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Hypo Sludge as Sustainable Construction Material for False Ceiling Panel

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Abstract: ***Rapid industrialization and paper manufacturing generate large quantities of hypo sludge, creating significant disposal and environmental challenges. This study investigates the feasibility of utilizing hypo sludge as a sustainable construction material for false ceiling panels by combining it with gypsum and polypropylene fiber. Eight different mix proportions were developed, including 100% hypo sludge, 100% gypsum, hypo sludge–gypsum combinations of 70:30, 65:35, and 60:40, and fiber-reinforced mixes of 70:25:5, 65:30:5, and 60:35:5. The developed specimens were experimentally evaluated for compressive strength, flexural strength, and water absorption. Gypsum improved bonding, strength, surface finish, and dimensional stability, while polypropylene fiber enhanced crack resistance, toughness, flexural performance, and durability. The fiber-reinforced mixes demonstrated better overall performance than hypo sludge-rich mixes. Among the investigated compositions, the 60:35:5 mix showed the best overall performance among the hypo sludge-based mixes. The study demonstrates that properly proportioned hypo sludge composites can provide a lightweight and sustainable alternative for non-structural interior false ceiling applications while reducing industrial waste disposal and supporting environmentally responsible construction practices.***

Keywords: Hypo Sludge, Gypsum, Polypropylene Fiber, False Ceiling Panel, Sustainable Construction etc.

I. INTRODUCTION

The rapid growth of industrialization and manufacturing activities has resulted in the generation of large quantities of industrial waste. Improper disposal of industrial by-products creates serious environmental and land-management problems because large areas are required for dumping and landfilling. Such disposal can also contribute to soil and water pollution. Consequently, the utilization of industrial waste materials in useful construction products has become an important approach in sustainable engineering. Converting waste into value-added construction materials can reduce disposal requirements, conserve natural resources, and support environmentally responsible development. Hypo sludge is a solid waste generated by paper manufacturing industries, particularly during recycling and bleaching processes. Large quantities of this material are produced and require appropriate disposal. The presence of calcium compounds and fibrous materials gives hypo sludge potential for use as a partial replacement material in construction applications. However, its direct application is limited by relatively lower strength, porous characteristics, high water absorption, and brittle behavior. Therefore, suitable binding and reinforcing materials are required to improve its engineering performance. False ceiling panels are widely used in residential, commercial, and institutional buildings. They provide an attractive interior finish and can be used for concealing electrical and mechanical services while contributing to thermal and acoustic functions. Conventional gypsum boards are commonly used because they provide a smooth surface, lightweight construction, and convenient installation. However, the increasing demand for sustainable and economical construction materials has encouraged research into waste-based alternatives that can provide adequate performance while reducing environmental impact.

Figure 1 : Hypo Sludge Dumping Area BGPPL Ballarpur

The present study investigates the development of a sustainable false ceiling panel using hypo sludge, gypsum, and polypropylene fiber. Gypsum is incorporated to improve bonding and the overall strength of the composite, while polypropylene fiber is used as reinforcement to improve crack resistance and flexural performance. Different proportions of hypo sludge and gypsum, with selected fiber reinforcement, are prepared and experimentally investigated. The study evaluates important properties including compressive strength, flexural strength, and water absorption using cast specimens and relevant Indian Standard procedures.

The research was motivated by the observation of a paper mill sludge disposal area at Ballarpur, Maharashtra, where vegetation was successfully growing over deposited sludge. This observation encouraged investigation into alternative uses of hypo sludge beyond disposal. A review of previous research indicated that paper mill sludge has been investigated for applications such as bricks, concrete, cement-based composites, and masonry products, while comparatively limited research has focused on its use in false ceiling panels. This provides an important basis for developing hypo sludge-based ceiling materials.

The study therefore aims to develop and evaluate an eco-friendly, lightweight, and economical composite material for non-structural false ceiling applications. By incorporating hypo sludge into the panel, the research seeks to reduce industrial waste disposal and dependence on conventional raw materials. The developed composite is intended to provide adequate mechanical performance, improved crack resistance, and acceptable durability for interior applications. Overall, the investigation supports sustainable construction by transforming an industrial waste material into a useful building product while contributing to waste minimization, resource conservation, and environmentally responsible construction practices.

A. Problem Identification

1) Increasing Hypo Sludge Generation: Paper manufacturing and recycling processes generate large quantities of hypo sludge. Continuous accumulation of this waste creates difficulties in safe disposal and requires substantial land for dumping, resulting in environmental and land-management concerns.
2) Environmental Pollution: Improper disposal of hypo sludge through open dumping or landfilling can contribute to land degradation and pollution of surrounding environmental resources. Effective utilization of this industrial waste is therefore required to minimize disposal-related problems.
3) Dependence on Conventional Materials: False ceiling systems commonly use conventional materials such as gypsum boards. Continued dependence on conventional raw materials increases resource consumption and creates a need for economical and environmentally sustainable alternatives.
4) Limited Engineering Performance of Raw Hypo Sludge: Although hypo sludge contains calcium compounds and fibrous materials, its direct construction application is restricted by lower strength, porous characteristics, water absorption, and brittle behavior. Therefore, suitable materials such as gypsum and polypropylene fiber are required to improve its performance.
5) Limited False Ceiling Applications: Previous studies have investigated hypo sludge in bricks, concrete, and cement-based products, but limited research has focused specifically on hypo sludge-based false ceiling panels. This creates a need to experimentally develop and evaluate a suitable composite for non-structural interior applications.

II. LITERATURE SURVEY

1) Chandra Sekar et al. (2023), investigated the development of sustainable concrete incorporating hypo sludge, basalt fibre, and latex. The study focused on reducing cement consumption and utilizing paper-industry waste as a construction material. Experimental investigations evaluated mechanical and durability-related properties of the developed concrete. The incorporation of hypo sludge demonstrated its potential as a partial replacement material, while basalt fibre and latex helped improve the performance of the composite. The study concluded that combining industrial waste with suitable reinforcement can produce useful construction materials while reducing environmental impacts. This research supports the present study's approach of combining hypo sludge with gypsum and polypropylene fiber.
2) Mahesh et al. (2023), developed several value-added products using secondary paper mill sludge, including bricks, briquettes, ground chakra bases, and eco-friendly composites. The sludge was dewatered, powdered, and combined with cement, manufactured sand, quarry dust, and fly ash for brick production. The resulting bricks achieved approximately 5.29 N/mm² compressive strength, 3.84% water absorption, and nil efflorescence. Other sludge-based products also demonstrated potential for practical applications. The researchers highlighted paper mill sludge as a useful waste resource rather than a disposal burden. Their findings demonstrate the feasibility of converting paper-industry sludge into sustainable products, supporting further investigation into lightweight non-structural ceiling panels.

3) Xia et al. (2023), presented a comprehensive review of sludge and sludge ash recycling for low-carbon construction materials. The researchers examined applications in cement clinker, concrete, bricks, ceramics, and other construction products. Their review showed that sludge-derived materials can contribute to resource conservation and waste reduction because many sludge components possess chemical characteristics suitable for cementitious applications. The study also discussed immobilization of potentially toxic elements within construction matrices, highlighting the importance of environmental safety during waste utilization. The authors identified further opportunities for improving sludge utilization and developing higher-value construction products. This review provides a broader sustainability basis for investigating hypo sludge-based false ceiling panels.

4) Chouksey et al. (2024), reviewed the utilization of paper mill lime sludge in various construction materials, including bricks, tiles, cement, mortar, and concrete. Their findings indicated that temperature-treated lime sludge can provide useful construction properties and partially replace conventional materials. The review reported that lime sludge replacement is generally limited to about 10–20% when used independently, while higher replacement levels can be achieved when combined with supplementary cementitious materials such as fly ash and metakaolin. The researchers emphasized that utilizing paper mill sludge can reduce natural-resource depletion and environmental impacts. Their study recommends further investigation into higher-value applications of paper-industry waste for sustainable construction.

5) Hussain (2024), investigated hypo sludge as a partial cement replacement in M30-grade concrete using replacement levels of 0%, 3%, 6%, 12%, and 15%. The study evaluated workability, compressive strength, flexural strength, and split tensile strength. Results indicated that concrete workability decreased as hypo sludge content increased, while mechanical strength improved with increasing replacement up to the identified optimum level. The study reported 12% hypo sludge as the optimum replacement percentage under the investigated conditions. These findings demonstrate that hypo sludge can contribute positively to construction composites when properly proportioned. The research supports the concept of optimizing waste-material content to achieve adequate performance in sustainable construction applications.

III. RESEARCH METHODOLOGY

A. *Proposed System*

Figure 2. Flowchart of the Proposed Research Methodology

- Raw Material Collection: Collect hypo sludge from paper-industry waste disposal areas along with gypsum, polypropylene fiber, and clean water.
- Material Characterization: Examine the physical and chemical characteristics of hypo sludge, gypsum, and polypropylene fiber before developing the composite.
- Mix Proportion Development: Prepare different combinations of hypo sludge and gypsum, including fiber-reinforced mixes with polypropylene fiber.
- Specimen Preparation: Properly mix the selected materials with water and cast specimens using suitable moulds for laboratory testing.
- Curing: Maintain the prepared specimens under appropriate curing conditions to achieve sufficient bonding and strength development.
- Experimental Testing: Evaluate compressive strength, flexural strength, and water absorption to determine mechanical and durability characteristics.
- Performance Analysis: Analyze the test results and study the influence of gypsum and polypropylene fiber on the composite properties.
- Comparative Evaluation: Compare the developed hypo sludge-based composite with conventional gypsum material based on strength, water absorption, suitability, and sustainability.
- Optimum Mix Selection: Identify the most suitable composition for lightweight, non-structural false ceiling panel applications.
- Sustainable Application: Utilize the optimized composite as an eco-friendly alternative while reducing industrial waste disposal and promoting sustainable construction.

B. Experimental Investigation

The experimental investigation included material collection, preparation of mix proportions, casting of specimens, curing, and testing of specimens for compressive strength, flexural strength, and water absorption as per relevant Indian Standard (IS) codes related to gypsum products and gypsum plaster boards.

The study mainly referred to the following Indian Standard codes:

- IS 2095 (Part 1): 2011 – Gypsum Plaster Boards Specifications
- IS 2542 (Part 1 to Part 8): Methods of Test for Gypsum Products
- IS 8272: Specification for Gypsum Ceiling Tiles and Panels.

A. Mix Proportions

Eight different mix compositions were prepared for the experimental investigation.

Table 1: Mix Composition

Mix ID	**Mix Composition**
M1	100% Hypo Sludge
M2	100% Gypsum
M3	70% Hypo Sludge + 30% Gypsum
M4	65% Hypo Sludge + 35% Gypsum
M5	60% Hypo Sludge + 40% Gypsum
M6	70% Hypo Sludge + 25% Gypsum + 5% Polypropylene Fiber
M7	65% Hypo Sludge + 30% Gypsum + 5% Polypropylene Fiber
M8	60% Hypo Sludge + 35% Gypsum + 5% Polypropylene Fiber

B. Preparation of Specimens:

1) Mixing Procedure

- The required quantities of gypsum and hypo sludge were measured according to the selected mix proportion.
- Dry mixing of gypsum, hypo sludge, and polypropylene fiber was carried out thoroughly to obtain uniform distribution.
- Water was added gradually to the dry mix to obtain a homogeneous paste.
- Proper mixing was done manually until uniform consistency was achieved.

2) Casting of Specimens

Cube and prism moulds were cleaned properly before casting.
After casting, the top surfaces were leveled and finished smoothly.

3) Cube Specimens

Figure 3: Cube Mould 70.06 x 70.06 x 70.06 mm

- Cube specimens were prepared for compressive strength testing as per IS 2542.
- The moulds were filled with prepared mix in layers.
- Proper compaction was carried out to remove air voids.

4) Prism Specimens

- Prism specimens were prepared for flexural strength testing as per IS 2542.
- The mix was placed uniformly in prism moulds and compacted properly.

Figure 4: Prism Size 100 x 100 x 200 mm

C. Experimental Tests Conducted

The prepared specimens were tested in the laboratory to evaluate the engineering properties of the hypo sludge–gypsum composite material intended for false ceiling applications. The tests were conducted according to relevant 29
Indian Standard (IS) codes referred for gypsum products and gypsum plaster boards.
The following tests were carried out:

1) Compressive Strength Test

Figure 5 : Compressive Testing machine

Table 2: Specimen Details Compression Test

Particular	Description
Type of Specimen	Cube
Specimen Size	70.6 mm × 70.6 mm × 70.6 mm
Number of Specimens	3 specimens for each mix
Testing Machine	Compression Testing Machine (CTM)

The compressive strength test was conducted to determine the load-carrying capacity of the developed hypo sludge–gypsum composite specimens. Cube specimens were prepared using different mix proportions and tested under compressive loading in a compression testing machine. The behavior of pure hypo sludge, gypsum, and fiber-reinforced mixes was compared. Pure hypo sludge showed lower strength and developed cracks at relatively lower loads, whereas gypsum addition improved bonding and compressive performance. The fiber-reinforced mixes provided improved resistance to cracking and failure.

2) Flexural Strength Test

Figure 6: Flexural Testing in UTM

Table 3: Specimen Details Flexural Test

Particular	Description
Type of Specimen	Prism
Specimen Size	1000 mm × 100 mm × 200 mm
Number of Specimens	3 specimens for each mix
Testing Method	Three-point loading method
Testing Machine	Universal Testing Machine (UTM)

The flexural strength test was performed to evaluate the bending resistance of the developed false ceiling material. Prism specimens prepared from different hypo sludge, gypsum, and polypropylene fiber combinations were subjected to flexural loading. Pure hypo sludge specimens exhibited lower resistance because of weak interparticle bonding and brittle behavior. Addition of gypsum improved internal bonding and bending strength. Polypropylene fiber further enhanced flexural performance by bridging cracks and reducing sudden brittle failure. Among the hypo sludge-based mixes, M8 demonstrated the highest flexural strength.

3) Water Absorption Test

Table 4: Specimen Details Water Absorption

Particular	Description
Type of Specimen	Cube
Specimen Condition	Oven dried
Water Immersion Duration	24 hours
Number of Specimens	3 specimens for each mix

The water absorption test was conducted to evaluate the moisture resistance and durability of the developed composite panels. Specimens from different mix proportions were exposed to water and their absorption behavior was observed. Pure hypo sludge exhibited high water absorption because of its porous and fibrous structure. Increasing gypsum content improved compactness and reduced voids, while polypropylene fiber further improved moisture resistance because of its non-absorbent nature. Fiber-reinforced specimens maintained better dimensional stability and surface integrity after immersion, indicating improved suitability for interior false ceiling applications.

IV. RESULTS AND DISCUSSION

The experimental results were analyzed to study the influence of gypsum and polypropylene fiber on the engineering properties of hypo sludge-based composite material. Comparative discussions were made between conventional gypsum specimens and modified hypo sludge composite specimens.

A. Mix Compositions

Table 5: Mix compositions

Mix ID	**Mix Composition**
M1	100% Hypo Sludge
M2	100% Gypsum
M3	70% Hypo Sludge + 30% Gypsum
M4	65% Hypo Sludge + 35% Gypsum
M5	60% Hypo Sludge + 40% Gypsum
M6	70% Hypo Sludge + 25% Gypsum + 5% Polypropylene Fiber
M7	65% Hypo Sludge + 30% Gypsum + 5% Polypropylene Fiber
M8	60% Hypo Sludge + 35% Gypsum + 5% Polypropylene Fiber

B. Compressive Strength Test Results

Table 6: Strength Test Results

Mix ID	Series 1 (N/mm²)	Series 2 (N/mm²)	Series 3 (N/mm²)
M1	0.10	0.12	0.20
M2	4.21	6.11	8.35
M3	0.10	0.12	0.18
M4	0.16	0.12	0.10
M5	0.12	0.14	0.17
M6	0.31	0.30	0.30
M7	0.34	0.35	0.30
M8	0.41	0.34	0.38

Table 7: Average Compressive Strength Values

Mix ID	Mix Composition	Average Compressive Strength (N/mm²)
M1	100% Hypo Sludge	0.10
M2	100% Gypsum	6.22
M3	70% Hypo Sludge + 30% Gypsum	0.13
M4	65% Hypo Sludge + 35% Gypsum	0.14
M5	60% Hypo Sludge + 40% Gypsum	0.15
M6	70% Hypo Sludge + 25% Gypsum + 5% Polypropylene Fiber	0.36
M7	65% Hypo Sludge + 30% Gypsum + 5% Polypropylene Fiber	0.35
M8	60% Hypo Sludge + 35% Gypsum + 5% Polypropylene Fiber	0.37

The compressive strength results showed considerable variation among the investigated mixes. The gypsum specimen demonstrated the highest strength due to its dense structure and better bonding characteristics, while pure hypo sludge exhibited the lowest strength because of weak bonding and porosity. Gypsum addition improved strength by enhancing particle bonding. Polypropylene fiber further improved performance by reducing microcracks and distributing loads effectively. Among the hypo sludge-based composites, M8 showed better compressive performance due to its higher gypsum content and fiber reinforcement.

C. Flexural Strength Test Results

Table 8: Flexural Strength Test Results

Mix ID	Series 1 (N/mm²)	Series 2 (N/mm²)	Series 3 (N/mm²)
M1	0.10	0.12	0.20
M2	4.21	6.11	8.35
M3	0.10	0.12	0.18
M4	0.16	0.12	0.10
M5	0.12	0.14	0.17
M6	0.31	0.30	0.30
M7	0.34	0.35	0.30
M8	0.41	0.34	0.38

Table 9: Average Flexural Strength Values

Mix ID	Mix Composition	Average Flexural Strength (N/mm²)
M1	100% Hypo Sludge	11.41
M2	100% Gypsum	25.97
M3	70% Hypo Sludge + 30% Gypsum	13.03
M4	65% Hypo Sludge + 35% Gypsum	13.03
M5	60% Hypo Sludge + 40% Gypsum	13.04
M6	70% Hypo Sludge + 25% Gypsum + 5% Polypropylene Fiber	13.45
M7	65% Hypo Sludge + 30% Gypsum + 5% Polypropylene Fiber	13.50
M8	60% Hypo Sludge + 35% Gypsum + 5% Polypropylene Fiber	13.60

The flexural strength test evaluated the bending resistance of the developed specimens. Pure gypsum showed good flexural performance due to its compact structure and cohesion, while pure hypo sludge exhibited lower resistance because of weak bonding and brittle behavior. Gypsum improved the flexural strength of mixes M3–M8. Polypropylene fiber further enhanced mixes M6–M8 by bridging cracks, improving toughness, and reducing sudden failure. Fiber-reinforced specimens showed gradual cracking, with M8 achieving the highest flexural strength among hypo sludge-based mixes.

D. Water Absorption Test Results

Table 10: Observed Water Absorption Values

Mix ID	Mix Composition	Water Absorption (%)
M1	100% Hypo Sludge	Melt
M2	100% Gypsum	17.69
M3	70% Hypo Sludge + 30% Gypsum	Melt
M4	65% Hypo Sludge + 35% Gypsum	Melt
M5	60% Hypo Sludge + 40% Gypsum	Melt
M6	70% Hypo Sludge + 25% Gypsum + 5% Polypropylene Fiber	61.26
M7	65% Hypo Sludge + 30% Gypsum + 5% Polypropylene Fiber	61.01
M8	60% Hypo Sludge + 35% Gypsum + 5% Polypropylene Fiber	61.05

The water absorption results showed that moisture resistance improved with gypsum and polypropylene fiber addition. Pure hypo sludge exhibited high water absorption due to its porous and fibrous nature, resulting in melting or dissolution during immersion. Gypsum improved compactness and reduced voids, while polypropylene fiber further enhanced moisture resistance because of its non-absorbent nature. Fiber-reinforced specimens showed better dimensional stability after immersion. Among the hypo sludge mixes, M8 demonstrated comparatively lower water absorption, indicating improved durability and suitability for interior false ceiling applications.

E. Comparison on Test Result

Table 11: Comparison of Test Results

Mix ID	Mix Composition	Compressive Strength (N/mm²)	Flexural Strength (N/mm²)	Water Absorption (%)	Observation
M1	100% Hypo Sludge	0.10	11.41	Melt	Cannot be preferred for false ceiling panel
M2	100% Gypsum	6.22	25.97	17.69	Cannot be preferred for false ceiling panel
M3	70% Hypo Sludge + 30% Gypsum	0.13	13.03	Melt	Cannot be preferred for false ceiling panel
M4	65% Hypo Sludge + 35% Gypsum	0.14	13.03	Melt	Cannot be preferred for false ceiling panel
M5	60% Hypo Sludge + 40% Gypsum	0.15	13.04	Melt	Cannot be preferred for false ceiling panel
M6	70% Hypo Sludge + 25% Gypsum + 5% Polypropylene Fiber	0.36	13.45	61.26	Cannot be preferred for false ceiling panel
M7	65% Hypo Sludge + 30% Gypsum + 5% Polypropylene Fiber	0.36	13.50	61.01	Can be preferred for false ceiling panel
M8	60% Hypo Sludge + 35% Gypsum + 5% Polypropylene Fiber	0.37	13.60	61.05	Best overall performance; recommended for false ceiling panels

Table 12: Overall Comparison

Property	Conventional Gypsum Mix	Developed Hypo Sludge Mix	Observation
Physical Properties			
Weight	Lightweight	Moderately lightweight	Easy to handle and install
Surface Finish	Smooth and uniform	Smooth after surface finishing	Comparable surface quality
Workability	Excellent	Good	Suitable for false ceiling applications
Mechanical Properties			
Flexural Strength (MPa)	20–30	10–15	Lower than conventional gypsum board but adequate for non-load-bearing false ceiling applications
Compressive Strength (MPa)	5–10	0–1	Lower compressive strength; suitable only for lightweight

			ceiling applications where compressive loads are minimal
Water Absorption (%)	15–18	55–65	Compared based on experimental results
Crack Resistance	Moderate	Improved	Fiber reinforcement helps reduce crack formation and improves durability
Environmental Properties			
Waste Utilization	No industrial waste utilized	Utilizes hypo sludge (industrial waste)	Promotes beneficial reuse of industrial waste
Industrial Waste Recycling	Not applicable	Yes	Reduces landfill disposal and supports waste recycling
Sustainability	Moderate	High	More environmentally friendly due to waste utilization and resource conservation

The developed hypo sludge mix offers an environmentally sustainable alternative to conventional gypsum. Although conventional gypsum provides higher mechanical strength, the hypo sludge mix offers adequate performance for non-structural false ceiling applications with minimal loading. Polypropylene fiber improves crack resistance and durability. Furthermore, utilizing paper-mill hypo sludge reduces industrial waste disposal, conserves resources, and can reduce material costs. Therefore, the developed composite provides a suitable, economical, and sustainable solution for lightweight false ceiling panels.

V. CONCLUSION

The study successfully investigated the feasibility of utilizing hypo sludge as a sustainable construction material for non-structural false ceiling panels. Different proportions of hypo sludge, gypsum, and polypropylene fiber were prepared and evaluated through compressive strength, flexural strength, and water absorption tests. The results showed that pure hypo sludge had poor mechanical and moisture-resistance characteristics, while gypsum improved bonding and strength. The addition of polypropylene fiber further enhanced crack resistance, toughness, and flexural performance. Among the hypo sludge-based mixes, M8 (60% hypo sludge + 35% gypsum + 5% polypropylene fiber) demonstrated the best overall performance, with a compressive strength of 0.37 N/mm² and flexural strength of 13.60 N/mm². The developed material was found suitable for lightweight, non-load-bearing false ceiling applications. The study also demonstrates that utilizing hypo sludge can reduce industrial waste disposal, promote resource conservation, and support sustainable construction practices. Therefore, the developed hypo sludge-based composite can be considered an economical and environmentally friendly alternative for selected interior false ceiling applications.

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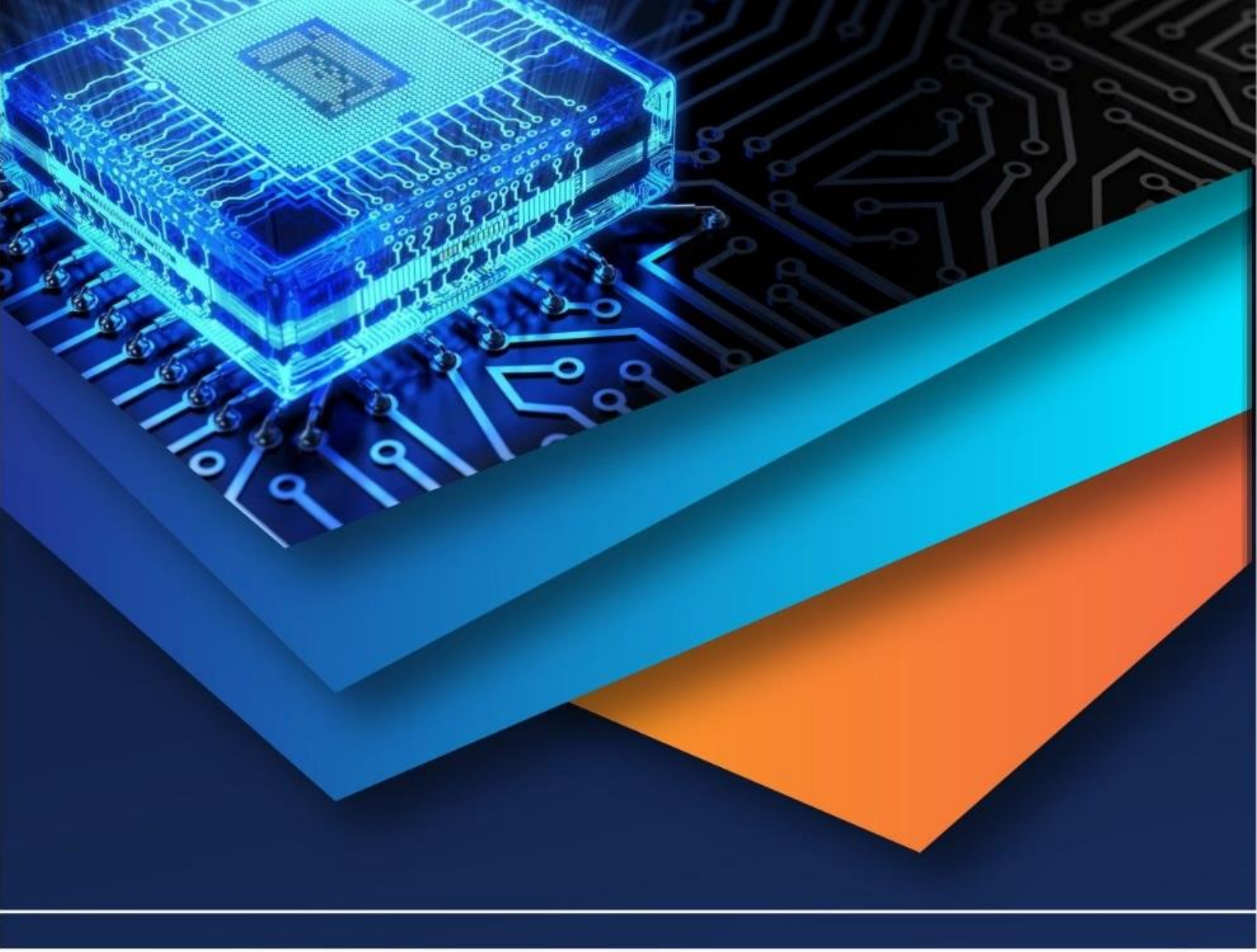

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