

## PAPER

# Personalized Upper Limb Assistive Device Socket for Phocomelia Patient Using Topology Optimization Techniques

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## ABSTRACT

Phocomelia is a congenital limb defect affecting the upper or lower limbs of newborns, significantly impacting their daily lives. Adaptive devices, such as prosthetic limbs, are crucial for helping individuals with phocomelia, yet designing and customizing these devices presents a complex challenge, as traditional prosthetic devices often do not cater to the specific needs of each patient due to their generic design. This study employs topology optimization and finite element analysis (FEA) to enhance the design and mechanical performance of these adaptive devices. The study focuses on improving design through material selection and topology optimization, analyzing mechanical behavior using FEA, and identifying potential improvements in strength and durability. Three materials—acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and polyethylene terephthalate glycol (PETG)—are evaluated with weight reductions ranging from 10% to 50%. Computational software is used for modeling and analysis based on an existing model from Universiti Teknologi MARA (UiTM), incorporating applied forces and fixed points. Results indicate the stiffness-to-weight ratio for each material and mass reduction scenario, alongside stress, strain, and displacement analyses. This study aims to advance adaptive device design by enhancing functionality and affordability, ultimately improving the quality of life for phocomelia patients.

## KEYWORDS

3D design, 3D printing, finite element analysis (FEA), phocomelia, topology optimization

## 1 INTRODUCTION

Phocomelia is a congenital disorder characterized by underdevelopment or absence of limbs, which can significantly impact the daily lives of affected individuals. This condition may present as abnormalities in either the upper or lower limbs,

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and in severe cases, it can involve both, leading to substantial disability. Research indicates that phocomelia often results from the loss of major bones, leaving the remaining limb components with various abnormalities [1]. Individuals with phocomelia frequently require assistive devices to enhance their functionality and independence in daily activities. Due to its rarity, limited public awareness, and the lack of advanced assistive technology, this condition receives significantly less attention than disorders like cerebral palsy or Down syndrome. Despite its impact, this condition has received almost no research attention, with only very minimal studies exploring ways to improve the quality of life for affected individuals [2]. Therefore, this study was undertaken to bridge this gap and provide meaningful support to both patients and caregivers. The design and customization of these adaptive devices, such as prosthetic limbs, present complex challenges. Traditional prosthetic devices often do not cater to the specific needs of each patient due to their generic design. However, the growing use of 3D printing technology has enabled the creation of more personalized assistive devices, addressing the need for tailored solutions [3]. Despite these advancements, optimizing these devices for individual characteristics remains a critical challenge [4]. finite element analysis (FEA) is a detailed method used to evaluate the structural performance of prosthetic and adaptive devices. FEA enables the computation of stress and strain within a model, facilitating pre-operative planning and design adjustments [5]. Studies such as those by Sangbaek Park et al. demonstrate the application of FEA in analyzing contact pressures and mechanical responses, further emphasizing its importance in device development [6].

Topology optimization is another advanced technique that enhances device design by optimizing material distribution within a given volume. Recent studies have shown that topology optimization can significantly improve the performance and efficiency of prosthetic devices while reducing weight and cost [7], [8]. This method helps in achieving a balance between functionality, comfort, and sustainability. This project aims to improve the design of upper limb assistive devices for individuals with phocomelia by utilizing topology optimization and FEA. The research focuses on optimizing a 3D model of an adaptive device made from three materials—acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and polyethylene terephthalate glycol (PETG)—through various weight reduction scenarios. PLA can withstand more stress, while PETG has the least deformation. ABS has the property in between the two for stress compression and deformation. The objectives include enhancing the design of the device, analyzing its mechanical behavior, and assessing improvements in strength and durability. This approach seeks to create more effective and efficient adaptive devices, ultimately enhancing the quality of life for patients with phocomelia.

## 2 MATERIALS AND METHODOLOGY

To address the challenges faced by individuals with phocomelia, a systematic approach was adopted to enhance the design and functionality of adaptive devices. The methodology involves several key stages, as outlined in the project flow chart (see Figure 1).

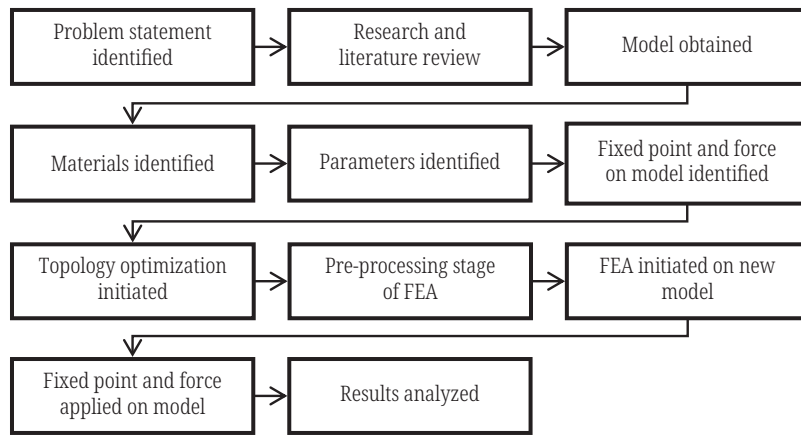


Fig. 1. Project methodology flowchart

The project began with the identification of a comprehensive 3D model of the upper limb adaptive device. The model used in this study was provided by Universiti Teknologi MARA (UiTM) Shah Alam, based on previous work by Mazlan et al. [2] (see Figure 2a). Topology optimization techniques were employed to systematically improve the design of the device. The focus was on reducing the device’s weight by 10% to 50% in 10% increments while ensuring its structural stability. It is to be noted that other factors affecting the result data, such as anisotropy of the material and other outside factors, are not included in the study.

Three materials—ABS, PLA, and PETG—were assessed for this project. Mechanical properties for PLA and PETG that are not available in SolidWorks were sourced from previous studies (refer to Table 1).

Table 1. Mechanical properties of ABS, PLA, and PETG materials

Material	Density (kg/m <sup>3</sup> )	Young’s Modulus (GPa)	Poisson Ratio	Tensile Strength (MPa)	Compressive Strength (MPa)
ABS	1050	2.4	0.37	50	55
PLA	1240	3.5	0.30	80	428
PETG	1290	2.2	0.33	53	55

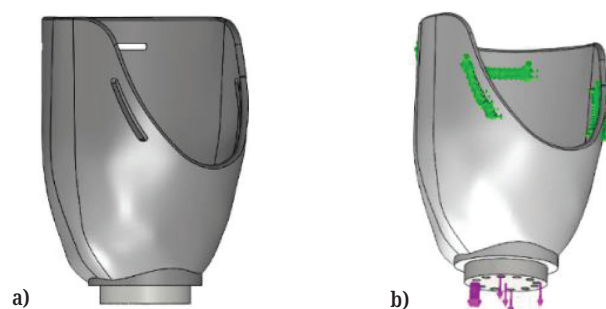


Fig. 2. (a) Adaptive device model used for the project [2], (b) Fixed point and force applied on the socket

Using SolidWorks software, the simulation process involved creating a new study and selecting the topology optimization study type. Fixed geometry and forces were applied to the model as shown (see Figure 2b). The simulation was run, the mesh was generated, and topology results were obtained. Following the topology optimization, the mesh was exported and saved as a new part file for further analysis. The saved

mesh file is imported into SolidWorks for FEA. A new static study is created, and fixed geometry and forces are re-applied. The study is run to perform meshing and FEA. The results for stress, strain, and displacement were analyzed for each material and percentage of weight reduction. The most significant design outcome was selected for 3D printing. The optimized design was 3D printed using a 3D printing machine. The final device was evaluated for weight reduction, aesthetics, comfort, practicality, and ease of ventilation [9].

This methodology aims to provide a comprehensive approach to designing more effective adaptive devices, enhancing both functionality and user experience for individuals with phocomelia.

### 3 RESULTS AND DISCUSSIONS

The analysis of this project's outcomes confirms the objectives and reveals significant insights into the potential of topology optimization and FEA for improving adaptive devices. This section presents the results from topology optimization and FEA for the materials of ABS, PLA, and PETG.

#### 3.1 Topology optimization

Topology optimization is a powerful numerical method that optimizes material distribution within a design space to enhance structural performance while considering loads, boundary conditions, and constraints [10]. This process aims to maximize the performance of the upper limb socket by adjusting material allocation. The iterative process systematically reduces material in areas with minimal impact on structural performance, leading to a lighter yet structurally efficient design based on applied loads and constraints (see Figure 2b). This computational approach, integrated with FEA, simulates structural behavior under specific loading conditions.

The optimization results for each material (ABS, PLA, and PETG) at different weight reduction intervals (10% to 50%) are depicted (see Figure 3). The topology optimization of ABS material reveals a progressive reduction in material while maintaining critical strength areas (see Figure 3a). The design effectively balances weight reduction with structural integrity, demonstrating the material's adaptability in various weight reduction scenarios. The topology optimization results for PLA, which generally retains more material when compared to ABS at equivalent weight reductions (see Figure 3b). PLA's higher stiffness and strength contribute to a more robust design, even at lower material percentages. PETG material exhibits a similar trend to PLA but with slightly less material retention (see Figure 3c). The optimization reflects PETG's ability to maintain its strength while achieving a reduced weight, though not as efficiently as polylactic acid.

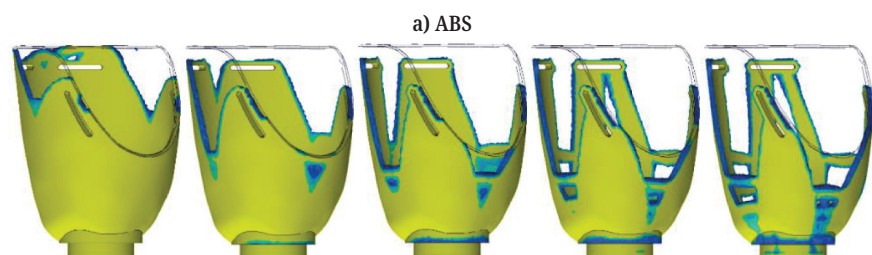
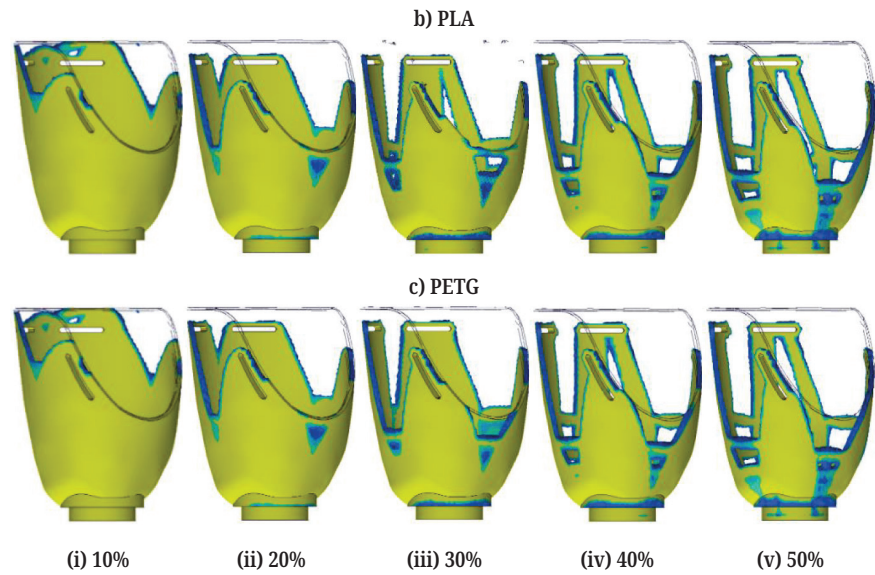


Fig. 3. (Continued)



**Fig. 3.** Topology optimizations of 10% to 50% reductions done on the model for each material: (a) ABS, (b) PLA, and (C) PETG

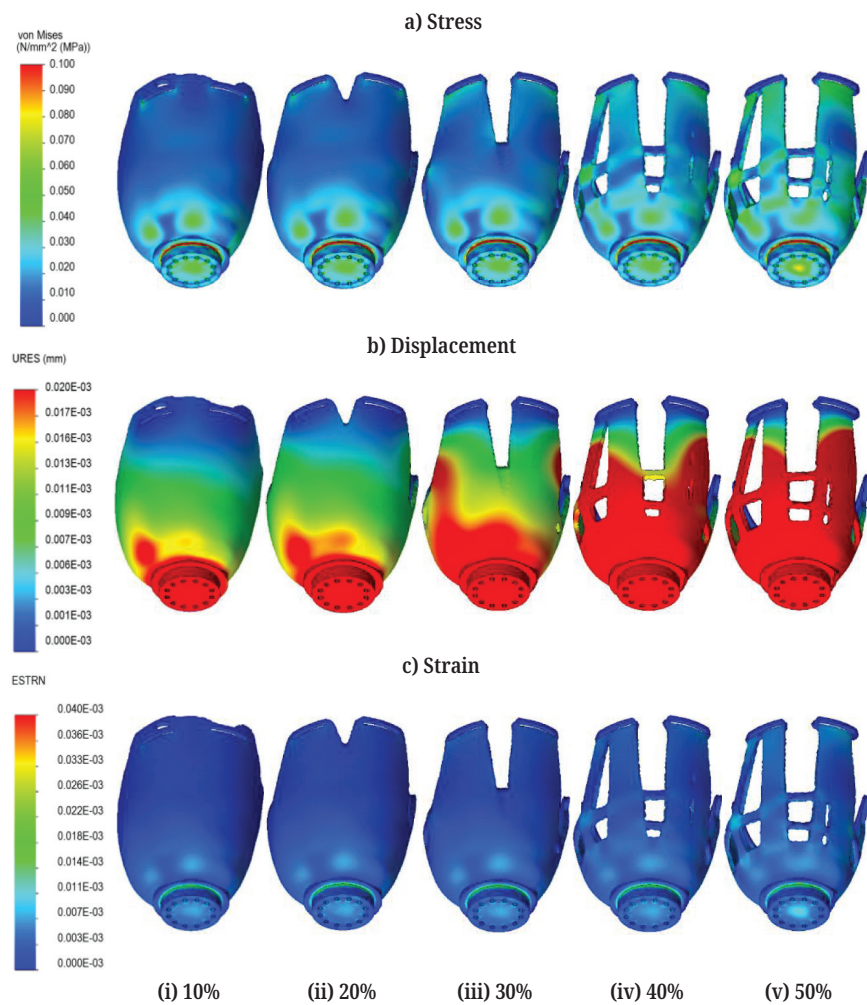
### 3.2 Effects of weight reduction on the limb socket

The results for FEA are representative of each socket with reduced weight at stress, displacement, and strain distribution. PETG material is known as one of the widely used materials for producing adaptive devices for patients; thus, the overall images of the model after going through topology optimization with a weight reduction of 10% to 50% from its original weight are shown (see Figure 4). Several variations of the adaptive device, each with a certain degree of material reduction of 10%, 20%, 30%, 40%, and 50%, are analyzed respectively (see Figure 4 (i) to (v)). The von Mises stress is included to quantify local failure and provide a computationally feasible solution that is resistant to unforeseen material failure [11]. It is a parameter used in engineering to ascertain the point at which a material would undergo plastic deformation. The equivalent stress is a consolidated figure that encompasses the primary stresses and is used for comparison with a material's yield strength. The key features to consider when selecting polymeric 3D printing material are maximum stress, yield stress, modulus of elasticity, elongation, and hardness. These properties are directly affected by the chemical composition of the material [12].

There is a noticeable change in the stress distribution throughout the model when the weight reduction percentage increases from 10% to 50% (see Figure 4a). The values obtained from 10% to 50% are 121.556 MPa, 133.674 MPa, 132.951 MPa, 132.951 MPa, and 148.746 MPa, respectively. At lower weight reductions, the stress is uniformly distributed, but there are concentrated regions of high stress indicated by the red zones. These occur where pressures are expected to be exerted. As the weight decreases, the high-stress spots become more prominent, suggesting that the material is less evenly distributed and that certain areas are under higher levels of stress. Both values and images indicate that with each increase in mass reduction, the structure may become less able to evenly distribute stress, leading to higher stress concentrations in certain areas. This could potentially result in a higher risk of material failure in those areas. The optimal design would balance the need for weight reduction with the structural integrity required to handle stress without yielding. However, the von

Mises yield criteria can be used merely for the preliminary analysis [13]; thus, it is important to take note of the strain and displacement distribution on the model.

The displacement distribution is demonstrated through the displacement scale, with the color gradient indicating the amount of displacement. Blue indicates no displacement, while red represents the highest displacement. The images show that as the weight reduction of PETG rises, there is a noticeable increase in the presence of red regions, particularly at the 50% weight reduction condition (see Figure 4b). This indicates more displacements and probably a lower performance under the simulated conditions. The displacement is especially visible at the bottom of the socket, where the load is likely to be applied. If the application requires minimum deformation, this outcome might be seen as a disadvantage. However, it is important to consider the scale value for PETG, where the maximum displacement scale is at 0.010 mm, lower than both ABS and PLA at 2.000 mm, based on the overall analysis. The reason is the average displacement values for ABS and PLA range from 1.900 mm to 2.700 mm, while for PETG, the data are recorded to be 0.019 mm to 0.027 mm.



**Fig. 4.** Effects of 10% to 50% weight reductions on the limb socket with PETG material with distributions in: (a) stress, (b) displacement, and (c) strain

Finite element analysis is commonly used to evaluate the biomechanical performance of structures via simulation, which involves analyzing displacement inside the structures and estimating the maximum stress levels [14]. The overall result for

PETG material can be seen through the graph results of FEA (see Figure 5). Among the several thermoplastic materials used in 3D printing, ABS stands out as particularly useful due to its numerous desired features, including affordability, widespread availability, and mechanical durability [15]. However, it is to be determined whether the statement is acceptable by comparing the results for ABS with the other two materials. Which are PLA and PETG. According to past studies, PLA material also demonstrated little deformation and obtained the best safety factor across all loading directions [16]. Nevertheless, this could be influenced by the constraints and force exerted on the model that was used.

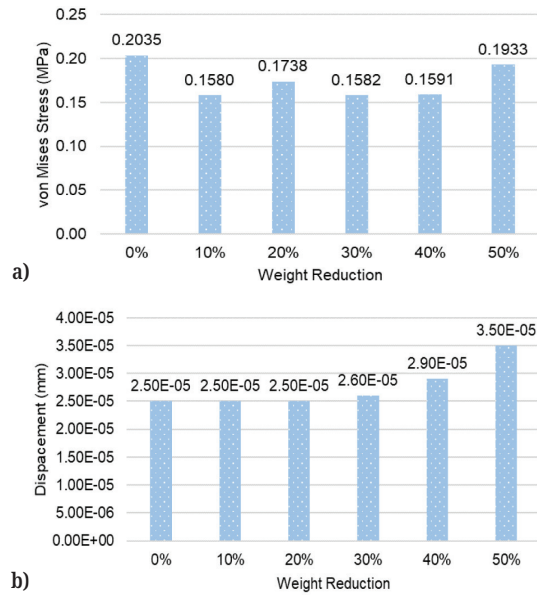


Fig. 5. Comparison of maximum: (a) von Mises stress and (b) displacement of PETG limb socket at different weight reductions on the model

The PETG material model indicates that the stress reaches 0.158023 MPa at 10% weight reduction, rising to 0.173777 MPa at 20%, and later decreases slightly at 30% weight reduction to 0.158202 MPa. At a 40% decrease in weight, the stress level remains stable at 0.159060 MPa and significantly rises to 0.193263 MPa at a 50% weight reduction. Based on the data points, it can be concluded that the stress levels generally increase with weight reduction, except for a slight drop at 30% (see Figure 5a). The initial drop in von Mises stress from 0% to 10% may be due to the relief cut at where stress is accumulated due to the weight reduction from the topology.

The displacement distribution data can be observed, where it remains constant at  $0.025 \times 10^{-3}$  mm for both a 10% and 20% decrease in weight, suggesting that there is no change in displacement between these two levels. There is a slight increase seen for weight reductions of 30% and 40%, with displacement values of  $0.026 \times 10^{-3}$  mm and  $0.029 \times 10^{-3}$  mm, respectively. At the 50% drop in weight, there is a more significant rise in displacement, measuring at  $0.035 \times 10^{-3}$  mm. This thus concluded that the displacement levels generally increase with weight reduction, starting at 20% weight reductions (see Figure 5b). PETG has shown outstanding results in displacement, and this is proven by a study done by Umer et al., where their study also showed that PETG material's displacement is better than the other plastic materials [17]. As for the strain on the model, the results obtained are insignificant with recorded values of  $0.001 \times 10^{-3}$  mm, thus the visual graph representation is not included.

A past study done by Jweeg et al., where their past studies evolved using the finite element approach to anticipate the efficiency of manufacturing prosthetics and determine their stress levels to provide recommendations for manufacturers [18]. They were able to conclude on what type of material should be used to produce their planned prosthetics. This is similar to this project as the model of the adaptive device was also obtained from a past study which is then carried out further to create new design ideas for adaptive devices and to identify suitable material. Each material possesses its unique traits and properties. However, it is important to note that the purpose of this study is to identify which material and at what weight reduction percentage is most suitable to be used. Identifying the stress and critical points of each result is crucial as the stress point could be distributed throughout the whole model body, contributing to where most of the compressive stress builds up, resulting in the occurrence of major von Mises stress [19]. The accuracy of the findings acquired using FEA can be confirmed by comparing them to experimentally observe stresses [20], which could be done.

### 3.3 Effects of materials selection

Each material applied to the socket model has its unique properties. These material properties play a huge role in the formation of stress and displacement on the model as shown, where the results displayed are for the limb sockets at 30% weight reduction (see Figure 6). ABS demonstrates greater stress concentration at constraints or places where loads are applied. As ABS is known for being strong and resistant to impact, there may be an even distribution of stress throughout the socket. ABS also exhibits a good balance between stiffness and flexibility, resulting in noticeable but controlled displacement under load. When the material bends in reaction to the load, the FEA may display such displacements. PLA, being stiffer than ABS, shows higher stress concentrations, especially in places with a smaller cross-section of material or near the areas where the load is applied. PLA also exhibits less displacement due to its rigidity. When it does deform, however, it cannot return to its original state as quickly as ABS, suggesting a more brittle response to stress. PETG, known for its exceptional durability and impact resistance, distributes stress more evenly, handling pressure without noticeable flaws. Its balanced displacement suggests superior flexibility compared to ABS and PLA, but maybe with less deformation. These findings suggest that PETG is a more viable material for producing functional, lightweight prosthetic sockets due to its flexibility and strength. While ABS is cost-effective and widely available, its higher stress concentrations may limit long-term performance. PLA, though rigid, may not be durable enough for high-impact usage. PETG emerges as a strong contender for manufacturing, balancing ease of 3D printing, structural integrity, and real-world performance.

The FEA results are supposed to indicate low stress and little displacement for each material while maintaining the socket's structural integrity. The exact form of the socket, the applied load conditions, and the basic material qualities will all affect the actual values and patterns. It is crucial to evaluate these findings in context with the specific application in question, taking into account the allowed ranges of stress and displacement for the user's comfort and safety. Every material will have benefits and drawbacks, and the prosthetic's unique needs—such as weight, durability, flexibility, and use environment—will determine which option is best. It was difficult to decide for certain which material was the best without knowing

the numerical values and the specifications for the prosthetic socket. Due to its durability and strong resistance to impact, ABS is appropriate for many common uses. However, due to its rigidity and potential for greater comfort, since it deforms less than other materials, PLA may not be as durable as the alternatives. With high toughness and better temperature resistance, PETG combines the benefits of ABS and PLA to possibly deliver the highest overall performance for a prosthesis that is subjected to a variety of pressures. The choice is also influenced by the prosthetic's design criteria, including affordability, comfort, and lifespan. The ideal material for real-world applications would be one that satisfies the user's particular demands while providing a balance of these qualities.

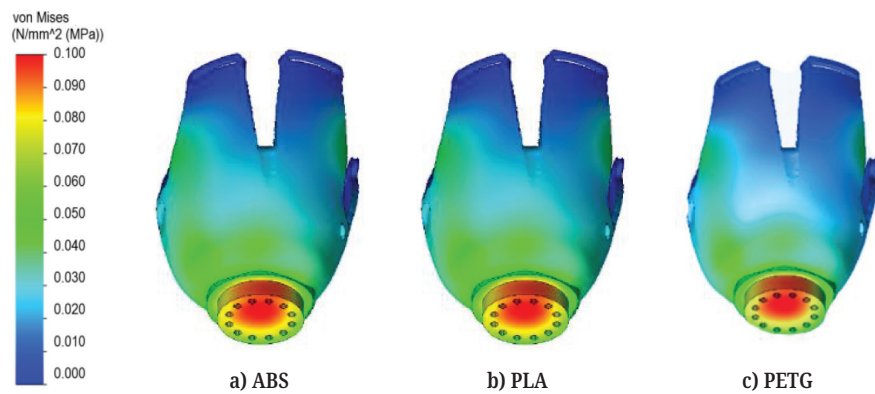


Fig. 6. The results of finite element analysis in terms of von Mises stress for ABS, PLA and PETG materials

The graphs visualize the results of the three different materials' mechanical characteristics applied at the limb socket at a 30% weight reduction (see Figure 7). The maximum von Mises stress values for each material are shown (see Figure 7a). Compared to the other materials, ABS material shows the lowest von Mises stress, at around 0.170968 units, suggesting that it may yield more easily under stress. At around 0.173729 units, PLA has a somewhat greater stress value than PETG, which is just slightly lower at roughly 0.158202 units. These values are greater than those of ABS and indicate that PETG and PLA can tolerate stress levels that are comparable with one another before they yield.

The displacement values for the same materials indicate the degree of deformation observed under loading (see Figure 7b). PLA has a comparable degree of displacement at around  $2.664 \times 10^{-3}$  mm, but ABS exhibits a significant displacement at roughly  $2.647 \times 10^{-3}$  mm. PETG, in sharp contrast, displays a displacement value that is far lower at  $0.026 \times 10^{-3}$  mm. This shows that, in comparison to ABS and PLA, PETG is much stiffer or more rigid under the circumstances, having very little deformation.

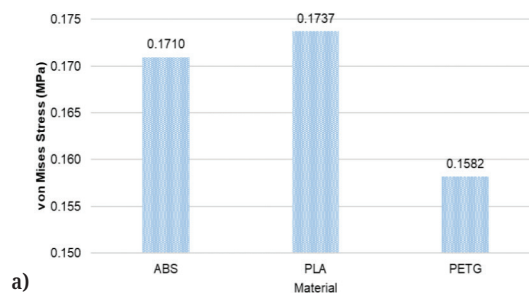
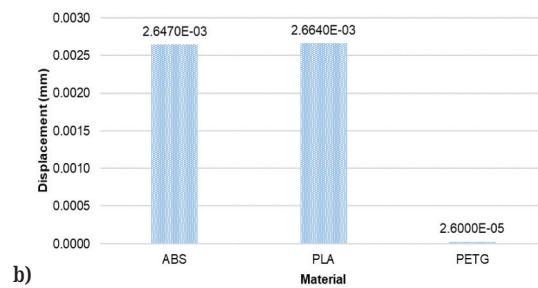


Fig. 7. (Continued)



**Fig. 7.** Comparison of maximum: (a) von Mises stress, and (b) displacement for different materials of limb socket at 30% weight reductions

The graphs provided a comparison of the mechanical characteristics of the various materials, which is essential for figuring out whether or not such materials are suitable for use in applications like limb sockets, where low deformation and stress resistance may be desired. It is most likely the case that the 30% weight reduction relates specifically to the design objective of lowering the limb socket's weight without affecting its structural integrity. Whether it was less stress, less deformation, or a combination of both, the selection between these materials would rely on the particular performance standards considered most important for the application.

## 4 CONCLUSION

Every material has its own limits, and the best option would weigh these considerations in accordance with the demands of the particular application. Fatigue strength, for example, can be a crucial consideration if the limb socket is used in an environment where it experiences a lot of repeated stress, which might change the selection of the most suitable material. Because PLA can withstand more stress and has a displacement that is similar to ABS, it may be the best-balanced option when all other variables are held constant and just the graph is considered. However, PETG would be the obvious option for applications needing little deformation under stress.

## 5 ACKNOWLEDGMENTS

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## 6 REFERENCES

- [1] S. Shafique, "Thalidomide – An overview and the species-specific teratogenicity," *Research Journal of Congenital Diseases*, vol. 2, no. 1, 2019. <https://doi.org/10.5281/zenodo.4768131>
- [2] M. A. Mazlan, N. Mohamad Hashim, N. A. Che Zakaria, and A. H. Abdullah, "3D printed assistive writing device for phocomelia patient," *Malaysian Journal of Medicine and Health Sciences*, vol. 17, no. SUPP13, pp. 7–11, 2021. [Online]. Available: [https://medic.upm.edu.my/upload/dokumen/2021122817292102\\_2021\\_0651.pdf](https://medic.upm.edu.my/upload/dokumen/2021122817292102_2021_0651.pdf) [Accessed Jan. 10, 2022].

- [3] J. K. Schwartz *et al.*, “Methodology and feasibility of a 3D printed assistive technology intervention,” *Disability and Rehabilitation Assistive Technology*, vol. 15, no. 2, pp. 141–147, 2020. <https://doi.org/10.1080/17483107.2018.1539877>
- [4] J. H. Kim *et al.*, “Application of a 3D-printed writing–typing assistive device in patients with cervical spinal cord injury,” *Appl. Sci.*, vol. 12, no. 18, p. 9037, 2022. <https://doi.org/10.3390/app12189037>
- [5] A. Z. E.-A. Arab *et al.*, “Finite-element analysis of a lateral femoro-tibial impact on the total knee arthroplasty,” *Computer Methods Programs Biomed*, vol. 192, p. 105446, 2020. <https://doi.org/10.1016/j.cmpb.2020.105446>
- [6] S. Park, S. Lee, J. Yoon, and S.-W. Chae, “Finite element analysis of knee and ankle joint during gait based on motion analysis,” *Med. Eng. Phys.*, vol. 63, pp. 33–41, 2019. <https://doi.org/10.1016/j.medengphy.2018.11.003>
- [7] Y. Sun and T. C. Lueth, “Design of bionic prosthetic fingers using 3D topology optimization,” in *2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, 2021, pp. 4505–4508. <https://doi.org/10.1109/EMBC46164.2021.9630390>
- [8] R. Calcerrada, A. Donoso, E. Aranda, D. J. McKeown, and F. Ramos, “Topology optimization of a rowing terminal device for an upper limb prosthesis,” *Advances in Engineering Software*, vol. 173, p. 103284, 2022. <https://doi.org/10.1016/j.advengsoft.2022.103284>
- [9] A. Kumar and D. Chhabra, “Multidisciplinary topology and material optimization approach for developing patient-specific limb orthosis using 3D printing,” *Rapid Prototyping Journal*, vol. 29, no. 8, pp. 1757–1771, 2023. <https://doi.org/10.1108/RPJ-12-2022-0435>
- [10] J. Park, D. Lee, and A. Sutradhar, “Topology optimization of fixed complete denture framework,” *Int. J. Numer. Methods Biomed. Eng.*, vol. 35, no. 6, p. e3193, 2019. <https://doi.org/10.1002/cnm.3193>
- [11] H. Wang, J. Liu, G. Wen, and Y. M. Xie, “The robust fail-safe topological designs based on the von Mises stress,” *Finite Elements in Analysis and Design*, vol. 171, p. 103376, 2020. <https://doi.org/10.1016/j.finel.2019.103376>
- [12] R. C. da Silveira Romero, A. A. Machado, K. A. Costa, P. H. R. G. Reis, P. Paiva Brito, and C. B. Santos Vimieiro, “Development of a passive prosthetic hand that restores finger movements made by additive manufacturing,” *Appl. Sci.*, vol. 10, no. 12, p. 4148, 2020. <https://doi.org/10.3390/app10124148>
- [13] V. Plesec, J. Humar, P. Dobnik-Dubrovski, and G. Harih, “Numerical analysis of a transtibial prosthesis socket using 3D-printed bio-based PLA,” *Materials*, vol. 16, no. 5, p. 1985, 2023. <https://doi.org/10.3390/ma16051985>
- [14] M. J. Peng *et al.*, “Intralesional curettage versus prosthetic replacement for bone tumors — a finite element analysis case of limb salvage simulation in biomechanics,” *Computer Methods Programs Biomedicine*, vol. 198, p. 105775, 2021. <https://doi.org/10.1016/j.cmpb.2020.105775>
- [15] A. Bastarrechea *et al.*, “Mechanical design of a low-cost ABS hand prosthesis using the finite element method,” *J. Phys. Conf. Ser.*, vol. 1736, no. 1, p. 012039, 2021. <https://doi.org/10.1088/1742-6596/1736/1/012039>
- [16] S. H. Mian, U. Umer, K. Moiduddin, and H. Alkhalefah, “Finite element analysis of upper limb splint designs and materials for 3D printing,” *Polymers*, vol. 15, no. 14, p. 2993, 2023. <https://doi.org/10.3390/polym15142993>
- [17] U. Umer, S. H. Mian, K. Moiduddin, and H. Alkhalefah, “Exploring orthosis designs for 3D printing applying the finite element approach: Study of different materials and loading conditions,” *Journal of Disability Research*, vol. 2, no. 1, pp. 85–97, 2023. <https://doi.org/10.57197/JDR-2023-0011>

- [18] M. J. Jweeg, H. A. Hamzah, M. Al-Waily, and M. A. Al-Shammari, "A finite element simulation of nano effects on stress distribution in a below knee prosthetic," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1067, no. 1, p. 012141, 2021. <https://doi.org/10.1088/1757-899X/1067/1/012141>
- [19] F. M. Rohjoni, M. N. A. A. Patar, J. Mahmud, H. Lee, and A. Hanafusa, "Finite element analysis of a transtibial prosthetic during gait cycle," *International Journal of Mechanical Engineering and Robotics Research*, vol. 9, no. 5, pp. 764–770, 2020. <https://doi.org/10.18178/ijmerr.9.5.764-770>
- [20] J. J. Singh, J. S. Mehta, R. Kumar, and G. Sapra, "FEA simulations of lower limb prosthetics," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1225, no. 1, p. 012030, 2022. <https://doi.org/10.1088/1757-899X/1225/1/012030>

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