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Mechanical Properties of Geopolymer Concrete Subjected to Elevated Temperature

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Abstract: The present study is to examine the influence of the sustained elevated temperature on hardened properties of the Geopolymer concrete (GPC), achieved by complete replacement of cement by GGBS and SCBA in the proportion of 70:30 and mixing with the sodium based alkaline activators with varying molar concentration of NaOH (4M,8M,12M). After completion of 28 days curing the specimens were kept inside the electric oven , capable of attaining a maximum temperature of 10000C and the required temperature of 2000C, 4000C, 6000C and 8000C was set. After a steady state is reached the specimens were sustained for a predetermined duration of 2 hours. After attaining the 2 hours sustained temperature specimens are set aside to cool to room temperature and tests are conducted to measure the residual strength of the specimens using proper experiment setup. The outcomes revealed that with increase of temperature the weight loss of specimens is increased and the residual compressive strength of the specimens is decreased, GPC has a better resistance against cracking and spalling up to 600 ^{0}C
Keywords: Weight loss, residual strength, compressive strength, flexural strength, split tensile strength.

I. INTRODUCTION

To reduce carbon emissions, attempts have been made to find substitutes for cement to minimize the environmental impact of the cement industry. The alternative material required for the production of concrete can be taken from the industries which are producing the materials in the form of waste like thermal industries are producing the waste called fly ash, steel industries are producing waste in the form of ground granulated blast furnace slag, similarly from the past few decades agro based industries also producing the waste in the form of bagasse ash, corncob ash, saw dust, rice husk ash etc. The disposal of these waste materials is a critical issue for industries due to land requirement and environmental constraints. Instead of simply dumping all these materials we can make use of this for the production of environmental friendly concrete/ eco sustainable concrete called GPC.

Davidovits [1] proposed that an alkaline liquid could be used to react with the silicon (S) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash, GGBS, rice husk ash and Bagasse ash to produce binders. Because the chemical reaction that takes place, in this case, is a polymerization process, and thus he coined the term 'Geopolymer' to represent these binders.

U R Kawade et.al., [2] explains the production of OPC emits pollutants up to 7 to 8 percent of total CO2 emission in the world, hence it's necessary to find the new alternative binder. In this paper the fly ash of low calcium content was taken and NaOH: Na2SiO3 was 2.5 with varying molar concentration of 12M,14M,16M of NaOH, and the Curing temperature was 60 degrees for 24 hours. This paper shows that the compressive strength increases as the molarity of NaOH increases viz., 37.4 to 41.8 MPa. The construction industry is in demand of the eco-friendly and the greener material; this problem can be used by using fly ash in GPC.

Omar A. Abdulkareema et.al., [3] explained the behaviour of lightweight GPC before and after the exposure of temperature like 400, 600, 800 degrees. The inclusion of the aggregates such as fine aggregates and the lightweight aggregate has better resistance to the elevated temperature, especially after 800 degrees. The lightweight GPC has no significant change in the dimension with the residual compressive strength which is 11.93 MPa. The lightweight GPC has a minimum weight loss and a low strength loss than the other concrete.

N B Singh et.al., (2000) [4] explains the hydration of SCBA blended OPC is studied. They partially replaced cement by SCBA in the rate of 10%, 20% and 30%. They observed water consistency of SCBA-blended cement increased with0increase of SCBA. Both initial setting time and final0setting time increased with increase in SCBA. Compressive strength is determined which showed that for 10% replacement of cement by SCBA, it is observed to be higher for all ages. It is concluded that SCBA act as a pozzolanic0material and0in its presence0the extent of0hydration is lower when compared0to normal mix.

R. Zhao et.al., [5] explained the spalling behavior of OPC concrete and the GPC using the surface exposure test and the standard gas furnace fire test.

There was no spalling in GPC whereas in OPC concrete a few places the spalling being encountered, the high strength OPC concrete exhibited severe spalling whereas the normal OPC concrete was had minor spalling. This depicts that GPC has a better fire resistance than the OPC concrete. The sorptivity test was conducted for both specimens, the GPC has high porosity than the OPC concrete which helps in evacuating the internal heat hence it has lesser tensile stress, which helps in reducing the risk of spalling. The advantages are in numerous over the OPC concrete at the same strength grade.

Z.Pan,J.Sanjayan,D.Kong et.al., [6] presents the effect of aggregate size on spalling of concrete in fire for that three different type of concrete in chemical compositions and strengths were investigated namely GPC and high strength and normal strength Portland cement concrete. Results shows that concrete containing 10mm aggregate spalled while the 14mm did not spall. Since this effect is same in the Geopolymer and Portland cement concretes, it is independent of the binder material used. This study shows that the degree of spalling has a good correlation to the fracture process zone length. Which increases with increasing aggregate size. This is in turn reduces the flux of the K.E from pore pressure and thermal stress that is released into the fracture front and thereby improves the spalling resistance.

Omar A. Abdulkareema et.al., [7] explained the inclusion of the aggregates such as fine aggregates and the lightweight aggregate has better resistance to the elevated temperature, especially after 800 degrees. The lightweight GPC has no significant change in the dimension with the residual compressive strength which is 11.93 MPa. The lightweight GPC has a minimum weight loss and a low strength loss than the other concrete.

M. Hussin, M.Bhutta, M.Azreen et.al.,[8] made a comparative study between the blended ash GPC at elevated temperature and ordinary Portland cement concrete was prepared as control concrete. GPC composite was prepared using blended ash, pulverized fuel ash and palm oil fuel ash obtained from agro industrial waste along with the alkaline activators and the prepared samples were heated up to the 8000 c to determine the mass loss, strength and micro structural changes due to thermal compact. This study suggests that the it is more feasible to use blended ash GPC than OPC concrete as source of construction material requiring fire resistant performance.

G.Gorhan, Gkurklu et.al., [9] explains the relationship between the alkaline solution concentration, curing temperature and curing time. To determine the effect of NaOH concentration on Geopolymer mortar for which three different molarities of NaOH sample was used (4M,6M,8M) along with the sodium silicate solution and samples were cured at two different temperatures (65^0C & 85^0C) to study the physical properties, mechanical properties and compressive strength from the seven days GPC after curing. as a result, it was observed that curing temperature, curing time had an effect on the physical properties and also observed that the NaOH concentration had an effect on the properties of the geopolymer mortar cured at 85 ^{0}C and also compressive strength of geo-polymer mortars cured at 850 c increased in the NaOH concentration. From the experimental results concluded that the optimal curing temperature and optimal NaOH concentration were 85^0C and 6M respectively.

G Nagalia, et.al., [11] depicts the compressive strength and microstructural properties of fly ash based GPC. In this study alumino silicate geopolymer with different alkaline solutions (NaOH, KOH, Ba(OH)2 & LiOH) were prepared by adding class C(9.42%CaO) and class F (1.29%CaO) fly ash.

J.Ren,H.Chen, et.al.,[14] Explained the flexural behavior of the FA and GGBS GPC beams exposure to elevated temperature. Conducted an comparison work between the four GPC beams & four OPC concrete beams subjected to three different heating cases at the rate of ISO 834. Results drawn are the GPC beams underwent a color change, severe cracking and no spalling after the exposure but under the load GPC beams exhibited a lower crack resistance and flexural stiffness and finally concluded that GPC beams shows a superior fire endurance when compared to OPC concrete beams.

Studies show that SCBA can be used as a construction material. The applications of SCBA can be used as a pozzolanic material, considered as new source for preparing alkali┐ activated binders, fillers in construction materials, as aggregates, and are summarized in this paper. Pozzolanic activity which includes calcinations and re-calcination temperatures, fineness, durations, crystal silicon dioxide and loss on ignition are discussed. SCBA utilization in construction materials gives a good solution for proper recycling and management of SCBA wastes.

Much research has been done so far on Fly ash, Rice-husk ash, silica fume, bagasse ash, GGBS, etc. There is very limited research on the complex behaviour of the combination of two source materials. Hence it's necessary to know the performance of the combination of two source materials such as Bagasse ash and GGBS and also to overcome the major drawback of the GPC i.e., workability to overcome this problem boric acid (1%) has been used

II. EXPERIMENTAL DETAILS

A. Ground granulated blast furnace slag (GGBS)

GGBS acts as a binder material in the GPC and it conforms to IS16714-2018. The physical properties and chemical composition of GGBS is indexed in table 1 and table 2 respectively.

B. Sugar cane bagasse ash (SCBA)

SCBA acts as an another binder material in the GPC and it conforms to ASTM C 618. The physical properties and chemical composition of SCBA is tabulated in table 3 and table 4 respectively.

C. Sodium hydroxide (NaOH) and Sodium silicate (Na2SiO3)

In this research work sodium hydroxide flakes and sodium silicate solution were used with a purity of 97%. The physical properties NaOH and Na2SiO3 is tabulated in table 5 and table 6 respectively.

D. Distilled water

Water is the primary most important element in GPC as it actually involves in the chemical reaction with sodium hydroxide pellets.

E. Boric acid

To achieve the workability in the GPC boric acid (1%) is used as additional material (16).

F. Coarse aggregates

In the present research work coarse aggregate of 20mm and 10mm downsize were used. The physical properties of coarse aggregates such as specific gravity and water absorption of the coarse aggregates were found to be 2.7 and 1.6% respectively. The physical properties of coarse aggregates were shown in the table 7.

G. Fine aggregates

The manufactured sand is utilized in the present work and conformed to zone IV as per IS 383- 1970. The physical properties of the M-sand are shown in the table 8

Table 1: Physical property of GGBS

Sl. No.	Physical property	GGBS
1	Specific gravity	2.90
2	Fineness	3.2%

Table 2: chemical composition of GGBS

Test Conducted	Results	Requirements As Per Is: 16714-2018
Manganese oxide as (MnO)(%)	0.08	Maximum 5.5
Magnesium oxide as (MgO)(%)	8.07	Maximum 17.0
Sulfide sulphur as (S)(%)	0.45	Maximum 2.0
Sulphate (SO_3)	0.18	Maximum 3.0
Insoluble residue (Max) (%)	0.78	Maximum 3.0
Chloride content	0.021	Maximum 0.1
Loss on ignition	0.08	Maximum 3.0
$\frac{CaO + MgO + \frac{1}{3}Al_2O_3}{SiO_2 + \frac{2}{3}Al_2O_3}$	1.28	Minimum 1.0
$\frac{CaO + MgO + Al_2O_3}{SiO_2}$	2.00	Minimum 1.0
Glass content (%)	89.2	Minimum 85.0

Table 3: Physical property of SCBA

Sl. No.	Physical property	SCBA
1	Specific gravity	1.59
2	Fineness	67%

Table 4: Chemical composition of bagasse ash

Sl.no.	Test	Unit	Results
1.	Silicon as SiO_2	%	76.062
2.	Iron as Fe_2O_3	%	5.609
3.	Aluminum as Al_2O_3	%	4.948
4.	Calcium as CaO	%	1.860
5.	Magnesium as MgO	%	1.487
6.	Sodium as Na_2O	%	0.552
7.	Potassium as K_2O	%	1.776
8.	Fixed carbon	%	0.71

Table 5: Physical properties of sodium hydroxide

Molecular formula	NaOH
Molecular weight	40g
Density	1470kg/m3
Specific gravity	1.47

Table 6: Physical properties of sodium silicate

Molecular formula	Na2SiO3
Molecular weight	122.062g
Density	1600kg/m3
Specific gravity	1.6

Table 7: Physical properties of coarse aggregate

Physical property	10mm aggregate	20mm aggregate
Sieve Analysis	IS:383-1970	IS:383-1970
Bulk density	The density of loose aggregates=1353.31 Kg/m^3 The density of compacted aggregates = 1534.16 Kg/m^3	The density of loose aggregates =1264Kg/m^3 The density of compacted aggregates = 1479 Kg/m^3
Water absorption	1.4%	1.6%
Specific gravity	2.72	2.7

Table 8: Physical properties of M-sand

Physical property	M Sand
Sieve Analysis	Zone-IV
Bulk density	The density of loose sand = 1317.53 Kg/m3 The density of compacted sand = 1572.96 Kg/m3
Water absorption	1.25%
Specific gravity	2.6

Table 9: Mix design for 1m^3 of concrete

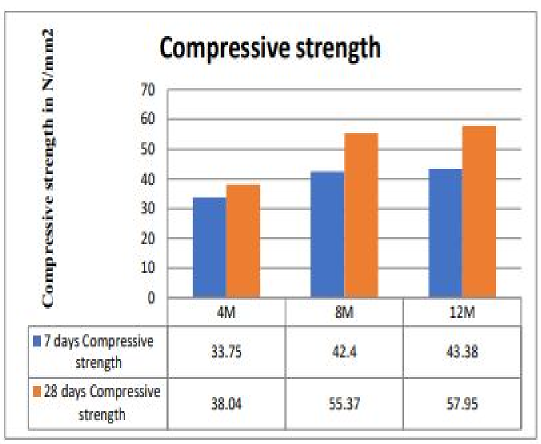
Mix-proportion per cubic meter	
GGBS	280kg
SCBA	120kg
Sodium hydroxide- solids	18.28
Distilled water	38.86
Sodium silicate	142.86
Fine aggregate –M sand	680
Coarse aggregate	1100
20 mm downsize aggregates	550
10 mm downsize aggregates	550
Water	50
Boric acid	1%

III. METHODOLOGY

GPC specimens were prepared as per the proportions shown in the table 9. The specimens were demoulded after 24 hours of casting, these specimens were kept under sunlight for ambient curing (27^{0}C) , for a period of 28 days. After completion of 28 days curingthe GPC specimens inclusive of cubes, cylinders & beams are subjected to the sustained elevated temperature condition in an electric oven. For each molar concentration all the specimens are kept inside the oven and heated at the intervals of 200^{0}C, 400^{0}C, 600^{0}C and 800^{0}C. once the desired temperature is achieved and it is allowed to sustain in the same temperature for 2 hours, to maintain the thermal gradient between the surface and Centre. Afterachieving the desired sustained temperature, the samples were allowed to cool inside the electric furnace at room temperature. Then specimens were kept under observation to observeany changes in the color of the specimens, cracking, spalling of the specimens. Then weight loss of the specimens has been measured. Later destructive tests were carried out to measure the residual strength of the specimens.

IV. RESULT AND DISCUSSION

Compressive Strength

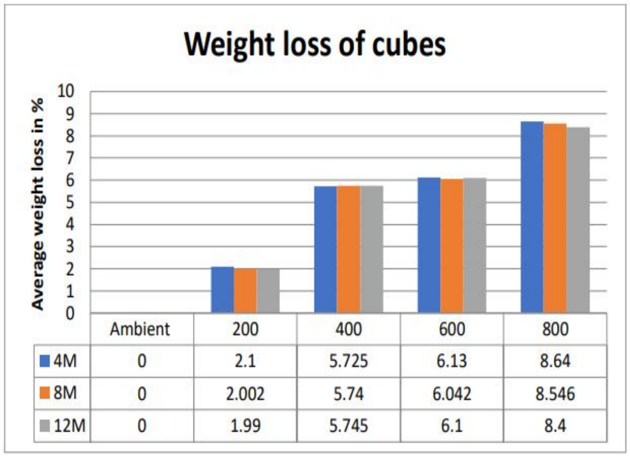


Graph 5.1: a comparative study of 7 days and 28 days' compressive strength on molarity of NaOH

The compressive strength of GPC will increase with increase in molar concentration. The setting time of gpc is lesser than the regular OPC concrete. Addition of boric acid by small dosage will improve the workability of GPC. In the present investigation commercially grade boric acid as has been used to check the feasibility of addition into the concrete mix. Increase molarity from 4M to 8M results in increase in strength by 17.3Mpa for 28days. Further increment of Molarity resulted in increase of strength by 2.58MPa for 28 days.

A. Weight loss

1) Weight loss of cubes

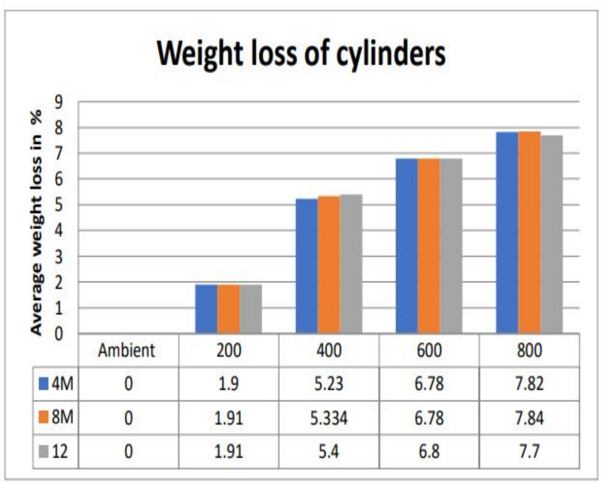


	Ambient	200	400	600	800
4M	0	2.1	5.725	6.13	8.64
8M	0	2.002	5.74	6.042	8.546
12M	0	1.99	5.745	6.1	8.4

Graph 3.1: Variation of weight loss in cubes with a rise in temperature on molarity of NaOH

From the graph 3.1 it is clear that the average weight loss in cubes of different molar concentration increases with increase in temperature for an exposure period of 2 hours. It is observed that there is no much difference in the weight loss of cubes with varying molar concentration of NaOH. The results indicate that the weight of loss of specimen is independent on Molarity. The weight loss is only due to shrinkage of concrete at elevated temperature.

2) Weight loss of cylinders



	Ambient	200	400	600	800
4M	0	1.9	5.23	6.78	7.82
8M	0	1.91	5.334	6.78	7.84
12	0	1.91	5.4	6.8	7.7

Graph 3.2: Variation of weight loss in cylinders with a rise in temperature on molarity of NaOH

From the graph 3.2 it is clear that the average weight loss in cylinders of different molar concentration increases with increase in temperature for an exposure period of 2 hours. It is observed that there is no much difference in the weight loss of cylinders with varying molar concentration of NaOH

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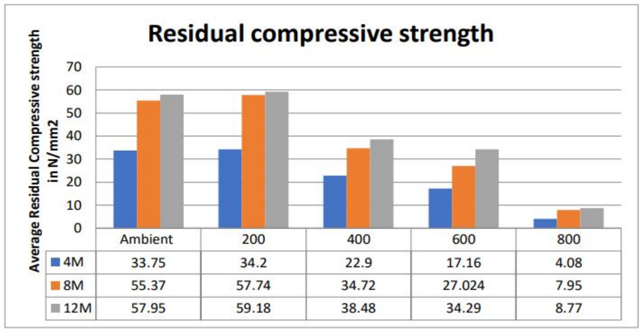
B. Residual strength

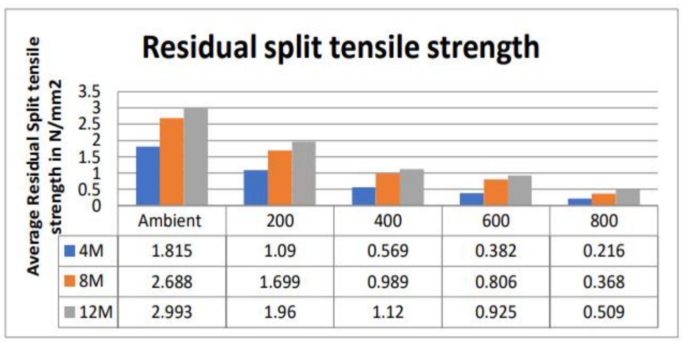
1) Residual compressive strength



Graph 3.4: Variation of residual compressive strength with a rise in temperature on molarity of NaOH

From the graph 3.4 it is clear that the average residual compressive strength of samples of different molar concentration of NaOH increases up to 200 ^{0}C with varying molar concentration, beyond 200 ^{0}C the residual compressive strength decreases as the temperature increases for an exposure period of 2 hours. The increase in residual compressive strength at 200 ^{0}C is due to rehydration process inside the concrete. The residual strength of GPC is reduced drastically at 600 0 c due to spalling effect. The strength of GPC is very less at 800 ^{0}C and from the above results we can also conclude that the difference in residual strength from 400 ^{0}C to 600 ^{0}C is maximum in comparison with 200 ^{0}C to 400 ^{0}C.

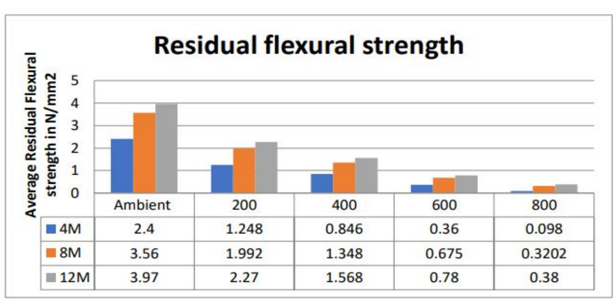
2) Residual split tensile strength



Graph 3.5: Variation of residual split tensile strength with a rise in temperature on molarity of NaOH

From the graph 3.5 it is clear that the average residual split tensile strength of the samples of different molar concentration decreases with increase in temperature for an exposure period of 2 hours. The split tensile strength of GPC is less than the conventional concrete and also results shows that increase in molarity will increase the split tensile strength of GPC. When the specimen is subjected to elevated temperature the residual strength of GPC decreases.

3) Residual flexural strength



Graph 3.6: Variation of residual Flexural strength with the rise in temperature on molarity of NaOH

From the graph 3.6 it is clear that the average residual flexural strength of the samples of different molar concentration decreases with increase in temperature for an exposure period of 2 hours. Flexural strength of GPC is also very low in comparison with conventional concrete. The above results indicate that the flexural strength of GPC will decreases with increase in sustained elevated temperature. At ambient temperature, higher molarity results in higher flexural strength of 3.97Mpa.

V. CONCLUSION

From the experimental study following conclusions were drawn:

1) The GPC undergoes a low rate of weight loss in the test specimens (cubes, cylinders, beams) during the early stage of heating (200^{o}C) which is up to 3%,after 200^{o}C the rate of weight loss is high which is up to 9%.
2) The GPC undergoes a strength gain in compressive strength, during theearly stage of heating (200^{o}C) which is up to 1.05 %, compared after 200^{o}C the rate ofstrength loss was high up to 80.5%.
3) The GPC undergoes a low rate strength loss in split tensile strength andflexural strength, during the early stage of heating (200^{o}C) which is up to 10.49% and 20.22%, compared after 200^{o}C the rate of strength loss was high up to 90.36% and 86.88% respectively.
4) Strength loss will be more in the case of specimens having 4M concentration of NaOH.
5) In the present study, the GPC did not show any surface cracks up to 600^{o}C and developed major surface cracks all around the specimen at an exposure temperature of 800^{o}C.

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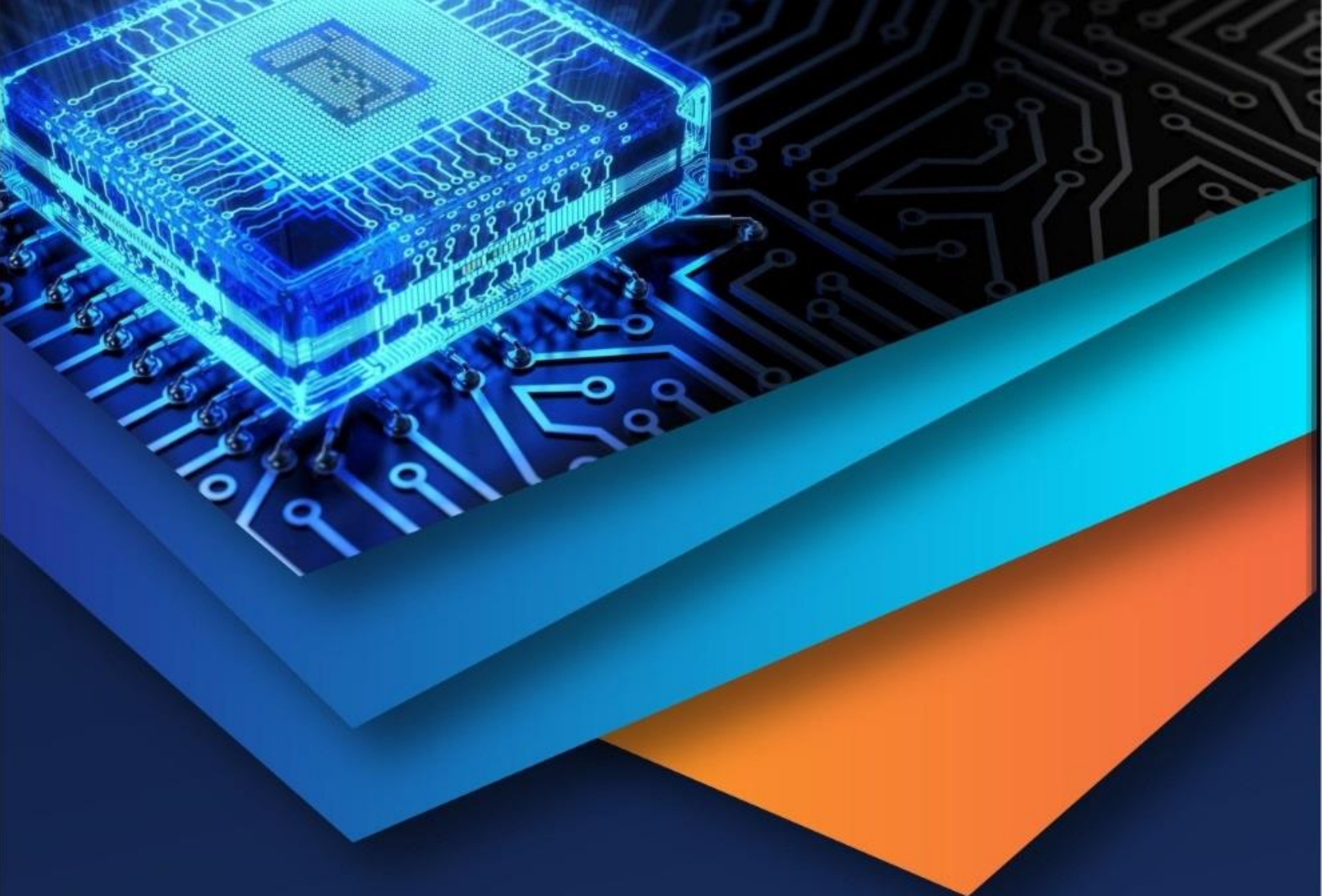

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