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Review on Recycled Concrete Aggregates

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Abstract— This review paper focuses on the mechanical and durability properties of concrete made with recycled concrete aggregates (RCA). Various techniques used by researchers: 1) replacing the proportion of normal aggregates by various recycled aggregate ie. RCA clay bricks, recycled marble, recycled granite and 2) replacing the ordinary Portland cement by flyash, baggese ash. The results observed showed 1) 25- 30% replacement with RCA showed minimal deteriorating effect and 2) whereas in case of recycled marble and granite in the form of recycled coarse aggregates performed well in the crushing test and displayed superior nature compared to natural aggregates. Tensile strength, flexural strength and resistance against sulphate attack; concrete made with RCA was inferior to control concrete whereas marble and granite in form of coarse aggregates was superior to control concrete.

Keywords— Recycled; concrete; RCA; compressive; strength; durability

I. INTRODUCTION

Construction and demolition waste is generated whenever any construction/demolition activity takes place such as demolishing old buildings, roads, bridges, fly overs, subways, remodelling etc. The disposal of waste has become a severe social and environmental challenge in the world. The possibility of recycling of waste from the construction industry is thus of environmental importance. Recycling C&D wastes can also help to conserve natural materials and to reduce the cost of waste treatment prior to disposal. It is a fact that the construction industry in India generates about billions of tons of waste annually. Projections for building material requirement of the housing sector indicate a shortage of aggregates to the extent of about 55,000 million cum. The practice of recycling C&D wastes is already followed in India but the use is only limited to activities in construction where there is no strength required like land filling. In more than 65% cases wastes such as metal, wood, plastics and glass have some market value and there are contractors who focus solely on dealing in C&D wastes but the use of RCA in form of normal aggregate's substitute is not observed. Recycling of aggregate material from construction and demolition waste may reduce the investment cost for disposing of wastes and buying new aggregates for the construction. To achieve a concrete mix, which have all the properties of concrete made with normal aggregates, some properties of aggregates which are to be recycled have to be taken into consideration, these properties include density, porosity, water absorption, abrasion and crushing. The concrete prepared from recycled concrete aggregates (RCA) should have required compressive strength, lesser than allowed value of permeability, freezing and thawing resistance, durability, workability, all these properties are the function of proportion of RCA in concrete; admixtures in cement, self -healing process, method of mixing, water to cement ratio will also be focused in this review.

II. PROPERTIES OF RECYCLED AGGREGATES

A. Density

The RCA have less density than the natural aggregates (NA) which is because of the fact that they have mortar attached to them which is less dense than the actual aggregate in an RCA .The physio-mechanical properties of concrete as observed by Sagoe-Crentsil are 2394kg/m^3 RCA and 2890kg/m^3 for NA i.e. a difference of 17% is there . The difference is due to the presence of pores in adhered mortar. R Somna et al used ground bagasse ash (GBA) as admixture in cement, he found out that the density of recycled aggregates with GBA was lower than control concrete aggregates because the specific gravity of GBA is 2.27 compared to 3.14 of ordinary Portland

cement and specific gravity of RCA was 2.49 compared to 2.73 in case of crushed limestone. Complete replacement of natural aggregates with RCA diminishes the density of concrete as compared to control concrete.

B. Porosity and water absorption

Porosity of recycled aggregates depends upon the source and property of adhered mortar. Hanifi Binici use recycled marble, granite and compared it with crushed lime stone and the water absorption of coarse marble aggregates was 1.4% and in case of coarse granite aggregates it was 1.5% whereas in case of lime stone which are used as normal aggregates it was 2.3% which is because of very low porosity of marble and granite. In another experiment Shayan and Xu observed that the water absorption of 0.5 to 1% in case of normal aggregates and 4 to 4.7% in case of RCA. So the high water absorption of RCA can be attributed to high porosity of mortar adhered to the aggregate part of RCA.

C. Crushing and L.A Abrasion Test

L.A. abrasion test is used to test the durability of RCA. It is observed by many researchers that the durability of RCA is less than normal aggregates. Sagoe-Crentsil et al observed the crushing value as 23.1% for RCA compared to 17.5% for basalt. This difference can be explained by the fact that the attached mortar to aggregate can break off easily because it is the weakest link in a recycled aggregate leading to more crushing value in RCA than that of normal aggregates.

D. Self-healing Process

Self-healing process is the process in which we immerse the recycled concrete aggregates in water which gives them a chance to improve their mechanical properties because un-hydrated cement present in attached mortar gets hydrated leading to more amount of CSH gel in concrete. Ali Abd Elhakam used the concrete made with 250kg/m^3 cement content with water to cement ratio as 0.6 and 75% replacement level with RCA and observed the increase in compressive strength by 36.6% and more interestingly after 56 days the compressive strength of 75% RCA concrete exceeded that of control concrete but it was not considered because of limited number of test specimens. Self-healing also played an important role in increasing the tensile splitting strength, bond strength and porosity of specimens, so self-healing plays important role in improving RCA properties.

III. COMPRESSIVE STRENGTH

The compressive strength of concrete made with recycle aggregates can vary depending on various factors like proportion of RCA, source of RCA, use of admixtures in cement, water to cement ratio, mixing method which are explained in detail.

A. Proportion of RCA

In an experiment conducted by Wai Hoe Kwan he observed that the concrete made with the higher replacement level of natural aggregates (NA) showed lower compressive strength. Concrete mixes were prepared 100% normal aggregates (control concrete), 15% replacement of normal aggregates with RCA , than 30% of RCA , 60% of RCA , 80 % of RCA were used replacing same level of NA by mass and it was observed that the compressive strength decreased with the increasing level of replacement . With the replacement level of 30% median of compressive strength calculated from graph indicated only 7.8% decrement in strength whereas when the replacement level was 60% of RCA there was a median drop of 36.7% as compared to the 30 % replacement level. So it can be inferred from the graph that till 30% of replacement level there is a marginal decrease in compressive strength, so this much amount of replacement is permissible. Refer graph-1, 2

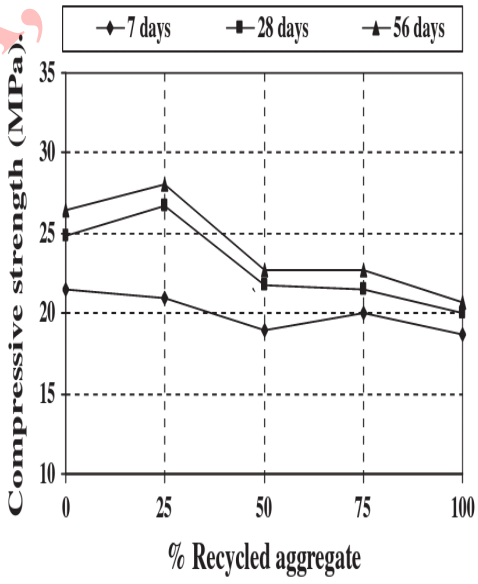

Figure-1 A graph showing effect of proportion of RCA on compressive strength

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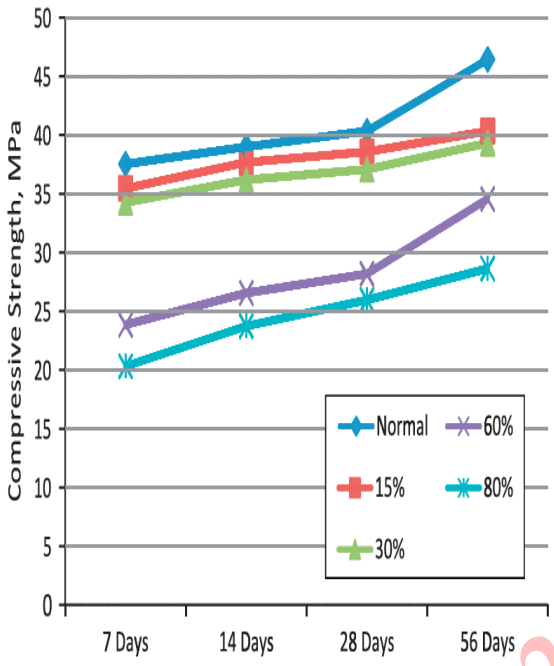

Figure-2 A Graph showing compressive strength v/s age of concrete at different proportions

B. Water to Cement Ratio

In another experiment performed by Exteberria et al, he replaced natural aggregates by RCA 0%, 25%, 50%, 100% by weight. In his result he found out that 25% replacement level in the in NA had marginal effect on compressive strength in concrete. But when he used 50% replacement level with RCA comparable compressive strength with of control concrete can be obtained by making adjustment in w/c ie. by decreasing the water to cement ratio by 4 to 10% but this method is not feasible for onsite mixing because it may lead to the decrease in workability of concrete mix but it gives comparable compressive strength to CC . The reason behind is that reduction in water to cement ratio leads to less water absorption by RCA aggregate leading to formation of strong bond between aggregate and new mortar because with high water content on aggregate surface the porosity and amount of crystal of $Ca(OH)_2$ is more and lesser amount of CSH gel leading to weaker bond and high porosity.

C. Sources of Recycled Aggregates

In an experiment performed by C.S Poon they used different sources of coarse aggregates i.e. crushed granite for control concrete (CC), recycled normal concrete (NC) and recycled high performance (HPC). The specimen prepared by NC showed 20.8% decrease in 28 day strength than CC compared to only 6.8% decrease in 28 day strength of HPC concrete and after 90 days strength of HPC was equal to the CC whereas strength of NC was 14.8% lower than CC. This difference in strength can be explained by the fact that between mortar, aggregate and bond at the mortar/aggregate interface , the interface is the weakest link in the structure and determines the whole strength, In case of HPC the bond is stronger which is observed in SEM(Scanning electron microscope) that in case of CC the interface had a lot of pores, large amount of $Ca(OH)_2$ crystals and small amount of CSH gel and in case NC concrete the interface consisted of loose granular compounds and porosity near surface was high but in case of HPC the interface consisted of high density of aggregates and porosity was less, Interface mainly consisted of CSH gel leading to stronger bond between RCA and matrix. Refer image-(1, 2). Hanifi Binici studied compressive strength using recycled marble and granite as replacements for natural aggregates, he observed that the 28 day compressive strength in recycled marble concrete was 43.9 to 44.4Mpa and 42.1 to 46Mpa in case of granite replacement concrete compared to only 24.1 to 26.2Mpa in case of control concrete, so using marble and granite prove very helpful in increasing the compressive strength

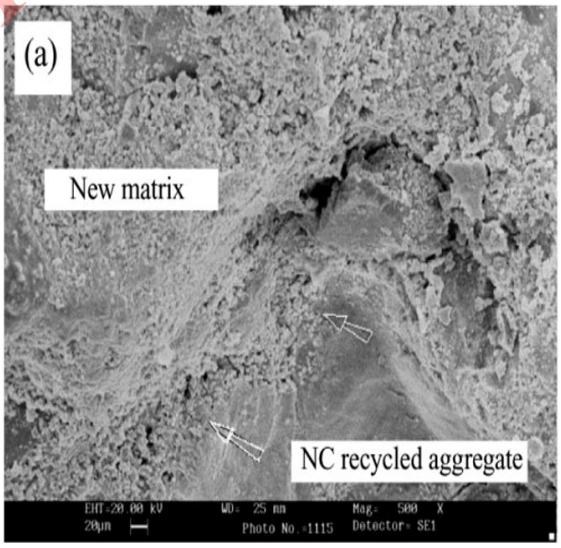

Figure-3 An image showing ITZ of newly formed matrix and NC recycled aggregate

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Figure-4 An image showing ITZ of newly formed matrix and HPC recycled aggregate

D. Mixing Method

Ali abd elhakam proposed the two stage mixing method which proved helpful in enhancing the properties of concrete as compared to concrete in which mixing of all components is done all together. Two Stage Mixing of RCA mix proved helpful because this technique increases the bond strength between cement and RCA and decreases the porosity of RCA. The approach used includes mixing the cement and water together in the first step and then RCA were introduced in the mix, they were mixed for 10 minutes, and in the second stage sand and natural aggregates were added and mixed till proper mix is obtained. Thus method is helpful in better bonding between RCA and cement because of high cement content in the first stage initially. This method improved the compressive strength by 10% to 45% as observed by Ali Abd Elhakam.

E. Admixtures in Cement

Mukesh Limbachiya studied the effect of flyash as an admixture in cement. Two types of mixture were prepared one with flyash 30% and different proportion of RCA (PCFA) and the other was prepared with Portland cement and different proportion of RCA (PC). It was observed that for same replacement of RCA the strength of PC was higher than PCFA initially but with time i.e. 14 days as observed in graph-2 strength of PCFA exceeded PC. However in case of PCFA increasing the proportion of RCA reduced the strength of concrete but it was way above the strength of PC at the same replacement level. So it can be inferred that deteriorating effect in strength of RCA is diminished by the use of flyash in later stages i.e. after 14 days because the reaction of the flyash is slower than normal Portland cement and at later stages the increased proportion of silica in flyash helps in increasing the amount of CSH gel in cement which result in more compressive strength.

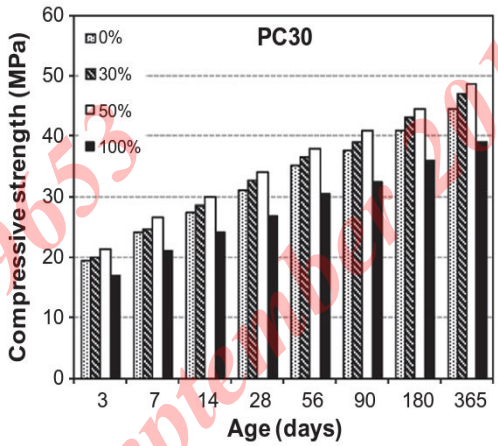

Figure-5 A graph showing compressive strength of PC at different levels of RCA replacement

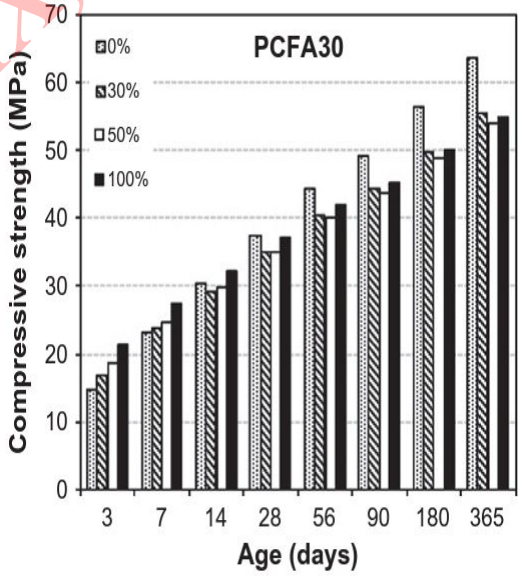

Figure-6 A graph showing compressive strength of P PCFA at different levels of RCA replacement

IV. TENSILE STRENGTH AND FLEXURAL STRENGTH

Similar to compressive strength the tensile strength also decreases with the increasing proportion of RCA substitution in concrete. J.Yang et al used RCA and CCB i.e. crushed clay bricks and he observed 8% and 14% reduction in 7 day and 28 day splitting tensile strength due to porosity of CCB and ineffective bonding. Hanifi binici on the other hand observed that the 28 day tensile splitting strength was approx. 3Mpa for granite and marble replacements for concrete compared to 2.1 to 2.4 Mpa for control concrete, he also studied the effect of RCA replacement on flexural strength of concrete, and observed 3% and 9% reduction in 7 day and 28 day flexural strength respectively when compared to control concrete. The failure plane was observed at the interface of aggregate and mortar mix which is similar to control concrete. He also observed that 28 day flexural strength varied from 6.4 to 6.9Mpa in case of recycled marble GBFS and between 6.3 to 6.5Mpa in case of recycled granite and GBFS, whereas in case of control concrete flexural strength was only 3.9 to 4.3Mpa, the big difference is because marble and GBFS show much better bonding between cement and aggregates; marble and GBFS form a good and condensed matrix.

V. DURABILITY AGAINST SULPHATES

Durability measures the survivability of concrete against deterioration occurring from pollution, acid rain etc. The main component which deteriorates the concrete are the sulphates who lead to spalling at the surface of concrete. Seung Tae Lee studied this effect by exposing the specimens made by 0%, 50%, 100% replacement of natural aggregates with RCA to the solution of magnesium sulphate for 15 months. After 15 months the visual examination of specimen was done and it was observed that the specimen white powdered substance was present at surface of all specimens. The specimens with 100% replacement of RCA showed excessive spalling at the corners as well as the faces due to the swelling and in case of 50% RCA replacement the effect was less intense and was almost equal control concrete therefore high deterioration can be due to the high porosity of 100% RCA present in the specimen, the sulphate solution entered the specimen and caused deterioration. Hanifi binici used sodium sulphate solution for testing the sulphate resistance, he observed that the concrete prepared with recycled marble and ground blast furnance slag as the replacements for coarse and fine aggregates respectively showed max resistance against sulphate attack as compared to control concrete,it is because hydration rate cement in marble and GBFS mix is faster than the control concrete specimen and therefore had less porosity and better resistance.

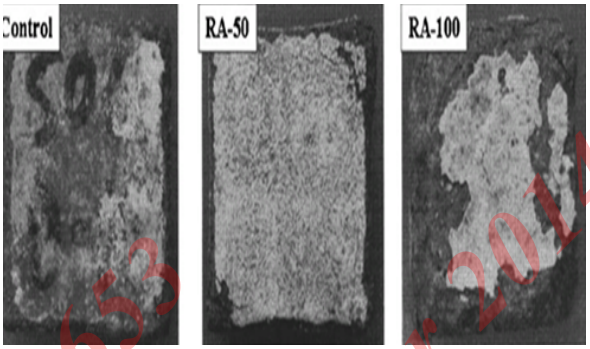

Figure-7 An image showing visual deterioration in concrete blocks at different levels of RCA when they are exposed to magnesium sulphate solution

VI. FREEZING AND THAWING RESISTANCE

Repetitive freezing of concrete have deteriorating effect on the elastic modulus of concrete. Mulheron reported that the durability of concrete having RCA showed better resistance against freezing and thawing as compared to the control concrete. Buck also investigated and found out that freezing and thawing resistance of the concrete containing recycled concrete increased in freezing and thawing tests. This is assumed to be the result of a reduction in frost response of the porous coarse aggregate particles A.Gokce studied the effect of entraining air in the source concrete, he prepared two types of concrete blocks one type had air entrained in source concrete i.e. B1 and B3 , second type didn't had air entrained in source concrete i.e.B1' and B3'. It was observed that the freezing and thawing durability of concrete made with non-air entrained RCA was quite poor and relative dynamic modulus of elasticity was obtained 60% low after 90 cycles whereas the concrete mix obtained from air entrained RCA had quite high frost resistance after 500 cycles and the freezing and thawing resistance was even superior to control concrete. It is also clear from the graph that stable relative dynamic modulus of elasticity compared to non-air entrained concrete. This research will prove very helpful in increasing the use of RCA in places where temperature goes below freezing point and fluctuates like in countries like Russia Alaska etc.

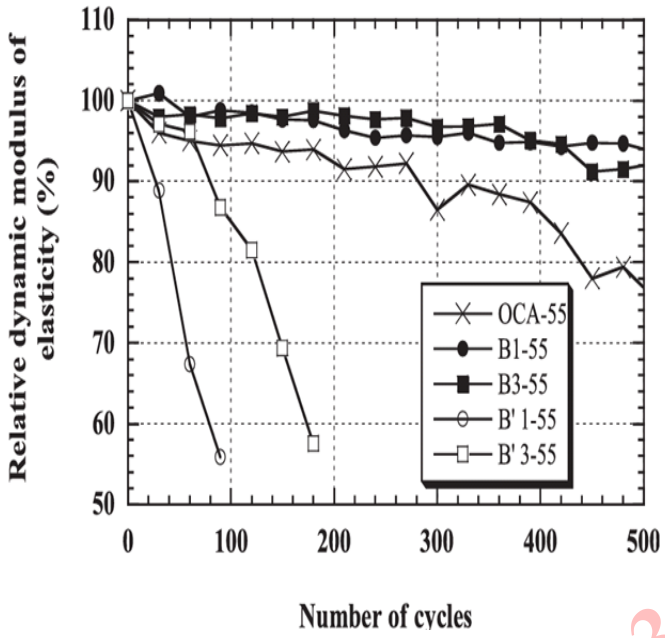

Figure-8 An image showing relative dynamic modulus of elasticity with and without air entrainment in source concrete

VII. CONCLUSION

In this review various properties of recycled aggregates were discussed like density, porosity, water absorption, L.A. crushing test, abrasion and self-healing process; recycled concrete aggregates showed inferior results as compared to normal aggregates whereas recycled granite and marble in the form of coarse aggregates superiority as compared to natural aggregates in terms of above mentioned properties.

Various properties of concrete made from recycled aggregates are discussed which includes compressive strength which further depends upon factors like proportion, source of recycled aggregates, use of admixtures in cement, water to cement ratio and mixing method; it was observed 25- 30% replacement with RCA showed minimal deteriorating effect; whereas in case of recycled marble and granite in the form of recycled coarse aggregates performed well in the crushing test and displayed superior nature compared to natural aggregates. Tensile strength, flexural strength and resistance against sulphate attack; concrete made with RCA was inferior to control concrete whereas marble and granite in form of coarse aggregates was superior to control concrete in terms of above mentioned properties. Freezing and thawing resistance were also discussed and it was found out that the aggregates prepared from air entrained in source concrete performed better than non-air entrained source concrete aggregates.

Overall, addition of RCA have deteriorating effect on concrete but further research and formation of standards considering the various properties discussed in this review will prove helpful for making environment friendly concrete; moreover mixing of RCA with inferior properties with suitable amount of recycled marble and granite as coarse with superior aggregates will help in compensating the inferior nature of RCA and concrete mixes with properties better than that of control concrete can be obtained and it will be a good topic for research considering the economy and environment.

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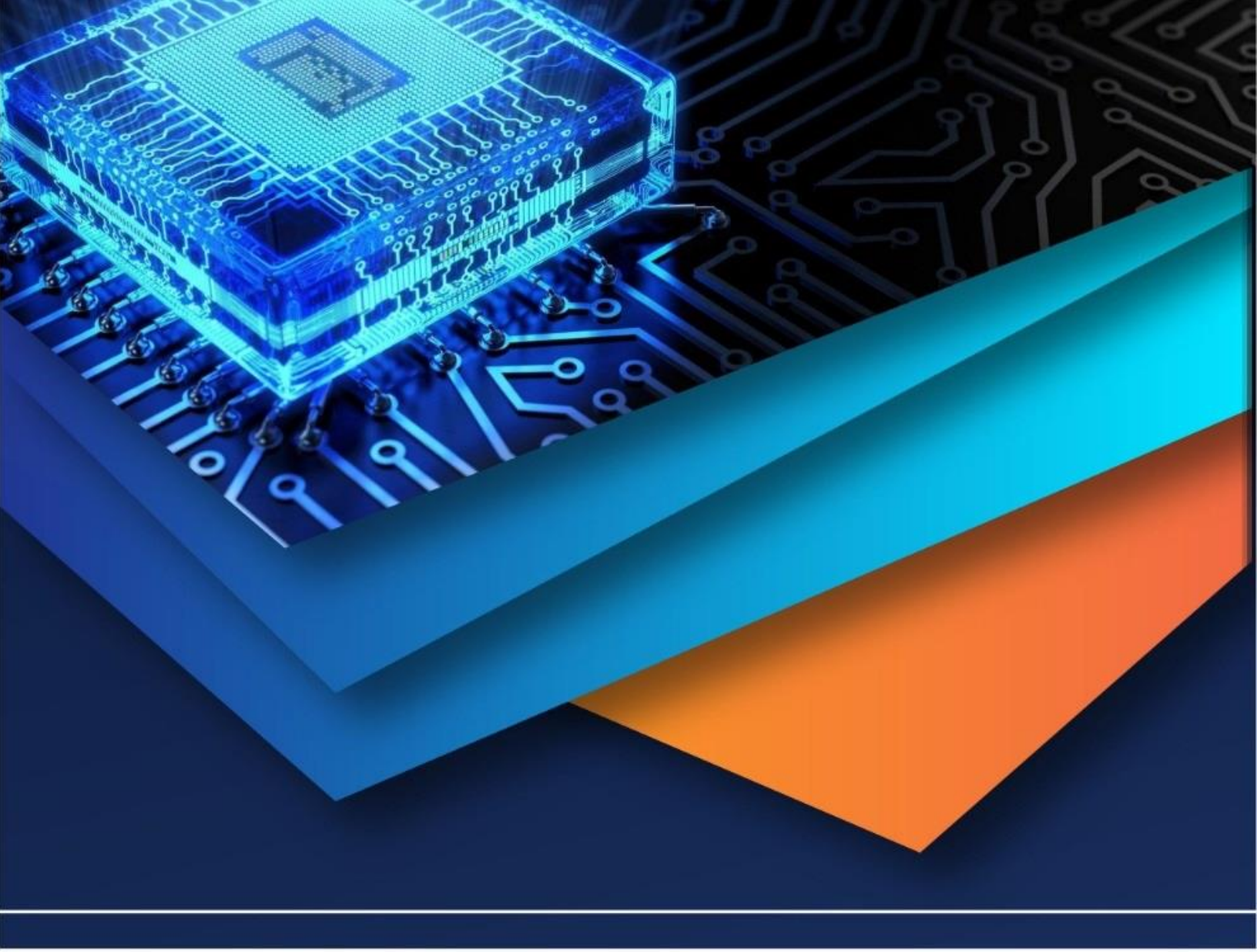

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