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Improving the Engineering Properties of Expansive Soil Using Bagasse Ash and Magnesium Chloride

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Abstract: Expansive soils present significant challenges in geotechnical engineering due to their high shrink–swell potential and poor strength characteristics, making them unsuitable for pavement and foundation applications without treatment. This study examines the stabilization of Black Cotton Soil, using bagasse ash (BA) and magnesium chloride ($MgCl_2$) as sustainable additives.

Bagasse ash was incorporated at 5%, 10%, 15%, and 20%, while $MgCl_2$ was added at 2%, 4%, 6% and 8% Laboratory investigations, including index properties, modified compaction, California Bearing Ratio (CBR), and triaxial strength tests, were performed on untreated and treated soil to assess changes in engineering behavior. The results indicated that BA and $MgCl_2$ effectively reduced soil plasticity and enhanced density and shear strength within moderate dosage ranges. Higher contents, such as 20% BA and 8% $MgCl_2$, produced inferior results, suggesting that excessive additive levels disturb the soil structure. Overall, the study confirms that the combined use of BA and $MgCl_2$ offers a practical and sustainable approach for improving the geotechnical performance of expansive soils.

Keywords: Expansive soil; Black Cotton Soil; Bagasse ash; Magnesium chloride; Soil stabilization; Compaction; CBR.

I. INTRODUCTION

Expansive soils constitute one of the most problematic geomaterials due to their high swelling pressure, shrink–swell behavior, and low shear strength. Their behavior is governed by the presence of active clay minerals—primarily montmorillonite, smectite, and illite—which exhibit a multilayer lattice structure capable of absorbing and desorbing water. The consequent volumetric instability leads to differential heave and settlement, causing structural distress in pavements, lightly loaded buildings, retaining structures, and utility lines. In India, expansive soils—commonly known as Black Cotton Soils—are predominantly found in the states of Andhra Pradesh, Telangana, Maharashtra, Gujarat, Madhya Pradesh, Karnataka, and Tamil Nadu, forming a continuous belt across central and southern regions. Similar problematic soils also occur in parts of Texas (USA), Sudan, South Africa, and Australia, making their stabilization a global engineering concern.

Conventional stabilization methods include lime, cement, and industrial chemicals; however, challenges such as cost, carbon emissions, and long-term environmental impact have prompted a shift toward sustainable alternatives. Bagasse ash (BA), an agro-industrial by-product generated from sugarcane processing, contains reactive silica and alumina that can participate in secondary cementitious reactions, reducing plasticity and improving soil structure. Magnesium chloride ($MgCl_2$), a highly hygroscopic chloride-based salt, influences interparticle bonding by altering the diffuse double layer thickness and promoting flocculation–agglomeration mechanisms.

The combined use of BA and $MgCl_2$ presents an opportunity to achieve both environmental and engineering benefits. Their interaction has the potential to modify the soil fabric, enhance compaction characteristics, and improve strength parameters under both static and repeated loading conditions. In the present study, Black Cotton Soil collected from Chintalapudi Mandal, Eluru District, AndhraPradesh is treated with varying dosages of BA and $MgCl_2$ to evaluate improvements in plasticity, density, bearing capacity, and shear strength through a series of laboratory investigations.

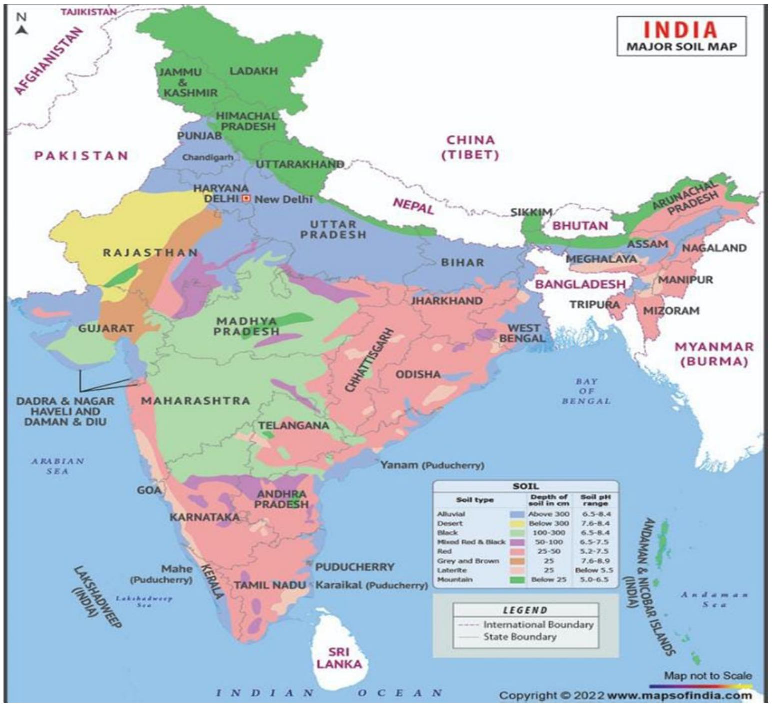

Fig.1. Map of Major Soil of India

The map illustrates the major soil types of India, highlighting extensive black cotton soil belts across Maharashtra, Madhya Pradesh, Gujarat, Karnataka, Telangana, and Andhra Pradesh.

II. MATERIALS AND METHODOLOGY

A. Materials

1) Expansive soil

The soil used in this study is a natural expansive soil locally known as Black Cotton Soil. It was collected from a depth of 1.0 m at Chintalapudi Mandal, Eluru District, Andhra Pradesh. The soil exhibits characteristic swelling behavior associated with montmorillonite-rich clays. Disturbed samples were transported in sealed bags to preserve natural moisture conditions. A preliminary test such as specific gravity, liquid limit, plastic limit, and grain-size analysis was conducted to classify the soil according to IS: 1498. Based on the index properties, the soil falls within the category of highly plastic clay (CH), confirming its expansive nature and suitability for stabilization studies.

Fig.2. Expansive Soil

2) Bagasse Ash (BA)

Bagasse ash was obtained as a by-product from a local sugar mill. The ash is predominantly siliceous and aluminous in nature, consisting of fine, non-plastic particles capable of participating in pozzolanic reactions when mixed with soil. BA was used at proportions of 5%, 10%, 15%, and 20% by dry weight of soil. Preliminary observations indicated that higher replacement levels, particularly 20%, did not yield favorable engineering behavior, suggesting the existence of an optimum dosage range.

Fig.3.Bagasse Ash

Table-1. Chemical Properties of Bagasse ash

S.NO	DESCRIPTION OF PROPERTIES	PERCENTAGE %
1	Silica (SiO_2)	64.38
2	Alumina (Al_2O_3)	11.32
3	Ferric Oxide (Fe_2O_3)	4.56
4	Calcium Oxide (CaO)	10.26
5	Magnesium Oxide (MgO)	0.85
6	Potassium Oxide (K_2O)	3.57
7	Sodium Oxide (Na_2O)	1.05
8	Manganese Oxide (MnO)	0.2

Table-2. Physical Properties of Bagasse ash

PROPERTY	TYPICAL VALUE
Colour	grey to dark grey
Specific gravity	1.9-2.3
bulk density	800-1100 kg/cm^3
moisture content	1-3%
ph value	8.0-9.0
Appearance	light, fluffy, siliceous powder
odor	odorless to faint burnt smell

3) Magnesium Chloride ($MgCl_2$)

Commercial-grade magnesium chloride flakes were used as the chemical additive. $MgCl_2$ is a hygroscopic salt well known for its ability to modify clay–water interaction and reduce diffuse double layer thickness. It was added to the soil at dosages of 2%, 4%, 6% and 8% by dry weight. Trials showed that 8 % $MgCl_2$ produced weaker results compared to moderate percentages, indicating reduced efficiency at excessive concentrations.

Fig.4.Magnesium Chloride ($MgCl_2$)

Table-3. Chemical Properties of Magnesium Chloride ($MgCl_2$)

PROPERTIES	DETAILS
Ionic composition	Mg^{2+} (25.5%), cl^{-} (74.5%)
Molecular weight (anhydrous)	95.21g/mol
Molecular weight (hexahydrate)	203.30g/mol
Chemical behavior in water	Reacts with carbonates, hydroxides; absorbs moisture readily (deliquescent)
Ph of aqueous solution	Slightly acid ph=5-6
Purity	95-99%

Table-4. Physical Properties of Magnesium Chloride ($MgCl_2$)

PROPERTIES	DETAILS
Physical state	White crystalline solids
odor	odorless
density	$2.32g/cm^3$
Crystal structure	Rhombohedral (anhydrous), monoclinic (hexahydrate)
color	white
grain texture	Fine crystalline/flake (for hexahydrate)
Thermal stability	Loses water molecules on heating

B. Methodology

This study was carried out in multiple phases to evaluate the effectiveness of Bagasse Ash and Magnesium Chloride ($MgCl_2$) in improving the engineering characteristics of expansive soil. The methodology includes soil collection, preparation of materials, proportioning of mixes, laboratory testing of untreated and treated samples, and analysis of the results.

1) Materials Collection

The expansive soil used in this study was collected from Chintalapudi Mandal, Eluru District, Andhra Pradesh, at a depth of 1.0–1.5 m below ground level to avoid surface impurities. The soil sample was air-dried, manually pulverized, and sieved through a 4.75 mm IS sieve to obtain a uniform mix for testing.

a) *Expansive Soil (Black Cotton Soil*): The collected soil was used as the base material for stabilization. The soil was identified as highly expansive black cotton soil (CH group) based on plasticity characteristics and free swell behavior.
b) *Bagasse Ash (BA):* Bagasse ash was collected from a nearby sugar industry. The ash was oven-dried, sieved through a 425-micron sieve, and stored in airtight bags. Bagasse ash primarily contains silica, alumina, and iron oxides, contributing to pozzolanic reactivity.
c) *Magnesium Chloride ($MgCl_2$):* Commercial-grade magnesium chloride flakes were used as a chemical stabilizer. $MgCl_2$ improves bonding between soil particles through ionic exchange and creates cementitious compounds in the presence of moisture.

2) *Mix Proportions*

Stabilization was carried out using varying proportions of Bagasse Ash and Magnesium Chloride.

Table-5. Admixture mixed percentages

S. NO	STABILIZING AGENT	PERCENTAGE USED
1	Bagasse Ash	5%,10%,15%,20%
2	Magnesium Chloride	2%, 4%, 6%, 8%

(Note: 20% mix showed poor results and was not considered optimum.)
(Note: 8% $MgCl_2$ showed undesirable behavior and was discarded.)
Both treated and untreated soil samples were tested for comparison.

3) *Laboratory Testing*

A series of laboratory tests were conducted on natural soil and stabilized mixes to evaluate improvements in engineering behavior. All tests were performed in accordance with Indian Standard (IS) code procedures.

a) *Differential Free Swell (DFS) Test IS 2720 – Part 40:* The soil's expansiveness was determined using distilled water and kerosene. The reduction in DFS values for treated samples was used to assess the effectiveness of stabilization in controlling swelling.
b) *Specific Gravity Test IS 2720 – Part 3:* Specific gravity of soil solids was measured using a pycnometer. This value helps understand the mineralogical composition and is essential for compaction and classification studies.
c) *Atterberg Limits Test IS 2720 – Part 5:* Liquid limit, plastic limit, and plasticity index were determined for both untreated and treated soils. The reduction in plasticity indicated improvement in workability and reduction in swelling potential.
d) *Standard Proctor Compaction Test IS 2720 – Part 7:* Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were obtained for different stabilizer combinations. The influence of Bagasse Ash and $MgCl_2$ on compaction characteristics was studied.
e) *California Bearing Ratio (CBR) Test IS 2720 – Part 16:* Soaked and unsoaked CBR values were determined to evaluate the potential use of stabilized soil in pavement subgrades.
f) *Unconsolidated Undrained (UU) Triaxial Test IS 2720 – Part 11:* Shear strength parameters, namely cohesion (c) and angle of internal friction (ϕ), were determined for both treated and untreated soils. The gain in shear strength helped assess the load-carrying ability of stabilized soil.

III. RESULTS AND DISCUSSIONS

A. Untreated Expansive Soil

Table .6. Results of Untreated Expansive Soil

SL. NO	PROPERTIES		SYMBOL	UNTREATED EXPANSIVE SOIL
1	Grain Size Distribution	Gravel%		0
		Sand%		10.89
		Silt%		19.23
		Clay%		69.91
2	Differential free swell (%)		DFS	100
3	Specific gravity		G	2.36
4	Liquid limit (%)		LL	82.84
5	Plastic limit (%)		PL	33.3
6	Plasticity index (%)		IP	49.51
7	Soil Classification			CH
7	Maximum Dry Density (gm/cc)		M.D. D	1.42
8	Optimum Moisture Content (%)		OMC	44.40
9	CBR Value (soaked) (%)		CBR	1.48
10	Cohesion (kg/cm^2)		C	0.83
11	Angle of internal friction (°)		ϕ	2

B. Untreated Expansive Soil

1) Differential Free Swell

Table .7. Differentials Free Swell of Expansive Soil

S.NO	MIX PROPORTIONS	DFS (%)
1	100% ES	100
2	83%ES+15%BA+2%Mgcl2	58.5
3	81%ES+15%BA+4%Mgcl2	47.5
4	79%ES+15%BA+6%Mgcl2	32.5

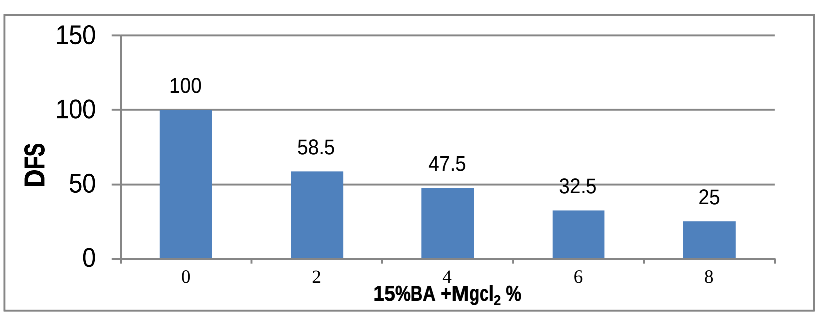

Fig.5.Graph shows 15%BA +Mgcl$_2$ **%** vs DFS

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2) Specific Gravity

Table.8. Specific gravity of Expansive Soil

S.NO	MIX PROPORTIONS	G
1	100% ES	2.36
2	83%ES+15%BA+2%Mgcl2	2.49
3	81%ES+15%BA+4%Mgcl2	2.53
4	79%ES+15%BA+6%Mgcl2	2.57

3) Atterberg Limit

Table.9. Atterberg limit of Expansive Soil

S.NO	MIX PROPORTIONS	Liquid Limit	Plastic Limit	Plasticity Index
1	100% ES	82.84	33.33	49.51
2	83%ES+15%BA+2%Mgcl2	58.15	34.8897	23.2668
3	81%ES+15%BA+4%Mgcl2	51.63	36.9516	14.69853
4	79%ES+15%BA+6%Mgcl2	44.91	37.5833	7.329236

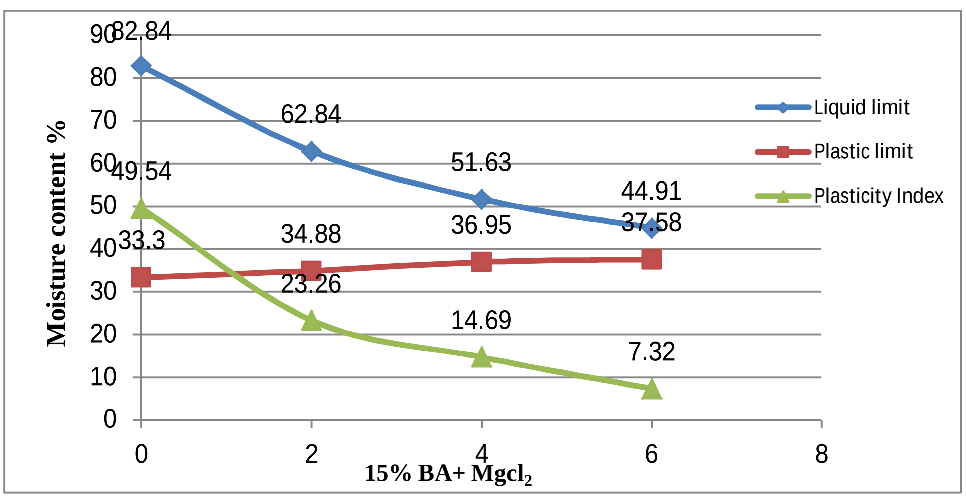

Fig.6.Graph shows Moisture content vs 15%BA +$Mgcl_2$

4) Standard Proctor Compaction Test

Table.10. Standard proctor compaction of Expansive Soil

S.NO	MIX PROPORTIONS	% Water content	Dry Density γd
1	100% ES	44.4	1.42
2	83%ES+15%BA+2%Mgcl2	41.9	1.45
3	81%ES+15%BA+4%Mgcl2	38.08	1.49
4	79%ES+15%BA+6%Mgcl2	34.22	1.57

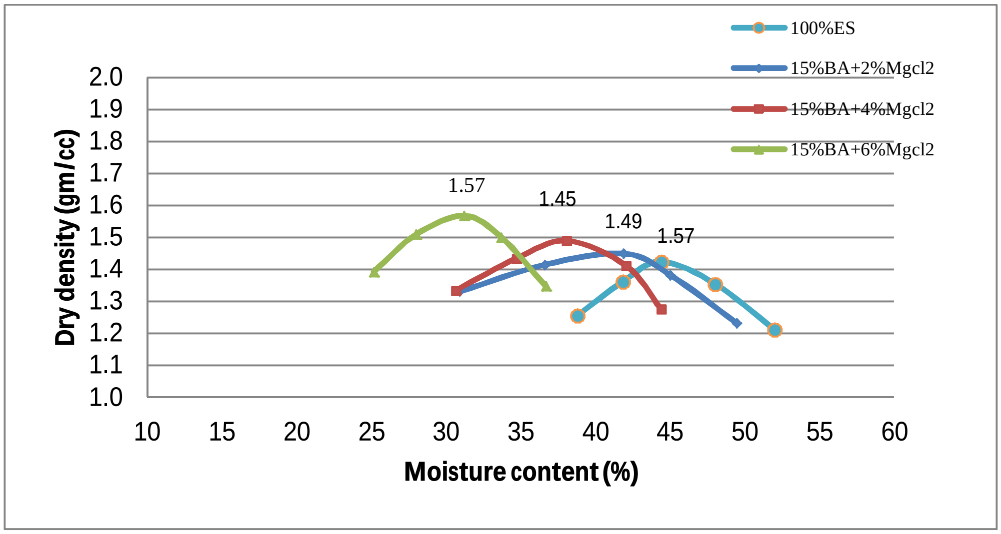

Fig.7. Graph shows Moisture content vs Dry density

5) California Bearing RATIO (CBR) Test

Table.11. California bearing ratio of Expansive Soil

S.NO	MIX PROPORTIONS	CBR %
1	100% ES	1.48
2	83%ES+15%BA+2%$Mgcl_2$	3.81
3	81%ES+15%BA+4%$Mgcl_2$	6.72
4	79%ES+15%BA+6%$Mgcl_2$	8.74

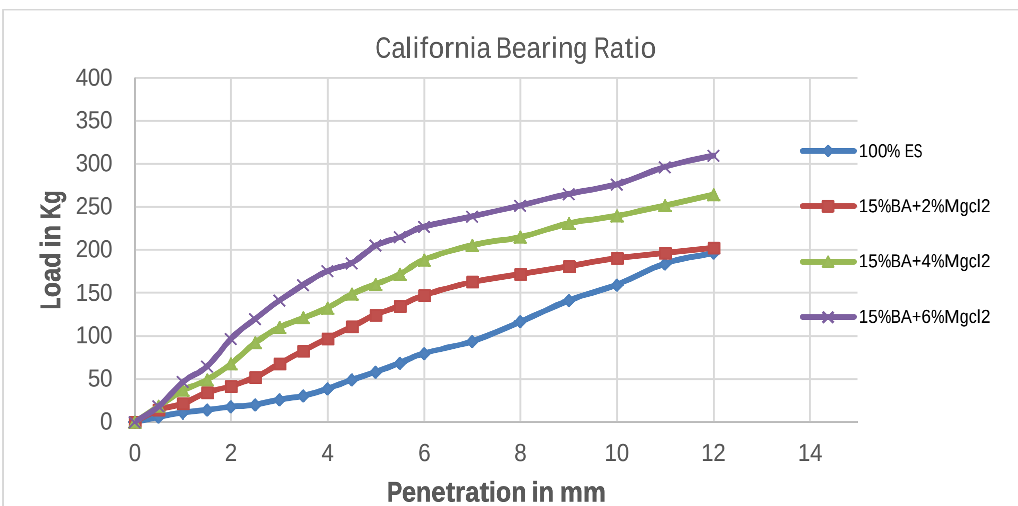

Fig.8.Graph of Penetration vs Load

IV. CONCLUSION

This study evaluated the effectiveness of Bagasse Ash (BA) and Magnesium Chloride ($MgCl_2$) in improving the engineering properties of expansive Black Cotton Soil collected from Chintalapudi Mandal, Eluru District. Based on the laboratory investigations carried out on both untreated and treated soil samples, the following conclusions are drawn:

1) The untreated soil exhibited a high Differential Free Swell (DFS) value of 100%, confirming its highly expansive nature. The addition of BA and $MgCl_2$ significantly reduced the swell potential, with the minimum DFS of 32.5% obtained for the mix containing 79% soil + 15% BA + 6% $MgCl_2$.
2) Specific gravity increased from 2.36 for untreated soil to 2.57 for the optimum treated mix, indicating an improvement in soil particle density due to chemical reactions and formation of stable compounds.
3) Atterberg limit results showed a considerable reduction in Liquid Limit and Plasticity Index with the addition of stabilizers. The Plasticity Index decreased from 49.51% to 7.32%, reflecting a substantial reduction in workability problems and swelling tendency.
4) Maximum Dry Density (MDD) improved from 1.42 g/cc (untreated soil) to 1.57 g/cc for the optimum mix, while the Optimum Moisture Content decreased from 44.4% to 34.22%. This demonstrates better soil packing and reduced moisture demand after stabilization.
5) The CBR value of the natural soil was very low (1.48%), making it unsuitable for pavement subgrades. Treated samples showed a significant increase, with the highest CBR of 8.74% achieved for the mix containing 15% BA and 6% $MgCl_2$, indicating improved suitability for pavement layers.

Laboratory results clearly show that moderate dosages of Bagasse Ash and Magnesium Chloride effectively enhance the strength, stability, and load-carrying capacity of expansive soil. Higher dosages such as 20% BA and 8% $MgCl_2$ produced inferior results, confirming that optimum stabilizer content is essential for achieving desirable performance. The combination of 15% Bagasse Ash and 6% Magnesium Chloride is identified as the optimum mix for improving the engineering behavior of the expansive soil used in this study. The use of BA and $MgCl_2$ provides a sustainable, cost-effective, and environmentally beneficial method for stabilizing expansive soils in geotechnical applications.

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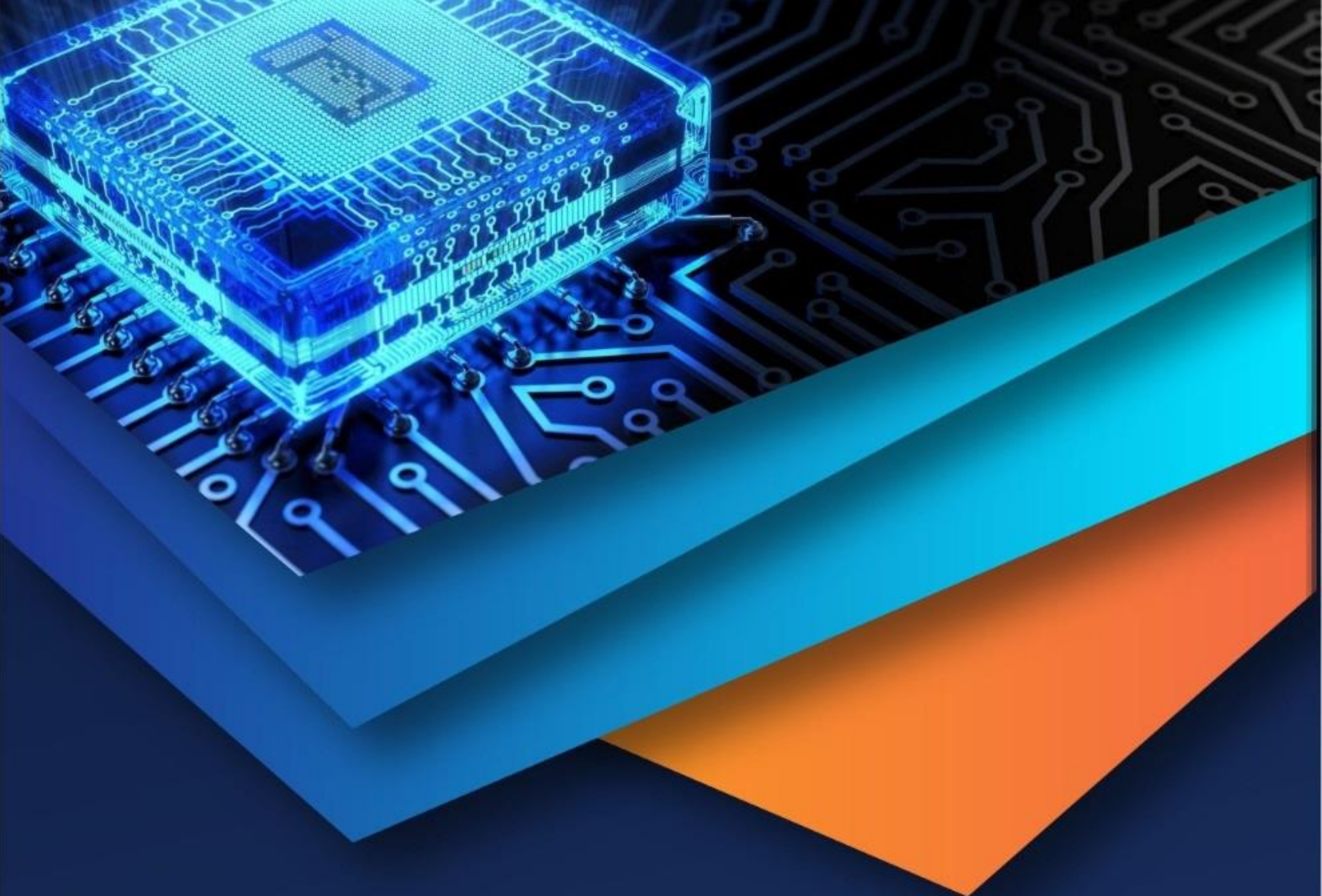

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