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High Strength Self-Compacting Concrete using Fly Ash

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Abstract — The growing use of concrete in special architectural configurations and closely spaced reinforcing bars have made it very important to produce concrete that ensures proper filling ability, good structural performance and adequate durability. Self-compacting concrete (SCC) is an innovative concrete that does not requires vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. Popularity of using self-compacting concrete (SCC) in concrete construction is increased in many countries, since SCC is effectively applied for improving durability of structures while reducing the need of skilled workers at the construction site. Nowadays, the ecological trend aims at limiting the use of natural raw materials in the field of building materials. But there is an increased interest in the use of alternative materials from various industrial wastes (by-product), which shows significant advantages in economic, energetic and environmental terms. One of such industrial wastes is fly ash which shows pozzolanic properties. This paper investigates the fresh and hardened properties of high strength self-compacting concrete (HSSCC) containing fly ash .The SCC trials were made as per EFNARC specifications at varying replacement levels (0%, 10%, 20%, 30%) of fly ash for M70 grade of concrete.

Keywords— HSSCC, Fly ash, Super Plasticizer, Rheological Parameters, Strength Properties, Nan-Su method for mix proportion.

I. INTRODUCTION

A. High Strength Self Compacting Concrete

Recently a new term “High Strength Self Compacting Concrete” is used for concrete mixture which possesses high workability, high strength, High density and low permeability. The High performance concrete called high strength self-compacting concrete has denser microstructure with low inherent “porosity” and permeability”, because of lower water cement ratio and use of mineral admixture in concrete.

With growing population, industrialization and urbanization, there is corresponding growth in the demand for infrastructure. Several studies have shown that the performance of concrete can be significantly increased by using mineral additives and specially, some industrial by products. Fly ash is one of the most effective mineral additives used in cement or concrete because of its cementations or pozzolanic properties.

Usually high strength self-compacting concrete mixtures have a high cement content that enhance the heat of hydration and may cause increased shrinkage that result in a potential of cracking and low durability. To overcome these problems cement can be replaced by pozzolanic material which can reduce heat of hydration and hence shrinkage. SCC mix always contain a powerful super plasticizer which necessary for producing a highly fluid concrete mix, while powder materials are required to maintain sufficient stability of the mix, hence reducing bleeding, segregation and settlement.

High strength self-compacting concrete having advance viscosity and workability can easily fill the mould without the necessity of using vibrators. High volume of mineral powdered is necessary for a proper self-compacting concrete design. In this study the effect of mineral admixture (Fly Ash) on the fresh and hardened properties of high strength self-compacting concrete has been investigated. Nowadays there is an increased interest in the use of alternative materials (waste) from various industrial activities, which presents significant advantages in economic, energetic and environmental terms .In this investigation High strength self-compacting concrete was prepared with fly ash using Nan-Su method for mix proportion.

B. Advantages of HSSCC

1) Saving of costs on machinery, energy, labours related to consolidation of concrete by eliminating it during concreting operation.
2) High level quality control due to more sensitivity of moisture content of ingredients and compatibility of chemical admixtures.
3) High quality finish, which is critical in architectural concrete, precast construction, as well as for cast-in-place concrete

construction.

4) Reduces the need for surface defects remedy.
5) Increase service life of formwork.
6) Industrialized production of concrete.
7) Covers reinforcement effectively. Thereby ensuring better quality cover reinforcement bars.
8) Reduction in the construction time.
9) Improvement in the quality, durability, and reliability of concrete structures due to better compaction and homogeneity of concrete.
10) Ease of placement results in cost saving through reduced equipment and labour requirement.
11) Improves working environment at construction site by reducing noise pollution.

C. Fly Ash

Fly ash or pulverized fuel ash is a residue from the combustion of pulverized coal collected by mechanical separators, from the fuel gases of thermal plants. The composition of fly ash varies with type of fuel burnt, load on the boiler and type of separation. Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Fly ash consists mostly of silicon dioxide, aluminium oxide and iron oxide and is hence a suitable source of aluminum and silicon for geo polymers. They are also pozzolanic in nature and react with calcium hydroxide and alkali to form calcium silicate hydrates (C-S-H).

The average particle size of fly ash is about 20 microns, which is similar to the average particle size of Portland cement. Particle below 10 microns provide the early strength in concrete, while particles between 10 and 45 microns react more slowly. The specific gravity of fly ash ranges between 2.0 to 2.4 depending on the source of coal. The fineness of fly ash is in the range of 250-600 m^2/kg. The development of high-strength SCC with FA is a positive contribution to the sustainability of concrete technology. The use of FA reduces the demand for cement, fine fillers and sand, which are required in high quantities in SCC. Fly Ash has been shown to be an effective addition for SCC providing increased cohesion and reduced sensitivity to changes in water content. However, high levels of FA may produce a paste fraction which is so cohesive that it can be resistant to flow. The use of fly ash in SCC mixture generally improves both its fresh and hardened properties.

Following are the advantages of using fly ash in HSSCC:

1) Reduction in global energy demand and production cost
2) Reduction in energy content
3) Enhancement in environmental sustainability (i.e. by reduction in CO^2 emissions)
4) Improves long term performance
5) Limited early heat generation
6) Improved resistance to sulphate attack

II. MATERIALS

A. Cement

Ordinary Portland cement 53 from Deccan cement Ltd. Conforming to IS: 12269 having specific gravity 3.15

B. Aggregates

All types of aggregates are suitable. The normal adopted size is ranged 16 to 20mm. Consistency of grading is of vital importance. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate and crushed stone with 16mm maximum size was used as coarse aggregate having specific gravity, fineness modulus and unit weight as given in Table I .

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TABLE I

PHYSICAL PROPERTIES OF COARSE AND FINE AGGREGATES

Sr. No.	Property	Fine Aggregate	Course Aggregate
1	Specific Gravity	2.66	2.95
2	Fineness Modulus	3.1	7.69
3	Water Absorption	1.62%	0.60%
4	Surface Texture	Smooth	--
5	Particle Shape	Rounded	Angular
6	Crushing Value	---	17.40
7	Impact Value	---	12.50

C. Fly ash

Pozzocrete (P100) is a high efficiency pozzolanic material. It is obtained by selection, processing and testing of fly ash resulting from the combustion of coal at electricity generating power stations. It is subjected to strict quality control procedures. P100 Confirms to IS: 3812 -1981. Fly ash was obtained from Dirk private Ltd., Nashik (M.S) India. The physical properties of fly ash are given in table II.

TABLE II

PHYSICAL PROPERTIES OF FLY ASH

Sr. No.	Physical Properties	Test Results
1	Color	Greyish white
2.	Specific Gravity	2.3
3.	Bulk weight (ton per m^3)	0.65 ton per m^3
4.	Loss on ignition	< 2.5%
5.	Particle size	Zero retention on 45 micron sieve less than 0.25%

D. Admixture

High range water reducing admixture called as super plasticizer are used for improving the workability for lower water-cement ratios without sacrifice in the compressive strength. Super plasticizers are essential components of HSSCC to provide necessary workability. The new generation polycarboxylated ether particularly used for SCC is Master Glenium Sky 8276 procured from BASF company has been used as super plasticizer. Its properties are given in table III.

TABLE III

BASF MASTER GLENIUM SKY 8276

Aspect	Pale yellow free flowing liquid
Relative density	1.10 ± 0.01
PH	>6
Chloride ion content	<0.2%

E. Water

Ordinary potable water available in the laboratory was used.

III. METHODOLOGY

Effect of Fly Ash on following properties of HSSCC:

A. Fresh Properties

1) Filling ability: The property of HSSCC to fill all corner of a formwork under its own weight is known as filling ability.

2) Passing ability: The property of HSSCC to flow through reinforcing bars without segregation or blocking.

3) Resistance to segregation: The property of HSSCC to flow without segregation of the aggregates.

Several methods are available to evaluate these main characteristic of HSSCC, the test have not been standardized by national or international organizations. The more common test used for evaluating the characteristics of fresh HSSCC are listed below.

a) The slump flow test
b) V-Funnel test
c) L-Box test

Fig. 1: Slump flow, V-funnel, L-box test

B. Hardened Properties

The tests used for evaluating the characteristics of hardened HSSCC are:

1) Compressive Strength Test
2) Split Tensile Strength Test
3) Flexural Strength

Fig. 2: Compressive Strength Test

Fig. 3: Split Tensile Strength Test

Fig. 4: Flexural Strength Test

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IV. MIX PROPORTIONING

A. Quantities of Materials required for 1m3 of HSSCC with Fly Ash

TABLE IV

QUANTITIES OF MATERIALS REQUIRED FOR 1M^3 OF HSSCC USING FLY ASH

Cement (kg/m^3)	Fly ash (Filler) (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
572	72	900	753	162
1	0.125	1.57	1.31	0.28

The mix proportion was based on the Nan-Su method. The mix design was carried out for M70 grade of High strength SCC with Fly ash as partial replacement of cement with a fraction of 0%, 10%, 20% & 30%.

TABLE V

MIX PROPORTIONING FOR 1M^3 OF HSSCC WITH FLY ASH

Mix	Cement (kg/m^3)	Fly ash (Filler) (kg/m^3)	Fly ash as Cement Replacement (kg/m^3)	Total Powder Content (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	W/P (0.23) (kg/m^3)	SP 0.8% (kg/m^3)
Mix-A	572	72	0.00	644	900	753	148	5.15
Mix-B	514.80	72	57.20	644	900	753	148	5.15
Mix-C	457.60	72	114.40	644	900	753	148	5.15
Mix-D	400.40	72	171.60	644	900	753	148	5.15

Mix-A: - 0% Replacement of Cement with Fly ash.
Mix-B: - 10% Replacement of Cement with Fly ash.
Mix-C: - 20% Replacement of Cement with Fly ash.
Mix-D: - 30% Replacement of Cement with Fly ash.

V. RESULT AND DISCUSSION

A. Effects on Fresh property of self-compacted concrete using Fly Ash

Fly ash was used to replace the cement content by three various percentages (0, 10, 20 and 30%). The partial replacement with Fly ash was carried out for M70 grade of concrete. It was observed that the workability tests performed in this investigation were as per EFNARC guidelines. The tests were Slump flow, L-box, and V-funnel. The acceptance criteria for HSSCC and results of workability tests on high strength SCC are shown in Table VI and VII respectively.

TABLE VI

HSSCC - ACCEPTANCE CRITERIA

Method	Properties	Range of values
Flow value	Filling ability	650-800mm
V-funnel	Viscosity	6-12 sec
L-box	Passing ability	0.8-1.0

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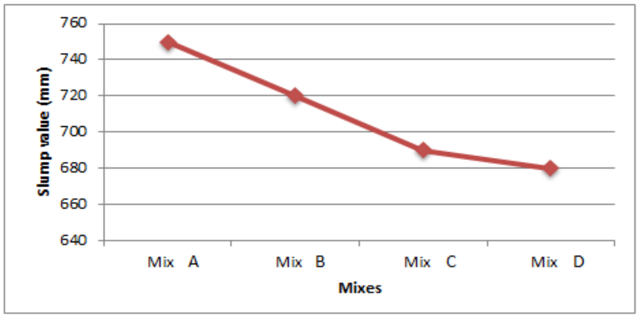
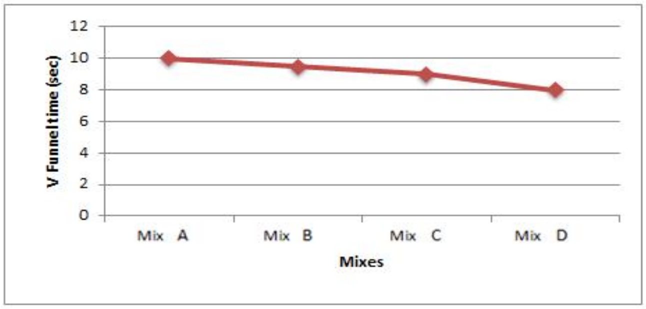
TABLE VII

TEST RESULTS FOR SELF-COMPATIBILITY

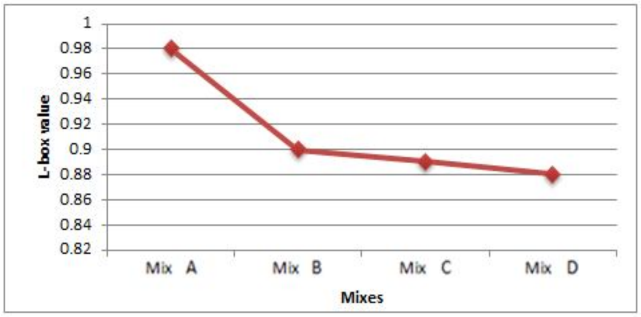
Mixes	Mix-A	Mix-B	Mix-C	Mix-D
Slump Flow Test	750	720	690	680
V-Funnel Test	10 sec	9.5 sec	9 sec	8 sec
L-Box Test	0.98	0.90	0.89	0.88



Graph 1: Slump Flow Value with Fly ash



Graph 2: V-funnel Value with Fly ash



Graph 3: L-Box Value with Fly ash

B. Effects on hardened properties of self-compacted concrete using Fly Ash

1) Compressive Strength: In order to study the effect of compressive strength, when fly ash was added into high strength SCC as replacement of cement, the cube containing different proportion of fly ash (0%, 10% , 20% & 30%) were prepared and kept for curing for 7, 28 and 90 days. It was observed that for replacement up to 20%, strength was increased and after that strength decreased. The 20% replacement level has given maximum strength but 30% replacement level has given optimum strength for M70 grade of concrete. Graph 4 shows variation of compressive strength with different mixes and age.

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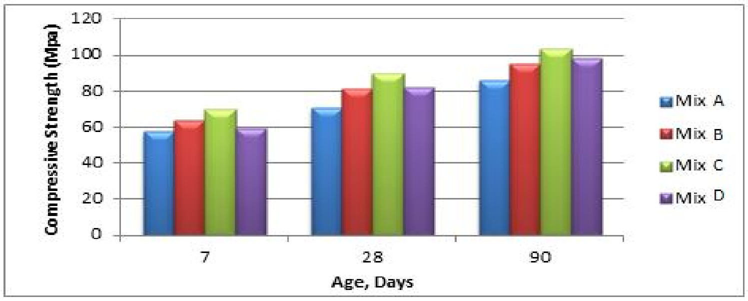
TABLE VIII
RESULTS OF COMPRESSIVE STRENGTH OF HSSCC WITH FLY ASH FOR 7, 28 & 90 DAYS

	Compressive Strength (MPa)		
Mixture No.	**7 days**	**28 days**	**90 days**
Mix-A	57.66	71.04	86.64
Mix-B	63.51	81.09	95.49
Mix-C	69.65	90.07	103.21
Mix-D	59.35	81.86	98.33

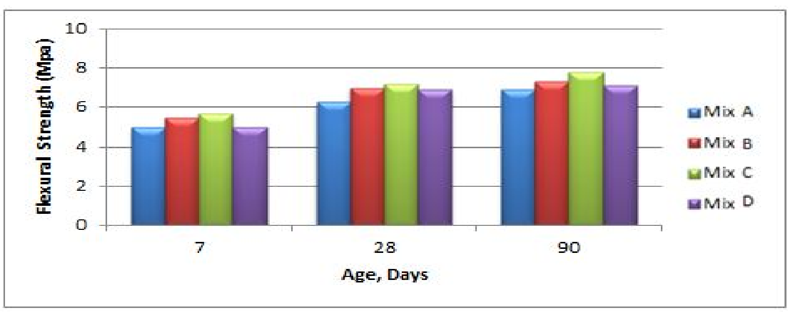


Graph 4: Variation of Compressive Strength with Age

2) *Flexural Strength:* In order to study the effect on flexural strength, when Fly Ash was added into high strength SCC as replacement of cement, the cube containing different proportion of fly ash (0%, 10%, 20% & 30%) were prepared and kept for curing for a period of 7, 28 and 91days. It was observed that for replacement up to 20%, the strength was increased and after that strength decreased. The 20% replacement level has given maximum strength but 30% replacement has given optimum strength for M70 grade of concrete. Graph 5 shows variation of Flexural strength with different mixes and age.

TABLE IX
RESULTS OF FLEXURAL STRENGTH OF HSSCC WITH FLY ASH FOR 7, 28 & 90 DAYS

	Flexural Strength (MPa)		
Mixture No.	**7 days**	**28 days**	**90 days**
Mix-A	5.0	6.3	6.9
Mix-B	5.5	7.0	7.3
Mix-C	5.71	7.2	7.8
Mix-D	4.98	6.9	7.1



Graph 5: Variation of Flexural Strength with Age

3) *Split Tensile Strength:* In order to study the effect on split tensile strength fly ash was added into high strength SCC as replacement of cement, the cube containing different proportion of fly ash (0%, 10%, 20% & 30%) were prepared and kept for curing for a period of 7, 28 and 90 days. It was observed that 20% replacement of fly ash gives the higher strength that is 3.66MPa, 4.36MPa and 5.06MPa at 7, 28 and 90 days respectively as compare to 0%, 10% and 30% replacement of fly ash. The 20% replacement of fly ash gives optimum strength but 30% replacement gives optimum strength for M70 grade of concrete. Graph 6 shows variation of split tensile strength with different mixes and age.

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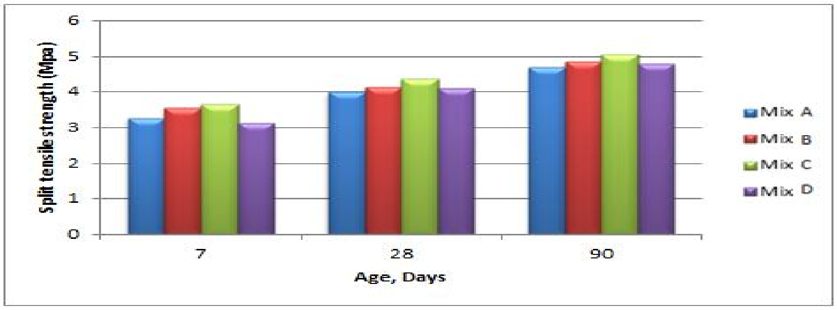
TABLE X

RESULTS OF SPLIT TENSILE STRENGTH OF HSSCC WITH FLY ASH FOR 7, 28 & 90 DAYS

Split Tensile Strength (MPa)			
Mixture No.	7 days	28 days	90 days
Mix-A	3.27	4.0	4.7
Mix-B	3.56	4.15	4.85
Mix-C	3.66	4.36	5.06
Mix-D	3.12	4.10	4.80



Graph 6: Variation of Split Tensile Strength with Age

VI. CONCLUSIONS

A. The use of mineral admixtures improves the performance of high strength SCC in fresh state and also avoids the use of VMAs.

B. HSSCC with fly ash has exhibits satisfactory results in workability, because of small particle size and more surface area.

C. At the water/ cement ratio of 0.23, slump flow test, V-funnel test, and L-Box test results were found satisfactory, i.e. passing ability, filling ability and segregation resistance are well within the limits as per the EFNARC.

D. The SCC mixes with the addition of 30% Fly ash gives an optimum strength for M70 grade

E. The results of hardened properties of HSSCC such as compressive strength, flexural strength and split tensile strength have shown that higher strength is obtained.

F. The compressive strength of M70 grade of concrete was monitored up to 90 days and has shown an increase in 18 to 20% over its 28 day strength. Similarly the split tensile strength and flexural strength was increased by 12 to 14% compared to the 28 day strength.

G. Use of fly ash in concrete can save the coal and thermal industry disposal costs and produces greener concrete for construction.

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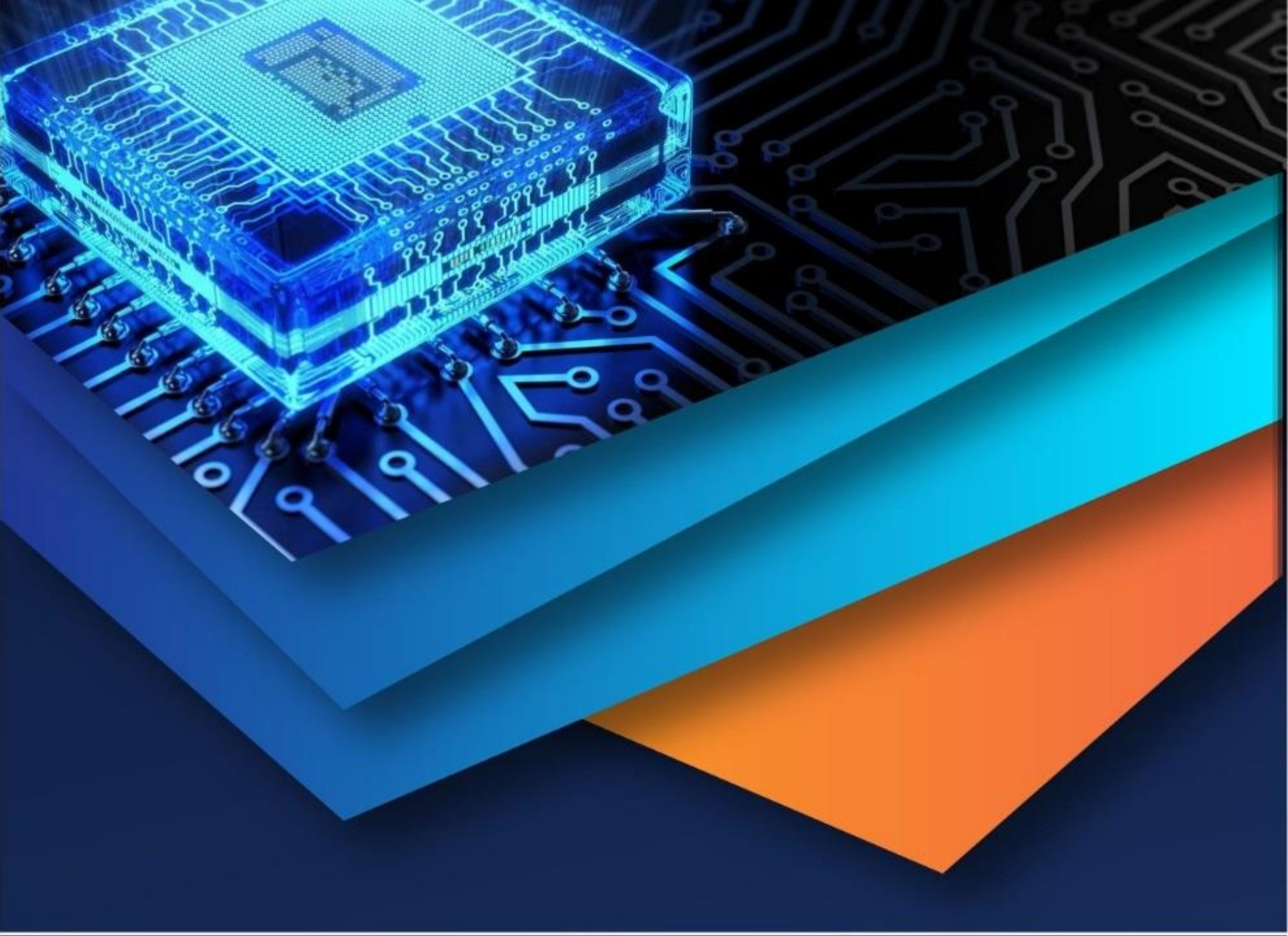

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