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Sustainable Construction – High Strength Concrete with Crushed Burnt Clay Brick Waste Aggregates

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Abstract: Crushed burnt clay brick aggregates are an alternative in areas where natural aggregates are either scarce or they are not suitable for durable concrete. Such aggregates are generally cheap and are readily available in many countries of South Asia, Africa and Middle East where otherwise quality aggregates are scarce and expensive. This investigation explores the possibility of using crushed burnt clay brick aggregates obtained from bricks with high crushing strength and low absorption in the manufacture of high strength concrete and it's performance. Wide ranging investigations covering most aspects of mechanical behavior and permeability were carried out for various mixes for compressive strengths of 60N/mm^2, 80N/mm^2 and 100N/mm^2. Compressive strengths of 60N/mm^2 and 80N/mm^2 were successfully achieved. A design procedure for design of high strength concrete mixes with crushed brick aggregates is thereafter proposed
Keywords: Sustainable construction, Recycled aggregates, Brick waste, High strength concrete

I. INTRODUCTION

Crushed burnt clay brick aggregates are being used as an alternative in low rise structures and concrete pavements in many countries of South Asia like India, Pakistan, Bangladesh, Sri Lanka along with other regions of Middle East and Africa, where good quality natural aggregates are scarce whilst good quality burnt clay bricks are produced cheaply and extensively. The use of crushed burnt clay brick aggregate for the production of high strength concrete and it's performance have not at all been investigated as yet [1-3]. High strengths are achieved by the use of good quality, well graded aggregates and w/c ratios reduced below 0.35 with the aid of superplasticising admixtures

II. RESEARCH SIGNIFICANCE

Keeping in view the vast usage of high strength concretes with better performance in recent construction practices the aim of this investigation was to explore the possible use of aggregates obtained by crushing good quality burnt clay bricks with high crushing strength and low absorption in the production of high strength concrete. The angular shape and rough texture of aggregates obtained by crushing good quality bricks improves the aggregate-mortar bond and higher crushing strength together with low w/c ratio should yield higher strength, making it a suitable and competitive structural material for use in the regions with scarce natural aggregates.

III.DESIGN OF MIXES

In order to establish a procedure for mix design a linear projection of compressive strength versus w/c ratio from Design of Normal Concrete Mixes method was considered initially beyond the limiting w/c ratio of 0.3 [4]. An initial estimate of density was made and later adjusted in the light of values actually obtained. Three mixes for characteristic strengths of 60, 80 and 100N/mm2 were designed using ordinary Portland cement, crushed burnt clay brick coarse aggregates (maximum 37.5mm diameter) and medium grade sand. Burnt clay bricks with crushing strength of 40N/mm2 were used for this testing. This mix design was then used further to design high strength concrete mixes with crushed burnt clay brick coarse aggregates by keeping the w/c ratio and the quantity of free water constant and altering the quantities of coarse and fine aggregates only to cater for the variation in densities. Table 1 gives the properties of aggregates and Table 2 gives the details of mixes. The grading of crushed burnt clay brick coarse aggregate is given in Figure 1. Up to 14 l/m3 of superplasticiser was used to maintain high workability with slumps in the range of 60 to 180mm [5,6].

IV.DESCRIPTION OF TESTS

Three specimens from three different batches were used in all tests. Specimens used for different tests were as follows: -

A. Compressive strength/density 150mm cubes, 150mm diameter, 300mm long cylinders.
B. Flexural strength 150x150x750mm beams.
C. Stress/strain behaviour 150mm diameter, 300mm long cylinders.

D. Static modulus of elasticity 150mm diameter, 300mm long cylinders.
E. Dynamic modulus of elasticity 150x150x750mm beams.
F. Ultrasonic pulse velocity 150mm cubes.
G. Initial surface absorption 150mm cubes.

All specimen were cured in water at 20^0 C for 42 days before testing.

V. DISCUSSION OF RESULTS

The properties of the high strength concretes produced are summarized in Tables 3 and 4.

A. Compressive Strength

Compressive strength tests on cubes at 7 days and 28 days showed that the rate of development of strength of crushed burnt clay brick aggregate concrete was similar to that for normal aggregate concrete. However, it was observed that satisfactory strengths could be achieved in 42 days, since due to low w/c ratios, water is required from external sources for hydration of cement. Hence a longer curing time is needed for the development of the required strength due to the slowing in the rate of moisture movement as hydration proceeds.

Figure 2 shows the range of compressive strengths achieved for different w/c ratios. Crushed burnt clay brick aggregate concrete developed 80 to 85% of its 42 day characteristic strength in 7 days and 90 to 95% in 28 days. Crushed burnt clay brick aggregate concrete developed a maximum compressive strength of 80N/mm^2 and a further reduction in w/c ratio did not result in an increase in compressive strength. The limiting factor is the strength of clay bricks from which the aggregate is obtained. Cylinder strengths of crushed burnt clay brick aggregate concrete were observed to vary from 60 to 63% of the cube strength as compared to 70 to 74% for high strength concrete with normal aggregates. The complete section of high strength concrete specimen tends to reach failure simultaneously hence failure of cubes and cylinders tends to be sudden and explosive. Sudden failure is likely to cause damage or injury unless protective measures are taken. A loading rate of 0.15 to 0.2N/mm^2/s was observed to be safe enough as compared to 0.2 to 0.4N/mm^2 specified by BS1881: Part 116:1983 [5].

B. Flexural strength

From the values given in Table 3, it can be seen that the flexural strength of concrete with crushed burnt clay brick aggregate varied from 8 to 11% for average compressive strengths in the range of 60 to 80N/mm^2. For concrete with normal aggregate the corresponding range is 9 to 11%. Hence the flexural strength values for concrete with brick aggregates are similar to those of concrete with normal aggregates. It was observed that failure in flexure across the section of test beams occurred by a crack through both the mortar and the aggregate particles in the case of concrete with brick aggregates similar to the control mix [5] .

C. Stress/strain behavior

Stress/strain relationships in compression are shown in Figures 3 and 4 for w/c ratios of 0.29 and 0.24 respectively. It was observed that the general form of the stress/strain characteristics of concrete with crushed burnt clay brick aggregates was similar to that for concrete with normal aggregates. Both the curves were observed to be virtually linear up to the point of failure, except for the initial small portion. However, the stiffness of the crushed burnt clay brick aggregate concrete proved to be much lower resulting in higher strains [5].

D. Static modulus of elasticity

The average static modulus of elasticity for concrete with crushed burnt clay brick aggregates was observed to be 36% lower than that for normal aggregate concrete.

E. Dynamic modulus of elasticity

The average dynamic modulus of elasticity for concrete with crushed burnt clay brick aggregate was observed to be 38% lower than concrete with normal aggregate.

F. Ultrasonic pulse velocity

The ultrasonic pulse velocities observed for different concretes are given in Table 4. Average pulse velocity across concrete with crushed burnt clay brick aggregate was observed to be 4.2kms as compared to 4.8kms for concrete with normal aggregate. Hence ultrasonic pulse velocity in the case of concrete with crushed burnt clay brick aggregate was observed to be 12.5% lower than concrete with normal aggregate which is due to the lower density of brick aggregates [5,6].

G. Density of hardened concrete

The average saturated and oven-dried densities for concrete with crushed burnt clay brick aggregate were 2335 and 2314kg/m^3 respectively, and 2480 and 2461kg/m^3, respectively, for normal aggregate concrete. Hence the saturated and dry densities of concrete with crushed burnt clay brick aggregate are about 6% lower.

H. Initial surface absorption (ISAT)

Results of ISAT are given in Table 4. Initial surface absorption for high strength concrete with crushed burnt clay brick aggregate was observed to be similar to high strength concrete with normal aggregates, varying from 5 to 6ml/m^2/s for 10-minute values and 2.0 to 3ml/m^2/s for one-hour values [5,6].

VI. CONCLUSION

Aggregate obtained by crushing burnt clay bricks with crushing strength of 40N/mm^2 have been used for high strength concrete up to a maximum compressive strength of 80N/mm^2 i.e. twice the crushing strength of bricks. Higher compressive strengths are likely to be possible with the use of higher strength burnt clay bricks. High strength concrete mixes designed for normal aggregate were observed to be practical for crushed burnt clay brick aggregates also since the workability of high strength concrete mixes depends on the efficiency and quantity of superplasticizer used. Compressive strengths of 60 and 80N/mm^2 were successfully achieved. Flexural strength of crushed burnt clay brick aggregate concrete in the high strength range was observed to be similar to high strength concrete with normal aggregate. The average static modulus of elasticity was observed to be 36% lower, average dynamic modulus 38% lower and about 6% lower densities were observed for high strength crushed burnt clay brick aggregates concrete as compared to high strength concrete with normal aggregate. Surface absorption was observed to be similar for both concretes.

VII. RECOMMENDATIONS

Coarse aggregates obtained by crushing burnt clay bricks can be used for the manufacture of high strength concrete. The following design procedure is recommended for design of high strength concrete with crushed burnt clay brick aggregates.

Step 1. Select w/c ratio against the desired strength from Figure 5 (Design Chart)
Step 2. Determine free water content from Table 5. Ensure the aggregates are in saturated surface dry condition.
Step 3. Determine cement content from w/c ratio and free water content.

$$Cement.content \equiv \frac{Free.Water.Content}{{}^{W}\!/_{C}.Ratio}$$

Step 4. Determine total aggregate content.
To determine the total aggregate content, an estimate of the wet compacted density is made from following: -
Fresh compacted density = 1025 x R.D.

Where R.D is relative density subject to a minimum value of 2.2.
Note: Minimum crushing strength of bricks crushed to obtain aggregates for high strength concrete should be around 40N/mm^2.
Calculate total aggregate content from: -
Total aggregate = wet compacted density - cement - water
Step 5. Determine fine and coarse aggregate contents.
Fine aggregates = %fines x Total aggregate content. Coarse aggregates = Total aggregate content - fine aggregates.

Use 30 to 28% fines, the higher value for higher w/c ratio and the lower one for lower w/c ratio varying from 0.29 to 0.16 respectively. Use of fine sand tends to increase the free water content whereas coarse sand tends further to reduce workability.

Type	Relative Density SSD	Bulk Density kg/m^3	Impact Value %	10% Fines Value kN	Absorption %
Crushed Burnt Clay	2.32	1126	31.6	144	2.76

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Brick Aggregates					
Normal Aggregate	2.49	1560	23	391	1.05

Table 1. Properties of aggregates

Characteristic Strength N/mm^2	W/C Ratio	Cement kg	Sand kg	Water kg	Aggregate kg	Super Plasticiser
60	0.29	465	515	135	1335	7 l/m^3
80	0.24	565	490	135	1260	9.1 l/m^3
100	0.19	710	450	135	1155	14.1 l/m^3

Table 2. Design of high strength concrete mixes.

Type of Aggregate	W/C Ratio	Cube Strength 7Days N/mm2	Cube Strength 28Days N/mm2	Cube Strength 42Days N/mm2	Cylinder Strength N/mm2	Flexural Strength N/mm2
Normal	0.29	49.30	57.91	62.22	43.74	6.42
	0.24	68.47	76.24	80.70	59.95	7.09
	0.19	83.97	100.13	106.72	87.42	9.29
Crushed Burnt Clay Brick	0.29	51.87	58.31	62.77	37.68	6.47
	0.24	66.61	72.89	80.82	49.23	6.82
	0.19	67.93	73.44	82.09	51.10	7.04

Table 3. Properties of high strength concrete.

Type of Aggregate	W/C Ratio	ISAT ml/m2/s	Elastic Modulus N/mm2	Dynamic Modulus N/mm2	Pulse Velocity km/s
Normal	0.29	3.0	24763.4	51378.2	4.79
	0.24	2.5	25190.7	54563.1	4.82
	0.19	2.0	25079.6	53684.7	4.84
Burnt Clay Brick	0.29	2.5	15686.1	32095.7	4.20
	0.24	2.0	15793.5	32758.4	4.20
	0.19	2.0	15981.6	32754.8	4.30

Table 4. Properties of high strength concrete.

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Maximum Aggregate Size	Water
40mm	135kg/m3
20mm	150kg/m3

Table 5. Determination of free water content

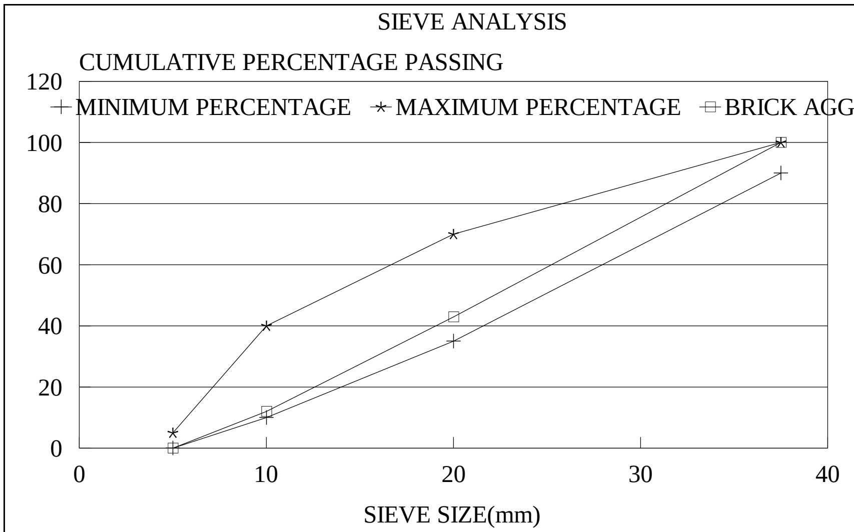

Figure 1. Sieve Analysis - Minimum and maximum percentages as given in BS 882.

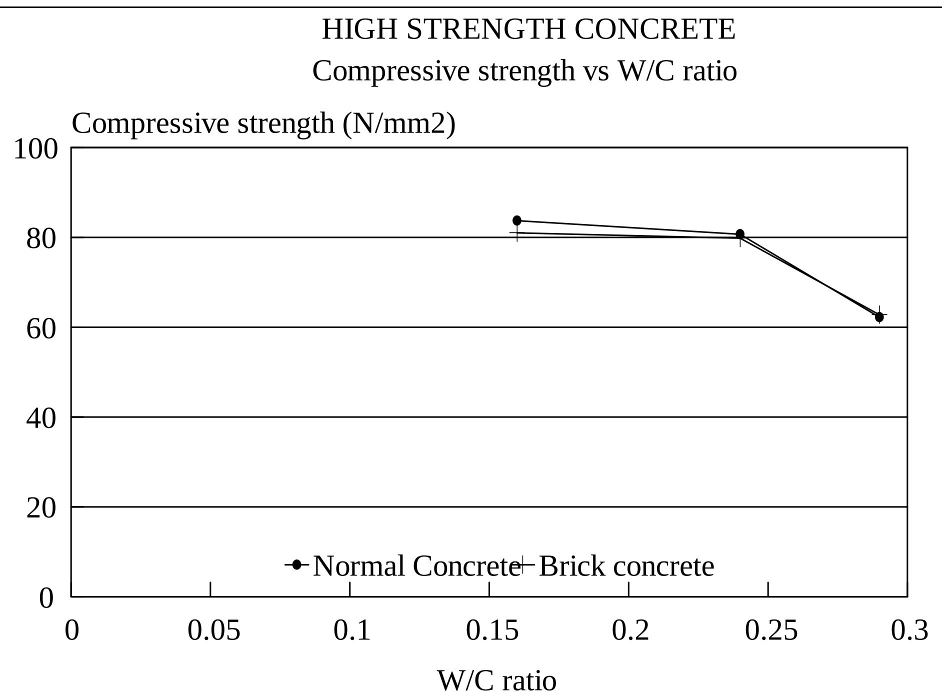

Figure 2. Compressive strength vs w/c ratio

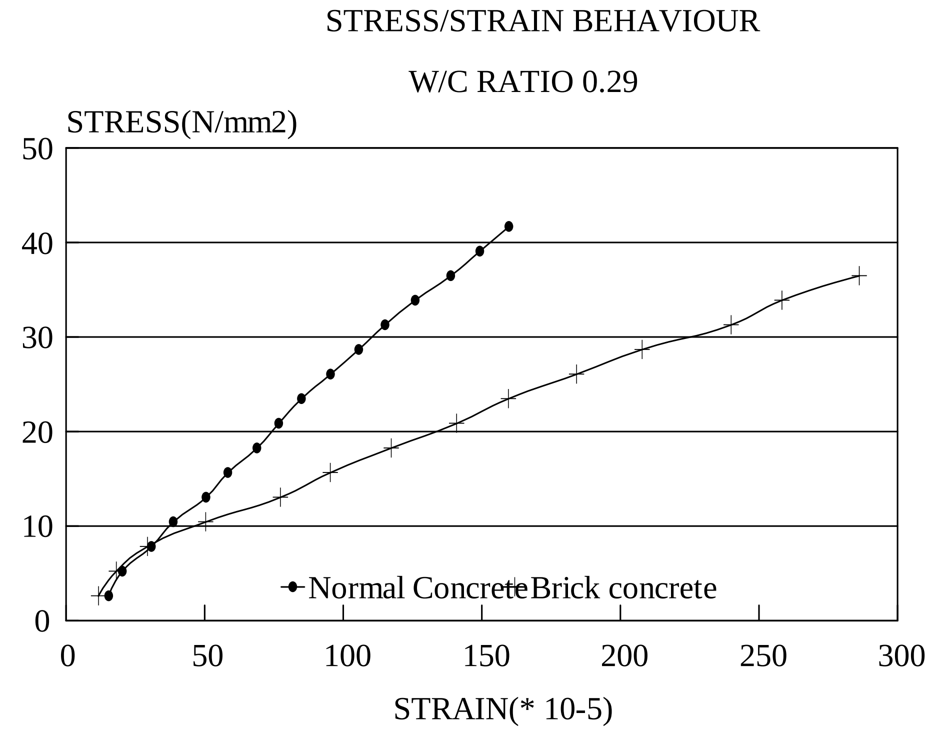

Figure 3. Stress/strain behaviour - w/c ratio 0.29

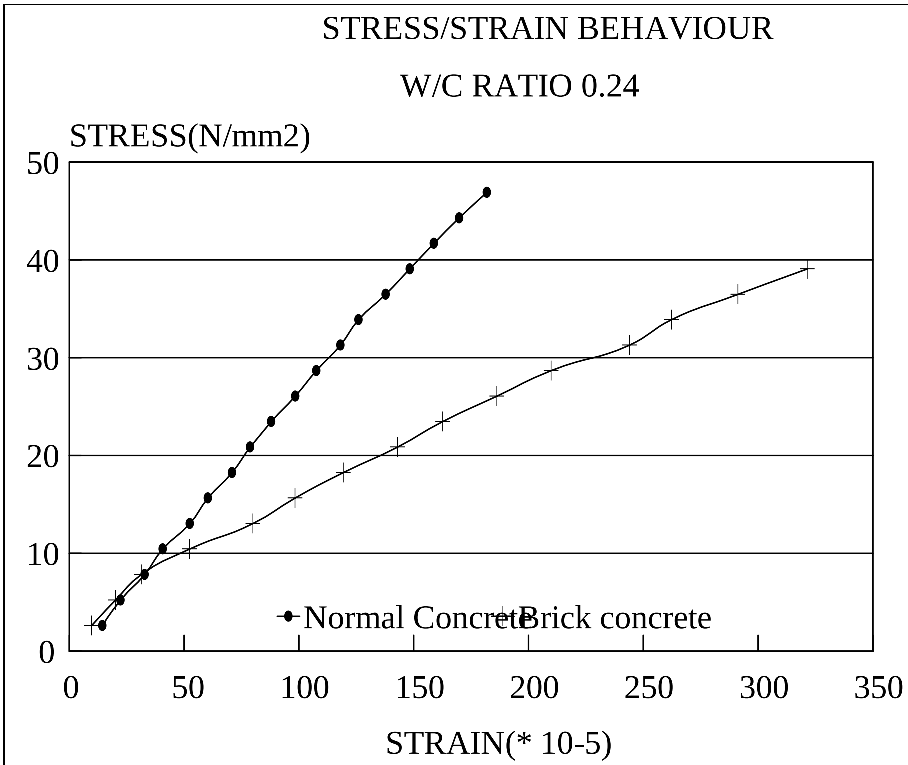

Figure 4. Stress/strain behaviour - w/c ratio 0.24

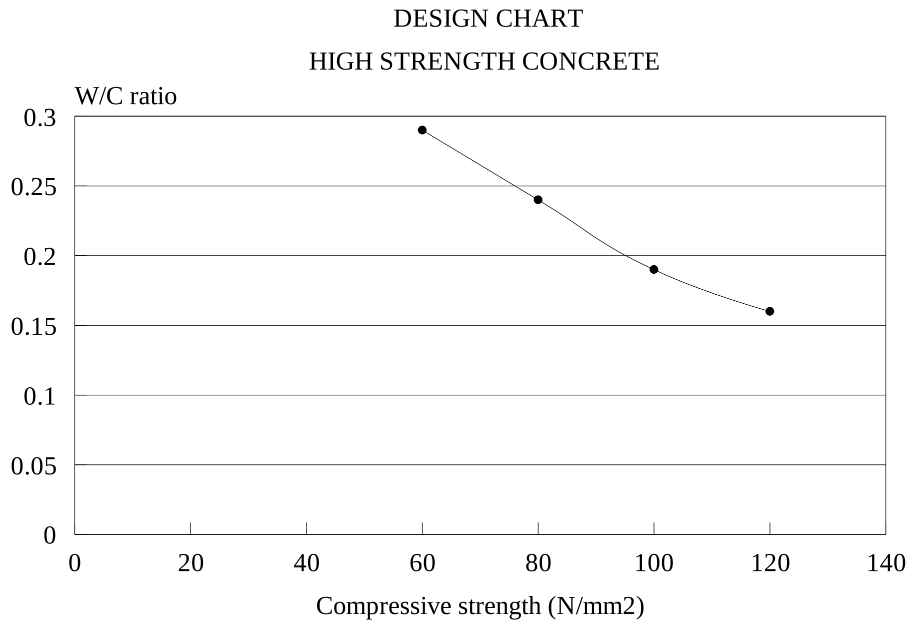

Figure 5. Design chart

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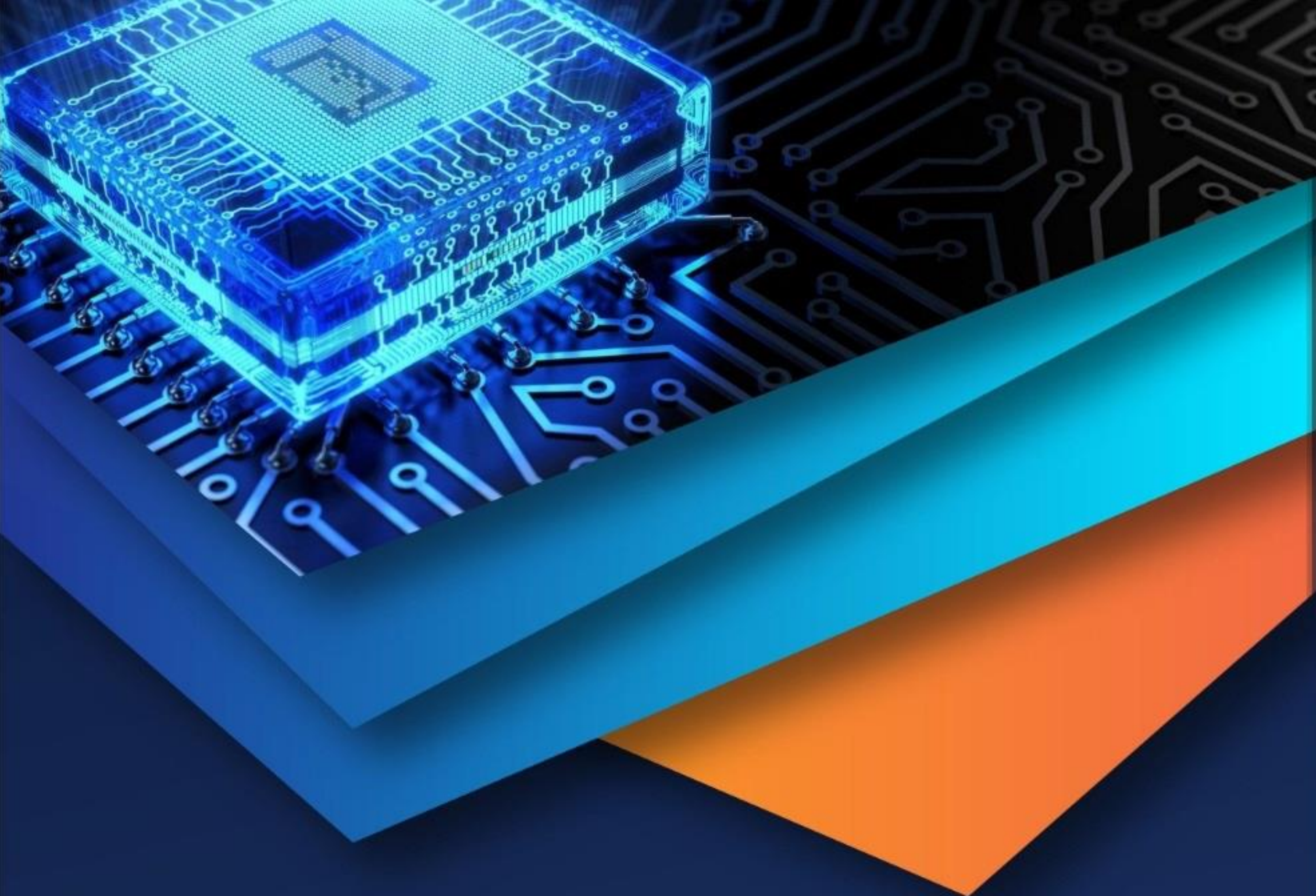

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