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Experimental Investigation on Elastic Properties of Concrete Incorporating GGBFS

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Abstract - Concrete is the most widely used man made construction material in the construction field all over the world. Concrete is made up of fine aggregates, coarse aggregate, cement and water for hydration of cement. Fine aggregates and coarse aggregates acts as filler material and cement acts as binding agent in concrete. In concrete cement plays a very important role in gaining strength but the major problem by the production of cement is liberation of large amount of CO_2 (green-house gasses) which is very dangerous to the environment. According to many researchers, the best way to overcome this problem is to use optimum amount of cement and its maximum replacement by pozzolana or cementitious materials such as fly ash, GGBFS (Ground granulated blast furnace slag), metakaolin etc. In the present work GGBFS is used as replacement material. The optimum replacement of GGBFS with cement is characterized by high compressive strength, low heat of hydration, resistance to chemical attack, better workability, good durability and cost-effectiveness. Also, an attempt has been made in predicting the elastic properties of GGBFS concrete as per various design standards and new relationships has been proposed.
Keywords: Ground granulated Blast furnace slag (GGBFS), modulus of elasticity, modulus of rupture, super-plasticizer and sustainability.

I. INTRODUCTION

Concrete is the most widely used man made construction material in the construction world. Concrete is made up of fine aggregates, coarse aggregates, cement and water for hydration of cement. Fine aggregates and coarse aggregates acts as filler material and cement acts as a binding agent in concrete. In concrete cement plays a very important role in gaining the strength, but the major problem by the production of cement is the liberation of large amount of CO_2 (green-house gasses) which is very dangerous to the environment. According to many researchers, the best way to overcome this problem is to use optimum amount of cement and its maximum replacement by pozzolana or cementitious materials such as fly ash, GGBFS, metakaoiln etc. In the present work GGBFS is used as a replacement material. The optimum replacement of GGBFS with cement is characterized by high compressive strength, low heat of hydration, resistance to chemical attack, better workability, good durability and cost-effectiveness [5]. The continuous hydration of un hydrated cement components to form more hydration products in addition to the reaction of GGBS with the liberated lime to form more C-S-H leading to increasing compressive strength[6,7]. The modulus of elasticity, modulus of rupture and compressive strength are very crucial properties of concrete, these are the basic parameters essential for estimating deflection in reinforced concrete structures. Design codes of various countries have derived empirical relations between elastic modulus, modulus of rupture and compressive strength of concrete at 28 days [9, 10, 11, 12, and 13]. In the present case an attempt has been made to study the design codes of various countries and establishing new relations. The Indian code of practice (IS: 456) recommends the empirical relation between the modulus of elasticity and cube compressive strength of concrete as follows:

$$E_C = 5000\ \sqrt{f_c}$$

The American code defines the relationship between modulus of elasticity and cylinder compressive strength for calculating deflection as follows:

$$E_C = 4734\ \sqrt{f_{c'}}$$

The New Zealand code defines the relationship between modulus of elasticity and cylinder compressive strength for calculating deflection as follows:

$$E_C = 4734\ (\sqrt{f_{c'}} + 6900)$$

The euro code recommends the empirical relation between the modulus of elasticity and cylinder compressive strength of concrete as follows:

$$E_C = 9500\ (\sqrt{f_{c'}} + 8)^{0.33}$$

The british code of practice (BS-8110) recommends the empirical relation between the modulus of elasticity and cube compressive strength of concrete as follows:

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$$E_C = 20000 + 0.2\sqrt{f_c}$$

Further the Indian code of practice also recommends the empirical relationship between the modulus of rupture and cube compressive strength of concrete are as follow:

$$f_r = 0.7\sqrt{f_c}$$

Similarly American code defines the modulus of rupture and cylinder compressive strength of concrete as follows:

$$f_r = 0.62\sqrt{f_{c'}}$$

The New Zealand code defines the modulus of rupture and cylinder compressive strength of concrete as follows:

$$f_r = 0.6\sqrt{f_{c'}}$$

The euro code recommends the empirical relation between the modulus of rupture and cube compressive strength of concrete as follows:

$$f_r = 0.3\,(f_c)^{0.67}$$

The Canadian code of practice defines the modulus of rupture and its cylinder compressive strength of concrete as follows:

$$f_r = 0.6\sqrt{f_{c'}}$$

where, E_C is the static modulus of elasticity at 28 days in MPa.

f_c is the cube compressive strength at 28 days MPa.

$f_{c'}$ is the cylinder compressive strength at 28 days in MPa.

f_r is the modulus of rupture of concrete at 28 days in MPa

The above empirical relationship is only for conventional concrete. Therefore, in the present work an attempt has been made to establish a new empirical relation between modulus of elasticity, modulus of rupture based on the compressive strength of concrete incorporating GGBFS.

II. GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

A. Introduction to GGBFS

Ground granulated blast furnace slag is a non-metallic material consisting essentially of Silicates and allumino silicates of calcium and other bases[1]. Those are developed in molten condition simultaneously with iron or steel in blast furnace. It is used as a replacing material to cement up to certain percentages. GGBFS is a by-product of iron and steel manufacturing process [2]. In which iron ore, coke and limestone are fed into the furnace, and the resulting molten slag floats above the molten iron at a temperature of about 1500 ^{0}C to 1600 ^{0}C. The molten slag has a composition of 30% to 40% silicon dioxide (SiO2) and approximately 40% CaO, which is close to the chemical composition of Portland cement. Cement with GGBFS replacement has emerged as a major alternative to conventional concrete and has rapidly drawn the concrete industries attention due to its cement, energy and cost savings, environmental and socio-economic benefits [3, 4]. Since the grain size of GGBFS is less than that of ordinary Portland cement, its strength at early ages is low, but it continues to gain strength over a long period. The benefit of adding GGBFS to the concrete as separate material rather than grinding it with the cement is:

Each material can be ground to its own optimum fineness.

The proportion can be adjusted to suit the particular project needs.

B. Benefits of using GGBFS in concrete

1) Sustainability: It has been reported that the manufacture of one tonne of Portland cement would generate 0.95 tonne of CO_2, where as one tonne of GGBFS would generate 0.07 tonne of CO_2. Thus by using GGBFS environment can be protected.

2) Setting Time: Setting time of the concrete is influenced by many factors such as water-cement ratio, temperature etc. With GGBFS the setting time will be slightly extended by 30min the effect will be more at high levels of GGBFS and the concrete will remain workable for longer periods.

3) Bleeding: The rate and amount of bleeding in concrete containing slag is usually less than that of conventional concrete because of relatively higher fineness of slag.

4) Strength: Strength development of concrete incorporating slag depends on fines, proportion of slag used in concrete mixture etc. In general the strength development of concrete incorporating slag is less at initial ages but achieves greater strength at later age.

5) Durability: The durability of the concrete structure can be improved by incorporating GGBFS in concrete by reducing the water permeability, increasing the corrosion resistance and sulphate resistance [8].

III.OBJECTIVES OF THE PRESENT WORK

To study the design codes of various countries for understanding the static modulus of elasticity, modulus of rupture and compressive strength relations and compared with the relationships to concrete containing GGBFS.

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To propose new relationships linking elastic properties with compressive strength of concrete using GGBFS at different ages.

IV. MATERIALS USED

A. Cement

Portland cement is one of the most commonly used additives in all type of constructions. In the present work OPC43 grade is used which conforms to IS4031-1988.

B. Fine Aggregates

Particles are angular in shape passing 4.75mm and conforming to grading zone-2 of IS383: 1970 with specific gravity of 2.61.

C. Coarse Aggregates

Aggregates of maximum size 20mm and 16mm, well graded cubical or rounded aggregate with specific gravity 2.68 are used. Aggregates are of uniform quality with respect to shape and grading.

D. Mixing Water

Ordinary potable water of normal pH 7 is used for mixing and curing the concrete specimen. Water should be free from acids, oils, alkalies, vegetables or other organic impurities.

E. Chemical Admixtures

An admixture is a material other than water, aggregates and cement. They are used to improve the workability or give special properties to the concrete. Conplast SP430 is a super plasticising slump retaining admixture is used in the present work. GGBFS is an admixture in partial replacement with cement.

Table 1. Properties of Conplast SP430

1	Specific gravity	1.20 to 1.22 at 300C
2	Chloride content	Nil. as per IS:9103-1999 and BS:5075
3	Air entrainment	Approx. 1% additional air over control

Fig. 1 Ground granulated blast furnace slag

Table 2. Chemical composition of GGBFS

Calcium oxide (CaO)	40-52%
Silicon dioxide (SiO_2)	10-19%
Iron oxide (FeO)	10-40%
Magnesium oxide (Mg0)	5-10%
Manganese oxide (MnO)	5-8%
Aluminium oxide (Al_2O_3)	1-3%
Phosphorous pent oxide (P_2 O_5)	0.5-1%
Sulphur (S)	<0.1

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Table 3. Physical properties of GGBFS

Characteristics	Values
Fineness (m^2/kg)	340
Specific gravity	2.87
Normal consistency (%) OPC+20% GGBFS OPC+40% GGBFS OPC+60% GGBFS	 28.6 29.4 31.0
Setting time Initial setting time (min) Final setting time (min)	 150 310

V. EXPERIMENTAL PROGRAM

The experimental programs consist of trial and error method of achieving the mix proportion and it was was found to be 1:1.495:3.10. Then the various percentages (0%, 20%, 40% and 60%) of GGBFS are added at the time of mixing and required dosage of super plasticizer is also added along with the water.

A. Preparation Of Test Specimen

Cube specimen of size 15cmx15cmx15cm, cylinder specimen of length 20cm and diameter 10cm, and prism of size 50cmx10cmx10cm were casted. The ingredients of concrete were mixed thoroughly in the mixer till uniform consistency was achieved. The specimens were compacted on a vibrating table. The specimens were demolded after 24 hours of casting and cured for 7, 14 and 28 days. In the experimental work total 108 specimens were casted which includes 36 cubes, cylinders and prisms.

B. Tests On Hardened Concrete

Following tests were conducted to determine the mechanical properties of the concrete
Compressive strength
Split tensile strength
Flexural strength

C. Compressive Strength Of Concrete

Among all the tests, the compressive strength test is the most important which gives an idea about all the characteristics of concrete, and it has a definite relationship with all the other properties of concrete i.e. these properties are improved with the improvement in compressive strength. Rate of application of load is 1.40KN/cm^2/min.
Compressive strength = (average load/ area of cross-section) N/mm^2

Fig. 2 Testing cubes for its compressive strength.

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Table 4. Compressive strength of concrete for various percentages of GGBFS in N/mm^2

Replacement of GGBFS, %	Cement, kg/m^3	GGBFS, kg/m^3	FA, kg/m^3	CA, kg/m^3	W/C	7 Days strength, MPa	14 Days strength, MPa	28 Days strength, MPa
0	412	0	616	1286	0.35	39.50	46.44	50.68
20	330	82	616	1286	0.35	35.66	42.80	52.55
40	247	165	616	1286	0.35	33.63	38.36	43.95
60	165	247	616	1286	0.35	30.85	34.50	39.70

D. Split Tensile Strength

The test is carried out by placing a cylinder specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter.

Split tensile strength= (2 P/ ∏ D L)

Where, P = load applied to the cylinder

D = diameter of the cylinder

L = Length of the cylinder

The main advantage of this method is that the same type of specimen and the same testing machine as are used for the compression test can be employed for this test. Strength determined in the splitting test is believed to be closer to the true tensile strength of concrete, than the modulus of rupture. Splitting strength gives about 5 to 10% higher value than the direct tensile strength.

Fig. 3 Compression testing machine testing cylinders for tensile strength.

Table 5. Tensile strength of concrete for various percentages of GGBFS in N/mm^2

Replacement of GGBFS, %	Cement, kg/m^3	GGBFS, kg/m^3	FA, kg/m^3	CA, kg/m^3	W/C	7 Days tensile strength, MPa	14 Days tensile strength, MPa	28 Days tensile strength, MPa
0	412	0	616	1286	0.35	3.65	4.50	4.70
20	330	82	616	1286	0.35	3.38	4.38	4.81
40	247	165	616	1286	0.35	3.07	3.15	3.45
60	165	247	616	1286	0.35	2.80	2.98	3.18

E. Flexural Strength Of Concrete

Flexural strength is one of the measure of compressive strength of concrete. It is a measure of an unreinforced concrete slab or beam to resist failure in bending. It is measured by loading 500x100x100mm concrete beam. It is expressed as modulus of rupture and determined by standard test method ASTM C-78 (third point loading) or ASTM (centre point loading).

Flexural strength of concrete is about 10-20% of the compressive strength of the concrete depending on size, type and volume of the coarse aggregates used. The flexural strength determined by third point loading is lower than the strength determined by centre point loading.

Modulus of rupture = (P L/ B D^2)

Where, P=load applied

L=Length of the prism

B=Width of the of the prism

D=Depth of the prism

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Fig. 4 Testing of beams for its flexural strength.

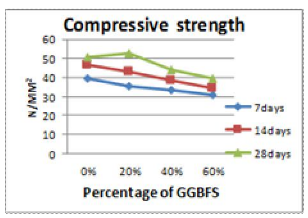
Table 6. Flexural strength of concrete for various percentages of GGBFS in N/mm^2

Replacement of GGBFS, %	Cement, kg/m^3	GGBFS, kg/m^3	FA, kg/m^3	CA, kg/m^3	W/C	7 Days flexural strength, MPa	14 Days flexural strength, MPa	28 Days flexural strength, MPa
0	412	0	616	1286	0.35	5.38	5.74	5.94
20	330	82	616	1286	0.35	5.10	5.41	6.15
40	247	165	616	1286	0.35	4.89	5.15	5.45
60	165	247	616	1286	0.35	4.74	4.98	5.19

VI. RESULTS AND DISCUSSIONS

A. Compressive Strength

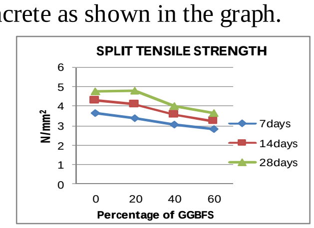
For concrete the main criteria to know the mechanical properties is compressive strength, in this case, the 7 and 14 days compressive strength of the GGBFS concrete is less than the conventional concrete. But the 28 days strength of concrete containing 20% of GGBFS is more as compared to conventional concrete i.e. optimum percentage of GGBFS for compression is 20% as shown in the graph.



Graph 1. Compressive strength V/s Percentage of GGBFS

B. Split Tensile Strength

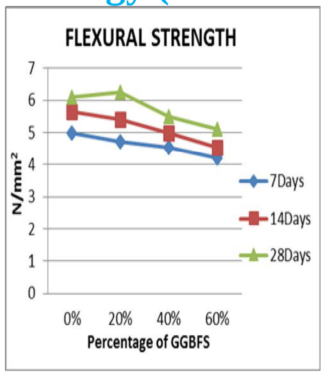
It is very difficult to measure the tensile strength of the concrete directly, so it is measured indirectly by placing the cylinder specimen horizontally and then applying the compression load. Here the 28 days tensile strength of concrete containing 20% of GGBFS is more as compared to conventional concrete as shown in the graph.



Graph 2. Split tensile strength V/s Percentage of GGBFS.

C. Flexural Strength

In this case test is conducted for the concrete containing various percentages of ground granulated blast furnace. Here the 7 and 14 days flexural strength of the concrete incorporating GGBFS for all dosages is less than the conventional concrete. But the 28 days strength of concrete containing 20% of GGBFS is more than the conventional concrete as shown in the graph.



Graph 3. Flexural strength V/s Percentage of GGBFS

D. Static Modulus Of Elasticity

Modulus of elasticity of concrete is a key factor for estimating the deformation of buildings and members, as well as a fundamental factor for determining modular ratio, which is used for the design of members subjected to flexure. It is frequently expressed in terms of compressive strength. Comparisons of static modulus of elasticity obtained experimentally and that obtained from using empirical expressions given design code of various country for both conventional concrete and GGBFS concrete is presented in the table 7 above. The table 7 shows that the static modulus of elasticity predicted by Indian code IS456: 2000 and euro code EC: 02 are higher than those predicted by American code (ACI: 318), New Zealand code (NZS: 3101) and British code (BS: 8110). Table 7 also shows that experimentally measured modulus of elasticity is higher than the British code (BS: 8110) and comparatively lower than all other design codes.

Table 7. Comparison of codal provision for static modulus of elasticity Ec in N/mm^2

Mixes	As per measured value, E_c	As per IS456 code	As per ACI: 318 code	As per New Zealand code NZS:3101	As per Euro code EC: 02	As per BS: 8110
Mix-1	25998.43	35594.94	30141.86	28038.78	34208.69	20010.13
Mix-2	26428.39	36245.68	30694.43	28426.30	34553.99	20010.51
Mix-3	24105.80	33147.39	28070.66	26586.22	32907.92	20008.79
Mix-4	23101.53	31503.96	26678.93	25610.19	32028.81	20007.94

Based on the regression analysis of the experimentally obtained test results, the proposed correlation of the modulus of elasticity and compressive strength of cylinder and cube for conventional and GGBFS based concrete are given below.

For cube compressive strength:

$$Ec = C1\sqrt{fc}$$

For cylinder compressive strength:

$$Ec = C2\sqrt{fc'}$$

Where, Ec is the static modulus of elasticity at 28 days in MPa.
fc is the cube compressive strength of at 28 days in MPa.
fc' is the cylinder compressive strength at 28 days in MPa.
C1, C2 Constants given in table below.

Table 8. Constants for empirical relationship between static modulus of elasticity and compressive strength
C1 for cube compressive strength.

Mixes	As per measured value, E_c	As per IS456 code	As per ACI: 318 code	As per New Zealand code NZS: 3101	As per Euro code EC: 02	As per BS: 8110
Mix-1	3651.98	5001. 10	4234	3938.59	4805.27	2810.81
Mix-2	3645.13	5002.66	4234.50	3921.33	4766.63	2760.39
Mix-3	3634.08	5000.55	4234.22	3997.29	4963.87	3018.15
Mix-4	3559.33	5000.34	4233.89	4064.59	5083.29	3175.46

Table 9. Constants for empirical relationship between static modulus of elasticity and compressive strength C2 for cylinder compressive strength.

Mixes	As per measured value, E_c	As per IS456 code	As per ACI: 318 code	As per New Zealand code NZS: 3101	As per Euro code EC: 02	As per BS: 8110
Mix-1	4083.24	5591.22	4735.28	4403.69	5373.10	3142.73
Mix-2	4076.04	5590.56	4734.85	4384.88	5329.25	3086.30
Mix-3	3985.65	5590.35	4733.85	4367.92	5312.34	2960.70
Mix-4	3910.9	5589.99	4732.99	4361.10	5299.85	2834.50

E. Modulus Of Rupture

Modulus of rupture is defined as a material's ability to resist deformation under loads. The Modulus of rupture represents the highest stress experienced within the material at its moment of rupture. Comparisons of flexural strength or modulus of rupture obtained experimentally and that obtained from using empirical expressions are given design codes of various countries for both conventional concrete and GGBFS concrete is presented in the above table. From the table it can be noticed that experimentally measured modulus of rupture is higher than the IS456 code, ACI318 code, NZS3101 code, EC: 02 code and Canadian code. The Table 10 below shows the details of empirical relationship between modulus of rupture versus cube compressive strength and modulus of rupture versus cylinder compressive strength respectively.

Table 10. Comparison of codal provision for flexural tensile strength of concrete f_r in N/mm^2

Mixes	As per measured value, f_r	As per IS456 code	As per ACI: 318 code	As per New Zealand code NZS: 3101	As per Euro code EC: 02	As per Canadian code of practice CSA
Mix-1	5.94	4.983	3.947	3.820	4.162	3.820
Mix-2	6.15	5.074	4.019	3.890	4.265	3.890
Mix-3	5.45	4.606	3.676	3.567	3.783	3.567
Mix-4	5.19	4.410	3.494	3.380	3.534	3.380

Based on the regression analysis of the experimentally obtained test results, the proposed correlation of the flexural strength and compressive strength of cylinder and cube for conventional and GGBFS based concrete are given below

For cube compressive strength:

$$f_r = C1\sqrt{f_c}$$

For cylinder compressive strength:

$$f_r = C2\sqrt{f_c'}$$

Where, f_r is the modulus of rupture of concrete at 28 days in MPa

f_c is the cube compressive strength of concrete at 28 days MPa.

f_c' is the cylinder compressive strength at 28 days in MPa.

C1 and C2 the Constants given in the tables above.

Table 12. Constants for empirical relationship between flexural tensile strength and compressive strength C2 for cylinder compressive strength.

Mixes	As per Measured value, f_r	As per IS456 code	As per ACI: 318 code	As per New Zealand code NZS: 3101	As per Euro code EC: 02	As per Canadian code of practice CSA
Mix-1	0.8340	0.6998	0.5545	0.537	0.5846	0.537
Mix-2	0.8483	0.6998	0.5545	0.537	0.588	0.537
Mix-3	0.8240	0.6998	0.5545	0.538	0.5706	0.538
Mix-4	0.8237	0.6994	0.5540	0.536	0.5608	0.536

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Table 13. Constants for empirical relationship between flexural tensile strength and compressive strength C2 for cylinder compressive strength.

Mixes	As per Measured value, f_r	As per IS456 code	As per ACI: 318 code	As per New Zealand code NZS: 3101	As per Euro code EC: 02	As per Canadian code of practice CSA
Mix-1	0.9330	0.782	0.6199	0.5800	0.653	0.5999
Mix-2	0.9485	0.783	0.6199	0.6000	0.657	0.5999
Mix-3	0.9190	0.768	0.6199	0.5850	0.637	0.5999
Mix-4	0.9209	0.750	0.6000	0.5630	0.627	0.5970

VII. CONCLUSION

The following conclusions are drawn from this experimental work;

The 7 and 14days compressive, tensile and flexural strength of GGBFS concrete is less than plain concrete but the 28 days strength of GGBFS concrete with 20% replacement is more than plain concrete further addition of GGBFS will decrease the strength. Thus optimum replacement percentage of GGBFS by weight of cement is up to 20%.

Even with the addition of super plasticizer, it was found that there was no appreciable increase in strength; this may be due to the slow reaction between super plasticizer and GGBFS.

The experimentally measured values of modulus of elasticity of GGBFS Concrete are lower as compared to Indian code IS456: 2000 and euro code EC: 02, American code (ACI: 318) and New Zealand code (NZS: 3101).

The static modulus of elasticity predicted by Indian code IS456: 2000 and euro code EC: 02 are higher than those predicted by American code (ACI: 318), New Zealand code (NZS: 3101) and British code (BS: 8110).

The experimentally measured modulus of elasticity is higher than the British code (BS: 8110) and coMParatively lower than all other design codes.

The experimentally measured modulus of rupture is higher than the IS-456 code, ACI: 318 code, NZS: 3101 code, EC: 02 code and Canadian code.

The new empirical relations for static modulus of elasticity, flexural strength, tensile strength, modulus of rupture and compressive strength of concrete incorporating different percentage of GGBFS in plain concrete are proposed.

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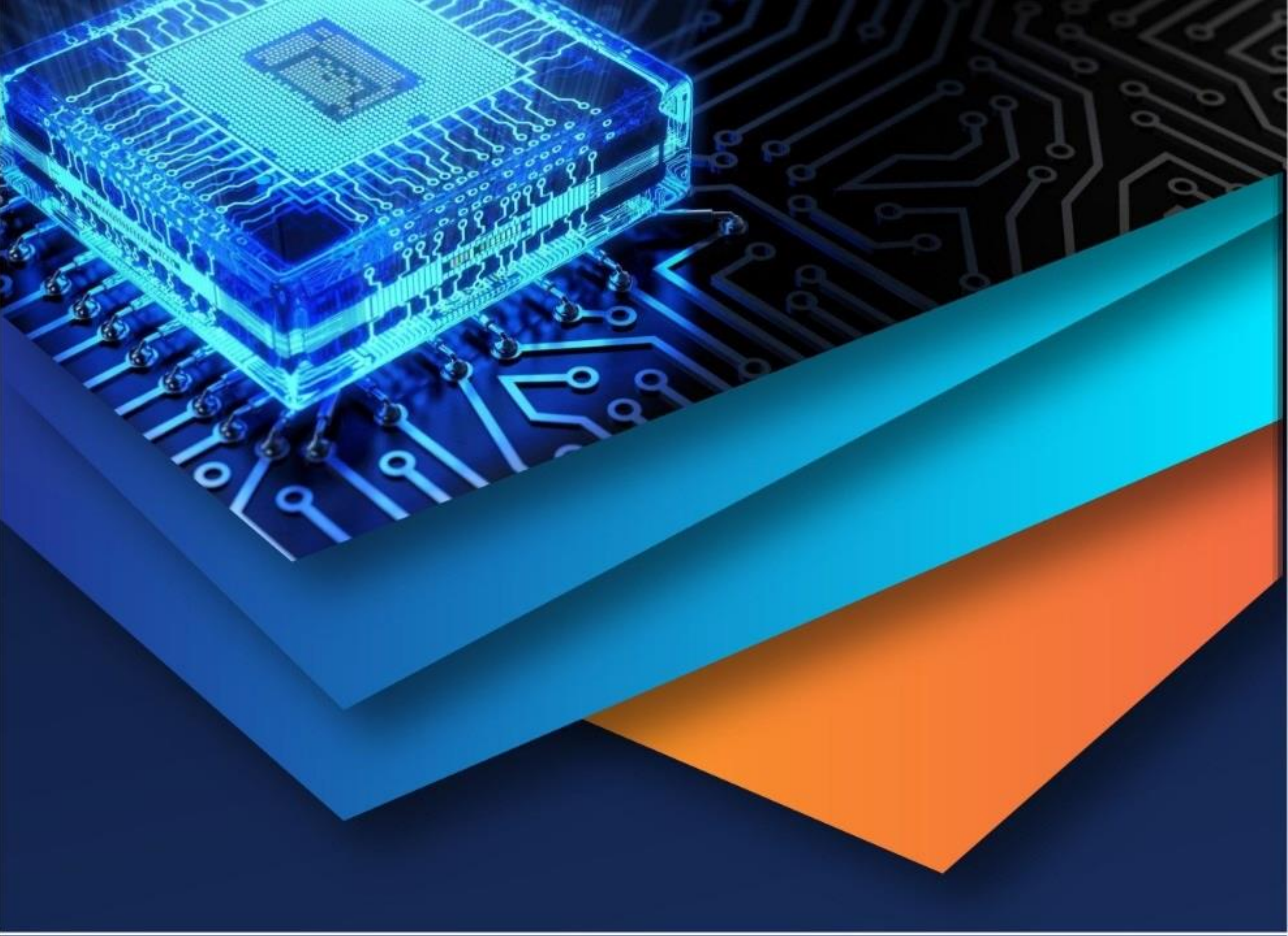

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