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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, while antibacterial performance was assessed using bacterial count analysis (CFU/g). Among all samples, the composition containing 75% ABS with 12.5% TiO₂ and 12.5% CuO exhibited the best performance, showing the highest tensile strength, compressive strength, and hardness 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

Acrylonitrile Butadiene Styrene (ABS) is a widely used thermoplastic polymer in engineering 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].

To overcome these limitations, reinforcement materials such as Titanium Dioxide (TiO₂) and Copper Oxide (CuO) are incorporated into the polymer matrix. TiO₂ is known for enhancing mechanical strength, hardness, and UV resistance due to its ceramic nature [3], while CuO provides strong antibacterial properties through the release of copper ions that disrupt bacterial 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-TiO₂ and ABS-CuO systems, limited research is available on ternary composites involving simultaneous incorporation of both TiO₂ 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 TiO₂ 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

The materials used in this study are listed below:

1) Matrix Material:

Acrylonitrile Butadiene Styrene (ABS) – Injection molding grade thermoplastic polymer.

2) Reinforcement Materials:

- Titanium Dioxide (TiO₂) – Industrial grade (anatase/rutile type), used for improving mechanical strength and UV resistance.
- Copper Oxide (CuO) – Industrial grade powder, used for enhancing antibacterial properties.

B. Sample Preparation

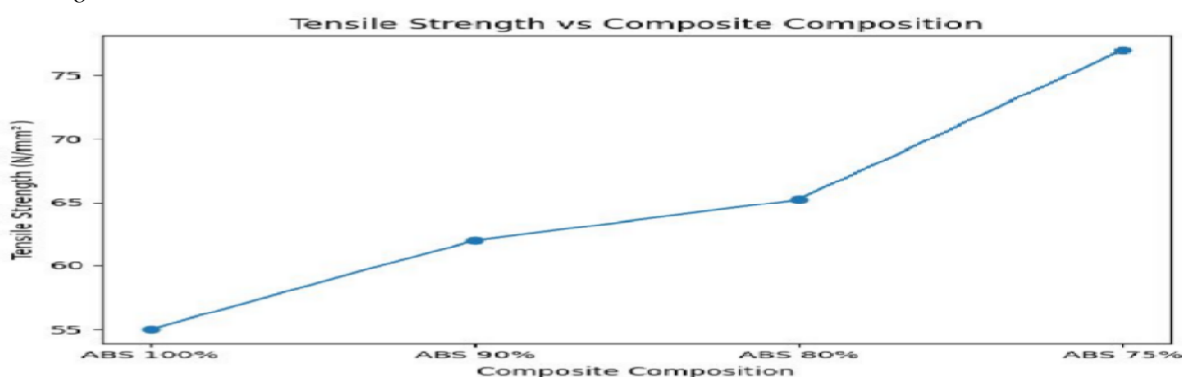
Four different composite samples were prepared by varying the reinforcement concentration while keeping equal proportions of TiO₂ and CuO in each mixture.

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

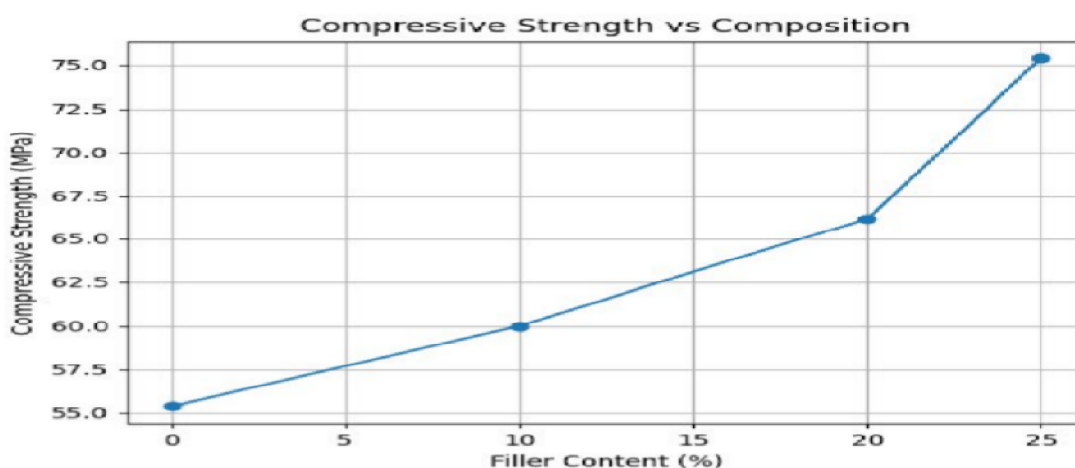
A. Mechanical Analysis:

1) Tensile Strength



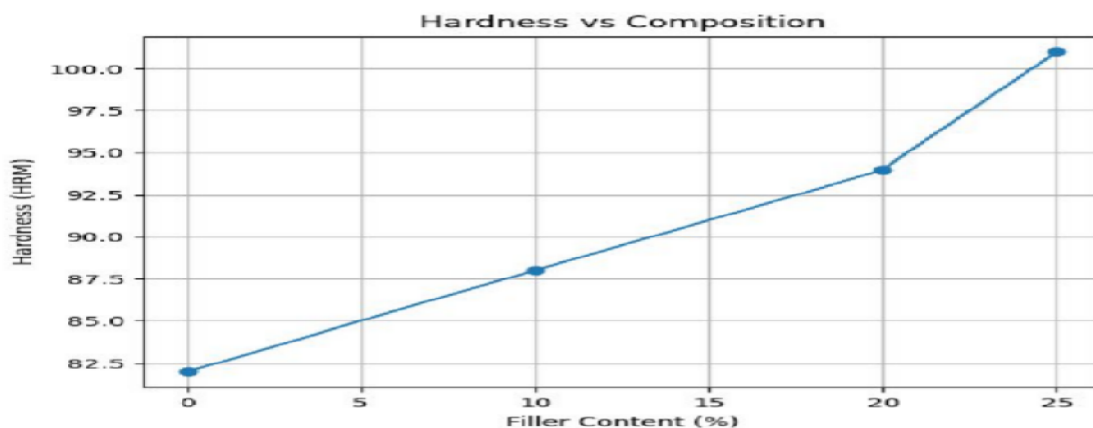
- Trend: Similar to the other properties, tensile strength improves as the ABS percentage decreases (meaning filler content increases).
- Values: *ABS 100%*: ~55.0 N/mm² *ABS 75%*: ~77.0 N/mm²
- Observation: The most significant "jump" in strength occurs between 80% and 75% ABS. This suggests that at 25% filler concentration, the reinforcement effect is most efficient, likely due to optimal distribution or interfacial bonding between the filler and the matrix.

2) Compressive Strength



- Trend: Compressive strength shows a steady upward trajectory with a sharper increase between 20% and 25% filler content.
- Values: The strength increases from roughly 55.5 MPa (0% filler) to approximately 75.5 MPa (25% filler)
- Observation: The filler particles are likely acting as load-bearing elements, reinforcing the ABS matrix and allowing it to withstand higher crushing forces.

3) *Hardness*



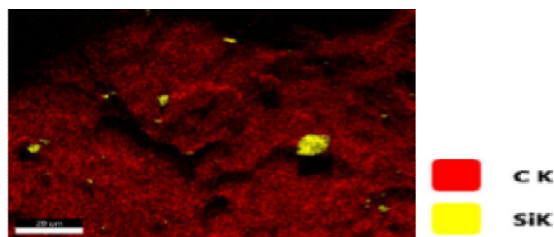
- Trend: There is a direct linear-to-exponential increase in hardness as filler content increases.
- Values: Hardness starts at approximately 82.0 HRM for 0% filler and rises to over 101.0 HRM at 25% filler content.
- Observation: The addition of filler particles effectively restricts polymer chain mobility, making the surface of the composite significantly more resistant to indentation.

4) *Morphological Analysis(EDS):*

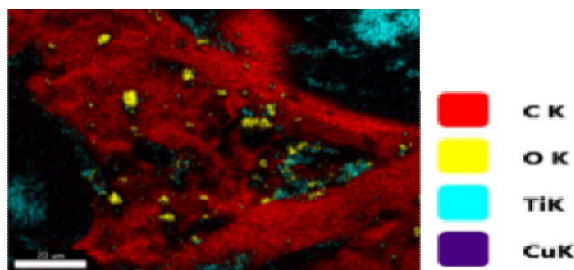
- *Energy Dispersive Spectroscopy(EDS) testing*

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 TiO₂ and CuO fillers in the ABS composite granules. The results provide insights into the incorporation and uniformity of the fillers within the polymer matrix.

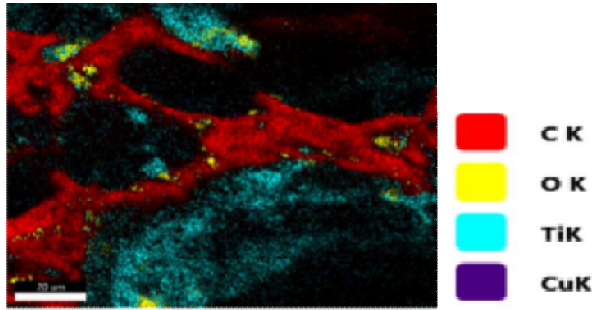
Sample1



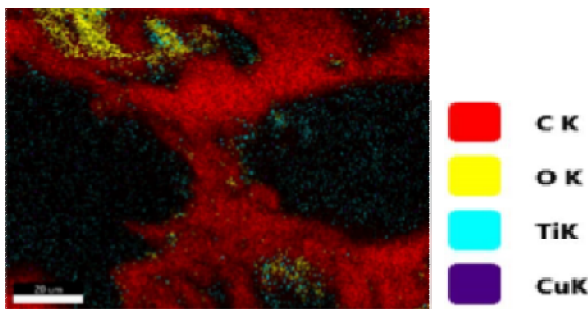
Sample2



Sample3



Sample4



Energy Dispersive Spectroscopy (EDS) analysis was performed to determine the elemental composition and confirm the presence of reinforcement material in the developed composite 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): TiO₂ content is lower than the expected ratio in quantitative EDS data. This is because EDS analyses only a thin surface layer, and TiO₂ 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 TiO₂ distribution in all samples.

Note-Copper(Cu): Cu shows 0% in all samples in the quantitative results. This is due to the 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.

Sample 2: Shows moderate Ti content and proper distribution of CuO confirmed by mapping.

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.

B. Antibacterial Performance:

The antibacterial performance of the developed composite was evaluated using bacterial count(CFU/g)analysis. The result showed a significant reduction in bacterial count with 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.

The observed antibacterial activity is primarily attributed to the presence of Copper Oxide (CuO). CuO particles release copper ions (Cu²⁺), which interact with bacterial cell membranes, leading to structural damage, disruption of cellular functions, and eventual cell death. This mechanism is effective even when CuO particles are embedded within the 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	Your Result (MPa)	Literature Result (MPa)	Research Paper
Sample1	100% ABS	55	41.4 MPa	TiO ₂ -ABS Nanocomposites Mechanical Properties Study
Sample2	90% ABS+5% Reinforcement	62	43.6MPa(5% TiO ₂)	Chemical, Mechanical and Physical Properties of TiO ₂ - ABS Nanocomposites
Sample3	80% ABS+10% Reinforcement	65.2	72MPa for ABS +10% TiO ₂	Mechanical Properties of 3D- Printed ABS/TiO ₂ Nanocomposites
Sample4	75% ABS+ 12.5% Reinforcement	77.02	70 MPa reported for reinforced ABS composites	ABS/TiO ₂ Composite Materials Study

B. Compressive Test

Sample	Composition	Your Result (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

Sample3	80% ABS+ Reinforcement	66.15	~65 MPa	TiO ₂ reinforced 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	<i>Development of ABS Polymer Composites Incorporating TiO₂ Fillers</i>
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	Present Study Result (CFU/g)	Bacterial Reduction(%)	Literature Result
Sample1	100% ABS	115	0%	No antibacterial activity in pure polymer
Sample2	ABS+TiO ₂ + CuO(Low%)	85	26% reduction	~20–30% bacterial reduction using 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 reduction for TiO ₂ reinforced polymers

Although TiO₂ has been reported to exhibit antibacterial activity, its effectiveness depends strongly on photocatalytic activation and surface exposure. In polymer composites, TiO₂ particles are partially embedded in the matrix, which may reduce their antimicrobial efficiency.

Copper oxide was therefore incorporated as an additional reinforcement due to its strong antibacterial activity through Cu²⁺ ion release. The combined TiO₂–CuO system provides both mechanical reinforcement and antibacterial functionality, making the developed 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 copper oxide was incorporated as an additional reinforcement because it provides antibacterial activity through copper ion release even under dark conditions. The combination of TiO₂ and CuO therefore ensures more reliable antimicrobial performance.

V. CONCLUSION

Based on the experimental results, **Sample 4 (75% ABS + 12.5% TiO₂ + 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 bacterial count. This indicates that increasing the reinforcement content up to 25% resulted in 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. The injection molding process proved to be an effective and practical manufacturing method, ensuring uniform dispersion of fillers and consistent quality of test specimens.

Overall, the study confirms that ternary composites based on ABS, TiO₂, and CuO can achieve 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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