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Mix Design of Self-Compacted Concrete as Per Indian Standard – A Case Study

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Abstract: Guidelines for mix design of self-compacting concrete are suggested in the literatures but there is no specific method suggested as such. An attempt is made to design the self-compacting mix by using Bureau of Indian Standard Guidelines for mix. This has been achieved by using various PPC, silica fume and with appropriate dose of superplasticizer.
Keywords: Self-compacting concrete, Superplasticizer, Paste content, Particle shape

I. INTRODUCTION

Self-compacting concrete (SCC) is a highly flowable, yet stable concrete that can spread readily into place, fill the formwork, ability to flow and fill densely reinforced or geometrically complicated structural elements, without segregation or excessive bleeding and compacted at maximum possible density under its own weight. SCC has many advantages over conventional concrete: (1) eliminating the need for vibration; self-finished (2) decreasing the construction time and labor cost; (3) reducing the noise pollution; (4) improving the interfacial transitional zone between cement paste and aggregate or reinforcement; (5) decreasing the permeability and improving durability of concrete, and (6) facilitating constructability and ensuring good structural performance. The SCC mix design seems to approach into various formulas, but it is describing onto common base referring to the fresh concrete rheological properties and to particle size modeling starting with the packing of all aggregates at a minimal inter particle voids to fill with optimal volume of paste [1]. Mix design of SCC in this paper was designed for a hydroelectric project to be used in gate groove.

II. MATERIALS

A. Cement

Portland Pozzolana Cement was used for the mix design of SCC. Physical suitability test of two contemporary cements has been done and tabulated as follows:

Table 1 Test result of cement samples

Suitability Tests	PPC-1	PPC-2
Normal consistency (%)	29.5	31.5
Setting Time (in minutes)		
Initial	130	185
Final	152	215
Soundness (in mm)	1.2	0.98
Fineness by residual, %	1.6	0.8
Comp Strength (in MPa)		
3 days	24.60	29.28
7 days	31.70	35.78
28 days	45.40	51.78

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B. Silica Fume

Silica fume (SF-I) was used as mineral admixture to improve permeability and viscosity of the SCC. Physical suitability test of silica fume sample had been done and tabulated below:

Table 2: Physical test results of silica fume sample

Parameters (% by mass)	Test values	Limits as per IS : 15388: 2003 (Reaffirmed 2017)
Moisture Content, %	0.24	3 % max.
Loss on Ignition, %	3.61	4 % max.
Silica, SiO_2 (%)	91.34	85 % min.
Total alkalis as Na_2O, % by wt.	0.71	1.5 % max.

C. Coarse Aggregate

Geologically rock was classified as Biotite–Schist and Micaceous–Schist fine to medium grained texture, poorly foliated and partially weathered. The major mineral constituents are quartz, biotite and muscovite. Good abrasion resistant, hard and compact rock. Maximum size of aggregate used in SCC mix was 20 mm. Suitability tests of coarse aggregates were conducted as per IS 2386 and confirming the IS 383-2016 [2] and the results are tabulated below

Table 3: Physical test results of coarse aggregate samples:

Test conducted	CA-I	CA-II
Sp Gravity	2.69	2.66
Water Absorption, %	0.70	0.78
Abrasion Value, %	29.32	29.14
Impact Value, %	19.39	18.32
Crushing Value, %	20.13	19.96
Elongation& Flakiness Indices, %	25.49	23.52

D. Fine Aggregate

The project was scarce of natural river sand. Hence, crushed sand was used in the project and it was manufactured from the rock available in rock quarry. Suitability tests of crushed fine aggregates were conducted as per IS 2386 and tabulated below. Both the crushed sands are confirming the specification requirement as per IS 383:2016 [2].

Table 4: Physical test results of fine aggregate samples

Test conducted	FA-I	FA-II
Sp Gravity	2.64	2.64
Water Absorption, %	1.45	1.29
Fineness Modulus	2.75	2.73

Table 5: Grading of Crushed Sand

Sample No → Sieve ↓	S-1	S-2	Criteria Limits for Zone-II
10 mm	100	100	100
4.75 mm	98.4	98.2	90-100
2.36 mm	82.6	82.2	75-100
1.18 mm	59.0	59.4	55-90
600 µm	45.4	44.8	35-59
300 µm	27.2	28.0	8-30
150 µm	12.6	14.8	0-20
<75 µm	5.4	6.6	-
FM	2.75	2.73	-

From the above table it can be seen that the FM varies from 2.75 to 2.73. The corresponding graphs for the gradation of S-1and S-2 are presented in fig 1.0 and fig 2.0. Upper and lower limits of the graph represents the boundary limits of crushed sand Grading Zone-II as per IS 383-2016[2]. Gradation curve of both the crushed sand was almost same though the source of the quarry was different. However manufacturing unit was same.

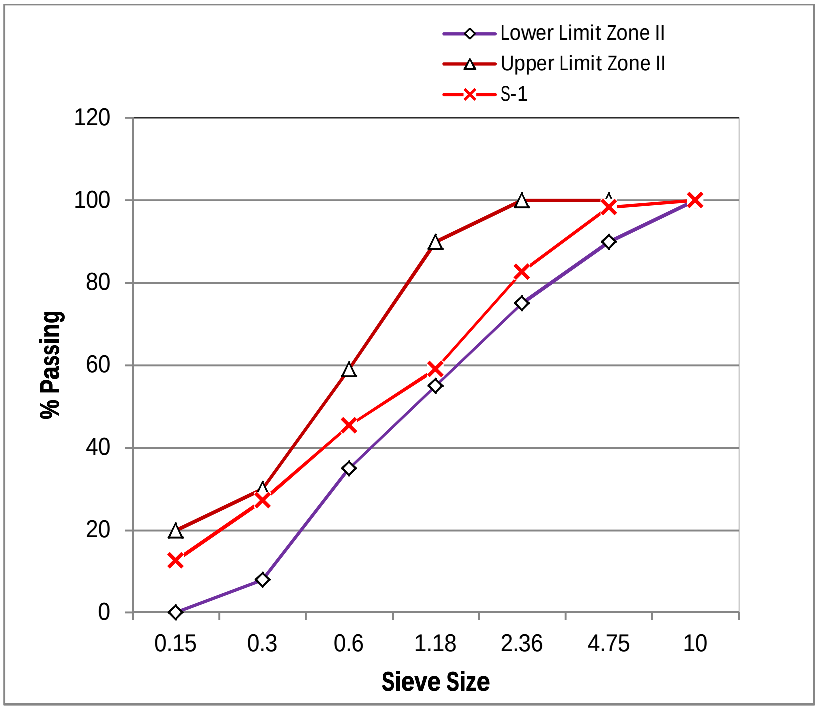


Fig 1 Gradation Curve

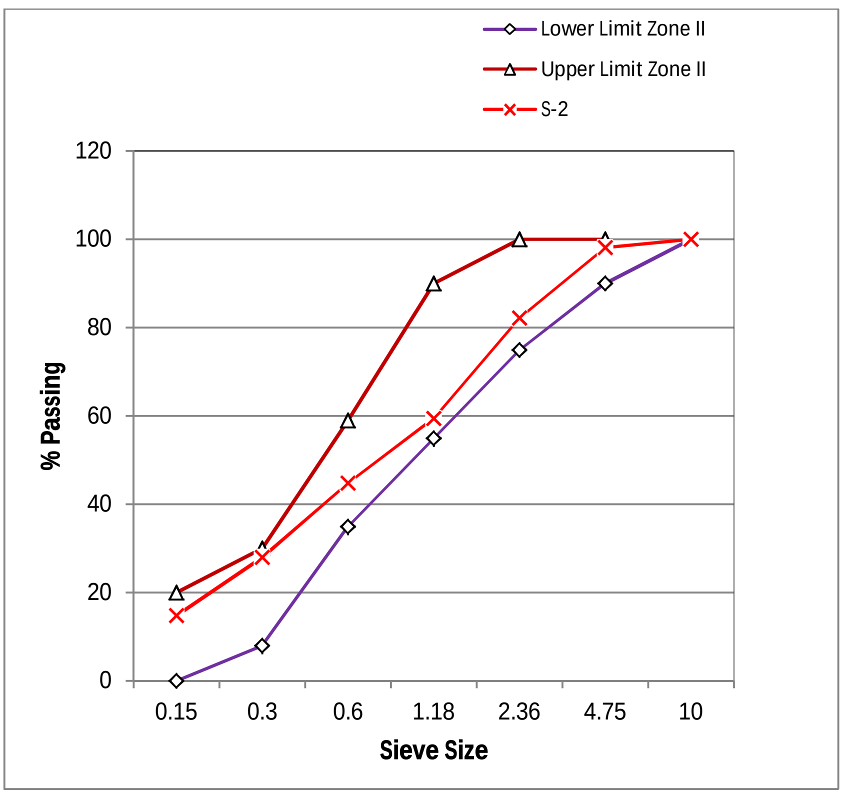


Fig 2 Gradation Curve

E. *Water*

Bore well water (W-1) at laboratory and river water (W-2) at site were used for mixing in SCC and their test parameters are as tabulated below. Both the water samples are meeting the criteria limits of IS 456:2000 (Reaffirmed 2016).

Table 6: Test result of Bore Well and River water samples

Sample no → Parameters ↓	W-1	W-2	Limits as per IS 456:2000 (Reaffirmed 2016) [3]
Acidity : ml of 0.02N NaOH required to neutralize 100 ml of water sample using Phenolphthalein as an indicator	2.30	1.6	5.0 ml Max.
Alkalinity : ml of 0.02N H_2SO_4 required to neutralize 100 ml of water sample using mixed indicator	22.00	22.5	25.0 ml Max.
pH value	7.65	7.96	Not less than 6.0
Chloride (as Cl^-), mg/l	101.53	5.0	2000 mg/l for concrete not containing embedded steel and 500 mg/l for concrete containing embedded steel
Sulphate (as So_4^{--}), mg/l	44.13	8.99	400 mg/l
Suspended solids, mg/l	10.00	78.70	2000 mg/l
Inorganic solids, mg/l	663.00	333.00	3000 mg/l
Organic solids, mg/l	59.00	32.00	200 mg/l

F. *Superplasticizer*

Commercially availability of superplasticizer are many such as Glenium, Structuro, viscocrete, muraplast etc. For this work Sika Viscocrete-2004NS was chosen after numbers of trials to check the compatibility with cement at site and it was confirming to IS 9103-1999 (Reaffirmed 2018)[4]. Chemically it was modified poly carboxylate based superplasticizer capable to reduce high range of water for very high workability.

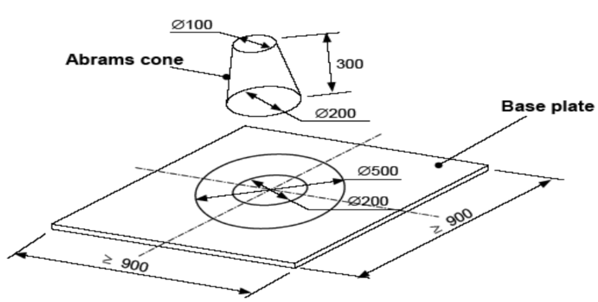
III. REQUIREMENTS AND TESTS OF SCC

The below mentioned four parameters required for SCC as per IS: 10262-2019 [5]

1) Filling ability (Flowability) - 760 – 850 mm
2) Passing ability (Flow through congested reinforcement) - 0.8 - 1
3) Segregation resistance (Homogeneity without segregation) - less than 15 %
4) Viscosity (Resistance to movement) - less than equal to 8 seconds.

A. *Test Procedure*

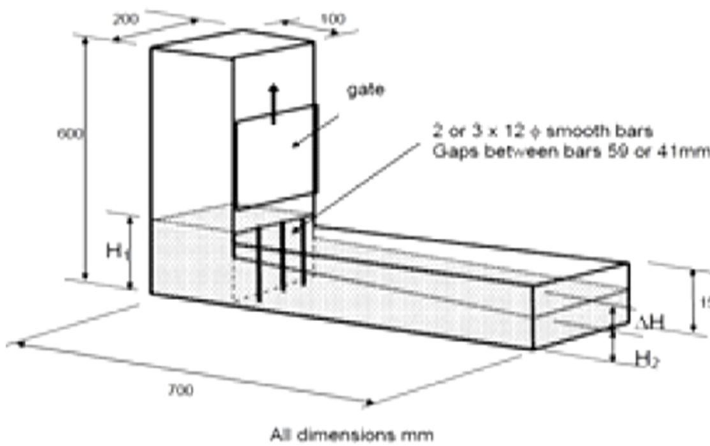
1) *Slump Flow Test:* The basic equipment used is the same as for the conventional slump test. The test method differs from the conventional one by the fact that the concrete sample placed into the mould is not rodded and when the slump cone is removed the sample collapsed [6]. The diameter of the spread of the sample is measured, i.e. a horizontal distance is determined as opposed to the vertical distance in the conventional slump test. It can give an indication as to the consistency, filling ability and workability of SCC. The SCC is assumed of having a good filling ability and consistency if the diameter of the spread reaches values between 550 mm to 850 mm. Schematic diagram of slump flow arrangement as shown below:



2) *L-Box Test:* The L-Box test evaluates the passing ability of SCC in a confined space. The L-Box is composed of vertical arm and horizontal arm. The concrete flow from the vertical arm through reinforcing bars and into the horizontal arm of the box. Once the test is completed, the ratio of the heights of the concrete at the two ends of the box, called the blocking ratio (BR), is used to evaluate the passing ability with obstruction as

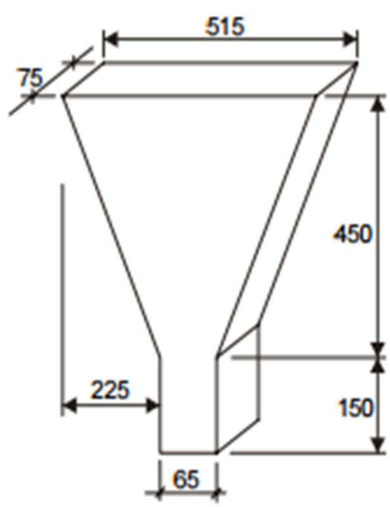
$$BR = H2/H1$$

Schematic diagram of L-Box arrangement as shown below:



This ratio shall lie between 0.8 to 1.0.

3) *Segregation Resistance:* This test is to check the ability of fresh concrete to remain homogeneous in composition while in its fresh state. Fresh concrete sample is allowed to stand for 15 min and any separation of bleed water is to be noted. The top part of the sample is then poured into a 4.75 mm sieve. After 2 minutes, the weight of material which has passed through the sieve is recorded. The segregation ratio (SR) is then calculated as the proportion of the sample passing through the sieve.
4) *V-Funnel Test:* Viscosity of the self-compacting concrete is obtained by using V-funnel where maximum size of the aggregate to be used is 20 mm. The time for the amount of concrete to flow through the opening is measured. If the concrete starts moving through the opening, it means that the stress is higher than the yield stress; therefore, this test measures a value that is related to the viscosity. If the concrete does not move, it shows that the yield stress is greater than the weight of the volume used. The amount of concrete needed is about 12 liters. Schematic diagram of V-Funnel arrangement as shown below:



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IV. MIX CONSIDERATIONS FOR SCC

For SCC shape and size of aggregates play crucial role apart from paste content and super plasticizers. Particles shape of the crushed sand was cuboidal and having good amount of fraction less than 0.125 mm size. Shape of the coarse aggregate was bit flaky. For M40A20 grade SCC mix water cementitious ratio was 0.4, maximum size of the aggregate 20 mm, paste volume 37.54 %, water to powder ratio 0.92, volume of fine aggregate 57.75 %, Sika Viscocrete-2004 NS @ 1.14 % and silica fume @ 5% by weight of cement was used. Observed compatibility test results are tabulated below

Table 7: Verification tests on fresh SCC mix

Tests	Observation	Limits
Slump Test	710 mm	For slump flow class 3 (SF3) – 760 mm – 850 mm)
L-Box Test	0.926	0.8 – 1.0
Wet sieving	12 %	Segregation resistance class 1 (SR2) – 15% <
V-Funnel Test	8.0 seconds	Viscosity class 1 (V1) - ≤ 8 seconds

Proposed Mix as below

Table 8: Proposed Mix for SCC

Description of Mix	Mix Proportion M40A20 for 1 m^3 SCC
Target Strength	48.25 MPa
Water Cementitious Ratio	0.40
Powder Content, kg/m^3	550
Water to powder ratio	0.93
Paste volume	37.54 %
Volume of Fine Aggregate	57.31 %
Cement, kg/m^3	436.50
Silica Fume, kg/m^3	13.50
Water, kg/m^3	178
Admixture, kg/m^3 (0.5 %)	2.25
Sand, kg/m^3	1000
Fraction of Coarse Aggregate, kg/m^3 20-10 mm (30%) 10-4.75 mm (70%)	 224 522
Compressive Strength 7 days age, MPa 28 days age, MPa	 34.18 49.41

V. DISCUSSION

To achieve a suitable viscosity, self-compacting concrete can be produced using a viscosity-modifying admixture or, more commonly, using a large amount of powder materials (cement and mineral additions). A superplasticizer is also used to control the shear stress [7]. In this experimentation of SCC, no stabilizing agents, such as viscosity-modifying admixture, were used. The pozzolanic material silica fume being used, as it offers improvements in concrete workability due to the spherical shape of the particles.

Different admixtures behave significantly different from each other even though they are all considered as superplasticizers of the same chemical family. Also, different cements of the same type can behave very differently. The differences are more evident in concretes with low water/cementitious ratios and high admixture dosages. The proper selection of superplasticizer type and dosage is necessary in terms of compatibility with the cement.

Particle shape of the fine aggregate and percentage finer than 0.125 mm size fraction significantly affect the flow of SCC keeping w/cm ratio and dose of the superplasticizer same. A well graded cuboidal shape grains of the fine aggregate perform well in compare to non-cuboidal shape of the grains in standard test consideration.

VI. CONCLUSION

In conclusion, self-consolidating concrete is an exciting and useful technology that has found many successful of the beat applications. Although the concept is not new, it has been around for a few decades but gradually new products are still emerging and better mix proportioning strategies are still in development. The new generation polycarboxylate-based superplasticizers has taken SCC a giant step forward. Meanwhile, multiple viscosity modifying admixtures are available, while researchers continue to seek better and cheaper recipes [8]. Indian standard tried to establish its definition and specification but still it requires modification. In absence of proper guidelines a successful mix depends on the experience and expertise of the producer.

VII. FUTURE COURSE OF ACTION

Indian standard gives only an outline for designing the SCC mix. Most of the percentage and parameters has to be considered on assumption or based on experience which requires further study. Since the degree of compaction in a structure mainly depends on the self-compactability of concrete and it must be checked just before casting at job site. Conventional methods of testing of self-compactability requires much time and quite laborious. Hence a methodology or standard device is required to be evolved to check the acceptance test of SCC. Though a Japanese researcher Ouchi et al (1999) developed a device to check the in situ acceptability criteria but it is not so popular and standardize. Work needed to do in this area.

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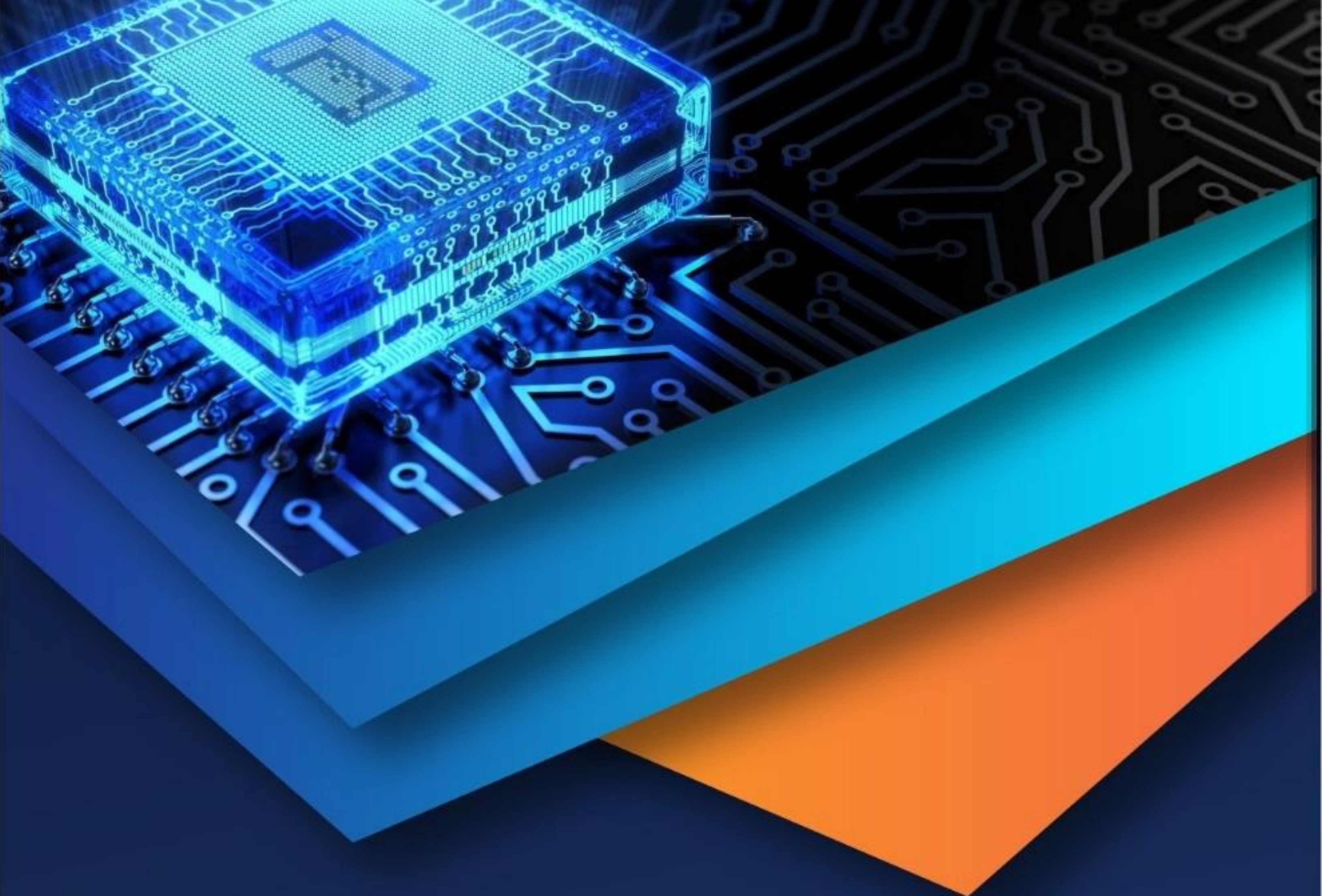

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