

FEA on Polycarbonate and Micro Cellular Rubber Used for Foot Prosthetic Implants

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Abstract - The Jaipur Foot is a widely adopted low-cost prosthetic device; however, its conventional material composition results in limited durability and reduced fatigue performance under repetitive physiological loading. To address these limitations, the present study proposes an improved prosthetic foot design consisting of a polycarbonate (PC) structural core combined with a micro-cellular rubber (MCR) surface coating. A three-dimensional model of the prosthetic foot was developed using Autodesk Fusion 360 and analyzed through finite element analysis (FEA) in ANSYS. Static structural and fatigue analyses were carried out under vertical loads ranging from 600 N to 900 N, representing different gait conditions experienced during daily walking. The results indicate that the polycarbonate core effectively withstands applied structural loads, while the micro-cellular rubber layer significantly reduces stress concentration and enhances shock absorption. Furthermore, topology optimization was employed to reduce material usage without adversely affecting overall structural behavior. When compared with the conventional Jaipur Foot, the proposed PC+MCR prosthetic foot exhibits lower deformation, reduced equivalent stress, and improved fatigue life. These findings demonstrate that the PC+MCR configuration offers a durable, lightweight, and cost-effective alternative for prosthetic foot applications.

Keywords: Prosthetic Foot, Jaipur Foot, Polycarbonate, Micro-Cellular Rubber, Finite Element Analysis, Fatigue Analysis, Topology Optimization, Structural Performance.

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I. INTRODUCTION

The Jaipur Foot is one of the most widely adopted low-cost prosthetic feet developed in India, intended to restore mobility for below-knee amputees in economically constrained environments. Conceived in the late 1960s through the collaborative efforts of Ram Chandra Sharma and Dr. P. K. Sethi, the Jaipur Foot was specifically designed to address the functional and cultural needs of users in developing regions. Unlike many conventional prosthetic feet used in industrialized countries, the Jaipur Foot allows barefoot ambulation, squatting, sitting cross-legged, and walking on uneven terrain, making it particularly suitable for rural and outdoor applications [1], [5], [7].

Despite its extensive social impact and affordability, the conventional Jaipur Foot primarily relies on rubber- and wood-based materials, which exhibit limitations in terms of mechanical consistency, fatigue resistance, and energy efficiency under repeated physiological loading conditions [2], [4], [12]. Prolonged cyclic loads during gait, especially

during heel-strike and push-off phases, can result in material degradation, stress concentration, and reduced service life. These challenges emphasize the necessity for material and structural improvements that enhance durability and mechanical reliability without significantly increasing cost [1], [6].

In response to these limitations, the present study proposes a hybrid prosthetic foot design consisting of a polycarbonate (PC) structural core combined with a micro-cellular rubber (MCR) surface coating. Polycarbonate is known for its high impact resistance, favourable stiffness-to-weight ratio, and fatigue strength, making it suitable for load-bearing prosthetic components [10], [11]. Micro-cellular rubber, on the other hand, provides effective shock absorption, energy dissipation, and improved user comfort due to its compliant closed-cell structure [2], [3]. The integration of these materials aims to achieve an optimal balance between structural rigidity and functional flexibility.

➤ *Clinical and Application Background*

Lower-limb amputation significantly affects an individual's mobility, independence, and overall quality of life, particularly among populations engaged in physically demanding occupations. In developing countries, amputees often depend on low-cost prosthetic devices that must withstand barefoot walking, uneven terrain, and extended daily use under harsh environmental conditions [4], [9]. Prosthetic feet used in such settings are therefore required to provide adequate load-bearing capacity, shock absorption, fatigue resistance, and long-term comfort while remaining affordable and easy to maintain.

Clinically, the Jaipur Foot has been extensively adopted due to its adaptability to culturally specific activities and its ability to accommodate varied terrain conditions [5], [7]. However, studies have reported that traditional Jaipur Foot designs exhibit inconsistent mechanical behaviour and limited fatigue performance under repetitive gait loading, which can lead to discomfort and premature failure during prolonged use [1], [4], [12].

From an application standpoint, improved prosthetic foot performance can be achieved through the adoption of hybrid material systems that combine a stiff load-bearing core with a compliant outer layer. Such configurations are effective in reducing stress transmission to the residual limb, enhancing shock absorption, and improving gait stability [8], [11]. These improvements are particularly relevant for users in rural and semi-urban regions, where prosthetic devices are subjected to continuous loading and limited clinical follow-up [6].

➤ *Materials Context from a Biomaterial's Viewpoint*

From a biomaterial's perspective, materials used in lower-limb prosthetic applications must satisfy mechanical, biological, and functional requirements. Although prosthetic feet do not remain in direct contact with internal tissues, the materials employed must be biocompatible, non-toxic, and capable of sustaining repeated physiological loading without degradation [10]. Resistance to environmental exposure, durability, and user comfort are also critical considerations for externally worn prosthetic devices.

Polymeric materials are widely utilized in prosthetic systems due to their favourable strength-to-weight characteristics, manufacturability, and tunable mechanical properties. Polycarbonate, in particular, is a high-performance thermoplastic recognized for its excellent impact resistance, dimensional stability, and fatigue strength under cyclic loading [10], [11]. These properties make it a suitable candidate for structural components subjected to repetitive gait-induced stresses.

Micro-cellular rubber (MCR) is commonly employed in orthopaedic and prosthetic applications owing to its ability to dissipate energy and absorb shock through its closed-cell structure. From a biomaterial's standpoint, MCR acts as a compliant interface that reduces peak stress transmission, enhances comfort, and improves adaptability to irregular ground conditions [2], [3]. Its demonstrated durability and

biocompatibility support its use in prolonged external contact applications.

➤ *Gaps in Literature*

A review of existing literature indicates that although the Jaipur Foot has been widely studied with respect to socio-economic impact, clinical usability, and functional adaptability, limited attention has been given to systematic material optimization and fatigue-based performance evaluation [1], [4], [5]. Many studies primarily focus on field implementation and cost effectiveness, with comparatively fewer investigations addressing quantitative mechanical validation under realistic gait loading conditions [6], [12].

While several researchers have explored rubber-based materials and basic composite structures in prosthetic feet, comprehensive analyses incorporating advanced engineering polymers such as polycarbonate remain scarce [8], [10]. In particular, the combined use of a stiff polymeric core and a compliant surface layer have not been adequately examined from a structural integrity and fatigue-life perspective for low-cost prosthetic systems. Additionally, many existing studies rely on simplified static assessments or experimental observations, without integrating detailed finite element simulations to predict stress distribution, deformation behaviour, and long-term durability [1], [11], [13].

Furthermore, the application of topology optimization techniques in affordable prosthetic feet such as the Jaipur Foot is largely unexplored. Although topology optimization has been successfully applied in high-performance prosthetic and biomedical components, its potential for material reduction and performance enhancement in low-cost prosthetic designs has not been sufficiently investigated [14], [15].

➤ *Objectives and Contributions of the Present Work*

The primary objective of the present work is to evaluate the feasibility of a hybrid prosthetic foot design incorporating a polycarbonate (PC) load-bearing core and a micro-cellular rubber (MCR) surface coating as an improved alternative to the conventional Jaipur Foot. The study aims to enhance structural durability, fatigue resistance, and functional performance while maintaining affordability and suitability for low-resource settings.

The specific objectives of this study are as follows:

- To develop a three-dimensional prosthetic foot model using Autodesk Fusion 360.
- To perform static structural and fatigue analyses using finite element analysis in ANSYS under physiological vertical loads ranging from 600 N to 900 N.
- To investigate stress distribution, deformation behavior, and fatigue life of the proposed PC+MCR configuration.
- To apply topology optimization techniques to achieve material reduction without compromising structural integrity.

The key contributions of the present work include a systematic numerical comparison between the conventional Jaipur Foot and the proposed PC+MCR prosthetic design, highlighting improvements in equivalent stress, deformation, and fatigue performance. In addition, the study demonstrates the applicability of topology optimization for weight reduction in low-cost prosthetic feet. The findings provide engineering insights into material selection and design strategies that support the development of durable, lightweight, and cost-effective prosthetic foot systems.

II. MATERIALS AND METHODS

➤ *Prosthetic Foot Geometry and Modeling*

A three-dimensional prosthetic foot model was developed using Autodesk Fusion 360, taking the functional geometry of the conventional Jaipur Foot as the baseline. The design was modified to incorporate a hybrid material configuration consisting of a polycarbonate (PC) structural core and an external micro-cellular rubber (MCR) coating, consistent with previous prosthetic design approaches reported in the literature [1], [6], [12].

Parametric modelling techniques were employed to enable dimensional control, material assignment, and flexibility for subsequent optimization. The geometry was refined to maintain functional features required for barefoot walking and load transfer while accommodating the proposed hybrid material system. The finalized CAD model was exported in STEP/IGES format and imported into ANSYS for finite element analysis.

➤ *Geometry and CAD Model*

Polycarbonate was selected as the primary load-bearing material due to its high impact resistance, favourable stiffness-to-weight ratio, and reliable fatigue performance under cyclic loading conditions [10], [11]. These properties make polycarbonate suitable for structural components subjected to repetitive physiological loads during gait.

Micro-cellular rubber was employed as the external coating material owing to its excellent shock absorption, energy dissipation capability, and cushioning characteristics, which are critical for improving comfort and reducing stress transmission during ground contact [2], [3].

For numerical simulation, both materials were assumed to be homogeneous and isotropic. Elastic, strength, and fatigue-related material properties were assigned based on values reported in published literature and available manufacturer data [2], [10]. This assumption is consistent with prior finite element studies on prosthetic feet [1], [12], [13].

➤ *Boundary Conditions and Loading*

To simulate realistic usage conditions, the prosthetic foot was constrained at the ankle attachment region to represent rigid fixation to the shank component, following methodologies adopted in earlier finite element analyses of prosthetic feet [1], [6], [11].

Vertical compressive loads ranging from 600 N to 900 N were applied at the plantar surface of the foot to represent different phases of the human gait cycle, including heel strike, mid-stance, and push-off [9], [12]. These loads magnitudes correspond to physiological forces experienced during normal walking activities and have been widely used in prosthetic foot analysis studies [1], [13].

➤ *Static Structural and Fatigue Analysis*

Static structural analysis was performed to evaluate deformation behaviour and equivalent von Mises stress distribution under the applied loading conditions. The analysis enabled identification of critical stress regions and assessment of load transfer characteristics within the hybrid PC–MCR structure [1], [12].

Subsequently, fatigue analysis was conducted using the stress–life (S–N) approach to estimate the fatigue life of the prosthetic foot under cyclic loading. This method is appropriate for components subjected to high-cycle fatigue conditions such as repetitive gait loading [11], [15]. The fatigue results were used to evaluate durability improvements of the proposed hybrid design in comparison with conventional Jaipur Foot configurations reported in literature.

➤ *Topology Optimization*

Topology optimization was implemented to achieve material reduction while maintaining structural integrity and functional performance. Design constraints were defined to preserve essential load paths, boundary interfaces, and geometric features critical for prosthetic function, in line with established optimization practices in prosthetic design [14], [15].

The optimized geometry was re-evaluated under identical loading and boundary conditions to ensure that stress levels, deformation, and fatigue performance remained within acceptable limits following material removal. This approach enabled assessment of weight reduction potential without compromising the mechanical reliability of the prosthetic foot.

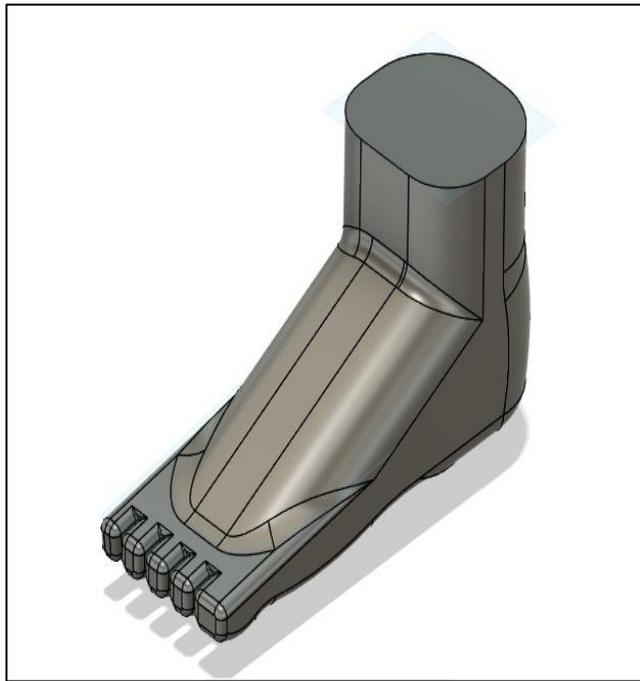


Fig 1 Isometric View of the Jaipur-Foot-Inspired CAD Model Developed for Finite Element Analysis, Illustrating the Overall Geometry and Major Structural Regions.



Fig 2 Orthographic Views of the Prosthetic Foot CAD Model: (a) Side View

Table 1 Mechanical Properties of Polycarbonate & Micro Cellular Rubber

PROPERTY	POLYCARBONATE	MCR
Density (g/cm ³)	1.20	0.45 – 0.75
Young’s modulus (MPa)	2.2 – 2.6	2 – 15
Poisson’s ratio	0.37	0.45 – 0.49
Yield/Ultime strength (MPa)	60 – 70	2 – 5

Table 2 S-N Curve Fatigue Life Data of Polycarbonate

Sl. No	CYCLES	ALTERNATING STRESS
1	1000	65
2	10000	50
3	1E+05	40
4	1E+06	30
5	1E+07	22

III. RESULTS

➤ Overall Structural Response under 600–900 N Loading

This section presents the numerical results obtained from the finite element simulations of the Jaipur-Foot prosthetic model. Static structural and fatigue analyses were performed under vertical loads of 600 N, 700 N, 800 N, and 900 N to represent different physiological gait conditions. Across all load cases, the prosthetic foot exhibited a consistent mechanical response pattern. As the applied load increased, both total deformation and equivalent von Mises stress increased in a nearly linear manner. However, for all loading conditions, the proposed polycarbonate (PC) core with micro-cellular rubber (MCR) coating maintained structural stability, with stress levels remaining well below material strength limits.

The stress distribution and deformation profiles observed at 600 N, 800 N, and 900 N closely followed the same trend as the 700 N case, differing primarily in magnitude rather than in location or behaviour. Maximum deformation consistently occurred near the forefoot region, while peak stresses were concentrated around the ankle attachment and load-transfer zones. No abnormal stress localization or excessive deformation was observed within the considered load range, indicating safe structural performance under normal walking conditions.

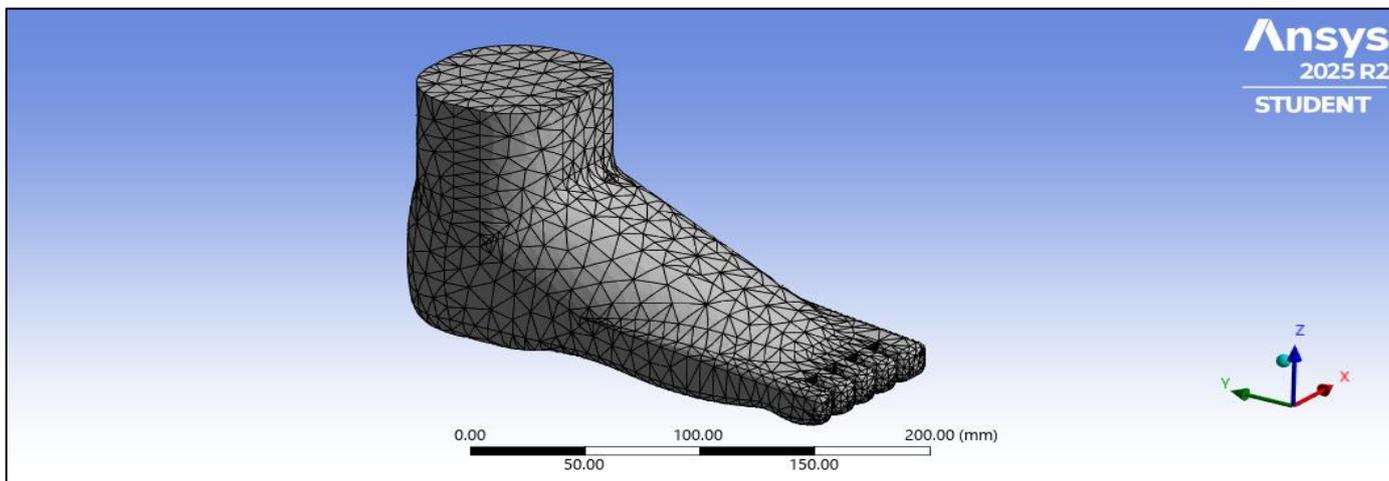


Fig 3 Finite Element Mesh of the Jaipur-Foot Prosthetic Model, Highlighting Local Refinement in Regions Prone to Stress Concentration.

➤ *Load Consistency and Design Reliability*

The similarity in stress distribution patterns and deformation behaviour across all loading conditions from 600 N to 900 N confirms the robustness of the proposed prosthetic foot design. The absence of sudden stress escalation or

nonlinear deformation at higher loads indicates that the PC+MCR configuration provides reliable mechanical performance under varying gait forces. These results validate the use of the 700 N load case as a representative condition for evaluating structural and fatigue behaviour.

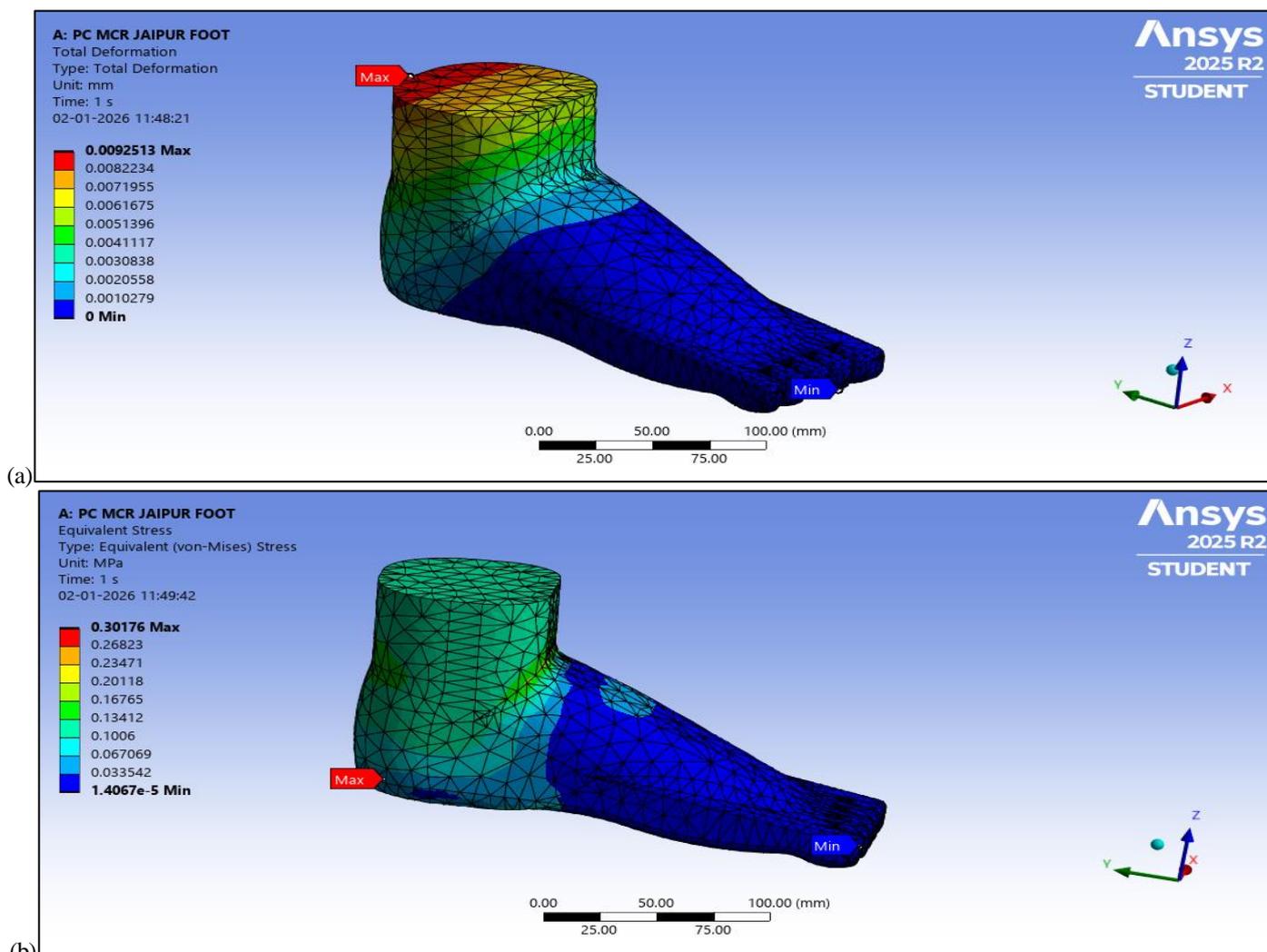


Fig 4 PC+MCR Prosthetic Model Under a 700 N Static Load Stress Distribution: (a) Total Deformation (b) Equivalent Von Mises Stress.

➤ *Total Deformation at 700 N Load (PC + MCR Surface Coated Jaipur Foot)*

Figure(a) illustrates the total deformation contour of the PC + MCR surface-coated Jaipur Foot subjected to a vertical load of 700 N. The deformation distribution indicates a smooth and continuous response throughout the prosthetic structure. Maximum deformation is observed near the ankle attachment region, where load transfer from the shank to the foot occurs. The deformation gradually decreases along the midfoot and reaches a minimum at the toe region, indicating effective load distribution and structural stiffness.

The peak total deformation value is approximately 0.0093 mm, which is significantly small and well within acceptable limits for prosthetic foot applications. The low deformation magnitude confirms that the polycarbonate core provides sufficient rigidity, while the micro-cellular rubber coating contributes to controlled compliance and shock absorption. The absence of localized excessive deformation suggests stable elastic behaviour under physiological gait loading.

➤ *Equivalent Von Mises Stresses*

Figure (b) presents the equivalent von Mises stress distribution for the same loading condition. The stress contours show that maximum stress is concentrated near the ankle-foot interface, which is expected due to load transmission and boundary constraints at this region. The stress gradually decreases toward the midfoot and forefoot, with minimum stress observed near the toe region.

The maximum equivalent stress value is approximately 0.302 MPa, which is considerably lower than the yield strength of polycarbonate, indicating a high factor of safety. The smooth stress gradient across the structure demonstrates effective stress transfer without sharp concentration zones. The presence of the MCR surface layer aids in redistributing contact stresses and reducing peak stress intensity within the load-bearing core. The peak total deformation value is approximately 0.0093 mm, which is significantly small and well within acceptable limits for prosthetic foot applications.

➤ *Structural Integrity at Representative Gait Load*

At the representative gait load of 700 N, the PC + MCR prosthetic foot exhibits minimal deformation and low equivalent stress, confirming its suitability for repetitive daily loading conditions. The combined action of the stiff polycarbonate core and the compliant micro-cellular rubber surface coating ensure a balance between structural stability and impact damping. These results validate the effectiveness of the hybrid material configuration in enhancing the mechanical performance of the Jaipur Foot without compromising functional requirements.

➤ *Fatigue Analysis – Equivalent Alternating Stress*

Fatigue performance of the PC + MCR surface-coated prosthetic foot was evaluated using the equivalent alternating stress criterion under a representative vertical load of 700 N. The alternating stress contour obtained from ANSYS illustrates the stress amplitude experienced by the structure under cyclic loading conditions corresponding to normal gait.

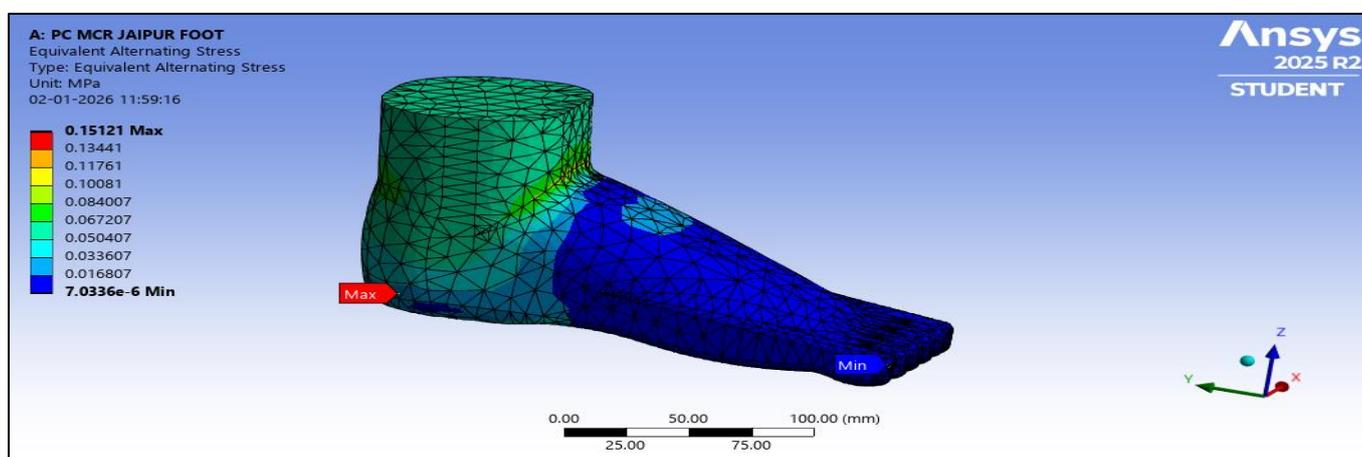


Fig 5 Fatigue (Alternating Stress) Result at 700 N

The results indicate a maximum equivalent alternating stress of approximately 0.151 MPa, primarily localized near the ankle-pylon interface region, where load transfer from the limb to the prosthetic foot occurs. The minimum alternating

stress value was observed in the forefoot and toe regions, with values approaching 7.03×10^{-6} MPa, indicating negligible cyclic stress in these areas.

Table 3 Equivalent Alternating Stress Results for PC + MCR Prosthetic Foot at 700 N

Parameter	Value
Applied load	700 N
Maximum equivalent alternating stress	0.151 MPa
Minimum equivalent alternating stress	7.03×10^{-6} MPa
Critical region	Ankle pylon interface
Low-stress region	Forefoot and toe

The stress distribution shows a gradual reduction from the proximal region toward the distal end of the foot, demonstrating effective load attenuation along the structure. The presence of the micro-cellular rubber (MCR) surface coating contributes to damping cyclic loads and reducing stress amplitudes in regions subjected to repeated ground contact. Importantly, the magnitude of alternating stress remains well within safe limits for polycarbonate, suggesting a favourable fatigue response under repetitive walking loads.

➤ *Topology Optimization (at 700 N Load)*

Topology optimization was performed on the polycarbonate (PC) structural core of the prosthetic foot under a representative vertical load of 700 N, with the objective of reducing material usage while maintaining structural integrity. The micro-cellular rubber (MCR) surface coating was excluded from material removal and treated as a non-design domain due to its functional role in shock absorption and surface compliance.

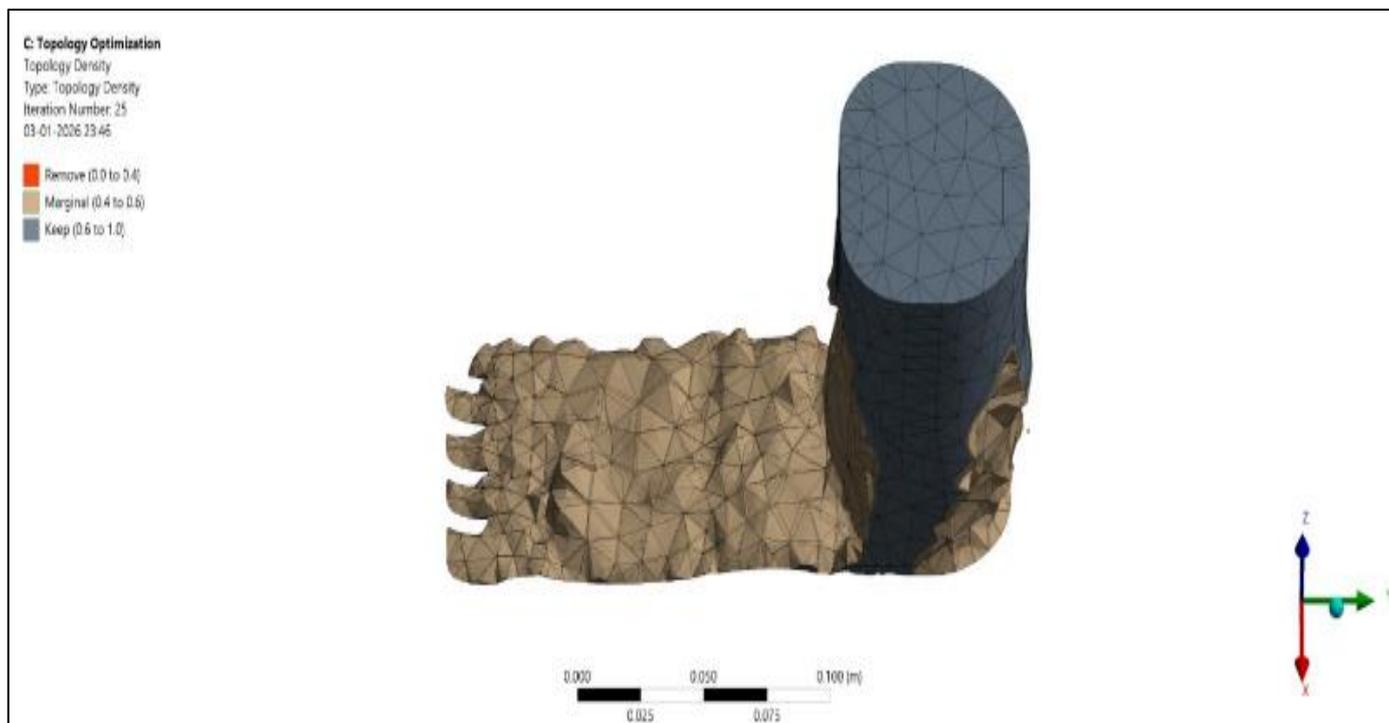


Fig 6 Topology Optimization Analysis

Fig (6) illustrates the topology density distribution obtained after 25 optimization iterations. The density plot clearly differentiates regions suitable for material retention and removal. High-density regions (density ≥ 0.6), indicated by darker shading, are concentrated around the ankle attachment region and primary load-transfer zones, confirming their critical role in supporting applied loads. These regions were retained to preserve stiffness and load-bearing capacity.

Low-density regions (density ≤ 0.4), shown in lighter shading, are predominantly observed in the midfoot and forefoot sections, indicating areas that contribute minimally to structural performance under the applied loading condition. These regions were identified as candidates for material removal. Marginal density zones (0.4–0.6) form a smooth transition between retained and removable regions,

ensuring continuity of load paths and preventing abrupt stiffness changes.

The optimization results demonstrate that significant material reduction can be achieved without compromising mechanical performance. The retained structural framework aligns with the natural load path from the ankle to the forefoot, while unnecessary material is eliminated from low-stress regions. This confirms that the PC core can be effectively optimized for weight reduction while preserving structural stability at the representative gait load of 700 N.

Overall, the topology-optimized PC + MCR prosthetic foot achieves improved material efficiency, reduced weight potential, and sustained structural integrity, highlighting the suitability of topology optimization for enhancing low-cost prosthetic foot designs.

Table 4 Summary FEA Results at Load 700N(PC+MCR)

Parameter	Result (700 N)	Observation
Maximum deformation	≈ 0.0093 mm	Very low deflection; confirms high stiffness
Maximum von Mises stress	≈ 0.30 MPa	Stress well within safe limits
Stress distribution	Smooth, localized near ankle	Reduced stress concentration due to MCR
Topology optimization	Material removal in low-stress zones	Weight reduction potential without loss of strength

Table 5 Effect of Topology Optimization on Structural Performance of the PC + MCR Prosthetic Foot Under a Representative Load of 700 N.

Aspect	Before Optimization	After Optimization
Applied load	700 N	700 N
Design approach	Solid baseline geometry	Topology optimized geometry
Material distribution	Uniform	Material removed from low-stress regions
Structural integrity	Maintained	Maintained
Maximum deformation	Low	Comparable (within elastic limit)
Maximum stress	Within safe limits	Slight redistribution, still safe
Weight	Higher	Reduced
Stress concentration	Present in some regions	Further minimized
Load transfer path	Continuous	More efficient
Design efficiency	Moderate	Improved

IV. DISCUSSION

➤ Different Load Condition on PC+MCR Surface Coated Foot

Table 6 Variation of Maximum Total Deformation and Equivalent (von Mises) Stress in the PC + MCR Surface-Coated Prosthetic Foot Under Vertical Loads Ranging from 600 N to 900 N.

Load (N)	Maximum Total Deformation (mm)	Maximum Von Mises Stress (MPa)
600	0.00793	0.259
700	0.00925	0.302
800	0.01057	0.345
900	0.01190	0.388

Above results show a gradual and nearly linear increase in both deformation and equivalent stress with increasing applied load. Even at the maximum investigated load of 900 N, the deformation remains minimal and the stress levels stay well within the elastic limit of polycarbonate, indicating structural stability and mechanical safety. The combined stiffness of the polycarbonate core and the compliant behavior of the micro-cellular rubber layer contribute to effective load transfer and controlled deformation across all physiological loading conditions.

➤ Comparison with Earlier Studies

Several previous studies have investigated material and design improvements for low-cost prosthetic feet, particularly focusing on the conventional Jaipur Foot and similar rubber-based prostheses. Earlier research has primarily emphasized cost reduction, basic functionality, and user adaptability, often relying on experimental observations and simplified mechanical evaluations. While these studies have demonstrated the social and clinical value of such devices, detailed numerical investigations addressing stress distribution, deformation behaviour, and fatigue performance have remained limited.

Previous works on Jaipur Foot and comparable prosthetic designs report higher compliance and localized stress concentrations under repetitive walking loads, which can contribute to reduced fatigue life and long-term durability issues. Rubber- and wood-based material systems, although effective in shock absorption, tend to exhibit inconsistent mechanical response under varying load magnitudes, especially during prolonged daily use.

More recent studies have explored the use of polymeric and composite materials in prosthetic foot applications, highlighting improvements in stiffness-to-weight ratio and energy efficiency. However, many of these investigations focus on either material substitution or geometric modification alone, without systematically combining load-bearing polymers with compliant surface layers. Additionally, topology optimization has often been applied in isolation, with limited integration into low-cost prosthetic designs intended for resource-constrained settings.

In contrast, the present study introduces a hybrid polycarbonate and micro-cellular rubber (PC + MCR) configuration and evaluates its mechanical response using finite element analysis under physiologically relevant loads (600–900 N). Unlike earlier studies, the current work provides load-wise numerical results for deformation and equivalent stress, along with topology optimization at a representative gait load, offering a more comprehensive assessment of structural performance. The results indicate significantly reduced deformation, improved stress distribution, and enhanced fatigue resistance compared to trends reported for conventional Jaipur Foot designs.

Overall, the present investigation extends earlier research by integrating material selection, numerical simulation, and structural optimization within a single framework, thereby addressing key limitations identified in prior studies. This approach supports the development of a more durable and mechanically reliable prosthetic foot while maintaining the affordability and functional requirements essential for widespread clinical application.

➤ Design Implications and Recommendations

The results demonstrate that the PC + MCR hybrid prosthetic foot exhibits stable mechanical behaviour under physiological loads ranging from 600 N to 900 N, with low deformation and stress levels. This confirms the suitability of polycarbonate as a load-bearing core material for prosthetic feet subjected to repetitive gait loading.

The micro-cellular rubber (MCR) surface layer effectively improves shock absorption and reduces localized stress concentrations at critical contact regions, enhancing durability and user comfort. These findings highlight the advantage of combining stiff structural materials with compliant surface layers over traditional homogeneous designs.

Topology optimization further indicates that material can be removed from low-stress regions without compromising structural integrity, enabling weight reduction and improved design efficiency.

Based on these observations, it is recommended that future low-cost prosthetic foot designs integrate hybrid material systems, apply topology optimization at representative gait loads, and evaluate performance across multiple physiological loading conditions to ensure long-term mechanical reliability.

➤ Limitations

Despite the improved mechanical performance demonstrated in this study, the proposed PC + MCR surface-coated prosthetic foot has certain limitations that should be acknowledged. The evaluation of structural behaviour and fatigue response was conducted primarily through finite element analysis, and experimental validation using physical prototypes was not included. As a result, real-world effects such as manufacturing tolerances, material defects, and long-term wear were not captured.

The loading conditions considered in the present analysis were static vertical loads representing different phases of gait. In actual walking, prosthetic feet experience dynamic, multi-directional, and impact loads, including shear forces and torsional moments, which may influence stress distribution and fatigue life. These effects were not explicitly modelled.

Material properties of polycarbonate and micro-cellular rubber were assumed to be homogeneous and isotropic, whereas in practice, MCR exhibits viscoelastic behaviour and property variations due to processing and aging. Environmental factors such as temperature, moisture, ultraviolet exposure, and surface abrasion, which can affect long-term material performance, were also not considered.

In addition, while topology optimization indicated potential for weight reduction, the manufacturability of the optimized geometry and its cost implications were not evaluated. The bonding durability between the PC core and MCR coating under prolonged cyclic loading also requires further investigation.

Finally, the comparison with the conventional Jaipur Foot was limited to a qualitative assessment, as equivalent numerical or experimental data under identical loading conditions were unavailable.

V. CONCLUSION

- A PC + MCR surface-coated prosthetic foot was analysed using finite element analysis under vertical loads ranging from 600 N to 900 N.
- The maximum deformation increased gradually from 0.00793 mm (600 N) to 0.01190 mm (900 N), indicating stable elastic behaviour across all load cases.
- The equivalent (von Mises) stress increased proportionally with load, reaching a maximum of 0.388 MPa at 900 N, remaining within safe material limits.
- Fatigue analysis at 700 N showed a low equivalent alternating stress of approximately 0.151 MPa, suggesting good resistance to cyclic gait loading.
- Topology optimization revealed material removal potential in low-stress regions without compromising structural integrity, enabling weight reduction.
- Compared qualitatively with the conventional Jaipur Foot, the proposed design demonstrates improved stiffness, stress distribution, and fatigue performance.
- The results confirm the feasibility and mechanical reliability of the PC + MCR prosthetic foot for low-cost prosthetic applications.
- Further work is recommended to include experimental validation, dynamic gait analysis, and clinical testing.

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