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Durability Study on Eco-Friendly Geopolymer Concrete using Recycled Waste Glass as Aggregate

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Abstract: Cement is an environmentally hazardous material because cement production is extremely energy and fossil fuel intensive, making it the third ranking producer of carbon dioxide emissions. Cement production is increasing by approximately 5% a year, making it one of the most environmentally destructive materials.. Cement substitutes and concrete alternatives are now available to assist in making concrete a truly eco-friendly material. The mixture of cement with other aggregate materials is the primary reason that concrete cannot bear an eco-friendly label. The heating and mixing process requires massive amounts of energy and emits alarming amounts of carbon dioxide into the atmosphere. Looking to combat the amount of greenhouse gases released as a by product of the concrete industry, green innovators have invented cement substitutes and alternative production methods to create a more earth-friendly product. In this research, geopolymer concrete is used as a Eco-friendly concrete and recycled waste glass is used as an alternative for coarse aggregate. M 20 grade Eco-friendly geopolymer concrete made with recycled waste glass coarse 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.
Keywords: Geopolymer concrete, Recycled Waste Glass Coarse Aggregate (RWGCA), Acid resistance test, Sulphate resistance test, Rapid chloride permeability test, Pull out test.

I. INTRODUCTION

Replacing energy-consuming Portland cement with recyclable materials and minerals offers two distinct benefits to the environment and it significantly reduces the amount of CO_2 released into the atmosphere and it minimizes massive landfill disposal. In this research geopolymer concrete is used instead of ordinary portland cement. Fly ash and Ground granulated blast furnace slag is chosen as the basic material to be activated by the geopolymerization process to be the concrete binder. The source material for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). In this research, sodium hydroxide pellets (NaOH) and sodium silicate (Na_2SiO_3) are used for making alkaline activator. Portland land cement is the most popular and widely used construction because of the availability of its raw materials and the preparations of concrete is easy when compare with geopolymer concrete. However, about one ton of carbon dioxide is released to the environment during production of one ton of cement that contributes to the green house effect and cement concrete deteriorates when exposed to the severe environment friendly. The above factors are overcome by gropolymer concrete and it is energy efficient and environment friendly [1].

River sand and coarse aggregate are obtained from natural resources. Crushed stone has now become the most widely consumed natural resources on the planet after fresh water. Yet, once crushed stone aggregate has been transformed into concrete, the components are bound forever and no longer available as resources. Therefore suggests that recycled waste glass is alternative building materials for coarse aggregate in concrete and it become economically viable. In this research recycled waste glass is used in white colour. The glass is then crushed and melted, which is then screened into required size for immediate use. The shape of the recycled glass is produced as angular size and the size of the aggregate is maintained 8 mm up to 16 mm for concrete production. Waste glass is not a bio-degradable material and at present it is dumped on a land which becomes a highly unsustainable option. To find a better solution to reduce the environmental issues caused by disposable of waste glass, it can be used as coarse aggregate in concrete. In geopolymer concrete, cement is 100% replaced by fly ash and ground granulated blast furnace slag with activator solution [2] [3] [4]. Recycled waste glass is potential to serve as precursor material in geopolymer production because of abundant amount of amorphous silica is in waste glass [5]. However only limited research has been conducted on waste glass as precursor material. The feasibility of using waste glass in geopolymer system is still largely unknown. Durability is defined as the capability to resist wearing action, chemical attacks, abrasion and any other process of deterioration while maintaining its desired engineering properties [6]. The main reason for deterioration in concrete structures is the corrosion of concrete due to its exposure to harmful chemicals containing in ground water, industrial wastes and sea water. It will affect the long term durability of the concrete. The chloride dissolved in water leads to porosity in concrete. M 20 grade Eco-friendly geopolymer concrete made with recycled waste

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glass coarse aggregate has been carried out for acid resistance test with 5% of H_2SO_4, sulphate resistance test with 5% of $MgSO_4$ added with 5% of Na_2SO_4, rapid chloride permeability test and pull out test. The results are compared with control mix geopolymer concrete.

II. EXPERIMENTAL PROGRAM

A. *Fly Ash*

Low-calcium class F type fly ash is used for this research work and it is obtained from Mettur Thermal Power Station, Tuticorin, Tamil Nadu, India. 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. 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. 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.

B. *Ground Granulated Blast Furnace Slag (GGBS)*

Ground granulated blast furnace slag is the industrial by-product obtained from steel industry. In this geopolymer concrete production, the cement is replaced by 50% of GGBS. For ambient curing conditions necessarily GGBS is added.. The advantage of using GGBS using in geopolymer concrete production is highly resist chemical attack and maintain excellent thermal properties. The specific gravity of GGBS is 2.90 and the colour is white. GGBS is obtained from Toshaly cements private limited, Andhra Pradesh, India conforming to IS:12089 (1987). The advantage of GGBS in geopolymer concrete is saving the natural resources and energy in cement manufacturing process and to reduce the CO_2 emissions from environment impact.

C. *Fine Aggregate*

River sand is used as fine aggregate. The specific gravity of the sand is 2.56 and the fineness modulus is 2.13. It conforms to Zone III according to 383-1970 [8].

D. *Recycled Waste Glass as Coarse Aggregate (RWGCA)*

The recycled waste glass used in this concrete production is in white colour and the shape of the glass aggregate is angular. The size of the aggregate is 8 mm to 16 mm. Before recycling process the waste glass is washed to remove the impurities. After the glass is crushed, melted and screened into required sizes for use. The specific gravity of the recycled waste glass coarse aggregate is 2.50. The chemical constituents of recycled waste glass coarse aggregate are shown in Table I. The Scanning Electron Microscope (SEM) images of recycled waste glass coarse aggregate are shown in Fig.I and Fig.II.

Table I Chemical Constituents of Recycled Waste Glass as Coarse Aggregate (RWGCA)

Constituent	SiO_2	$CaCo_3$	Na	MgO	Ca
In Percentage	78.80	5.44	8.39	1.84	5.53

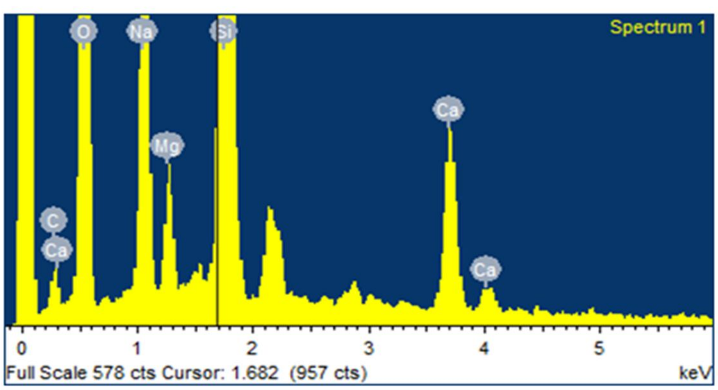

Figure I SEM Images of Recycled Waste Glass as Coarse Aggregate (RWGCA)

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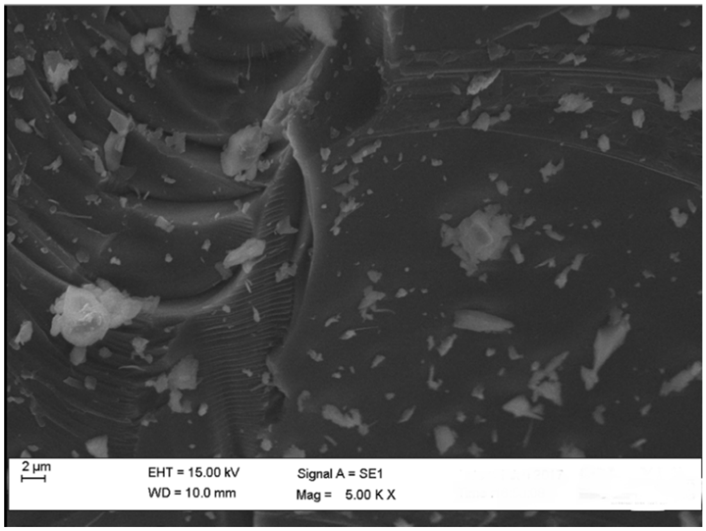

Figure II SEM Images of Recycled Waste Glass as Coarse Aggregate (RWGCA)

E. Alkaline Liquid

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. The alkaline solution is prepared prior to 24 hours before concrete manufacturing.

F. Chemical Admixtures

Fosroc Conplast SP 430 super plasticizer is used to for the concrete production. To improve the durability and workability of the concrete chemical admixture is used. In this mix design, the admixture quantity is calculated by 0.7% weight of the cement.

G. Water

Locally available portable water which is free from organic impurities is used for this concrete manufacturing work.

H. Mixing, Casting and Curing

The geopolymer concrete constituents are fly ash, ground granulated blast furnace slag, fine aggregate, recycled waste glass as coarse aggregate, water, admixture and sodium silicate solution with sodium hydroxide pellets in the ratio by mass 2.5 has been used for concrete manufacturing. The following Fig.III shows the materials used for preparation of concrete. Concrete grade of M 20 mix with the ratio of 1:2.75:3.36 is used for control mix geopolymer concrete and the same mix is used for 100% replaced with recycled waste glass as coarse aggregate. NaOH of concentration 8M is used for the concrete design mix. The constituents of geopolymer mix is shown in Table II.

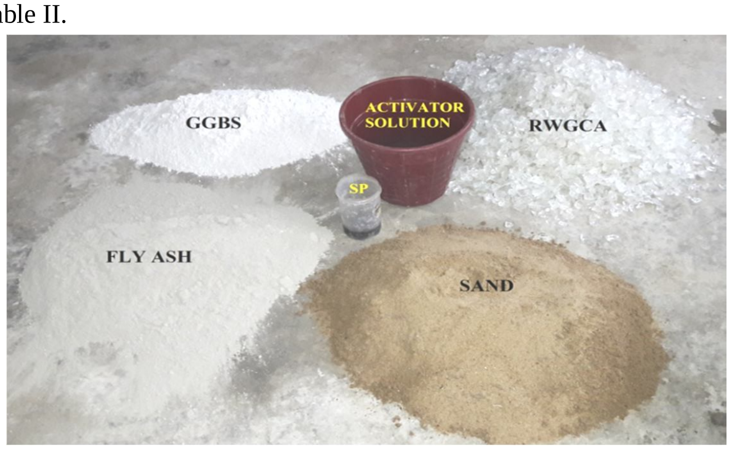

Figure III Materials used for RWGCA Geopolymer Concrete

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Table II Constituents of RWGCA 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	2.5
NaOH Pellets	13.89
Na_2SiO_3	108.50
Water	29.51
Fine Aggregate	928.26
Recycled Waste Glass as Coarse Aggregate (RWGCA)	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, and pull out test, totally eighteen cubes of size 100 × 100 × 100 mm are cast for geopolymer concrete in control mix made with crushed stone aggregate and recycled waste glass as coarse aggregate. Three cylinders of size 100 mm diameter and 200 mm long made with recycled waste glass as coarse aggregate are cast for rapid chloride permeability test. The results are compared with control mix geopolymer concrete.

Two types of curing are adopted in geopolymer concrete. One is heat curing by oven or heating champers and another one is ambient curing. Ambient curing is adopted in this research work. The specimens are demoulded after 24 hours and kept in room temperature for curing. All the above tests are carried out for control mix concrete and recycled waste glass as coarse aggregate concrete as per IS 516-1959 [9].

III. TESTING PROCEDURE

A. Compressive Strength Test

The geopolymer control concrete and recycled waste glass as coarse aggregate cubes are kept in room temperature for 28 days. 1000 KN capacity of compressive testing machine is used to apply the load. The load is gradually increases until the cube is failure. The maximum load taken by each specimen during the test is recorded. The average of three test results is the strength of the cube. The results of M 20 grade control concrete and RWGCA concrete is 29 MPa, 30 MPa respectively.

B. Acid Resistance Test

The cube specimens of control concrete and RWGCA 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 Fig.IV. 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 tabulated in Table III.

Figure IV Specimens Immersed in H_2SO_4 Solution

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Table III Percentage of Loss in Weight and Percentage of Loss in Strength

Sl.No.	Mix Designation M20	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	2.520	2.515	0.197%	29.00	28.52	1.66
2.	RWGCA Mix	2.403	2.400	0.126%	30.00	29.70	1.00

C. Sulphate Resistance Test

The cube specimens of control concrete and RWGCA concrete cubes are weighed before immersing in acid made with 5% of $MgSo_4$ added with 5% of Na_2So_4 solution. The concentrated magnesium sulphate and sodium sulphate are dissolved in required water. The specimens are immersed in solution as shown in Fig.V. 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 tabulated in Table IV.

Figure V Specimens Immersed in $MgSo_4$ with Na_2So_4 Solution

Table IV Percentage of Loss in Weight and Percentage of Loss in Strength

Sl.No.	Mix Designation M20	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	2.452	0.236%	29.00	28.48	1.80
2.	RWGCA Mix	2.370	2.360	0.197%	30.00	29.62	1.27

D. Rapid Chloride Permeability Test (RCPT)

The RCPT is conducted as per ASTM C1202-10 [10]. The specimens of 100 mm diameter and 50 mm thick control concrete and RWGCA concrete is positioned in a cell containing a fluid reservoir on both sides. One side filled with 3% of NaCl solution and other side is filled with NaOH solution.. 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. The total charged passed is determined and this is used to rate the concrete. The system is connected and 60 V is applied for 6 hours. Readings are taken every 30 minutes. 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 Fig.VI. RCPT Test results is given below in Table V.

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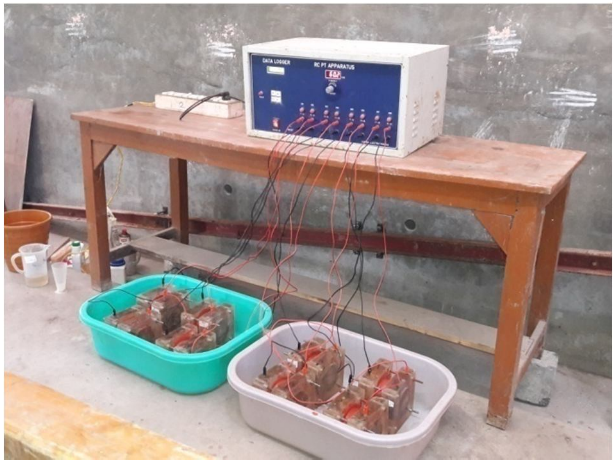

Figure VI RCPT Test Set up

Table V RCPT Test Results

Mix Designation M20	Q = Charge Passed in Coulombs	RCPT charges in Coulombs	Remarks
RWGCA Concrete	3298.50	2976.90	Moderate

E. Pull Out Test

Pull out test or Bonding test is the stress transfer mechanism between steel and concrete. This bonding makes possible to combine the behaviour of concrete in front of compression and the high tensile strength of steel in reinforced concrete. When a bar embedded in a concrete matrix is subjected to a tensile strength, the stress transfer from steel to concrete is produced through angled compressive strengths that are originated at the ridges, depending on its angle. The radial component of this compressive strength is balanced with a tensile ring that appears in the concrete surrounding the bar. That causes internal longitudinal cracks. 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 test specimens for pull out are shown in Fig. VII. The test method follows the ASTM C-900-06 procedure. The pull out test set up RWGCA Specimen is shown in Fig. VIII. The pull out test testing RWGCA concrete specimen after failure pattern is shown in Fig. IX. The average pull out strength for control mix and RWGCA mix are tabulated is given in Table VI.

Figure VII RWGCA Specimens Before Testing

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Figure VIII Pull Out Test Set up (RWGCA Specimen)

Figure IX Crack Pattern after Testing

Table VI Pull Out Test Results

Sl.No.	Mix Designation	Pull Out Strength (kN)
1.	Control Mix	56.56
2.	RWGCA Mix	56.00

IV. RESULTS AND DISCUSSIONS

The compressive strength of M 20 grade control concrete and RWGCA concrete used in this study is 29 MPa, and 30 MPa respectively. In acid resistance test, the percentage of weight loss in control mix is determined 0.197% and the same as RWGCA mix concrete is 0.126%. The percentage of strength loss of control mix concrete and RWGCA mix concrete is determined after 90 days immersed in acid are 1.66% and 1.00% respectively. The percentage of weight loss and the percentage of strength loss of RWGCA mix concrete is lower than the control mix concrete.

In sulphate resistance test, the percentage of weight loss in control mix is determined as 0.236% and the same in RWGCA mix concrete is 0.197%. The percentage of strength loss of control mix concrete and RWGCA mix concrete is determined after 90 days immersed in acid are 1.80% and 1.27% respectively. The percentage of weight loss and the percentage of strength loss of RWGCA mix concrete is lower than the control mix concrete.

In RCPT, the charges passed in coulombs is 2976.90 and the chloride penetrability is moderate. In pull out test the bonding strength is determined for control mix is 56.56 kN and the RWGCA mix is 56.00 kN. The pull out test results shows the RWGCA mix concrete is marginally lower than the control mix concrete.

V. CONCLUSSIONS

The basic reasons for concrete deterioration is categorized into two, one of its surface wear or loss of mass due to abrasion, erosion and cavitations and another one is due to normal temperature and humidity gradients. Generally acidic fluids would increase the porosity of concrete structure. Because of non pore structure recycled waste glass coarse aggregate the weight loss and strength loss is minimum compare with the control mix coarse aggregate. Sulphate resistance test results also show the weight loss is minimum compare with the control mix. The chloride penetrability is moderate and in pull out test RWGCA mix having better bonding strength and the mix did not show significant effects on the pull out tests. Hence in durability aspects RWGCA mix concrete shows good resistance against acidic, chloride and sulphate attack.

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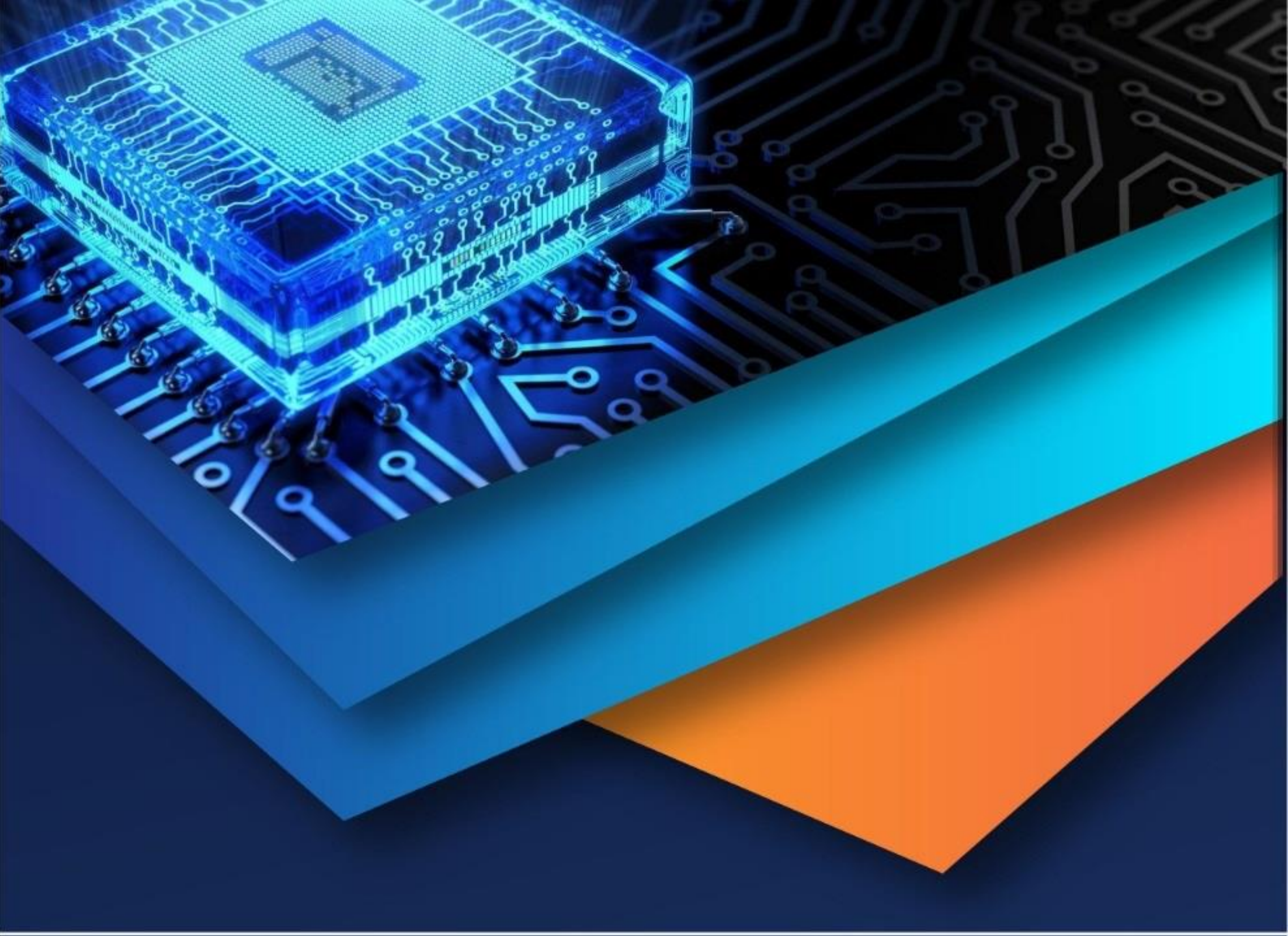

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