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Stabilization of Expansive Soil Using Bagasse Ash and Geopolymers to Suit as Subgrade in Flexible Pavement

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Abstract: Expansive soils are considered problematic due to their sensitivity to moisture changes, leading to ground heave or settlement that damages structures and causes major economic losses. To address this, stabilization using industrial waste materials offers a cost-effective and eco-friendly solution. An eco-friendly, nontraditional stabilizer sugarcane bagasse ash (SCBA) and geopolymer was used for soil improvement. The dry soil–SCBA blend was activated with a alkaline solution composed of sodium metasilicate and sodium hydroxide in a fixed 70:30 ratio respectively. Laboratory tests were conducted to analyze the influence of varying percentages of sugarcane bagasse ash on varying percentage of geopolymers. Differential free swell Test, Modified Proctor Compaction Test, Atterberg Limits, and California Bearing Ratio (CBR) tests were performed. The Atterberg Limits, Dry Density and CBR of the Expansive soil has been improved on addition of 10% Bagasse ash and 3% Geopolymers as an optimum percentages. The present study demonstrates that the combination of industrial waste and chemical additives can be an effective, economical, and sustainable technique for the stabilization of expansive soil.
Keywords: Expansive Soil (ES), Sugarcane Bagasse Ash (SBA), Alkaline Activators Geopolymers (AAG)

I. INTRODUCTION

Expansive soils, commonly referred to as black cotton soils (BC soils), occupy nearly 20% of India's geographical area and are well known for their suitability for cotton cultivation. These soils exhibit significant volume changes in response to seasonal moisture variations due to their unique physical and chemical composition. The presence of the clay mineral montmorillonite is primarily responsible for their pronounced swelling and shrinking behavior. When moisture increases, the soil absorbs water and expands; when it dries, it contracts, often causing severe cracking and ground movement.

These soils are generally residual in nature, formed in situ through the chemical decomposition of parent rocks such as basalt and trap. Their engineering properties reflect their high clay content and mineralogy. Typically, expansive soils possess a liquid limit of 50%–100%, plasticity index of 25%–65%, and shrinkage limit of 8%–18%, indicating high plasticity and susceptibility to volume change.

Because of these characteristics, expansive soils present considerable challenges in geotechnical engineering. Structural foundations, pavements, and other infrastructure constructed on such soils often experience distress without proper treatment. Therefore, understanding the origin, nature, swelling mechanism, and behavior of expansive soils is essential. This paper reviews existing research and highlights the need for effective stabilization techniques to improve their engineering performance and ensure long-term structural stability.

II. OBJECTIVE OF THIS PRESENT STUDY

1) To determine the properties of expansive soil.
2) To access the influence of varying dosage of Bagasse ash (6%, 8%, 10%, 12% by dry weight of soil) on the strength characteristics of expansive soil and finalizing the optimum percentage addition of bagasse ash.
3) To access the effect of varying dosage of geopolymers (1%, 1.5%, 2%, 2.5%, 3%, 3.5% by dry weight of soil) on the strength properties of the expansive soil treated with an optimum percentage addition of geopolymers to the treated expansive soil.
4) To perform the cyclic plate load tests on both the treated and untreated expansive soil subgrade model flexible pavements in the laboratory.

III. MATERIALS AND METHODOLOGY

A. Materials

1) Expansive Soil

The expansive soil used for this research was collected from Thummalapalli village, Allavaram mandal, Dr. B.R. Ambedkar district, Andhra Pradesh. The expansive soil was collected by method of disturbed sampling at 1.5 m depth below the ground surface and transported in truck to the laboratory. Before testing, the soil was air dried, pulverized and sieved with 4.75mm sieve and soil was processed through a 4.25 micron IS Sieve for consistency testing as per requirement of the laboratory tests.

Fig 1 Expansive soil

2) Sugarcane Bagasse Ash (SBA)

The Sugar Cane Bagasse Ash (SCBA) was collected from Nava Bharat Venturesl ltd (Sugar Division), Samarlakota, Andhra Pradesh.. Bagasse is defined as fibrous residue of sugar cane stalks that remains after extraction of sugar (Hofsetz et al, 2012) when burnt gives ash as shown in Fig. The chemical composition analysis of the Bagasse Ash was carried out by Atomic Absorption Spectrophotometer (AAS) machine at Government laboratory of mines and Geology.

Fig 2 Bagasse Ash

3) Alkaline Activators Geopolymers (AAG)

Geopolymers are inorganic alumino-silicate materials formed by reacting alkaline activators like sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) with alumino-silicate-rich materials such as fly ash or slag. This reaction creates a strong Si–O–Al network, resulting in materials with excellent strength, durability, and chemical resistance. In this study, geopolymers synthesized using NaOH and Na_2SiO_3 act as sustainable binders and eco-friendly alternatives to Portland cement, reducing carbon emissions and energy use. In geotechnical engineering, they enhance soil stability, durability, and load-bearing capacity, while also serving in waste encapsulation and heavy metal immobilization, promoting sustainable construction practices

Table 1 Chemical properties of Alkaline Activators Geopolymers

S.NO	Chemical properties	Chemical Formula	Sodium Hydroxide (NAOH)	sodium silicate(Na_2SiO_3)
1	Silica	Sio_2	-	36
2	Alumina	Al_2O_3	-	-
3	Iron Oxide	Fe_2O_3	-	0.05
4	Calcium Oxide	Cao	-	-
5	Magnesium Oxide	MgO	0.1	-
6	Sodium Oxide	Na_2O	77.48	12
7	Potassium Oxide	K_2O	-	-
8	Loss on Ignition(LOI)	-	-	3.5
9	Water	H_2O	22.52	68

B. Mix Proportions

Expansive soil was stabilized by preparing sample mixes containing varying proportions of Bagasse ash and Alkaline Activators Geopolymers. Bagasse ash mix proportions were 6%, 8%, 10%, and 12% were initially examined to identify the optimum percentage. Subsequently, the Expansive soil with an optimum of bagasse ash percentage was further treated with Alkaline Activators Geopolymers at incremental percentages of 1%, 2%, 3%, and 4% to evaluate its additional improvement potential.

IV. LITERATURE REVIEW

Kiran et al. (2013) mixed different percentages (4%, 8% and 12%) of Bagasse Ash and observed that the blend of Bagasse Ash with different percentages of cement for black cotton soil imparted significant changes in values of MDD, CBR and UCS. The MDD values got increased from 1.516 g/cc to 1.65 g/cc for addition of 8% Bagasse Ash with 8% cement, CBR values got increment from 2.12 to 5.3 for addition of % Bagasse Ash with 8% cement and UCS values got changed to 174.91 KN/m² from 84.92 KN/m² for addition of 8% Bagasse Ash with 8% cement.

abat (2012) had investigated the effects of bagasse ash and lime sludge on OMC, MDD, UCS, soaked CBR and Ps of an expansive soil area. The best stabilization effects were obtained when the optimum percentage of Bagasse Ash was 8% and Lime sludge was 16%. The effects of compaction delay and moulding water content on CBR of the soil stabilized at the optimum proportion were also studied. At the optimum proportion the stabilizer is cost effective and the molding water content and compaction delay affected the CBR value of the stabilized soil significantly.

Gandhi (2012) had studied the effect of addition of bagasse ash (up to 10%) on WL, WP, IP, SL shrinkage index (SL) Free Swell Index, P. and found a decrease in all values with increase in percentage of bagasse ash.

Manikandan and Moganraj (2014) had found that the combined effect of bagasse ash and lime were more effective than the effect of bagasse ash alone in controlling the consolidation characteristics of expansive soil along with the improvement in other properties.

Amrisha Khandelwal, S.M.ASCE ; Krishna Kumar Patel ; and Vishwajeet Pratap Singh (2024) This study aimed to address pavement cracking caused by the high swell-shrink behavior of expansive soils, resulting from fluctuations in moisture content and high clay content, by using an eco-friendly nontraditional additive: sugarcane bagasse ash (SCBA)based geopolymer. The study involved a dry mixture of soil and SCBA, mixed with a liquid alkaline activator consisting of a fixed70:30 weight ratio of 1 M sodium metasilicate and 10M sodium hydroxide. By varying the SCBA content from 5% to 30% by weight of dry soil and keeping the amount of liquid alkaline activator constant, the volume change behavior of the expansive soil was observed.

V. RESULTS & DISCUSSION

Table -2Properties of untreated Expansive soil

SI.NO	Properties		Symbol	Untreated Expansive Soil
1	Partical Size Distribution	Gravel (%)		0
		Sand (%)		5.8
		Silt (%)		22.97
		Clay (%)		71.23
2	Differential Free Swell (%)		DFS	100
3	Specific gravity		G	2.46
4	Liquid Limit (%)		W_L	75.2
5	Plastic Limit (%)		W_P	31.5
6	Plasticity Index		I_P	43.7
7	Soil classification			CH
8	Maximum Dry Density (g/cc)		M.D.D	1.47
9	Optimum Moisture Content (%)		O.M.C	25.85
10	california Bearing Ratio (%)		CBR	1.52
11	california Bearing Ratio (%)		C	94.62
12	Angle of internal friction		ϕ	3.7

A. Differential Free Swell

Table-3 Mix Proportions Used For Testing

S.NO	Mix proportions	DSF
1	100%ES	100
2	89%ES+10%BA+1%(NAOH+Na2SiO3)	36
3	88%ES+10%BA+2%(NAOH+Na2SiO3)	24
4	87%ES+10%BA+3%(NAOH+Na2SiO3)	18
5	86%ES+10%BA+4%(NAOH+Na2SiO3)	16

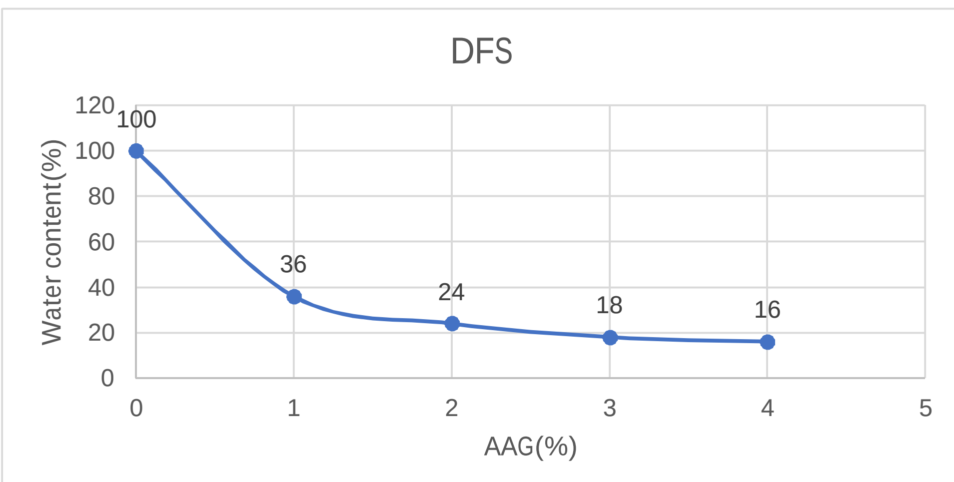

Figure 3 Variation of DFS of ES Treated with 10% of BA with Different Percentages of AAG

Table -3 show that the DFS values decreases from 100% to 18% on addition of optimum percentage BA and AAG addition of AAG from 1%to 4%.

B. Atterberg limits

Table – 4 Show LL, PL, PI treated MC soil

S.NO	Mix proportions	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
1	100%ES	75.26	31.54	43.72
2	89%ES+10%BA+1%(NAOH+Na2SiO3)	69.31	35.12	34.19
3	88%ES+10%BA+2%(NAOH+Na2SiO3)	58.49	37.45	21.04
4	87%ES+10%BA+3%(NAOH+Na2SiO3)	47.84	39.59	8.25
5	86%ES+10%BA+4%(NAOH+Na2SiO3)	46.23	40.27	5.96

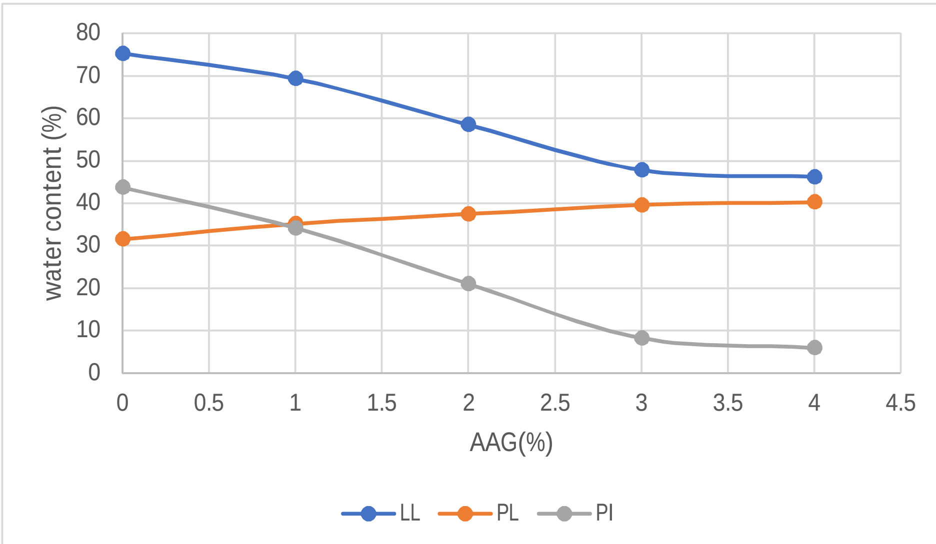

Figure 4 Variation of LL, PL and PI of MC Treated with 10% of FS with Different Percentages of AAG

Table -4 show that the PL, LL, PI values decrease from 43.72% to 8.46% on addition of optimum percentage BA and AAG addition of AAG from 1% to 4%.

C. OMC & MDD

Table-5 OMC and MDD values of treated MC soil

S.NO	Mix proportions	OMC	MDD
1	100%ES	28.85	1.52
2	89%ES+10%BA+1%(NAOH+Na2SiO3)	22.41	1.65
3	88%ES+10%BA+2%(NAOH+Na2SiO3)	18.64	1.73
4	87%ES+10%BA+3%(NAOH+Na2SiO3)	17.53	1.76
5	86%ES+10%BA+4%(NAOH+Na2SiO3)	19.24	1.72

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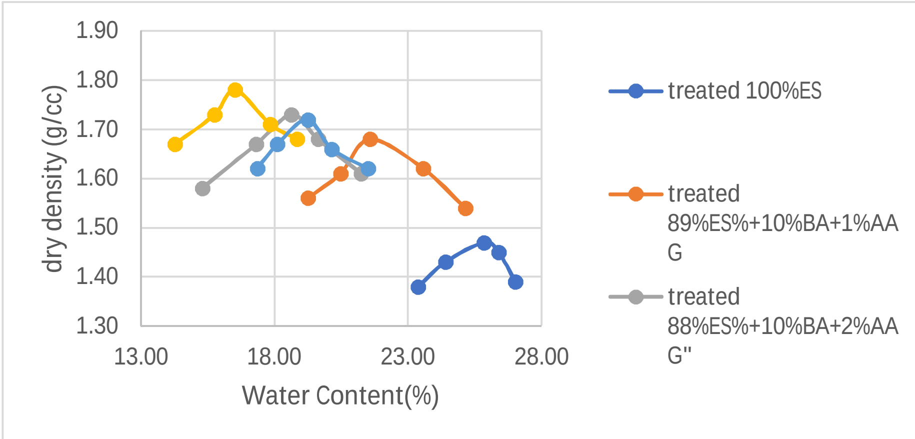

Figure 5 Variation of OMC and MDD of MC treated with 10% BA with various percentages of AAG

Table 5 show that the OMC values decrease from 25.85% to 16.53% on addition of optimum percentage 1% to 4% and AAG addition of AAG from 1% to 4%. The MDD values of the treated MC soil was observed to be increased from 1.47g/cc to 1.728g/cc on addition of optimum percentage BA and AAG addition of AAG from 1% to 4%. The optimum % of AAG Is 3.

D. California Bearing Ratio (CBR)

Table-6 CBR Test Results for different mix proportions

S.NO	Mix proportions	CBR (%)
1	100%ES	1.52
2	89%ES+10%BA+1%(NAOH+Na2SiO3)	6.74
3	88%ES+10%BA+2%(NAOH+Na2SiO3)	7.65
4	87%ES+10%BA+3%(NAOH+Na2SiO3)	8.26
5	86%ES+10%BA+4%(NAOH+Na2SiO3)	7.14

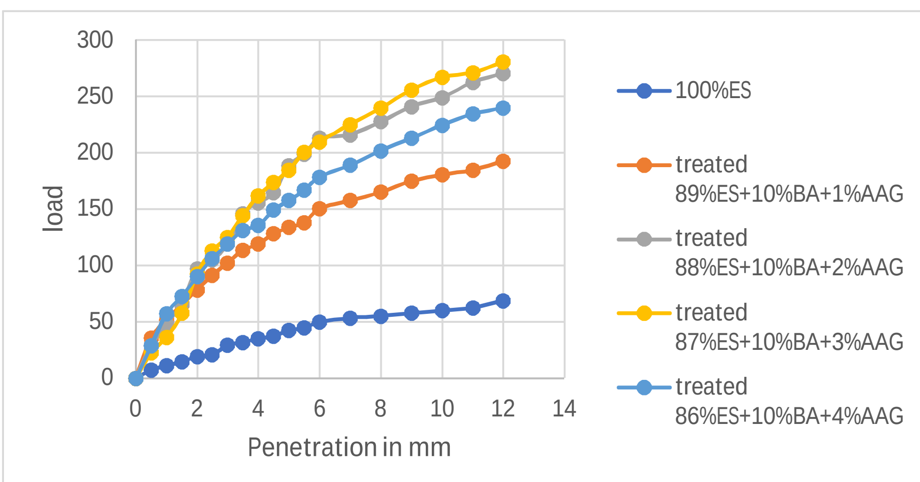

Figure 6 Variation of CBR of MC Treated with 10% BA and Various percentages of AAG

Table-6 shows that CBR is increased from 1.52% to 8.26% after adding Optimum percentage BA and AAG addition of Optimum AAG from 3% mix.

Table -7 Properties of untreated and treated values of Expansive soil

S.NO	Properties	Symbol	Untreated Expansive soil	Expansive soil +10%BA	Expansive soil + 10%BA + 3% Geopolymer
1	Liquid limit	W_L	75.2	61.18	47.84
2	Plastic limit	W_P	31.5	34.28	39.59
3	Plasticity Index (%)	I_P	43.7	26.9	8.25
4	Specific gravity	G	2.46	2.54	2.63
5	Differential Free Swell (%)	DFS	100	45	18
6	Optimum Moisture Content (%)	OMC	28.85	21.97	17.53
7	Maximum Dry Density (g/cc)	MDD	1.52	1.63	1.76
8	California Bearing Ratio (%)	CBR	1.52	5.14	8.26
9	Angle of friction (^{0})	ϕ	2.46	4.17	4.92
10	Cohesion(kN/m$^{2)}$	C	135.62	93.12	79.32

VI. CONCLUSION

1) It is observed from the laboratory test results that the Differential Free Swell Index of Expansive soil has been reduced by 55% on the addition of 10% Bagasse Ash (BA) and it has been further reduced by 82% with an addition of 3 % Alkali activated geopolymer (AAG) when compared with untreated Expansive Soil.
2) It is observed from the laboratory test results that the Liquid limit of Expansive soil has been decreased by 18.6% on the addition 10% BA of and it has been further decreased by 36.38% with an addition of 3% AAG.
3) It is observed from the laboratory test results that the Plastic limit has been increased by 8.82% on addition of 10% BA and it has been further increased by 25.68% with an addition of 3% AAG.
4) It is observed from the laboratory test results that the Plasticity Index has been decreased by 38.44% on addition of 10% BA and it has been further decreased by 81.12% with addition of 3% AAG.
5) It is observed from the laboratory tests that the OMC of the Expansive soil has been decreased by 23.84% on the addition of 10% BA and it has been further decreased by 39.23% with addition of 3 % AAG.
6) It is observed from the laboratory tests that the MDD of the Expansive Soil has been increased by 7.2% on the addition of 10% BA and it has been further increased by 46.15% with addition of 3% AAG.
7) It is observed that the CBR of the Expansive Soil has been increased by 238.15% on the addition of 10% BA and it has been further increased by 443.42% with addition of 3% AAG.

The addition of Bagasse ash and Geopolymers improved particle bonding and reduced the plasticity of Expansive soil , leading to a notable increase in CBR strength. These enhancements siginificantly boosted the soil load bearing capacity, making the treated Expansive soil suitable and durable for use as a effective pavment subgrade material.

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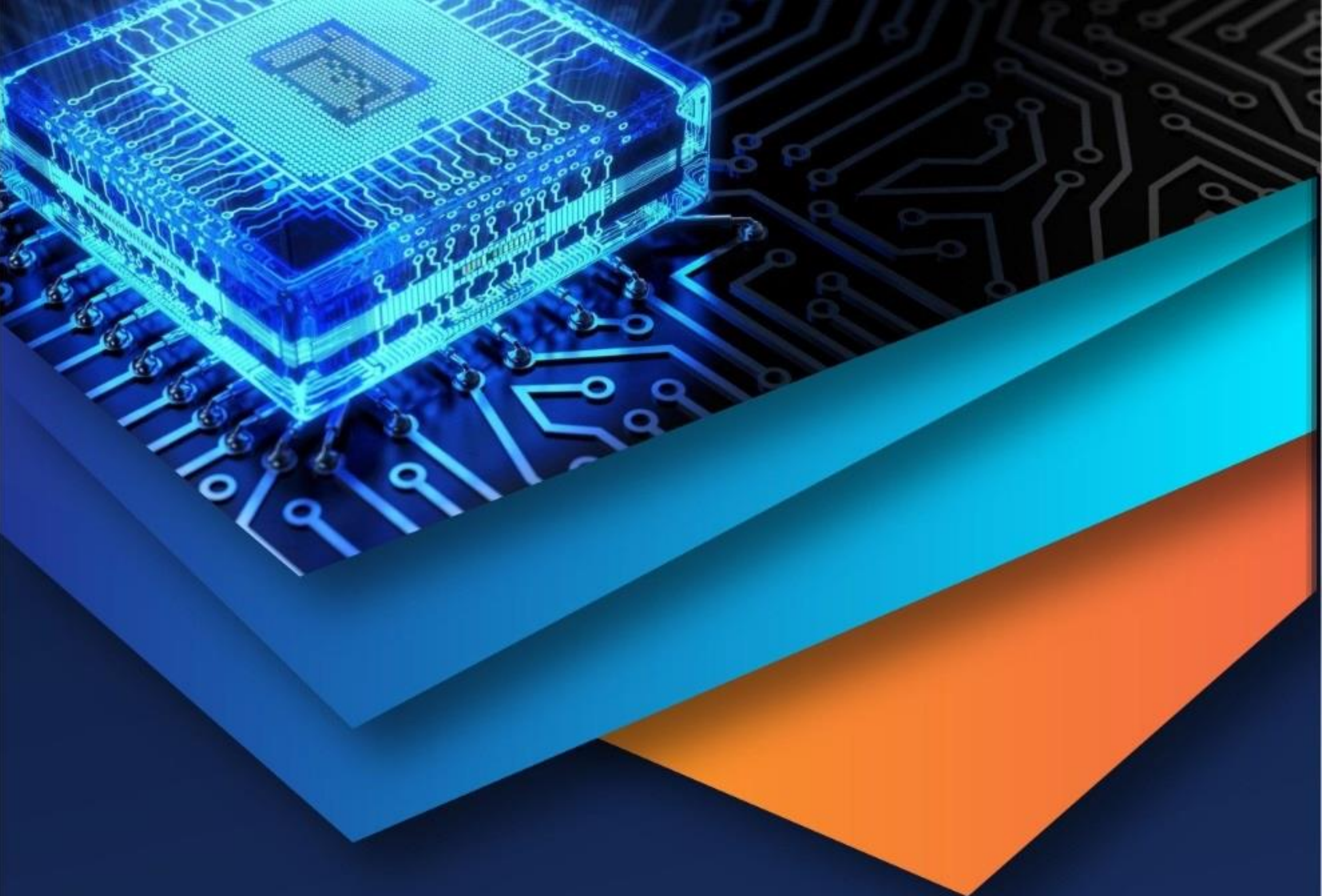

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