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Literature Review on Properties of Geopolymer Concrete replacing Natural River Sand with mineral Admixtures as Fine Aggregate

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Abstract: Due to the advantage of decrease in carbon footprint with the use of cement-less geopolymer concrete, researchers had focused towards the study of the behaviour of geopolymer concrete on micro- and macro-scales. Recent researches are in a continuous process to improve the mechanical properties of geopolymer concrete by replacing natural river sand with other admixtures as fine aggregate. The objective of this review is to summarize and discuss the reported findings on the replacement of river sand with various materials like fine bone China ceramic, recycled fine aggregate, Waste marble aggregate, shredded rubber, iron tallings etc., The micro-structural properties of the such developed Geoploymer Concrete are discussed with the help of XRD and SEM results. It is also to be noted that the strength parameters are greater than that of Conventional Concrete.
Keywords: Geopolymer concrete, fly ash, slag, Marble Slag, Iron Tailings, NMR, XRD, SEM

I. INTRODUCTION

Geopolymer is the latest advancement of cement, after gypsum cement and Ordinary Portland Cement (OPC)..'Geopolymer' shall be referred as amorphous alkali aluminosilicate or alkali-activated cements[1].Geopolymer concrete is prepared by polymerizing the aluminosilicates like fly ash (FA),metakaolin (MK), slag (SG), rice husk ash (RHA), and high calciumwood ash (HCWA) by activation using alkaline solution. The polymerization requires quick reaction of silica (Si)-alumina (Al) under alkaline conditions which subsequently creates three-dimensional polymeric chain of SiAOAAlAO bonds. Unlike OPC or pozzolanic cements,geopolymer utilizes the polycondensation of silica and alumina and a high alkali content to attain compressive strength[2]. Geopolymer incorporatet OPC develops calcium silicate hydrates (C-S-H) as well as polycondensation of silica and alumina and a high alkali content to attain compressive strength. The following reactions occur during geopolymerization reaction is as follows [3]

$$(Si_2O_5Al_2O_2)_n + H_2O + OH^- \rightarrow Si(OH)_4 + Al(OH)^{4-}$$

$$Si(OH)_4 + Al(OH)^{4-} \rightarrow (\overset{|}{\underset{|}{Si}} - O - \overset{|}{\underset{|}{Al}} - O)_n + 4H_2O$$

Materials or compounds that contain Si and Al in amorphous state can be used to produce geopolymer concrete. The hydration products of Fly Ash or Metakaolin sodium aluminosilicate hydrate gels. Metakaolin based geopolymer is better than the other hydrates as it is more persistent as its properties. Despite its advantages, it requires higher water-demand hence resulted in severe rheological problems. In the meantime, Fly Ash-based geopolymer provides higher durability. [2]

A schematic representation on formation of fly ash-based geopolymers/concrete is shown in Fig. 1. [4]

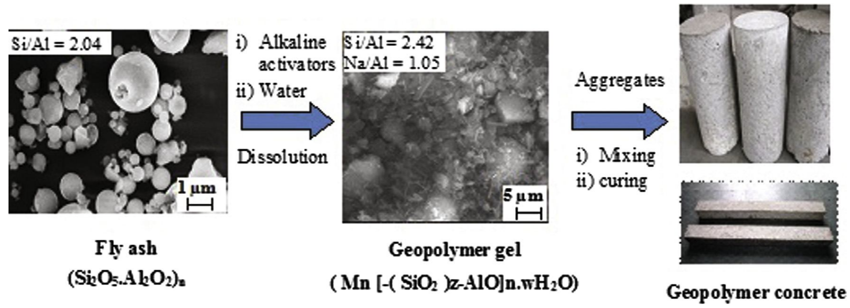

Fig. 1. Conversion of fly ash into geopolymers/concrete.[4]

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Water is released in this reaction that is normally consumed during dissolution and provides workability to the mixture during handling. This is in contrast to the chemical reaction of water in Portland cement mixture during the hydration process where water is absorbed and heat is generated. The hydration products of metakaolin/fly ash activation are zeolite type. Sodium aluminosilicate hydrate gels is with different Si/Al ratio whereas the major phase produced in slag activation is calcium silicate hydrate with a low Ca/Si ratio. Many physical properties of geopolymers prepared from various aluminosilicate sources may seem to be similar but their microstructures and chemical properties vary to a large extent. The metakaolin-based geopolymer has an advantage that it can be manufactured consistently, with predictable properties both during the preparation and development. However, its plate-shaped particles lead to rheological problems, increasing the `complexity of processing as well as the water demand of the system [2-4]

The over-exploitation of the river sand in the developing countries like India leads to several environmental problems such as reduction of the water table level, destroying the flora & fauna of river, soil erosion etc.[5]. Mining of river sand, thus, poses a heavy threat to the enivironment and ecological balance. Researchers have worked on crushed stone sand or quarry dust as a replacement to natural river sand in the concrete[6–8].Workability of concrete gets decreased when the river sand was replaced with Quarry Dust. It was due to the uneven shape and texture of these particles and therefore high dosages of superplasticizers and water reducing admixtures need to be added in the concrete mixture to improve its workability [9–12]. Also mining and crushing of the stones for quarry dust lead to the detrimental effects on thee nvironment. The crushing units emit particulate matter which lead to air pollution and the heavy equipments causes the noise pollution. There are limited quarrying sources which are not sufficient to meet the increasing demand of the quarrying dust [12]. Thus there is a need to find an apt subsititute to the river sand which does not destruct the environment and helps to meet the future demand of the fine aggre-gates in the concrete.

This paper presents a comprehensive review of the impact on properties of geopolymer concrete when the natural river sand is replaced with other suitable materials.

II. SIGNIFICANCE OF THE STUDY

Geopolymer Concrete is finding its way towards replacing conventional concrete , but still, the research is limited to very few mineral admixtures as fine aggregate. The scope of acceptability of many suitable materials as fine aggregate in geoploymer concrete is discussed in this paper.

III. FINE BONE CHINA CERAMIC AGGREGATE

Salman Siddique et. Al [13] used Fine Bone China Ceramic Aggregates as fine aggregates in geopolymer concrete. The compressive strength of geopolymer concrete was increased by 20.51%. When 40% of fine aggregate was replaced by bone china, the silica content was maximum. When 60% of fine aggregates was bone china, CSH and Ettringite content were maximum. The pozzolonic activity was superior. For a bandwidth greater than 2000 /cm there were two broad shoulder bands for the formation of $Ca(OH)_2$ and for the bandwidth lesser than 2000 /cm the intensity of $CaCO_3$ was higher with a higher wave number. The band range was 410-780 /cm. In the NMR analysis, the first peak corresponded to unhydrated cement paste and the second peak to the CSH behaviour which was a poor crystalline structure. The mix with 40% replacement corresponded to the high degree of polymerisation and the mix with 60% replacement to the slight increase in chain length. Results indicate superior pozzolanic behavior for fine bone china aggregate. All the compositions of fine bone china aggregate concrete had higher or similar compressive strength as that of the control concrete.[14 & 15]

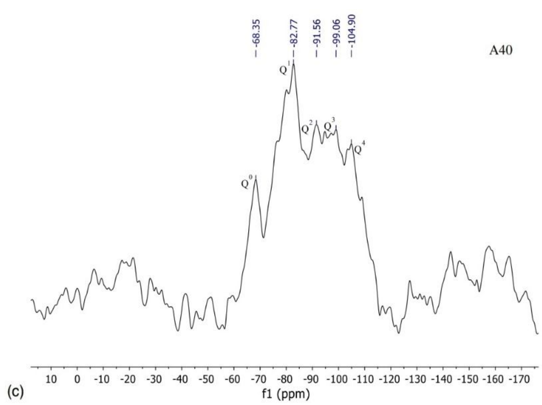

Fig. 2. NMR spectra of Geopolymer Concrete with 40% replacement [13]

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IV. RECYCLED FINE AGGREGATE

Recycled fine aggregates were used as fine aggregate replacement by Zhen Liu et Al.[16] The compressive strength of geopolymer concrete decreased with increase in w/c ratio [17-19]. From XRD results, the main constituents were found to be quartz and calcium carbonate which could be a result of the carbonation process. Small humps were formed in the XRD pattern due to the amorphous phase of CSH at room temperature. Due to the high porosity and water absorption of the OCP, the wall effect created by the natural aggregate may weaken or even vanish which resulted in the formation of a four phase composite material for both GRAC and OC-RAC samples. With increase in w/c ratio, there was no well developed interfacial transition zone between the new geopolymer/cement paste and the old cement paste.

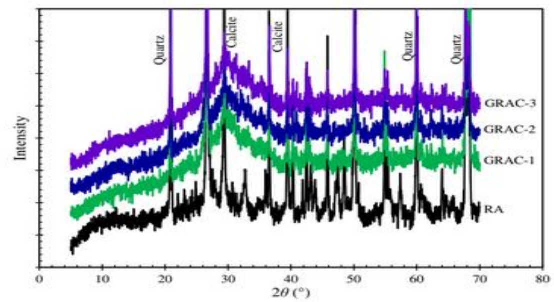

Fig. 3. XRD patterns of OCP from RA and NCP from GRAC specimens [16]

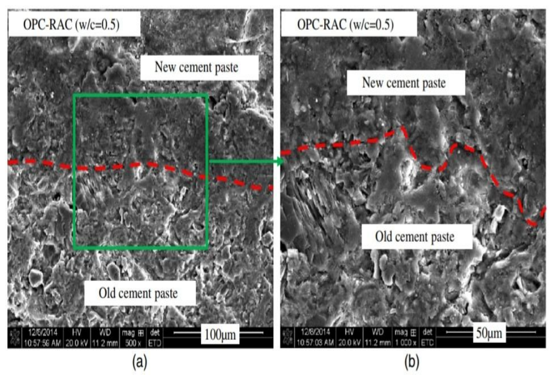

Fig. 4.SEM of GRAC Speimens[16]

V. DESERT DUNE SAND

Desert dune sand was used as fine aggregate replacement by Ehab Shehab et Al [20]. 95% of 28 day compressive strength of standard geopolymer concrete was attained in 7 days. The broad bands associated with the stretching vibrations of H-OH group(3200-3600 /cm) and bending vibrations of O-H group(1600-1700 /cm) were present White nano-sized spots identified were N-A-S-H on the surface of activated matrix of air cured samples.

Mixture		Binder	Aggregates		Alkaline activator solution					
Mix number	Designation	Slag	Fine	Coarse	SS	SH	AAS:slag	SP	Total	Curing
1	1A	450	600	1,100	177	70	0.55	11.25	2,408.25	Air
2	2A	450	600	1,100	161	64	0.50	11.25	2,386.25	
3	3A	450	600	1,100	145	58	0.45	11.25	2,364.25	
4	1IW	450	600	1,100	177	70	0.55	11.25	2,408.25	Intermittent water
5	2IW	450	600	1,100	161	64	0.50	11.25	2,386.25	
6	3IW	450	600	1,100	145	57	0.45	11.25	2,363.25	
7	1CW	450	600	1,100	177	70	0.55	11.25	2,408.25	Continuous water
8	2CW	450	600	1,100	161	64	0.50	11.25	2,386.25	
9	3CW	450	600	1,100	145	57	0.45	11.25	2,363.25	

Fig.5 .Mixture proportions [20]

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The main strength contributing reaction product was found to be Calcium Aluminosilicate Hydrate from microstructure characterisation. It's morphology was irregular shapes spread throughout the water cured AASC microstructure. CSH was also found but it's morphology could not be distinguished from CASH.The lowest absorption rate of water was at a rate of 3.25%.The sorptivity was very low with an initial sorptivity of 22.63 mm. Intermittent water curing produced AASC with 197% and 116% higher resistivity than air and continuous water curing regimes respectively.

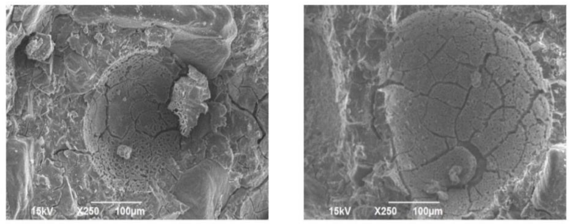

Fig.6 . SEM of the specimen [20]

The intermittent water curing techniques produced a more durable concrete with lower sorptivity and absorption and higher resistivity. Resistivity was not significantly affected by mixture proportioning. From the stress-strain curve, the slope of the chord between the stress corresponding to 40% of ultimate load and stress attributed to a longitudinal strain of 0.00005. Because of the increase in volume of hydrates and filling capacity of hydrotalcite, it contributes to the early compressive strength.

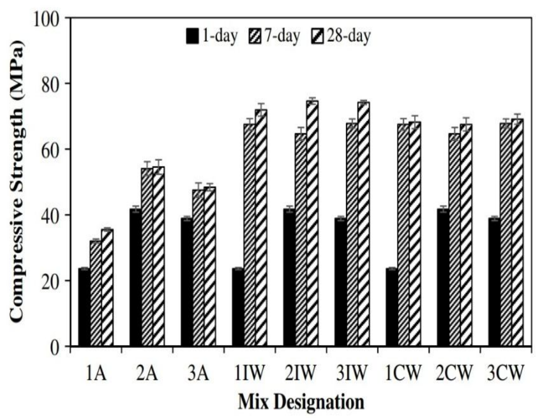

Fig.7 . Compressive strength development[20]

VI. FLY ASH AMORPHOUS SILICA

Fly ash amorphous silica was used as fine aggregates by Sudhakar M. Rao et Al [21]. The compressive strength variation was less than 5%.The glass phase sharpen between 6 and 16 degrees and a broad hump was shown by fly ash between 2θ values of 6 to 15 degrees. The microstructure consisted of rounded grains. The friction angles developed by sand particles ranged from 27(loosely packed round grains) to 45 degrees(densely packed angular grains). The specific gravity of fly ash amorphous silica, river sand and fly ash were 2.59, 2.61 and 2.15 respectively. The higher specific gravity of fly ash amorphous silica particles were considered to be because of the dense packing of Si-O-Al-O- units [22].

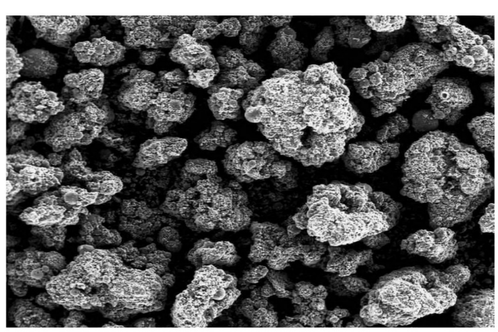

Fig.8 . SEM of FAPS specimen [21]

VII. GLASS AGGREGATES

When glass aggregate were used in under-reinforced beams, with respect to the general load bearing capacity and load-deflection behaviour, the compressive strength was similar to that of conventional concrete beams.{23-27] When the same aggregates were used in sheer controlled beams, the performance was not as much as that of conventional beams because of the reduction in tensile capacity of glass aggregate-concrete and reduced aggregate interlocking due to smaller size of glass aggregates.[23]

Fig.9 Fly ash/glass beam at failure [23]

VIII. IRON ORE TAILINGS

Iron ore tailings were used as fine aggregates by Gabriela Cordeiro Silva et al [28]. When iron ore tailings were used as fine aggregates upto 80%, the compressive strength was 35 MPa and when replaced upto 10% and 20%, the strength was 50 MPa. The water absorption was upto 20% less than that of natural aggregates. The porosity was upto 20% less than that of natural aggregates. Iron ore tailings were found to consist of 63.9% silicon oxide, 35.5% iron oxide, 1.209% aluminium oxide. The results showed that there were no expansive or deleterious substances in significant concentration. The main constituents were found to be SiO_2 (quartz), Fe_2O_3 (hematite) and $Al_2Si_2O_5(OH)_4$ (kaolinite). After air-drying, the humidity of natural fine and coarse aggregates was 1.5% and that of iron ore tailings was 3%. The low humidity content of iron ore tailings makes it possible to be used as a material in the production of pavers.

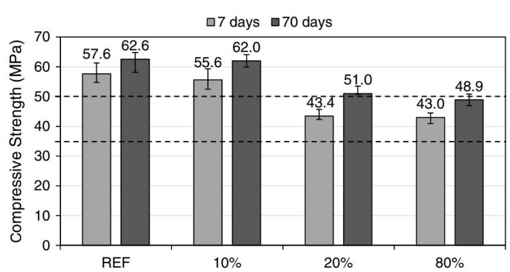

Fig.10 Compressive strength values for pavers [28]

IX. WASTE MARBLE SLUDGE

Waste marble sludge was used as fine aggregates by Nezih Kamil Salihoglu et al [29] The compressive strength obtained was high. The compressive strength of the sample containing fly ash and NaSilNaOH was 16 MPa and it increased to 30 MPa when marble sludge was added. Addition of clay led to the reduction of compressive strength by 26% in the sample containing marble sludge and fly ash, 34% in the sample containing marble sludge with cement and 38% in the sample containing fly ash, cement and sludge. The addition of gypsum led to an overall decrease in the compressive strength of all the samples. The strength went down from 47 MPa to 25 MPa in the sample containing fly ash, cement, marble sludge and NaSilNaOH solution.

The strain rate had a general increasing effect on average equivalent damping.There was an increase in ductility upto 16.7% for an increase in strain rate by two and three orders of magnitude.

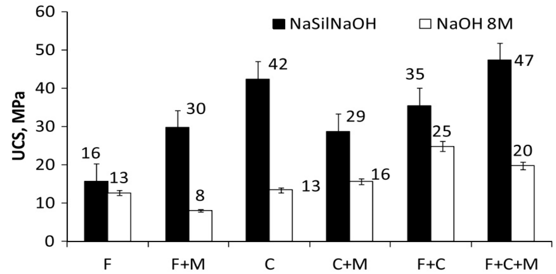

Fig.11 Compressive strength values [29]

X. SHREDDED RUBBER

Shredded rubber was used as fine aggregates by Ayman Moustafa et al [30]. When shredded rubber was partially replaced as fine aggregates in geopolymer concrete upto 20%, the reduction in compressive strength for one and three layers was 34.1% and 25.1% respectively when compared to a reduction of 41.9% in unconfined concrete. The loss in strength for one and three layers was 28.5% and 19.8% when compared to a reduction of 32.6% in unconfined concrete. The strain rate increase by two and three magnitude resulted in an increase of compressive strength by 20%. There was a high increase in modulus of elasticity of upto 100% for an increase in the strain rate by two and three orders of magnitude. As the strain energy of CFFT increased, the dissipated energy increased upto 27%. The dissipated energy of RCFFT increased upto 60% when rubber aggregates were added. The strain rate had a general increasing effect on average equivalent damping. There was an increase in ductility upto 16.7% for an increase in strain rate by two and three orders of magnitude.

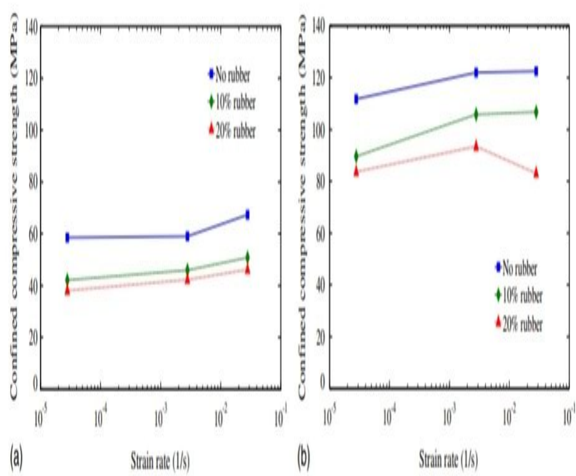

Fig.12 Compressive strength results [30]

XI. CONCLUSIONS:

From this Literature study, it is evident that, when the natural river sand is replaced with the admixtures discussed in this paper, the strength parameters of Geopolymer Concrete get enhanced. Geoplymer Concrete with 40% replacement corresponded to the high degree of polymerization. With increase in w/c ratio, there was no well developed interfacial transition zone between the new geopolymer/cement paste and the old cement paste. The increase in volume of hydrates due to the admixtures and filling capacity of hydrotalcite, the early compressive strength gets increased.

XII. SCOPE OF FUTURE WORK:

A. Experimental investigation shall be carried out by replacing the river sand with a suitable admixture as a fine aggregate.
B. The optimum percentage of the replacement shall be found it.
C. The investigation shall be then extended to study the durable properties.
D. The impact of the micro-structural properties on the strength and durable properties shall be investigated.

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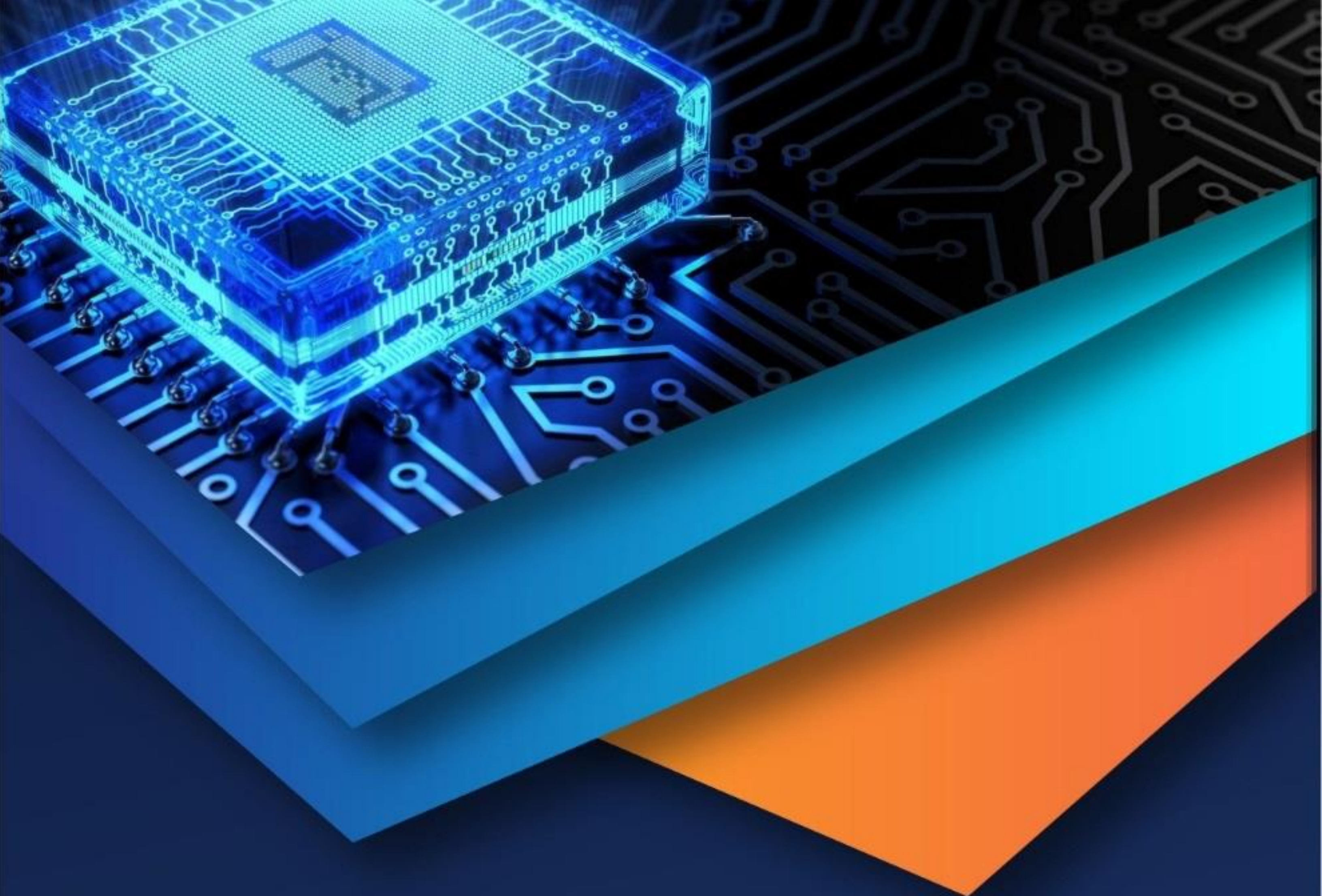

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