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Study on the Replacement of Construction & Demolition Waste Materials as Fine Aggregates in the Production of Low Strength Concrete

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***Abstract**: The construction industry is searching for a more ecological material which can provide a good sustainability and also have the eco-friendly label. The quest to protect the environment has enabled researches to find alternate materials which can fit the concrete matrix to produce a concrete that can meet the demand of the construction industry. The purpose of this research is to substitute traditional materials with construction and demolition waste by keeping the same slump value and by replacing natural fine aggregates (NFA) with Construction and Demolition Waste (C&D) materials and investigate their properties on fresh and hardened concrete. To determine and compare the properties, different tests were performed to evaluate the workability, density, compressive strength, flexural strength and absorption of each concrete mix. The results demonstrated that, construction and demolition waste materials with a define slump range decreases the compressive strength and flexural strength, and the water absorption increases with increasing C&D content.*

***Keywords**: Concrete, Construction & Demolition Waste, Fresh and hardened properties, M_{20} Grade, Fine aggregates*

I. INTRODUCTION

In the dawn of this new era, the increase in growth rate in economy and population have made the construction industry as one of the most important sectors of any country. With the rapid expansion of the global population, the demand for new housing and related infrastructures has led to the over exploitation and consumption of large amount of natural resources and energy for the production of the concrete. This situation has led to the generation of large amount of construction and demolition waste which has a negative impact for the environment and on human health.

In Europe about 3000 million tons of Construction and Demolition Waste (C&D) materials are generated each year and about one third consists of concrete debris, which is mostly used for landfilling (Bravo, et al., 2015). Construction and demolition waste accounts for approximately 40% of Australia's solid waste materials, with 160 million tonnes of virgin aggregates being mined every year. In 2008, a total of 19 million tonnes of C&D waste was disposed of in Australia, in which only 10.5 million tonnes, or 55%, of this waste was recycled, leaving 45% of waste sent to landfills around Australia (Shaikh, 2016). Scotland's 9 million tonnes of C&D waste account for over 44% of the country's total annual waste, in which 75% is being re-used (Medina, et al., 2014). According to Eurostat, the total amount of waste produced in the European Union in 2010 was over 2.5 billion tonnes, of which 35% is derived from construction and demolition activities. In order to manage economic growth with preservation of natural legacy, the European Directive 2008/98/CE has set a target for year 2020, which states that 70% of construction and demolition waste materials must be recycled (European Commission Portal, 2017).

The construction sector utilises more raw materials and energy than any other activity, and this has an important adverse effect on the environment which on a long run can prove to be irreversible. Many researchers have demonstrated that C&D is hazardous to the environment, and Tolaymat, et al. (2004) found that from 13 samples of C&D materials collected from recycling facilities, 11 samples were characterised with leachable heavy metal concentration comprising of arsenic and lead.

The re-use of C&D has become a top priority for some emerging countries like Denmark and Netherlands who have implemented waste management systems for C&D materials. With the growing concern for the depletion of natural resources and the excessive generation of construction and demolition waste (C&D) materials, emphasis on the re-use of C&D waste from the construction industry is being considered as an innovative path towards sustainability.

Many researches on C&D waste materials have been conducted on coarse aggregates replacement and works on fine aggregates replacement is very limited in the literature reviews. Most of the authors have concentrated their effort on compressive strength of

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concrete samples and experiments on durability have not been deeply elaborated. The water/cement ratio has been maintained as constant for almost all works, alternative method has not be discussed for the use in a commercial point of view. The main purpose of this experiment is to maintain workability through a defined range of slump values by comparing the properties of C&D waste materials with that of natural fine aggregates and their impact on the strength and durability of the finish product.

Fig. 1 Land fills deposit of C&D waste materials

Many researches have been conducted to evaluate the influence of C&D waste materials in concrete and their properties been defined. Khoshkenari, et al. (2014) showed that both coarse and fine recycled aggregates are about 20% lighter than normal aggregates. Evangelita and de Brito (2007) obtained an increase of 45% in water absorption by immersing samples containing 100% of recycled fine aggregates. The latter found that this property varies proportionally with aggregate replacement ratio. J. Raman and Sriram (2017) stated that recycled aggregate concrete absorb 42% more water than natural aggregates and replacement of 30% of recycled aggregates decreases the compressive strength by 20-40%. Zaharieva, at al. (2003) evaluated the capillary water absorption of concrete with fine and coarse recycled aggregates (RA) from Construction and Demolition (C&D) recycling plant. They maintained the slump in all mixes and found that full replacement of coarse natural aggregates increased this property by 16%. Moreover, the integral use of natural aggregates (fine and coarse) caused an increase of capillary water absorption of 42%. Anastasiou, et al. (2014) studied the use of fine aggregates in concrete with fly ash and steel slag. The results showed that the use of fine aggregates from C&D increases concrete’s porosity and reduces its durability. However, by using steel slag, the concrete partly recovers the strength and durability loss. Padmini, et al. (2009) pointed out that recycled aggregate from concrete (RAC) requires more water for the same workability than traditional concrete, the latter also highlighted that the density, compressive strength and modulus of elasticity of RAC are lower than that of control concrete. However, gas and water permeability test, rate of carbonation and risk of reinforcement corrosion are higher. Thomas, et al. (2014) stated that the replacement of natural aggregate in control concretes by recycled concrete lead to a reduction on the fatigue limit and on the compressive strength. Otsuki (2003, pp.443-451) pointed out that chloride penetration in high strength recycled aggregate in concrete was inferior to an equivalent concrete with natural aggregate, using a recycled aggregate with 4.5% of water absorption. Cadersa and Ramchuriter (2014) investigated the feasibility use of recycled coarse concrete aggregate as an alternative to natural coarse aggregate in structural concrete. The results obtained showed that the compressive strength, flexural strength and modulus of elasticity were lowered with an increase in recycled aggregate. The latter attributed the decrease due to weak bonding.

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II. MATERIAL PROPERTIES AND MIX PROPORTIONING

In the present experimental investigation, construction and demolition materials have been used as a partial replacement of natural fine aggregates in the concrete mixes. The effect of replacing different percentages of C&D waste materials as a supplementary material to concrete mixes on their compressive strength, , flexural strength and water absorption were studied. The details of the experimental investigations are as follows. The materials used in this research are as follows

A. Cement

The Ordinary Portland Cement (OPC) used in this research is of type CEM II 42.5 which is available from on the local market. The components and test properties of cement id reported in Table 1.

Table 1 Chemical & Physical Properties of Cement

Components/Test	Results
SiO_2 (%)	20.24
CaO (%)	62.73
Al_2O_3 (%)	5.22
Fe_2O_3(%)	3.08
MgO (%)	3.43
Loss of Ignition (LOI)	1.20
Specific Gravity (g/cm^3)	3.04
Initial setting time (min)	130
Final setting time (min)	195
Colour	Grey

B. Natural Fine Aggregates

The natural fine aggregates (NFA) were obtained from our local aggregate plant and from same plant as for coarse aggregate. The source of the fine aggregate are from crushed basaltic rocks. The size of NFA ranges from 0-4 mm.

C. Construction and Demolition Waste (C&D)

The C&D were obtained from dumping ground for construction and demolition waste in the West of Mauritius. The C&D materials was obtained in its raw form containing solid waste like papers, wood, glass and piece of metal. The C&D waste contained mainly of concrete rubbles from old buildings and from concrete waste from ongoing construction sites. For this experiment, all these unused materials were removed manually and the remaining content was sieved through a sieve size of 5.0 mm as per BS 812: Part 103.1: 1985. The passing material was collected and stored in a container, and the retained materials were discarded. Before using the materials, it was placed in an oven for 24 hrs at 105ºC, so as to get rid of the moisture containing in the material.

Fig. 2 Finish product after sieving process

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Preliminary test were conducted on both natural and C&D wastes. These tests included sieve analysis, specific gravity, bulk density and water absorption test. All data obtained were used for the formulation of the mix design process. The Table 2 below gives the density, specific gravity and water absorption of the natural fine aggregates (NFA) and C&D waste, and figure 5 shows the grading of the NFA and C&D waste materials used in this study.

Table 2 Physical Properties of Natural Fine Aggregates and C&D

Tests Properties	Results	
	NFA	C&D waste
Specific Gravity (Mg/m^3)	2.91	2.66
Water Absorption (%)	2.50	7.20
Bulk Density (Mg/m^3)	1.765	1.63
Sand Equivalent Value (%)	84.0	51.0

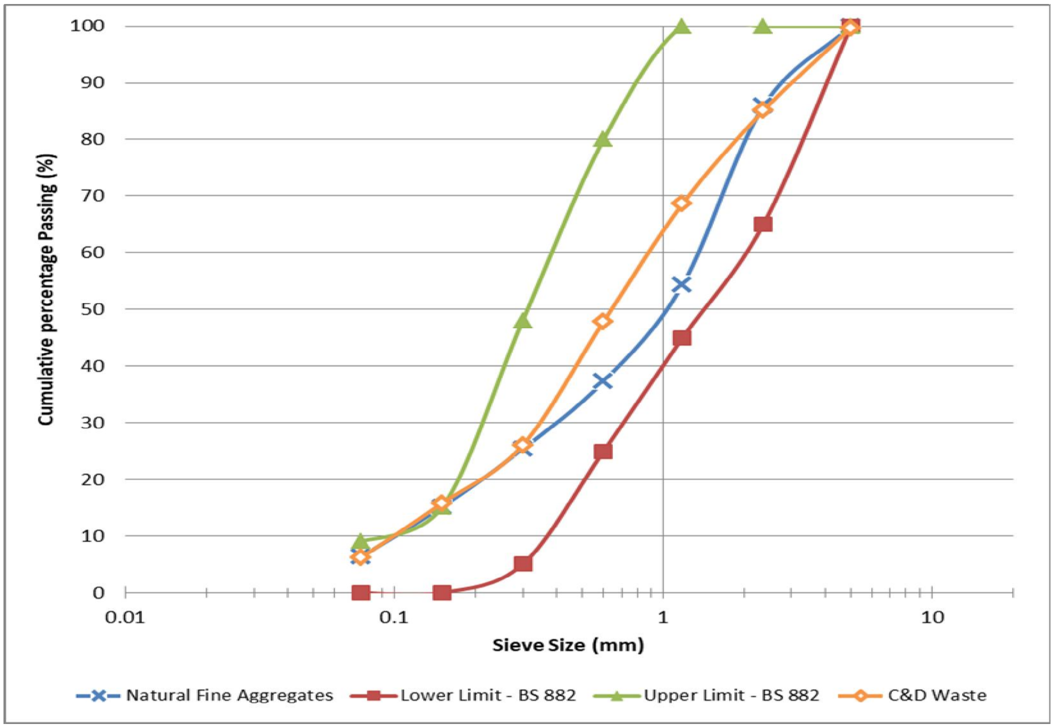

Fig. 3 Particle size distribution of nauturalfine aggrgegate and C&D waste materials

D. Natural Coarse Aggregate (NCA)

The natural coarse aggregates (NCA) were obtained from our local aggregate plant, and consist of crushed basaltic rocks. The coarse aggregates were separated into 2 different grading which are the 14-20 mm and 6-10 mm and their properties are shown as per Table 3 below.

Table 3 Physical Properties of natural coarse aggregates

Tests Properties	*Results*
	Coarse Aggregates
Specific Gravity (Mg/m^3)	*2.775*
Water Absorption (%)	*2.05*
Bulk Density (Mg/m^3)	*1.76*
Los Angeles Value (%)	*33.35*
Aggregate Crushing Values (%)	*26.85*
Sulphate Test (%)	*0.06*

E. Water
Water from tap was utilised for this experiment.

F. Admixture
Admixture of type Plastiment 900R MU was added to the concrete to improve workability and retain the required slump over a much longer period during transportation over longer distance. The admixture was added at a rate of 0.25% by weight of cement in each batch.

G. Mix Design
For this research 5 concrete mixes were prepared, with B0 as the control mix containing 100% of natural fine aggregates (NFA). The variation of replacement of NFA with C&D waste materials was experimented using 25%, 50%, 75% and 100% of sieved C&D in each mix. The DOE Method was used for the mix design process, which consist of tables and charts available at the Building Research Establishment (BRE). The concrete was designed for a compressive strength of 20 MPa with slump value ranging from 130-150 mm.

The following data were used for the mix design:

1) Characteristic Compressive Strength at 28 days : 20MPa
2) Target mean strength : 27 MPa
3) Cement : OPC CEM II 42.5
4) Design Slump : 60 – 180 mm
5) Natural Fine Aggregate : Crushed rock sand with 37.3% passing 600 µm sieve size
6) Natural Coarse Aggregate : Crushed Basaltic rock with maximum size of 20 mm
7) Relative density of Natural Aggregates (SSD) : 2.83

The Table 4 below shows the mix proportion of materials in 1 m3 of concrete mix on Saturated Surface Dry Condition (SSD).

Table 4 Proportion of materials

		Materials(Kg)				
Specimen Type	% of C&D	Cement Content (Kg)	Natural Fine Aggregates (Kg)	Natural Coarse Aggregates (Kg)	C&D (Kg)	Free Water Content (Kg)
B0	0	308	1010	932	0	225
B1	25	308	758	932	252	225
B2	50	308	505	932	505	225
B3	75	308	252	932	758	225
B4	100	308	0	932	`1010	225

H. Trial Mixes
Trial mixes were conducted to obtain the desired workability. This was performed by controlling the free water content in the mix, and was adjusted as per the requirement of the mix to be in the acceptable range of 130 – 150 mm slump. The corrected water content refers to the amount of free water being withheld.

Table 5 Corrected water content in the trial mixes

Specimen Type	% of C&D	Cement content (Kg)	Corrected Water Content (Kg)	Natural Fine Aggregates (Kg)	Natural Coarse Aggregates (Kg)	Slump Value
B0	0	308	147	1010	932	140
B1	25	308	187	758	932	143
B2	50	308	211	505	932	139
B3	75	308	220	252	932	138
B4	100	308	224	0	932	142

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The concrete was mixed according to BS 1881: Part 125: 1986 with a drum mixer in the laboratory. Half of the coarse aggregates are added followed by fine aggregates and then the remaining half coarse aggregates are added in the drum mixer. The materials are mixed in the drum for 15 secs to 30 secs. The mixing is continued and half of the water content is added during the next 15 secs. The whole batch is mixed for a total of 2 mins to 3 mins and then stopped and the content in the mixer is covered and left for 5 mins to 15 mins. The cement and bagasse ash is mixed separately in a container and added to the wet batch in the mixer, and the whole is mixed for another 30 secs. The remaining water is added over the next 30 secs and mixing is continued for at least 2 mins and not more than 3 mins.

After completion of the mixing, the concrete is discharge onto a clean non-adsorbent surface and mixed thoroughly using a hand tool to ensure uniformity before sampling.

Fig 4 Drum mixer used for mixing concrete in laboratory

III. EXPERIMENTAL INVESTIGATION

A. Compressive Strength

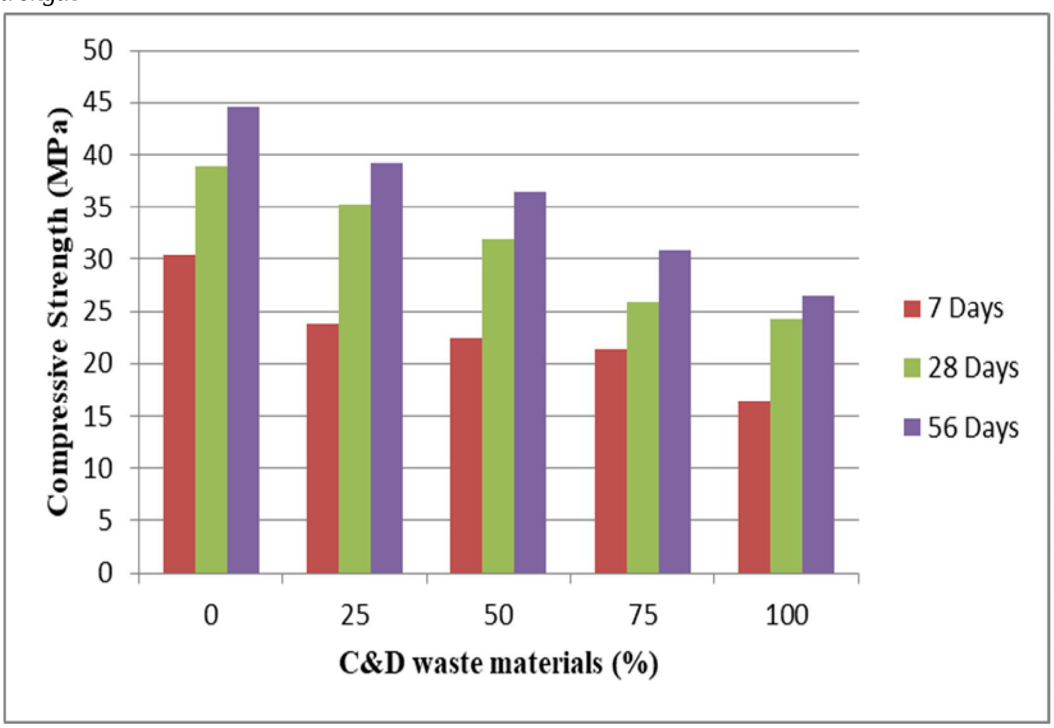

Fig 5 Compressive strength of natural fine aggregates and C&D waste materials in concrete

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The compressive strength test of the concrete samples containing C&D at different proportion and days is illustrated in Figure 5.
It is observed that the compressive strength increases as the age increases, however it is also noted that as percentage of C&D increases, the strength decreases significantly. At 28 days, the strength of the samples deceases by 9.24% when 25% of C&D is added and decreases further to 15.12% when 50% is added. At 75% and 100% of C&D addition, the strength decreases considerably to 33.21% and 37.44%. This decrease in compressive strength is attributed due to insufficient hydration and a weak interface-zone formed between different components of the concrete matrix owing to a large amount of old cement paste on the surface of the recycled fine aggregates (Raman, et al., 2017).

B. Flexural Strength

The graph below shows that the flexural strength decreases with increasing percentage of C&D waste materials. At 28 days of curing, the flexural strength decreases by 5.98% with 25% of C&D addition and 19.18% for 50% addition of C&D waste materials to the concrete. Moreover, the difference between control mix and 100% of C&D waste materials added is significantly very high with a decrease of 41.65%. The high porosity content and the low specific gravity of C&D material are due to insufficient hydrated cement paste, which results in creating voids in the concrete mix and decreasing the strength.

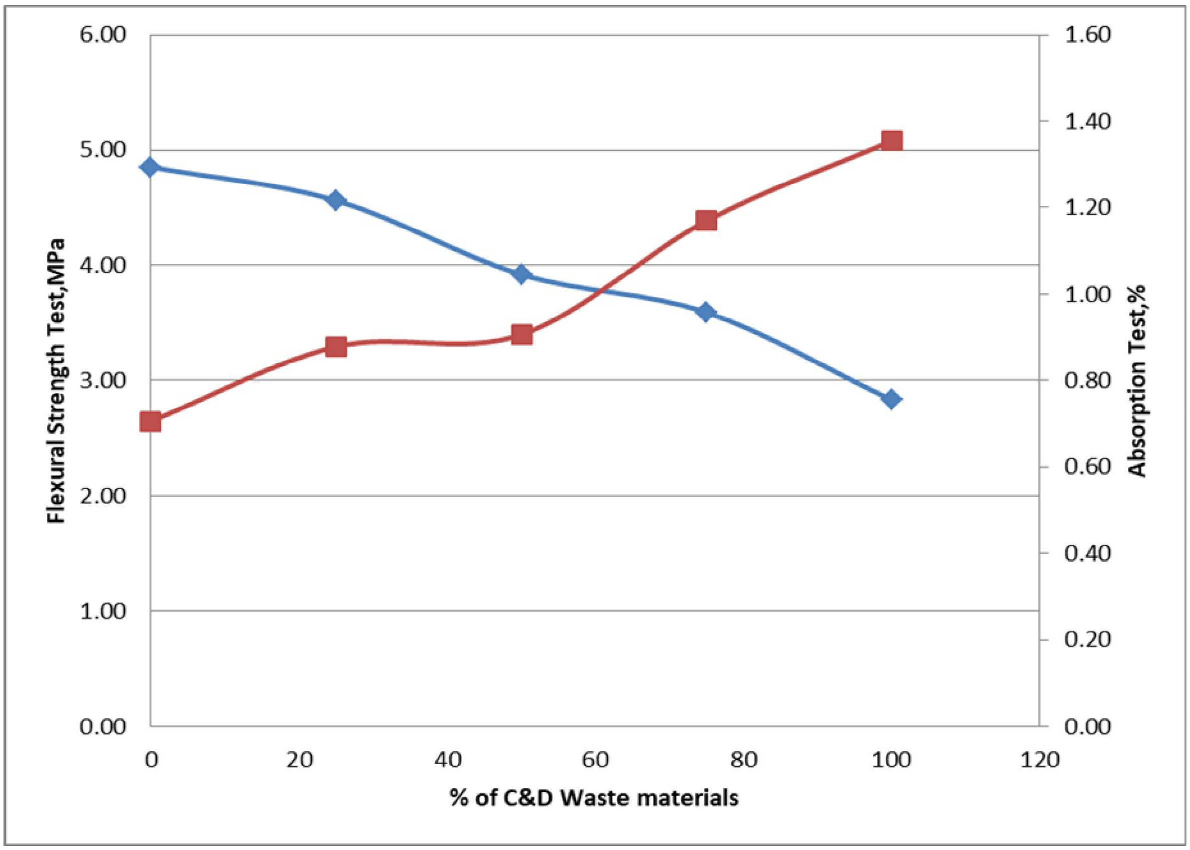

Fig 6 Flexural Strength Test and Absorption Test of C&D waste materials in concrete

C. Absorption Test

The water absorption variation of all mixes is shown in figure 6. The water absorption increases with increasing amount of C&D waste materials. With 25% and 50% of C&D waste materials the absorption is increased by 0.17% and 0.20% respectively. The percentage absorption for 75% and 100% are 0.46% and 0.64%. The 25% and 50% addition of C&D waste materials to the concrete exhibits almost the same properties. The high porosity content of C&D waste materials enables the absorption of more water than the control mix.

IV. CONLUSION

Many studies have concentrated their efforts in elaborating a matrix that could well pass the mechanical tests as well as the durability test, however, the workability of the mix is compromised during this process and much work done is required, which make the does not make the concrete suitable during laying. This study brings the balance between the mechanical properties and the durability properties and ensures that a good workability is maintained throughout the mix and laying process. In the above study, an investigation was carried out where natural fine aggregates were replaced by construction and demolition waste materials at 25%, 50%, 75% and 100%, in order to evaluate the mechanical and durability properties of the concrete. This experiment showed that C&D waste materials have a high absorption value, as the hydrated cement paste adhered is weak and porous. The water absorption increases as the amount of C&D waste materials is increased and this can be attributed to the high porosity of C&D waste materials. The compressive strength and flexure of the concrete decreases as the amount of C&D waste material are increased. From the results obtained, it can be deduced that construction and demolition waste materials can be used at an optimum content of 25% together with 75% of natural fine aggregates for low strength concrete utilisation. The construction and demolition waste is an alternative way to preserve our natural resources and make a step ahead in protecting and safeguarding our environment.

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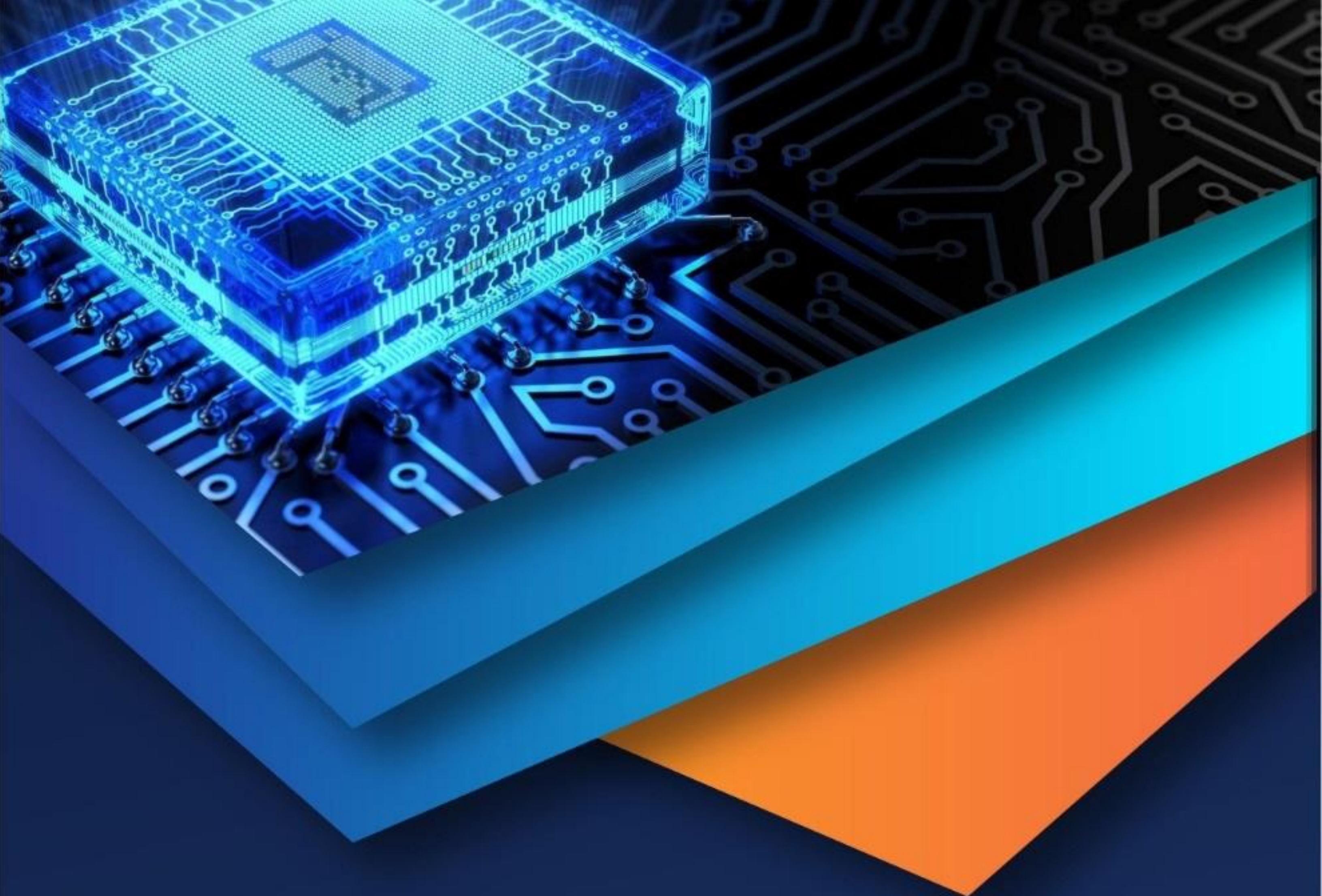

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