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Geotechnical Enhancement of Subgrade Soils Using Recycled Polymeric Waste

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Abstract: Expansive soils such as black cotton soil pose significant challenges in civil engineering works due to their high swelling and shrinkage potential, low bearing capacity, and poor stability under varying moisture conditions. To overcome these limitations and promote sustainable development, the present study focuses on improving the engineering characteristics of black cotton soil through the incorporation of recycled polymeric waste (plastic strips). The experimental program involved conducting a series of tests including Sieve Analysis, Atterberg Limits, Standard Proctor Compaction Test, Unconfined Compressive Strength (UCS) Test, and California Bearing Ratio (CBR) Test on both untreated soil and soil reinforced with different percentages (1%, 2%, and 3%) of plastic waste by dry weight of soil. The results revealed that the inclusion of plastic waste significantly enhances the geotechnical properties of the soil. The maximum dry density (MDD) increased while the optimum moisture content (OMC) slightly decreased, indicating better compaction behavior. The UCS and CBR values showed a remarkable improvement at an optimum dosage of 2% plastic content, beyond which the enhancement became marginal. This improvement is primarily attributed to the interlocking and tensile resistance of the randomly distributed polymeric fibers within the soil matrix, which provide confinement and reduce deformation under load. The study demonstrates that using recycled polymeric waste as a soil stabilizer not only enhances the strength and stability of problematic soils but also offers an eco-friendly and cost-effective solution for solid waste management. Therefore, this method can be effectively adopted in rural and low-volume road construction, contributing to sustainable geotechnical engineering practices.
Keywords: Black Cotton Soil, Soil Stabilization, Recycled Polymeric Waste, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR)

I. INTRODUCTION

Soil is the fundamental material for all civil engineering structures, and its properties greatly influence the performance and safety of construction works. Expansive soils such as black cotton soil exhibit undesirable engineering behavior including high swelling, shrinkage, and poor load-bearing capacity. These characteristics often lead to structural failures like cracking and settlement in pavements, buildings, and embankments. In recent years, the stabilization of weak soils using industrial and domestic wastes has gained significant attention as a sustainable alternative. Among these, the utilization of recycled polymeric waste offers a dual advantage — it reduces environmental pollution caused by non-biodegradable plastics and simultaneously improves soil performance. This research investigates the effect of incorporating recycled polymeric waste strips into black cotton soil to enhance its geotechnical characteristics. Laboratory tests were conducted to study changes in compaction behavior, strength, and bearing capacity of the treated soil compared to natural soil. Recycled polymeric wastes, particularly Low-Density Polyethylene (LDPE) from milk pouches, represent a significant environmental challenge due to their non-biodegradable nature and accumulation in landfills and water bodies. India generates substantial quantities of LDPE waste, especially from household and commercial dairy packaging, which, if not properly recycled, poses serious ecological hazards. By incorporating crushed LDPE into black cotton soil, the present study addresses two critical objectives simultaneously: improving the geotechnical properties of expansive soils and providing an environmentally sustainable solution for polymer waste management. The process involves collecting milk pouches from tea stalls in Kalmeshwar, Nagpur, crushing them using an agglomerator machine, and blending the resulting particles with black cotton soil in controlled proportions of 1%, 2%, and 3% by weight. The blended soils are then subjected to standard geotechnical tests to evaluate changes in compaction, shear strength, plasticity, and other relevant properties, and the results are compared with untreated black cotton soil to quantify the improvements achieved through stabilization.

II. PROPOSED METHODOLOGY

A. *MATERIALS USED*

1) *Plastic Waste:* Plastic waste, or plastic pollution, is 'the accumulation of plastic objects (e.g.: plastic bottles and much more) in the Earth's environment that adversely affects wildlife, wildlife habitat, and humans. But the production and disposal of plastic generate greenhouse gases and hazardous waste. Plastic and the chemicals it emits are building up on land and in oceans, lakes, rivers, ice, and air, and the resulting damage to human and ecological health is currently poorly understood. Cigarette butts — whose filters contain tiny plastic fibers — are the most common type of plastic waste found in the environment. Food wrappers, plastic bottles, plastic bottle caps, plastic grocery bags, plastic straws, and stirrers are the next most common items.The production of plastic in India is increasing day by day. LDPE can be used mostly in packaging industry. Milk pouches are generally made up of LDPE. Most of the garbage that generates in household is due dairy product packages like milk pouches, yogurt pouches, buttermilk pouches. Also, there are around 40 to 50 milk pouches generated in every tea stall. This plastic can be recycled but if it does not reach the recycling unit then it can create problems. So here plastic is also used for stabilization process.

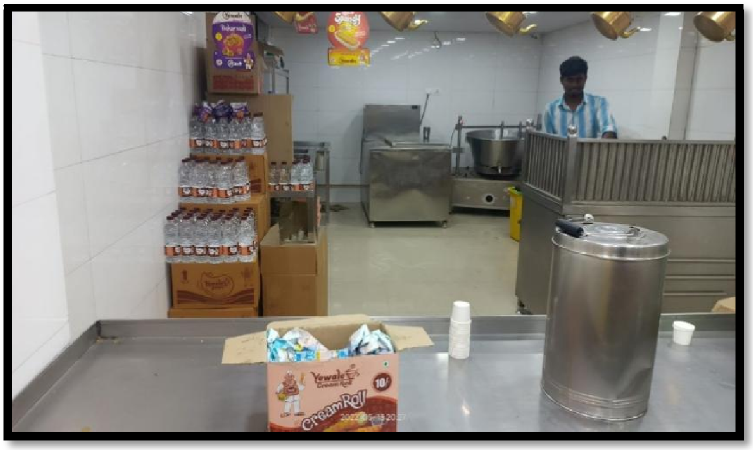

Figure.2.1: collection of milk pouches from various tea stalls

2) *Expansive / Black Cotton Soil:* Black cotton soil is inorganic clay formed in regions having poor drainage conditions. It contains varieties of mineral elements and is very sensitive to water or moisture. Its name stems from its ability to favor cotton crops grown on it. It can be classified into shallow, medium, and deep black cotton soil. It is mainly known as black cotton soil because this soil is most suitable for the cotton crop. Along with cotton, the soil is suitable for the cultivation of crops like groundnut, wheat, tobacco, chillies, and jowar. The chemical stabilization of soils is a relatively broad term that is used when chemical reagents such as quicklime, Calciment Lime Kiln Dust (LKD), cement, Bitumen, or other industrial co-products and bi-products are used to increase the strength of subgrade soil. Black cotton has consistent chemical properties which are not influenced by their formation. Expansive soils, which are also called as swell-shrink soil, have the tendency to shrink and swell with variation in moisture content. So, Building a foundation in black cotton soil is so risky. The swelling and shrinkage of expansive soil cause the settlement of building. When dry, it is very hard, but it loses strength completely when wet. It results in the development of the cracks in house.

Table 2.1: Properties of black cotton soil

Properties	Values
Liquid limit (%)	65.07
Plastic limit (%)	32
Specific Gravity (G)	2.69
Optimum moisture content (%)	21.77
M.D.D (g/cc)	1.54

Figure.2.2: Collection of expansive soil

Milk pouches are collected from different tea stalls from Kalmeshwar Market area and black cotton soil collects from Katol Road, kalmeshwar.

B. METHODOLOGY

The present experimental investigations aims at the detailed study of stabilization/ modification of locally available expansive soil using plastic waste. The experimental programme conducted in this study is comprised of index tests, compaction tests, shear tests, unconfined compressive strength tests, CBR tests and consolidation tests in conformity with approved standards on soil alone and also on stabilised soils to evaluate their individual swelling, compaction, strength, compressibility and drainage characteristics. The material properties, sample preparation, instrumentation, testing methods, and the scope of the experimental programme are presented in the following sections.

The methodology involves series of steps-

- Procurement of materials
- Preparation of soil sample
- To conduct test on the prepared soil sample to calculate soil sample.
- To treat the soil sample with proportions of plastic waste.
- To conduct test on plastic waste treated sample.

1) Preparation of Sample

Plastic mix with black cotton soil-

- Proportion: - 1%, 2% and 3%
- 1st trial – 1.0 % plastic = 1%
- 2nd trial – 2.0 % plastic = 2%
- 3rd trial – 3.0% plastic = 3%

Figure.2.3: washing of milk pouches

Figure.2.4: crushing of milk pouches by agglomerator machine

Figure.2.5: mixing of plastic and BC soil

III. RESULTS & DISCUSSION

A. BLACK COTTON SOIL

Table 3.1: Various Tests Results on Black Cotton Soil Alone

Test Name	Unit	Test 1	Test 2	Test 3	Test 4	Test 5
Liquid Limit	%	65.29	67.28	62.15	64.28	66.69
Plastic Limit	%	35.86	34.20	29.58	30.50	29.88
Plasticity Index	%	29.42	33.08	32.57	33.78	36.81
Shrinkage Limit	%	13.20	14.60	14.12	14.60	15.11
Free Swell Index	%	100	90	95	90	110
UCS	Kg/cm^2	0.600	0.850	0.660	0.820	0.732
Light Compaction (MDD)	g/cc	1.55	1.52	1.50	1.54	1.51
Light Compaction (OMC)	%	20.67	21.00	22.15	21.50	22.86
CBR at 2.5 mm (Soaked)	%	4.98	4.07	3.17	3.62	3.62
CBR at 5 mm (Soaked)	%	4.22	3.92	3.02	3.02	3.32

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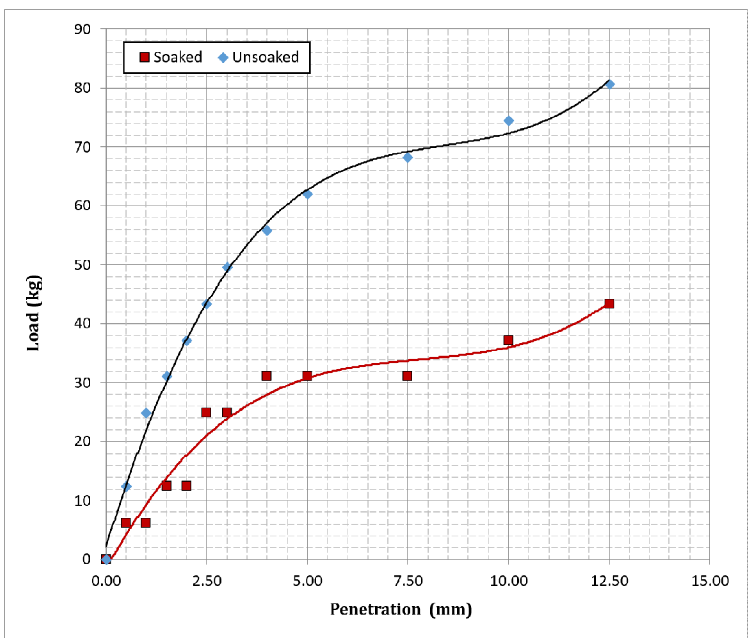
B. SOIL + PLASTIC (1%,2% and 3%)

1) Plastic 1%

a) C.B.R

Sample 1

Condition		Unsoak		Soak	
Penetration Reading		Load		Load	
Division	mm	Division	kg	Division	kg
0.00	0.00	0.00	0.00	0.00	0.00
50.00	0.50	0.40	12.40	0.20	6.20
100.00	1.00	0.80	24.80	0.20	6.20
150.00	1.50	1.00	31.00	0.40	12.40
200.00	2.00	1.20	37.20	0.40	12.40
250.00	2.50	1.40	43.40	0.80	24.80
300.00	3.00	1.60	49.60	0.80	24.80
400.00	4.00	1.80	55.80	1.00	31.00
500.00	5.00	2.00	62.00	1.00	31.00
750.00	7.50	2.20	68.20	1.00	31.00
1000.00	10.00	2.40	74.40	1.20	37.20
1250.00	12.50	2.60	80.60	1.40	43.40
CBR @ 2.5 mm		7.17		7.81	
CBR @ 5 mm		7.02		7.51	



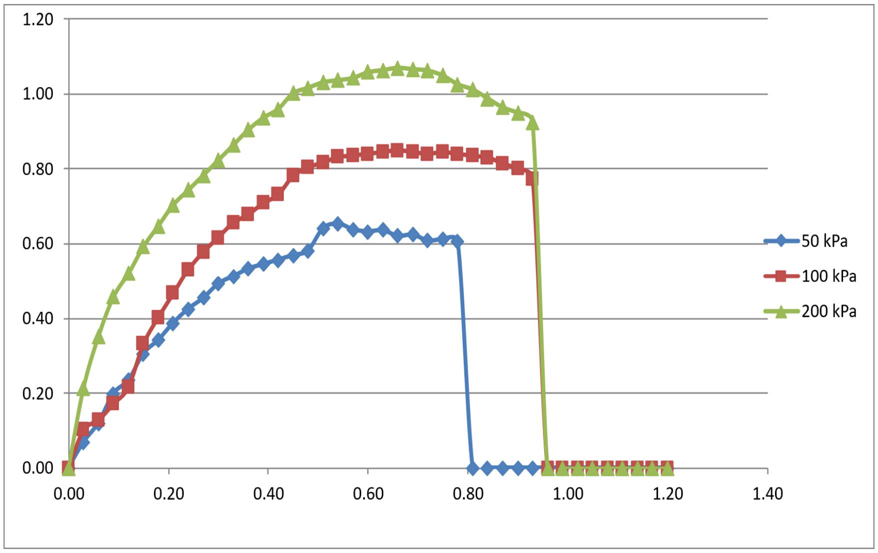
Graph.3.1: Load penetration Curve for sample 1

b) Direct Shear Test

Sample 1

Normal stress	Shear stress at failure	Shear Displacement at Failure		
50	64.12	0.78		

100	83.36	0.93		
150	104.90	0.93		
			Final Values	
C =	43.34	kPa	0.433	kg/cm²
φ =	0.407		22.15	⁰



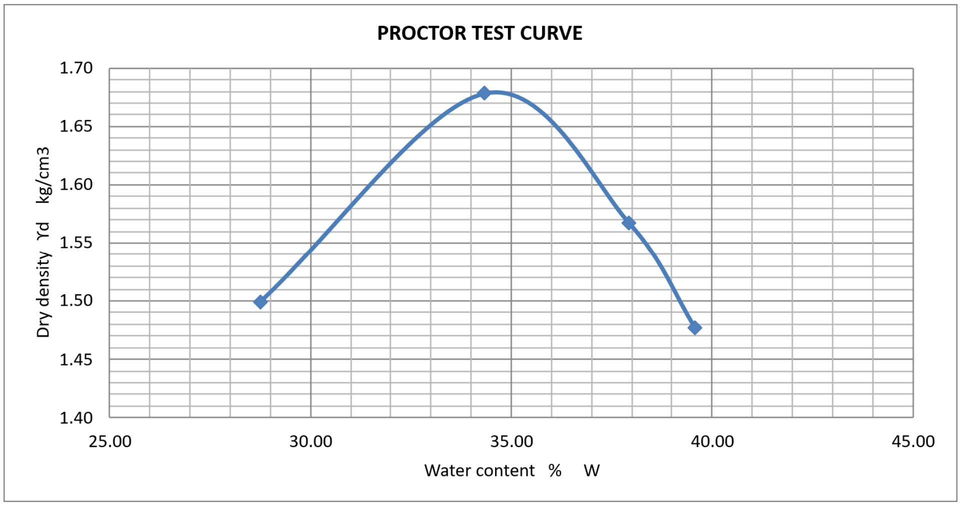
Graph.3.2: Direct shear test for sample 1

c) *Proctor Test (Compaction Curve for Black cotton soil with plastic)*

Sample 1

OMC=34.34, MDD=1.68

		01% Plastic + B.C Soil		Mould Weight 'M2' (gm):				5935	
Weight of Can (W1)	gm	17.6	14.24	17.33	14.25	14.5	17.64	13.38	17.44
Weight of Can + Wet Soil (W2)	gm	85.01	72.32	51.83	53.78	82.05	72.05	60.69	59.48
Weight of Can + Dry Soil (W3)	gm	63.56	66.65	40.5	47.25	62.8	57.65	46.9	47.9
Water Content = ((W2-W3)X100)/(W3-W1)	%	46.67	10.82	48.90	19.79	39.86	35.99	41.14	38.02
Average Water Content (w)	%	28.74		34.34		37.92		39.58	
Weight of Soil + Mould (M1)	gm	7865		8190		8097		7996	
Weight of Mould (M2)	gm	5935		5935		5935		5935	
Wet Density (Dw) = (M1-M2)/V	g/cc	1.93		2.26		2.16		2.06	
Dry Density = Dw/[1+(w/100)]	g/cc	1.50		1.68		1.57		1.48	



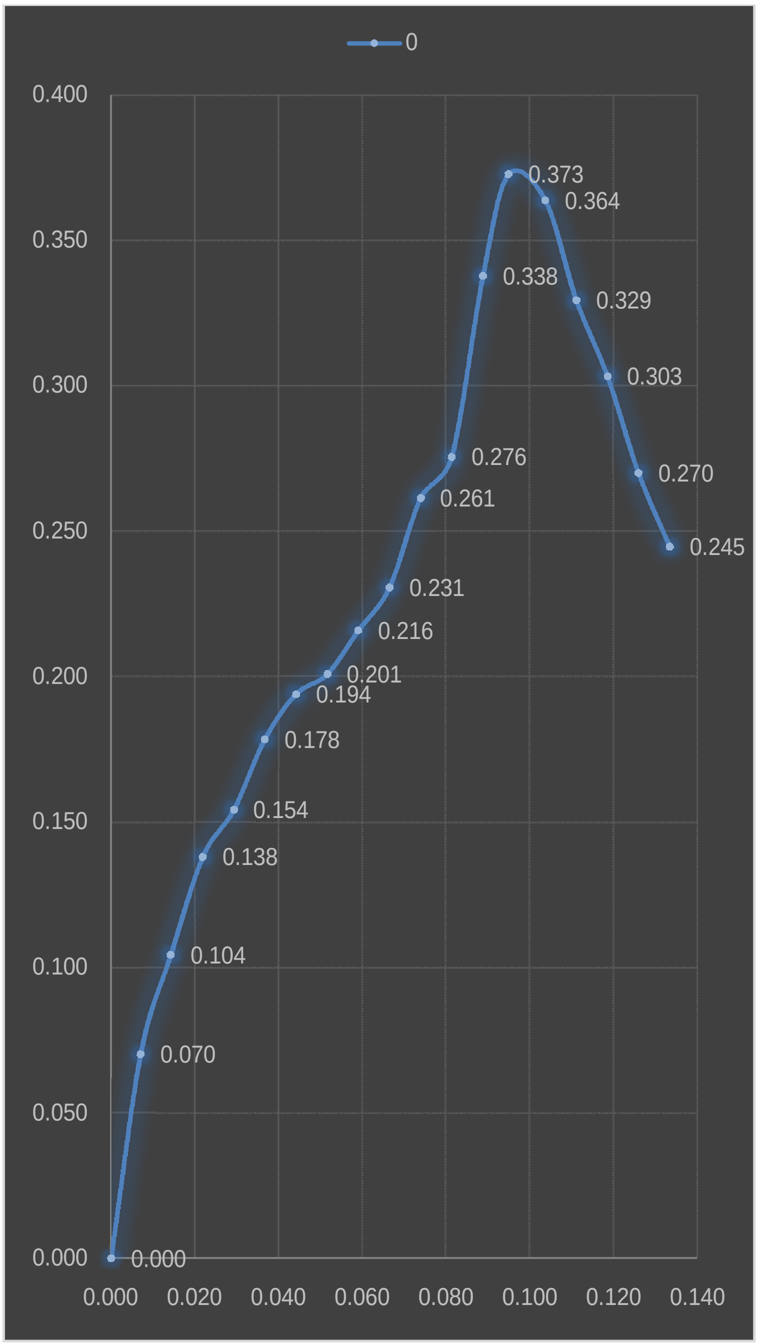
Graph.3.3: Proctor test curve for sample 1

d) UCS TEST

Sample 1

Axial Deformation (mm)	Axial Strain	Area (cm^2)	Load (Kg)	Comp. Strength (Kg/cm^2)
0	0.000	11.34	0	0.000
0.53	0.007	11.42	0.8	0.070
1.08	0.014	11.50	1.2	0.104
1.66	0.022	11.59	1.6	0.138
2.22	0.029	11.68	1.8	0.154
2.79	0.037	11.77	2.1	0.178
3.35	0.044	11.86	2.3	0.194
3.92	0.052	11.95	2.4	0.201
4.48	0.059	12.05	2.6	0.216
5.05	0.066	12.14	2.8	0.231
5.61	0.074	12.24	3.2	0.261
6.18	0.081	12.34	3.4	0.276
6.74	0.089	12.44	4.2	0.338
7.21	0.095	12.61	4.7	0.373
7.87	0.104	12.64	4.6	0.364

8.44	0.111	12.75	4.2	0.329
9.00	0.118	12.86	3.9	0.303
9.57	0.126	12.97	3.5	0.270
10.13	0.133	13.08	3.2	0.245
Unconfined Compressive Strength=			0.373	Kg/cm²



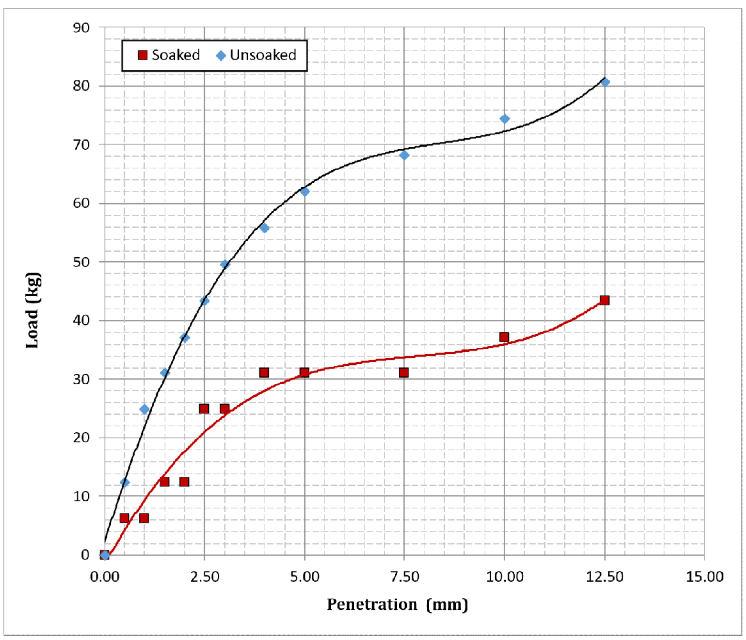
Graph.3.4: UCS Test Curve for sample 1

2) Plastic 2%

a) C.B.R

Sample 1

Condition		Unsoak		Soak	
Penetration Reading		Load		Load	
Division	mm	Division	kg	Division	kg
0.00	0.00	0.00	0.00	0.00	0.00
50.00	0.50	0.40	12.40	0.20	6.20
100.00	1.00	0.80	24.80	0.20	6.20
150.00	1.50	1.00	31.00	0.40	12.40
200.00	2.00	1.20	37.20	0.40	12.40
250.00	2.50	1.40	43.40	0.80	24.80
300.00	3.00	1.60	49.60	0.80	24.80
400.00	4.00	1.80	55.80	1.00	31.00
500.00	5.00	2.00	62.00	1.00	31.00
750.00	7.50	2.20	68.20	1.00	31.00
1000.00	10.00	2.40	74.40	1.20	37.20
1250.00	12.50	2.60	80.60	1.40	43.40
CBR @ 2.5 mm		7.17		7.81	
CBR @ 5 mm		7.02		7.51	



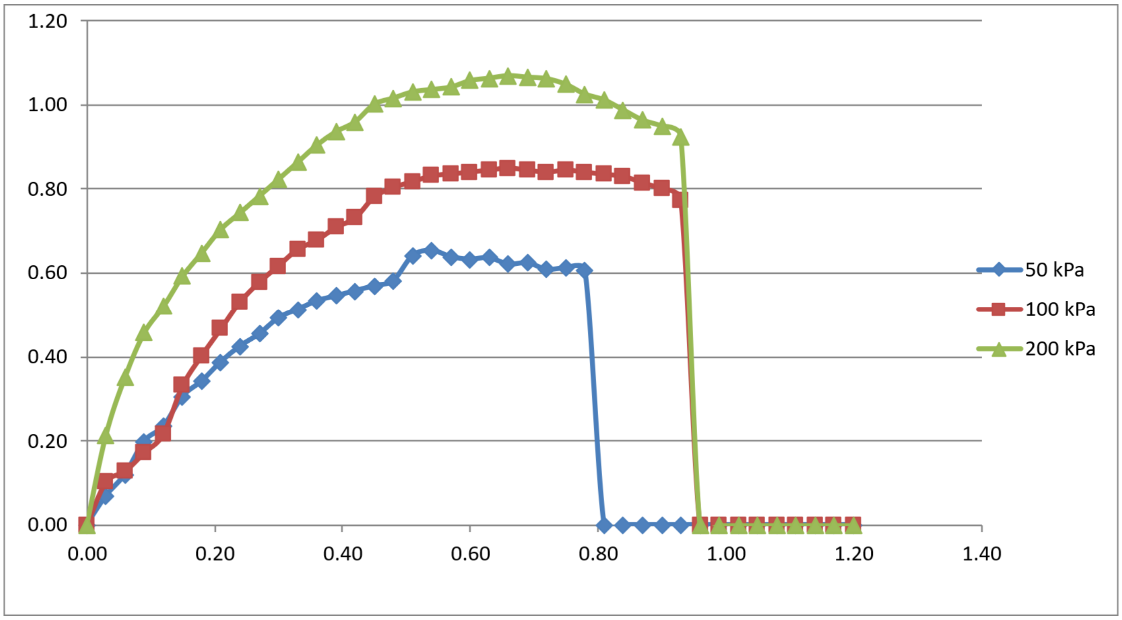
Graph.3.5: Load penetration Curve for sample 1

b) Direct Shear Test

Sample 1

Normal stress	Shear stress at failure	Shear Displacement at Failure		
50	64.12	0.78		

100	83.36	0.93		
150	104.90	0.93		
			Final Values	
C =	43.34	kPa	0.433	kg/cm²
φ =	0.407		22.15	⁰



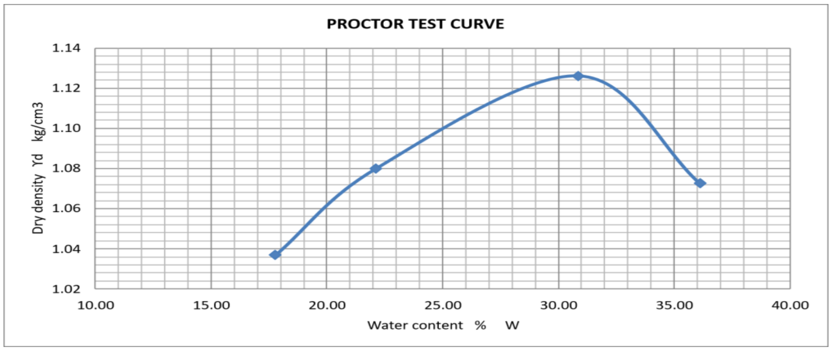
Graph.3.6: Direct shear test for sample 1

c) Proctor Test (Compaction Curve for Black cotton soil with plastic)

Sample 1

OMC=30.87, MDD=1.13

SAMPLE ID:		02% Plastic + B.C Soil		Mould Weight 'M2' (gm):				5935	
Weight of Can (W1)	gm	17.6	14.24	17.33	14.25	14.5	17.64	13.38	17.44
Weight of Can + Wet Soil (W2)	gm	85.01	72.32	51.83	53.78	82.05	72.05	55.1	59.48
Weight of Can + Dry Soil (W3)	gm	71.65	66.65	45.05	47.25	64.02	61.05	43.82	48.54
Water Content = ((W2-W3)X100)/(W3-W1)	%	24.72	10.82	24.46	19.79	36.41	25.34	37.06	35.18
Average Water Content (w)	%	17.77		22.12		30.87		36.12	
Weight of Soil + Mould (M1)	gm	7156		7254		7409		7395	
Weight of Mould (M2)	gm	5935		5935		5935		5935	
Wet Density (Dw) = (M1-M2)/V	g/cc	1.22		1.32		1.47		1.46	
Dry Density = Dw/[1+(w/100)]	g/cc	1.04		1.08		1.13		1.07	



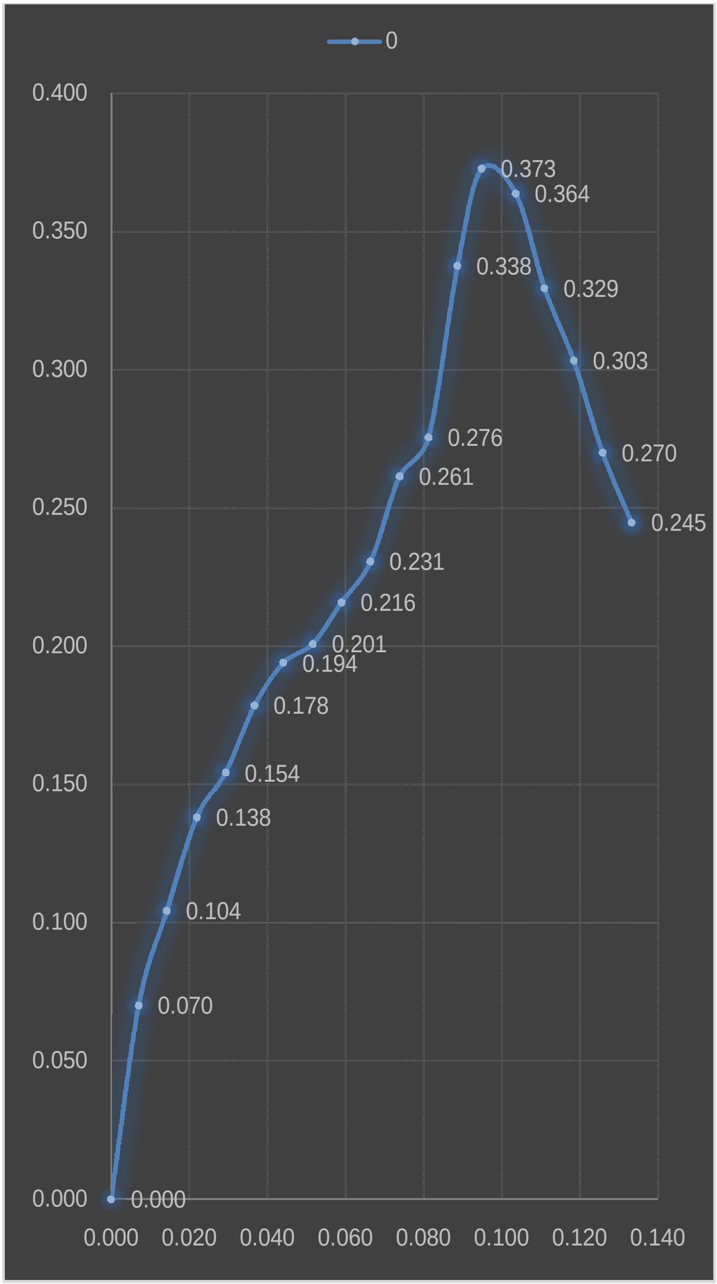
Graph.3.7: Proctor test curve for sample 1

d) UCS TEST

Sample 1

Axial Deformation (mm)	Axial Strain	Area (cm²)	Load (Kg)	Comp. Strength (Kg/cm²)
0	0.000	11.34	0	0.000
0.49	0.006	11.41	0.5	0.044
0.78	0.010	11.45	0.8	0.070
1.12	0.015	11.50	0.95	0.083
1.35	0.018	11.54	1.1	0.095
1.7	0.022	11.59	1.3	0.112
2.1	0.028	11.66	1.6	0.137
2.5	0.033	11.72	1.8	0.154
3.1	0.041	11.82	1.9	0.161
3.4	0.045	11.87	2.1	0.177
3.7	0.049	11.92	2.4	0.201
4.2	0.055	12.00	2.5	0.208
4.5	0.059	12.05	2.7	0.224
5.6	0.074	12.24	3.2	0.262
5.9	0.078	12.29	3.4	0.277
6.1	0.080	12.32	3.5	0.284
6.4	0.084	12.38	3.2	0.259
6.8	0.089	12.45	3.1	0.249

7.1	0.093	12.50	2.6	0.208
7.5	0.099	12.58	2.4	0.191
Unconfined Compressive Strength=			0.284	Kg/cm²



Graph.3.8: UCS Test Curve for sample 1

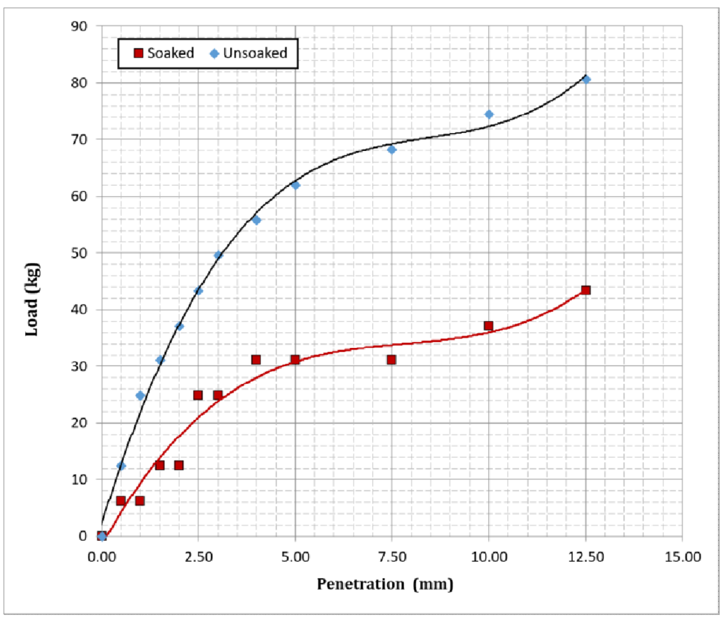
3) *Plastic 3%*

a) *C.B.R*

Sample 1

Condition	Unsoak	Soak
Penetration Reading	Load	Load

Division	mm	Division	kg	Division	kg
0.00	0.00	0.00	0.00	0.00	0.00
50.00	0.50	0.40	12.40	0.20	6.20
100.00	1.00	0.80	24.80	0.20	6.20
150.00	1.50	1.00	31.00	0.40	12.40
200.00	2.00	1.20	37.20	0.40	12.40
250.00	2.50	1.40	43.40	0.80	24.80
300.00	3.00	1.60	49.60	0.80	24.80
400.00	4.00	1.80	55.80	1.00	31.00
500.00	5.00	2.00	62.00	1.00	31.00
750.00	7.50	2.20	68.20	1.00	31.00
1000.00	10.00	2.40	74.40	1.20	37.20
1250.00	12.50	2.60	80.60	1.40	43.40
CBR @ 2.5 mm		7.97		7.81	
CBR @ 5 mm		7.92		7.91	

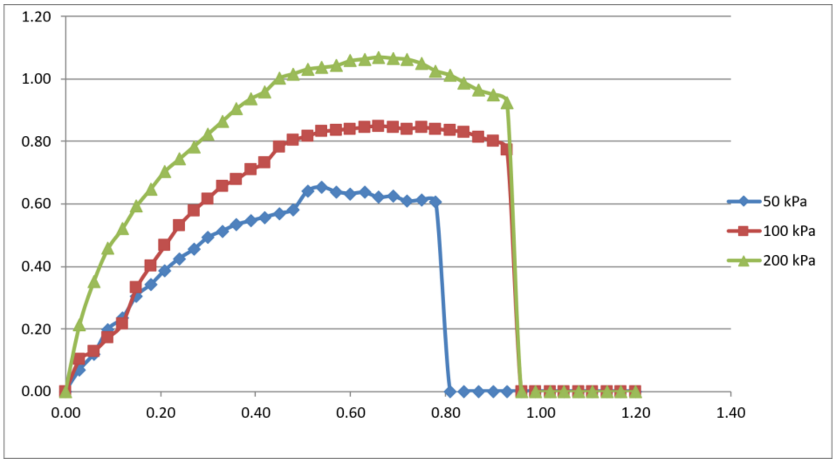


Graph.3.9: Load penetration Curve for sample 1

b) Direct Shear Test

Sample 1

Normal stress	Shear stress at failure	Shear Displacement at Failure		
50	64.12	0.78		
100	83.36	0.93		
150	104.90	0.93		
			Final Values	
C =	43.34	kPa	0.433	kg/cm²
φ =	0.407		22.15	⁰



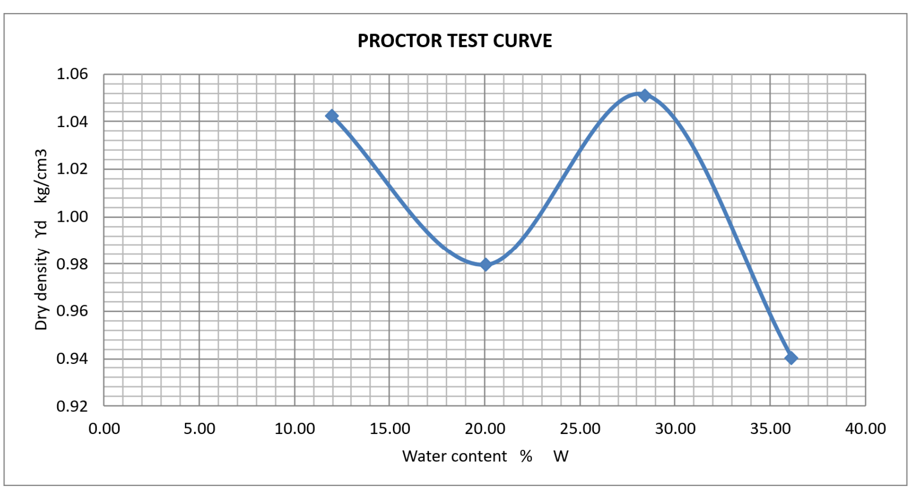
Graph.3.10: Direct shear test for sample 1

c) Proctor Test (Compaction Curve for Black cotton soil with plastic)

Sample 1

OMC=28.43, MDD=1.05

		03% Plastic + B.C Soil		Mould Weight 'M2' (gm):				5935	
Weight of Can (W1)	gm	17.6	14.24	17.33	14.25	12.87	17.64	13.38	17.44
Weight of Can + Wet Soil (W2)	gm	85.01	72.32	51.83	53.78	72.05	60.75	55.1	59.48
Weight of Can + Dry Soil (W3)	gm	77.21	66.65	46	47.25	59	51.17	43.82	48.54
Water Content = ((W2-W3)X100)/(W3-W1)	%	13.09	10.82	20.33	19.79	28.29	28.57	37.06	35.18
Average Water Content (w)	%	11.95		20.06		28.43		36.12	
Weight of Soil + Mould (M1)	gm	7102		7111		7285		7215	
Weight of Mould (M2)	gm	5935		5935		5935		5935	
Wet Density (Dw) = (M1-M2)/V	g/cc	1.17		1.18		1.35		1.28	
Dry Density = Dw/[1+(w/100)]	g/cc	1.04		0.98		1.05		0.94	



Graph.3.11: Proctor test curve for sample 1

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d) UCS TEST

Sample 1

Axial Deformation (mm)	Axial Strain	Area (cm²)	Load (Kg)	Comp. Strength (Kg/cm²)
0	0.000	11.34	0	0.000
0.47	0.006	11.41	1.5	0.132
1.17	0.015	11.51	1.8	0.156
1.75	0.023	11.60	2.5	0.215
2.41	0.032	11.71	2.9	0.248
3.05	0.040	11.81	3.1	0.263
3.69	0.049	11.91	3.4	0.285
4.33	0.057	12.02	3.9	0.324
4.97	0.065	12.13	4.25	0.350
5.61	0.074	12.24	4.75	0.388
6.25	0.082	12.35	5.25	0.425
6.89	0.091	12.47	5.78	0.464
7.53	0.099	12.58	6.25	0.497
8.17	0.108	12.70	6.98	0.550
8.81	0.116	12.82	7.4	0.577
9.45	0.124	12.95	7.2	0.556
10.09	0.133	13.07	6.5	0.497
10.73	0.141	13.20	6.1	0.462
11.37	0.150	13.33	5.9	0.443
12.01	0.158	13.46	5.4	0.401
12.65	0.166	13.60	5.2	0.382
Unconfined Compressive Strength=			0.577	Kg/cm²

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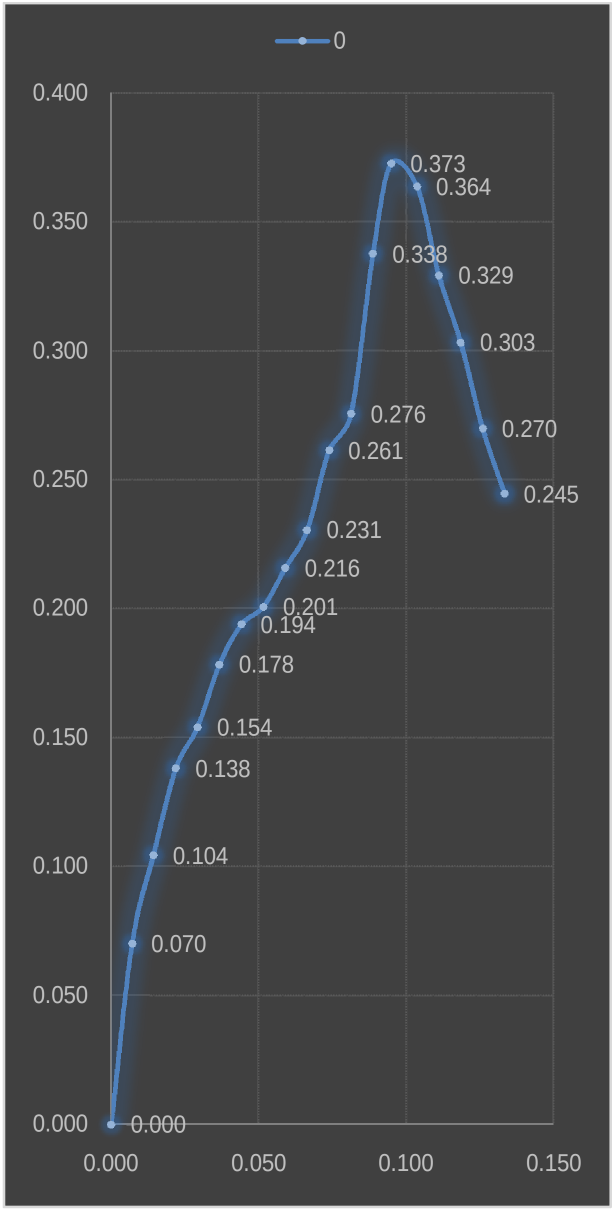

Graph.3.12: UCS Test Curve for sample 1

IV. CONCLUSION

Based on the experimental results and analysis, it was concluded that black cotton soil in its natural state possesses poor engineering characteristics, such as high plasticity, excessive swelling potential, and low bearing capacity, rendering it unsuitable for direct use as a subgrade material in road construction. The inclusion of recycled polymeric waste in the form of plastic strips significantly improved the strength and stability of the black cotton soil. The enhancement was most prominent at 2% plastic content, beyond which the improvement became marginal due to uneven mixing and the possible formation of voids within the soil matrix. The Unconfined Compressive Strength (UCS) values exhibited a considerable increase with the addition of plastic, indicating higher shear strength and resistance to deformation. Similarly, the California Bearing Ratio (CBR) values showed substantial improvement, confirming that the treated soil could effectively function as a subgrade or sub-base layer for low to medium traffic pavement sections. Moreover, the utilization of waste plastic not only enhanced the soil's performance but also offered an environmentally sustainable method for managing non-biodegradable solid waste.

Overall, the stabilization of black cotton soil using recycled polymeric waste proved to be an economical, eco-friendly, and technically viable solution, particularly suitable for rural road construction and other geotechnical engineering applications.

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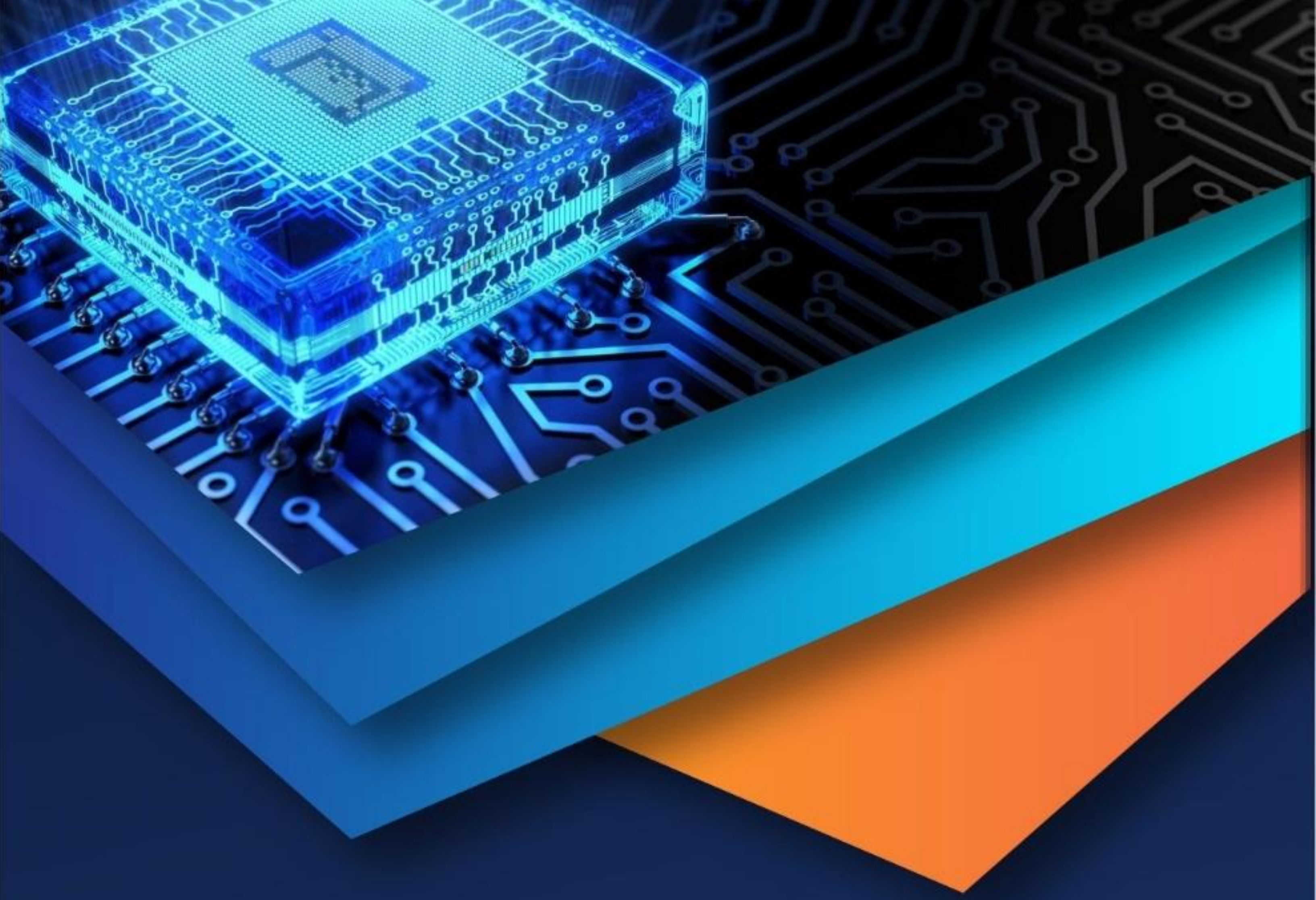

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