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# Study of Fracture Mechanics on Fibre Reinforced Concrete.

Mihir Dedge[1], Prathmesh Wanjale[2], Yash Mutha[3], Nikhil Lohokare, Ganesh Jarad[5]
[1, 2, 3, 4, 5]*Department of Civil Engineering, PadmaBhushan Vasantdada Patil Institute of Technology, Pune, India.*

***Abstract:*** ***Fracture mechanics gives a basic understanding of the characteristics of the structure afterload is being imposed on it. To avoid failure of the structure, analysis of fracture mechanics is very important. Fracture mechanics is the study of causes of cracks in a structure. A fracture means a crack of some length, the length of which increases upon loading. Fracture mechanics is about when that crack becomes critical and cannot sustain the load imposed upon it. When the crack gets to sufficient long length that the crack propagation goes from stable from unstable. For the structure to develop cracks, some energy is needed, that energy is called fracture energy. Examination of the energy for understanding the limit of tensile stress a structure can sustain is crucial. Usually for the development of crack three-point load method is used. A wide assortment has been proposed for this technique, to be executed.***

***Keywords: Fracture Mechanics, Fracture Energy, Three-Point load, Cracks, Tensile Stress.***

## I. INTRODUCTION

### A. *Fracture*

When a structure goes through some kind of stress, there is a development of cracks or it even breaks the structure into two separate parts. This development of cracks is called Fracture. Failure of a material can also be called as Fracture. The beginning of the causes of a fracture depends upon the irregularities of a material, such as pores, cracks, cavities, etc. The fracture usually starts within the material and then reaches the surface.

### B. *Modes of Fracture*

1) *Mode 1* - Opening Mode: A fracture displacement (tensile stress) normal to the crack surface.
2) *Mode 2* - Sliding Mode: Shear stress parallel to the crack and perpendicular to the crack front.
3) *Mode 3* - Tearing Mode: A shear stress parallel to the plane of the crack and parallel to the crack front. This is also caused because of sliding motion.

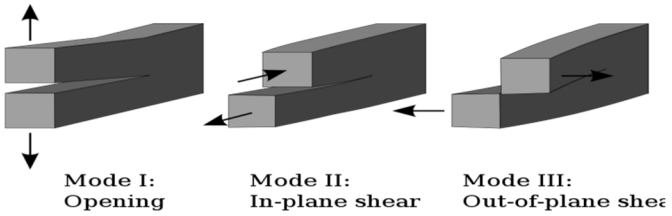



Fig 1. Modes of Failure.

### C. *Fracture Mechanics*

Fracture mechanics is the study of crack propagation. The analytical solid method is used to compute the driving force on a crack. It also helps to characterize the material's resistance to fracture. The theory of physics of stress-strain is applied to find the numbers, through which one can find the desired result through various types of calculations. This result helps during design. Various studies on the fracture surfaces of the material are done to understand and study the causes of failures, it is used with fracture mechanics. Damage tolerance is something that needs to consider during designing, as it tells us the ability of a structure to sustain defects until the repair of the structure is needed. And the main prediction to be made for Damage tolerance is the crack growth. Study crack growth tells us the reason and the amount of crack developing in the material. Many researchers have studied fracture mechanics in different forms such as experimental and analytical studies. To properly examine the fracture mechanics of material various factors are to be considered and they are, deformation behavior, failure behavior, and type of loading. The main problem while designing against fracture with high strength materials is that the existence of cracks can modify the stresses to such a proportion that the analyzed elastic stress does not match the indispensable design.

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There are two approaches to find out the deformation behavior. And they are Linear Elastic Fracture Mechanics (LEFM) or Elastic-Plastic Fracture Mechanics (EPFM). EPFM approach is more workable than LEFM.

Elastic-Plastic Fracture Mechanics - (EPFM): Elastic-Plastic Fracture Mechanics can analyze the fracture parameters like fracture energy and stress intensity factor. The Study of the rate of crack propagation and the crack surface is dependent on these two parameters. The two ways to find these fracture parameters are the direct and indirect methods. The direct method is contingent on material behavior. And the indirect method is contingent on size.

Linear Elastic Fracture Mechanics - (LEFM): When the size of the plastic zone around the crack tip is small in comparison with the domain size, which is a big problem, which causes a fracture. Linear Elastic Fracture Mechanics deals with these kinds of problems. LEFM helps in solving or finding out the safety and life expectancy of cracked structure and components.

### *D. Fracture Energy*

When the energy is squandered per unit area, it is called fracture energy. Fracture energy is always dissipated in the fracture process zone. The energy required for the crack extension is called fracture energy. The formula used to calculate fracture energy is an area under the load-deflection curve divided by the total crack area.

$$G_f = \frac{g_f(\alpha_0)}{A\,E_c}$$

Fig 2. Fracture Energy Formula.

Ec = Young's elastic modulus of concrete

A = slope of the size effect regression plot for failure

$G_f$ (αo} = non-dimensional energy release rate calculated according to linear elastic fracture mechanics.

Usually, for finding out fracture energy, the procedure recommended by RILEM is being used. At the point, when concrete fails in tension its deformation behavior is characterized by peak stress and the energy required to develop the crack. The tensile strength of the material is established at the peak stress, to control the crack propagation with great ease is a difficult task, fracture energy helps in controlling it.

### *E. Crack Propagation*

The structures are designed to withstand various types of loads and that too heavy load. While designing some factor of safety is considered for loading, so that the admissible stress is never attainted. In this study, fracture mechanics plays an important role as it helps in analyzing the material which exhibits cracks. The initial crack development is caused when the margin of security for loading is being breached while inherent flaws of the material and flaws during casting of the material. And from the initial development, the crack spreads, and various cracks are developed as the heavy load is still impacting the structure. The Activity of widespread of the cracks from the initial crack development is called as crack propagation. Analysis of crack propagation is necessary because it helps us understand the causes and also helps us correct the mistakes done while concrete mix or while handling the material.

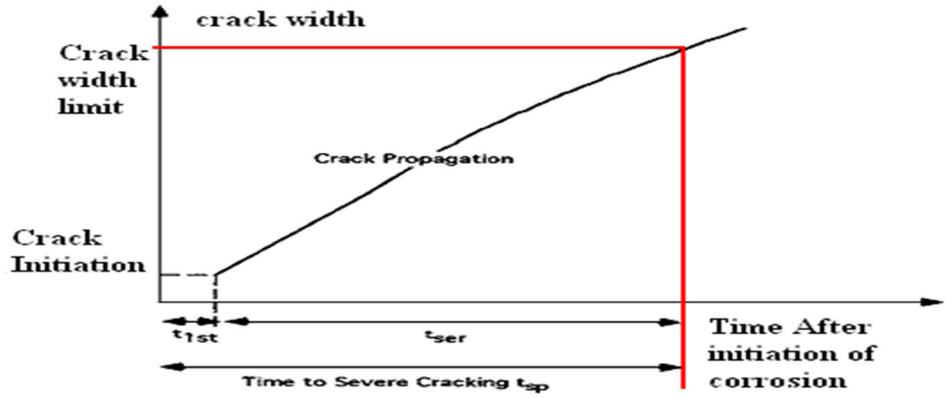



Fig 3. Crack Propagation.

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## II. REVIEW OF LITERATURE

*A. Tittle: Glass Fibre Reinforced Concrete*

*1) Authors:* Muhammed İSKENDER, Bekir KARASU

The author reported that

*a)* The Fundamentals of any material are the physical and mechanical properties of it. With the help of scientific studies and tests, the author has done enough to elucidate us that the two main factors that change the properties of GFRC are the Quality of Material and Accuracy of the Production method.

*b)* The use of Glass Fibre is an old and efficient way to reinforce concrete. But the endanger in using glass is that it is low alkali resistance to corrosion but the insertion of a high level of zirconium dioxide can neutralize that.

*c)* When fibres are added to the concrete, it increases the compressive strength. But if the fibre is added more than needed, then it gradually decreases the strength aspect.

*d)* One of the great applications of fibre reinforcement is that it resists the propagation of cracks and helps in reducing the sudden failure of the structure of concrete, increases load-carrying capacity in the concrete structure.

*B. Tittle: Experimental Studies On Glass Fiber Concrete*

*1) Authors:* J.D. Chaitanya Kumar, G.V. S Abhilash, P. Khasim Khan, G. Manikanta Sai, V. Taraka Ram.

The author indicated that

*a)* The special attributes of glass fibres are that it has high tensile strength and it is fire resistance. Therefore, it is sustainable during fire accidents and also helps in reducing the loss of damage.

*b)* In this experiment, E-Glass fibre has been used as it gives great properties like good electrical insulation and resistance to heat as well.

*c)* The best way to measure if the material is good enough to use in construction work is a detailed study of flexural strength. Flexural strength can be defined as the amount of stress and force a structure can withstand such that it resists any bending failure.

*d)* The Formula used to analyze the flexural strength in this experiment is:

Flexural Strength (Mpa) = $pl / bd2$

P=Failure Load

L=c/c distance

b=width of the specimen

d=Depth of the specimen.

*C. Tittle: Strength Aspects Of Glass Fibre Reinforced Concrete*

*1) Authors:* Avinash Gornale, S Ibrahim Quadri, S Mehmood, Quadri, Syed Md Akram Ali, Syed Shamsuddin Hussaini.

The authors noticed that:

*a)* Glass Fibre has various types like E-Glass, S-Glass, R-Glass, etc. But it can be also classified into thin, thick, long, short glass fibres. It's nothing but the ways to cut the fibre sheets into pieces according to the use. In that, thin and short hair-shaped glass fibres as very useful, it reduces the cracking while the concrete is stiffening but this ability works only within a few hours after the glass fibre is poured in the concrete mix.

*b)* The Glass Fibre used as reinforcement in the concrete is Cem-Fil Anti-Crack HD. It has a special ability to control and prevention of cracking in freshly mixed concrete, it has very high workability, etc. It has a modulus of elasticity of 72 Gpa.

*c)* To have various kinds of data for the profound study, slump cone tests were done on M-20, M-30, and M-40 with and without glass fibre. The addition of glass fibre in the slump cone test is a new concept but it is clearly observed that the increase in the volume of glass fibre results in loss of slump.

*D. Tittle: Glass Fibre Reinforced Concrete Use In Construction*

*1) Authors:* Pshtiwan N. Shakor, S.S Pimplikar.

The authors have reported that:

*a)* One downfall that the authors observed the glass fibre is that it loses a proportion of pristine strength when placed in a Portland cement setting.

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*b)* There is a way to replace the recommended seven-day curing period of AR Glass Fibre Reinforced Concrete. That is the addition of 5% of the polymer, without any moist curing.
*c)* To achieve maximum efficacy, the casted concrete should be installed in such a manner that the load is applied to the top part which is the uppermost surface during the casting of concrete in a mould.
*d)* If the weight of glass fibre keeps on increasing in normal concrete, it naturally affects the cohesiveness between the particles of concrete. Results in reducing the compressive strength, flexural strength, and tensile strength.

*E. Tittle: An Experimental Study On Tension Softening Behavior Of Fibre Reinforced Concrete*

*1) Authors:* K. Krupuavram, M.P. Surya Prakash.

The authors have indicated that:

*a)* One way of increasing tensile softening behavior and fracture energy is to increase the fibre % in the concrete mix. This trait is seen in steel fibre reinforced concrete.
*b)* There can be an increase in the static compressive strength from the normal or original compressive strength achieved by the concrete mix. But to give this boost of static compressive strength, fibre must be added. The range of increase of static compressive strength is from 0% to 25% of the initial compressive strength.
*c)* A characteristic that the steel fibre has which is better than glass fibre is that, even if the concrete is reinforced with traditional reinforcement. Steel fibre still helps in increasing some amount of compressive strength.
*d)* Fibre is usually added to the concrete mix in a random manner. But if fibre is added in the same alignment as the direction of tensile stress, then the tensile stress increases by 133%. And if it is randomly distributed, the tensile stress increases from a range of 0% to 60%.
*e)* Fibre reduced the permeability of concrete, which helps to reduce the water from bleeding.

*F. Tittle: Modified Fracture Energy Method For Fibre Reinforced Concrete*

*1) Author:* JUHÁSZ Károly Péter

The author noticed that

*a)* Re3 number and σ-ε diagram are the two different parameters through which the performance of the fibres can be measured. These two parameters are affected by or depend on the strength class of concrete and fracture energy.
*b)* The real effect of fibre starts to kick in when the cracks start appearing. Fibre helps in limiting the crack propagation, which cannot be done until the cracks do not start to appear. Till then the tensile strength of the concrete will be the same as it was before.
*c)* The most important function is, the fibres detaching from the concrete matrix. If this does not happen, the fibres will break and its effect will not be seen.
*d)* While calculating the ductility of concrete, the fracture energy considered is the area under the tensile stress (σ) and the crack mouth distance (w).

*G. Evaluation of the fracture energy methods used in fibre reinforced concrete pavements by the maximum undamaged defect size concept.*

*1) Authors:* Hossam El-Din Sallam, Muhammad Mubaraki

The authors have indicated that:

*a)* The fracture in every structure is not the same, it depends on various factors. And one of the factors is a notch-base fracture. The concept used to predict the type of fracture is the maximum undamaged defect size.
*b)* The strength of the material is not affected by the maximum undamaged defect-size. It just explains the maximum size of the defect present in a material.
*c)* RILEM (Reunion Internationale des Laboratories et Experts des Materiaux) committee 50-FMC (2l) has recommended formula to calculate the fracture energy.

Gf= Area of P-δ Curve / Net Area of the Cracked Section.

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*H. Experimental Study On Steel Fibre Reinforced Concrete For M-40 Grade*

*1) Authors:* A.M. Shende, A.M. Pande, M. Gulfam Pathan.

The authors have noticed that:

*a)* Steel fibre helps in neutralizing the concrete deficiencies like low tensile strength, limited fatigue life, incapable of accommodating large deformation, and low impact strength.

*b)* The inherent weakness of concrete. That is, the Micro-cracks on the mortar-aggregate surface can be nullified with the inclusion of steel fibres in the concrete mix.

*c)* The flexural strength is calculated by the formula: (P X L) / (b X d x d)

P = Failure Load.

L = Centre to centre distance between the support.

b = Width of specimen.

d = Depth of specimen.

## III. SPECIFICATIONS

*A. Glass Fibre*

| SR.NO | GLASS FIBRE PROPERTIES | QUANTITY | UNIT |
|---|---|---|---|
| 1. | Fibre Length | 12 | Mm |
| 2. | Aspect Ratio | 857 | ---- |
| 3. | Specific Gravity | 2.68 | g/cm cube |
| 4. | Modulus of Elasticity | 72 | Gpa |
| 5. | Tensile Strength | 1700 | Mpa |
| 6. | Chemical Resistance | Very High | ---- |
| 7. | Electrical Conductivity | Very Low | ---- |
| 8. | Softening Point | 860 | °C |
| 9. | Material | Alkali Resistant Glass | ---- |
| 10. | Shape | Straight | ---- |

*B. Steel Fibre*

| SR.NO | STEEL FIBRE PROPERTIES | QUANTITY | UNIT |
|---|---|---|---|
| 1. | Fibre Type | Crimped type fibre | ---- |
| 2. | Length | 30 | mm |
| 3. | Diameter | 0.5 | mm |
| 4. | Density | 7850 | Kg/m cube |
| 5. | Tensile Strength | 940 | Mpa |
| 6. | Aspect Ratio | 60 | ---- |

## IV. ADVANTAGES

*A. Glass Fibre*

*1)* Glass Fibre is light in weight. Lightweight makes it economical.

*2)* Addition of glass fibre results in an increase of tensile strength, flexural strength, and impact strength.

*3)* Fibres do not rust like steel, due to this trait of fibre, a protective concrete cover thickness to prevent rusting is not needed.

*4)* Shrinkage of cracks can be easily controlled by Alkali Resistance Glass Fibre.

*5)* Glass Fibre has very high electrical insulation, which makes it future-proof, by reducing the cost of installation and future inspections are reduced remarkably.

*6)* When compared with steel and aluminium, glass fibre has a significantly lower heat distribution gradient.

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*B. Steel Fibre*

*1)* Steel fibres, when used in concrete improves the crack, impact, and fatigue resistance.
*2)* They act as crack arrestors.
*3)* One of the main advantages of steel fibre is that it increases the tensile strength and toughness.
*4)* It shows great resistance to impact.
*5)* The Permeability, dusting, and wearing on the surface is reduced by the use of steel fibre.

## V. APPLICATIONS

*A. Glass fibre is Applied in the Following Cases*

*1)* Building Renovation work.
*2)* Acoustic barriers and screens.
*3)* Water and drainage work.
*4)* Architectural cladding.
*5)* Bridge and tunnel lining panels.
*6)* Permanent formwork method of construction.

*B. Steel Fibre Is Applied In The Following Cases*

*1)* Tunnel lining.
*2)* Sleepers.
*3)* Manholes.
*4)* Covers.
*5)* Risers.
*6)* Pipes.
*7)* Burial Vaults.
*8)* Curbs.
*9)* Septic Tank.

## VI. RESULTS AND DISCUSSION

*A. Tittle: Glass Fibre Reinforced Concrete*

*1)* The incorporation of glass fibre has a consequence of high compressive strength but the immoderate amount of glass fibre can result in a reduction of the strength of concrete due to a decrease in workability.
*2)* Modulus of elasticity is not affected by the use or addition of fibre in concrete.
*3)* Inclusion of Glass fibre as reinforcement in concrete has a positive effect on flexural strength and stress-strain curve. The reason is that the increase in aspect ratio and energy absorption makes it more effective.
*4)* Glass Fibre Reinforced Concrete mix is 50-70% lighter than the traditional concrete mix.
*5)* The most important observation that the authors made was, 6% fibre content concrete block had the highest flexural strength.

*B. Tittle: Experimental Studies On Glass Fiber Concrete*

*1)* The common thing concluded in compressive strength test, flexural strength tests a split tensile strength is that 1% fibre content concrete block has the highest compressive strength, flexural strength, and split tensile strength, whereas 0.5% fibre content concrete block has the lowest compressive strength, flexural strength and split tensile strength.
*2)* The authors concluded that the workability increases with the addition of fibre content only till 1% but after 1% when the fibre content is added the workability keeps on reducing.

*C. Tittle: Strength Aspects Of Glass Fibre Reinforced Concrete*

*1)* The workability reduces as the fibre content keeps on increasing, but this perplexity can be avoided by adding plasticizers or super-plasticizers.
*2)* It has been closely observed that the compressive strength and flexural strength gradually increases. Whereas, in the case of split tensile strength, a sudden spike of ultimate strength can be seen.

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3) The results which conclude the increase in compressive strength, flexural strength, and split tensile strength are observed to be 20% to 30%, 25% to 30%, and 25% to 30% at 3,7, and 28 days respectively when compared with 28 days strength of plain concrete.

*D. Tittle: Glass Fibre Reinforced Concrete Use In Construction*

1) 2% glass fibre content concrete block gave around 10% more flexural strength than 1.5% glass fibre content concrete block.
2) The ratio of ft/fc (tensile strength to compressive strength) is affected by the air entrainment in the concrete block. The Reason being, the compressive strength is lowered more than the tensile strength due to the presence of air. It results in the reduction of flexural strength.
3) The authors observed that the use of 20 mm coarse aggregate the air-entraining is increased, to resolve this issue of reduced flexural strength, a 10 mm coarse aggregate has been proven feasible.
4) Best results are obtained for 1.5% of the cementitious weight gained. Other percentage either results in bad workability or does not give the required compressive strength.

*E. Tittle: An Experimental Study On Tension Softening Behavior Of Fibre Reinforced Concrete*

1) The maximum tensile strength procured was in M70 grade concrete with 1.5% fibre content. That is 3.69 N/mm sq.
2) The authors precisely concluded that when there is an increase in fibre percentage, there is an increase in post-cracking in both high strength and normal strength concrete.
3) The results, uniaxial tensile strength of High strength concrete having 78.17-91.7 Mpa and in normal strength concrete the compressive strength being 44.5-60.5 Mpa.

*F. Tittle: Modified Fracture Energy Method For Fibre Reinforced Concrete*

1) The sigma (crack opening relationship between two different concrete points) was the same after 0.375mm.
2) The value of fracture energy during the crack opening is not the same as the newly added fracture energy. And keeping this in mind, the fracture energy cannot be considered as the only way to model the fibre reinforced concrete.
3) The author also concluded that the added fracture energy is in relation to the cement grout and does not depend upon the fracture energy of the concrete.

*G. Evaluation Of The Fracture Energy Methods Used In Fibre Reinforced Concrete Pavements By The Maximum Undamaged Defect Size Concept*

1) In comparison between steel fibre and glass fibre, the maximum value of CMOD a deflection is greater in steel fibre but the condition being, same crack-depth ratio.
2) In maximum load, the steel fibre had a lower value than glass fibre.
3) The fracture energy was calculated by the formula given from RILEM Committee 50-FMC. The result showed that the notched beam with high values were more stable and reliable.
4) To evaluate the precision of calculating fracture energy, the maximum undamaged defect size has proven reliable and feasible.

*H. Experimental Study On Steel Fibre Reinforced Concrete For M-40 Grade*

1) 3% fibre content concrete beams have the highest compressive strength, split-tensile strength, and flexural strength as compared to 0%, 1%, 2% fibre content concrete beams.
2) Aspect ratio 50 has the highest strength properties when compared with other aspect ratios.
3) After the addition of fibres, it is evident that there is an increase in compressive strength, flexural strength, and split-tensile strength by 11 to 24%, 12 to 49%, and 3 to 41% respectively.

## VI. CONCLUSION

The modern way of construction is complex, competitive, and has to be aesthetically good. To fulfil all of these needs, concrete structures are built in small areas and small gaps. And in these small gaps, it is not possible to reinforce concrete with steel. In such cases, fibre is used as reinforcement. With the above research, it's evident that when fibre used as reinforcement in concrete

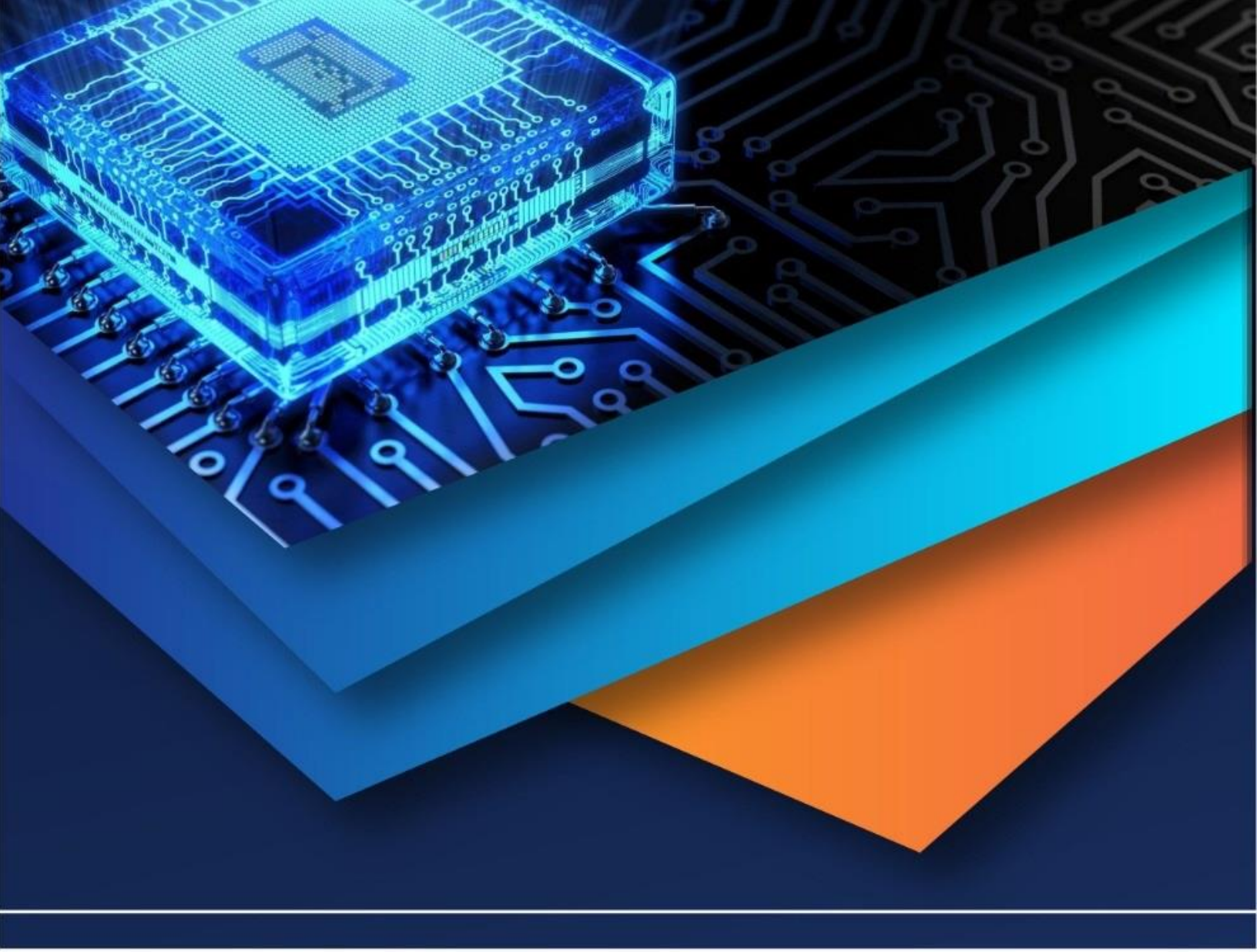
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increases the compressive strength, flexural strength, and split-tensile strength. Not as much as steel, but significantly higher than the plain concrete. The research above proves that 1% fibre content concrete beams/blocks have the highest strength properties. As the fibre percentage keeps on increasing, the workability of the concrete mix keeps on decreasing gradually. The Water-Cement ratio plays a vital role in the workability of concrete. A good water-cement ratio determined from various papers is 0.45. The one great trait that the fibre has over steel is that it is fire resistant to some degree. Utilizing fibre in future construction techniques will not only be feasible but also be economical.

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