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Appropriate Selection of Materials for Making Durable Self Compacting Concrete for Using in Underground Structures

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***Abstract:** Selecting appropriate and suitable ~~of~~ materials plays an important role in concrete mix design to meet the general requirements of European guidelines for self-compacting concrete and to ensure a balance between deformability and stability. The type of selected materials and the ratios of concrete ingredients can be affected by the fresh and hardened properties of the concrete. In the contract agreement of the Mumbai Metro underground project, the technical specifications clearly state the values of limits set for achieving the durability parameters for the life of 120 years of the structure. According to the requirement of the site conditions Self-compacting concrete was designed with available material, special material like Ultra GGBS- Alccofine 1203 and crystalline waterproofing admixture. Self-compacting concrete is superior concrete than the traditional concrete with high workability, no segregation, no bleeding, and it is also suitable for use in structures with long-distance pumping in the instant case i.e., more than 120-meter length in Underground NATM tunnels, cross-passages, and the concrete structure of the underground metro station box. The paper presents a comparison between concrete mix designs and their achieved test parameters suitable for the contract specification of Mumbai metro underground project*

***Keywords:** Self-compacting concrete, Concrete Mix Design, Fresh & Hardened Properties of concrete, Durability, Application in the structure*

I. INTRODUCTION

The Mumbai Metro underground project is designed for 120 years of life of concrete structures. In the agreement the technical specifications clearly state the values of limits set for achieving the durability tests parameters like RCPT, Water permeability, moisture moment, drying shrinkage etc. Appropriate and suitable selection of supplementary cementitious materials such like GGBS, Ultrafine GGBS-Alccofine, Crystalline growth admixture etc., is required for improving durability, decreasing permeability, surface finish ability, and improving the overall hardened properties of concrete. Rheological properties of Self-compacting concrete are advanced than traditional normal slump concrete and the hardened properties of concrete are the same as traditional normal slump concrete [1]. Self-compacting concrete is suitable for a fast rate of concrete placement, with faster construction times and ease of flow around dense reinforcement without vibration or a little bit of surface tamping to get a better surface finish. It ensures good homogeneity, pumping ability, best surface finish, consistent concrete strength, and durability of the concrete structure. “The rheology of concrete describes the flowability, mobility, and stability of fresh concrete. The hardened concrete properties like compressive strength, flexural strength, split tensile, etc., are specifically struck by the composition of concrete ingredients. In the Mumbai region, river sand is not available and therefore construction industries are totally depending on crushed stone sand. According to site requirements, only Self-compacting concrete was suitable due to long-distance pipe pumping and congested reinforcement in the structure. Hence Self-compacting concrete was developed by conducting several numbers of concrete mix trials and found that appropriate selection of materials is required for optimizing concrete mix design with low cementitious content and for achieving standards requirements for flowability by slump flow, and sieve segregation resistance tests as per specification mentioned in European standard [3]. Chemical admixtures i.e., high-performance superplasticizers required for optimized the cementitious content and minimize the W/C ratio for production of Self-compacting concrete [4].Addition of special material like, Ultrafine GGBS (easily available in Indian market at manufacturer) and Crystalline growth waterproofing admixture helps for making economical and durable concrete with less cementitious contents.

II. CONCRETE INGREDIENTS

A. Cement

OPC 53 Grade cement of M/s Ultratech is used. Physical & Chemical tests results values are as given in Table 1 & 2 [1].

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B. GGBS

Ground granulated blast furnace slag (GGBS) of M/s JSW obtained from Pen, Raigad, Maharashtra, India. The physical and chemical properties of GGBS are given in the Table 1 and Table 2, respectively [1].

C. Ultrafine GGBS -Alccofine

Ultrafine GGBS (UFGGBS) commercially available as Alccofine-1203 is a low calcium silicate-based mineral additive which is generally used in lieu of of silica fume in high-performance concrete [5] due to lower cost and easy availability in Indian market. UGGBS- Alccofine 1203 is a slag based SCM having ultra-fineness with the optimized particle size distribution [6].

Table 1. Physical Properties of Cement, GGBS and UGGBS-Alccofine 1203 [1]

Physical Properties	Cement (OPC-53)	GGBS	UFGGBS-Alccofine 1203
W-M-Y	14-04-2021	14-04-2021	14-04-2021
Specific Gravity	3.13	2.9	2.92
Fineness(m2/kg)	288.2	482.5	2857
Particle size, micron D_{10} D_{50} D_{90} D_{95}	-	-	1.6 4.5 9.2 10.8
Normal consistency (%)	29.0%	-	-
Soundness (Autoclave) (%)	0.020	0.020	-
Setting time (min.) Initial Final	130 215	-	-
Strength (N/mm2) 3days 7days 28days	36.5 46 69		
Slag Activity Index, % 1. At & 7 days 2. At & 28 days	-	72.8 85.4	92.5 108.4

Table 2. Chemical Properties of Cement. GGBS and UFGGBS-Alccofine 1203 [1]

Chemical Properties	Cement	GGBS	UFGGBS-Alccofine 1203
Loss on ignition, % by mass	2.98	0.10	0.32
Glass content, % by mass	-	87.24	86.92
Magnesium Oxide (MgO)	1.76	0.17	7.56
Total Sulphur (SO3), % by mass	2.9	0.25	0.22
Insoluble residue, % by mass	0.93	-	-
Alkali Content, % by mass	0.22	0.2	0.22
Total Chloride content, % by mass	0.017	0.011	0.015

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"Ordinary Portland Cement OPC-53 grade, GGBS and UFGGBS-Alccofine are conformed to Indian Standard Specifications IS: 269-2015, IS 16714-2018and IS 16715-2018" [7] [8] [9]

D. Chemical admixtures and crystaline growth waterproofing admixture

"Poly carboxylic ether-based superplasticizer admixture brand name Sika ViscoCrete 5138 M/s Sika are used to bring out the required water reduction and maintain the dispersing effect during the time required for transportation and placement at the site.Sika ViscoCrete 5138 is a high-performance superplasticizer (H.P.S) and specially developed for high workability, flowable, and self-compacting concrete mix. In the product datasheet of Crystalline growth waterproofing admixture brand name SIKA 101 H of M/s Sika. The use of crystalline waterproofing admixtures (CWA) has the potential of improving the durability and reducing the permeability of concrete structures especially those exposed to environments like soil face structures of underground structures" [10]

Table 3. Physical Properties of high-performance superplasticizer and crystalline admixtures

Characteristics	*(H.P.S) Product Name- Sika ViscoCrete 5138*	*C.W.A-Product Name Sika 101 H*
Density (kg/lit)	1.125	1.3
Appearance	Brown	Gray Powder
pH	6.43	-
Dry material content	42.49	-
Chloride (as Cl), % by Mass	< 0.01	< 0.01
Dosage (%) by mass of cement	0.2 to 2	0.8 to 1
Permeability to water vapor at 3 bar pressures	-	Impermeable
Initial set time at 30 deg temperature	-	40 minutes

"Concrete admixtures are conformed to Indian Standard Specifications I S: 9103:1999" [11] and Crystalline Waterproofing admixture confirmed to manufacturer technical product data sheet.

E. Aggregates

In the Mumbai region, Maharashtra, India, river sand is not available, and therefore construction industries are totally depending on manufactured sand.

Coarse aggregate and Manufactured sand are obtained from the nearest source i.e., Kunde vahal, Panvel, Raigargh, Maharashtra. Fine aggregate- M/sand and coarse aggregate are conformed to Indian Standard Specifications IS: 383-2016 [2].

Table 5 shows the physical properties of the coarse and fine aggregates.

Table 5. Physical Properties of Coarse and Fine Aggregates [1]

Physical tests	*Coarse aggregate*	*Fine aggregate - Crushed stone sand*
Specific gravity	2.78	2.75
Water Absorption (%)	1.89	2.91
Bulk density (kg/m3)	1470	1730

III. CONCRETE MIX DESIGN

"The concrete mix is designed as per absolute volume method according to the Indian standard -Concrete mix proportioning Guidelines to meet environmental exposure conditions of Mumbai city, Maharashtra i.e., considered a severe condition" [12]. "The properties of the concrete ingredients differ from one state to another state of the same country, and it is totally depending on the actual environmental exposer condition of the site and quality of available concrete ingredients for making suitable concrete mix" [13]. Concrete mix compositions are presented in Table 6

Table 6. Abstract of all trial mixes which were conducted for finalizing the suitable Self-compacting concrete M40 Grade for Mumbai Metro project. Total 8 numbers of concrete trials were conducted using different kinds of materials and found two concrete mixes are matching the requirement of self-compacting concrete as per the requirement of European guideline and durability parameters of the technical specification of contract agreement of underground metro projects.

Trial Mix No	*Cement (Kg/m3)*	*GGBS (Kg/m3*	*UGGBS-Alccofine 1203 (Kg/m3)*	*Powder (Kg/m3)*	*W/P Ratio*	*C.A (Kg/m3)*	*F.A Crushd Sand (Kg/m3)*	*C.A/FA ratio (%)*	*Water (Kg/m3)*	*H.P.S (Kg/m3)*	*C.W.A (Kg/m3)*	*Remarks*
TRA	315	165	-	480	0.31	1049	816	56/44	150	7.2		Not Satisfactory
TRB	330	170	-	500	0.3	999	883	53/47	150	9.0		Not Satisfactory
TRC	350	170	-	520	0.31	930	851	52/48	165	7.02		Not Satisfactory
TRD	360	180	-	540	0.31	1029	773	57/43	167	8.1		Not Satisfactory
TRE	360	180	-	540	0.30	927	848	52/48	160	8.64		Not Satisfactory
TRF	360	180	-	540	0.30	927	848	52/48	160	8.64	5.4	Not Satisfactory
TR1	360	200	-	560	0.32	770	972	44/56	179	8.1		Satisfactory
TR2	330	200	20	550	0.32	778	981	44/56	176	7.7	5.50	More satisfactory

A. Test Procedures

"Self-compacting concrete is able to flow under its self-weight without segregation, bleeding without vibration and these behaviors of concrete can be ensured by Flowability tests, and Sieve segregation resistance tests of concrete to determine the flowability, passing ability, and segregation resistance of Self -compacting concrete according to BS: EN 12350 Part 8, 9, 10, 11, and 12" [14]

Fig.1 Slump Flow Test

Fig.2 Funnel test

Fig 3. L-Box test

Fig 4. U- Box Test

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Fig 5. Sieve Segregation resistance Test

Comparison of fresh concrete and hardened concrete tests of concrete trial mix no - TR 1& TR 2 revealed that there was large difference in the test values of both fresh and hardened concrete for the two mixes; and this may be due to improvement in pore structure and pore size due to use of UFGGBS (Alccofine 1203) and crystalline waterproofing chemical admixture.

Table 7. Comparative statement for fresh concrete properties of Self-compacting concrete M40 Grade, Trial Mix no TR 1 & TR 2 – Trials for SCC were conducted for design time 3 hours and obtained results are presented below.

Mix	*Slump flow (mm)*	*T500 (sec)*	*V-funnel T f (sec)*	*V-funnel T5min (sec)*	*L-box Blocking ratio(H2/H1)*	*U-box Difference (mm)*	*Segregation Resistance*	*Remarks*
TR1	*540*	*5*	*21*	*32*	*0.75*	*32*	*7.9*	*Results are satisfactory*
TR2	*580*	*5*	*15*	*21*	*0.8*	*19*	*7.5*	*Results are found more Satisfactory*

Table 8. Comparative statement of Hardened Concrete Test results for self-compacting concrete trial mix no- TR 1& TR 2.

Sl. NO.	*Test Description*	*Acceptance Requirement as per contract specification for Lab trial*	*TR-1 Results obtained*	*TR-2 Results obtained*
1	Compressive Strength at 28 days	Target strength at the time of trial – 48.25 N/mm2	48.34 N/mm2	60.22 N/mm2
2	RCPT	700 Coulombs (during lab trial)	782 coulombs	652.5coulombs
3	Water Permeability	10 mm	6 mm	5.7 mm

4	Flexural strength	> 0.7 √fck = 5.42 N/mm2	6.25 N/mm 2	7.3 N/mm 2
5	Split tensile strength	> 0.5 √fck = 3.87 N/mm2	5.01 N/mm 2	5.62 N/mm 2
6	Drying Shrinkage	0.05 % (Max)	0.026 %	0.009 %
7	Moisture Moment	0.03 % (Max)	0.018 %	0.011 %
8	Chloride content	0.5 % (Max)	0.34 %	0.32 %
8	Sulphate content	3.7 % (Max)	1.87 %	1.88 %

It has been observed that trial mix no- TR 1 even though has achieved the maximum parameters of acceptance criteria of the underground metro project contract specifications in the lab trials; some values observed very close to the requirements, and some were less than the required values like passing ability values of L box, U-box, compressive strength and RCPT values of the lab trial. Hence obtained results values were compared and found trial mix no- TR 02 is achieving all the acceptance criteria of the contract specified limits values and the same concrete mix is selected for working concrete at site.

Table 9. Selected trial Mix no -2 for Self-compacting concrete M40 Grade (10 MSA) [1]

Cementitious (Kg)			*Water (Kg)*	*Fine Aggregate Crushed Sand (kg)*	*Coarse aggregate (10 MSA) (Kg)*	*H.P.S (Kg)*	*C.W. A*
`Cement	GGBS	UFGGBS	176	981	778	7.7	5.5
330	200	20					

Table 10. Test Results of Selected trial Mix no -TR 02 for Self-compacting concrete M40 Grade in Laboratory [1]

Test Observation	*Property*	*Acceptance Limits as per European Guideline*	*Initial*	*1hr*	*2hrs*	*3 hrs.*
Slump-flow class SF1	Flowability/Filling Ability	≥ 520mm, ≤ 700mm	660	650	610	580
T500	Viscosity Flowability	between 3-7 Sec	4	4	4.5	5
V5min	viscosity Flowability	---	15	18	22	21
V Funnel Tv VF 2	Viscosity Flowability	≥ 7S, ≤ 27s	11	13	14	15
L Box (H2/H1)	Passing Ratio	≥ 0,75	0.85	0.85	0.82	0.8
U Box Deference	Height difference	30 mm Max	0	14	18	19
Sieve Segregation	Segregation Resistance	< 23 %	9.5	9.2	8.4	7.5
Ambient Temperature			26.5	27.5	28.2	29.4

Mix proportion of selected mix design TR 02 implemented at the site for Tunnel NATM concrete and NATM cross passages and a total of 32508 cum concrete quantity was executed from 25th Feb 2020to 30th July'2021. "The flowing ability and passing ability of concrete mix is checked according to conformity criteria for the properties of Self-compacting concrete at the site and observed results are as below" [3].

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Table 11. The Average Test Results of Site executed Self-compacting concrete mix during concreting (Samples taken for tests- 5118 numbers)

Test Observation	*Property*	*Acceptance Limits as per European Guideline*	*Results obtained at Batching Plant*	*Results obtained (around 1 to 2 hrs after batching time)*	*Minimum-Maximum Values Observed at site*	*Remarks (Comparison with 2 hrs results of TR 9)*
Slump-flow class SF1	Flowability/Filling Ability	≥ 520mm, ≤ 700mm	630	560	520 – 610	-40 mm than TR 2
T500	Viscosity Flowability	between 3-7 Sec	4	6	4-7	-1.5 sec than TR2
V5min	viscosity Flowability	---	-	-		Not Taken
V Funnel Tv VF 2	Viscosity Flowability	≥ 7S, ≤ 27s	-	-		Not Taken
L Box (H2/H1)	Passing Ratio	≥ 0,75	-	-		Not Taken
U Box Deference	Height difference	30 mm Max	-	-		Not Taken
Sieve Segregation	Segregation Resistance	< 23 %	-	-		Not Taken
Concrete temperature		26.5	27.5	28.2	26-29	- 1.2 deg at site

All the parameters of tests are not checked at the site since shifting of all testing equipment's is not possible at the point of concreting at the site, but slump flow, T 500 mm checks, and the temperature has been measured for 5118 transit mixers and their average values are cited in above table

Sample of concrete cubes of the working structures were taken as per requirements of contract technical specifications and results of 7 days, 28 days, and 56 days are presented in the table below.

Table 12. The Compressive Strength of site casted cubes for M40 grade Self-compacting concrete (in N/mm2) [1]

SI. No	Age of casted Cubes	No. Samples	Avg. Compressive Strength of Samples in N/mm2	% Of Compressive Strength Gaining	Standard Deviation in N/mm2	% Coefficient Of Variation
1	7 days	8	40.14	66.66	1.82	3.03
2	28 Days	35	60.22	100		
3 56 days 8 65.09	108.08					

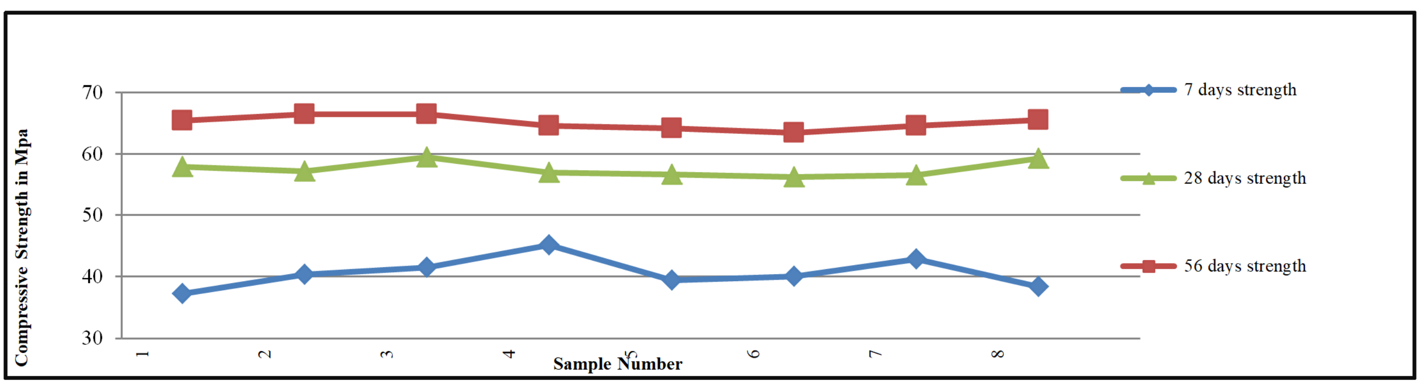

Fig 8. Strength of site casted cubes for 7 days, 28 days and 56 days

IV. CONCLUSIONS

1) Selecting appropriate and suitable concrete ingredients and optimization of powder content in concrete mix, helps to improve the results of flowability, passing ability in the structure and for best results of durability parameters of the concrete.
2) Self-compacting concrete can be easily placed for long distance pumping and in congested locations due to dense reinforcement without vibration during the placement.
3) Crystalline waterproofing admixture plays effective role for reducing permeability and to increase durability of the structures.
4) Low values of Water permeability (WPT) and RCPT were due to addition of UFGGBS (Alccofine) and partly may be due to use of crystalline waterproofing admixture.
5) Since SCC allows the use of more powder enabling use of various SCM's selecting appropriate and suitable mineral admixtures in various forms combined with high level PCE's and crystalline waterproofing chemical admixture can yield a very low permeability Concrete with high durability and sustainability with longer service life.

A. CRediT authorship contribution statement

Sandip Sonule: Acquisition of data; Analysis and interpretation of data; On site execution; Drafting of manuscript
H. Jayarama: Review and editing of the manuscript; Funding acquisition; Permission and approval
Partha Sarath Ojha: Review and editing of manuscript
C.M Jadhav: Review and editing of manuscript; Funding acquisition; Permission and approval
Dr. K.C Tayade: Analysis and interpretation of data; Review and editing of manuscript.

B. Compliance with ethical standards

Conflict of interest - On behalf of all authors, the corresponding author states that there is no conflict of interest.

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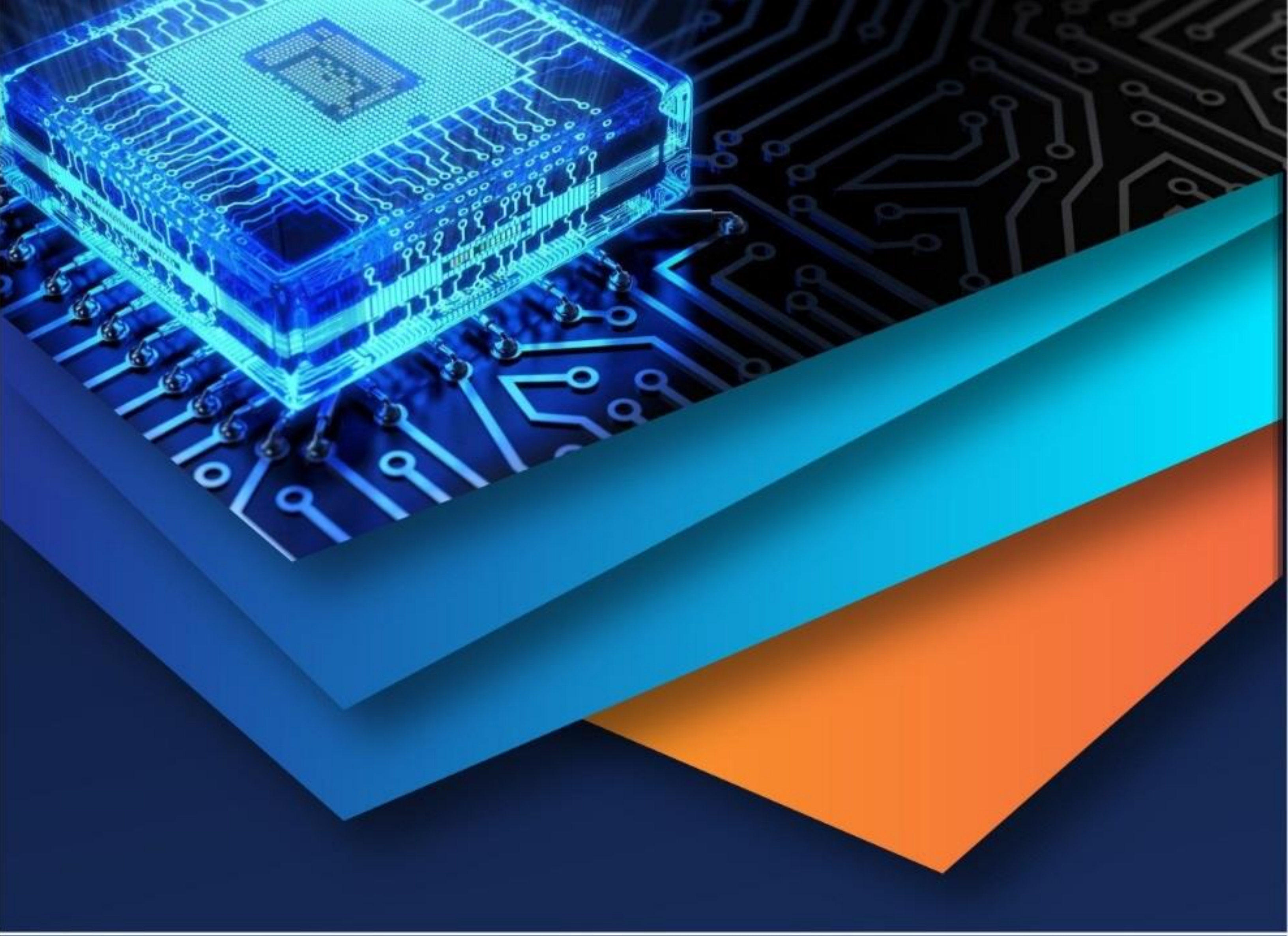

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