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Determination of Single Parameter for Serviceability Requirements of Fibre Reinforced Concrete: Study of Fracture Characteristics

Umar Islam Wani[1], Er. Ajay Kumar[2], Er. Mukesh Kumar[3]
[1]M.Tech Scholar, [2]Assistant Professor, [3]Head of the Department, Department of Civil Engineering, Universal Institiue of Engineering and Technology

***Abstract:** This The influence of fibre reinforcement on crack propagation in concrete was studied . Thirty-five double torsion specimens, made with three types of fibres (fibre glass , straight steel fibres and deformed steel fibres) were tested . The variables were the fibre volume and size of the fibres. The test results indicated that the resistance to rapid crack growth increased somewhat with increasing fibre content up to about 1.25% - 1.5% by volume. The degree of compaction had an enormous effect on the fracture properties .The fracture toughness increased with fibre content up to about 1.25% by volume, and then decreased , due to incomplete compaction. It was found that in this test geometry, fibres did not significantly restrain crack growth. It was also observed that once the crack had propagated down the full length of the specimen, the system changed from a continuous system to a discontinuous system, consisting of two separate plates held together by the fibre reinforcement. Different types of fibres did not significantly affect the fracture toughness.*

***Keywords:** Fibre glass, straight steel fibers, deformed steel fibers, fracture toughness.*

I. INTRODUCTION

Concrete is heterogeneous and complex substance. It is a well know fact that modern construction industry is largely dependent on concrete. Concrete has been modified from time to time to improve its properties. Improving strength properties alone does not meet the requirements of serviceability of the structure. Thus various attempts have been made to make the concrete meet its serviceability as well as strength characteristics. One of the important type of modified concrete is fibre reinforced concrete which has a huge potential of meeting the serviceability as well strength requirements of concrete. Portland cement concrete containing metallic or polymer fibres is commonly known as fiber-reinforced concrete. The fibres help to increase resistance to shrinkage cracking and service-related cracking in plastics. Fibers aren't meant to be used as primary reinforcement. Fibers are added to concrete throughout the manufacturing process. They're helpful in shotcrete and thin overlays that aren't thick enough to support reinforcing bars, and they're impact, vibration, and blast resistant. However, because of its strength and serviceability, fibre reinforced has a restricted use. The scope of this research is limited to serviceability requirements with respect to crack development.

A. Serviceability requirements of concrete

A concrete building should be functional and execute its future function during its operational time so as to gratify serviceability limit state. Extreme deflection must not cooperate structural role or exist visually unattractive. Fractures must not exist unpleasant or huge adequate to root difficulty by strength. Manipulative pro serviceability limit state entail mounting precise forecasts of structural instant along with time-reliant buckle. Non-linear behavior of material which mainly is obsessed by crack, strain stiffen, sneak, and contraction, make this much tricky. Fibre reinforced concrete provides a good solution to serviceability requirements of concretes with regards to crack development and especially in light construction.

B. . Applications of fibre reinforced concrete

Fibre reinforced concrete has broad variety of application within civil production. With fresh technologies they are becoming more and more important in various engineering applications. It is quite possible to further diversify the applications. Some of the important applications of fibre reinforced concrete are as follows.

1) 'Commercial': Floors on the outside and inside, graceful material, slab, parking masses, as well as roads.
2) 'Prominent Decks': Construction of viable and business complex harden deck as well as eminent formwork at airport, marketable building, shopping malls, and other locations.
3) Highways,' Roadway & Bridges: 'SCC', pasty-toppings, obstruction rails, cut back and drain exertion, pervious material, resonance reduction barrier, plus so forth are all examples of traditional concrete pavement.
4) Mining & Tunneling: Pre - cast concrete segments and shotcrete may be used for 'tunnel lining', 'shafts', slant stabilisation, and cesspool exertion, among other things.

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II. LITERATURE REVIEW

An Stresses around cracks have been studied in detail by many people. In 1913, Inglis showed that stresses around an elliptical hole (An ellipse is frequently used to describe a crack's overall shape.) in a uniformly stressed plate could be' expressed as

$$\partial r = \partial(1 + 2\sqrt{a/}P)$$

Where ∂r=resultant stress in r direction

∂ = applied stress

a = length of the semi-major axis , or one-half of the crack length

Ᵽ = radius of warp at slant of ellipse.

In 1920, based on tests on precracked glass specimens, Griffith concluded that "for an infinitesimally small amount of crack extension,the decrease in stored elastic energy of a cracked body under fixed grip conditions is identical to the decrease in potential energy under conditions of constant loading". Griffith demonstrated that the difference between the energy that could be released if the fracture was expanded and the energy required to build new surfaces was the driving factor for crack extension. He demonstrated that, using an energy-rate balancing technique,

$$\partial F = \frac{\sqrt{2E\alpha}}{A}$$

Which is very similar to equation given by Inglis, even though they were derived from different considerations. By defining the energy release rate (crack driving force) as G, and noting that this crack driving force equals the surface energy of the newly formed surface , 2y, (two new surfaces are created due to cracking) , it can be concluded that

$$G = 2y$$

A. Stress Intensity Approach

Using Westergaard's solution, failure resulting from the stress field which is associated with the crack tip can be divided into three categories. These categories are generally referred to as :

Mode I tension failure (crack hole)
Mode II in 'shear failure'(plane)
Mode III anti 'plane shear failure' (twisting)

These failure modes are shown in Figure 2.1, 2.2 and 2.3 respectively. In fracture analysis, Mode I failure is the most important mode, and will be the only one discussed here. In 1959, by rearranging Westergaard's solution, Irwin obtained a term, K, which depended only on the applied stress and crack length.

B. Effective Crack Length

The effective crack length must include the effect of this zone .In the case of a plane strain specimen, plastic deformation is more difficult at the center of thick specimens, which are more likely to cleave than to plastically deform. Irwin estimated that the plastic zone for thick specimens is reduced by a factor of three.

C. Mechanics of Failure Applied to Fibre Reinforced Concrete

It is now well established that concrete failure is due to progressive internal cracking. Failure occurs when a substance that was once essentially continuous becomes essentially discontinuous. Richart, Brandtzaeg, and Brown discovered that the volume of concrete initially reduced under uniaxial compressive force, as would be predicted based on elastic theory. .However, when the applied load reached about two-thirds of the ultimate load, the volume of the concrete started to increase . They discovered that the apparent volume of the concrete specimen was greater than the starting volume of the specimen at ultimate stress. From this, they concluded that the bulging and eventual The material failed as a result of internal tension-induced microcracking that spread throughout the specimen, and this has subsequently been confirmed by many other investigators .

D. Test specimen for measurement of fracture parameters

A number of specimen geometries have been developed to measure fracture parameters and crack propagation. The most common are

1) Edge cracked tensile specimen
2) Centre cracked tensile specimen
3) Double cantilever beam specimen
4) Double torsion specimen

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E. Double torsion technique

By considering the double torsion specimen as shown in Fig 2.5 as two rectangular elastic sections, Williams and Evans showed that the stress intensity is a function only of the specimen dimensions, the applied load and Poisson's ratio.

III.EXPERIMENTAL METHODOLOGY

A. Materials

Normal Portland cement (OPC 43) was used to prepare the concrete. The fine aggregate was commercially available concrete sand, and the coarse aggregate was 3/8" '9.5' (mm) pea grate. All aggregate were stored at ambient laboratory moisture conditions. Headed for advance function of 'mixes', two types of admixtures were used, water falling means as well as air entraining means. Three types of fibres were used. These were alkali and acid resistant 'fibreglass', 'steel fibres'(straight) and 'steel fibres'(deformed). Two types of fibreglass were used —'filaments per fibre bundle' (204) and 'filaments per fibre bundle' (102). They are been chopped strand in 25. 4 mm lengths .The straight steel fibres consisted of '12. 8' and '25. 5'mm in length fibres with cross-sectional dimensions (0.254 x 0.559) mm.

Table IApparent load relaxation data for cement paste (1)

Mix Series	Fibre Volume % by weight	Weight (kg)			
		Cement	Water	Sand	Fibre
Glass Fibre (GF)	0	38.5	19	77	0
	0.25	38.5	19	77	0.45
	0.5	38.5	19	75	1
	0.75	38.5	19	74	2
	1.0	38.5	19	73	2.5
	1.25	38.5	19	72	3
	1.5	38.5	19	72	3.5
	2.0	38.5	19	70	4

Table IICorresponding load relaxation data for cement paste (1)

Corresponding Background Relaxation (b)	True Relaxation	Velocity	Stress Intensity
Slope $(\frac{dp}{dt})_a$	$(\frac{dp}{dt})_{b-(\frac{dp}{dt})_a}$	V × 10^{-2} cm/sec	K
0.6	5.6	11.4	0.4
0.4	1.2	1.8	0.34
0.11	0.09	0.18	0.33
0.02	0.58	0.07	0.32

Table III Apparent load relaxation data for cement paste (2)

Apparent Relaxation (a)				
Load(kg) p	Load(kg) 'dp'	Paper(cm) 'Dm''	Time(sec) 'Dt'	Slope $(\frac{dp}{dt})_b$
127	68	1.3	15	4.5
118	73	3.7	43	1.7
111	29	5.5	65	0.5
109	18	11.4	135	0.13
107	3.6	19	225	0.02

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Table IV Corresponding load relaxation data for cement paste (2)

Corresponding Background Relaxation (b)	True Relaxation	Velocity	Stress Intensity
Slope$(\frac{dp}{dt})_a$	$(\frac{dp}{dt})_{b-(\frac{dp}{dt})_a}$	V × 10^{-2} cm/sec	K
0.4	4.1	16.7	0.33
0.24	1.46	6.1	0.31
0.07	0.43	1.8	0.3
0.02	0.11	0.34	0.29
0.006	0.014	0.02	0.28

B. Cement Paste Specimen Relaxation

The corresponding background relaxation was obtained by reproducing the background relaxation curve of the specimen below the apparent relaxation curve with the initial load fall of curvatures at similar value of x. vertical line was drawn through the intercepted point of the applied load on the apparent relaxation curve which cut a point on the background relaxation curve. A tangential line was drawn to the background relaxation curve at this point . The equivalent backdrop recreation was slope of this line.

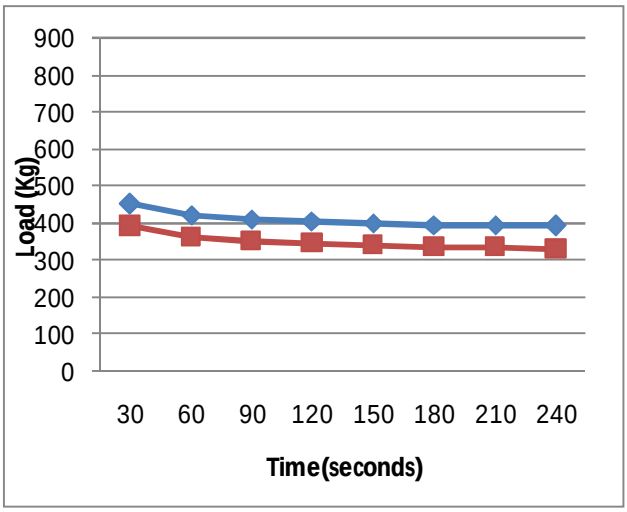

Figure 1Load Relaxation Curve for cement paste specimen

C. Parameters in Fibre Reinforced Concrete Specimen

No There is strong indication that adding up 'fibres' in material improves properties of material section. Some of important parameters which are significant for this research purpose are discussed below in following sections. A comparison can be seen from the various graphs that were interpreted after an extensive research. The important parameters involved are:

1) Fracture Toughness
2) Compliance
3) V-K Plot

D. Fracture Toughness

Fibre reinforced concrete is difficult to compact fully, and a poorly compacted specimen will leave voids and pores in the finished product. Weight intensities dropped even as fibre content was increased owing to inadequate compression.The weight density curves obtained can be characterized by an inverted V.The weight density of the specimens normally increased with increasing fibre content and reached its peak number at concerning one to one point two five percent of fibre by volume, then started to decline. In general, the shape of the fracture toughness vs fibre volume curves follows the same pattern as the weight density vs fibre volume curves. This demonstrates that amount of concrete compression has an impact on fracture toughness.On greater fibre contents , the trend of the fracture toughness vs fibre volume for the BSF series does not follow the same pattern as the weight density vs fibre volume curve.

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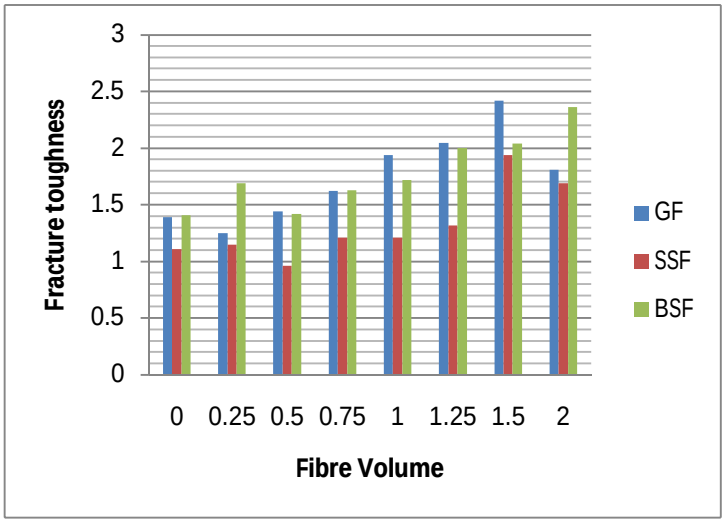

Figure 2Variation of 'fracture toughness' with 'fibre volume'

E. Compliance

System adherence was measured using 'two' samples. Gradient of adherence vs 'crack length curve' of BSF sample is larger than that of SSF sample. This suggests that sample BSF is much more elastic than sample SSF, as one would assume given lower density of the BSF sample.

Table V Compliance of SSF test specimen

Crack Length (in)	Load	Deflection	Average Compliance
4	2	2	10
	4	3	7.5
	6	3.2	5.3
	8	4	5
	10	7	7
7	2	2	10
	4	3.2	8
	6	5.5	9.2
	8	6.8	8.5
	10	9.5	9.5
16	2	3.5	17.5
	4	5.5	13.75
	6	7.8	13
	8	10	12.5
	10	13	13

F. V-K PLOT

The load relaxation data and summary of results for the V-K charts are tabulated in Tables. Values of the fracture toughness and the crack velocity were calculated using equations as follows:

1) $K_I = P\,\varphi\,\left(\frac{3(1+V)}{WTt}\right)^{1/2}$

2) $V = y/BP^2\left(\frac{dp}{dt}\right)$

Where,

K= Fracture toughness

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Table VI Summary of results for the V-K curves

Mix Series	Fibre Content	Slope	Correlation coefficient
Glass Fibre	0	33.3	0.8
	0.25	22.4	0.85
	0.50	26.5	0.95
	0.75	31.6	0.98
	1.0	33.8	0.96
	1.25	50	0.98
	1.50	33.8	0.94
	2.0	41.8	0.96
Straight Steel Fibre	0	29	0.97
	0.25	16	0.98
	0.5	11.3	0.9
	0.75	32	0.97
	1.25	29.3	0.99
	1.5	29.9	0.92
	2.0	63	0.95
Bend Steel Fibre	0	37.1	0.90
	0.25	41.1	0.99
	0.5	48.6	0.96
	0.75	30.9	0.97
	1.25	86	0.99
	2.0	56	0.96

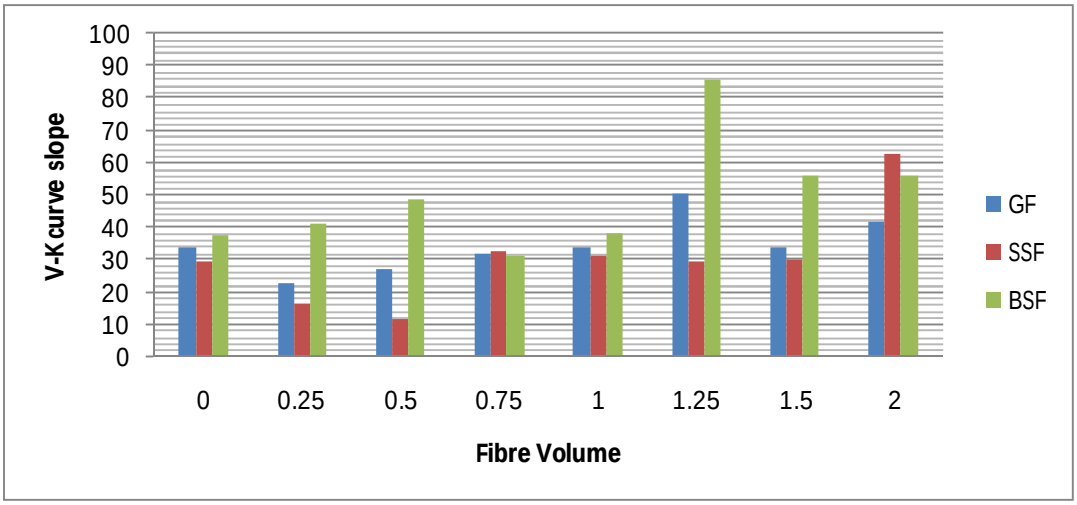

Figure 3Slope data representation of V-K curve

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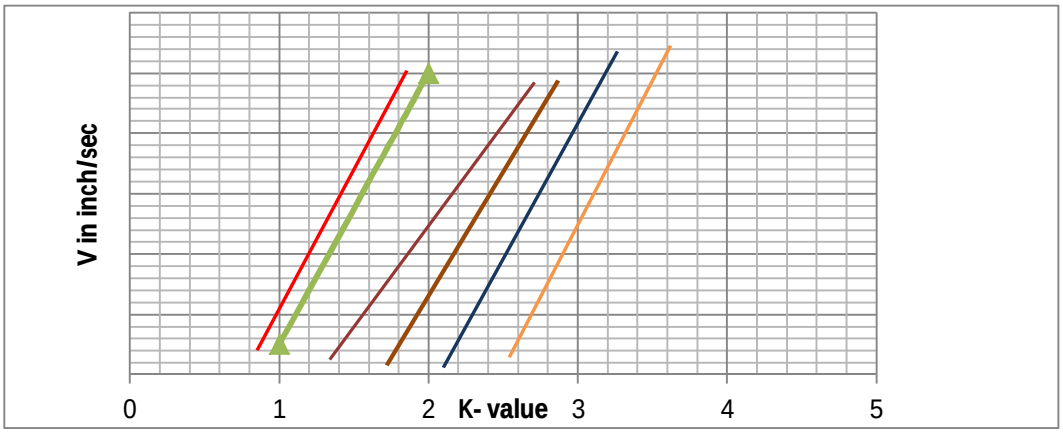

Figure 4V-K curve slope for glass fibre concrete

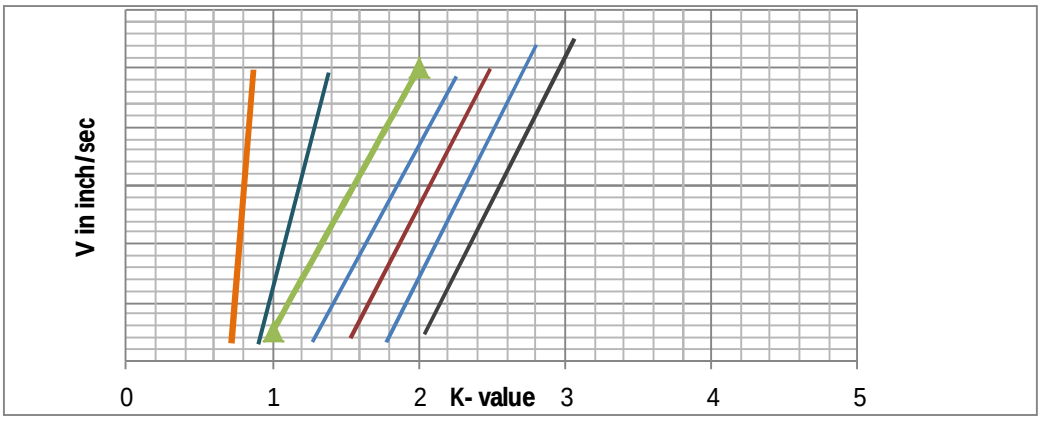

Figure 5V-K curve slope for straight steel fibre concrete

IV. CONCLUSIONS

The findings reported in earlier section are an effort to determine impact of fibre reinforcing over development of cracks in material. The subsequent conclusion should be derived from the examination of test outcomes:

1) Subcritical crack growth should be considered when measuring the fracture parameters of cementitious materials .
2) A minimum specimen size should be determined in order t o get valid results.
3) The gradient and interception of Characteristic curve are unaffected by various kinds of fibre.
4) The degree of compaction affects the fracture properties of the specimens. Fibre levels well over 1.5 percent of total volume are not recommended until extra importance is paid to compression operation.
5) When fibre content of specimen was at 1.25 percent by volume, the weight density of the specimen began to drop. This recommends that while fibre volume was more than 1.25%, full compaction was not achieved.
6) Fibre content enhances fracture toughness to around 1.25 percent. This suggests that great improvement was developed in concrete at this particular fibre content. This result can be utilized to further research on the performance of the concrete at this particular percentage of fibres.
7) Residual strength of the specimen increases with increasing fibre content. This strength seems also to depend on the pullout resistance of the fibre reinforcement.
8) The results show that crack development can be used as a parameter for fulfilling serviceability requirements in mass production of fibre reinforced concrete. However a specific mathematical model needs to be developed which could automatically take care of different types fibres used and their relative percentage in a batch.
9) Fibres have no major effect on crack formation inside this experimental topography.

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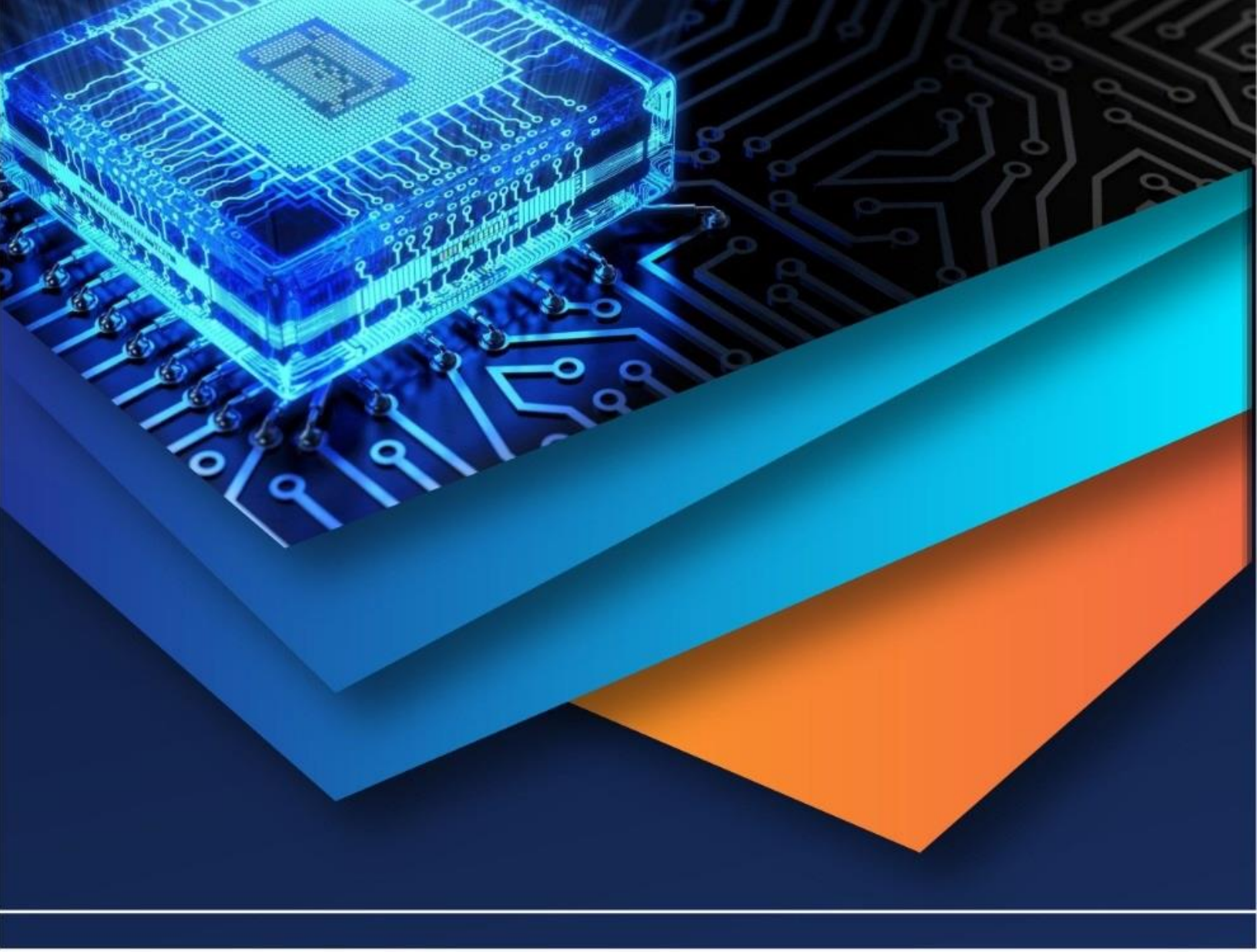

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