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Experimental Analysis on the Characteristics of Concrete by Incorporating Steel Slag as Partial Replacement of Sand

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Abstract: Steel slag is a by-product obtained in the manufacture of pig iron in the blast furnace and is produced by the blend of constituents of iron ore with limestone flux. Presently in India, owing to restricted methods of use, massive amounts of iron and steel slag are deposited in the yards of every production facility, occupying significant agricultural land, and seriously polluting the entire ecosystem. Meanwhile, the application of ecological environment protection has limited the mining of gravel, leading to a shortage of natural aggregate. Numerous studies have sought to replace natural aggregate in concrete with steel slag aggregate due to its good engineering qualities. The current research work is to investigate the concrete's characteristics for M40-grade concrete by substitution of sand with steel slag at 10%, 20% and 30% during various curing ages. Several experiments were conducted on the characteristics of the concrete, compressive strength, and durability properties (such as water absorption and rapid chloride permeability test) up to the age of 90 days.
Keywords: Steel Slag, M40 Grade Concrete, Compressive Strength, Water Absorption, Rapid Chloride Penetration Test.

I. INTRODUCTION

In order to achieve sustainability and lower CO_2 emissions, the building industry emphasises the use of alternative materials due to the rising urbanisation and excessive use of concrete. Cement, fine aggregate, coarse aggregate, and water are the typical ingredients of concrete. Between 60 and 80 percent of the volume and 70 to 85 percent of the mass of concrete are made up of aggregates. For concrete's strength, dimensional stability, and volume stability, aggregates play major role. These materials help to make concrete mixes more compact. River sand, which is one of the fine aggregate constituents used in the production of conventional concrete, the need of sand is more in growing countries to mitigate the fast infrastructure development. The increasing need for sand leads to a scarcity of high-quality sand, particularly in India where natural sand reserves are depleting, posing a serious threat to the environment. The rapid removal of sand from the bed of a stream causes a variety of problems, including the loss of soil layers that retain water and the riverbanks slipping (Sankh et al., 2014). Therefore, it must be crucial to discover a substitute for natural sand. According to a report by The Energy and Resources Institute (TERI), India generates over 62 million tons (MT) of waste in a year. Only 43 MT of total waste generated gets collected, with 12 MT being treated before disposal, and the remaining 31 MT simply discarded in wasteyards. The Journal of Urban Management (December 2021) reports that the 62 MT of waste generated annually includes 7.9 MT are unwanted inorganic waste of mining & industrial division. The Indian Central Pollution Control Board (CPCB) recently projected that annual waste generation in India will increase to 165 MT by 2030. To safeguard the environment, efforts are being made for using industrial waste in concrete for conserving natural resources and reduce the cost of construction materials. Assuming industrial by- product in the form of cementitious material and fine aggregate for concrete production can be considered one of the environmental benefits and shows better performance in concrete. Different types of industrial by-product currently used as industrial waste materials such as waste foundry sand, copper slag, fly ash, Steel slag, ground granulated blast furnace slag (GGBS), metakaolin etc., these waste products pollute the environment and cause problems for landfills.

One possible mineral additive for sand replacement in concrete is steel slag, Steel slag is a by-product obtained in the manufacture of pig iron in the blast furnace and is produced by the blend of constituents of iron ore with limestone flux. Its common minerals consist of C_3S, C_2S, $C_{12}A_7$, C_4AF, C_2F, RO phase (Cao, FeO–MgO–MnO solid solution), Fe_3O_4, and free-CaO [1–3]. The minerals of C_3S, C_2S, $C_{12}A_7$, C_4AF, and C_2F exhibit cementitious performances when they are mixed with water. Steel slag produced in large quantity all over the world. India is the second largest steel producing country in the world and about 19 million tonnes of steel slag is generated in the country as a solid waste, which will increase to 60 million tonnes by the year 2030.

(About 200 kg of steel slag is generated in one tonne of steel production) [4]. The purpose of the current research is to investigate the durability (such as water absorption and rapid chloride permeability test) analysis of concrete for M40-grade concrete by substitution of sand with steel slag in different proportions at different curing ages. The tests are conducted, and the test results are compared with control samples without replacement. The steel slag processing system are shown in fig. 1 below.

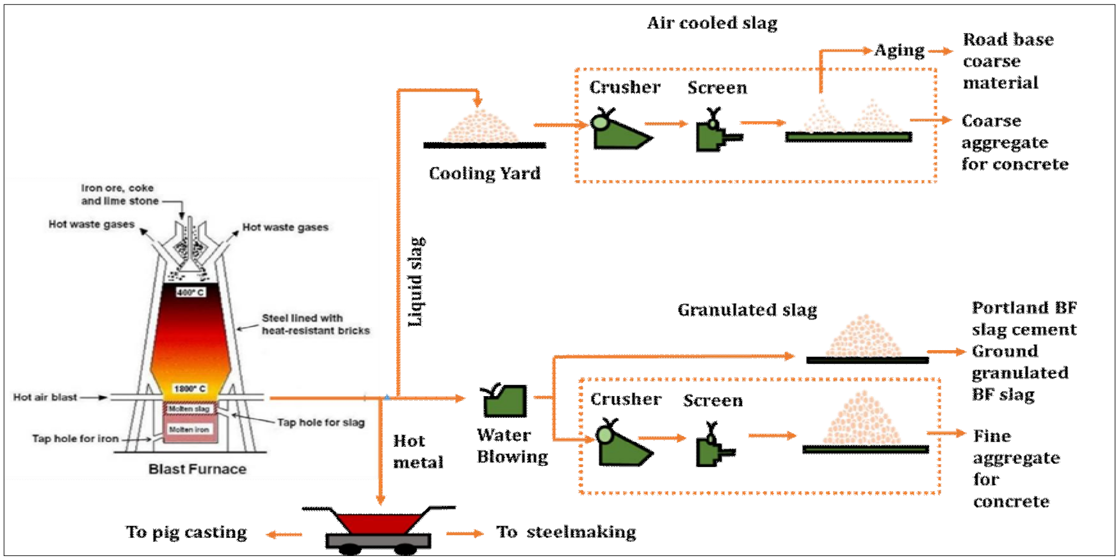

Fig. 1 Steel Slag and its Processing [5]

II. MATERIALS AND METHODOLOGY

A. *Cement*

OPC of 53 grade was used in this work, which conformed to IS: 12269 – 2013[6] and the physical properties are shown in Table 1.

Table - 1 Physical Properties of Cement.

S.No.	Characteristics	Values
1.	Fineness	3.2%
2.	Consistency	30
3.	Initial setting time	33
4.	Specific gravity	3.16

B. *Fine aggregate (River Sand)*

River sand was used as fine aggregate, and satisfied the requirements for grading zone-II of IS 383 - 2016 [7]. Its specific gravity and fineness modulus values were 2.55 and 2.63 respectively.

C. *Coarse aggregate*

Locally available gravel of 12 mm size was used as coarse aggregate. Its specific gravity was 2.68 and fineness modulus was 6.88.

Table - 2 Physical Properties of Fine and Coarse aggregate.

S.No.	Characteristics	F.A.	C.A.
1.	Fineness Modulus	2.63	6.88
2.	Specific Gravity	2.55	2.68
3	Bulk Density	1520 Kg/m^3	1669 Kg/m^3
4.	Water absorption	0.86%	0.68%

D. Steel slag

Steel slag was collected from Bhilai steel plant, Durg, Chhattisgarh. It was black in colour. The chemical composition of Steel slag is given in Table 2. Specific gravity and fineness modulus of Steel slag is 2.48 and 2.70 respectively. Fineness modulus values of fine aggregate (2.63) and Steel slag (2.70) indicate that they are almost similar in particle size.

Table – 3 Chemical composition of the steel slag used in the study.

Chemical compounds	**Formula**	**% of chemical compounds**
Calcium oxide	CaO	42.90
Iron oxide	Fe_2O_3	18.20
Silica	SiO_2	14.20
Alumina	Al_2O_3	1.40
Magnesium oxide	MgO	9.59
Sulphur	S	1.69
Manganese Oxide	MnO	1.77

E. Chemical Admixture

Forsoc Aura-mix 400 super-plasticizer is a high-water-reducing admixture that was used. It is a light-yellow colour with a PH value of 6.0.

III. MIX PROPORTIONS

Table 4 shows mixture proportion ratios. The control mixture was designed to achieve 40 mpa compressive strength after 28 days. The mix design was carried out by IS 10262 – 2019. Then river sand was replaced with 10%, 20%, and 30% steel slag. The control mixture was designated as M0, and mixtures with 10%, 20%, and 30% steel slag were designated as M10, M20, and M30, respectively. Moreover, a high-water reduction agent based on Forsoc Aura-mix superplasticizer was employed according to ASTM C 494:2019 [8].

Table - 4 Mix Proportion

Mix ID	Cement (Kg/m^3)	Steel Slag (Kg/m^3)	F.A. (Kg/m^3)	C.A. (Kg/m^3)	Water (Kg/m^3)	Superplasticizer (Kg/m^3)
M0	430	0	1100	1400	193	2.60
M10	391.5	110	990	1400	193	2.60
M20	348	220	880	1400	193	2.60
M30	304.5	330	770	1400	193	2.60

Note: FA and CA denotes Fine aggregate and Coarse aggregate respectively.

IV. RESULT AND DISCUSSION

A. Compressive strength

Table 5 shows the compressive strength of concrete at different percentage of steel slag. Compressive strength of control mixture of normal concrete without Steel slag is 50.21 MPa, 51.30 MPa and 52.85 MPa at 28, 56 and 90 days respectively. Compressive strength at 28 days of concrete mixtures made with 10%, 20% and 30% Steel slag as fine aggregates gained 4%, 11% and 19% respectively more compressive strength in comparison with Control mixture i.e., without Steel slag. At the age of 56 days, mixtures containing 10, 20 and 30% Steel slag as fine aggregates gained 5%, 11% and 19% respectively more compressive strength as compared to 56 days mixture without Steel slag. At the age of 90 days, mixtures containing 10, 20 and 30% Steel slag as fine aggregates gained 5%, 12% and 20% respectively more compressive strength as compared to 90 days mixture without Steel slag. On the curing age of 56 days and 90 days, the increment in compressive strength percentage of mixtures containing Steel slag is more than control mixes. Increase in compressive strength at all ages with increase in Steel slag content exhibits that with inclusion of Steel slag got denser, resulting in improved strength. Fig. 2 demonstrates that increasing the steel slag replacement causes the compressive strength to rise during any testing period.

Table – 5. Compressive strength of concrete at different replacement of steel slag

Mixing ID	Curing age (Days)		
	28D	56D	90D
M0	49.9	50.85	52.5
M10	51.9	52.88	55.125
M20	55.39	56.44	58.8
M30	59.38	60.51	63

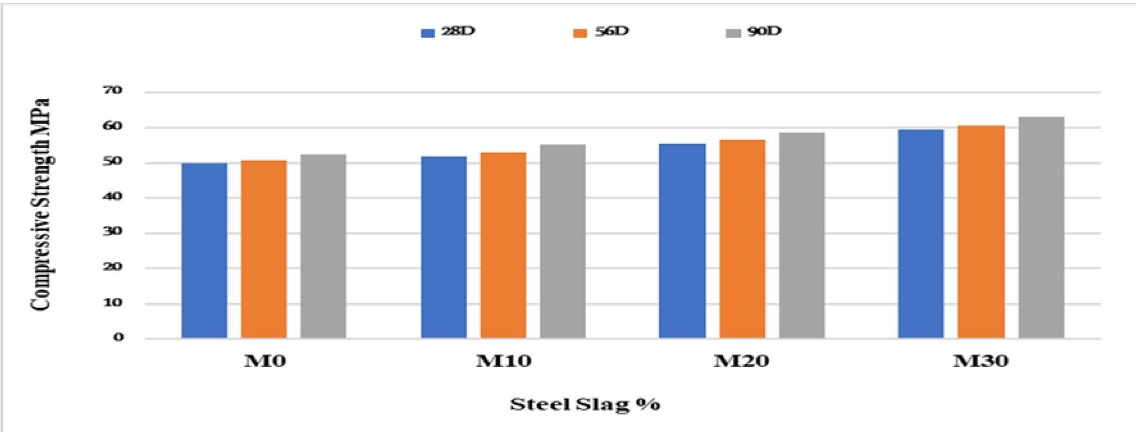

Fig. 2. Impact of Steel slag on compressive strength of concrete.

B. *Water Absorption*

The durability of concrete mostly built upon the movement of water through it. Water absorption is a simple criterion to find a measure of concrete resistance to exposure in aggressive environments. Water absorption results of Steel slag in mixtures up to 90 days are shown in Fig. 2. Water absorption of mixture without Steel slag replacement with fine aggregates is 4.72%, 4.65% and 4.06% at 28, 56 and 90 days. Findings indicates that as the percentage of Steel slag increases the percentage of water absorption decrease in all concrete mixtures and same in case of curing age due to increment in passage of time water absorption decreases. Curing age of 28 days, mixtures incorporating 10, 20 and 30% Steel slag as fine aggregates gained 4.5, 4.12, and 3.91% less absorption as compared to 28 days mixture without Steel slag. At 56 days, mixtures consist of 10, 20 and 30% Steel slag as fine aggregates gained 3.62%, 3.51%, and 2.2% less absorption as compared to 56 days mixture without Steel slag. Results of 90 days indicates that mixtures containing 10, 20 and 30% Steel slag as fine aggregates gained 2.25%, 2.0%, and 1.1% less absorption as compared to mixture without Steel slag at same age. Water absorption generally related to the structural pores (inter-layer C–S–H) and porous paste, aggregate interface zone, especially more at initial stage [29].

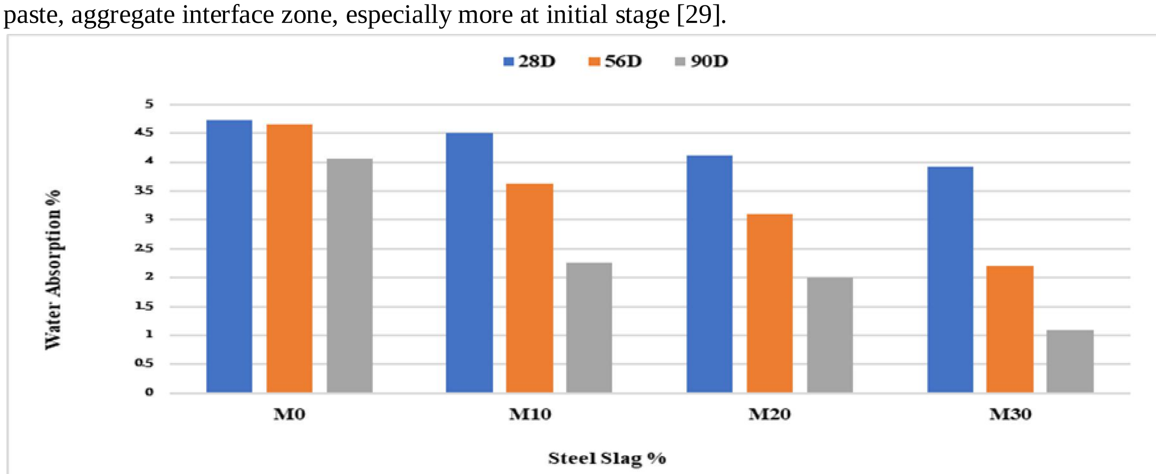

Fig. 3. Impact of steel slag on water absorption.

C. Rapid Chloride Permeability Test

Rapid Chloride permeability test (RCPT) determines the resistance to penetration of chloride ions. The rapid chloride permeability test RCPT-ASTM C -1202 is commonly used to evaluate the resistance of concrete to chloride ions ingress owing to its simplicity and rapidity. Fig. 3 depicts lesser decrease in permeability at all levels of river sand replacement with Steel slag and shows that permeability decreases with increase of curing age at all replacement levels. It shows the result values of 7days are 1530^{0}C, 1490^{0}C, 1433^{0}C and 1375^{0}C at 0, 10, 20 and 30% replacements of sand with Steel slag and the result values at 28days are 1270^{0}C, 1205^{0}C, 1175^{0}C and 1080^{0}C at 0, 10, 20 and 30% replacements of sand with Steel slag. Furthermore at 56 days the result values are 1179^{0}C, 1155^{0}C, 1138^{0}C and 1121^{0}C at 0, 10, 20 and 30% replacements of sand with Steel slag. Moreover, at the curing age of 90 days the result values are 1078^{0}C, 1049^{0}C, 1032^{0}C and 1018^{0}C at 0, 10, 20 and 30% replacements of sand with Steel slag. The value of coulomb charge passed (chloride permeability) decreased with increase in Steel slag content, which is an indication of concrete matrix becoming denser because of inclusion of Steel slag. These permeability results reinforce the results of compressive strength, where strength has improved because of denser concrete matrix.

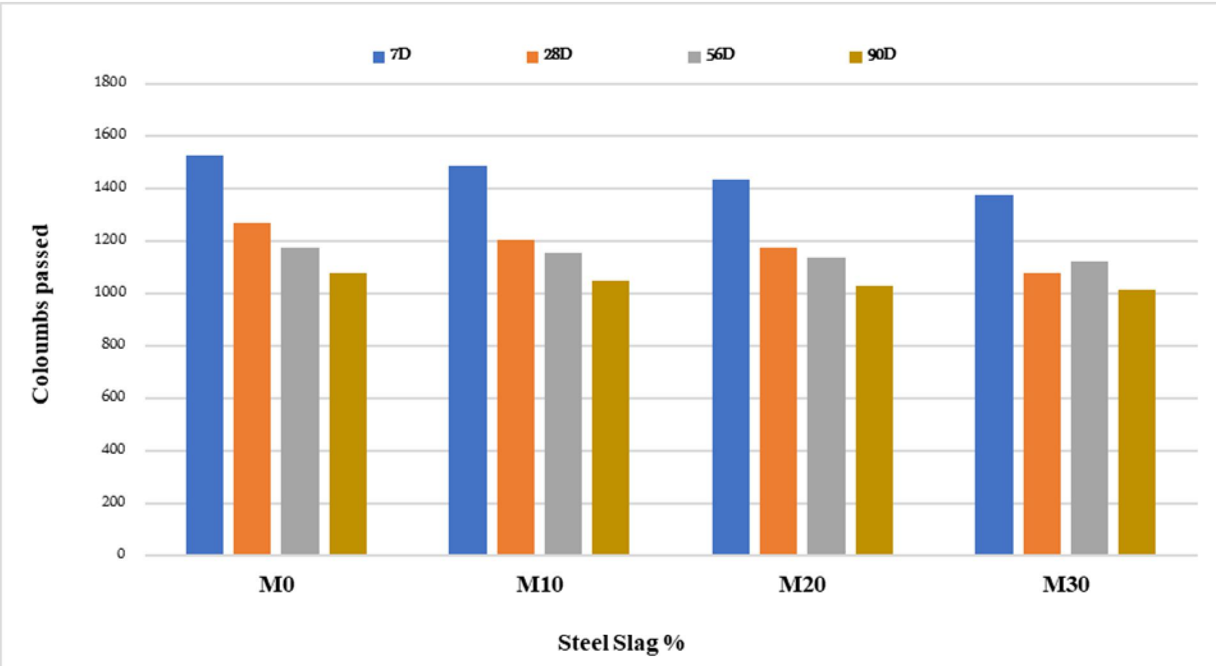

Fig. 4. Impact of steel slag on the rapid chloride permeability.

V. CONCLUSION

The following are the conclusions drawn from this investigation:

1) The compressive strength of mixtures increases with steel slag content and with age. At 28,56 and 90 days for 30% replacement level strength increases by 19%, 19% and 20% respectively over the control mix.

2) At all curing ages, compositions containing steel slag absorbed less water than control combinations. This suggests that adding steel slags to the concrete made it denser.

3) A good resistance against chloride ion penetration is provided by the steel slag concrete mixture. Comparing steel slag combinations to mixtures without steel slag, the cumulative charge that flowed through them was lower.

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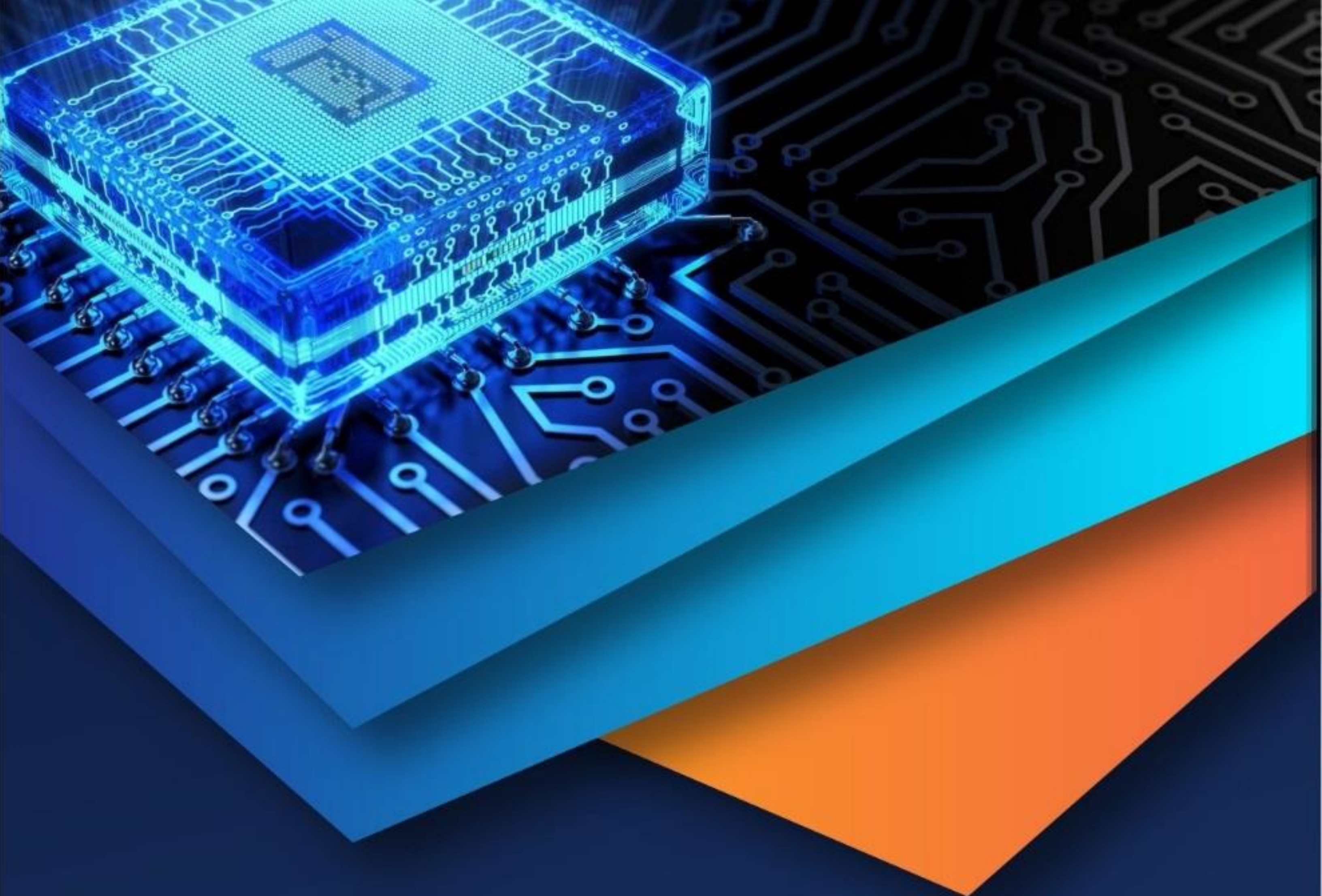

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