# Design, Structural Analysis, and Fabrication of a 3D Printed Spectacle Frame using PLA Material

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**Abstract:** This paper presents the design, analysis, and fabrication of a 3D printed spectacle frame using Polylactic Acid (PLA) material, with a strong emphasis on ergonomic fit, structural integrity, and customization potential. The spectacle frame was meticulously modeled in SolidWorks, incorporating anthropometric measurements sourced from established ergonomic research to ensure a comfortable and secure fit for a wide range of users. Special attention was given to designing features that accommodate users with non-standard facial dimensions, including those with disabilities. To validate the mechanical performance of the design, a static structural analysis was conducted using ANSYS software, evaluating stress distribution and deformation under typical handling conditions. Based on the analysis results, necessary optimizations were made, and the final design was fabricated using Fused Deposition Modeling (FDM) technology. PLA was chosen for its lightweight nature, ease of processing, good surface finish, and biodegradability, making it ideal for consumer wearables. The resulting prototype demonstrated promising structural strength, dimensional accuracy, and user-centric design. This project highlights a streamlined and cost-effective workflow for developing customized wearable products through the integration of CAD modeling, simulation, and additive manufacturing, opening avenues for personalized healthcare and assistive devices

**Keywords:** 3D Printing, Spectacle Frame, PLA, Ergonomic Design, SolidWorks, ANSYS, FDM, Structural Analysis

## Chapter I: Introduction

### *A. Background:*

Additive manufacturing, widely known as 3D printing, has revolutionized the way products are designed and manufactured across various sectors. Its ability to fabricate complex, lightweight structures with high precision and minimal material waste has made it particularly valuable for creating customized consumer products. Among these, wearable devices such as spectacle frames stand to benefit significantly due to their direct interaction with the human body, where comfort, fit, and personalization are crucial.

Unlike traditional manufacturing methods that rely on fixed molds and standard sizes, 3D printing offers design flexibility and customization capabilities, making it ideal for producing eyewear tailored to individual facial dimensions. This opens up possibilities not only for aesthetic variation but also for ergonomic improvement and inclusive design.

### *B. Problem Statement:*

Conventional spectacle frames are typically mass-produced in a few standardized sizes, which may not accommodate the diverse range of facial structures among users. Individuals with unique facial proportions or those with disabilities may find it difficult to wear standard frames comfortably. Furthermore, traditional manufacturing processes are less adaptable for one-off or small-batch production, making personalized solutions economically unfeasible.

There is a growing demand for personalized and ergonomically optimized spectacles that can be produced efficiently and sustainably. Additive manufacturing, with its capacity for on-demand production and design flexibility, presents a promising solution to this challenge.

### C. *Objectives:*

- To explore the use of additive manufacturing (3D printing) for developing ergonomic and fully functional spectacle frames.
- To address the limitations of conventional eyewear manufacturing by enabling rapid, cost-effective customization through digital fabrication.
- To design spectacle frames that are not only structurally reliable but also tailored to individual comfort and fit.
- To support sustainable manufacturing practices by utilizing biodegradable materials like PLA and minimizing production waste.
- To demonstrate the potential of personalized eyewear solutions for individuals with non-standard facial

dimensions or disabilities, who may struggle with conventional frame sizes.

- To promote inclusive design by leveraging digital tools and ergonomic data to create accessible and user-specific products

### *C. Methodology Overview:*

The process begins with the 3D modeling of the spectacle frame in SolidWorks, incorporating anthropometric data to ensure ergonomic compatibility. A static structural analysis is then performed using ANSYS to evaluate stress distribution and identify potential weak points in the design. Upon validation, the model is fabricated using PLA material through FDM 3D printing. The final printed prototype is evaluated for structural integrity, visual quality, and ergonomic suitability. The study demonstrates a practical workflow for producing personalized, functional, and sustainable eyewear using digital tools and additive manufacturing techniques.

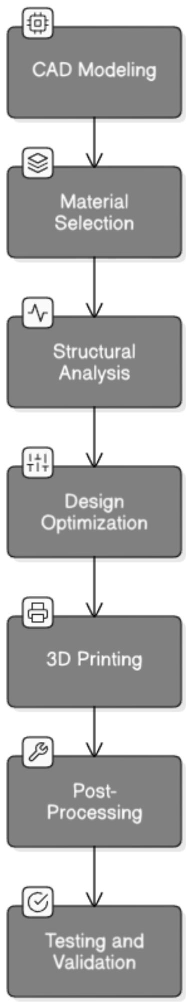


Fig.1 Workflow Diagram

## Chapter II: Literature Review

The development of customized spectacle frames using additive manufacturing techniques such as 3D printing has garnered significant attention in recent years. This chapter presents a review of the key studies and advancements relevant to the design and fabrication of spectacles, particularly focusing on anthropometric considerations, material selection, and 3D printing technologies.

C. N. Rosyidi et al. [1] conducted a detailed study on head and facial anthropometry for determining critical dimensions of glasses frames. Their research emphasized the importance of aligning frame design parameters with anthropometric measurements to ensure user comfort and fit. Such data plays a crucial role in the ergonomic design process, particularly when developing customizable frames via 3D printing.

In a study focusing on the Indian population, S. Maseedupalli et al. [2] provided an extensive dataset of facial dimensions that are vital for designing spectacles suited to regional anatomical variations. Their findings support the necessity for region-specific customization, a key motivation behind using additive manufacturing for spectacle production.

The potential of 3D printing technology in customizing eyewear frames was demonstrated by O. Ayyildiz [3], who explored the feasibility of using 3D printing to create bespoke spectacles. The study highlighted significant benefits such as design flexibility, rapid prototyping, and cost efficiency, particularly for individuals with non-standard facial structures.

A comprehensive review by F. Tsegay et al. [4] analyzed the advancement of smart eyeglasses fabricated through 3D printing technologies. The study discussed materials, design considerations, and challenges, emphasizing the growing role of smart materials and the need for robust structural designs when employing 3D printing methods.

Similarly, L. Lee et al. [5] evaluated the current state and future prospects of 3D-printed spectacles. Their research identified key challenges such as material limitations, durability concerns, and the precision required for optical components, while also recognizing the transformative potential of additive manufacturing in eyewear customization.

Earlier work by C. Schubert et al. [6] provided a broader overview of innovations in 3D printing across fields from optics to biomedicine. Their article outlined how advancements in additive manufacturing technologies could revolutionize product customization, including ophthalmic applications such as personalized spectacle frames.

Furthermore, the U.S. Department of Health & Human Services [7] offers a general overview of common eye disorders and diseases, underscoring the significance of ergonomically sound and properly fitting spectacles, particularly for individuals with visual impairments or ocular conditions.

This body of literature collectively demonstrates the interdisciplinary approach required for successful development of 3D printed spectacles—integrating anthropometric data, material science, and additive manufacturing techniques. The insights from these studies directly inform the methodology and design decisions in the present project.

## Chapter III: Design and Material Selection.

**A. *CAD Modeling:*** The 3D design of the spectacle frame was created using SolidWorks, a powerful CAD software that allows for precision modeling and parametric design control. The design aimed to achieve an optimal balance between aesthetics, comfort, and mechanical reliability. Ergonomic considerations were central to the modeling process, and anthropometric data from established research sources were referenced to ensure the design would accommodate a broad range of users.

To enhance user comfort, the geometry of the spectacle was tailored to match the average curvature of the human face. Key regions—such as the nose bridge and temple arms—were refined to reduce pressure points, distribute weight evenly, and ensure a snug fit. The design incorporated smoothed edges and adequate flexibility to support long-term use without discomfort.

Additionally, this project considered the needs of individuals with non-standard facial dimensions due to disabilities or unique anatomical conditions. The parametric nature of CAD modeling allowed for easy customization, ensuring that personalized spectacle frames can be developed quickly for such users.CAD renderings of the complete spectacle, including orthographic and isometric views, are provided in Appendix A.

Fig.2 Frame design.

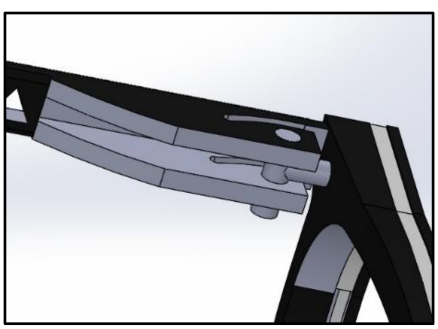

Fig. 3 Customized design of joints for arms

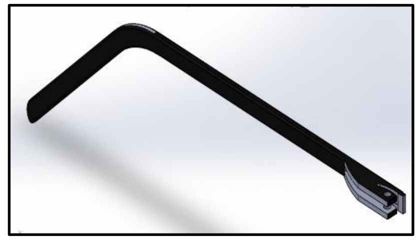

Fig.4 Spectacle arm before topology optimization

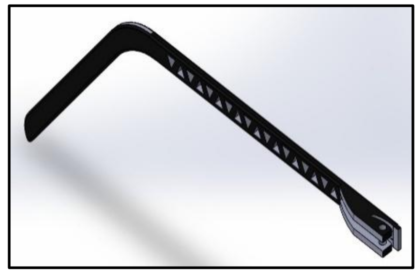

Fig.5 Spectacle arm after topology optimization

Fig.6 Final spectacle frame design

**B. *Material Selection:***

The material selected for the fabrication of the spectacle frame was Polylactic Acid (PLA), a biodegradable thermoplastic derived from renewable resources such as corn starch and sugarcane. PLA is one of the most commonly used materials in Fused Deposition Modeling (FDM) 3D printing due to its user-friendly printability and stable performance.

**Key Properties of PLA:**

- Tensile Strength: ~60 MPa
- Young's Modulus: ~3.5 GPa
- Glass Transition Temperature: ~60°C
- Biodegradability: High
- Surface Finish: Smooth, with minimal post-processing
- Printability: Excellent, with low warping and good dimensional control

**Why PLA was chosen:**

- It provides a smooth surface finish ideal for wearable items in contact with the skin.
- The low shrinkage rate during cooling ensures dimensional accuracy—critical for ergonomic fit.
- Its environmental friendliness aligns with modern sustainable manufacturing goals.

- PLA is affordable and readily available, making it an ideal material for prototyping and small-scale production.
- While PLA offers numerous advantages, it does have some limitations in terms of flexibility and heat resistance, which could affect its durability in high-temperature environments or under rough mechanical use.

**Alternative Material Consideration: PETG**

An alternative to PLA is Polyethylene Terephthalate Glycol (PETG), which offers a good balance between strength, flexibility, and thermal resistance. PETG is slightly more challenging to print compared to PLA but provides superior impact resistance and long-term durability.

**Advantages of PETG:**

- Higher toughness and flexibility than PLA, reducing the risk of cracking or snapping.
- Better thermal performance, with a glass transition temperature around 80°C.
- Suitable for daily-use wearables that require higher resistance to mechanical stress and environmental exposure.
- PETG would be especially beneficial in applications where the spectacles are subject to more rugged use, or for end-users in hotter climates.

## Chapter IV: Simulation and Analysis.

To ensure that the 3D printed spectacle frame meets the required structural integrity and can withstand typical forces encountered during daily use, a static structural analysis was conducted using ANSYS Workbench. This analysis helped identify areas of high stress concentration, deformation, and potential failure under operational loads.

**A. *Objective of the Simulation:***

The primary objective of the simulation was to evaluate the mechanical behavior of the spectacle frame when subjected to typical loading conditions, such as:

- Bending of the temple arms during wearing and removal
- Compression at the nose bridge due to the weight of the spectacle
- Handling stresses during usage

This analysis ensured that the design was structurally sound before proceeding to the 3D printing stage.

***B. Simulation Setup:***

Geometry and Import

The finalized CAD model created in SolidWorks was exported in .STEP format and imported into ANSYS for simulation. The model was cleaned and simplified by removing unnecessary fillets or cosmetic features to optimize mesh quality and reduce computation time.

Material Properties:

PLA material was defined in ANSYS using the following mechanical properties:

| **Property** | **Value** |
|---|---|
| Young's Modulus | 3.5 GPa |
| Poisson's Ratio | 0.36 |
| Yield Strength | 60 MPa |
| Density | 1250 kg/m³ |

These properties were derived from the PLA datasheet and verified from credible sources to ensure realistic simulation behavior.

Meshing

A fine mesh was generated to accurately capture the stress distribution, especially around critical regions such as:

- The hinge joint
- Nose bridge
- Bending region of the temple arms

| **Parameter** | **Value** |
|---|---|
| Mesh Size | 1mm |
| Total nodes | 75178 |
| Number of elements | 51415 |
| Element type | Tetrahedron |

***C. Boundary Conditions and Loads:***

Realistic boundary conditions were applied to simulate the actual usage of the spectacle.

Fixed supports were applied at the nose pads and/or contact points with the face.

A force of 0.3924 N was applied at the end of each temple arm to simulate bending during wear.

Gravity was also considered in the analysis to simulate the self-weight of the spectacle.

***D. Results and Interpretation:***

The results of the simulation were analyzed using stress and deformation plots.

<u>Maximum Equivalent Stress (von Mises):</u> <u>7.2859 MPa</u>

This value was compared to the yield strength of PLA to ensure safe operation under normal use.

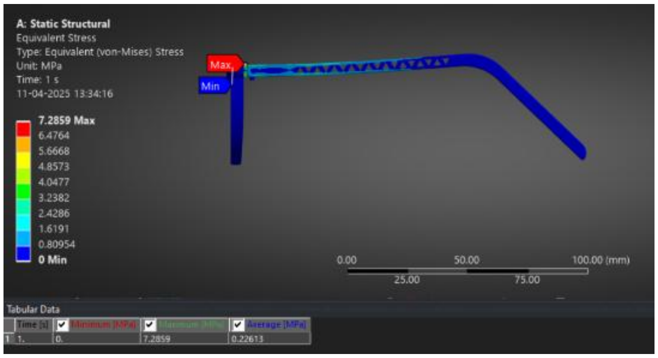


Fig.7 Equivalent stress in Spectacles

Maximum Deformation: 0.034 mm

The deformation was primarily observed at the temple arms and nose bridge area. The values remained within acceptable limits, ensuring user comfort and structural stability.

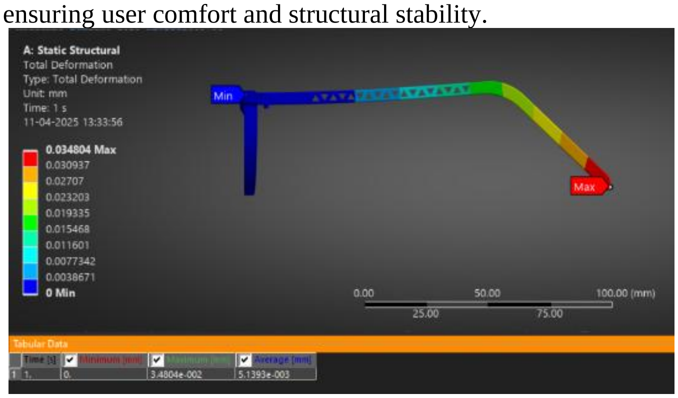


Fig.8 Deformation in Spectacles

Maximum Equivalent Elastic Strain: $3.6543\times10^{-5}$ mm/mm

The strain remained very low, indicating elastic behavior and no risk of permanent deformation under the given loading conditions.

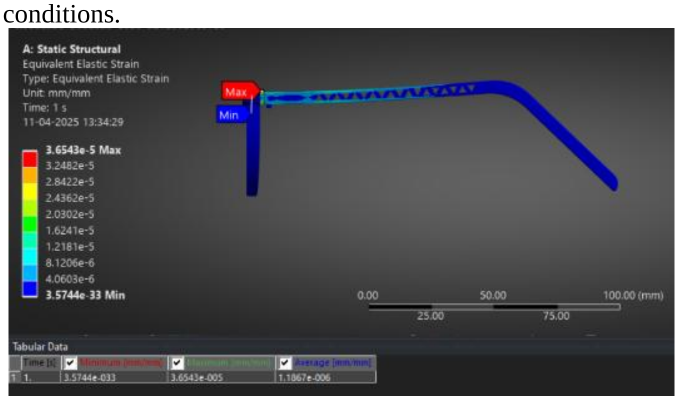


Fig.9 Elastic Strain in Spectacles

Maximum Principal Stress: 7.118 MPa

This stress was observed near the fixed support region, corresponding to the areas of highest tensile stress. Since this value is still below the yield strength of the material, structural integrity is preserved.

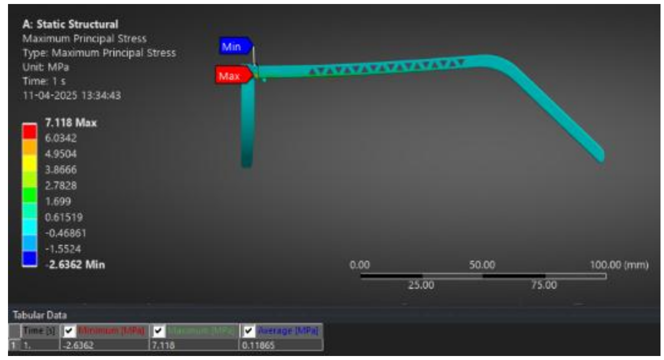


Fig. 10 Principal Stress in Spectacles

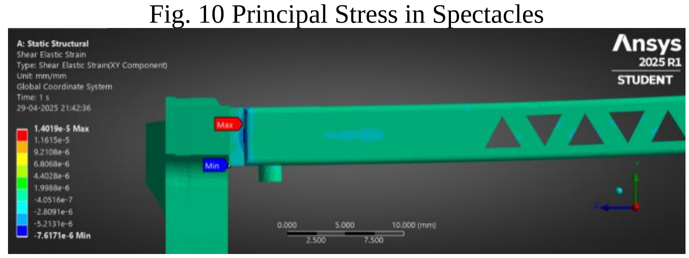


Fig. 11 Shear Elastic Strain in Spectacles

Shear Elastic Strain (XY Component): $1.4019\times10^{-5}$ mm/mm

This output represents the shear deformation between layers in the XY plane. The maximum shear strain is $1.4019\times10^{-5}$ mm/mm, mainly concentrated around the hinge area, showing torsional effects during loading.

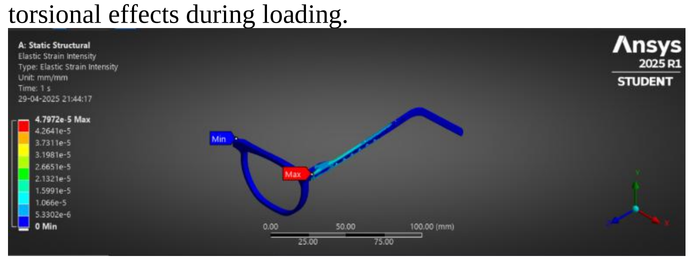


Fig. 12 Elastic Strain Intensity in Spectacles

Elastic Strain Intensity: $4.7972\times10^{-5}$ mm/mm

This result shows the maximum elastic deformation experienced by the spectacle frame. The highest strain occurs near the hinge, indicating it is the most flexible and stressed region.

| **Step No.** | **Stage** | **Action Performed** |
|---|---|---|
| 1 | Import Geometry | Imported STEP file of spectacle frame into ANSYS Workbench |
| 2 | Engineering Data | Added PLA material manually with:<br>- Density = 1250 kg/m³<br>- Young’s Modulus = 3.5 GPa<br>- Poisson’s Ratio = 0.36<br>- Yield Strength = 60 MPa |
| 3 | Model Preparation | Opened model in SpaceClaim for cleaning, simplification, and part separation |

| Step No. | Stage | Action Performed |
|---|---|---|
| 4 | Named Selections | Created named selections for hinges, supports, and loading faces |
| 5 | Meshing | Applied fine mesh (1 mm); attempted 0.2 mm and 0.01 mm but reduced due to license limits<br>Used "Face Sizing" to improve mesh quality at joints and thin features<br>Verified mesh quality using Mesh Metrics |
| 6 | Static Structural Setup | Added Static Structural module in Workbench |
| 7 | Boundary Conditions | Applied Fixed Support on lens-holding frame region |
| 8 | Force Application | Applied Force of 0.392 N (equivalent to 40 g) at the end of temple (stick)<br>Set direction of force using components or face normals |
| 9 | Solution Setup | Inserted solution outputs:<br>- Equivalent (Von-Mises) Stress<br>- Total Deformation<br>- Factor of Safety (via manual calculation)<br>- Elastic Strain Intensity<br>- Shear Elastic Strain |
| 10 | Solving | Solved after mesh refinement and reduced geometry (half model to avoid license error) |
| 11 | Post-processing | Interpreted stress concentration regions and deformation behaviour |
| 12 | Manual Calculations | Calculated Factor of Safety:<br>FOS = UTS/σ = 60 MPa/7.2859 MPa ≈8.23 |

## Chapter V: Fabrication and Testing

***A. Fabrication Process:***

After finalizing the design and validating it through structural analysis, the fabrication of the spectacle frame was carried out using Fused Deposition Modeling (FDM), a widely used 3D printing technique known for its affordability, speed, and accessibility.

***B. Printing Setup:***

The slicing of the CAD model was done using PrusaSlicer. Careful attention was paid to layer height, infill percentage, and support generation to balance strength and print quality.

- Printer Used: Anycubic Kobra Neo
- Layer Height: 0.2mm
- Nozzle Diameter: 0.2mm
- Infill Density: 100%
- Print Speed: 60mm/s
- Support Structures: Enabled only for Frame
- Bed Temperature: 65°C

These parameters were selected to ensure dimensional accuracy, smooth surface finish, and mechanical strength suitable for wearable applications.

***C. Material Handling:***

Polylactic Acid (PLA) filament was used for printing due to its ease of processing, good dimensional stability, and low warping tendency. The filament was stored in a moisture-free environment prior to printing to prevent defects such as stringing or layer adhesion issues.

***D. Post-processing:***

Post-processing was required owing to the optimized printing parameters. Support materials were carefully removed, and minor sanding was performed to smoothen the edges and contact surfaces for enhanced user comfort. No chemical treatment was applied to preserve the material's integrity.

***E. Fit and Comfort Evaluation:***

A test fitting was carried out on individuals to verify the ergonomic performance. The frame was observed for:

- Stability on different face sizes
- Pressure distribution on the nose and ears
- Flexibility and spring-back behavior of the arms

Feedback confirmed that the frame was comfortable and lightweight, with good grip and no noticeable discomfort during prolonged wear.

***F. Customization Advantage:***

One of the major advantages observed during the fabrication process was the ability to easily customize the dimensions of the spectacle to accommodate users with unique facial features, including those with asymmetry or medical conditions requiring special fitting. By modifying the CAD parameters, new iterations can be generated and printed with minimal time and cost investment, showcasing the real potential of 3D printing in personalized wearable design.

## Chapter VI: Results

The main goal of this project was to design and 3D print a spectacle frame that fits well, is strong enough for regular use, and can be customized for different users. The steps followed during the project gave successful results.

***A. Design Output:***

A complete design of the spectacle frame was made in SolidWorks. The shape and size were based on ergonomic data from research, which helped make the frame comfortable for different face types. The design was improved through a few versions before finalizing it.

***B. Analysis Results:***

We tested the strength of the frame using ANSYS software. A static structural analysis was done to check how much stress and bending the frame could handle. The results showed:

Maximum stress: 7.2859 MPa

Maximum deformation: 0.034 mm

These results proved that the frame can handle normal use without breaking or bending too much.

***C. 3D Printing Outcome:***

The final design was printed using PLA material and the FDM method. After printing, we checked the shape, size, and finish. The printed frame was light in weight and kept its proper shape. The quality of printing was good for wearing use.

Fig.13 3D Printed Spectacles

***D. Comfort and Fit Check:***

The frame was tested by different users. It fit well and was comfortable to wear. It didn't press too hard on the face and stayed in place. The design matched the ergonomic needs as planned.

***E. Customization Advantage:***

One of the best results was that the frame could be easily changed in size and shape to fit users with different face structures, including those with special needs or disabilities. 3D printing made it easy to create such customized frames quickly and at low cost.

## Chapter VII: Conclusion and Future Scope

***A. Conclusion:***

This project showed how 3D printing can be used to make custom spectacle frames that are comfortable, strong, and lightweight. PLA was a good choice of material because it is easy to print and strong enough for daily use. The ability to design and make frames for people with different facial dimensions, especially those with disabilities, is a major benefit of this method.

***B. Future Scope:***

- Use of Better Materials: Materials like PETG or TPU can be tested in the future for better flexibility and strength.
- Improved Features: New design ideas like flexible arms, clip-on parts, or adjustable sizes can make the frame more useful.
- Face Scanning: 3D face scanning can help in making perfectly fitting frames for each person quickly.
- Commercial Use: This method can be used by eyewear companies to offer customized glasses at a low cost.
- Eco-Friendly Designs: In the future, eco-friendly materials can be used to reduce plastic waste and make the process more sustainable.

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