemical deterioration. These findings highlight the suitability of steel fibre reinforced M50 concrete for applications such as bridges, pavements, industrial floors, and high-rise structures where both strength and durability are critical requirements.

Despite the considerable progress made in this field, certain research gaps remain. Most studies have focused primarily on strength characteristics, while comparatively fewer investigations have addressed both strength and durability performance simultaneously for M50 grade concrete. Furthermore, the optimum dosage of steel fibres varies among studies due to differences in material properties, fibre geometry, and testing conditions. Therefore, a comprehensive experimental investigation is required to evaluate the combined effect of steel fibres on the strength and durability properties of M50 concrete and identify the most suitable fibre content for practical engineering applications.

The review of existing literature indicates that while significant progress has been made in bridge risk assessment, there remains a need for integrated approaches that combine traditional risk evaluation techniques with modern predictive analytics. Particularly in the Indian context, limited research has focused on applying machine learning algorithms for proactive risk prediction in river bridge construction projects. Therefore, the present study aims to address this gap by developing a comprehensive framework that integrates qualitative risk assessment with Random Forest-based predictive modeling for effective risk management in large-scale bridge infrastructure projects.

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III. METHODOLOGY

A. Materials

M50 grade concrete was prepared using Ordinary Portland Cement (OPC) 53 Grade conforming to IS 12269:2013, natural river sand as fine aggregate, crushed coarse aggregate of maximum size 20 mm, potable water, and a polycarboxylate ether-based superplasticizer. Hooked-end steel fibres with a length of 35 mm, diameter of 0.55 mm, aspect ratio of 64, and tensile strength of approximately 1100 MPa were used as reinforcement. The physical properties of the constituent materials were determined in accordance with relevant Indian Standard specifications.

B. Mix Proportioning

The concrete mix was designed for a target compressive strength of 50 MPa following the guidelines of IS 10262:2019 and IS 456:2000. The control mix consisted of cement, fine aggregate, coarse aggregate, water, and superplasticizer with a water–cement ratio of 0.36. Steel fibres were incorporated at different volume fractions of 0%, 0.5%, 1.0%, 1.5%, and 2.0% to evaluate their influence on the strength and durability characteristics of concrete. The details of the concrete mixes are presented in Table 1.

Table 1. Concrete Mix Combinations

Mix ID	*Steel Fibre Content (%)*
SF0	0.0
SF0.5	0.5
SF1.0	1.0
SF1.5	1.5
SF2.0	2.0

C. Specimen Preparation

The required quantities of cement, fine aggregate, and coarse aggregate were dry mixed until a uniform blend was obtained. Steel fibres were then gradually added to ensure uniform distribution and prevent fibre balling. Water mixed with superplasticizer was added to the dry mix, and thorough mixing was carried out to obtain a homogeneous concrete mixture. Fresh concrete was cast into moulds and compacted using a table vibrator. After 24 hours, the specimens were demoulded and cured in water at room temperature until the testing age.

D. Experimental Program

The experimental investigation included workability, strength, and durability assessments of the prepared concrete mixes. The testing program is summarized in Table 2.

Table 2. Experimental Testing Program

Test	*Specimen Size*	*Standard*
Slump Test	Fresh Concrete	IS 1199:2018
Compressive Strength	150 × 150 × 150 mm Cube	IS 516:2018
Split Tensile Strength	150 × 300 mm Cylinder	IS 5816:1999
Flexural Strength	100 × 100 × 500 mm Beam	IS 516:2018
Water Absorption	100 mm Cube	ASTM C642
Acid Resistance	100 mm Cube	ASTM Standards
Sulphate Resistance	100 mm Cube	ASTM Standards

E. Strength Evaluation

Compressive strength tests were conducted on cube specimens after 7, 28, and 56 days of curing. Split tensile strength tests were performed on cylindrical specimens, while flexural strength was determined using beam specimens under two-point loading conditions. The average values obtained from three specimens were considered for analysis.

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F. Durability Assessment

The durability performance of the concrete mixes was evaluated through water absorption, acid resistance, and sulphate resistance tests. Water absorption was measured to assess the permeability characteristics of concrete. For acid resistance, specimens were immersed in a 5% sulphuric acid (H_2SO_4) solution for 28 days, and the percentage weight loss and residual strength were determined. Similarly, sulphate resistance was evaluated by exposing specimens to a 5% sodium sulphate (Na_2SO_4) solution and measuring the reduction in mass and compressive strength.

G. Data Analysis

The experimental results obtained from all tests were analyzed and compared with those of the control mix. The influence of steel fibre content on compressive strength, split tensile strength, flexural strength, water absorption, acid resistance, and sulphate resistance was evaluated using graphical and statistical comparisons. The optimum steel fibre dosage was identified based on overall mechanical and durability performance.

This systematic approach enabled a comprehensive assessment of the effect of steel fibres on the strength and durability properties of M50 grade concrete.

IV. RESULTS AND DISCUSSIONS

A. Slump Test Results

The workability of concrete decreased with increasing steel fibre content due to increased internal friction and reduced flowability.

Table 3. Slump Test Results

Mix ID	*Steel Fibre Content (%)*	*Slump (mm)*
SF0	0.0	95
SF0.5	0.5	88
SF1.0	1.0	80
SF1.5	1.5	72
SF2.0	2.0	65

B. Compressive Strength Results

The compressive strength increased with fibre addition up to 1.5%, after which a slight reduction was observed due to reduced workability and fibre clustering.

Table 4. Compressive Strength Results (MPa)

Mix ID	*7 Days*	*28 Days*	*56 Days*
SF0	38.5	52.4	55.6
SF0.5	40.2	54.8	58.2
SF1.0	42.1	57.6	60.5
SF1.5	44.3	60.8	63.7
SF2.0	43.5	59.1	62.0

C. Split Tensile Strength Results

Steel fibres significantly improved tensile strength by bridging cracks and delaying crack propagation.

Table 5. Split Tensile Strength Results

Mix ID	*28 Days (MPa)*
SF0	4.25
SF0.5	4.82
SF1.0	5.31
SF1.5	5.92
SF2.0	5.74

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D. Flexural Strength Results

The addition of steel fibres greatly improved flexural performance and toughness.

Table 6. Flexural Strength Results

Mix ID	*28 Days (MPa)*
SF0	5.60
SF0.5	6.28
SF1.0	6.95
SF1.5	7.68
SF2.0	7.42

E. Water Absorption Test Results

Water absorption decreased with increasing fibre content, indicating improved durability.

Table 7. Water Absorption Results

Mix ID	*Water Absorption (%)*
SF0	4.20
SF0.5	3.95
SF1.0	3.60
SF1.5	3.25
SF2.0	3.30

F. Acid Resistance Test Results

Specimens were immersed in 5% H_2SO_4 solution for 28 days.

Table 8. Acid Resistance Results

Mix ID	*Weight Loss (%)*	*Residual Strength (MPa)*
SF0	7.20	46.8
SF0.5	6.10	49.2
SF1.0	5.30	52.6
SF1.5	4.40	56.4
SF2.0	4.60	55.8

G. Sulphate Resistance Test Results

Specimens were immersed in 5% Na_2SO_4 solution for 28 days.

Table 9. Sulphate Resistance Results

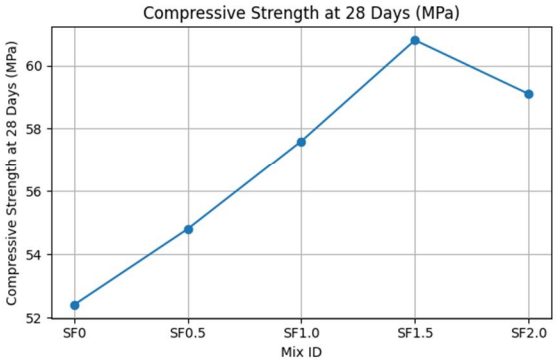
Mix ID	*Weight Loss (%)*	*Residual Strength (MPa)*
SF0	4.80	48.2
SF0.5	4.10	50.5
SF1.0	3.50	53.8
SF1.5	2.90	57.1
SF2.0	3.10	56.3

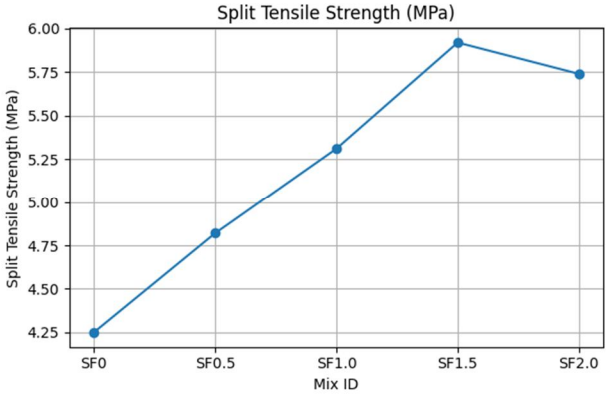
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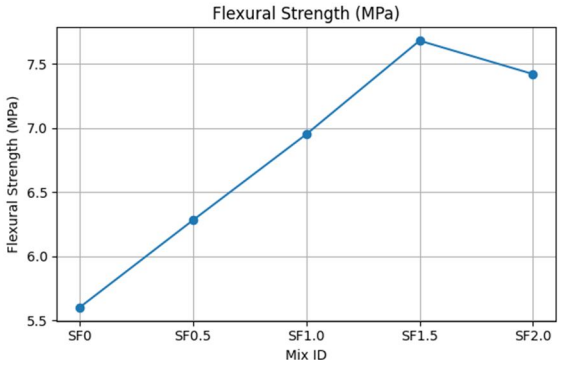
H. Summary of Results

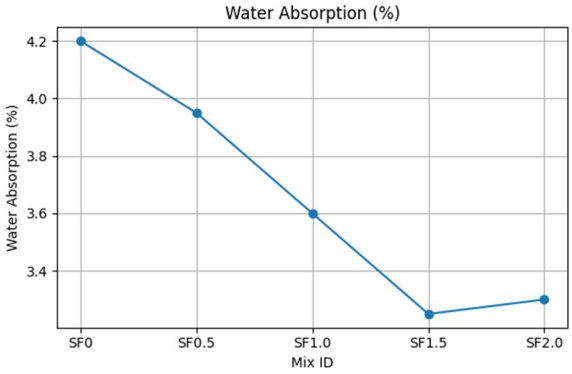
Table 10. Optimum Performance Comparison at 28 Days

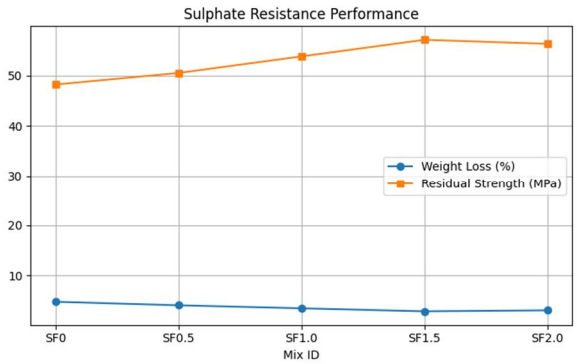
Property	*SF0*	*SF1.5*	*Improvement (%)*
Compressive Strength (MPa)	52.4	60.8	16.0
Split Tensile Strength (MPa)	4.25	5.92	39.3
Flexural Strength (MPa)	5.60	7.68	37.1
Water Absorption (%)	4.20	3.25	22.6 Reduction
Acid Weight Loss (%)	7.20	4.40	38.9 Reduction
Sulphate Weight Loss (%)	4.80	2.90	39.6 Reduction

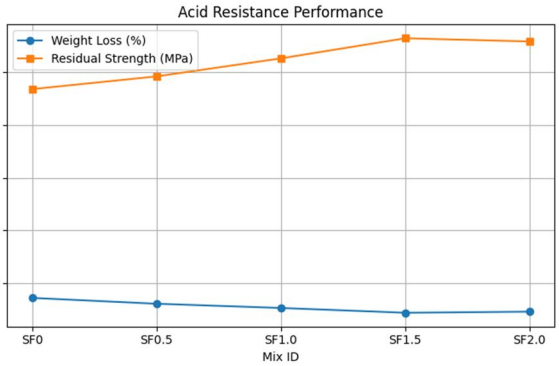












V. DISCUSSION

The results indicate that steel fibre incorporation significantly enhanced the mechanical and durability properties of M50 concrete. The highest performance was achieved at 1.5% steel fibre content, where compressive strength increased by approximately 16%, split tensile strength by 39%, and flexural strength by 37% compared to conventional concrete. Durability characteristics also improved considerably through reduced water absorption and lower deterioration under acid and sulphate exposure. Therefore, 1.5% steel fibre content can be considered the optimum dosage for M50 concrete in terms of strength, durability, and practical application.

VI. CONCLUSIONS

Based on the experimental investigation conducted on the strength and durability properties of M50 grade concrete incorporating steel fibres, the following conclusions can be drawn:

1) The incorporation of steel fibres significantly influenced the mechanical and durability characteristics of M50 concrete. The performance of concrete improved with increasing fibre content up to an optimum level.
2) The workability of fresh concrete decreased with the increase in steel fibre content. The slump value reduced from 95 mm for conventional concrete (SF0) to 65 mm for concrete containing 2.0% steel fibres (SF2.0) due to increased internal friction and fibre interlocking.
3) Compressive strength showed a gradual increase with the addition of steel fibres. The maximum 28-day compressive strength of 60.8 MPa was obtained for the SF1.5 mix, representing an improvement of approximately 16% over conventional concrete.
4) Split tensile strength improved considerably with fibre incorporation. The highest tensile strength of 5.92 MPa was achieved at 1.5% steel fibre content, corresponding to an increase of approximately 39% compared to the control mix.
5) Flexural strength exhibited significant enhancement due to the crack-bridging action of steel fibres. The maximum flexural strength of 7.68 MPa was recorded for the SF1.5 mix, which was about 37% higher than that of conventional concrete.
6) The addition of steel fibres improved the durability characteristics of concrete by reducing permeability and restricting crack propagation. Water absorption decreased from 4.20% for the control mix to 3.25% for the SF1.5 mix.
7) Acid resistance and sulphate resistance of concrete improved with the inclusion of steel fibres. Fibre-reinforced specimens exhibited lower weight loss and higher residual compressive strength after exposure to aggressive chemical environments.
8) The optimum performance was achieved at 1.5% steel fibre content, which provided the best balance between workability, strength enhancement, and durability performance.
9) The incorporation of steel fibres transformed the brittle behavior of conventional M50 concrete into a more ductile and crack-resistant material, thereby enhancing structural reliability and service life.
10) Based on the overall results, steel fibre reinforced M50 concrete with 1.5% fibre content is recommended for high-performance applications such as bridges, industrial floors, pavements, airport runways, tunnels, and high-rise structures where superior strength and durability are required.

A. Future Scope

1) Investigation of hybrid fibre systems combining steel fibres with synthetic or natural fibres.
2) Study of long-term durability under marine and extreme environmental conditions.
3) Evaluation of fatigue and impact resistance of steel fibre reinforced M50 concrete.
4) Application of steel fibre reinforced concrete in precast and sustainable construction systems.
5) Microstructural analysis using SEM and XRD techniques to understand fibre–matrix interaction.

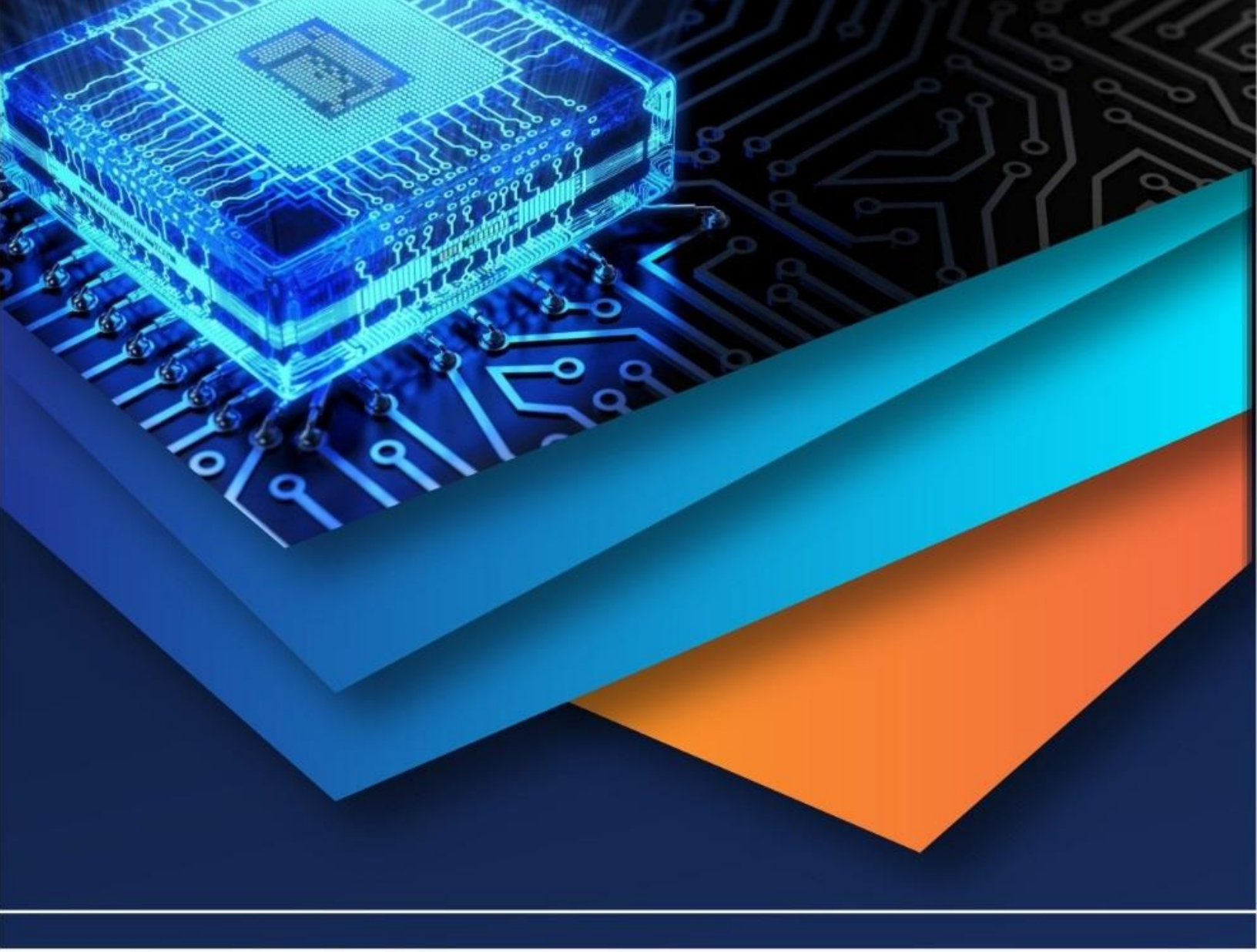
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