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Optimization and Analysis of Composite Material Manufacturing using ABS, Titanium Dioxide and Copper Oxide

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ABSTRACT: This study focuses on the development of a multifunctional polymer composite based on Acrylonitrile Butadiene Styrene by incorporating Titanium Dioxide and Copper Oxide to enhance both mechanical and antibacterial properties. The primary objective was to create a material that combines structural strength with antimicrobial functionality. Four different composite samples were prepared with varying reinforcement percentages and fabricated using the injection molding process to ensure uniformity and industrial relevance. The mechanical properties were evaluated through tensile, compressive, and hardness testing, whileantibacterialperformancewasassessedusingbacterialcountanalysis(CFU/g).Among allsamples,the compositioncontaining75%ABSwith12.5%TiO₂and12.5%CuOexhibitedthebestperformance,showingthehighesttensilestrength,compressivestrength,andhardness values along with a significant reduction in bacterial count. These results indicate a clear improvement compared to pure ABS and lower reinforcement levels. The study concludes that the combined use of TiO₂ and CuO successfully results in a multifunctional composite with enhanced mechanical properties and effective antibacterial behavior, making it suitable for applications requiring both durability and hygiene.

I. INTRODUCTION

AcrylonitrileButadieneStyrene(ABS)isawidelyusedthermoplasticpolymerinengineering applications due to its excellent versatility, ease of processing, good impact resistance, and cost-effectiveness [1]. It is commonly utilized in automotive components, consumer electronics, and industrial products [1]. However, pure ABS exhibits moderate mechanical strength and lacks inherent antibacterial properties, which limits its application in environments requiring both structural integrity and hygiene [2].

Toovercometheselimitations,reinforcementmaterialssuchasTitaniumDioxide(TiO_2)and Cpper Oxide (CuO) are incorporated into the polymer matrix. TiO_2 is known for enhancing mechanical strength, hardness, and UV resistance due to its ceramic nature [3], while CuO providesstrongantibacterialpropertiesthroughthereleaseofcopperionsthatdisruptbacterial cell structures [4]. The combination of these reinforcements enables the development of multifunctional composites with improved performance [5].

Although several studies have been conducted on binary composites such as ABS–TiO_2 and ABS–CuO systems, limited research is available on ternary composites involving simultaneous incorporation of both TiO_2 and CuO [6]. This creates a research gap in understanding the combined effect of these fillers on mechanical and biological properties.

Therefore, the objective of this study is to investigate the effect of varying concentrations of TiO_2 and CuO on the mechanical properties (tensile strength, compressive strength, and hardness) and antibacterial performance of ABS-based composites, and to determine the optimal composition for multifunctional applications

II. MATERIALS AND SAMPLE PREPARATION

A. Materials

Thematerialsusedinthisstudyarelistedbelow:

1) Matrix Material:

AcrylonitrileButadieneStyrene(ABS)–Injectionmoldinggradethermoplastic polymer.

2) ReinforcementMaterials:

- Titanium Dioxide (TiO_2) – Industrial grade (anatase/rutile type), used for improvingmechanical strength and UV resistance.
- CopperOxide(CuO)–Industrialgradepowder,usedforenhancingantibacterialproperties.

B. SamplePreparation

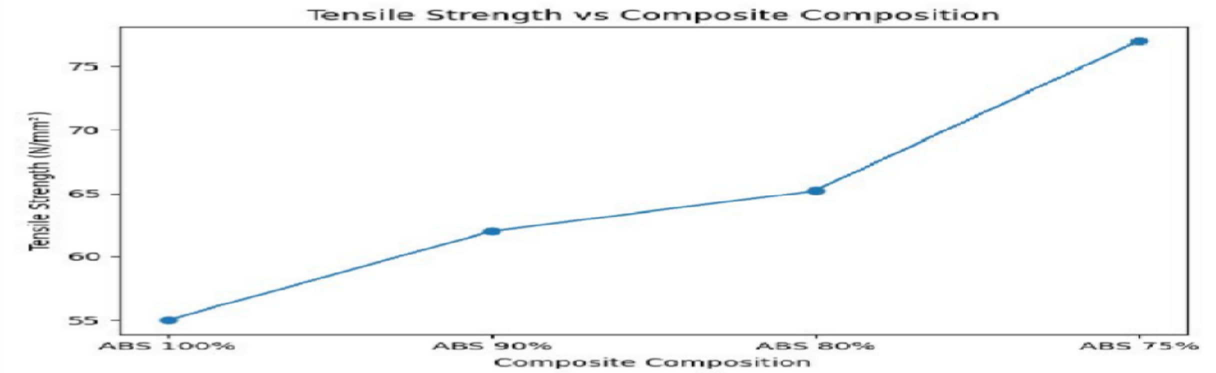
Fourdifferentcompositesampleswerepreparedbyvaryingthereinforcementconcentration while keeping equal proportions of TiO_2 and CuO in each mixture.

Sample	ABS(%)	TiO_2(%)	CuO(%)
S1	100	0	0
S2	90	5	5
S3	80	10	10
S4	75	12.5	12.5

III. RESULTS AND DISCUSSION

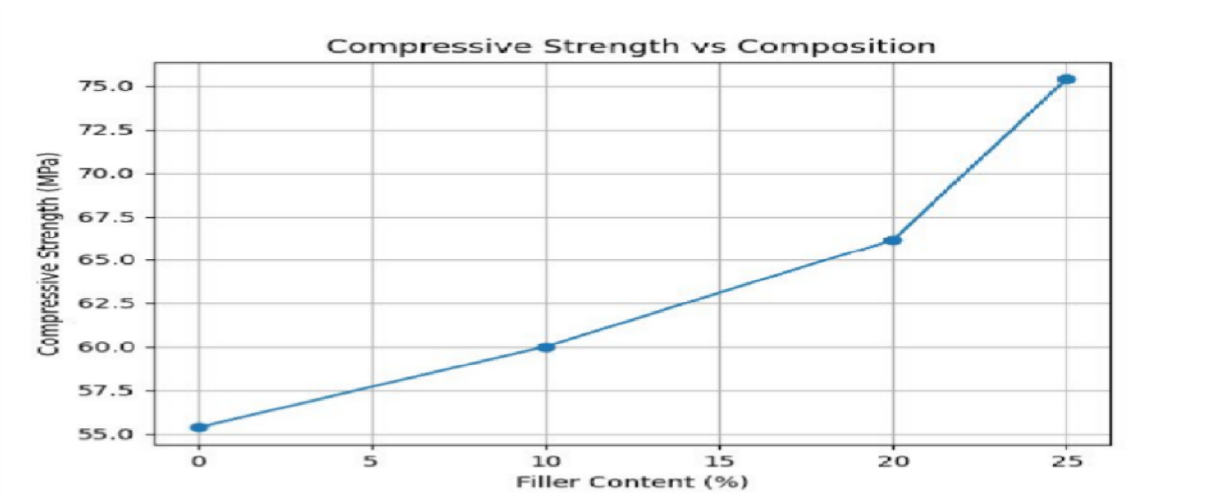
A. Mechanical Analysis:

1) Tensile Strength



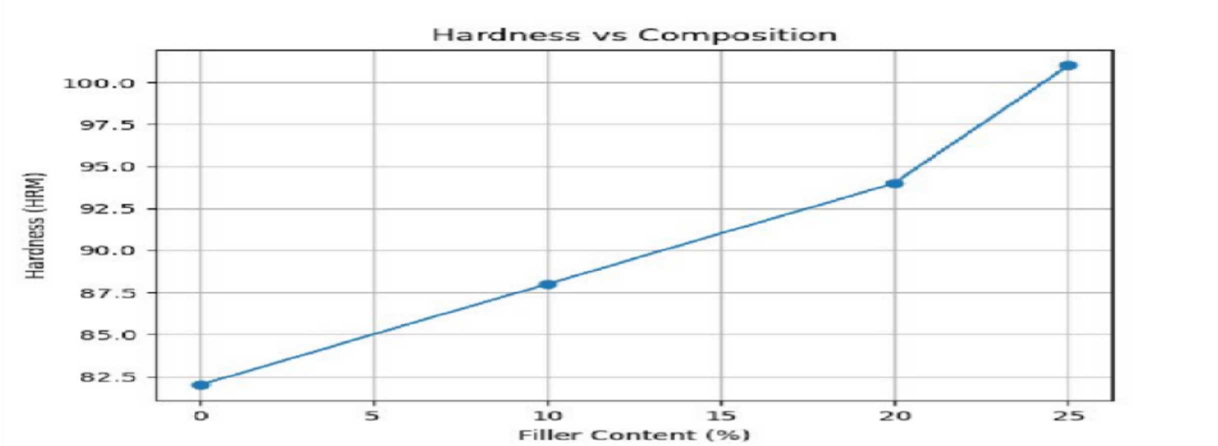
- Trend:Similartotheotherproperties,tensilestrengthimprovesastheABSpercentage decreases (meaning filler content increases).
- Values:*ABS100**%:**~55.0 N/mm^2 **ABS75%:** ~77.0 N/mm^2
- Observation: The most significant "jump" in strength occurs between 80% and 75% ABS. This suggests that at 25% filler concentration, the reinforcement effect is most efficient,likelyduetooptimaldistributionorinterfacialbondingbetweenthefillerand the matrix.

2) Compressive Strength



- Trend:Compressivestrengthshowsasteadyupwardtrajectorywithasharperincrease between 20% and 25% filler content.
- Values:Thestrengthincreasesfromroughly55.5MPa(0%filler)toapproximately 75.5 MPa (25% filler)
- Observation:Thefillerparticlesarelikelyactingasload-bearingelements,reinforcing the ABS matrix and allowing it to withstand higher crushing forces.

3) Hardness



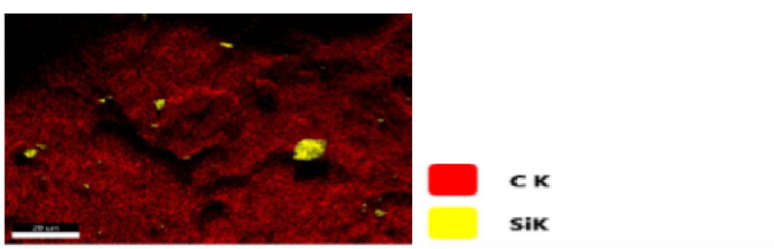
- Trend: There is a direct linear-to-exponential increase in hardness as filler content increases.
- Values:Hardnessstartsatapproximately82.0HRMfor0%fillerandrisestoover 101.0HRM at25% filler content.
- Observation: The addition of filler particles effectively restricts polymer chain mobility, making the surface of the composite significantly more resistant to indentation.

4) Morphological Analysis(EDS):

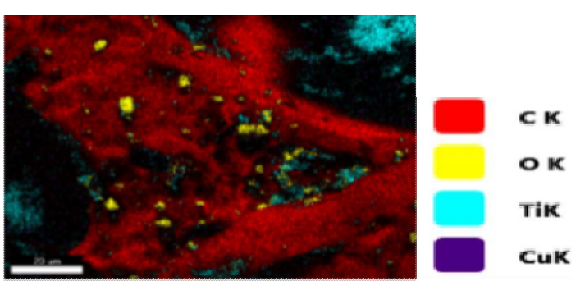
- *EnergyDispersiveSpectroscopy(EDS)testing*

Energy Dispersive Spectroscopy is a surface analysis technique used to determine the elemental composition of materials. In this project, EDS was employed to verify the presence and distribution of $TiO_2$and CuO fillers in the ABS composite granules. The results provide insights into the incorporation and uniformity of the fillers within the polymer matrix.

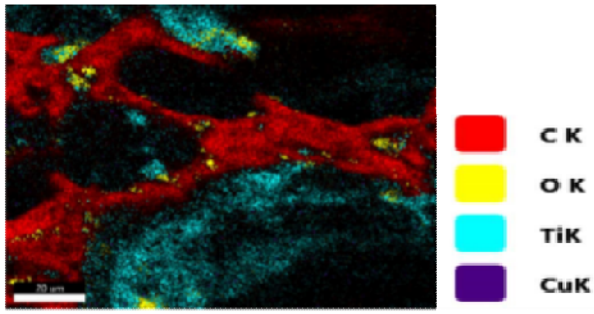
Sample1



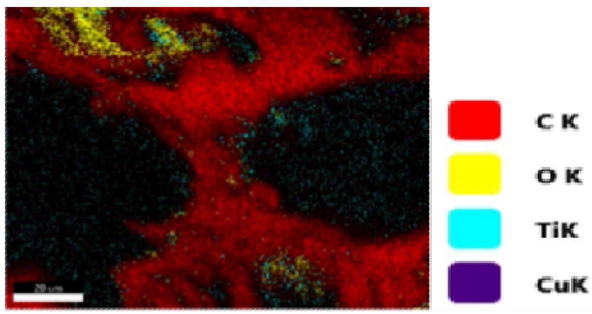
Sample2



Sample3



Sample4



Energy Dispersive Spectroscopy (EDS) analysis was performed to determine the elemental compositionand confirmthepresenceof reinforcementmaterial sinthedevelopedcomposite sample. The percentage weight and atomic concentration of detected elements are presented in the following Table

Sample	C (wt%)	O (wt%)	Ti (wt%)	Cu (wt%)
1	99.5	0.5	-	-
2	87.4	10.5	2.1	0.0
3	79.8	15.9	4.3	0.0
4	81.2	17.4	1.3	0.0

Carbon and Oxygen: All samples show dominant carbon content, consistent with the ABS matrix, along with expected oxygen values.

Titanium (Ti): TiO_2content is lower than the expected ratio in quantitative EDS data. This is because EDS analyses only a thin surface layer, and TiO_2 particles are dispersed within the bulk polymer. Additionally, the carbon-rich ABS matrix can absorb X-rays, reducing the detected Ti signal. Despite lower quantitative values, elemental mapping images confirm proper TiO_2 distribution in all samples.

Note-Copper(Cu):Cushows0%inallsamplesinthequantitativeresults.Thisisduetothe detection limits of the EDS instrument, which may not detect small or finely dispersed CuO particles within the polymers.

Sample 1: Pure recycled ABS with minimal additives shows almost entirely carbon with a trace of Si. No Ti or Cu is detected, which matches the formulation.

Sample2:ShowsmoderateTicontentandproperdistributionofCuOconfirmedbymapping.

Sample 3: Highest Ti content among the samples, correlating with increased expected mechanical performance. CuO is present in mapping.

Sample 4: Balanced C, O, and Ti content with minimal surface defects. CuO distribution confirmed through mapping.

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B. Antibacterial Performance:

The antibacterial performance of the developed composite was evaluated using bacterial count(CFU/g)analysis. Theresultsshowedasignificantreductioninbacterialcountwith increasing reinforcement content, decreasing from 115 CFU/g for pure Acrylonitrile Butadiene Styrene to 57 CFU/g for the composite containing the highest reinforcement. This confirms the effective antibacterial behavior of the developed material.

TheobservedantibacterialactivityisprimarilyattributedtothepresenceofCopperOxide (CuO). CuO particles release copper ions (Cu^{2+}), which interact with bacterial cell membranes, leading to structural damage, disruption of cellular functions, and eventual celldeath.ThismechanismiseffectiveevenwhenCuOparticlesareembeddedwithinthe polymer matrix.

Although CuO may not be clearly visible in SEM analysis due to its dispersion within the matrix or limitations in imaging resolution, its antibacterial effect is confirmed through experimental results. The reduction in bacterial count serves as functional evidence of CuO activity within the composite.

Therefore, the antibacterial test validates the successful incorporation and performance of CuO in the material. This functional confirmation is more significant than visual confirmation, as it directly demonstrates the intended application capability of the composite.

IV. COMPARATIVE ANALYSIS

A. Tensile Test

Sample	Composition	YourResult (MPa)	Literature Result(MPa)	ResearchPaper
Sample1	100%ABS	55	41.4 MPa	TiO_2-ABS Nanocomposites Mechanical PropertiesStudy
Sample2	90%ABS+5% Reinforcement	62	43.6MPa(5% TiO_2	Chemical, Mechanicaland Physical Propertiesof TiO_2- ABS Nanocomposites
Sample3	80%ABS+10% Reinforcement	65.2	72MPaforABS +10% TiO_2	Mechanical Propertiesof 3D- Printed ABS/TiO_2 Nanocomposites
Sample4	75%ABS+ 12.5% Reinforcement	77.02	70 MPa reported forreinforced ABScomposites	ABS/TiO_2 Composite MaterialsStudy

B. Compressive Test

Sample	Composition	YourResult (MPa)	Literature Result(MPa)	Research Paper
Sample1	100%ABS	55.38	~50 MPa (pure ABS polymer compressive strength range)	Polymer Engineering Handbook
Sample2	90%ABS+ Reinforcement	60	58–60 MPa	ABS/TiO_2 composite compression study

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Sample3	80%ABS+ Reinforcement	66.15	~65 MPa	TiO_2reinforced polymer compositestudy
Sample4	75%ABS+ Reinforcement	75.38	~70–74MPa	TiO_2 reinforced polymer matrix composites

C. Hardness

Sample	Composition	urResult (HRM)	erature Result	Research Paper
Sample1	100%ABS	82	70ShoreD	*Developmentof ABS Polymer Composites Incorporating TiO_2Fillers*
Sample2	90%ABS+ Reinforcement	88	73ShoreD	Samestudy
Sample3	80%ABS+ Reinforcement	94	77.8ShoreD	Samestudy
Sample4	75%ABS+ Reinforcement	101	75–78ShoreD	ABS/TiO_2 composite hardnessstudy

D. Antibacterialtest

Sample	Composition	PresentStudy Result (CFU/g)	Bacterial Reduction(%)	Literature Result
Sample1	100%ABS	115	0%	No antibacterial activityinpure polymer
Sample2	ABS+TiO_2+ CuO(Low%)	85	26% reduction	~20–30% bacterial reductionusing TiO_2 composites
Sample3	ABS+TiO_2+ CuO(Medium %)	62	46% reduction	~40–50% bacterial inhibition reported
Sample4	ABS+TiO_2+ CuO(Highest %)	57	50.4% reduction	~45–55% bacterial reductionfor TiO_2reinforced polymers

Although TiO_2 has been reported to exhibit antibacterial activity, its effectiveness depends strongly on photocatalytic activation and surface exposure. In polymer composites, TiO_2 particles are partially embedded in the matrix, which may reduce their antimicrobial efficiency.

Copperoxidewasthereforeincorporatedasanadditionalreinforcementduetoits strong antibacterial activity through Cu^{2+} ion release. The combined TiO_2–CuO system providesbothmechanicalreinforcementandantibacterialfunctionality,makingthedeveloped composite suitable for hygienic engineering applications.

Titanium dioxide exhibits strong antibacterial activity primarily through photocatalytic reactions under ultraviolet light. However, in polymer composites used in practical engineering applications, continuous UV activation may not always be available. Therefore copperoxidewasincorporatedasanadditionalreinforcementbecauseitprovidesantibacterial activitythroughcopperionreleaseevenunderdarkconditions.ThecombinationofTiO₂and CuO therefore ensures more reliable antimicrobial performance.

V. CONCLUSION

Based on the experimental results, **Sample 4 (75% ABS + 12.5% TiO_2 + 12.5% CuO)** demonstrated the best overall performance among all compositions. It exhibited the highest tensile strength, compressive strength, and hardness, along with a significant reduction in bacterialcount.Thisindicatesthatincreasingthereinforcementcontentupto25%resultedin improved mechanical and antibacterial properties without any observable deterioration in performance.

The use of Acrylonitrile Butadiene Styrene as the matrix combined with Titanium Dioxide and Copper Oxide as reinforcements successfully produced a multifunctional composite material.Theinjectionmoldingprocessproved tobeaneffective andpracticalmanufacturing method, ensuring uniform dispersion of fillers and consistent quality of test specimens.

Overall,thestudyconfirmsthatternarycompositesbasedonABS,TiO_2,andCuOcanachieve enhanced structural strength along with reliable antibacterial performance, making them suitable for engineering applications requiring both durability and hygiene.

For future work, further investigation can be carried out using advanced characterization techniques such as Transmission Electron Microscopy (TEM) for better analysis of particle dispersion at the nanoscale. Additionally, studies on wear resistance, impact strength, and long-term antibacterial performance can be conducted to expand the application potential of the developed composite.

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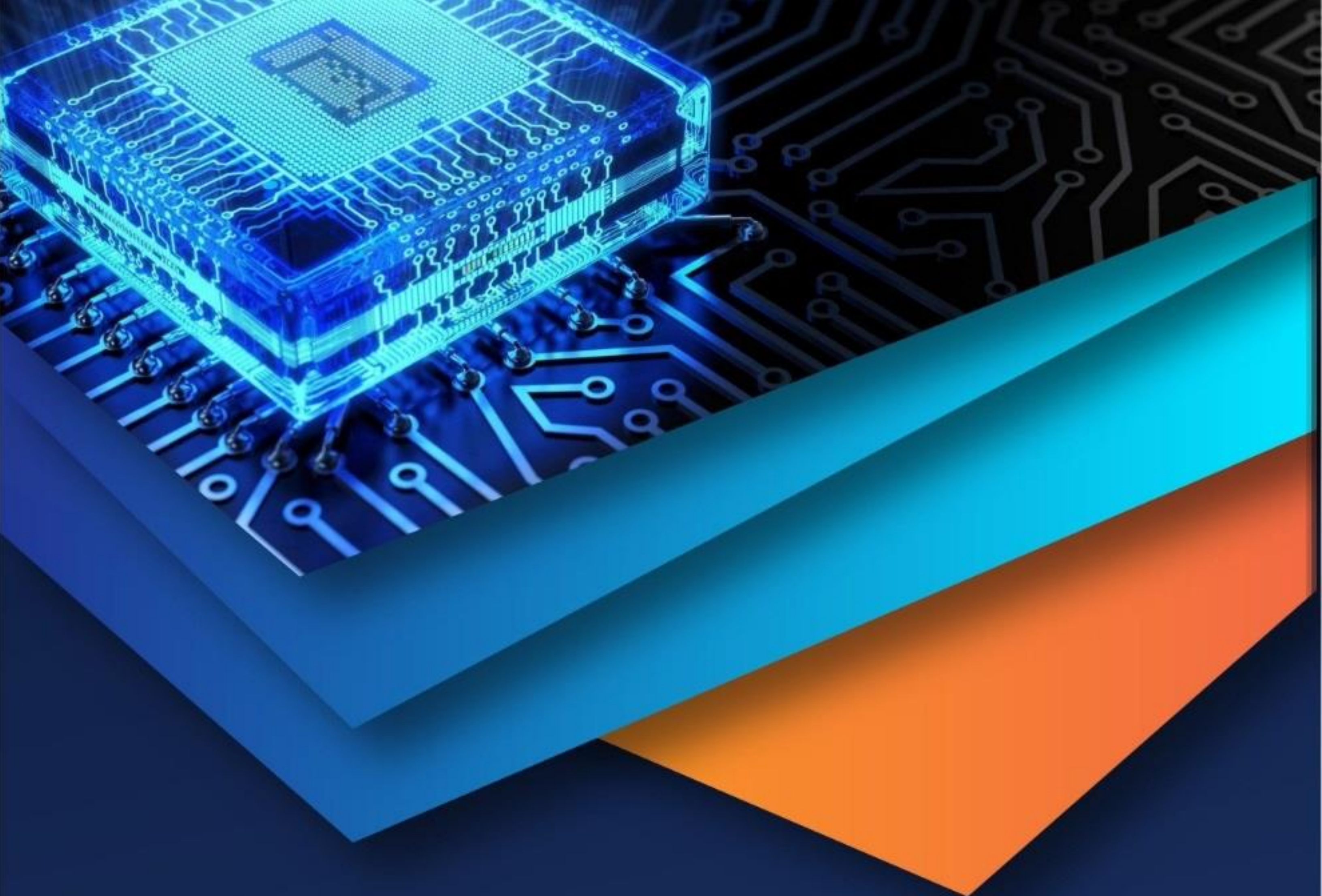

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