iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** VI **Month of publication:** June 2025

DOI: https://doi.org/10.22214/ijraset.2025.72002

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

Improved Crashworthiness of Automotive A-Pillars Through Hybrid Composite Reinforcement: An Experimental Study on Tensile and Compressive Performance

Arjun Alias Ajay U. Shimpi[1], Kedar H. Inamdar[2], Aniket C. Patil[3]
Department of Mechanical Engineering, Walchand college of engineering, Sangli, INDIA

Abstract: This study investigates the structural enhancement of automotive A-pillars using a hybrid composite filler composed of epoxy resin, hardener, crushed wood, and glass fibre. The research compares the mechanical performance of hollow mild steel tubes with their composite-filled counterparts through rigorous tensile and compression testing. The Result demonstrated a 23.6% improvement in tensile strength and a 25.6% increase in compressive load capacity for the composite-filled specimens, along with superior energy absorption and controlled deformation. These findings highlight the potential of hybrid composites to optimize crashworthiness while maintaining lightweight design principles, offering significant implications for automotive safety engineering.
Keywords: Automotive A-pillar, epoxy resin, glass fibre, crushed wood filler, hybrid composite, tensile strength, compressive resistance, crashworthiness, lightweight materials, structural reinforcement

I. INTRODUCTION

Automotive A-pillars (shown in Fig. 1) are critical structural components that ensure passenger safety during collisions, particularly in rollover and side impact scenarios [1]. Traditional designs rely on thick steel sections to satisfy safety standards, often at the expense of increased vehicle weight and fuel inefficiency. Recent advancements in composite materials have provided new avenues for lightweight and robust structural solutions [2].

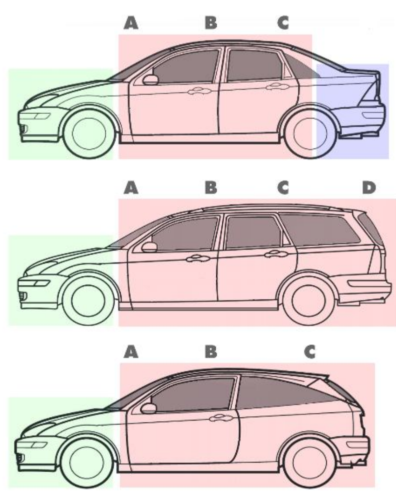


Fig. 1 Typical configurations and placements of support pillars in (a) sedan, (b) hatchback, and (c) station wagon body styles [3].

This study builds on prior research by, who explored composite reinforcements in centre pillars and extended the investigation to A-pillars using a novel hybrid filler system [4]. The filler combines epoxy resin for adhesion, glass fibre for stiffness, and crushed wood for energy dissipation—a synergy inspired by the work on natural fillers in epoxy matrices [5], [6], [7]. By experimentally validating this approach, this study addresses gaps in real-world applicability, as noted in their review of A-pillar modifications [8,9].

The objectives of this study wear as follows:

- The study examines the tensile and compressive performance gains achieved through hybrid composite reinforcement [10].
- Analysis of failure modes and energy-absorption mechanisms.
- To give experimental insights for automotive designers to balance weight reduction for crashworthiness of the material [11].

II. MATERIALS AND FABRICATION

The base structures of the test samples were fabricated using square mild-steel tubes. Dimensions of each tube were kept as 25.4 mm × 25.4 mm with a wall thickness of 0.8 mm and a total length of 203.2 mm. A composite mixture of epoxy resin and hardener was used as a filler material. To enhance the mechanical properties of the filler, crushed wood and chopped glass fibres were added to the resin mixture.

During fabrication process, the mild steel square tubes made firstly. The Steel sheets were first cut to the required size and then bent into a square cross sectional profile. These profiles then welded to form closed hollow tubes. After making hollow steel structures filler materials were prepared. The Epoxy resin was mixed with an appropriate amount of hardener. A mixture of evaluated quantities of crushed wood and glass fibre material wear added to this mixture to form a composite filler.

The resulting composite mixture then carefully poured into the hollow steel tubes to ensure complete filling of the square tube internal cavity. The filled specimens then kept for the curing process. The curing was done at room temperature for a period of 15 days to allow the resin matrix to harden and bond effectively with the steel structure which formed solid composite specimens [12].

Fig. 1. Step-by-step fabrication flowchart (cutting (1) → Shaping (2,3&3) → welding (6).

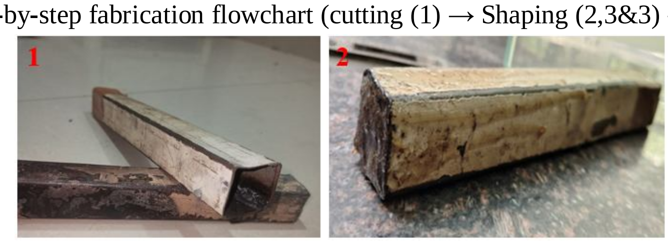


Fig. 2. Images showing Cross-sections of hollow (1) vs. composite-filled (2) tubes specimen.

Two distinct types of test specimens were prepared for the study:

1) Hollow A-pillar Specimen: These specimens consisted solely of the steel square tubes without any internal filling. They represent the baseline or reference structural condition.

2) Solid or Resin-Filled A-pillar Composite Specimen: These specimens were fabricated by filling the hollow steel tubes with the prepared epoxy-based composite mixture (epoxy resin + hardener + crushed wood + glass fibre). The result was a solid composite structure intended to replicate enhanced A-pillar designs with improved structural and energy-absorbing capabilities.

III. EXPERIMENTAL SETUP

Mechanical characterization of the test specimens was performed using a Universal Testing Machine (UTM) with a maximum load capacity of 100 kN. experiments were designed to evaluate the structural performance of both hollow and composite-filled A-pillar specimens under uniaxial loading conditions. And Two types of mechanical tests were conducted: uniaxial tensile testing and uniaxial compression testing.

The uniaxial tensile tests were conducted as per the ASTM D3039 standard, [13]. which was suitably modified to fit the square cross-sections of the specimens. The tests were conducted at a constant displacement rate of 2 mm/min. Specially designed end-grip fixtures were used for uniform load application and minimize slippage or stress concentration at the specimen ends. During the test, the specimens were kept under axial tensile loading until failure occurred. The key parameters measured were the ultimate tensile load, tensile strength, and elongation at break point. The measured values were used to analyse load bearing capacity and ductility of the materials under tension.

Uniaxial compression tests were conducted as per the ASTM E9 guidelines [14]. During this test, each specimen was placed vertically between the two flat compression plates of the UTM. The axial load was gradually and uniformly applied until the specimen buckled or completely collapsed.

The primary measurements taken during compression testing included the peak compressive load, compressive strength, and the observed failure mode. The measured data was used to evaluate the structural stiffness and failure characteristics of the specimens subjected to compressive stress.

IV. TENSILE TEST RESULTS AND ANALYSIS

Tensile testing was conducted to evaluate the axial load carrying capacity of two A-pillar specimens. a conventional hollow steel tube and a steel tube filled with composite which was reinforced internally with a hybrid filler consisting of epoxy resin (epoxy resin with hardener), crushed wood, and glass fibre.

All test specimens were dimensionally prepared to ensure consistency and comparability of the results. Each A-pillar specimen had a square hollow cross-section measuring 25.4 mm X 25.4 mm, with a wall thickness of 0.8 mm and an overall length of 203.2 mm. Tensile testing was performed using a calibrated Universal Testing Machine (UTM) operating in displacement-controlled mode. The loading was sapplied at a constant rate of 2 mm/min in accordance with ASTM standards for tensile testing of both metallic and composite structural components [13].

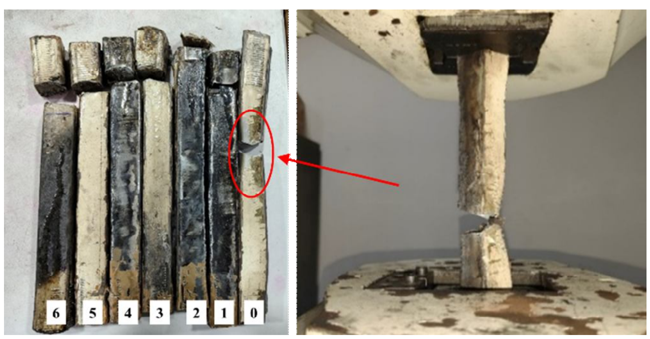


Fig. 3. Image of Test Specimens Post-Failure Tensile Test.

In Fig. 3, the tensile test specimens are shown with their failure patterns. Specimen marked 0 represents the hollow specimen, In Fig. 3, the tensile test specimens are shown with their failure patterns. Specimen marked 0 represents the hollow specimen, while specimens marked 1 to 6 are composite specimens.

A. Tensile Test Observations

The mechanical performance of modified A-pillar specimens was investigated by uniaxial tensile tests which were conducted on two distinct configurations of A-pillar specimens. The first configuration consisted of a traditional hollow mild steel section, which served as the control benchmark. The second configuration combined a composite-filled variant, in which the hollow interior was reinforced with epoxy resin and hardener, mixed with crushed wood and short glass fibres. This hybrid composite matrix was intended to improve the mechanical strength and stiffness of the A-pillar while maintaining a feasible manufacturing process.

The experimental results revealed notable differences in the mechanical response between the two specimen types. The control specimen, fabricated from mild steel, exhibited typical ductile behaviour under tensile loading. It experienced substantial plastic deformation, manifested by significant elongation and the formation of a well-defined necking region prior to fracture. This mode of failure is indicative of high energy absorption and formability.

In contrast, the composite-filled A-pillar specimens demonstrated a different response. These specimens exhibited increased stiffness and higher ultimate tensile strength compared to the control. The reinforcement provided by the epoxy-glass-wood matrix contributed to enhanced load-bearing capacity; however, this came at the expense of ductility. Failure occurred in a brittle manner, with minimal plastic deformation and abrupt fracture propagation, suggesting a lower ability to absorb impact energy. This behaviour underscores the typical trade-off between strength and toughness when incorporating rigid composite reinforcements into metallic frameworks.

A detailed comparison of the mechanical properties, including ultimate tensile strength, elongation at break, and axial stiffness, is presented in Table I. These results provide a quantitative basis for assessing the suitability of composite-filled A-pillar designs in automotive structural applications, particularly where weight reduction and strength enhancement are prioritized over ductility.

TABLE I. TENSILE TEST RESULTS COMPARISON

Property	Unit	Hollow Specimen	Composite-Filled Specimen
Maximum Load	KN	19.74	24.40
Ultimate Tensile Strength	MPa	32.91	39.09
Yield Load	kN	14.89	21.26
Yield Strength	MPa	24.81	34.02
Displacement at Max Load	mm	83.15	50.25
Maximum Displacement	mm	94.70	52.73
Elongation	%	45.00	4
Initial Cross-sectional Area	mm	6.00	625.00
Final Cross-Sectional Area	mm^2	4.60	529.00
Reduction in Area	%	23.33	15.36
Final Gauge Length	mm	145.00	145.00

B. Analysis of Results

1) *Strength Enhancement:* The composite-filled specimen withstood a higher load of 24.40 kN, compared to 19.74 kN for the hollow specimen, indicating a ~23.6% improvement. The composite-filled specimen exhibited a ~19% increase in ultimate tensile strength compared to the hollow specimen, rising from 32.91 MPa to 39.09 MPa. This confirms the effectiveness of the epoxy-fibre-filler combination in improving axial strength.
2) *Elongation Reduction:* Ductility decreases sharply, with elongation at break dropping from 45% in the hollow specimen to 4% in the composite-filled specimen. This reduction is typical in stiff, brittle composites and is attributed to the presence of wood particles and glass fibber
3) *Load Transfer Efficiency:* The internal hybrid filler effectively distributed the tensile load, minimizes stress concentration zones, and delays crack initiation. The combination of resin bonding and fibre bridging contributed to the enhanced structural response.

C. Failure Mode

The hollow specimen failed through ductile necking, which is typical for of thin-walled mild steel under tension. The composite-filled specimen failed via brittle fracture initiated at the filler–metal interface. The presence of glass fibre contributed to high strength but also led to crack propagation. along stiff inclusions, while crushed wood introduced minor stress concentration sites where cracks could be initiated. No delamination was observed externally, but internal filler cracking was likely responsible for the sudden failure.

V. COMPRESSION TEST RESULTS AND ANALYSIS

Compression testing was conducted to assess the axial crush resistance and structural stability of two A-pillar configurations: a conventional hollow steel tube and a composite-filled steel tube reinforced internally with a hybrid filler comprising epoxy resin (epoxy resin and hardener), crushed wood, and glass fibre.

Fig. 4. Image of Compression Test Specimens Post-Failure.

In Fig. 4, the test specimens and their failure patterns are shown. Specimen marked 0 represents the hollow specimen, while specimens marked 1 to 6 are composite specimens.

All specimens were fabricated with uniform dimensions to ensure consistency and comparability of results. Each A-pillar specimen featured a square hollow cross-section measuring 25.4 mm × 25.4 mm, a wall thickness of 0.8 mm, and an overall length of 203.2 mm. Compression testing was conducted using a calibrated Universal Testing Machine (UTM) under displacement-controlled loading conditions. The compressive load was applied axially at a constant rate of 2 mm/min, in accordance with the ASTM E9 standards for compression testing of metallic and composite structures [14].

A. Compression Test Observations

Compression testing was carried out on both hollow and composite-filled A-pillar specimens to assess their structural integrity under uniaxial loading conditions. This test configuration was designed to simulate crash scenarios such as roof crush during vehicle rollover or side-impact collisions, where the A-pillar plays a critical role in passenger protection and cabin integrity.

The hollow mild steel specimen exhibited an early onset of local buckling, primarily initiated at geometric imperfections or unsupported regions along the column. The buckling event was followed by a sudden and unstable collapse, indicative of a lack of post-buckling strength and energy absorption capacity. This type of failure shows the limitations of thin-walled hollow sections in withstanding compressive loads without reinforcement. In contrast, the composite-filled A-pillar specimen demonstrated a markedly improved load-bearing response. The internal composite core, comprising an epoxy-hardener matrix reinforced with crushed wood and short glass fibres, contributed to increased structural stiffness and delayed the initiation of local buckling. The failure mode was characterized by a more gradual and progressive deformation, resulting in a controlled collapse mechanism. This behaviour suggests that the composite infill not only enhances axial compressive strength but also contributes to additional stability and energy dissipation through material homogenisation and constraint effects. A comparative summary of key parameters, including peak compressive load, deformation mode, and energy absorption characteristics, is provided in Table II. These findings support the potential of composite-filled metallic structures in improving crashworthiness in automotive design applications.

TABLE II. COMPRESSION TEST RESULTS COMPARISON

Property	Unit	Hollow Specimen	Composite-Filled Specimen
Maximum Compressive Load	KN	26.85	33.72
Compressive Strength	MPa	44.80	56.30
Yield Load	kN	17.00	22.00
Yield Strength	MPa	27.20	35.20
Displacement at	mm	12.40	8.80

Max Load			
Maximum Displacement	mm	16.90	10.20
Initial Cross-sectional Area	mm²	625.00	625.00
Post-Failure Shape Retention	%	~25%	~80%
Reduction in Area	%	20.48	12.80

B. Analysis of Results

1) *Strength Enhancement:* The composite-filled specimen showed comparitvely higher compressive load-bearing capacity 33.72 kN as compared to 26.85 kN for the hollow specimen. The results showed an improvement of about 25.6% of the maximum load capacity. The compressive strength was observed to be increased from 44.80 MPa (hollow) to 56.30 MPa (composite-filled), which validated the effectiveness of the hybrid filler in enhancing resistance against axial crushing.
2) *Deformation Control:* The hollow specimen showed an early local buckling and rapid collapse when the critical load was exceeded. Whereas the composite-filled specimen showed resistance to deformation more effectively and failure was progressive and controlled. The internal filler acts as a structural core that provided lateral stability to thin steel walls and reduced the risk of abrupt collapse.
3) *Energy Absorption and Structural Retention:* The composite-filled specimens retained a higher degree of structural integrity after failure. As compered to the hollow specimen, which had been through severe distortion, the filled specimen maintained its shape that indicated a greater energy absorption and post-crash performance. This proved that filler helped to ditribute loads and prevent localized damage due to cumbined effect of epoxy for bonding, glass fibre for stiffness, and crushed wood for energy dissipation.

C. Failure Mode

The hollow specimen showed sudden local buckling and wall collapse which are the characteristics of thin-walled steel tubes under axial compression. Whereas the composite-filled specimen showed gradual and progressive deformation with no immediate wall collapse. The initial failure was observed internally probably due to cracking within the epoxy–wood–glass fibre matrix and propagated outward as the load increased. The hybrid filler opposed the steel wall deformation and absorbed part of the compressive force which delayed the total collapse. No large-scale delamination or external rupturing was observed. This proved the strong adhesion between the filler and tube wall.

VI. DISCUSSION AND CONCLUSION

The results showed the feasibility and benefits of using epoxy-based composite fillers in tubular steel A-pillars to enhance its mechanical properties. The hybrid configuration improves the tensile and compressive performance while maintaining a lightweight design, suggesting its potential for automotive crash-resistant components. These performance improvements align with broader trends in automotive materials engineering, as noted by in their review of multiphase composites. However, the trade-off between strength and ductility requires further investigation, as observed in. Future research could explore thermoplastic matrices or alternative fibre architectures to mitigate ductility loss while preserving strength gains.The results validated hybrid composites as a viable solution for A-pillar reinforcement, offering measurable crashworthiness improvements. Given the importance of weight savings in electric vehicles, these findings support industry adoption, highlighting the need for further optimization.

To summaries, this study investigates the structural enhancement of automotive A-pillars using a hybrid composite filler, demonstrating a 23.6% improvement in tensile strength and a 25.6% increase in compressive load capacity, highlighting the potential of hybrid composites to optimize crashworthiness while maintaining lightweight design principles.

VII. ACKNOWLEDGMENT

The author gratefully acknowledges the Department of Mechanical Engineering, Walchand College of Engineering, Sangli for providing the necessary infrastructure and research facilities. The authors also extend their sincere appreciation to the laboratory staff for their assistance in specimen fabrication and mechanical testing.

REFERENCES

[1] J. Kelkar and S. Gadre, "Reinforcement of automotive A-pillar," Int. J. Innovative Sci. Res. Technol., vol. 8, no. 5, pp. 1562–1565, May 2023.

[2] F. Khan and N. Hossain, "Advances of composite materials in automobile applications – a review," Kuwait J. Sci., Feb. 2024.

[3] A. Kyriazis, D. Koulocheris, S. Polydoras, and C. Vossou, "An AM-oriented vehicle chassis' A-Pillar design approach," MATEC Web of Conferences, vol. 318, art. no. 01027, 2020.

[4] J.-H. Kang and J.-W. Lee, "Design of centre pillar with composite reinforcements using hybrid moulding method," Korean J. Automot. Eng., Apr. 2021.

[5] N. Sienkiewicz and M. Dominic, "Natural fillers as potential modifying agents for epoxy composition: a review," Polymers, vol. 14, no. 2, p. 265, Jan. 2022. DOI: 10.3390/polym14020265

[6] Pickering, K.L., Efendy, M.G.A., Le, T.M. "A review of recent developments in natural fibre composites and their mechanical performance." Composites Part A: Applied Science and Manufacturing, 83, 98–112.

[7] K. Devendra and T. Rangaswamy, "Strength characterization of E-glass fiber reinforced epoxy composites with filler materials," J. Miner. Mater. Charact. Eng., vol. 1, pp. 353–357, Nov. 2013.

[8] S. A. Bello and J. O. Agunsoye, "Epoxy resin-based composites: mechanical and tribological properties – a review," J. Mater. Sci. Eng., vol. 37, no. 4, pp. 500–524, 2015.

[9] M. Gajjar and J. Makadia, "Modification of A-pillar by composite materials," Int. J. Creative Res. Thoughts, vol. 10, no. 2, pp. 82–87, Feb. 2022.

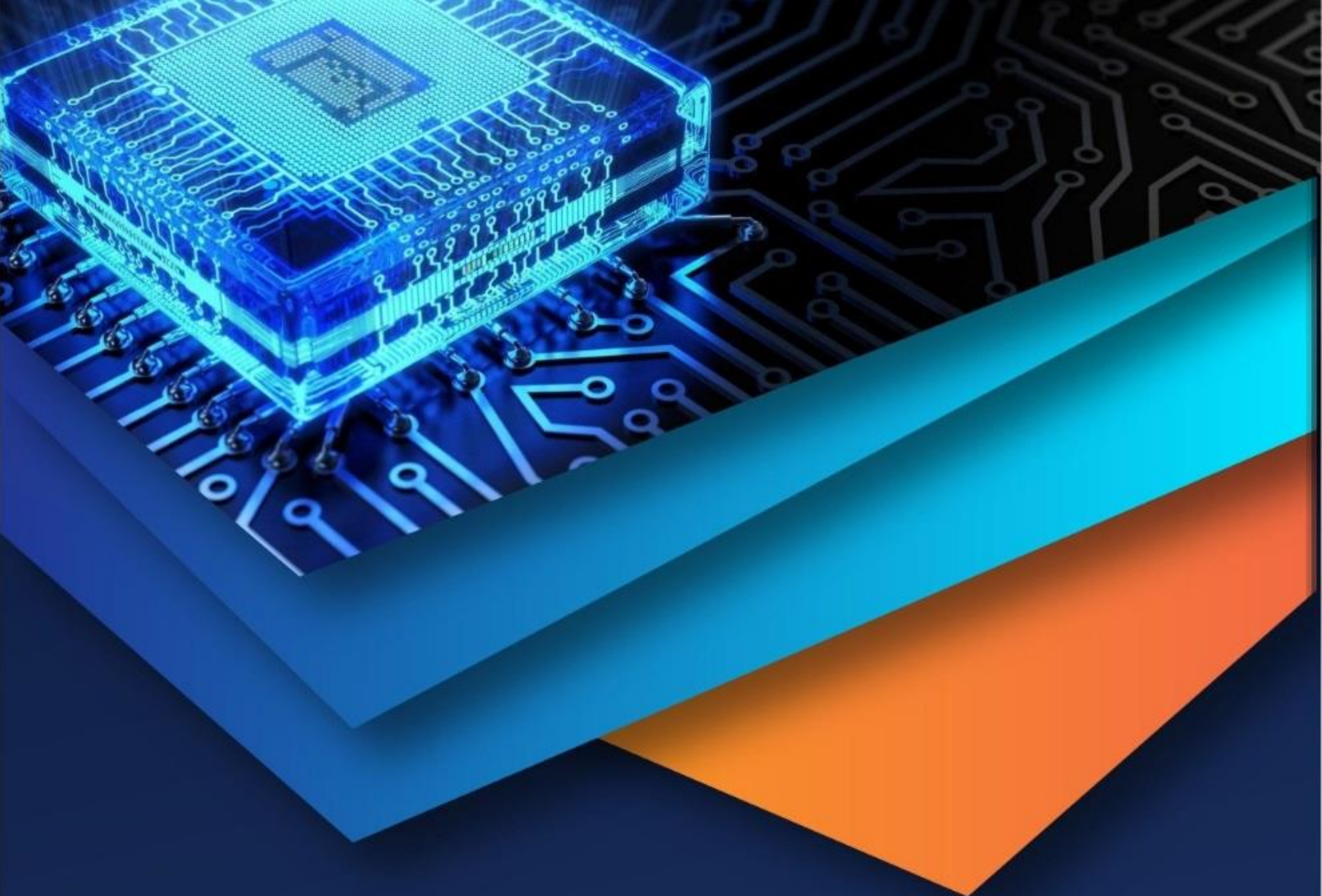
[10] Tarfaoui, M., Nachtane, M., Saalaoui, M., et al. "Crashworthiness performance of hybrid composite structures for automotive applications." Composite Structures, 244, 112304. https://doi.org/10.1016/j.compstruct.2020.112304 (2020).

[11] Song, J., Chen, C., Zhu, S. et al. "A review on crashworthiness performance of automotive structures using composite materials." Engineering Structures, (2020). 211, 110561.

[12] Z. Liu and P. Li, "UV-heat dually curable epoxy resin composites with low filler contents and high curing speed," J. Ind. Polym. Mater., Jun. 2024

[13] "ASTM E8/E8M-21. Standard Test Methods for Tension Testing of Metallic Materials.

[14] "ASTM E9-19. Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY