JPOST Journal of Prosthetics Orthotics and Science Technology
Volume 4, Number 1 Year 2025
ISSN (online): 2962-8016
DOI: 10.36082/jpost.v4i1.2045

Pineapple Leaf Fiber and Polyester Fabric Composite as a Material for Transtibial Prosthetic Socket Fabrication

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Abstract

Background: A transtibial prosthesis restores mobility and functionality for individuals with below-knee amputations, with the socket serving as a vital interface between the residual limb and the prosthesis. In Indonesia, prosthetic sockets are commonly made from plastic, valued for strength and durability but criticized for non-sustainability, and high import costs. Locally sourced and cost-effective materials, such as pineapple leaf fiber, have gained attention as sustainable alternatives, offering lightweight and durable solutions. However, the natural fiber's appearance may impact amputee satisfaction. Combining pineapple leaf fibers with polyester fabric could address these limitations by improving aesthetics without compromising functionality.
Aims: This study aimed to develop and evaluate a transtibial prosthetic socket fabricated from pineapple leaf fibers and polyester fabric, focusing on accessibility, affordability, and enhanced usability for Indonesian amputees.
Methods: The study used a quantitative experimental design that included creating composite materials with specific ratios of pineapple leaf fiber, epoxy resin, and polyester fabrics and fabricating transtibial prosthetic sockets using the lamination method. The socket was fitted to a transtibial amputee to ensure proper alignment and function. Over six weeks, the participant used the prosthesis in daily activities while data was collected on comfort, durability, and walking performance, along with feedback through interviews and questionnaires.
Results: Amputee demonstrated improved mobility in daily activities, with slight endurance limitations during extended walking. Satisfaction was high regarding comfort, fit, aesthetics, and reliability.
Conclusion: The composite material is a viable alternative for transtibial sockets, promoting sustainability and accessibility. Refinements for endurance and broader applications of natural fibers are recommended.

Keywords: *Composite; Pineapple leaf fiber; Prosthesis*

Article History

Received date: 30-11-2024
Revised date: 05-05-2025
Accepted date: 24-05-2025

Journal Prosthetics Orthotics and Science Technology (JPOST)
e-ISSN 2962-8016
Organized by Department of Prosthetics and Orthotics
Published by Poltekkes Kemenkes Jakarta I
email: jpost@poltekkesjakarta1.ac.id

Introduction

A prosthesis is an externally applied medical device designed to replace a missing limb and restore both functional and structural support for individuals with limb loss (Ministry of Health of the Republic of Indonesia, 2024). A transtibial prosthesis, commonly referred to as a below-knee prosthesis, replaces the anatomical structures of the distal tibia, distal fibula, foot, ankle, and surrounding soft tissues following amputation. Prostheses are composed of several integral components, including the socket, socket liner, adapter, pylon, and prosthetic foot. These components must be precisely assembled using specialized techniques to ensure optimal function, comfort, and biomechanical performance.

Among these components, the socket plays a critical role in connecting the residual limb to the prosthesis. The socket is custom designed to fit the residual limb and anatomical structure of the amputee. In Indonesia, sockets are typically fabricated from materials like polypropylene plastic, polyethylene, and composite materials strengthened with fiberglass. Fiberglass is widely used because it is lightweight and durable; however, its rigidity can cause skin irritation, and it is non-recyclable. Additionally, fiberglass often requires importation, making it costly and less accessible.

The limitations of fiberglass underscore the need for alternative materials that are locally available, affordable, and comfortable for amputees. Natural fibers from plants, such as pineapple leaf fiber, banana stem fiber, rattan fiber, and ramie fiber, have been explored as sustainable alternatives (Odusote et al., 2019). Among these, pineapple leaf fiber stands out due to its high availability and favorable mechanical properties. Indonesia produces approximately 1.39 million tons of pineapples annually (Karolina et al., 2022), leading to a significant supply of pineapple leaf fibers. These fibers are primarily used in handicrafts, but their application in prosthetics could enhance their value.

Pineapple leaf fiber is a potential material for prosthetic socket development. Its high cellulose content (70-82%) and structural characteristics contribute to strong and lightweight composites with excellent fiber-matrix adhesion. These composites are also cost-effective, stiff, and easy to process, making pineapple leaf fiber a viable alternative to fiberglass for advanced composite fabrication (Hoque et al., 2021). However, pineapple leaf fiber composites have some limitations, such as visibly retaining the original fiber texture, which can affect the aesthetic appeal of the prosthesis (Chittappa & T, 2023). Aesthetics are crucial for user satisfaction, as amputees who perceive their prostheses as visually pleasing report higher confidence and satisfaction levels (Lee et al., 2022).

To address these concerns, combining pineapple leaf fiber with other materials, such as polyester fibers, offers a promising solution. Polyester fibers are flexible, elastic, and compatible with human skin (Irwanto, 2023). They are also widely available, inexpensive, and come in various patterns, allowing for aesthetic customization. When combined with pineapple leaf fiber, this material can produce prosthetic sockets that are strong, lightweight, comfortable, visually appealing, and environmentally friendly.

The fabrication of a transtibial prosthetic socket involves several steps, starting with the assessment and measurement of the residual limb. This is followed by creating a negative cast to capture the limb’s shape and pressure points based on anatomical principles. The negative cast is then filled with Plaster of Paris to produce a positive cast, which is shaped and refined according to the amputee's measurements. Finally, composite materials are layered onto the shaped cast to create a high-quality socket. By incorporating innovative materials such as pineapple leaf and polyester fibers,

this process can produce functional and aesthetically pleasing prosthetic sockets that meet the needs of Indonesian amputees.

Methods

This research is a quantitative approach with an experimental method, specifically applying a one-shot case study design. In this approach, a single amputee is subjected to a specific treatment, and the outcomes are observed and analyzed. The purpose of this testing is to evaluate whether the results obtained from the group can be generalized to a broader population. After six weeks, amputees were assessed using the Trinity Amputation and Prosthesis Experience Scales (TAPES). This evaluation focused on activity limitations while wearing the prosthesis and satisfaction with its various aspects.

Results

The study began with the preparation of composite materials, including calculating the composite composition, assembling the layers, and conducting material testing. Following this, the composite layering for transtibial prosthetic sockets was completed by laminating over a positive cast and fitting it to transtibial amputee. Below are the key steps undertaken during the research:

1. **Composite Fabrication**

After assessment, the composite was prepared using the hand lay-up method, involving manual arrangement of pineapple leaf fibers on layers of polyester fabric, which were then coated with resin to form a durable material. Pineapple leaf fibers were chosen for their high strength and lightweight properties, while polyester fabric was selected for its flexibility, durability, and aesthetic options. The fabric's design enhanced the visual appeal of the socket.

2. **Pineapple Fiber Spinning**

The fibers were spun by local natural fiber artisans using a four-pedal weaving machine. This process produced soft, non-porous fibers essential for protecting the amputee’s skin from irritation caused by the composite material. After trials and adjustments, the fibers met specific criteria: tightly woven, non-porous, tear-resistant, adequately thick, smooth, and lightweight, making them suitable for transtibial socket fabrication.Figure 1 shows the final product of the fiber.



Figure 1. *Spinned pineapple leaf fiber*

3. **Transtibial Amputee Assessment**

Amputees with transtibial amputation level were assessed to determine specific needs such as body weight, mobility level, and stump measurements. This data served as the basis for designing and fabricating prosthesis sockets.

4. Casting

The stumps were cast using Plaster of Paris Bandage to create a negative cast. This negative cast was then filled with Plaster of Paris Powder to form a positive cast, which was rectified following biomechanical principles.

5. Rectification

Adjustments were made to the positive cast to ensure it matched the amputee's anatomy and met biomechanical requirements. This process corrected any imperfections and ensured the socket fit accurately.

6. Fabrication

Final fabrication involved using the prepared composite material to produce the transtibial prosthetic socket. The focus was on ensuring strength, durability, and comfort while adhering required standards. Final socket is presented in figure 1.



Figure 2. *Transtibial prosthetics socket*

7. Fitting

a) Static fitting: The prosthesis was fitted to the amputee, with initial checks ensuring the stump was in good condition. A stump sock, soft liner interphase, and transtibial prosthesis were applied in sequence. Static alignment verified proper load distribution (e.g., on the patella tendon and soft tissue), appropriate angles (adduction, flexion, external rotation), and alignment of socket and prosthetic foot. The trim line and prosthetic height were also checked to ensure comfort while sitting and standing.
b) Dynamic fitting: The amputee walked to analyze their gait pattern. Adjustments were made to achieve the most natural gait possible. The goal was to optimize alignment for smooth walking. After optimized fitting, the amputee used the prosthesis for six weeks.

8. Post-Use Evaluation

After six weeks, amputees were assessed using the Trinity Amputation and Prosthesis Experience Scales (TAPES). This evaluation focused on activity limitations while wearing the prosthesis (table 1) and satisfaction with its various aspects (figure 3).

Table 1. Activity restriction

Activities	Justification
Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports	Not limited
Climbing several flights of stairs	Not limited
Running for a bus	Not limited
Sport and recreation	Not limited
Climbing one flight of stairs	Not limited
Walking more than a mile	Limited a little
Walking half a mile	Limited a little
Walking 100 metres	Not limited
Working on hobbies	Not limited
Going to work	Not limited

Source: Research data

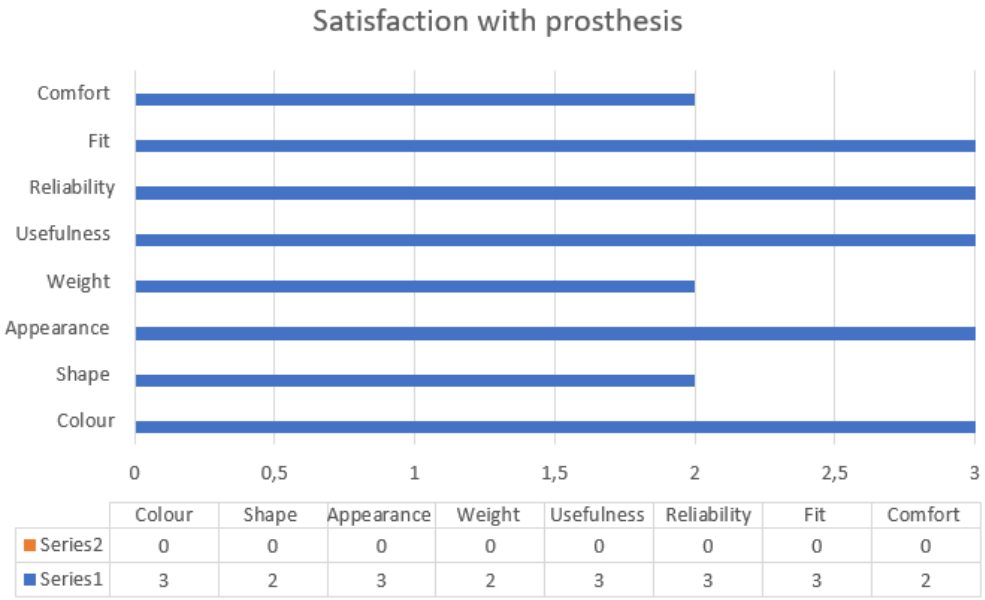


***Figure 3**. Satisfaction with prosthesis*

Discussion

Based on the data, the amputee has a relatively high level of functional ability, as most activities are not limited. Here's the further explanation:

a) Vigorous activities: The amputee reports no limitation, indicating they can engage in activities like running, lifting heavy objects, and participating in sports without difficulty.

b) Climbing several flights of stairs, running for a bus, and climbing one flight of stairs: These activities also show no limitations, suggesting that the amputee has enough strength and mobility for tasks requiring physical exertion, such as stair climbing and quickly moving from

one place to another.

c) Sport and recreation: There is no limitation reported here either, meaning the amputee is able to participate in recreational activities freely.

d) Walking more than a mile and walking half a mile: For these activities, the amputee reports some limitations, though it is only a slight restriction. This may indicate some fatigue when walking longer distances, possibly related to other factors like stamina.

e) Walking 100 meters: No limitation is reported, suggesting the amputee can comfortably walk short distances.

f) Working on hobbies and going to work: These daily activities also show no limitations, indicating that the prosthesis is functional enough to support the amputee in performing regular tasks and maintaining a quality of life.

The data indicates that the amputee has largely regained functionality with minimal restrictions, particularly in activities requiring strength and mobility, such as climbing stairs and engaging in vigorous activities. However, slight limitations in walking longer distances suggest areas where further improvements may be necessary. These improvements could involve adjustments to the prosthesis, physical therapy, or other interventions aimed at enhancing endurance (Klenow et al., 2018). It would also be beneficial to investigate whether these limitations stem from the prosthesis itself or other factors, such as pain, fatigue, or muscle weakness.

Regarding the amputee's satisfaction, the high scores for reliability, fit, usefulness, and appearance demonstrate the prosthesis's success in meeting core functional and aesthetic needs. The consistent performance of the prosthesis is likely attributed to the use of strong composite materials, such as pineapple leaf fibers, which provide durability and strength (Malalli & Ramji, 2022). A well-fitting socket ensures minimal discomfort and efficient force transfer during movement, with the accurate casting and rectification processes likely contributing to this outcome (Baldock et al., 2023). The prosthesis effectively supports the amputee’s daily activities, indicating that the design has successfully replicated the functionality of the lost limb.

In terms of appearance, the high satisfaction score reflects the design's aesthetic success. The color of the prosthesis also received positive feedback, suggesting that the chosen color and polyester pattern align well with the amputee's aesthetic preferences. Overall, the prosthesis appears to meet both functional and aesthetic expectations, contributing to the amputee's high level of satisfaction.

Conclusion and Recommendation

The data suggests that the amputee has experienced significant functional recovery following the use of the transtibial prosthesis. The amputee reported no limitations for most physical activities, including vigorous tasks such as running, lifting heavy objects, climbing multiple flights of stairs, and engaging in sports or recreation. Additionally, there were no limitations in walking short distances (100 meters), working on hobbies, or going to work, indicating that the prosthesis is effective in supporting the amputee's daily activities and maintaining independence.

However, the amputee did experience slight limitations when walking longer distances, such as over a mile or half a mile. This suggests that while the prosthesis provides substantial mobility, there may be room for improvement in endurance or comfort for longer walks. These minor restrictions could

be addressed through further adjustments to the prosthesis or additional physical therapy to enhance stamina and reduce any discomfort during extended walking.

Overall, the results indicate that the transtibial prosthesis is effective in restoring functionality for most activities, but further improvement may be needed to optimize performance in longer-duration mobility tasks. The overall satisfaction with the transtibial prosthesis is high, particularly in areas such as comfort, fit, reliability, and usefulness. The amputee expressed strong satisfaction with the fit and comfort of the prosthesis, indicating that it meets functional needs and provides a reasonable level of comfort for daily use.

The prosthesis' reliability and usefulness were also rated highly, suggesting that it effectively serves its intended purpose without frequent issues. The appearance and shape of the prosthesis received positive feedback as well, with the color and design aligning well with the aesthetic preferences. This suggests that both the functional and aesthetic considerations were adequately addressed in the design of the prosthesis.

In summary, the amputee's satisfaction with the prosthesis is overwhelmingly positive across all aspects, indicating that the device is both functional and comfortable, while also meeting aesthetic expectations. This high level of satisfaction points to the effectiveness of the prosthesis in improving the amputee's daily living and overall well-being.

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