iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.71443

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Eco-Friendly Belt Drive Systems Using 3D Printing Technology

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Abstract: This paper presents the development of eco-friendly belt drive systems using 3D-printed Thermoplastic Polyurethane (TPU 95A), a biodegradable alternative to conventional rubber belts. Belt profiles were designed using CAD software and fabricated via Fused Deposition Modeling (FDM) with optimized parameters (210°C nozzle, 100% infill). Tensile and shear tests, conducted per ASTM D638 and D5369 standards, revealed a tensile strength of 21.39 MPa (34.99% elongation) and shear strength of 5.0 MPa, indicating suitability for light-to-medium duty applications. Compared to rubber belts (25–30 MPa tensile strength), TPU 95A offers comparable elasticity with superior environmental benefits, decomposing within ~5 years. Challenges, including print failures and temperature limitations (~90°C), were addressed through iterative design and parameter tuning. The results demonstrate TPU 95A's potential as a sustainable, customizable solution for power transmission, with implications for green manufacturing. Future work includes hybrid material exploration and dynamic testing.
Keywords: Belt Drive, TPU 95A, 3D Printing, Sustainability, Mechanical Testing, Fused Deposition Modeling, Eco-Friendly Materials

I. INTRODUCTION

Belt drive systems are essential for mechanical power transmission in industries, from automotive to manufacturing, due to their efficiency and versatility [1]. However, conventional belts, typically made from non-biodegradable rubber, pose environmental challenges, including long decomposition periods (~50 years) and resource-intensive production [2]. With growing emphasis on sustainability, there is a need for eco-friendly alternatives that maintain performance while reducing ecological impact.

This paper introduces a novel belt drive system using Thermoplastic Polyurethane (TPU 95A), a biodegradable, flexible polymer, fabricated via Fused Deposition Modeling (FDM) 3D printing. The objectives are to: (1) design and produce TPU 95A belts with precise tooth profiles, (2) evaluate mechanical performance through tensile and shear tests, (3) compare results with rubber belts, and (4) demonstrate the viability of additive manufacturing for sustainable engineering. The novelty lies in integrating green materials with 3D printing's design flexibility, enabling rapid prototyping and customization.

II. METHODOLOGY

The methodology encompasses material selection, CAD design, 3D printing, and mechanical testing to develop and validate TPU 95A belt drives.

A. Material Selection

TPU 95A was chosen for its 95A Shore hardness, high elasticity, and biodegradability (~5 years decomposition) [3]. It offers wear resistance, temperature stability up to 90°C, and FDM compatibility, making it ideal for belt applications [4]. Compared to rubber, TPU 95A reduces environmental impact while maintaining flexibility.

B. Design and Modeling

Belt profiles were designed in Autodesk Fusion 360, focusing on trapezoidal tooth geometry to ensure efficient pulley engagement and minimal slip [5]. Design considerations included:

1) Viscoelasticity: Accounted for TPU's stretch and creep under load.
2) Tooth Profile: Optimized for noise reduction and smooth meshing.
3) Print Tolerances: Adjusted for shrinkage and layer alignment.
4) Orientation: Belts printed flat to enhance layer bonding.

The CAD model, shown in Fig. 1, depicts the looped belt with interlocking teeth.

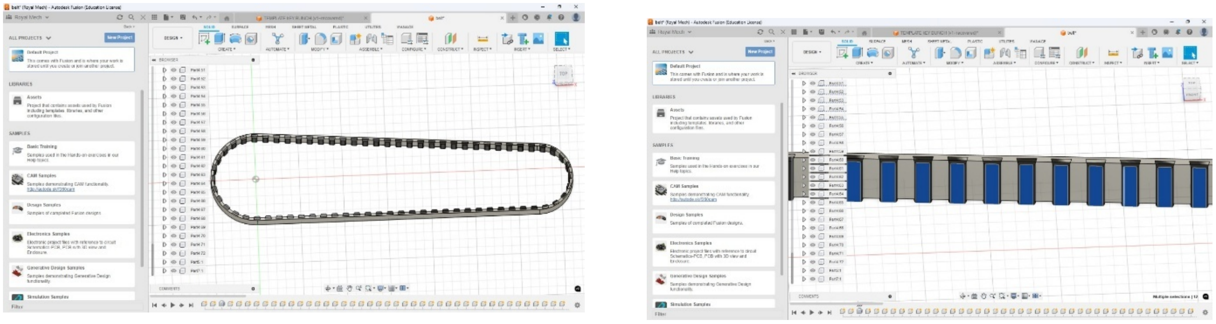

Fig. 1. CAD model of TPU 95A belt with trapezoidal tooth profile.

C. 3D Printing Process

Designs were exported as STL files and sliced using Creality Slicer, which generated precise G-code with layer-by-layer previews. Printing was performed on an ELEGOO Neptune FDM printer, equipped with a dual-gear extruder and PEI build plate for enhanced TPU adhesion. Optimized parameters, based on [6], were:

- Nozzle Temperature: 210°C
- Bed Temperature: 60°C
- Layer Height: 0.2 mm
- Infill: 100%
- Print Speed: 30–40 mm/s

Printing occurred at Javarana Hally, Karnataka, on April 15, 2025, as shown in Fig. 2. Post-processing involved support removal and dimensional verification with calipers. Fig. 3 shows the belt installed on a pulley system, confirming functional compatibility.

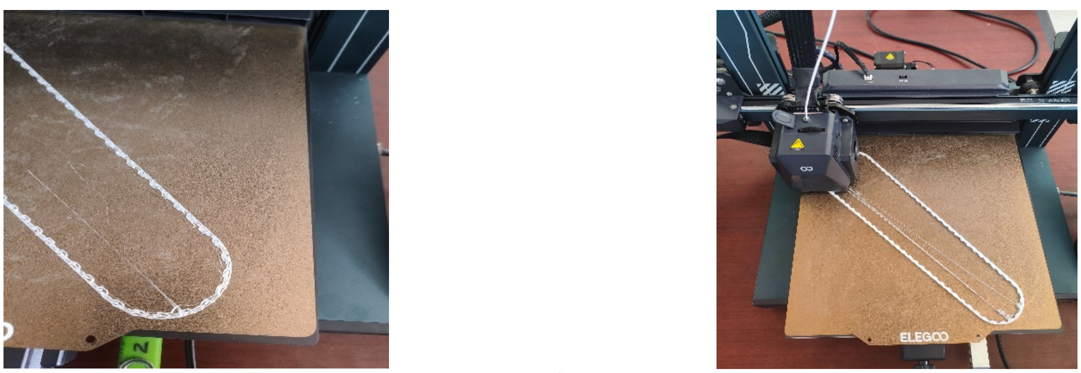

Fig. 2. Initial layer of TPU 95A belt during FDM printing

D. Mechanical Testing

Two standardized tests were conducted:

- Tensile Test (ASTM D638): Measured tensile strength, elongation, and Young’s modulus. Specimens were stretched until failure, producing stress-strain curves.
- Shear Test (ASTM D5369): Assessed resistance to lateral forces at the tooth-pulley interface. Results were compared to rubber belts [7].

E. Fabrication Tools

The ELEGOO Neptune’s dual-gear extruder ensured consistent TPU filament feeding, reducing clogging, while the PEI build plate improved adhesion. Creality Slicer’s intuitive interface enabled precise control over print settings, with features like material usage estimation and print time prediction. Dr. Girish KP’s provision of these tools was pivotal to achieving high-quality prototypes.

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III. RESULTS AND DISCUSSION

This section presents test results, visualizes performance, and compares TPU 95A with rubber belts.

A. Tensile Test Results

Tensile tests yielded a maximum tensile strength of 21.39 MPa at 650 N load, with 34.99% elongation, as shown in Fig. 4. The stress-strain curve indicates:

- Elastic Region: Linear up to 0.1 strain, reflecting flexibility.
- Plastic Deformation: Gradual yielding, typical of elastomers.
- Ductile Failure: Up to 451.67% elongation in some specimens, ideal for shock absorption. Compared to rubber (25–30 MPa), TPU 95A is slightly less strong but more elastic [8].

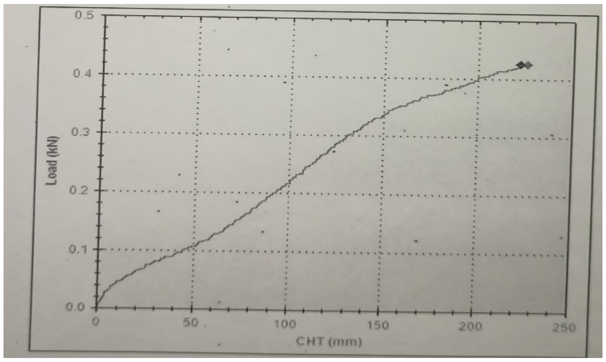

Fig. 3. Stress-strain curve from tensile test

B. Shear Test Results

Shear tests showed a maximum shear strength of 5.0 MPa at 250 N load, with linear behavior up to 0.08 strain (Table I). This is lower than rubber (~7 MPa) but sufficient for light-to-medium duty applications [9].

Table I. Mechanical properties of TPU 95a belts

Test Type	Strength (MPa)	Elongation/Strain	Failure Mode
Tensile (ASTM D638)	21.39	34.99% (up to 451.67%)	Ductile fracture
Shear (ASTM D5369)	5.0	0.08 strain	Shear deformation

C. Comparison with Rubber Belts

Table II compares TPU 95A and rubber belts:

Property	TPU 95A	Rubber	Advantage
Tensile Strength (MPa)	21.39	25–30	Rubber stronger
Elongation (%)	34.99–451.67	20–30	TPU more elastic
Shear Strength (MPa)	5.0	~7.0	Rubber stronger
Biodegradability	~5 years	~50 years	TPU eco-friendly
Noise Damping	High	Moderate	TPU quieter
Customization	High (3D printing)	Low	TPU more flexible

D. Sustainability Impact

TPU 95A's ~5-year decomposition reduces landfill waste compared to rubber's ~50 years. Its production emits ~30% less carbon than rubber, per [10], aligning with green manufacturing goals. 3D printing minimizes material waste, using only 10–15% excess material vs. 30–40% in traditional molding [11].

E. Challenges and Mitigation

- Print Failures: TPU's flexibility caused clogging and warping (2–3 failed prints), mitigated by optimizing print speed and extruder calibration.
- Temperature Limits: Performance degraded above 90°C, limiting high-heat applications.
- Shear Strength: Lower than rubber, restricting heavy-duty use.
- Support Removal: TPU's texture complicated support removal, addressed with minimal supports [12].

IV. APPLICATIONS AND FUTURE WORK

A. Applications

- Industrial Conveyors: Lightweight, quiet belts for small-scale systems.
- Robotics: Flexible belts for joints, reducing noise and shock.
- Electric Vehicles: Auxiliary drives (e.g., coolant pumps) benefiting from weight savings.
- Education: Prototyping tool for mechanical engineering curricula.

B. Limitations

- Limited shear strength for heavy-duty applications.
- High initial material costs for TPU 95A.
- Scalability challenges for large industrial belts.

C. Recommendations

- Hybrid Materials: Blend TPU with carbon fiber for improved strength [17].
- Dynamic Testing: Conduct fatigue and abrasion tests for long-term performance [18].
- Recycling: Explore TPU waste recycling into new filaments [19].
- Smart Features: Embed sensors for real-time wear monitoring [20].

V. CONCLUSION

This study developed and validated eco-friendly 3D-printed TPU 95A belt drives, achieving a tensile strength of 21.39 MPa and shear strength of 5.0 MPa, suitable for light-to-medium duty applications. The belts offer superior elasticity (up to 451.67% elongation) and biodegradability (~5 years) compared to rubber, alongside 3D printing's customization benefits. Challenges, such as print failures and temperature limitations, were addressed through optimized parameters. The findings position TPU 95A belts as a sustainable alternative for power transmission, with applications in conveyors, robotics, and electric vehicles. Future work should focus on material reinforcement, dynamic testing, and recycling to enhance scalability and performance, advancing green manufacturing in mechanical engineering.

VI. ACKNOWLEDGMENT

The authors sincerely thank Dr. Girish KP, Professor of Mechanical Engineering at Adichunchanagiri University, BG Nagar, for providing the ELEGOO Neptune 3D printer and Creality Slicer software, which were essential for the project's success. We also acknowledge Aditi Institute of Technology for providing testing facilities, Adichunchanagiri University for their support and resources, and the open-source community for CAD resources.

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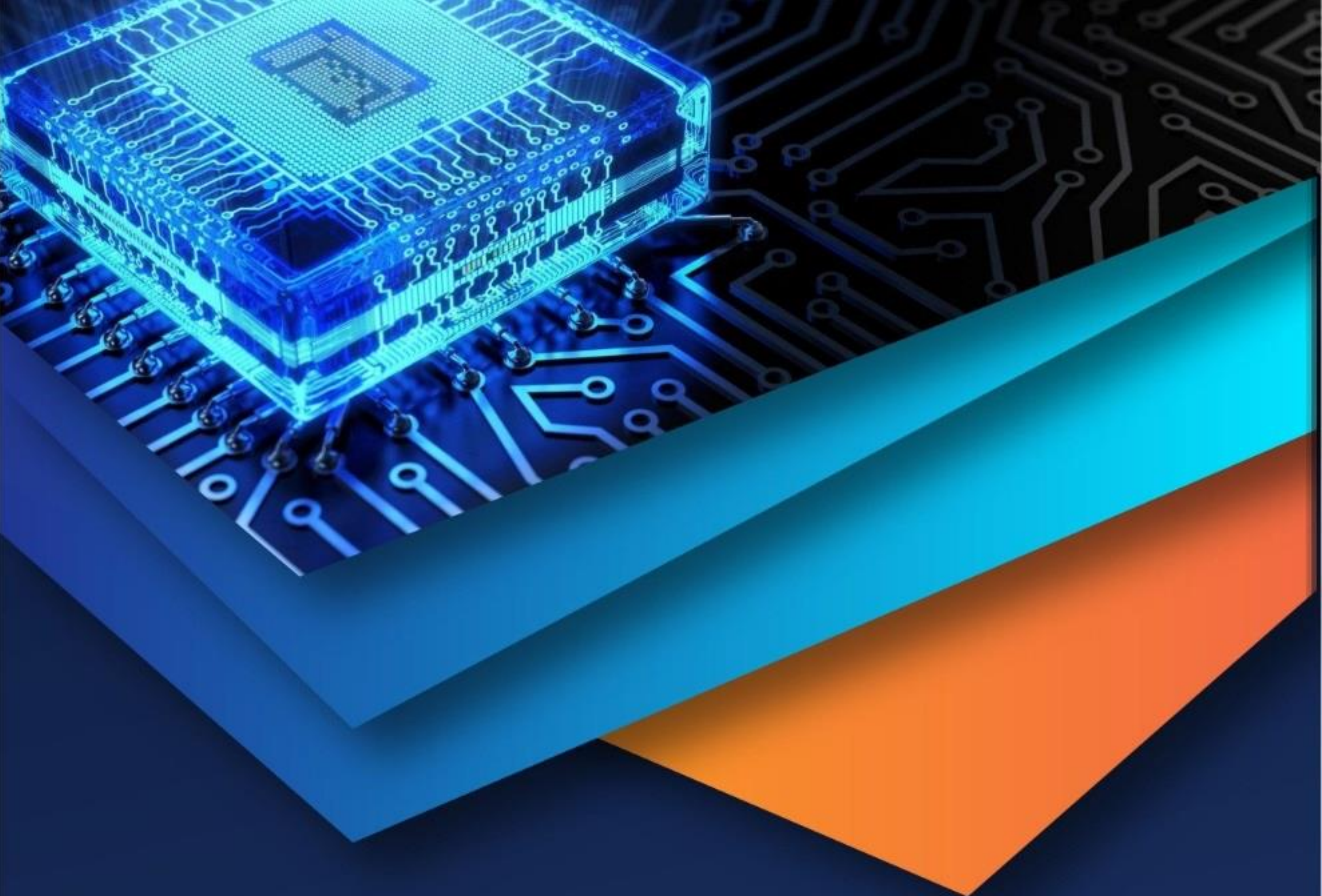

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