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Durability and Strength Analysis of Cement Treated Soils for Sub-Base and Base Layers of Pavement

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Abstract: The development and growth in economy of the country is primarily depended on the connectivity within the country and region around. The basic and most utilized for of transportation used is the roadways and highways transportation. Good quality metal aggregate is required in large quantity for construction of roads which is scarce in nature. One alternative to this problem is to use the locally available soil by stabilising it with help of cementitious material so that it can be effectively used. The strength and durability are the basic requirements for any stabilised material to be used for road construction and thus in this paper the strength and durability characteristic of 3 soils treated with cement has been tested. The test used for strength evaluation is CBR test & 7 day UCS test and wet-dry durability test has been considered for durability evaluation for cement treated soils. The minimum dosage of cement based on then residual strength and mass loss percent criteria was calculated. It was reported that the amount of cement required for stabilisation is largely depended on the type of soil and vary accordingly.
Keywords: Low volume road; Durability of soil; Cement treated soil; Wetting-drying test; Residual UCS.

I. INTRODUCTION

For sustainable growth of the country it is essential to enhance the R policy which means Reduce, Reuse and Recycle. The policy is likewise followed in the case of the highway and road network construction by Reducing the use of good quality natural aggregates scare in nature, Reusing the material acquired as waste from old construction sites and other industries and Recycling these materials acquired.

The best way to enhance the sustainability of construction is to use the locally available material such as soil, debris, and other aggregates which are naturally not suitable for use in construction. These materials which are locally available and in large quantity can be enhanced in their properties by stabilising them with any cementitious material available. The stabilised materials are largely used for construction in many countries globally.

The natural occurring aggregates are weak in their strength and possess low strength which can be enhanced by stabilising them by means of mechanical compaction and by providing reinforcement to the soil matrix with addition of binders in chemical form such as cement, lime, bitumen or any other agent [8].Stabilization of Soil can be explained as enhancement in the characteristics of natural obtained soil with aim to acquire the desired properties. The important properties which are enhanced include strength, durability and volumetric change of soil.

Many a techniques is presented for stabilization of soil. For soil the durability can be termed as its property by virtue of which the soils performance is assessed under the consecutive cycles of freeze-thaw and wet-dry test. These test methods are adopted based on the climatic conditions of the region from where the soil is selected for testing. For hilly areas and area with subzero temperature the freeze-thaw test id adopted while wet-dry test is adopted for other regions [9] Separate guidelines are presented by different agencies for the type of stabilizer that should be adopted for particular type of soil selected on the basis of physical and chemical property & amount of stabilizer for economical and efficient results.

Literature work available in this regard is limited accounting for Indian soils. IRC SP 89-2010 states that wetting drying test should be used for testing the durability of stabilized soil.

Based on the soil type the quantity of stabilizer necessary for least Mass loss standards distinguishes and accordingly no standard quantity of stabilizer can be recommended to be used for all soil types irrespective of diverse properties. Variance among the suggested standards of Mass loss of global agencies and the Indian standards differ. Thus in this paper the required amount of cement has been calculated meeting the Indian Standards for mass loss and durability.

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II. LITERATURE REVIEW

In this part the previous research done on the context of durability and residual UCS by various authors and on various soil types using number of stabiliser contents in varying ratio and the findings observed by authors has been presented.

A. Stabilisation

Soil stabilization is defined as the alteration of normal soil & aggregate to mend its properties and features. Advantages by stabilization comprise of ability to use weak material causing reduction in budget and saving precious time required for carrying decent material for fill. The use of stabilization has enlarged recently because nearly all soils can be stabilized with some exceptions like organic soils, highly plastic clays, and poorly reacting sandy soils. Usually soil with 5 - 35% passing IS 75-micron sieve marks for best stabilized soils. Stabilization can be vindicated by causes such as great transference price and absence of decent quality material. Usually subgrades have low strength & stabilization permit the use of nearby material. Cementitious materials stabilize soils and modify their characteristics through various chemical reactions such as exchange of cation, flocculation of soil, agglomeration in soil mass and most important pozzolanic reactions. Production of hydration products by cement causes increase in strength and support values of base materials leading to enhanced performance of treated material. Different stabilizers are available commercially which use separate techniques for stabilizer. Major components of Portland cement are calcium-aluminates and calcium-silicates which on mixing with water reacts and causes hydration to form calcium-silicate-hydrate CSH and calcium-aluminate-hydrate as well as excess calcium hydroxide which are main cementing compounds responsible for the cementious action. This formation of cementitious material, and calcium hydroxide (lime) makes Portland cement a suitable material to be used as stabilizer. The stabilization of soil with cement causes reduction in its permeability which result in formation of a material that is moisture resilient and highly durable which restrains leaching over long period of time. Also the thicknesses of CTB are less as compared to granular bases carrying the same traffic because CTB distributes the load over a large area. Normally the cement contents used for stabilization range between 3 – 10% cement by dry weight of soil resulting a 7-day UCS of about 2.1 to 5.5 MPa. The Portland Cement Association Handbook, 1956 recommends the amount of soil to be used for stabilisation based on the classification of soil as per AASHTO.

B. Durability

[7] Defined durability as the capacity of soil to hold constancy and integrity even after number of years of exposure to the action of weathering. [4] defined it as capability of material to sustain its integrity and uphold satisfactory residual strength in long-term against harsh climatic condition.[2] designated that wet-dry cycles fissures were introduced and spread producing unadorned variations in properties of soil, mainly in residual strength. [1] Verified clayey soil with and established that increased soaking time causes significant decrease in durability index for initial soaking period of about upto 15 days. [3] Completed durability test on sand and gravel and established that UCS strength has a non-linear power relationship with durability in terms of mass loss % and that increase in W-D cycle results a decrease in mass loss [9] indicated that long testing time of durability tests forces many highway agencies to agree a least 7-day unconfined compressive strength. They established that a minimum seven-day UCS value of 2.2 MPa achieves the durability standards suggested by PCA (1992). **[6]** used clayey soil and did wet-dry test and found that the strengths diminish considerably with increase in wet-dry cycle for all samples with 7 days curing were not able to pass the suggested mass loss value after only first wet-dry cycle although 7 and 12% CCR samples (28 days cured) sustained up to the second w-d cycle it indicates that w-d cycle strength is reliant on unsoaked strength and OMC and MDD of soil impact the strength and durability..[5] tested Kaolin clay soil by Japanese Highway Society durability test procedure for wetting–drying in which sample is submerged in water for 24 hr then oven drying at 72°C for 24 hr and then brushing which conclude 1 wet-dry cycle. They established that submergence of sample in first stage cause de-acceleration of chemical reaction interrupting the bonding of soil particles. They also reported decrease in compressive strength with increase in wet-dry cycles particularly for initial cycles then with an increase in wet-dry cycles the effect decreases.

III.MATERIALS USED

This section contain the details of materials used, sample preparation and testing procedures.

A. Soils used

Three soils collected from construction site of low volume road in Rajnandgaon and Narayanpur districts of Chhattisgarh State were used. The soils were tested for physical and chemical properties presented in Table 1. The soils were classified as SM (Silty Sand) for soil 1 and CL (Low Compressible Clay) for soil 2 and 3 as per Unified soil Classification System and A-2-6, A-4 and A-6 for soil 1, 2 and 3 as per AASHTO Classification. The gradation curve of soils is presented in Figure 1.

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B. Cement Used

Cement used was Portland Pozzolana Cement and test for properties of cement were conducted prior to its use.

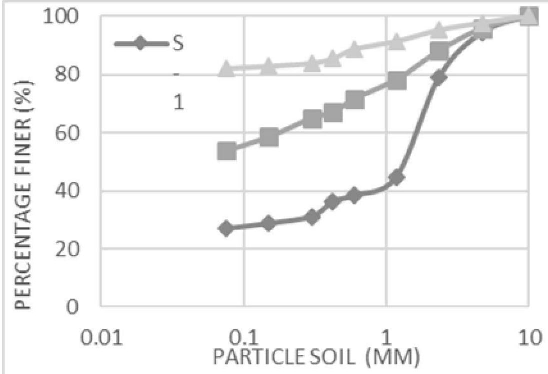

Figure 1 particle size distribution curve of soil.

TABLE 1
Physical Properties Of Soils

Test Property of Soil	Soil Type		
	S-1	S-2	S-3
Grain Size Analysis			
Gravel (%)	6.60	5.20	4.40
Sand (%)	63.40	39.00	12.40
Silt and Clay (%)	29.00	55.80	83.20
Uniformity Coefficient (C_u)	4.05	24.98	4.10
Coefficient of Curvature (C_c)	0.54	34.48	0.53
Atterberg Limits			
Liquid Limit, (%)	36.10	32.00	36.75
Plastic Limit, (%)	24.00	21.00	25.00
Shrinkage Limit (%)	16.23	11.40	10.00
Plasticity Index, (%)	11.30	10.20	14.00
Free Swell Index (%)	9.00	6.00	18.00
Plasticity Product	3.10	5.49	11.51
Classification (as per USCS)	SM	CL	CL
Classification (as per AASHTO)	A-2-6	A-4	A-6
Specific Gravity	2.87	2.64	2.66
Optimum Moisture Content (W_{om}) (%)	10.4	11.6	12.05
Maximum Dry Density (γ_d) (kN/m3)	20.5	18.1	17.7
California Bearing Ratio (CBR) (Soaked)	6.09%	6.28%	3.48%
Unconfined Compressive strength (UCS), MPa	0.66	0.12	0.89

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IV. METHOD USED

Five different cement contents were selected for stabilisation of soil with interval of 3% ranging from 0% to 12 %. Since three soils had different initial properties thus more cement quantity was selected for both wet-dry and UCS test. For all the initial tests relevant Indian Standard codes were used IS 2720 (Part – 1 to 16). The size of sample used for UCS test was 3.8 mm dia and 76 mm height while for wet-dry test the specimens dimension used was 100mm dia and 127mm height.

Figure 2. Specimen prepared for wet-dry test.

Figure 3 Wet-Dry Specimens after 7 day curing.

A. Unconfined Compressive Strength (UCS) test

UCS test was conducted after 7 days of moist curing. Two specimens for each cement content were used and average value was reported. Digital Unconfined Compression Testing machine was used.

B. Durability

The durability test was performed as per Portland Cement Association, Soil-cement laboratory handbook (1956) comprising of 12 cycles of wetting and drying and brushing. After 12 cycles the samples were oven-dried to a constant weight and oven-dried weight for each sample was used for mass loss calculation.

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Figure 4 wetting phase of Wet-Dry test.

C. Residual UCS

The residual UCS test was conducted on samples after 12 wet-dry cycles and water capillary rise test. The samples were oven-dried at 50°C up to constant mass and then submerged in water for 4h prior to testing for UCS. The load was applied at the rate of 1.25mm/min until the failure of the sample.

V. RESULTS AND DISCUSSION

A. Durability

The W-D durability test result expressed as mass loss percentage of the initial dry weight of soil for different stabilizer content for all three soils is shown in Figure5. It may be observed that for 0% cement sample of soil 1 both the specimens could

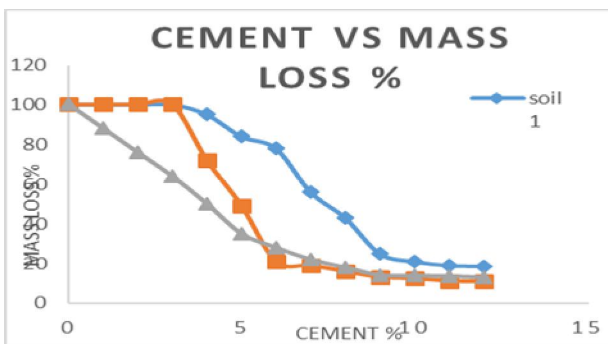

Figure 5. Cement vs mass loss curve for all soils.

not sustain even first wet-dry cycle. The specimens started dismantling within 30 minutes of immersion in water with clear disfiguring of surface and within 2.30 hours of submergence both the specimen with 0% cement dismantled. The visual effect of dismantling can be observed from Figure 6. The 3% cement sample of soil 1 continued up to the 3rd cycle. The accumulation of 3% cement increased the durability by 2 wet-dry cycles for soil 1. The natural sample without ant stabiliser for soil 3 sustained up to 2nd cycle while the 3% stabilized sample was whole up to end of test even though the mass loss was crucial. Soil 3 was only soil to sustain 12 wet-dry cycles for 3% cement content.

These observations are same as encountered by [6] where stabilized samples of CCR and cement for 7 days curing could not pass the suggested criteria after first cycle. Higher mass loss was reported for the three initial cycles and decreased subsequently with increasing cycles which was also reported by [5]. The reduction in mass loss after 3rd cycle can be accredited to the increase in strength of soil cement blend, samples were cured for 7 days causing improper strength development. During the initial 3 wet-dry cycles soil and cement react to form Calcium-Silicate-Hydrate (C-S-H) gel liable for strength development. Completion of 3 wet-dry cycles takes 6 days which provides time for the cement to react and produce strong bond with soil decreasing mass loss rate. The mass loss for 6% cement sample of soil 2 and soil 3 was found to be 21 and 27% while soil 1 mass loss was 75%. Since soil 1 had the least amount of (silt + clay) content, about only 29% whereas soil 2 and soil 3 had 55 and 83 %. It was detected that soil 3 had a maximum amount of. (Silt +clay) content produced maximum durability. With increasing cement content, rate of mass loss

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decreased. Following PCA cement content, rate of mass loss decreased. Following PCA guideline, no soil passed the 10% limiting mass loss criteria. Nevertheless, all soils passed IRC limiting mass loss criteria of 20% for base and 30% for subbase and shoulder. IRC commend a least UCS value of 1.7 MPa for 30% mass loss for sub-

Figure 6 Breaking of specimen during wetting.

Base and 3 MPa for 20% mass loss after 7 day soaking. The wet-dry cycle had maximum effect for soil 1 having maximum sand. As the mass loss of soil 1 was higher than soil 2 and 3. The wet-dry test needs a great period of time around a month which turn out to be inappropriate for projects with time-boundation so many researchers propose that a minimum 7 day UCS strength that justifies durability. for the soils used for this research day UCS value was used to calculate cement content and was found to be 15% for base and 6.5% for sub-base for soil-1, 9% for base and 5% for sub-base for soil-2 and 12.4% for base and 5.5% for sub-base for Soil -3. The cement content satisfying the 7 day UCS criteria were found acceptable for mass loss percentage criteria as well. An obvious relation exist among cement content and mass loss (%) and also 7 days UCS and mass loss %

The cement content amount necessary to achieve the mass loss standards calculated on the 7 days UCS was establish to be vary for different soils and hence diverse equations are needed to forecast the mass loss % on basis of 7 day UCS. Minimum UCS of 3.0 Mpa designate that durability is vital factor for the mix design of stabilized material. IRC (2012) endorse least 7 day UCS values of 1.5 MPa and 1.72 MPa for soils to be used for pavement construction. The ahead of time cracking at interface layer was due to lack of bonding amid layers and hence the samples stabilized with small cement displayed greater inconsistency in the result whereas the sample with greater cement content portrayed lesser difference which was also stated by[3]. It was detected that all soils had a greater amount of loss all through initial cycles which was be likely to drop later. The trend for a drop in the degree of mass loss with an upsurge in the cycle number was set up dissimilar for all soils since the soils distinguished in their grain distribution and basic properties. Soil 2 portrayed maximum rate of loss for up to cycle 3which dropped to nearly even rate and then once more increased between cycle 9 & 11. The loss flanked by cycle 11 and 12 was very low for high cement content for all three soils. Therefore, it can be stated that after a certain verge more addition of cement do not deliver any helpful effects so using additional quantity of cement in mixing may not essentially deliver improved outcomes. Soil 3 portrayed similar kind of tendency with higher loss during initial cycle and a weakening in loss rate with the upsurge in number of cycles. The trend for the normalized mass loss was found lowest for soil 3 which could be the reason that soil 3 had maximum amount of fines. Also, the trend followed by all soils is similar to observed by [3] i.e. with the increase in cement content the soil line of normalized mass loss goes down which is observed for all three soils tested.

B. Residual UCS

The specimens after 12 W-D cycle were tested for the effect of the w-d cycle on the residual strength of samples. The samples were oven-dried at a constant temperature of 55°c until constant weight. Then the specimens were submerged in water at room temperature for 4 hrs prior to testing for residual UCS. For 7 day cured specimen of soil 1 surge in UCS was 22 % when cement content was increased by 3 % while for the same specimen after 12 cycles the 4h soaked UCS increased about 18 %. For soil 2 the 7 days UCS increased 50 % while residual UCS increased 170 % for the same addition of 3% cement. For soil no 3 the surge in 7 days UCS was 54% while it was 25% for residual UCS. Soil 2 had maximum increase in UCS for both 7 day and residual UCS followed by soil 3 whereas soil 1 had the minimum rise in UCS with the addition of cement for both the cases. It was described that with a rise in cement content the percentage decrease in UCS due to w-d cycle also reduced. For soil 3 the reduction amid 7 day UCS and residual soaked UCS was 33% for 9% cement and 18% for 12 % cement. For soil 2 the decrease in UCS for 9% cement stabilized sample was 80% while it was 65% for 12% cement stabilized sample. Soil 1 validated an exclusion in this case as for 9%

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Volume 7 Issue IX, Sep 2019- Available at www.ijraset.com

cement stabilized specimen of soil 1 reduction in UCS after the w-d cycle was 60% while it intensified to 63% reduction for 12% cement stabilized sample. It was observed that soil 3 had the least decrease in UCS and soil 2 had maximum decline in UCS the reason for this anonymity in behavior can be attributed to the presence of high silt and clay content in soil 3. The bond formed between fine soil and cement is strong enough to hold the soil particles together even after being subjected to multiple cycles of wet-dry.

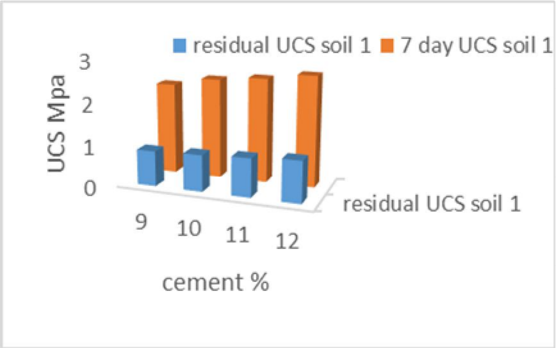

Figure7. 7 day vs residual UCS soil 1.

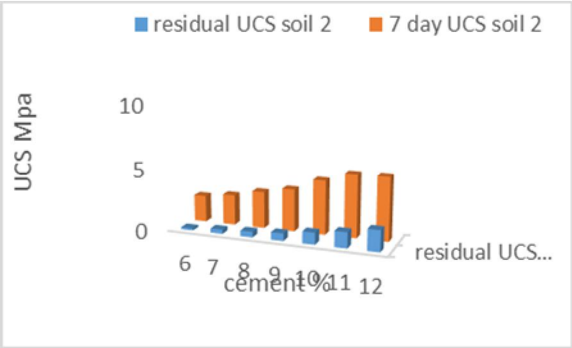

Figure 8. Residual vs 7 day UCS soil 2

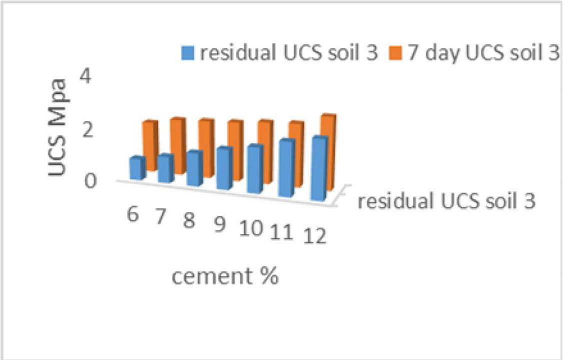

Figure 9. Residual vs 7 day UCS soil 3

VI. CONCLUSION

Based on the results obtained from testing stabilised soil for durability, strength and residual strength it was concluded that 7 day unsoaked UCS value of stabilised soil can be used to predict the mass loss percent after 12 wet-dry cycle. The residual strength was calculated by soaked UCS test and it was observed that soil samples stabilised with cement possess good strength even after being subjected to 12 wet-dry cycles.

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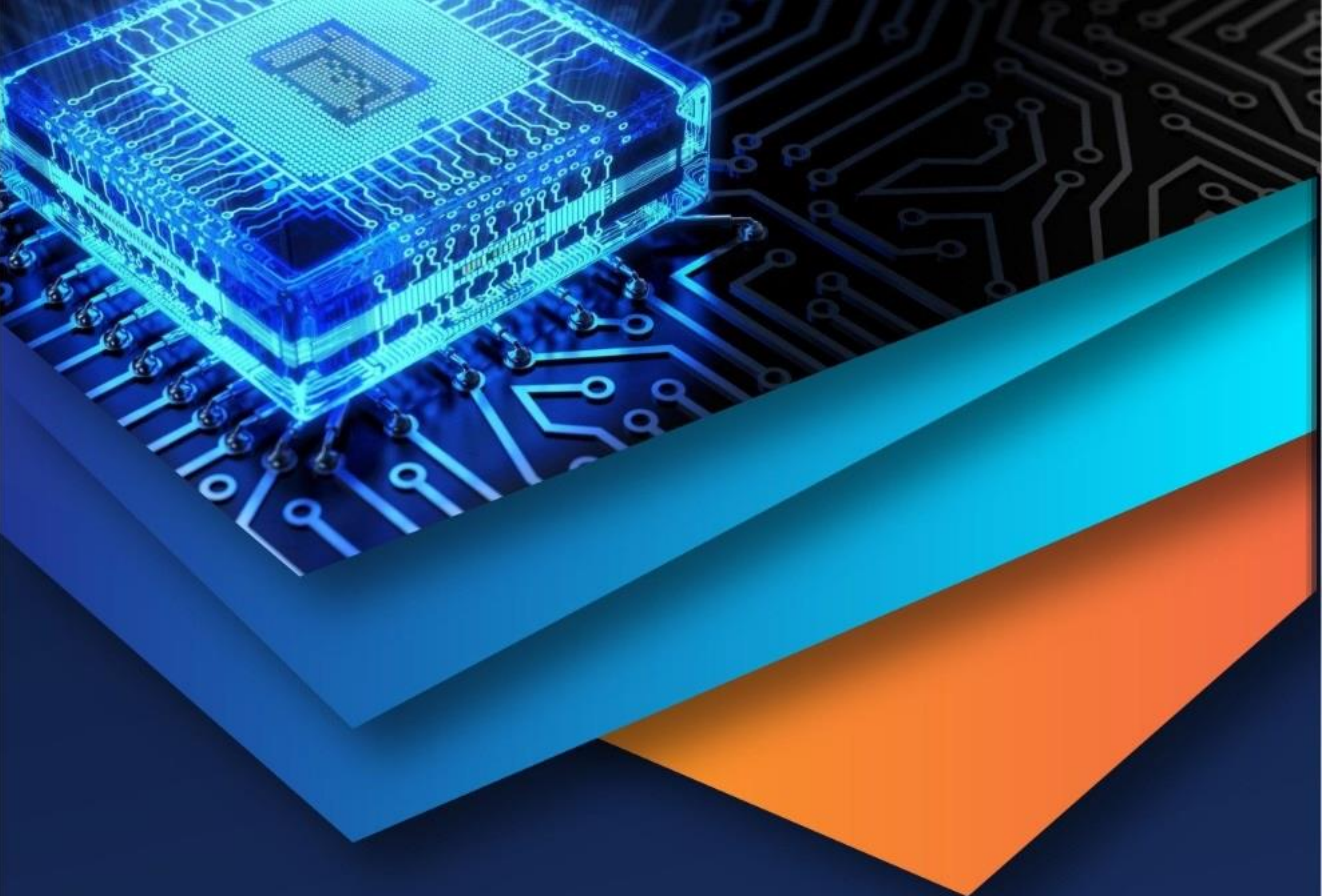

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