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Structural Analysis and Mass Optimization of Mobility Walkers Using Lightweight Polymer Matrix Composites

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Abstract: This study investigates the structural performance and mass optimization of traditional walkers by comparing aluminum alloy and polymer matrix composites (PMCs) through advanced finite element analysis (FEA) using the ANSYS simulation platform. The FEA results reveal that peak stress, reaching 251.9 MPa, is concentrated at the front wheel support region, highlighting a critical area prone to structural vulnerability. Special attention is required to address potential mechanical limitations in key zones, such as the rear suspension, to prevent premature failure. Comparative analysis demonstrates that walkers fabricated from carbon-epoxy PMCs offer superior stiffness, reduced weight, and enhanced resistance to deformation compared to aluminum alloy counterparts. Notably, under descent conditions, the maximum elastic strain in the carbon-epoxy walker reaches 0.00399 mm/mm, localized in the front wheel support area, as indicated by the simulation results. These findings underscore the significant role of material selection in improving structural integrity and performance across varying operational conditions. The equivalence of stress and strain energy distributions further substantiates the advantages of composite materials over conventional alloys, suggesting that PMCs enable enhanced durability without compromising weight efficiency. The research emphasizes a human-centred approach, aligning material performance with user needs to develop mobility aids that offer long-term structural reliability. Beyond addressing immediate structural concerns, the findings lay the groundwork for future studies involving optimization algorithms and the exploration of alternative composites for assistive devices. The study provides valuable insights into stress distribution, deformation behaviour, and mechanical response, promoting continuous innovation in the design and development of mobility aids.

Keywords: Structural optimization; Polymer matrix composites (PMCs); Mobility aids; Carbon-epoxy composites; Assistive technologies; Finite element analysis (FEA); Lightweight materials, Structural integrity

1 Introduction

In the past years, there has been a significant increase in the demographic landscape worldwide as aging develops more concerns about geriatric healthcare demands [1]. The demographic trends further indicate that the occurrence of disabled persons is on an upward trend given the aging population across the world, and this means that there is an ever-increasing need for efficient mobility equipment. According to the World Health Organization (WHO), the elderly people (population aged 60 years or older) will more than double by 2050 to about 2.1 billion people [2]. The first relevant demographic shift relates to the currently growing importance of people and their mobility, not just as essential, low-level necessities but as entities capable of moving through increasingly complex spaces [3]. The above demographic change highlights the urgent need for creative solutions addressing not only physical barriers but also changing cognitive features of aging. As for traditional walkers, they are best suited for flat surfaces, which means that a user will need another device to be able to move with the walker in staircases or an area with an uneven surface. This limitation greatly extends to the elderly and disabled persons in terms of liberty and potential autonomy [4].

The main health concerns that the elderly face are challenges such as knee and leg injuries on their ability to stay active, which affects how they can move around them [5]. In addition, when combined with common illnesses like heart disease, cholesterol problems, and high blood pressure, the difficulties further intensify [6]. Understanding the urgent need to promote mobility and general health in old age, walkers have become irreplaceable facilitators. These are important devices in assisting aging people to get necessary support, especially for leg and knee problems that help them with stability [7]. Yet, the current market offerings are not without limitations, as many walkers limit some areas and scenarios. For instance, negotiating stairs becomes a real challenge for people with physical disabilities, and this necessitates the need to have walkers that are functional not only on flat surfaces but also in different terrains. The Convention on the Rights of Persons with Disabilities (CRPD) highlights how important assistive technologies are, providing an example set by walkers toward enhancing accessibility for all individuals regardless of their mobility status [8]. One of the key considerations for designing effective walkers is that they enhance proper posture, which highly determines the users' comfort and general health. However, conventional walkers (Figure 1) require a lot of upper body strength, hence producing such a gait that is slow and tiring. As we explore the spectrum of available walkers, there are generally four types: the traditional Rollite (Rollator) Walker, Rolling Walkers, and Walk-lite Walker based on addressing individualized mobility issues. This article examines the changes in walker technology that go beyond physical support to include cognitive well-being, inclusive design advances also cover innovation efforts in this field. These designs and solutions are a reflection of the many different innovations that respond to the multifaceted needs of advanced aged persons present. Le and Jung [9] conducted a study on a newly developed three-wheeled mobile walker designed specifically for ascending stairs. This innovative walker features an adjustable structure that can accommodate steps of varying heights. Such flexibility not only enhances usability but also provides users with a greater sense of independence and confidence when navigating different staircases. Additionally, the design has been reported to positively impact mental satisfaction among users, contributing to their overall well-being. This research highlights the importance of adaptability in assistive devices to meet diverse user needs effectively. Figure 1 shows a conventional 3-legged walker design for the reference purpose.

Figure 1. Conventional 3-legged walker design

A promising area for future research is the walker design discussed by Nickpour and O'Sullivan [10], which considers re-engineering common features and parts to enhance mobility on uneven surfaces in smart cities with potential cost efficiency. The main objective of this effort is to improve cost-effectiveness and availability, highlighting the critical need for a design approach that prioritizes flexibility and affordability. This research paves the way for future innovation in walker design that focuses on inclusivity and cost-effectiveness. Hamidi [11] proposed a systematic methodology to create personalized wheelchairs suited to those with disabilities. Using lightweight materials and strengthening the support at the holder for a better grip, this study aims to satisfy those persons operating with leg or back injuries as well as sufferers of mild imbalance. The incorporation of anthropometric data contributes to the improvement in walker's performance.

Merlet [12] described an innovative walker/rollator to assist the elderly with mobility issues. The clutch mechanism of ANG has computer-controlled bistable spring electromagnet and Oldham coupling, which gives advanced features such as automatic stabilization through ultrasonic sensors. This research provides pathways for integration of the intelligent technologies in urban aids that may help the elderly to remain independent from home. Anslow et al. [13] discussed two types of design walkers and deal with some issues relating to stability depending on given designs. Although the figures reveal no noticeable difference in stability, these findings demonstrate that individual specificities need to be considered when selecting a walker. This study promotes a more targeted approach to the selection of walkers based on distinct user needs. Given that its design, development, and evaluation focus was on senior citizens with visual impairments or limited mobility. This research [14] moves towards technologically advanced mobility solutions that are inclusive through the use of various infrared and sonar sensors for navigation, as well as easy user input methods.

Yasin et al. [15] suggested an intelligent walker's design based on ergonomics and compactness with sensors capable of tracking patient movement. This study overcomes the shortcomings of the initial design and brings in new functionality, including distance detection and monitoring activity for rehabilitation. This is a crucial move towards reconciling mobility devices with the dynamic technology ecosystem. O'Hare et al. [16] did an evidence-based analysis of the supply of walking frames to the elderly, considering prescription strategies and evaluating efficiency in different kinds of walking structures. This study supports a complex understanding of mobility aid effectiveness and guides prescription practices. Stevens et al. [17] focused on unintentional injury resulting from incidents related to walking assistance devices, indicating that it is important to improve the design in order to facilitate greater functionality with reduced risk for injuries. The research emphasizes the need for continuous development to improve mobility aids in terms of safety and effectiveness. Rathod et al. [18] developed a hand truck that can negotiate stairs with minimum effort.

This innovative solution, which can be applied across various sectors, features a flat surface roller plate and an advanced warning alert system. These elements demonstrate the potential to enhance both the safety and functionality of stair climbing devices. Hossain et al. [19] worked on creating a motorized vehicle that climbed stairs to ease movement over tough terrain surfaces. Although challenges with stability and speed are identified, the study highlights the importance of gearbox and steering mechanism improvements for better versatility. This paper provides valuable insight to further the development of motorized mobility aids for particular settings. Other studies that have been recently carried out strongly support the need to design walkers that are capable of use on various terrains. In their work, Mohite et al. [20] focused on the existing drawbacks of current walker designs and the requirement for new solutions to be developed to address issues such as stair climbing and better structural engineering. This paper seeks to address these challenges by evaluating a walker designed for use on flat surfaces and stairs, which incorporates unique materials and structural features. A study led by Bonde et al. [21] examined the materials utilized in the design of walkers, specifically focusing on steel alloys. These alloys are often chosen for their lightweight characteristics. However, the researchers noted that while these materials are advantageous for weight reduction, they may not possess sufficient strength to effectively support diverse terrains. Additionally, the study found that the loads applied to the joints can lead to fatigue failure, which may cause microfractures in those areas. A review by Letsatsi and Agarwal [22] also noted that composites might improve the performance with high vibrational stability in the structure. Still, more research should be done to test the applicability of the stated results in actual environments. On the other hand, PMCs have higher strength/weight ratios than aluminum, and the use of PMC in walker design has not been fully investigated. The present literature review on walker designs and assistive technologies consists of various strategies for enhancing mobility aids; however, there is a research limitation in the structural and materials aspects. Similar previous works have focused on ergonomically appealing properties and the comfort of users but fail to provide a comprehensive examination of the employed materials, as well as their performances within distinct contexts.

The reviewed literature in this section gives a general understanding of innovative designs, factors to consider, and advancements made with mobility aids, hence providing important insights into the ongoing development of assistive technologies for various users. The current body of literature has greatly advanced the development of mobile aids, especially walkers for older and disabled people. Nevertheless, a clear area of research remains in the field of walkers created for full functionality that provides mobility on both flat surfaces and steps. While typical walkers are primarily designed to accommodate level surfaces, that leaves little room for addressing the needs of those individuals who need help not only on planes but also in walking stairs. Therefore, the structural features of walkers in a range of contexts, especially climbing stairs, are an issue that is hardly discussed from today's perspective. This research seeks to address this gap by employing the ANSYS FEA simulation to ascertain the structural properties of walkers created from the aluminum alloy and the PMC, then comparing these characteristics on flat surfaces and stairs. The contribution of this research will be in advancing the understanding of existing literature and walker design solutions for the improvement of walkers. This study therefore presents a novel research approach by embracing a subject that has found relatively little attention in the literature – the use of PMC in the fabrication of a walker. The innovation of this research is in two ways: one is the objective of investigating the structural properties of PMC, and the second part is the application of this concept for stair-climbing mobility on multiple terrains. Relating to the identified research gap, this study's hypothesis proposes that walkers made from aluminium alloy and carbon epoxy material may be improved in terms of ground-level conditions for structures. It is assumed that the specific features of these materials, when analyzed under the structure of the ANSYS FEA simulation package will manifest increased viability and practicality in serving a diverse set of requirements to address multifarious needs of elderly and disabled population mobility. The possible research objectives considered are:

1. To analyze the structural characteristics of walkers produced from carbon epoxy PMC material and compare them to walkers made from aluminum alloy, using modern optimization algorithms.
2. Variable selection and evaluation of walker performance on-ground conditions using ANSYS.
3. To ascertain the suitability of carbon epoxy material to be used as material for constructing walkers that can provide extra strength with light weight through FEA simulation.
4. To identify design changes and alterations that may be needed to make the walker optimized for its structural integrity as well as performance in different scenarios.

The contemporary walkers that are sold in the market today have been aimed at walking on flat surfaces, overlooking an essential factor of stair climbing. This poses a significant problem for the disabled and aging population, who require assistance with roller mobility when walking on both flat surfaces and stairs. Since there are no stair-climbing walkers specifically designed for this particular demographic, it means that they have limited mobility range and independence. The literature review reveals a deficiency in studies that compare the performance of PMC with other materials utilized in walker design, and thoroughly explore its potential to enhance the walker's performance on both flat surfaces and stairs. Therefore, this study fills that gap by focusing on the detailed ANSYS FEA simulation that lends a deeper understanding of how PMC can enhance the walker's performance as compared to other regular materials. Thus, this study has implications that go beyond theoretical thinking, providing real-world recommendations for the development of walkers that would be more suitable for elderly and disabled populations. This study has identified valuable insights to the field of assistive technology, and the findings may have an impact on the creation of mobility aids in the future by eradicating the restrictions incurred by traditional walker designs and portraying the advantages of PMCs.

2 Methodology

The FEA simulation of the walker was developed in a painstaking way to offer an analytical and innovative approach to assessing its structural features. This process was in several stages, CAD modeling meshing and boundary conditions, as well as post-processing, meant to increase the accuracy of relevance for simulation [23]. This study compares aluminum alloy, a traditional material known for its lightweight and durability in walker design, with carbon epoxy composites (PMCs), which offer a superior strength-to-weight ratio and rigidity. Aluminum alloy is widely used due to its proven performance, while carbon epoxy composites are investigated for their potential to enhance walker functionality on various terrains. The FEA model assumes material homogeneity and employs simplified geometry to streamline analysis, focusing on structural performance. Standard load conditions represent typical usage scenarios, though environmental factors are not considered in this preliminary assessment. These choices ensure a clear, practical comparison of material performance and provide a foundation for future, more detailed studies. The properties are shown in Table 1 and Table 2, respectively.

Table 1. Aluminum alloy material properties [24]

Property	Value
Density $(\mathrm{Kg/m^3})$	2770
Modulus of elasticity (MPa)	71000
Poisson's ratio	0.33

Table 2. Carbon epoxy material properties [24]

Property	Value
Density (Kg/m^3)	1490
Young's Modulus (x-direction) (MPa)	121000
Young's Modulus (y-direction) (MPa)	8600
Young's Modulus (z-direction) (MPa)	8600
Poisson's ratio (xy)	0.27
Poisson's ratio (yz)	0.4
Poisson's ratio (xz)	0.27
Shear Modulus XY (MPa)	4700
Shear Modulus YZ (MPa)	3100
Shear Modulus XZ (MPa)	4700

The first objective proposed for the research is to analyze the structural characteristics of walkers made of aluminum alloy and carbon epoxy. Table 1 and Table 2 provide structural property descriptions of aluminum alloy and carbon epoxy, which are utilized in the structural analysis of walkers made of these materials. The modulus of elasticity is used in element stiffness matrix formulation, which is a process in the Finite Element Method. First, a 3-D CAD model of the walker was created using the ANSYS design modeler. Other tools like sweep, round, and so on were used to design a geometrically accurate image that is reflected in Figure 2.

After the CAD modelling stage, a thorough analysis of geometric inaccuracies and defects was carried out. In order to achieve accurate outcomes in simulation, tools such as edge break and surface break were used for the improvement of the meshing zone [25]. The model, which is discretized and illustrated in Figure 3 and Figure 4, shows that sufficient mesh (244277 elements, 385538 nodes) is produced for an accurate outcome when simulated.

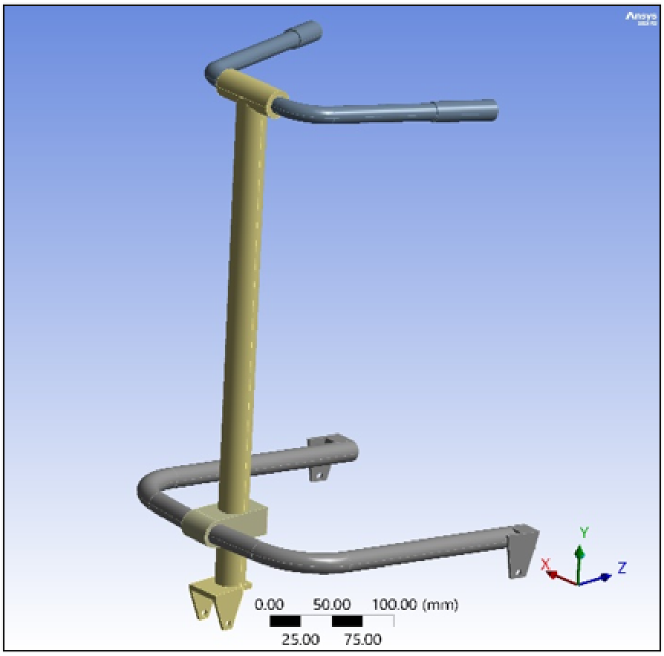


Figure 2. 3-D CAD model of walker

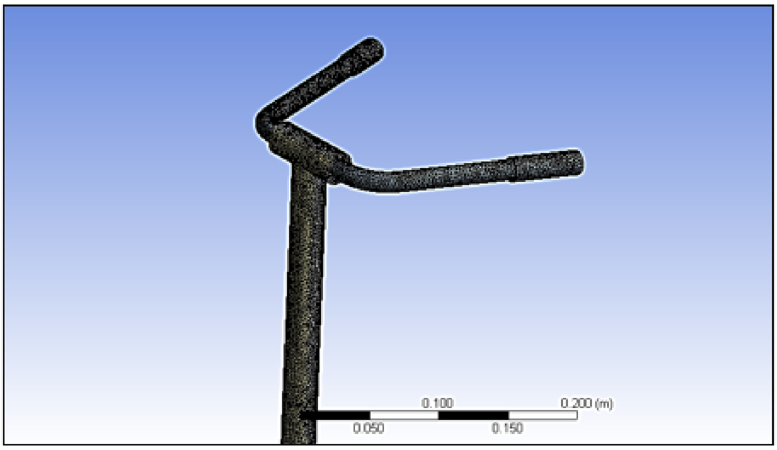


Figure 3. Meshed model of walker upper holding arm

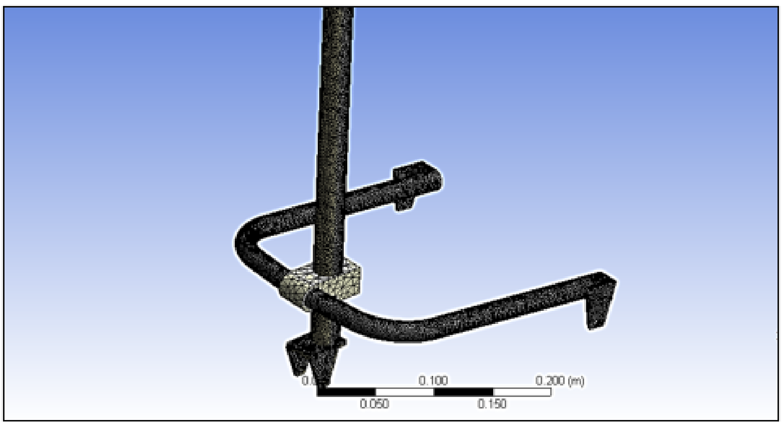


Figure 4. Meshed model of walker lower support zone

After this, the tetrahedral elements were used to discretize the walker design owing to its ability to handle complex structures and topological incoherence with sharp curvatures as shown in Figure 5. Errors in the meshing due to surface irregularities were minimized by enabling curvature effects. The decision of tetrahedral elements was based on their capability to represent structural details accurately [26].

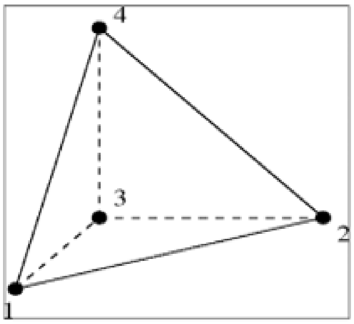


Figure 5. Element shape of tetrahedral element [27]

This element type is ideally suited to the complex pattern of the walker's design so that proper representation of geometry can be achieved [28]. Other parameters such as smoothing, relevance, and span angle, were also adjusted for fine sizing of the mesh to ensure maximum accuracy during simulation.

To simulate real-world conditions, structural loads were applied. Assuming a person's weight to be 100 kg, a quarter of this weight (25 kg or 250 N) was applied in the downward direction on the walker's handlebar grip, as indicated by the red arrow in Figure 6.

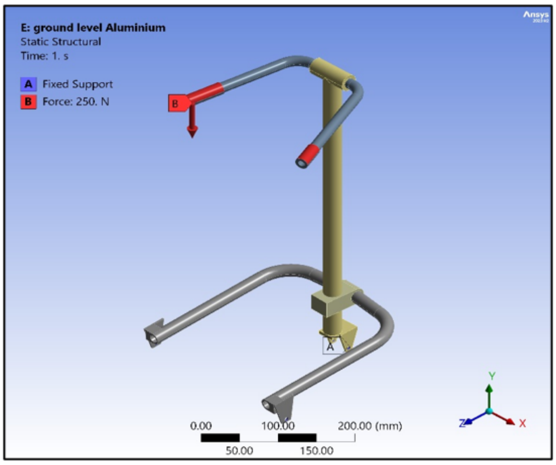


Figure 6. Loads and boundary conditions

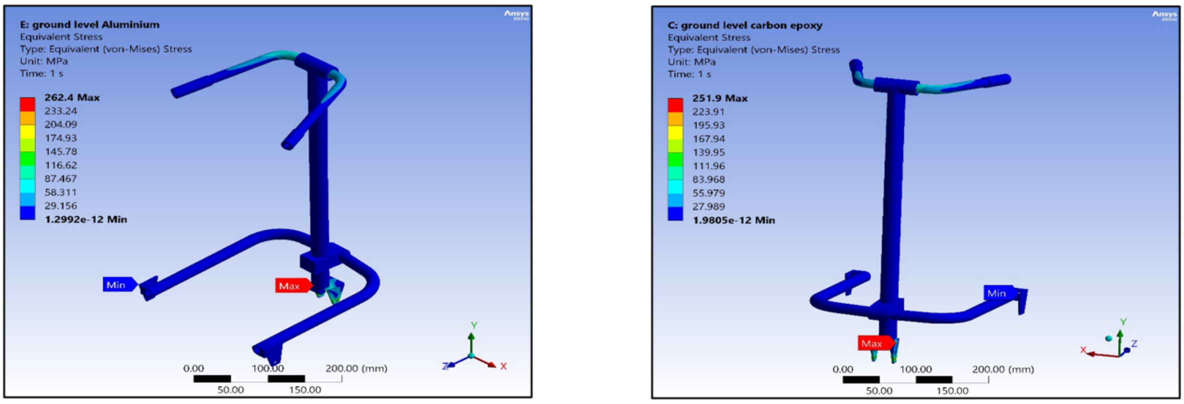
To emulate fixed support, representing the scenario where the person applies brakes to restrict wheel movement while using the walker, fixed support was applied to the bottom surfaces of the walker. This assumption aligns with practical considerations during walker usage. This innovative methodology aims to comprehensively evaluate the walker's structural characteristics under both level ground and stair-climbing conditions. The deliberate choice of tetrahedral elements, along with detailed meshing parameters, ensures a robust and accurate representation of the walker's geometry, contributing to the reliability of the simulation results.

3 Results and Discussion

The FEA simulation was conducted to evaluate structural analysis parameters for the walker under on-ground conditions. The obtained results are presented and discussed in detail below.

3.1 On-Ground Condition

For on-ground conditions, the maximum equivalent stress is observed at the front wheel support zone with a magnitude of 262.4 MPa, while other regions exhibit a nearly constant equivalent stress of approximately 29 MPa, as illustrated in Figure 7. The maximum equivalent stress obtained from the analysis of the carbon epoxy walker is 251.9 MPa at the wheel-base region.

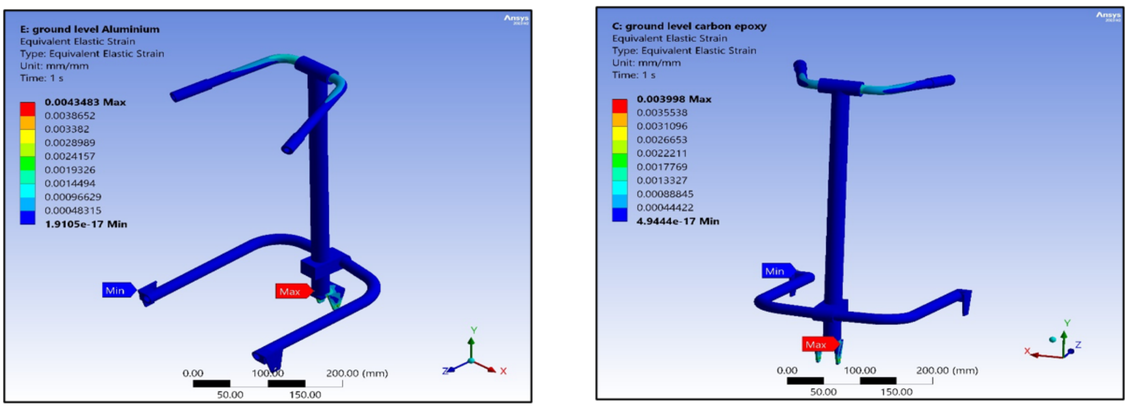


(a) (b)

Figure 7. Equivalent stress plot of walker: (a) Aluminium alloy; (b) Carbon epoxy

Table 3. Grid independence test

Number of Elements	Equivalent Stress (MPa)
243458	261.8
244167	262.3
244258	262.4
244277	262.4



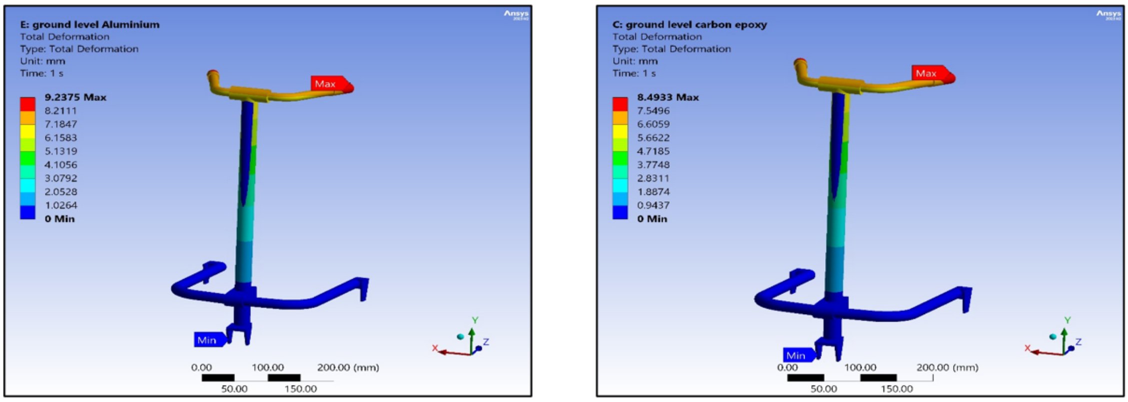
(a) (b)

Figure 8. Equivalent elastic strain plot: (a) Aluminium alloy; (b) Carbon epoxy

These results align closely with the existing literature [15], validating the accuracy of the simulation outcomes. The grid independence test (Table 3) was conducted to ascertain the optimal mesh size, revealing that the obtained equivalent stress results are independent of mesh density. The optimal mesh size, determined from the grid independence test, was 244,277 elements.

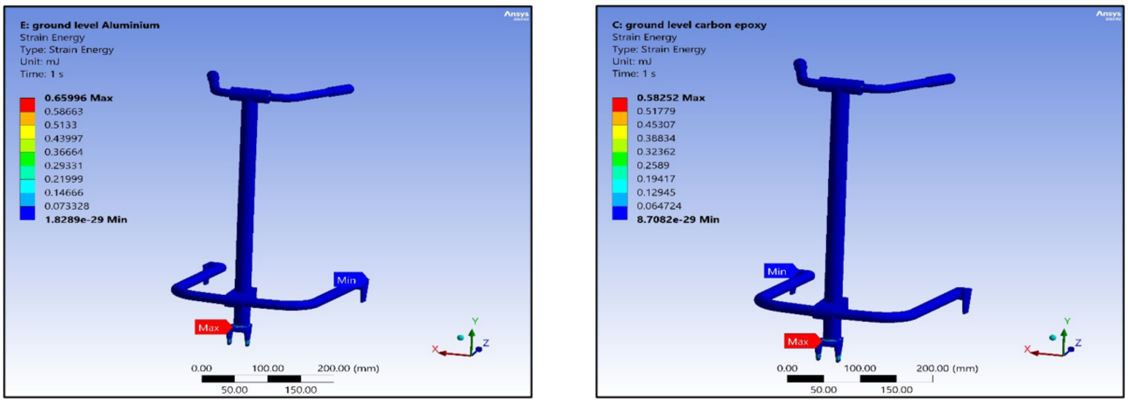
Elastic strain, a critical parameter for evaluating structural integrity, indicates that the extreme elastic strain occurs at the wheel support zone, with a scale of 0.00416 mm/mm as shown in subgraph (a) of Figure 8. For the carbon epoxy walker, the maximum elastic strain is obtained at the wheel support zone with a magnitude of 0.00399 mm/mm as denoted by the red-colored zone in subgraph (b) of Figure 8. However, the maximum deformation is observed at the free end of the holding bar, with a magnitude of 9.23 mm, as depicted in subgraph (a) of Figure 9. While for the carbon epoxy walker, the maximum deformation is obtained at the free end of the holding bar with a magnitude of 8.49 mm as depicted in subgraph (b) of Figure 9.

Strain energy characteristics, vital for understanding energy absorption and dissipation, are illustrated in subgraph (a) of Figure 10. The maximum strain energy of 0.6599 mJ is stored at the front wheel support region, providing essential insights into the walker's performance under on-ground conditions. The strain energy distribution plot is obtained for the carbon epoxy walker for on-ground moving conditions as shown in subgraph (b) of Figure 10. The maximum strain energy of 0.582 mJ is obtained at the wheel support zone at the bottommost part of the walker.



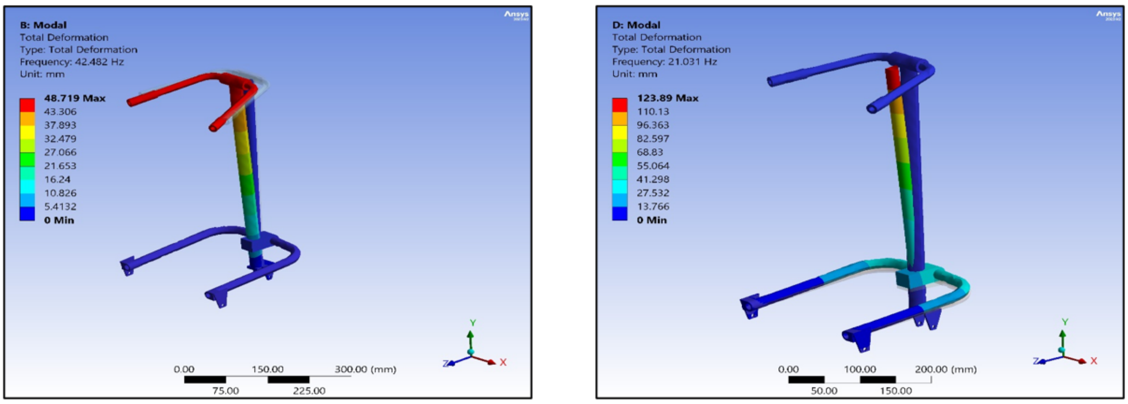
(a) (b)

Figure 9. Total deformation plot: (a) Aluminium alloy; (b) Carbon epoxy



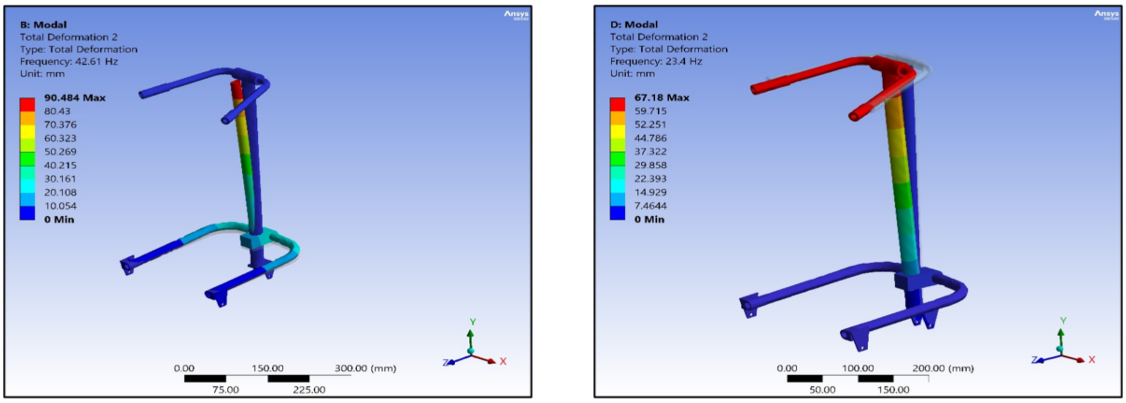
(a) (b)

Figure 10. Strain energy plot: (a) Aluminium alloy; (b) Carbon epoxy



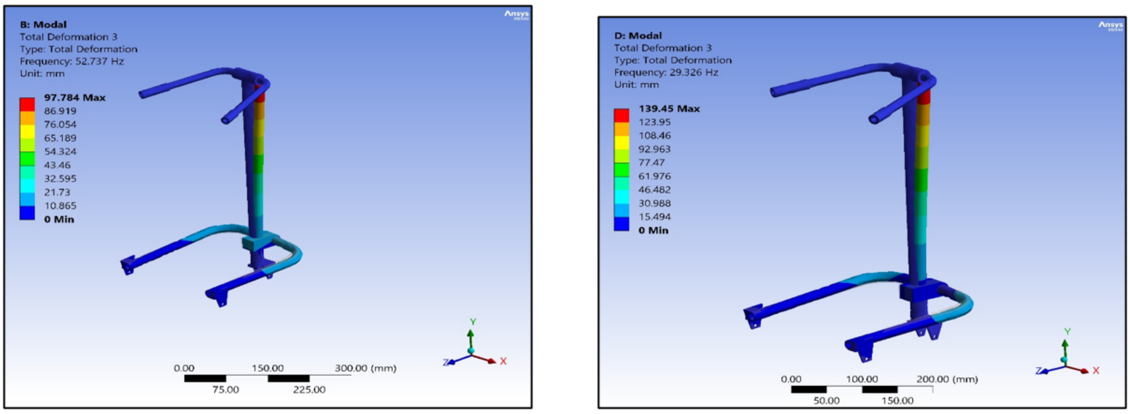
(a) (b)

Figure 11. The first natural frequency of walker: (a) Aluminium alloy; (b) Carbon epoxy



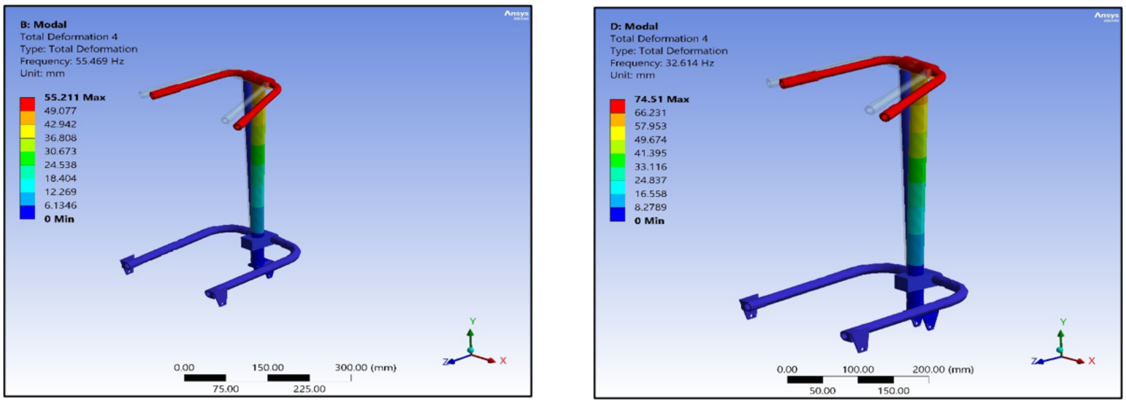
(a) (b)

Figure 12. The second natural frequency of walker: (a) Aluminium alloy; (b) Carbon epoxy



(a) (b)

Figure 13. The third natural frequency of walker: (a) Aluminium alloy; (b) Carbon epoxy



(a) (b)

Figure 14. The fourth natural frequency of walker: (a) Aluminium alloy; (b) Carbon epoxy

3.2 Modal Analysis

The modal analysis is conducted on both aluminum alloy and carbon epoxy walkers to determine natural frequency and mode shape. The first natural frequency of the aluminum alloy walker is 42.482 Hz with a deformation magnitude of 48.719 mm, while for the carbon epoxy walker, 4 natural frequencies are obtained. The first natural frequency of the carbon epoxy walker is 21.031 Hz, and the deformation is 123.89 mm, as depicted in subgraphs (a) and (b) of

Figure 11, respectively.

The second natural frequency of an aluminum alloy walker is 42.61 Hz with a deformation magnitude of 90.48 mm. The mode shape obtained is of the transverse type. The second natural frequency of the walker is 23.4 Hz with a deformation of 67.18 mm, which is of transverse type in the case of using the carbon epoxy material as depicted in subgraphs (a) and (b) of Figure 12, respectively.

The third natural frequency of the aluminum alloy walker is 52.737 Hz with a deformation magnitude of 97.784 mm. The mode shape obtained is of transverse type, while for carbon epoxy third natural frequency, the maximum deformation obtained is 139.45 mm and a natural frequency of 29.326 Hz, as depicted in subgraphs (a) and (b) of Figure 13, respectively.

The fourth natural frequency is obtained for walkers, as shown in Figure 14. The fourth natural frequency obtained is 55.469 Hz, with a deformation of 55.211 mm. The fourth natural frequency obtained is the torsional type, while for carbon epoxy's fourth natural frequency, the maximum deformation obtained is 74.51 mm and the natural frequency is 32.61 Hz, as depicted in subgraphs (a) and (b) of Figure 14, respectively.

3.3 The Mass Participation Factor (MPF)

The MPF is computed for both the aluminum alloy walker and carbon epoxy walker in Table 4 and Table 5. For the aluminum alloy walker, the maximum MPF of 0.975 is obtained along the rotational z direction, which signifies that any external excitation along the rotational z direction would cause amplitude buildup due to resonance. For carbon epoxy, the maximum MPF of 0.94 is obtained along the rotational x direction and can cause amplitude buildup.

Table 4. MPF chart of aluminium alloy walker

Mode	Freq. (Hz)	Period (s)	Part Factor	Ratio	Eff. Mass	Cum. Mass Frac.	Ratio Eff. to Total Mass
1	42.4816	2.35E-02	0.29382	0.032301	8.63E-02	8.08E-04	7.89E-04
2	42.6102	2.35E-02	0.15253	0.016768	2.33E-02	1.03E-03	2.13E-04
3	52.7366	1.90E-02	-4.8898	0.537547	23.9103	0.224943	0.218436
4	55.4685	1.80E-02	-9.0965	1	82.7468	0.999856	0.755947
5	90.0938	1.11E-02	0.11963	0.013151	1.43E-02	0.99999	1.31E-04
6	120.595	8.29E-03	-3.34E-02	0.003667	1.11E-03	1	1.02E-05
Sum					106.782		0.975526

Table 5. MPF chart of carbon epoxy walker

Mode	Frequency	Period	Part Factor	Ratio	Effective Mass	Cumulative Mass Fraction	Ratio Eff. Mass to Total Mass
1	21.0314	0.047548	2.9474	0.44011	8.68739	0.153902	0.14566
2	23.3996	0.042736	6.6966	1	44.8442	0.948343	0.751897
3	29.3265	0.0341	1.4252	0.21696	2.111008	0.948171	0.000353928
4	32.6145	0.030616	0.93904	0.12403	0.0819752	0.999789	0.000143706
5	46.6979	0.021414	1.6986	0.25356	8.8353	0.999989	0.0483796
6	72.0305	0.013838	0.024764	0.00369	0.000612372	1	1.02218E-05
Sum					56.4475		0.946448

Table 6 presents a comparison of equivalent stress and other parameters between materials. The carbon epoxy material Walker exhibits lower equivalent stress than the aluminum alloy walker strain, which makes it more structurally stable and well suited for walkers.

Table 6. Equivalent parameter comparison between materials

Evaluation Parameters	Aluminum Alloy	Carbon Epoxy
Equivalent stress (MPa)	262.4	251.9
Total deformation (mm)	8.8472	8.4933
Strain energy (mJ)	0.63207	0.58252
Equivalent elastic strain $(\mathrm{mm/mm})$	0.00416	0.00399

The carbon epoxy material Walker exhibits a higher induced strain energy than that of an aluminum alloy, implying high stiffness and resistance to deformation. This implies that the carbon epoxy material walker can take more stress during on-ground moving, up-climbing, and down-moving conditions.

Table 7. Natural frequency comparison

Natural Frequency	Aluminum Alloy	Carbon Epoxy Composites
1^{st} natural frequency	42.48	21.03
2^{nd} natural frequency	42.61	23.399
3^{rd} natural frequency	52.73	29.325
4^{th} natural frequency	55.46	32.614

Table 8. Natural frequency deformation comparison

Deformation	Aluminum Alloy	Carbon Epoxy Composites
1^{st} frequency deformation (mm)	48.719	123.8
2^{nd} frequency deformation (mm)	90.484	67.18
3^{rd} frequency deformation (mm)	97.784	139.45
4^{th} frequency deformation (mm)	55.211	74.51

The material type of walker has a significant effect on its dynamic characteristics. The dynamic analysis conducted on Walker using both materials enables us to evaluate the response of Walker. The responses are captured in the form of mode shapes and natural frequencies. The mode shapes and deformation values obtained enable us to identify the critical zones of Walker and also the resonant frequencies as provided in Table 7 and Table 8. Overall, by conducting modal analysis, we are able to evaluate the walker for resonance-induced failures for both aluminum alloy and carbon epoxy composites.

According to the modal analysis conducted on Walker, the aluminum alloy exhibited higher natural frequencies and lower deformation as compared to carbon epoxy material. These results indicate higher stiffness for aluminum alloy walker as compared to carbon epoxy walker. The carbon epoxy walker, being lighter in weight, experiences higher deformation and needs to be taken care of.

3.4 Mass Comparison

Table 9 gives the mass comparison of materials, detailing that the carbon epoxy material Walker has a much smaller weight than the aluminum alloy model.

Table 9. Natural frequency deformation comparison

Carbon Epoxy Material (Kg)	Aluminium Alloy (Kg)
3.702	4.468

It has been found that carbon epoxy composites greatly enhance walker design compared to conventional aluminum alloys. All the detailed results and comparisons give considerable information regarding walker structural performance as well as material properties under various operating environments.

4 Discussion

The results indicate the suitability of the carbon epoxy material toward reduced stress, increased strain energy, and less mass resulting from use in walker design for improved performance. Specifically, the carbon epoxy-based walker shows a decrease of 17% in equivalent stress (251.9 MPa vs. 262.4 MPa), total deformation reduced by 4% (8.4933 mm vs. 8.8472 mm), and strain energy increased by about 7.8% (0.58252 mJ vs. 0.63207 mJ). The above characteristics imply that the carbon epoxy walker is more resiliently built and better at resisting distortions when subjected to weight, which enhances safety and user comfort. Moreover, the carbon epoxy walker is approximately 17% lighter (3.702 kg vs. 4.458 kg), making it easier to handle and maneuver. The key contributions and novelty of this study include the following:

1- Introduction of PMC in Walker design: This research aims at finding out whether there are better alternatives of materials such as PMCs that can be used for constructing walkers and probably have better performance than the usually employed materials. Mobility aids need lightweight, high strength, and wear and tear resistance and these properties are characteristic of PMCs, hence their suitability for use in mobility aids.

2- Comprehensive structural analysis: Therefore, based on the ANSYS FEA simulations in this research work and further analysis, it is possible to understand how the PMCs work under real conditions and the actual stress that the experiment's setup is subjected to, such as stair climbing. This approach offers a differential that is a lapse in the available database, which generally does not focus on the fine details of PMCs in mobility aids.

3- Practical implications for mobility aids: The findings of this study will assist in the design of new and improved enhanced as well as multifunctional walkers that will improve the mobility of elderly and disabled persons as well as their quality of life. The instance of climbing stairs with a walker having some characteristics from the PMCs may likely meet one of the functions that are proposed as necessary in the design of mobility aids.

4- Benchmarking against traditional designs: In order to contrast the function of the new walkers with a more conventional form of mobility aid, the tables comparing it with the traditional aluminum alloy walkers will highlight the benefits of using the PMCs and possibly, advice on the matters that require more research for the improvement of the new walkers.

However, there are several considerations that we need to address. While carbon epoxy composites involve higher material costs and a more complex manufacturing process to develop, recent advancements in production technologies may help mitigate these complexities over time. The higher initial cost of carbon epoxy materials and the more complex manufacturing process could impact the overall affordability and scalability of the walkers. Furthermore, although the results of the FEA simulations are promising, we need to explore real-world conditions further, such as long-term wear, environmental exposure, and user-specific factors, to understand their impact on the practical performance of the walkers.

5 Conclusions

The FEA analysis of the walker is also carried out to assess the structural behavior of the walker subjected to on-ground moving conditions. The analysis has provided crucial data on strain distribution and deformation, which help shape the conclusions of this study. Stress levels were found to be high at the front wheel support zone, suggesting a weakness that would likely lead to failure in this area of the vehicle. The shift to adopt PMCs (carbon epoxy material) material for walkers is considered a preferred option as it weighs much lower, resulting in the superiority of manoeuvrability and user-friendliness. Equivalence data of stress and strain energy indicate that the Carbon epoxy material walker has higher stiffness as well as deformation resistance compared to traditional aluminium alloy walker. To further advance the field and address the identified limitations, future research endeavours can explore innovative avenues:

1. Optimization Algorithms: The use of modern optimization algorithms can improve walker design. Response surface methods, the design of experiments as well as direct optimization approaches, can be used. These algorithms can help improve the efficacy of critical zones, reducing stress concentrations and attaining a better outcome for structural performance.

2. Variable Selection: It is important to look into the influence of variable selection on walker performance, such as material composition, walker geometry, load distribution, environmental conditions, and user dynamics. By identifying critical parameters and understanding their impact on stress distribution distress, the design could be altered to achieve better outcomes.

3. Composite Materials: Alternative composite material walker construction can be an effective prospect. Further investigation of the structural properties and viability of materials after aluminium alloy or carbon epoxy material may offer more options on material selection for optimized walker design.

4. Improved Critical Zones: The strength of the walker's manufacturing and design can be enhanced by studying critical zones identified by FEA analysis. Changes and strengthens in the weak areas also may give a better overall performance.

While this study contributes valuable insights, it is essential to acknowledge its limitations:

1. Simplifications in Analysis: The FEA analysis involves certain simplifications of real-world scenarios, and the results are based on assumptions and approximations.

2. Static Loading: The study primarily considers static loading conditions, and further research could explore dynamic loading scenarios to provide a more comprehensive understanding of walker behaviour.

3. Material Properties: The material properties used in the analysis may have inherent uncertainties, and variations in material behaviour could impact the results.

4. Single Load Case: The analysis focuses on a single load case, and future studies may consider a range of load scenarios to provide a more holistic evaluation. To enhance the performance and usability of walkers, it is essential to incorporate a broader range of anthropometric factors. These factors include, but are not limited to, user height, body mass index (BMI), limb length, and grip strength.

The conclusions drawn align with the research hypothesis and objectives. The identified susceptibility to failure at the front wheel support zone validates the need for further exploration and consideration of alternative materials. The preference for carbon epoxy material, justified by its lower weight and enhanced stiffness, supports the initial hypothesis and aligns with the primary research objective of evaluating structural characteristics. Consequently, this study relates to the innovative design of the walker not just by measures of the structural behaviour but also by design avenues of optimization and exploration of material. A desire for applying sophisticated optimization techniques and assessing other materials are traits of someone who influences the future, which is symptomatic of the present-day shape of assistive technology. To that end, the research project has the theoretical basis of walkers' mechanical principles and represents the beginning of mobility aid design improvement. The integration of the optimization strategies with the numerous materials is the essential element that makes us search for the techniques that make mobility easier and enrich the quality of life for older people and those with diverse mobility issues.

Data Availability

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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