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Durability Aspects of Recycled Waste Glass Fine Aggregate in Geopolymer Concrete

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***Abstract:** Recycled waste glass is potential to serve as precursor material in geopolymer production because of abundant amount of amorphous silica is in waste glass. There has been an increasing significant interest in the development of concrete production with recycled waste glass as fine aggregate is effectively used. An attempt is made to use waste glass as fine aggregate in concrete. In concrete, cement is being used as a binding material which produces equal amount CO_2 emission to the atmosphere. In geopolymer concrete, 100% cement is replaced by fly ash and GGBS with activator solution. The performance of geopolymer concrete in terms of mechanical and durability properties is studied. M 20 grade mix is used for conventional concrete and the same proportion with NaOH of 8 Molar (8 M) is used for geopolymer concrete production with recycled waste glass as fine aggregate. Comparison is also made with geopolymer control concrete using sand as fine aggregate. M 20 grade geopolymer concrete made with recycled waste glass fine aggregate has been carried out for acid resistance test with 5% of H_2SO_4, sulphate resistance test, rapid chloride permeability test and pull out test. The results are compared with control mix geopolymer concrete.*

***Index Terms:** Acid resistance test, Sulphate resistance test, Rapid chloride permeability test, Pull out test, Recycled Waste Glass Fine Aggregate (RWGFA)*

I. INTRODUCTION

The increasing significant interest development of concrete production with recycling waste glass as fine aggregate is effective for environmental conservation and economical advantage. The recycled waste glass fine aggregate is used as fine aggregate in concrete and no reaction is detected with fine particle size. Once the particle size is reduced, it contributes to the mortar act as micro-structural properties resulting in an evident improvement of its mechanical performance. Water absorption is decreased and the durability is increased with increase the waste glass content in concrete and thus making concrete is light weight in nature. The global consumption of river sand is very high, due to the enormous use of concrete. In this situation the good quality of river sand is demand for concrete production [1]. Also deepening of the river courses causing bank slides and disturb the underground water stratum and etc., [2]. Recycling of this waste glass by converting it to aggregate components could save landfill space and reduce the demand for extraction of natural resources. There has been an increasing significant interest in the development of concrete production with recycled waste glass as fine aggregate is effectively used [3] [4]. Low calcium fly ash (ASTM Class F) is used as the binder, instead of ordinary Portland cement [5] [6]. The silica and alumina in low calcium fly ash (ASTM Class F) are activated by a combination of sodium hydroxide and sodium silicate solution to form geopolymer paste that binds the aggregate and other un-reacted materials. In this study, the size of the recycled waste glass size of 3 mm and down 3 mm is used [7] [8]. The glass size is influenced the microstructure of the concrete and it leads to denser and less permeable concrete [9]. M 20 grade concrete made with recycled waste glass fine aggregate has been carried out for acid resistance test with 5% of H_2SO_4, sulphate resistance test, rapid chloride permeability test and pull out test. The results are compared with control mix geopolymer concrete.

II. EXPERIMENTAL PROGRAM

A. Fly ash

The source material of class F type fly ash is rich in silicon (Si) and aluminium (Al) and less than 10% of lime (CaO). Low-calcium fly ash has been used to manufacture the geopolymer concrete when the silicon and aluminium oxides constituted by 75% to 80% by mass. The carbon content of the fly ash is indicated by less than 2% of mass. Low-calcium class F type fly ash is obtained from Mettur Thermal Power Station, Tuticorin, Tamil Nadu, India. . The specific gravity of fly ash is 2.40 and the colour is gray. The lighter in colour indicates lower carbon content presents in the fly ash. Class F type fly ash is fine grained material of spherical and the particle size distribution tests revealed that 80% of the fly ash are smaller than 50 microns.

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B. Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag is obtained from Toshaly cements private limited, Andhra Pradesh, India, conforming to IS: 12089 (1987). GGBS is industrial by-product obtained from steel industry. In this geopolymer concrete production, the cement is replaced by fly ash and GGBS of equal quantity. For ambient curing, 50% of fly ash is replaced by GGBS for concrete production. The advantage of using GGBS using in geopolymer concrete production is to resist chemical attack and maintain excellent thermal properties. The specific gravity of GGBS is 2.90 and the colour is white. Adding Ground granulated blast furnace slag in geopolymer concrete production is saving natural resources and reduce the carbon emissions.

C. Recycled Waste Glass as Fine Aggregate (RWGFA)

The sample of recycled waste glass fine aggregate is shown in Figure 1. The physical properties of recycled waste glass fine aggregate are given in Table 1. The Scanning Electron Micrograph (SEM) images of recycled waste glass fine aggregates are shown in Figure 2. An X –Ray Fluorescence (XRF) is used to determine the chemical composition of the recycled waste glass. The chemical composition of recycled waste glass fine aggregate is given in Table 2. The glass is washed to remove the impurities then it is crushed and melted. After that it is screened into required size for immediate use. The size of the recycled waste glass is 3 mm and down 3 mm.

Figure 1. Recycled Waste Glass as Fine Aggregate

Table 2. Physical Properties of Recycled Waste Glass as Fine Aggregate (RWGFA)

Physical Property	Test Result
Specific gravity	2.56
Size of the aggregate	3mm and down 3 mm

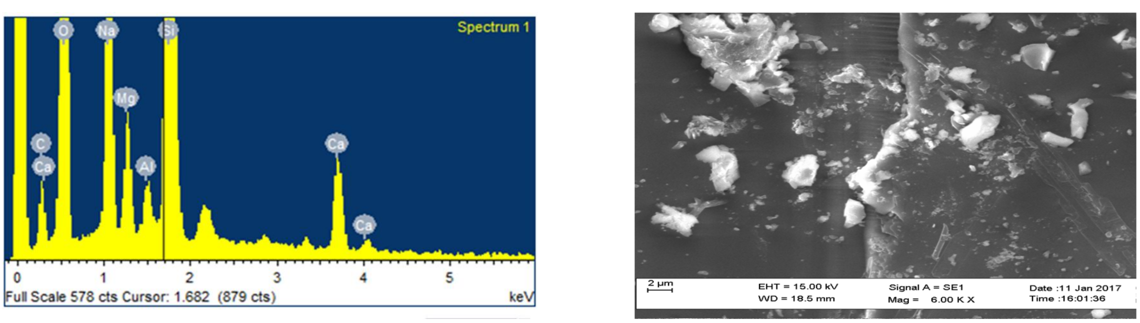

Figure 2 SEM Images of Recycled Waste Glass as Fine Aggregate (RWGFA)

Table 2. Chemical Constituents of Recycled Waste Glass as Fine Aggregate (RWGFA)

Constituent	SiO_2	$CaCo_3$	Na	MgO	Ca	Al_2O_3
In Percentage	78.01	7.83	8.60	1.81	3.02	0.61

D. Coarse Aggregate

Coarse aggregates used are of machine crushed stone, angular in shape passing through 20 mm IS sieve and retained on 4.75 mm IS sieve and it is conforming to IS 383-1970 [10]. The properties of coarse aggregates are as follows. The specific gravity is 2.76 and the Fineness modulus is 7.13.

E. E. Alkaline Solution

The alkaline solution is prepared prior to 24 hours before concrete production. Sodium hydroxide pellets (NaOH) with 98% purity and sodium silicate solution (Na_2SiO_3) is used for geopolymer concrete manufacturing. The sodium silicate solution with sodium hydroxide ratio by mass is taken as 2.5. The sodium hydroxide pellets are dissolved in water to make a alkaline solution with required concentration. NaOH of 8 Molar (8 M) is used for this concrete manufacturing. If the molecular weight of NaOH is 40, in order to prepare 8 molar solution, 320 grams of sodium hydroxide pellets are dissolved in one litre of water.

F. Super Plasticizer

Super plasticizer, Fosroc SP -430 is used. The use of chemical admixtures improves the slump loss and result in better durability and workability. In this mix SP of 0.7% weight of the cement is used.

G. Water

Potable, fresh and clean water which is free from organic matter is used in this concrete production

H. Mixing, Casting and Curing

Figure 3 shows the materials used for preparation of concrete. River sand is used for control mix geopolymer concrete and the same mix is used for 100% replaced with recycled waste glass as fine aggregate. Geopolymer concrete is made with same mix proportion used in M 20 grade conventional cement concrete. The mix proportion of cement concrete is 1:2.75:3.36. In geopolymer concrete preparation, NaOH of 8M is used in the concrete mix. The geopolymer concrete constituents are fly ash, ground granulated blast furnace slag, recycled waste glass as fine aggregate, coarse aggregate, water and super plasticizer. Sodium silicate solution with sodium hydroxide pellets in the ratio by mass 2.5 has been used for concrete manufacturing. The constituent of geopolymer mix is given in Table 3.

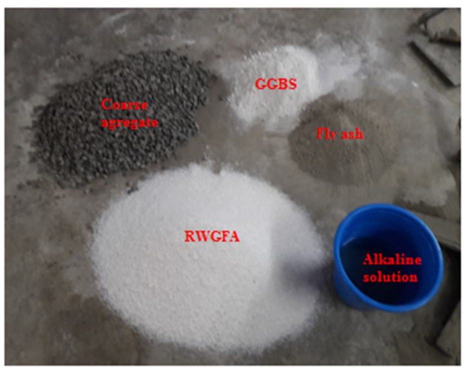

Figure 3. Materials used for RWGFA Geopolymer Concrete

Table 3. Constituents of RWGFA Geopolymer Concrete

Description	Quantity in kg/m^3
Fly ash 50% + GGBS 50%	337.55
(Na_2SiO_3 + NaOH) / Fly Ash & GGBS	0.45
Na_2SiO_3 / NaOH	2.50
NaOH Pellets	13.89
Na_2SiO_3	108.50
Water	29.51
Recycled Waste Glass as Fine Aggregate (RWGFA)	928.26
Coarse Aggregate	1134.17
SP	2.24

To determine the compressive strength, acid resistance test with 5% of H_2SO_4 , sulphate resistance test with 5% of $MgSO_4$ added with 5% of Na_2SO_4 totally eighteen cubes of size 100 × 100 × 100 mm and for pull out test, six cubes of size 150 × 150 × 150 mm are cast for concrete made with river sand as fine aggregate and made with recycled waste glass as fine aggregate. Three cylinders of size 100 mm diameter and 200 mm long made with recycled waste glass as fine aggregate are cast for rapid chloride permeability test. The specimens are demoulded after 24 hours and cured in room temperature for ambient curing. All the above tests are carried out for control mix concrete and recycled waste glass as fine aggregate concrete as per IS 536-1959 [11]. The results are compared with control mix geopolymer concrete.

III. TESTING PROCEDURE

A. Compressive Strength Test

Compressive testing machine 1000 KN capacity is used to apply the load. The load is gradually increases until the cube is failure. During the test, the maximum load taken by control concrete and recycled waste glass as fine aggregate concrete specimens are recorded. The average of three test results is the strength of the cube. The results of M 20 grade control concrete and RWGFA concrete is 29 MPa, 29.30 MPa respectively.

B. Acid Resistance Test

The cube specimens of RWGFA concrete and control concrete cubes are weighed before immersing in acid made with 5% of H_2SO_4 solution. The specimens are immersed in H_2SO_4 solution as shown in Figure 4. The solution was checked periodically for ensuring constant concentration throughout for 90 days. The specimens are taken out after 90 days, the surface is wiped off using wire brush. Then the specimens are weighed and the specimens are tested for compressive strength. The percentage loss of weight of the specimen and the percentage loss of compressive strength are given in Table 4.

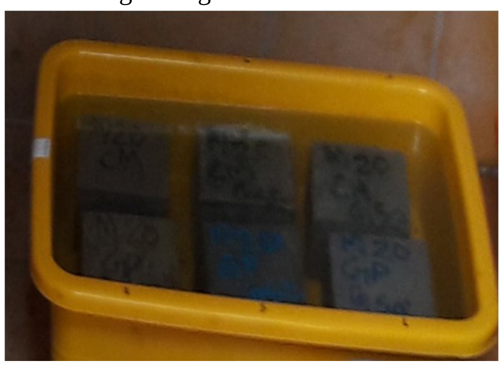

Figure 4. Specimens Immersed in H_2SO_4 Solution

Table 4. Percentage of Loss in Weight and Percentage of Loss in Strength

Sl. No.	Mix Designation M 20	Initial Weight in Kg.	Final Weight in Kg.	% of Weight Loss	Initial Compressive Strength in MPs	Final Compressive Strength in MPs	% of Strength Loss
1.	Control Mix	2.502	2.457	1.79	29.00	28.40	2.06
2.	RWGFA Mix	2.460	2.420	1.62	29.30	28.80	1.70

C. Sulphate Resistance Test

The cube specimens of control concrete and RWGCA concrete cubes are weighed before immersing in acid made with 5% of Na_2So_4 added with 5% of $MgSo_4$ solution. The concentrated magnesium sulphate and sodium sulphate are dissolved in required water. The specimens are immersed in solution as shown in Figure 5. The solution was checked periodically for ensuring constant concentration throughout for 90 days. After 90 days the specimens are taken out and the surface is wiped off using wire brush. Then the specimens are weighed and the specimens are tested for compressive strength. The percentage loss of weight of the specimen and the percentage loss of compressive strength are given in Table 5.

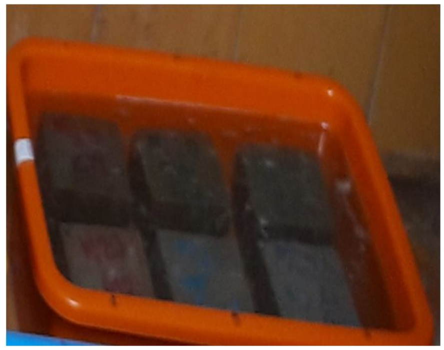

Figure 5. Specimens Immersed in $MgSo_4$ with Na_2So_4 Solution

Table 5. Percentage of Loss in Weight and Percentage of Loss in Strength

Sl. No.	Mix Designation M 20	Initial Weight in Kg.	Final Weight in Kg.	% of Weight Loss	Initial Compressive Strength in MPs	Final Compressive Strength in MPs	% of Strength Loss
1.	Control Mix	2.460	2.455	0.203	29.00	28.48	1.79
2.	RWGFA Mix	2.365	2.358	0.295	29.30	28.73	1.95

D. Rapid Chloride Permeability Test (RCPT)

The test procedure follows as per ASTM C 1202-10 [12]. The specimens of 100 mm diameter and 50 mm thick control concrete and RWGFA concrete is positioned in a cell containing a fluid reservoir on both sides. 3% of NaCl solution 3% of NaOH solution are filled in right side and left side respectively. A DC voltage is applied over the cell of negative terminal connected to the reservoir containing the NaCl solution and the positive terminal connected to the reservoir containing NaOH solution, causing the negatively charged chloride ions to migrate towards the positive terminal. 60 V current is applied for 6 hours and every 30 minutes readings are noted. At the end of 6 hours the specimens are removed from the cell and the amount of coulombs passed through the specimens are calculated. The test set up of RCPT with specimens are shown in Figure 6. RCPT Test results are given in Table 6.

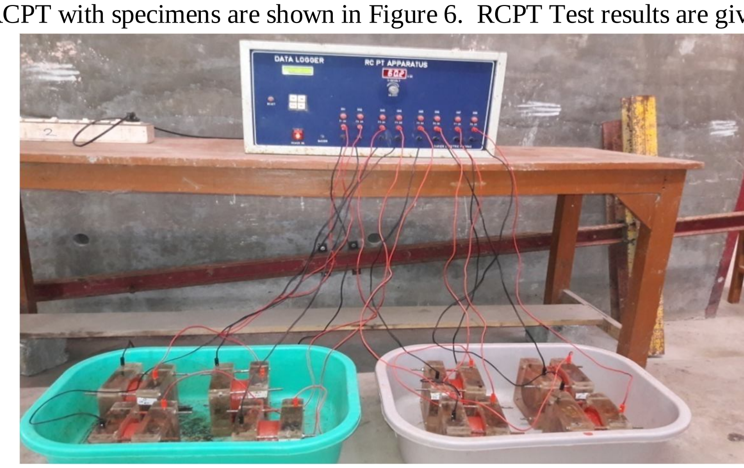

Figure 6. RCPT Test Set up with specimens

Table 6. RCPT Test Results

Mix Designation M 20	Q=Charge Passed in Coulombs	RCPT charges in Coulombs	Remarks
RWGFA concrete	3315.79	2992.50	Moderate

E. Pull Out Test

The pull out strength is determined by measuring the maximum force required to pull the insert from the mass. Pull out test is the stress transfer mechanism between steel and concrete. Pull out test method follows ASTM C -900-6 procedure. In this test 150 × 150 mm cube specimen with 12 mm reinforced bar is placed in centre of the cube and the bar is embedded up to the end. The length of the bar is 60 cm. The pull out test set up RWGFA Specimen is shown in Figure 7. The specimen after testing is shown in Figure 8. The average pull out strength for control mix geopolymer concrete and recycled waste glass geopolymer concrete (RWGFA) mix are given in Table 7.

Figure 7. Pull Out Test Set up with specimen

Figure 8. Specimen after testing

Table 7. Pull Out Test Results

Mix Designation	Pull Out Strength (kN)
Control mix	56.56
RWGFA mix	55.94

IV. RESULTS AND DISCUSSIONS

The compressive strength of M 20 grade control concrete and RWGFA concrete used in this study is 28 MPa, and 28.20 MPa respectively. In acid resistance test, using 5% concentration of sulphuric acid the percentage of weight loss in control mix is determined 1.79% and the same as RWGFA mix concrete is 1.62%. The percentage of strength loss of control mix concrete and RWGCA mix concrete is determined after 90 days immersed in acid are 2.06% and 1.70% respectively. The percentage of weight loss and the percentage of strength loss of RWGFA mix concrete is lower than the control mix concrete.

In sulphate resistance test, the percentage of weight loss in control mix is determined as 0.203% and the same in RWGCA mix concrete is 0.295%. The percentage of strength loss of control mix concrete and RWGFA mix concrete is determined after 90 days immersed in acid are 1.79% and 1.95% respectively. The percentage of weight loss and the percentage of strength loss of RWGFA mix concrete is lower than the control mix concrete.

In rapid chloride permeability test, the charges passed in coulombs is 2992.50 and the chloride penetrability is moderate. In pull out test the bonding strength is determined for control mix is 56.56 kN and the RWGFA mix is 55.94 kN. The pull out test results shows the RWGFA mix concrete is marginally lower than the control mix concrete.

V. CONCULUSSIONS

Chemical resistance of concrete depends on the selection of materials and wearing actions, erosions and cavitations. Commonly acid fluids would increases the porosity of concrete structure. Due to the lower water absorption in recycled waste glass fine aggregate is better performance in durability test results. The recycled waste glass fine aggregate the weight loss and strength loss is better than control mix concrete using river sand as fine aggregate. Sulphate resistance result also shows the better performance then control mix concrete. The rapid chloride permeability test results shows the chloride penetration in recycled waste glass as fine aggregate sample is very low. In pull out test RWGFA mix having better bonding strength and the mix did not show significant effects on the pull out tests. Hence in durability aspects recycled waste glass as fine aggregate (RWGFA) mix concrete shows good resistance against acid attack, sulphate attack and chloride attack.

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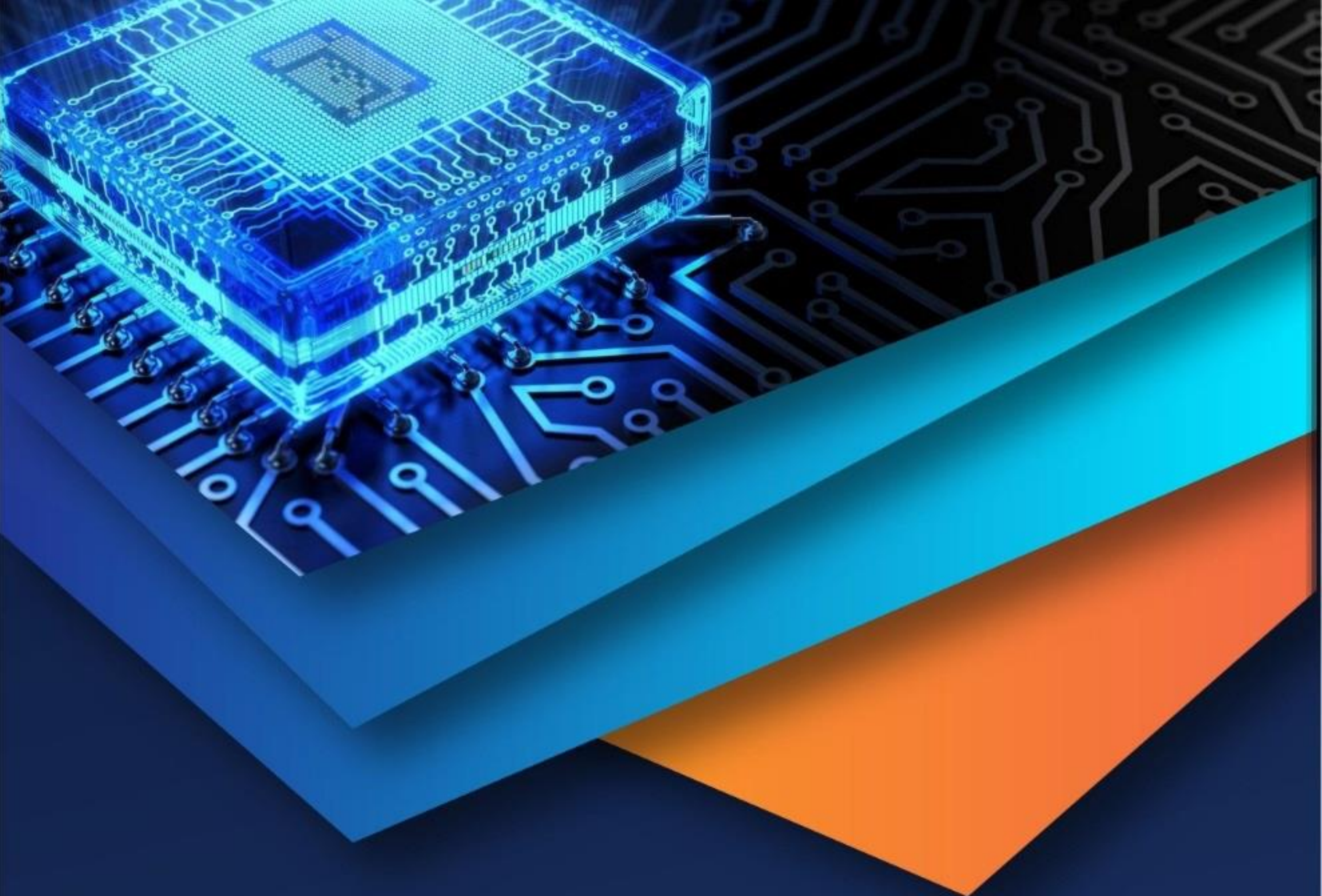

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