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Experimental Study on Mechanical Properties of Concrete Containing Copper Slag and Waste Ceramic Powder

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Abstract: Cement is mainly utilized for construction in present time because of its need but simultaneously its drawbacks to environment also require attention. Also if we leave waste material directly to the environment, it might cause serious environmental issues. These waste materials can be utilized to produce new products so that natural resources can be used more efficiently. By using Copper slag and waste ceramic powder in concrete we can protect global environment from impact of cement production as emission of CO_2 is less to environment. An experimental study has been carried out to explore the possibility of using waste ceramic powder and copper slag and as a partial replacement of Cement and Fine Aggregate respectively in concrete. In this dissertation concrete is casted for M40, M50 and M60 grade and the partial replacement of concrete materials were decided to re-use industrial waste such as copper slag is replacement by weight of sand and the ceramic waste powder as replacement by weight of cement. The cubes, cylinders, beams were casted and tested for compression, Split tension, Flexural strength at 28 days curing of concrete and durability at 91 days of curing of concrete. The obtained results are compared with conventional concrete.
Keywords: Copper slag, Ceramic waste powder, Mechanical properties, Durability, Concrete strength, Higher grade.

I. INTRODUCTION

The growing demand of infrastructural development in the developing countries leads to consume more concrete. It is reported that the requirement of cement in India is likely to touch ~550 million tons by 2020 with a shortfall of ~230 million tons (~58%) and the demand for cement has been constantly increasing due to increased infra-structural activities of the country. To meet the demand of the production of concrete, large quantity of Ordinary Portland Cement (OPC) is used as main binder material. But production of OPC requires large quantity of natural resources and it is also energy extensive process and also releases huge amount of greenhouse gas in the environment. The production of 1 ton of OPC has been found to emit 1 ton of gaseous CO_2 and the cement industry is believed to cause approximately 6% of global emissions of CO_2. As a result, environmental degradation and protection of natural resources are becoming very important issues to be taken care of to promote sustainability in the construction industries. Therefore, usage of supplementary cementitious materials in concrete has got a great momentum to protect the environment.

Ceramic Powder Indian ceramic production is 100 Million ton per year. About 15 to 30 percent waste material generated from the total production of ceramic and these waste is not recycled in any form. There are some of the studies focused the reuse of ceramic wastes in construction industry. The advancement of concrete technology can reduce the consumption of natural resources. They have forced to focus on recovery, reuse of natural resources and find other alternatives. The use of the replacement materials offer cost reduction, energy savings, good superior products, and fewer hazards in the environment.

Table 1 Chemical composition of waste ceramic powder

Compounds	Percentage
Silica (SiO_2)	66.16%
Alumina (Al_2O_3)	18.27%
Iron Oxide (Fe_2O_3)	3.23%
Calcium Oxide (CaO)	3.30%
Magnesium Oxide (MgO)	0.72%
Sodium Oxide (Na_2O)	0.82%
Potassium Oxide (K_2O)	2.88%
Loss on Ignition	4.62%

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Fig. 1 Ceramic waste powder

A. *Copper Slag*

Copper slag is considered as a waste material which could have a promising future in construction industry as partial replacement of fine aggregates. Silicon oxide is the major component of the sand and it is also found to be hug amount in copper slag as well. Thus, the common component of sand and copper slag makes their properties quite similar to each other. Thus we replace copper slag in concrete. Copper slag have been widely used for sand blasting, glass, road base construction, and cement and concrete industries. Copper Slag as fine aggregate exhibited similar mechanical properties as that containing conventional sand and coarse aggregates.

Table 2 Chemical composition of copper slag

Compounds	Percentage
Silica (SiO_2)	25.84%
Iron Oxide (Fe_2O_3)	68.29%
Alumina (Al_2O_3)	0.22%
Calcium Oxide (CaO)	0.15%
Sodium Oxide (Na_2O)	0.58%
Potassium Oxide (K_2O)	0.23%
Manganese Oxide (Mn_2O_3)	0.22%
Titanium dioxide (TiO_2)	0.41%
Sulphur Trioxide (SO_3)	0.11%
Copper Oxide (CuO)	1.22%
Loss of Ignition	4.59%

Fig. 2 Copper slag

The study concluded that 5 per cent copper slag substitution for cement gave a similar strength performance as normal concrete whereas 50 per cent copper slag can be used as replacement of sand in order to obtain concrete with good strength and durability requirements. Therefore, this presents the study of the effect of copper slag as a partial and full replacement of fine aggregate in concrete.

II. MECHANICAL PROPERTIES

A. *Compressive Strength Test*

The test used for determining the strength of concrete under applied load. The test is done on compression testing machine. It was done as per IS 516-1959. For the cube compression test, the specimens used generally for the most of the work, the moulds of size having 150x150x150mm are used for the test. A tamping rod of steel bar having 16mm diameter and 60cm long and bullet pointed at lower end should be use for compaction. The concrete is filled in the mould in approximate 3 layers of having each layer size 5 cm approximately. The concrete distribution should be evenly either by mechanical vibrator or by hand tamping. Each layer of the concrete should be compacted well and the compaction should not be less than 35 strokes per layer using tamping rod. Then after the levelling of top surface should be done and make the surface smooth by using trowel. Then the test specimens are removed from the moulds after 24h. The compressive strength can be calculated as the following formula.

Compressive Strength (MPa) = (Failure load) / (C/S area of cube specimen)

B. Split Tensile Strength Test

The determination of tensile strength can be done by split tensile strength test of concrete. This test was done as per IS 5816-1970. A cylindrical mould of having standard size of 300mm length and 150mm diameter is used for the test. For the casting procedure, the cylindrical mould is filled by concrete mix in 3 layers of having equal depth approximately. A tamping rod of steel bar having 16mm diameter and 60cm long and bullet pointed at lower end should be use for compaction. Then after, the test specimens are removed from the moulds after 24h. The splitting tensile strength is calculated by using the following formula:

$$\text{Split Tensile strength (MPa)} = (2 \times P) / (\pi \times D \times L)$$

Where, P = failure load, D = diameter of cylinder, L = length of cylinder.

Fig. 3 Compression testing machine

Fig. 4 Split tensile test

C. Flexural Strength Test

Generally, the standard size of beam specimen is 150x150x750mm but another size of beam specimens 100x100x500mm are used for the testing purpose when the aggregate size is lower. The beam failure occurs in bending when the acting stress at the bottom surface of the beam exceeds the limit and it is termed as modulus of rupture.

D. Four Point Flexure test

this type of test, loads are applied equally at the distance of 1/3rd part from the both supports of the testing specimen. Therefore, it has the same reaction at both of the supports. Under such type of loading, beam is subjected to pure bending at the 1/3rd portion of centre of beam as shown in figure.

The flexural strength of beam for this can be calculated as the following formula.

$$\text{Flexural strength (MPa)} = (P \times L) / (b \times d^2)$$

Where, P = Failure load, L = Centre to Centre distance between the support, b = width of specimen, d = depth of specimen at point of failure.

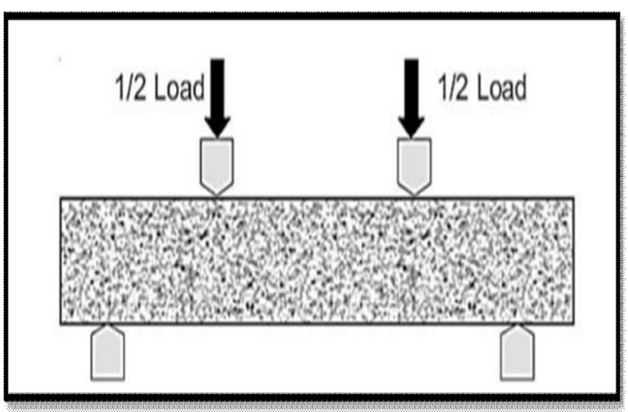


Fig. 5 Four point test setup

Fig. 6 Flexure strength test

III. DURABILITY

We have carried out five durability test in this experimental work and the test names are following as (i) Hydrochloric acid attack test {HCL} (ii) Sulphuric acid attack test {H_2SO_4} (iii) Sodium sulphate attack test {Na_2SO_4} (iv) Magnesium sulphate attack test {$MgSO_4$} and (v) Sorptivity test. And the results of all the test are described below.

IV. DESIGN MIX METHODOLOGY

In the methodology carried out the concrete mix design For M40, M50 and M60 grade of concrete using IS 10262:2009.
Data of Mix design for M40 grade of concrete as per IS 10262:2009 is shown in table 3.
Data of Mix design for M50 grade of concrete as per IS 10262:2009 is shown in table 4.
Data of Mix design for M60 grade of concrete as per IS 10262:2009 is shown in table 5.

Table 3 Mix design of M40 grade

Water	Cement	F.A.	C.A.	Super Plasticizer
151	420	768	1111	1.89
0.36	1	1.83	2.65	0.0045

Table 4 Mix design of M50 grade

Water	Cement	F.A.	C.A.	Sikament 170 (H)
147.6	422	621	1284	5.064
0.35	1	1.472	3.043	0.012

Table 5 Mix design of M60 grade

Water	Cement	F.A.	C.A.	Super Plasticizer
141.61	504.21	683.24	1108.13	4.668 lit.
0.29	1	1.35	2.19	0.8

V. EXPERIMENTAL STUDY

For compressive strength test, cube specimens of dimensions 150x150x150 mm are casted for M40, M50 and M60 grade of concrete. For Split tensile strength test, cylinder specimens of dimensions 150 mm diameter and 300 mm height are casted for M40, M50 and M60 grade of concrete. For flexural strength test, beam specimens of dimension 150x150x750mm are casted for M40, M50 and M60 grade of concrete.

Table 6 List of different mix proportions

Type	Cement	Sand	C.W.P.	C.S.
M1	100%	100%	0%	0%
M2	97.5%	60%	2.5%	40%
M3	95%	60%	5%	40%
M4	92.5%	60%	7.5%	40%
M5	90%	60%	10%	40%
M6	87.5%	60%	12.5%	40%
M7	85%	60%	15%	40%

A. Casting and Testing Procedure

1) For Compression Test

Fig. 7 Casted cubes Fig. 8 Testing cubes

2) For Split Tensile Strength Test

Fig. 9 Casting and testing of cylinder

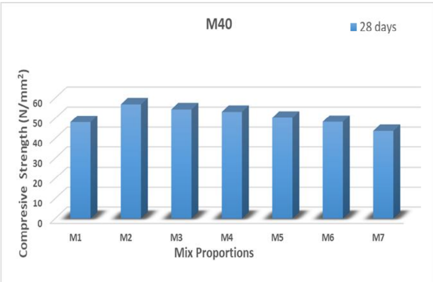
3) For Flexural Strength Test

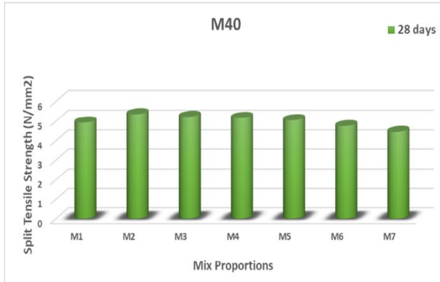
Fig. 10 Casting and testing of beam

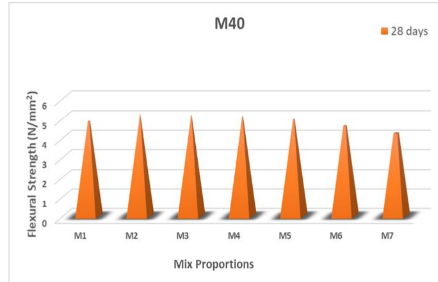
Fig. 11 Curing of specimen at specified days

VI. RESULTS

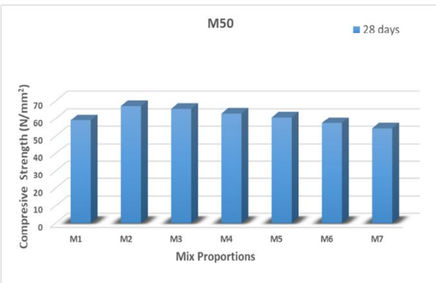
Results of M40 grade concrete for compression test, split tensile test and flexural test is expressed and shown below in graphs respectively

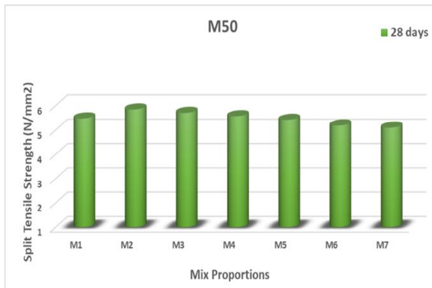


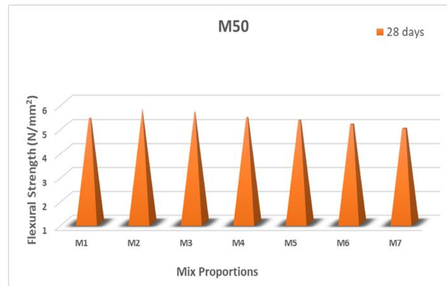




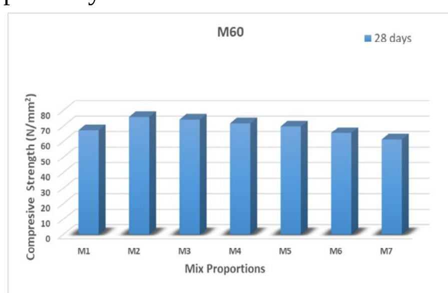
Results of M50 grade concrete for compression test, split tensile test and flexural test is expressed and shown below in graphs respectively.

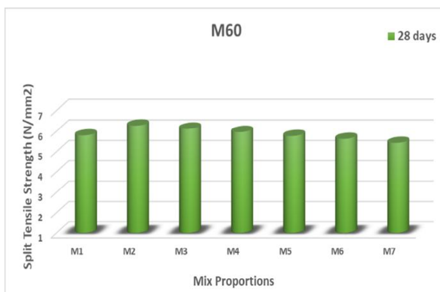


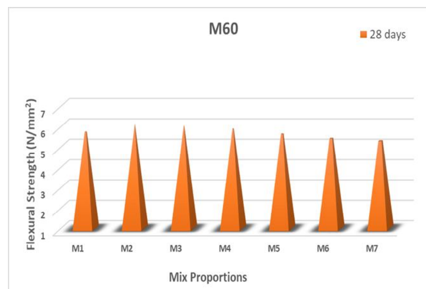




Results of M60 grade concrete for compression test, split tensile test and flexural test is expressed and shown below in graphs respectively.

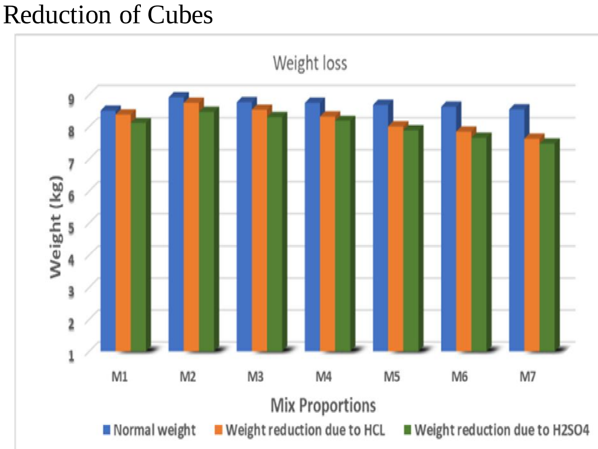


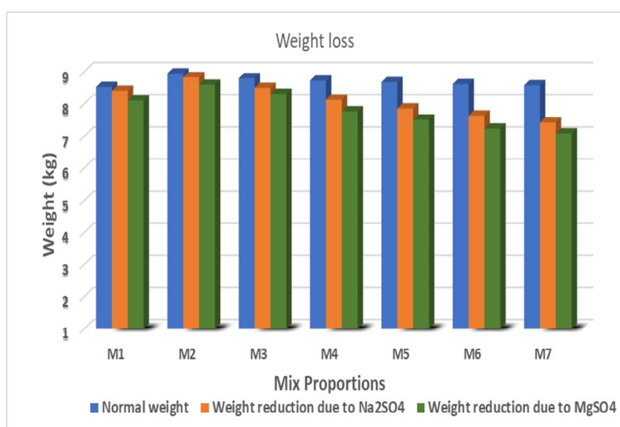




A. Durability Test Results

Weight Reduction of Cubes





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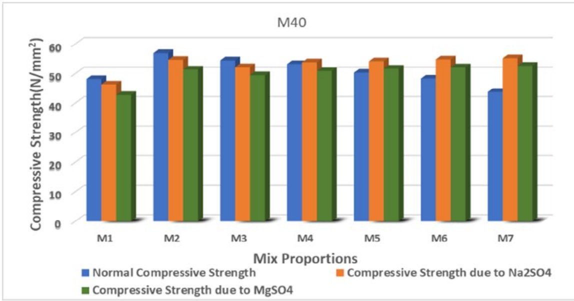
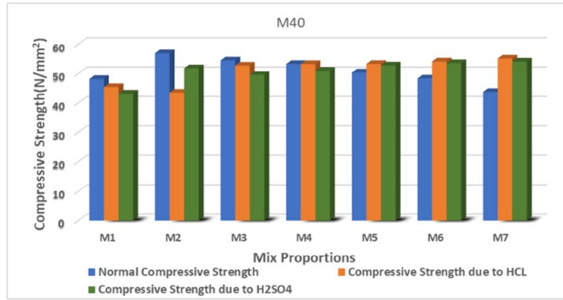
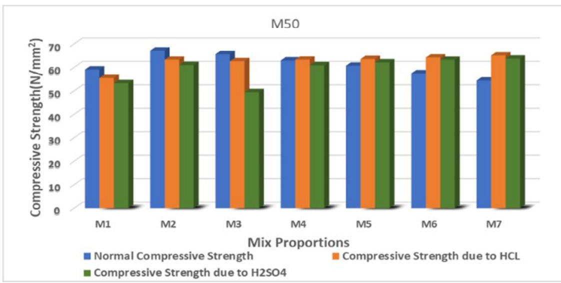


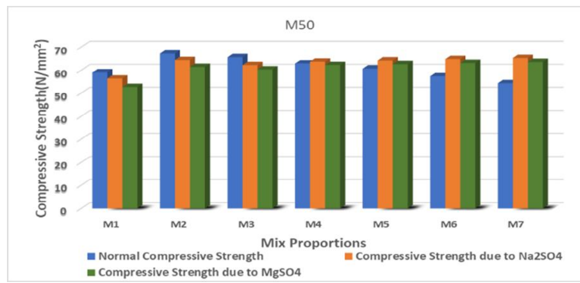
Compressive Strength of M40 grade cubes after performing durability test in Acid Attack



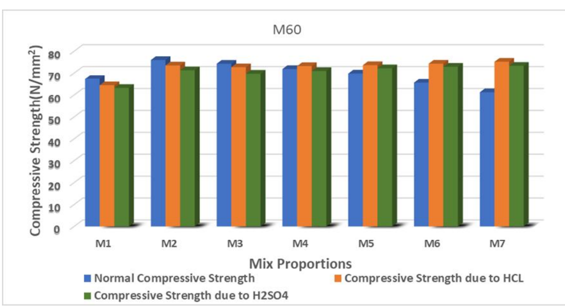
Compressive Strength of M40 grade cubes after performing durability test in Sulphate Attack



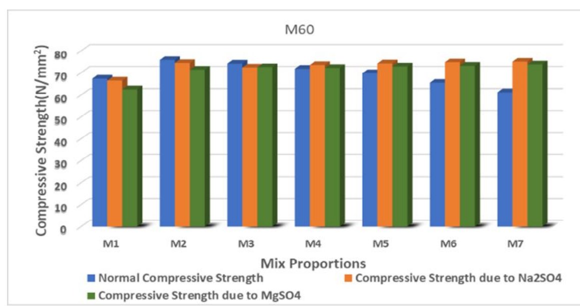
Compressive Strength of M50 grade cubes after performing durability test in Acid Attack



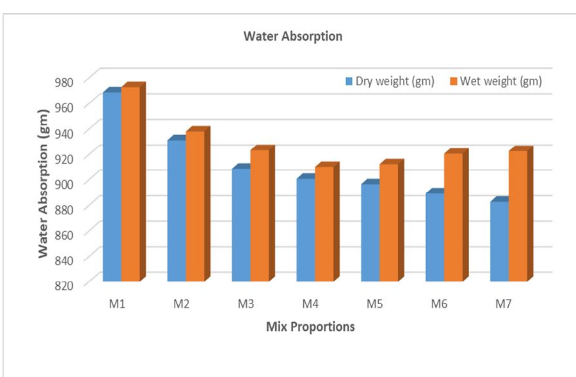
Compressive Strength of M50 grade cubes after performing durability test in Sulphate Attack



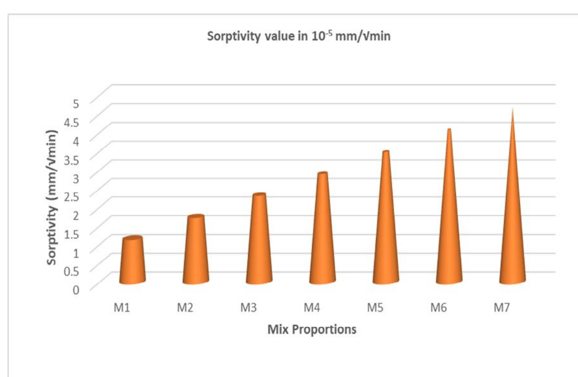
Compressive Strength of M60 grade cubes after performing durability test in Acid Attack



Compressive Strength of M60 grade cubes after performing durability test in Sulphate Attack



Water Absorption of Sorptivity ecimens



Sorptivity test results for M40 grade

VII. CONCLUSION

A. Un-till the result obtained high Compressive strength of M40, M50 and M60 grade of concrete is achieved 19%, 15% and 14.5% increment respectively at 2.5% replacement with Ceramic powder & at 40% replacement with Copper Slag.

B. For Split tensile strength of M40, M50 and M60 grade of concrete is achieved 9%, 7% and 8.5% increment respectively at 2.5% replacement with Ceramic powder & at 40% replacement with Copper Slag.

C. For Flexure strength of M40, M50 and M60 grade of concrete is achieved 9%, 8% and 7.5% increment respectively at 2.5% replacement with Ceramic powder & at 40% replacement with Copper Slag.

D. Strength of concrete increasing by replacing with waste material till their optimum replacement limit. Further, increment of waste materials replacement, the strength reduces.

E. In the durability test, the compression strength of concrete increasing compared to the normal M40, M50 and M60 grade of concrete at 15% replacement with Ceramic powder & at 40% replacement with Copper Slag. From the durability results, it is observed that the strength due to H_2SO_4 and $MgSO_4$ is lesser than the strength due to HCL and Na_2SO_4.

F. From the durability test, it is cleared that the durability of concrete is increased due to ceramic powder.

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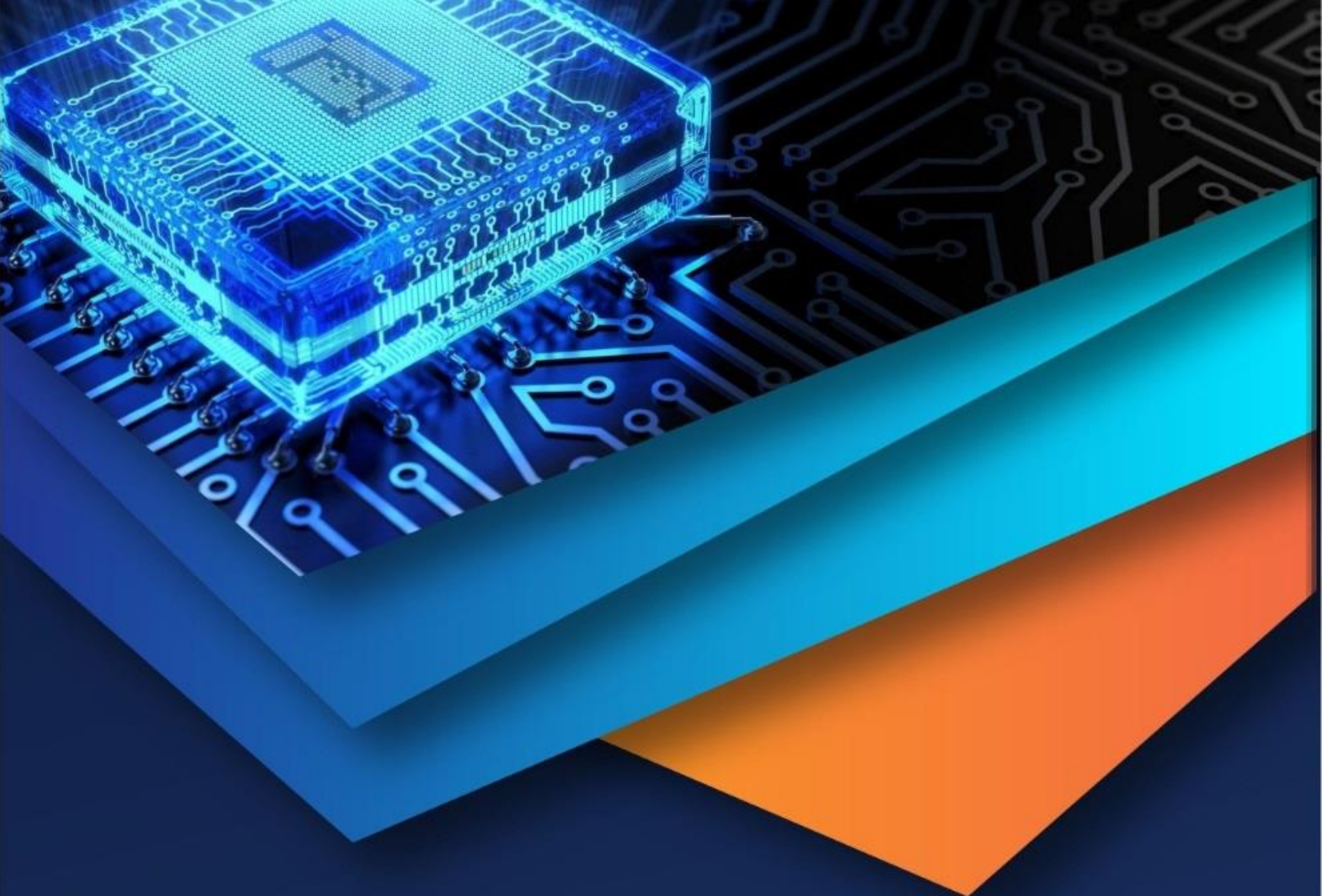

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