



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 9.935

Volume 15, Issue 5, May 2026

Design and analysis of Lightweight Composite Control Arm

Bobade Anagha Chandrashekhar¹, Prof Hajare B. S.²

ME, Department of Mechanical Engineering, VACOE, Ahilyanagar, India¹

Professor and Head, Department of Mechanical Design, VACOE, Ahilyanagar, India²

ABSTRACT: This study focuses on the design and structural evaluation of a lightweight automotive control arm using composite material reinforcement as a replacement for conventional steel components. The primary objective is to achieve significant mass reduction without compromising strength, stiffness, or service life. The study integrates topology optimization at the conceptual design stage to identify an optimal load-carrying geometry, ensuring efficient material distribution before composite lay-up design. A detailed CAD model is developed based on the optimized topology and subsequently analyzed using Finite Element Analysis (FEA) under realistic suspension loading conditions. Orthotropic CFRP material properties and various orientations are incorporated to determine an effective laminate stacking sequence. Results indicate that the optimized composite control arm offers notable reductions in weight, enhanced stiffness-to-mass ratio, and comparable or superior mechanical performance relative to traditional steel control arms. The findings demonstrate the potential of combining topology optimization with advanced composite materials to achieve high-performance, lightweight suspension components in modern automotive applications.

KEYWORDS: Composite Control Arm, Topology Optimization, Carbon Fiber Reinforced Polymer (CFRP), Finite Element Analysis (FEA), Lightweight Automotive Components, Structural Evaluation, Suspension System, Orthotropic Material Properties, Laminate Stacking Sequence, Mass Reduction, Stiffness-to-Weight Ratio.

I. INTRODUCTION

The automotive industry is continuously evolving toward the development of lightweight, fuel-efficient, and high-performance vehicles. One of the most effective strategies to achieve these goals is the reduction of vehicle weight, especially in structural and suspension components. Among various suspension parts, the control arm plays a vital role in maintaining wheel alignment, supporting vehicle stability, and transmitting loads between the chassis and wheels during motion. Traditionally, control arms are manufactured using steel or aluminum alloys because of their high strength, durability, and cost-effectiveness. However, these conventional materials increase the overall vehicle weight and unsprung mass, which negatively affects fuel efficiency, ride comfort, handling performance, and emission levels. To overcome these limitations, advanced composite materials such as Carbon Fiber Reinforced Polymer (CFRP) are increasingly being considered as alternatives to metallic control arms. Composite materials offer superior strength-to-weight ratio, corrosion resistance, and enhanced stiffness while significantly reducing component mass. In this project, the design and analysis of a lightweight composite control arm are carried out using CAD modeling and Finite Element Analysis (FEA). The study focuses on evaluating structural performance, stress distribution, deformation characteristics, and weight reduction under realistic loading conditions. The proposed composite control arm aims to improve vehicle efficiency, durability, and suspension performance while maintaining the required mechanical strength and safety standards.

II. LITERATURE REVIEW

1. Liu et al. (2024) – Energy Absorption of CFRP Honeycombs

This study investigates the impact energy absorption behaviour of CFRP honeycomb structures with different ply configurations. Experimental and numerical analyses show that ply orientation, thickness, and core geometry significantly affect damage mechanisms such as delamination, fibre breakage, and matrix cracking. Foam-filled honeycombs exhibit improved toughness due to delayed densification and modified load paths. The authors demonstrate that optimized lay-ups produce extended force-displacement plateaus, indicating better energy absorption.

The study highlights that energy absorption depends more on failure mechanisms than material density. These findings emphasize the importance of tailored laminate design for crash-resistant composite structures.

2. Wang (2023) – Topology Optimization & Suspension Dynamics

This paper applies topology optimization concepts to improve the dynamic performance of an inerter-based suspension system. A quarter-car model integrated with a power-driven damper (PDD) is optimized using particle swarm techniques. The optimized system shows a significant reduction in vibration response compared to passive systems. The study highlights the importance of considering both structural layout and dynamic behaviour simultaneously. It also demonstrates that ignoring dynamic interactions can lead to suboptimal designs. The work reinforces the need for multi-physics optimization in suspension component development.

3. Tang et al. (2024) – Review of Topology Optimization

This review provides a comprehensive overview of topology optimization methods for structural design. It explains the standard workflow involving design domain definition, FEM analysis, sensitivity evaluation, and iterative material redistribution. The authors discuss challenges such as handling nonlinear problems, computational cost, and manufacturability constraints. They highlight limitations in applying topology optimization to composite materials due to anisotropy. Future directions include multi-material, multi-physics, and manufacturing-aware optimization approaches. The study provides a strong theoretical basis for applying topology optimization in lightweight composite structures.

4. Ćurković et al. (2024) – Comparison of Optimization Platforms

This study compares multiple topology optimization software tools using a robotic arm case study. The results show that different platforms produce significantly varying designs in terms of weight reduction, structural integrity, and manufacturability. The authors emphasize that optimization outcomes depend heavily on algorithm selection and parameter settings. The study highlights the importance of integrating manufacturing constraints during the optimization process. It also suggests that optimization should not be treated as a standalone step but part of a complete design workflow. These insights are valuable for applying topology optimization in real-world engineering components.

5. Zhong et al. (2024) – Fatigue in Off-Axis CFRP Laminates

This paper examines fatigue damage behaviour in CFRP laminates subjected to off-axis loading conditions. The results show that off-axis orientations accelerate matrix cracking, fibre debonding, and delamination. Laminates with $\pm 45^\circ$ orientation exhibit significantly lower fatigue life compared to 0° laminates. The study also correlates stiffness degradation with progressive damage accumulation. It emphasizes that composite components must be designed considering multi-directional fatigue loading. The findings highlight the importance of fibre orientation and manufacturing quality in ensuring durability.

6. Zhang et al. (2024) – Impact Behaviour of CFRP Sandwich Panels

This study investigates the impact performance of carbon-fibre sandwich panels with different core types and lay-ups. Honeycomb cores show better energy absorption due to progressive buckling, while foam cores fail more abruptly. Face-sheet orientation significantly influences damage distribution and failure patterns. The research demonstrates that both core structure and laminate design play a crucial role in impact resistance. It also highlights the importance of considering dynamic loading conditions in composite design. These insights are relevant for designing durable lightweight components subjected to impact loads.

7. Dojan et al. (2025) – Manufacturing of CFRP Composites

This paper reviews scalable additive manufacturing techniques for continuous carbon-fibre reinforced thermoset composites. It discusses challenges such as fibre alignment, resin impregnation, void formation, and curing control. The authors emphasize that manufacturing quality directly affects mechanical properties like strength and fatigue life. They also analyze cost trends and highlight the potential of automation to reduce production costs. The study notes that while additive manufacturing offers design flexibility, trade-offs exist between complexity, cost, and production time. It suggests hybrid manufacturing approaches for large-scale automotive applications.

8. Baddour et al. (2024) – Advances in CFRP Materials

This review discusses recent developments in continuous carbon-fibre composites with thermoplastic matrices. It compares thermoset and thermoplastic systems in terms of performance, processing, and recyclability. Thermoplastic composites offer faster manufacturing and improved damage tolerance. The paper highlights advances in automated fibre placement and in-situ consolidation techniques. It also discusses fatigue behaviour and potential automotive applications. The study suggests that thermoplastic CFRPs could play a key role in future lightweight vehicle structures.

III. PROBLEM STATEMENT

- Conventional automotive control arms made from steel or aluminum significantly contribute to the overall weight of the suspension system, negatively impacting fuel efficiency, emissions, and vehicle handling. While composite materials, such as carbon-fiber reinforced polymers, offer superior strength-to-weight ratios and excellent fatigue and corrosion resistance, their adoption in suspension components remains limited due to challenges in structural design, manufacturability, and cost justification.
- Additionally, conventional control arm geometries are not optimized for composite material behavior, leading to inefficient material usage and sub-optimal performance.
- There is therefore a need to develop a structurally efficient, lightweight composite control arm that meets or exceeds the mechanical performance requirements of traditional metallic control arms. The project also requires an evaluation of economic feasibility to assess whether composite control arms can be viably produced and implemented at scale.

IV. OBJECTIVES

The aim of this research is to design, analyze, and evaluate the feasibility of a lightweight composite control arm for automotive suspension systems, supported by a structured supplier cost analysis to ensure industrial applicability. The primary objectives are:

- To develop a lightweight composite control arm geometry that achieves significant weight reduction compared to conventional steel or aluminum counterparts without compromising safety or performance.
- To perform finite element analysis (FEA) for evaluating stresses, deformations, and safety factors under static, dynamic, and fatigue loading conditions representative of real-world vehicle operation.
- To evaluate and compare different composite materials (e.g., carbon-fiber-reinforced polymer, glass-fiber-reinforced polymer, hybrid composites) based on their mechanical properties, manufacturability, and suitability for suspension components.
- To conduct experimental testing using the UTM (Universal Testing Machine) in order to validate FEA predictions and confirm the real-world applicability of the design. This study aims to address these gaps by designing, analyzing, and evaluating a composite material reinforced control arm that balances performance, durability, manufacturability, and cost for modern automotive applications. To overcome these limitations, advanced composite materials such as Carbon Fiber Reinforced Polymer (CFRP) are increasingly being considered as alternatives to metallic control arms. Composite materials offer superior strength-to-weight ratio, corrosion resistance, and enhanced stiffness while significantly reducing component mass. In this project, the design and analysis of a lightweight composite control arm are carried out using CAD modeling and Finite Element Analysis (FEA). The study focuses on evaluating structural performance, stress distribution, deformation characteristics, and weight reduction under realistic loading conditions. The proposed composite control arm aims to improve vehicle efficiency, durability, and suspension performance while maintaining the required mechanical strength and safety standards.

V. RESEARCH METHODOLOGY



Flow Chart of the work

In recent years, advanced composite materials especially carbon fiber reinforced polymers (CFRP)—have emerged as promising alternatives for structural automotive applications. CFRP offers a superior strength-to-weight ratio, excellent fatigue resistance, and corrosion resistance, making it well-suited for components subjected to cyclic and multi-axial loading. Additionally, the anisotropic nature of composite materials enables tailored stiffness and strength through controlled fibre orientation and laminate design. Despite these advantages, the application of CFRP in suspension components remains limited due to challenges related to design optimization, manufacturing complexity, and cost considerations.

To fully exploit the benefits of composite materials, advanced design methodologies such as topology optimization have gained significant attention. Topology optimization allows for the systematic distribution of material within a given design space to achieve maximum structural efficiency under specified loading conditions. When combined with composite materials, this approach enables the development of lightweight structures that follow optimal load paths while minimizing unnecessary mass. This study focuses on the design and structural analysis of a lightweight composite control arm reinforced with carbon fiber. Initially, finite element analysis (FEA) is performed on conventional metallic control arms to establish a baseline for comparison. Subsequently, topology optimization is employed to obtain an efficient structural layout, which is then redesigned using CFRP. The optimized composite control arm is evaluated under realistic loading conditions to assess deformation, stress distribution, and strain characteristics. The results aim to demonstrate the effectiveness of combining topology optimization with advanced composite materials to achieve significant weight reduction while maintaining or improving structural performance.



Novelty of work: The present work introduces a systematic approach that integrates topology optimization with carbon fiber reinforced composite design for an automotive control arm. Unlike conventional studies that either focus solely on material substitution or geometric optimization, this work combines both aspects to achieve an efficient load-bearing structure with minimal weight. The optimized geometry is derived based on actual load paths, ensuring effective material utilization rather than relying on traditional design modifications. Another key novelty lies in the comparative analysis between conventional metallic materials such as Mild Steel and AISI 1040 and an optimized carbon fiber reinforced polymer (CFRP) configuration. This enables a clear demonstration of the structural advantages offered by composites in terms of reduced deformation, lower stress concentration, and improved stiffness characteristics.

Furthermore, the study considers realistic suspension loading conditions, making the analysis more representative of practical automotive applications. In addition, the work extends beyond theoretical modelling by incorporating considerations for manufacturability and proposing experimental validation in future stages. This holistic approach, combining advanced optimization techniques, composite material application, and practical feasibility assessment, distinguishes the study from conventional control arm design methodologies and contributes toward the development of next-generation lightweight suspension components.



VI. FINITE ELEMENT ANALYSIS

The finite element method (FEM), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method yields approximate values of the unknowns at discrete number of points over the domain. To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements.

In the first step, the element equations are simple equations that locally approximate the original complex equations to be studied, where the original equations are often partial differential equations (PDE). The process, in mathematical language, is to construct an integral of the inner product of the residual and the weight functions and set the integral to

zero. In simple terms, it is a procedure that minimizes the error of approximation by fitting trial functions into the PDE. The residual is the error caused by the trial functions, and the weight functions are polynomial approximation functions that project the residual. The process eliminates all the spatial derivatives from the PDE, thus approximating the PDE locally with

- A set of algebraic equations for steady state problems,
- A set of ordinary differential equations for transient problems.

These equation sets are the element equations. They are linear if the underlying PDE is linear, and vice versa. Algebraic equation sets that arise in the steady state problems are solved using numerical linear algebra methods, while ordinary differential equation sets that arise in the transient problems are solved by numerical integration using standard techniques such as Euler's method or the Runge-Kutta method.

FEM is best understood from its practical application, known as finite element analysis (FEA). FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm. In applying FEA, the complex problem is usually a physical system with the underlying physics such as the Euler-Bernoulli beam equation, the heat equation, or the Navier-Stokes equations expressed in either PDE or integral equations, while the divided small elements of the complex problem represent different areas in the physical system.

In present research for analysis ANSYS (**A**nalysis **S**ystem) software is used. Basically, its present FEM method to solve any problem. Following are steps in detail

1. Geometry
2. Discretization (Meshing)
3. Boundary condition
4. Solve (Solution)
5. Interpretation of results

Workbench contain analysis of different types namely static, modal, harmonic, explicit dynamics, CFD, ACP tool post, CFX, topology optimization etc. as per problem defined.

Step 1: Details of material namely copper, steel, grey cast iron, composite material, fluid domain material is defined in engineering data. i.e. ANSYS default material is structural steel.

Step 2: Import of geometry created in any CAD software namely CATIA, PRO E, SOLIDWORK, INVENTOR etc. in geometry section. If any correction is to be made it can be created in geometry section in Design modeller or space claim.

Step 3: In model section after import of component

- Material is assigned to component as per existing material
- Connection is checked in contact region i.e. bonded, frictionless, frictional, no separation etc. for multi body components.
- Meshing or discretization is performed i.e. to break components in small pieces (elements) as per size i.e. preferably tetra mesh and hexahedral mesh for 3D geometry and for 2 D quad or tria are generally preferred.

Step 4: Boundary condition are applied as per analysis namely in fixed support, pressure, force, displacement, velocity as per condition.

Step 5: Now problem is well defined and solve option is selected to obtain the solution in the form of equivalent stress, strain, energy, reaction force etc.

|

VII. MANUFACTURING OF THE COMPONENT

The manufacturing of the reinforced lower control arm was carried out using a manual composite layup process with carbon fiber sheets and resin solution. Initially, the existing lower control arm surface was cleaned thoroughly to remove dust, grease, rust, and other contaminants. Surface preparation was further improved by sanding or grinding the surface to enhance the bonding strength between the metal substrate and the composite layer.



Fig. Carbon Fiber sheet cut according to the LCA dimensions

Carbon fiber sheets were then cut according to the required dimensions. A resin solution, along with the required hardener, was prepared in the specified mixing ratio to form the binding matrix. The resin was uniformly applied over the prepared surface of the lower control arm, and the carbon fiber sheets were carefully placed over the coated region.



Fig. Carbon fiber reinforcement using resin solution

Additional resin was applied on top of the carbon fiber layers to ensure proper impregnation and eliminate dry spots. Rollers and brushes were used to remove trapped air bubbles and achieve uniform resin distribution throughout the laminate. Multiple layers of carbon fiber sheets were applied in critical stress regions to improve stiffness and load-bearing capability.

After completion of the layup process, the reinforced component was allowed to cure at room temperature for the required curing period to achieve proper hardening of the composite structure. Once curing was completed, finishing operations such as trimming excess material and surface smoothing were carried out. The final reinforced lower control arm was then visually inspected for defects such as voids, improper bonding, or delamination before proceeding for structural testing and validation.

FEA of Existing Lower Control Arm (MS)

Geometry:



Fig. Geometry of Existing LCA

Material Properties:

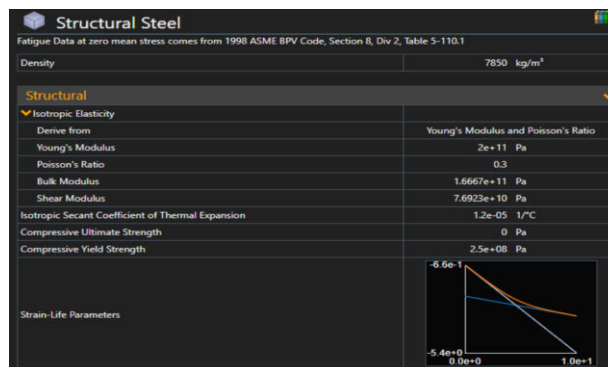
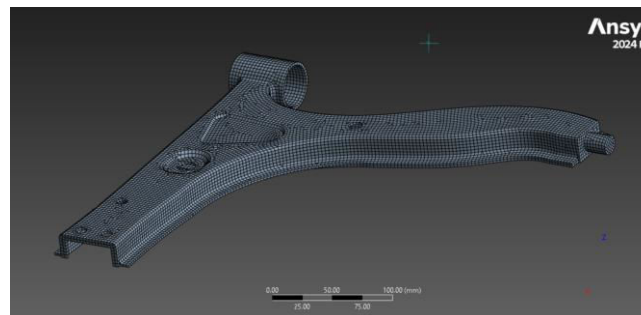


Fig. Material Properties of Mild Steel

Meshing:



Physics Preference	Mechanical	Statistics
Element Order	Program Controlled	Nodes 28496
Element Size	3.0 mm	Elements 23917

Fig. Meshing Details of Existing LCA

Boundary Conditions:

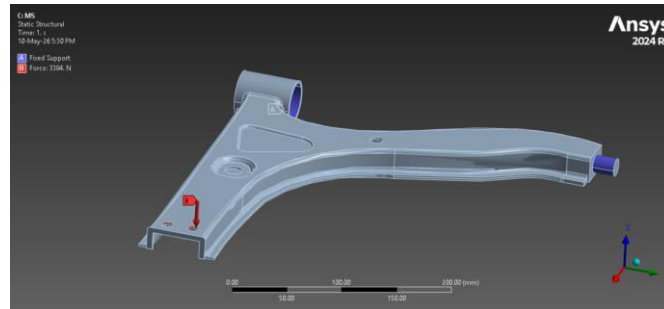


Fig. Boundary conditions for static structural analysis of Existing LCA (MS)

VIII. RESULTS

Total Deformation:

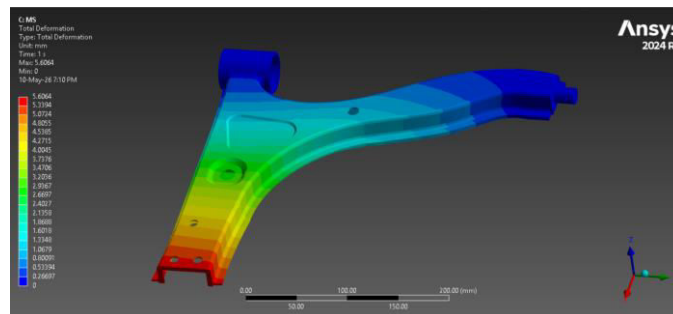


Fig. Total Deformation of Existing LCA (MS)

Equivalent Stress:

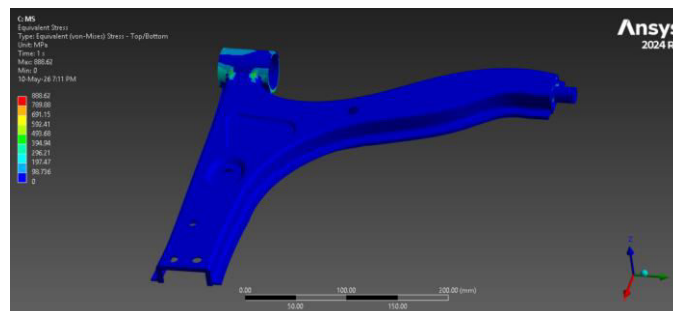


Fig. Equivalent Stress of Existing LCA (MS)

Equivalent Elastic Strain:

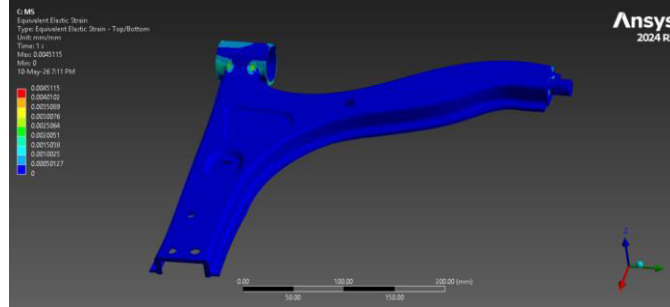


Fig. Equivalent Elastic Strain of Existing LCA (MS)

FEA of Existing Lower Control Arm (AISI 1040)

Material Properties:

AISI 1040	
Density	7.85e-06 kg/mm ³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+05 MPa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+05 MPa
Shear Modulus	76923 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	415 MPa
Tensile Ultimate Strength	620 MPa
Tensile Yield Strength	415 MPa

Fig. Material Properties of AISI 1040

Results:

Total Deformation:

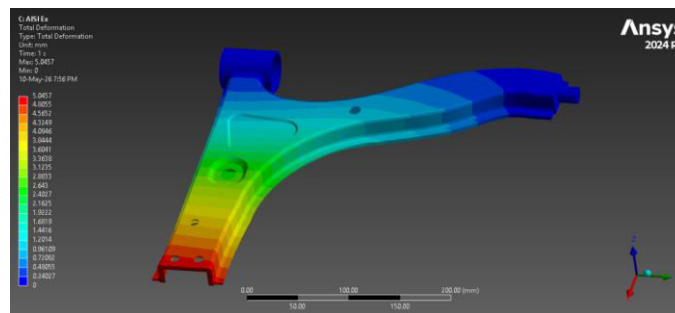


Fig. Total Deformation of Existing LCA (AISI 1040)

Equivalent Stress:

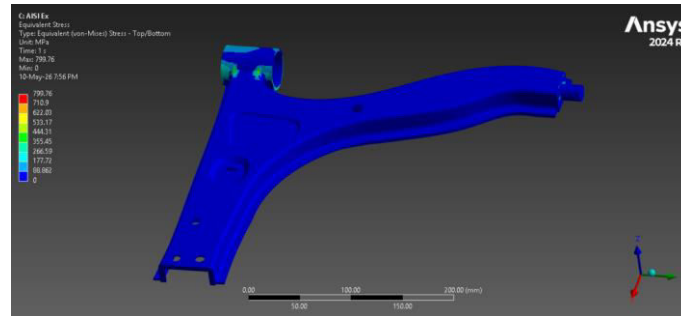


Fig. Equivalent Stress of Existing LCA (AISI 1040)

Equivalent Elastic Strain:

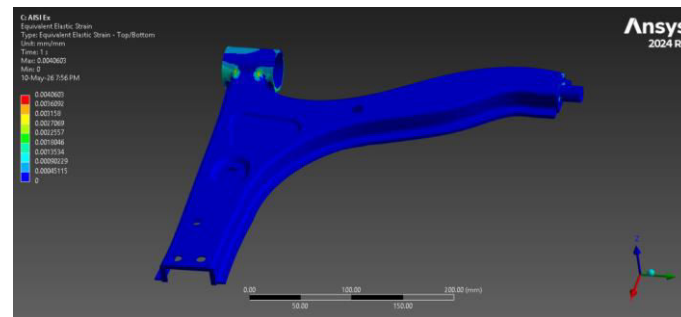
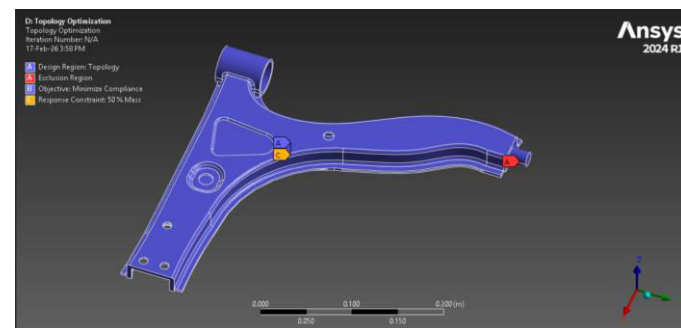


Fig. Equivalent Elastic Strain of Existing LCA (AISI 1040)

Topology Optimization:



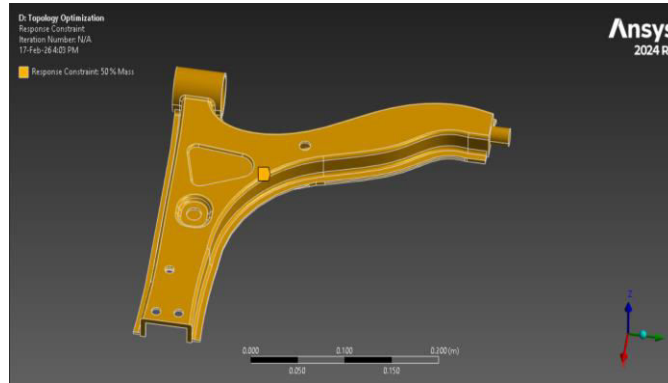


Fig. Boundary conditions for topological optimization

RESULTS

Topology Density:

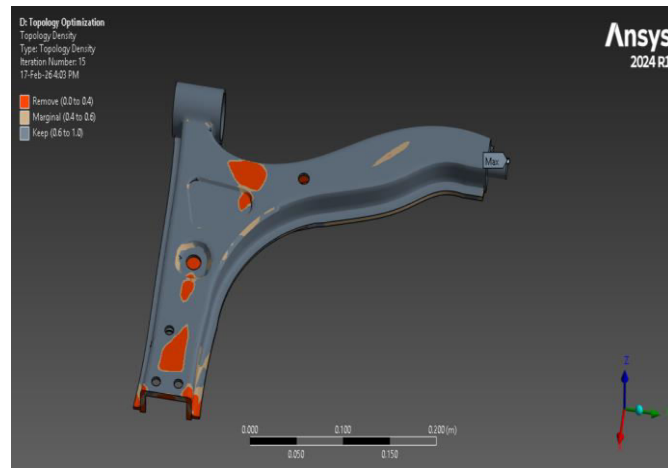


Fig. Topological Density

Topology Elemental Density:

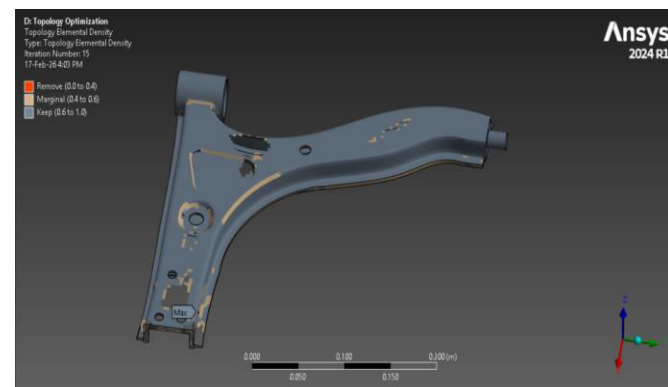


Fig. Topology Elemental Density

FEA of Optimized Composite Reinforced Lower Control Arm (CFR LCA):

Geometry:

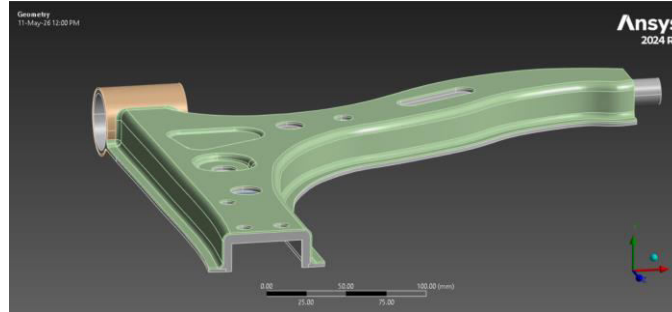


Fig. Geometry of optimized CFR LCA

Material Properties:

AISI 1040	
Density	7850 kg/m ³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+11 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+11 Pa
Shear Modulus	7.6923e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	4.15e+08 Pa
Tensile Ultimate Strength	6.2e+08 Pa
Tensile Yield Strength	4.15e+08 Pa

Fig. Material Properties of AISI 1040

Carbon Fiber (290 GPa)	
Carbon 290 GPa fibers only	
Density	1800 kg/m ³
Structural	
Orthotropic Elasticity	
Young's Modulus X direction	2.9e+11 Pa
Young's Modulus Y direction	2.3e+10 Pa
Young's Modulus Z direction	2.3e+10 Pa
Poisson's Ratio XY	0.2
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.2
Shear Modulus XY	9e+09 Pa
Shear Modulus YZ	8.2143e+09 Pa
Shear Modulus XZ	9e+09 Pa

Fig. Material Properties of Carbon Fiber 290 GPa

Meshing:

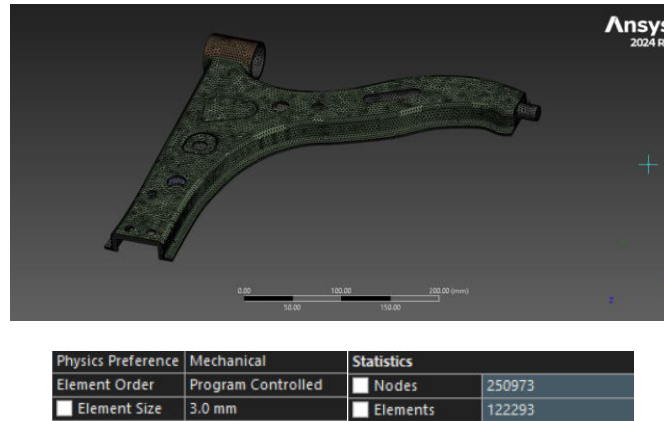


Fig. Meshing Details of optimized CFR LCA.

Boundary Conditions:

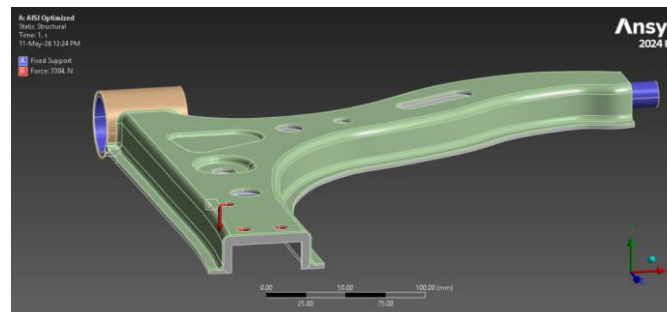


Fig. Boundary conditions for Static structural analysis of optimized CFR LCA.

Results:

Total Deformation:

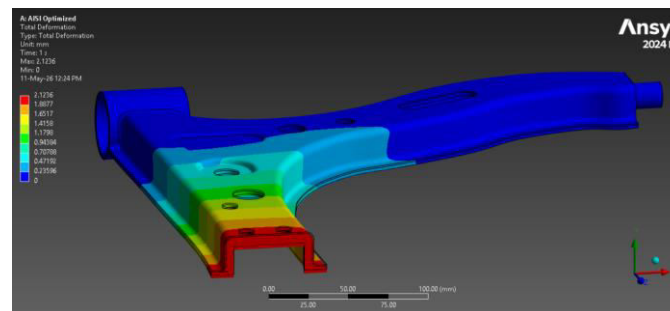


Fig. Total Deformation of the optimized CFR LCA

Equivalent Stress:

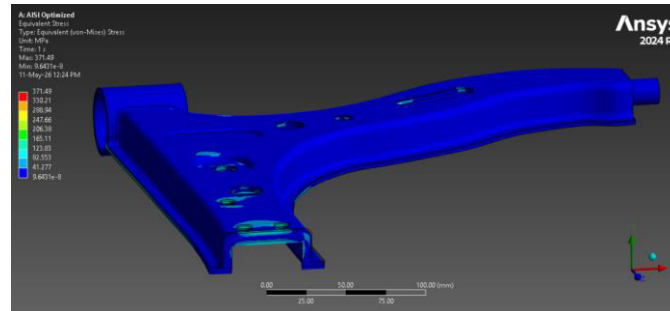


Fig. Equivalent Stress of the optimized CFR LCA

Equivalent Elastic Strain:

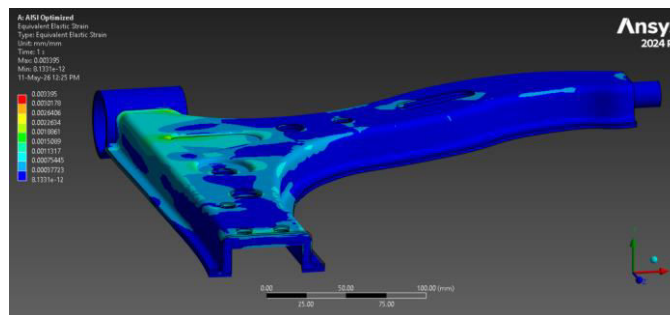


Fig. Equivalent Elastic Strain of the optimized CFR LCA

FEA RESULTS

Finite Element Analysis (FEA) was initially performed on the existing lower control arm (LCA) using two conventional materials: Mild Steel (MS) and AISI 1040 steel. The MS control arm exhibited a total deformation of 5.6064 mm, an equivalent (von-Mises) stress of 888.62 MPa, and an equivalent elastic strain of 0.0045115. Similarly, the AISI 1040 control arm showed a total deformation of 5.0457 mm, an equivalent stress of 799.76 MPa, and an equivalent elastic strain of 0.0040603 under identical loading and boundary conditions.

Following this, topology optimization was carried out to identify an efficient material distribution and reduce unnecessary mass while maintaining structural integrity. The optimized geometry was then reinforced using Carbon Fiber Reinforced Polymer (CFRP), and FEA was performed on the redesigned composite control arm. The CFRP-reinforced optimized LCA demonstrated a significantly reduced total deformation of 2.1236 mm, an equivalent stress of 371.49 MPa, and an equivalent elastic strain of 0.003395.

The results clearly indicate a substantial improvement in structural performance when transitioning from conventional steel materials to a topology-optimized CFR composite design. The composite control arm shows drastically reduced deformation and strain values, along with significantly lower stress levels compared to the metallic counterparts.

IX. EXPERIMENTAL TESTING

A Universal Testing Machine (UTM) is a mechanical testing device used to evaluate the mechanical and structural properties of materials and components under different loading conditions such as tension, compression, bending, and shear. It is widely used in engineering and research applications to determine properties including strength, stiffness, deformation, and load-carrying capacity.

The working principle of a UTM is based on the controlled application of load through a movable crosshead driven by hydraulic or electromechanical systems. A load cell measures the applied force, while displacement sensors or extensometers record the corresponding deformation of the specimen.

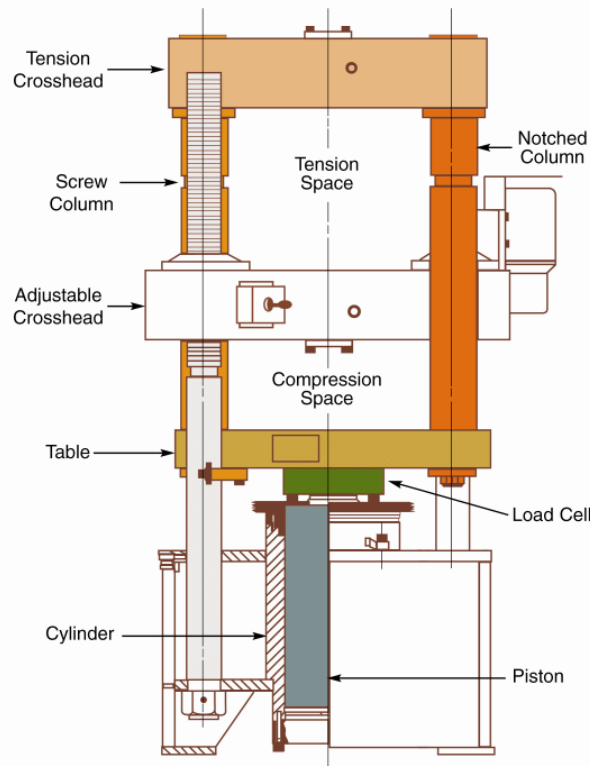


Fig.Schematic Diagram of a UTM

Experimental Procedure:

1. The reinforced lower control arm specimen was first inspected visually to ensure proper bonding of the composite layers and absence of visible defects such as cracks, voids, or delamination.
2. The Universal Testing Machine (UTM) was calibrated, and appropriate compression testing fixtures were installed before conducting the experiment.
3. The specimen was carefully positioned between the compression platens of the UTM, ensuring proper alignment to achieve uniform load distribution during testing.
4. A compressive load was applied gradually at a controlled loading rate until the required load condition or structural response was achieved.
5. During the test, the applied load and corresponding deformation values were continuously recorded by the UTM system.



Fig. Specimen under Compression test using UTM

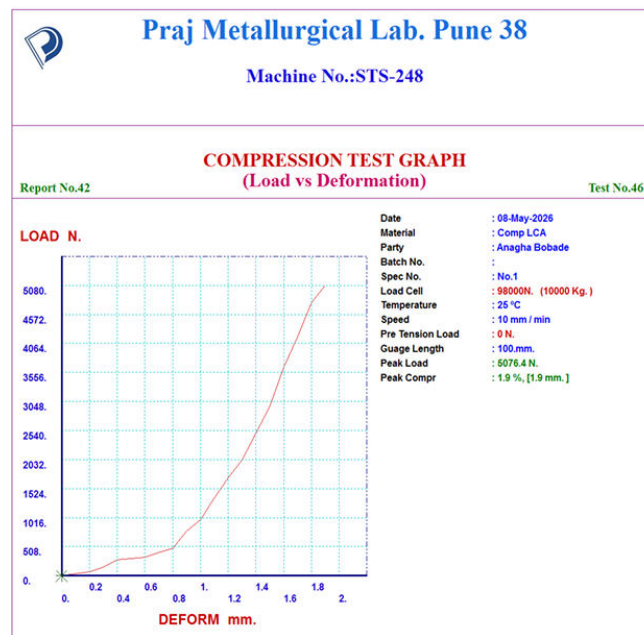


Fig. Compression test graph for CFR LCA using UTM

X .CONCLUSION

The study successfully demonstrates that combining topology optimization with carbon fiber-reinforced composite materials leads to the development of an efficient and lightweight automotive control arm. The optimized design was evaluated and compared with conventional Mild Steel and AISI 1040 steel control arms under identical loading conditions. The results revealed that the Carbon Fiber Reinforced (CFR) composite control arm exhibited superior structural performance, including higher stiffness, lower stress concentration, and reduced elastic strain. These improvements indicate that composite materials, when integrated with optimized geometry, can effectively enhance the mechanical behavior of suspension components while significantly reducing overall weight. The reduction in component weight contributes to lower unsprung mass, improved fuel efficiency, enhanced ride comfort, and better vehicle handling performance. In addition to numerical analysis, the optimized CFR composite control arm was successfully fabricated and experimentally tested using a Universal Testing Machine (UTM). The experimental observations showed close agreement with the Finite Element Analysis (FEA) results, confirming the validity, reliability, and accuracy of the simulation model used in the study. The research concludes that carbon fiber-reinforced composite control arms possess strong potential for modern automotive suspension systems due to their lightweight

nature, high strength-to-weight ratio, durability, and improved structural efficiency, making them suitable for future high-performance vehicle applications.

REFERENCES

- 1) S. S. Rao, *Engineering Optimization: Theory and Practice*, 4th ed. Hoboken, NJ, USA: Wiley, 2009.
- 2) R. M. Jones, *Mechanics of Composite Materials*, 2nd ed. Philadelphia, PA, USA: Taylor & Francis, 1999.
- 3) J. N. Reddy, *Mechanics of Laminated Composite Plates and Shells: Theory and Analysis*, 2nd ed. Boca Raton, FL, USA: CRC Press, 2004.
- 4) D. Gay, S. V. Hoa, and S. W. Tsai, *Composite Materials: Design and Applications*, Boca Raton, FL, USA: CRC Press, 2003.
- 5) M. F. Ashby, *Materials Selection in Mechanical Design*, 4th ed. Oxford, U.K.: Butterworth-Heinemann, 2011.
- 6) K. Kaw, *Mechanics of Composite Materials*, 2nd ed. Boca Raton, FL, USA: CRC Press, 2005.
- 7) P. K. Mallick, *Fiber-Reinforced Composites: Materials, Manufacturing, and Design*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2007.
- 8) O. Sigmund and K. Maute, "Topology optimization approaches: A comparative review," *Structural and Multidisciplinary Optimization*, vol. 48, no. 6, pp. 1031–1055, Dec. 2013.
- 9) M. P. Bendsøe and O. Sigmund, *Topology Optimization: Theory, Methods, and Applications*, Berlin, Germany: Springer, 2003.
- 10) S. Rajendran and S. Vijayarangan, "Optimal design of a composite leaf spring using genetic algorithms," *Computers & Structures*, vol. 79, no. 11, pp. 1121–1129, 2001.
- 11) A. Shokrieh and D. Rezaei, "Analysis and optimization of a composite leaf spring," *Composite Structures*, vol. 60, no. 3, pp. 317–325, 2003.
- 12) N. Ganesan, R. Velmurugan, and P. K. Gupta, "Finite element analysis of composite structures for automotive applications," *Journal of Reinforced Plastics and Composites*, vol. 28, no. 12, pp. 1457–1471, 2009.
- 13) Z. Liu et al., "Energy absorption behavior of carbon-fiber-reinforced composites," *Materials*, vol. 17, no. 17, p. 4257, 2024.
- 14) J. Wang, "Topology optimization design and dynamic performance for suspension components," *Vehicles*, vol. 15, no. 1, p. 8, 2023.
- 15) T. Tang et al., "Topology optimization: A review for structural designs," *Materials*, vol. 17, no. 23, p. 5970, 2024.
- 16) P. Ćurković et al., "Comparative analysis of topology optimization platforms for engineering design," *Technologies*, vol. 8, no. 5, p. 98, 2024.
- 17) Z. Zhong et al., "Study of fatigue damage behavior in off-axis CFRP laminates," *PMC*, 2024.
- 18) X. Zhang et al., "Investigating the impact behavior of carbon fiber-based sandwich panels," *PMC*, 2024.
- 19) F. Dojan et al., "Additive manufacturing of carbon fiber-reinforced thermoset composites: Scalable methods," *PMC*, 2025.
- 20) Amsalu et al., "Numerical analysis of fiber-reinforced composite material static behavior," *PMC*, 2024.
- 21) J. Zhang et al., "Design and performance study of carbon fiber–aluminum composite connections for lightweight structures," *Coatings*, vol. 14, no. 7, p. 785, 2024.
- 22) M. Baddour et al., "Advances in continuous carbon-fiber composites and thermoplastic matrices," 2024.
- 23) H. Es-Said and M. ElSayed, "Lightweight composite materials for automotive applications," *Journal of Materials Engineering and Performance*, vol. 22, no. 4, pp. 1011–1020, Apr. 2013.
- 24) K. J. Bathe, *Finite Element Procedures*, Upper Saddle River, NJ, USA: Prentice Hall, 1996.
- 25) J. H. Choi and D. H. Kim, "Structural design and optimization of automotive suspension components using composite materials," *International Journal of Automotive Technology*, vol. 15, no. 5, pp. 789–796, 2014.



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details