Development, Validation, and Comparative Evaluation of a Novel Pharmaceutical Textile Microscope Against Marketed Microscope

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Abstract - *Textile engineering plays a crucial role in healthcare and public safety, where fiber microstructure directly influences the performance of medical and protective materials. This study presents the design, development, and evaluation of a novel, low-cost textile microscope fabricated using additive manufacturing. The device was constructed through the assembly of 32 precision-designed components using the Anet ET4 Plus 3D printer, with optimized parameters and polylactic acid (PLA) as the primary material. The CAD model was processed using Ultimaker Cura to achieve high-resolution fabrication without support structures. The performance of the developed textile microscope was comparatively evaluated against a standard Olympus microscope using various textile and healthcare-related samples, including surgical masks, N95 masks, dressing bandages, and cotton fibers. Observations indicate that the proposed microscope provides comparable imaging capability for fiber morphology, pore structure, and sample analysis, while offering significant advantages in portability and ease of handling. The results demonstrate that fiber characteristics such as diameter, orientation, and porosity can be effectively analyzed using the developed system, supporting applications in textile quality control, pharmaceutical materials, and protective fabrics. Furthermore, the microscope shows strong potential for industrial, forensic, and educational use due to its low cost and scalability through 3D printing. In conclusion, the proposed textile microscope represents a practical, cost-effective alternative to conventional microscopy systems, enabling accessible and real-time fiber analysis for diverse applications in healthcare and textile engineering.*

Key Words: Textile Microscopy, 3D Printed Microscope, Fibre Morphology, Additive Manufacturing, Healthcare Textiles, Filtration Efficiency, Portable Microscopy, Polylactic Acid (PLA)

1. INTRODUCTION

Textile engineering has increasingly become a vital field in healthcare and public safety, where fiber science and microscopic analysis play a central role. From medical compression bandages used in treating venous leg ulcers to protective face masks designed to reduce viral transmission, the performance of these products is closely linked to the microstructure of the fibers. Characteristics such as fiber orientation, porosity, and mechanical behavior significantly affect their effectiveness, durability, and user comfort [1,2].

In the case of compression bandages, research shows that the design of woven structures and the treatment of yarns are crucial in achieving the desired therapeutic pressure. Advanced techniques, including spectroscopic analysis, have been used to evaluate bandage porosity and predict optimal tension levels [3]. When experimental findings are compared with theoretical predictions based on Laplace's law, noticeable differences are often observed, highlighting the complex nature of textile behavior under practical conditions [1]. Materials such as cotton and viscose-lycra exhibit different load and elongation characteristics; cotton tends to generate higher pressure but may lead to fluctuations during movement [2]. Innovations such as double-weft constructions and the incorporation of silver nanoparticle-treated yarns demonstrate how fiber-level modifications can enhance antimicrobial performance and support wound healing [4].

Similarly, the development of protective face masks during the COVID-19 pandemic highlighted the importance of textile fiber structure in filtration efficiency and safety. Guidelines from the World Health Organization emphasize the role of proper material selection and multi-layer construction in effective mask performance [5]. Microscopic studies reveal that fiber morphology, pore size distribution, and surface treatments directly influence a mask's ability to trap particles while maintaining breathability [6].

Materials such as electro spun nanofibers, melt-blown polypropylene, and spun bond nonwovens have been extensively studied for their filtration capabilities at the nanoscale [9,12]. While nanofiber-based layers offer high surface area for particle capture, they may face limitations in mechanical strength and durability. Hybrid structures combining micro- and nanofibers, particularly in modified melt-blown fabrics, have shown improved performance by enhancing filtration pathways while maintaining user comfort [10].

Comparative studies of different face masks—including surgical masks, cotton masks, FFP2 and FFP3 respirators, antiviral polyester, and silk masks—provide deeper insights into their structural and mechanical properties. Techniques such as scanning electron microscopy (SEM), pore size analysis, and tensile testing show that multi-layered masks like FFP2 and FFP3 achieve filtration efficiencies of up to ~98% due to dense fiber arrangements and reduced porosity [7,8]. However, this often comes with reduced mechanical flexibility. In contrast, cotton and silk masks offer more uniform fiber orientation and better breathability, while antiviral polyester masks incorporate treatments such as silver chloride for self-sanitizing properties [4,6].

Taken together, these studies emphasize a common principle: the microscopic characteristics of fibers form the foundation for designing effective medical and protective textiles. Whether used for therapeutic compression or respiratory protection, these materials must balance performance, durability, and comfort. Advances in microscopy—from SEM imaging to spectroscopic porosity analysis—enable precise characterization of textile structures and guide innovations in yarn engineering, fabric construction, and multi-layer design [10,11]. Ultimately, textile science plays a transformative role in healthcare, where microscopic fiber behavior translates into improved patient outcomes and enhanced public safety.

1.1 Development of the Novel Textile Microscope Using 3D Printing Technology

The development of the novel textile microscope was accomplished using advanced additive manufacturing techniques, involving the precise fabrication and assembly of 32 individual components. The printing process was carried out using the Anet ET4 Plus (Model 84 Plus 1850, China), selected for its capability to deliver high dimensional accuracy and reliability in producing intricate geometries. The complete design was initially conceptualized and validated within a computer-aided design (CAD) environment, where each component was meticulously dimensioned and verified to ensure proper alignment, tolerance control, and functional integration.

Following validation, the finalized CAD model was exported to Ultimaker Cura (version 5.10.2), which was employed as the slicing platform to generate machine-readable instructions (G-code) for the printing process. Material selection was carefully considered, and PLA (polylactic acid) was chosen due to its favourable properties, including biocompatibility, ease of processing, and adequate mechanical strength for structural components.

To achieve optimal performance, the printing parameters were systematically optimized. A high infill density of 90% was implemented using a honeycomb pattern, providing a balance between structural strength and material efficiency. The layer thickness was maintained at 0.1 mm to ensure fine resolution, smooth surface finish, and accurate reproduction of micro-scale features. Build plate adhesion was maintained at 100% throughout the process to eliminate risks of warping or detachment. Notably, the design was executed without the need for support structures, reflecting the efficiency of the CAD optimization and print orientation strategy.

The resulting device was a fully functional textile microscope, fabricated with high fidelity to the original design specifications. This work demonstrates the practical feasibility of utilizing 3D printing technology for the development of advanced scientific instrumentation. Furthermore, the approach highlights significant advantages over conventional commercially available microscopes, including reduced manufacturing cost, enhanced portability, and the ability to customize design features for specific textile analysis applications.

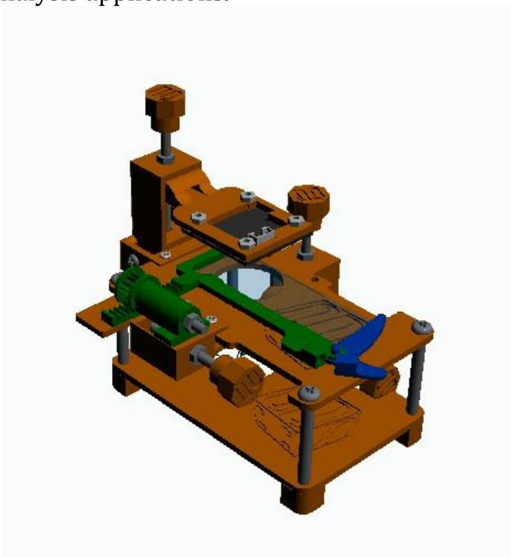

Fig 1- CAD design of proposed Textile microscope

Fig 2-Manufactured Textile microscope as per above proposed model

Part lists by module

Body

Item	Quantity
1_Top_plate	1
2_Bottom_plate	1
4_Manipulator_SliderHolder_X	1
6_Manipulator_Slide	1
7_Rack_Gear	1
8_Pinion_Gear	1
9_Holder_Slide	1
12_Slide_Retainer	1
13_Manipulator_M4_Nut	1
14_Plate_Base	4
M3 nut	6
M3x 10 mm	6
M4 nut	5
M4x 40 mm	2
M5x 45 mm	4

Illumination module

Item	Quantity
3_Manipulator_X	1
5_Manipulator_Z	1
10_Holder_laser	1
13_Manipulator_M4_Nut	2
AsphericLens	1
Laser modulus	1
LensHolder	1
LensRetainer	1
M4 nut	7
M4x 40 mm	2

Camera module

Item	Quantity
3_Manipulator_X	1
5_Manipulator_Z	1
11_Holder_Camera	1
13_Manipulator_M4_Nut	2
Camera	1
M3 nut	4
M3x 6 mm	4
M4 nut	7
M4x 40 mm	2

Fig 3-Part lists by module

Part lists by type

3D printed

Item	Quantity
1_Top_plate	1
2_Bottom_plate	1
3_Manipulator_X	2
4_Manipulator_SliderHolder_X	1
5_Manipulator_Z	1
6_Manipulator_Slide	1
7_Rack_Gear	1
8_Pinion_Gear	1
9_Holder_Slide	1
10_Holder_laser	1
11_Holder_Camera	1
12_Slide_Retainer	1
13_Manipulator_M4_Nut	5
14_Plate_Base	4

Illumination and Camera

Item	Quantity
AsphericLens	1
Laser modulus	1
LensHolder	1
LensRetainer	1
Camera	1

Screws and nuts

Item	Quantity
M3 nut	10
M3x 6 mm	4
M3x 10 mm	6
M4 nut	19
M4x 40 mm	6
M5x 45 mm	4

Fig 4- Parts lists by type

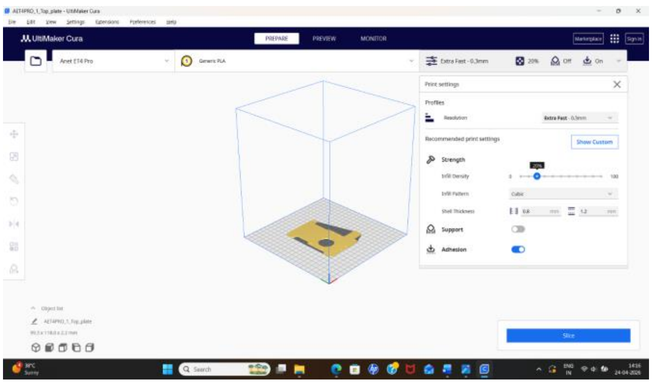

Fig 5- Ultimaker cura 5.12.0- slicing software for 3D printing used for designing

1.2. Preparation of slides

Firstly, the slides are washed with alcohol and air dried. The sample is then loaded on the slide, depending upon the nature of the sample paraffin oil is used if necessary. The cover slip is mounted upon the sample.

1.3 Observing the prepared slide under the Olympus microscope

The prepared slide is then observed under the microscope under the suitable magnification. The image is captured with the help of microscope camera and software.

1.4. Observing the Fiber sample under the Textile microscope

When observing under Textile microscope the sample is directly placed on the sensor of the microscope, if the sample is solid in nature paraffin oil is used which aids in better resolution. The sample is directly observed on a screen and an image is taken with the help of software for the comparative studies.

2. RESULT

Textile microscopy offers strong marketing applicability by transforming technical validation into consumer-facing value propositions. By enabling fiber identification, brands can confidently market authenticity and premium quality; fabric structure analysis provides evidence of innovation and durability that can be showcased in campaigns; blend analysis supports performance-based claims such as comfort, elasticity, or resilience; quality control and defect detection reinforce narratives of flawless craftsmanship and reliability; and counterfeit detection strengthens brand protection and consumer trust. The result obtained after observing the different samples under both the microscopes suggests that the Textile microscope is equally good as the Olympus microscope which is used as a standard for this experiment, and the Textile microscope having handling advantages along with its portability makes it fairly better microscope for emergency testing and other microscopically applications. The comparative study is shown in table 1.

Table -1: Fabric Samples used for comparison study.

Sr.no	Samples	Type of samples	Typical size range	Pharmaceutical studies
1	Surgical mask	solid	~10-30µm	Used as protective barrier; prevents microbial contamination in hospitals and pharmaceutical manufacturing areas.
2	Dressing bandage	solid	~15-25µm	Used for wound dressing; study of fiber structure helps in understanding absorbency and drug-loaded dressing materials.

3	N[95] mask	solid	~1-10µm	High-efficiency filtration (≥95% for 0.3 µm particles); important in infection control and sterile pharmaceutical environments.
4	Antiseptic bandage	solid	~15-25µm	Contains antimicrobial agents; microscopic study helps evaluate fiber porosity and drug retention capacity
5	Cotton	solid	~12-25µm	Natural fiber used in pharmaceutical preparations (absorbent cotton, gauze); analyzed for purity, fiber morphology, and absorbency.

The output received after observing the samples under both the microscopes:

1.Surgical Mask:

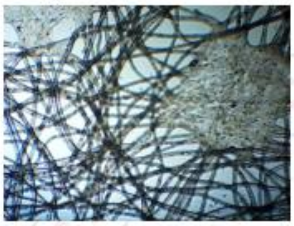

Fig no 5.a: Olympus microscope

Fig no 5 .b: Textile microscope

2.Dressing bandage:

Fig no 6.a: Olympus microscope

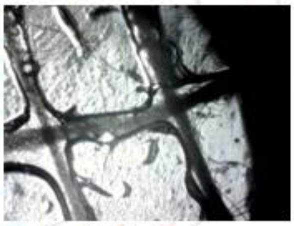

Fig no .6 b: Textile microscope

3.N[95] Mask:

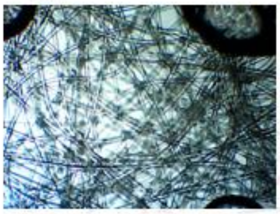

Fig no 7.a: Olympus microscope

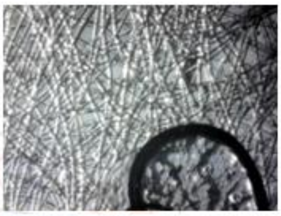

Fig no 7.b: Textile microscope

4.Antiseptic bandage:

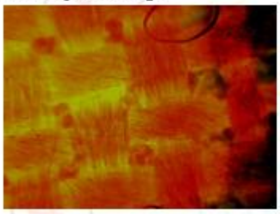

Fig no 8.a: Olympus microscope

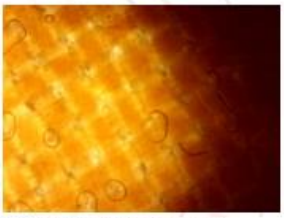

Fig no 8.b: Textile microscope

5.Cotton:

Fig no 9.a: Olympus microscope

Fig no 9.b: Textile microscope

Industrial Applicability and Market Value of the Novel Textile Microscope

1. Textile Manufacturing & Quality Control

The novel textile microscope enables fiber identification, blend analysis, and defect detection, ensuring raw material authenticity and consistent product standards. Its portable design makes it suitable for on-site inspections in mills, garment factories, and export houses.

2. Pharmaceutical & Healthcare Textiles

The microscope is applicable in analyzing surgical masks, N95 masks, dressing bandages, and antiseptic bandages. These applications are critical where fiber morphology and porosity directly affect safety and therapeutic performance. It also supports the development of drug-loaded dressings and antimicrobial fabrics by validating fiber structure and retention capacity.

3. Forensic & Anti-Counterfeit Applications

The microscope is useful in counterfeit detection of branded fabrics and medical textiles, protecting both manufacturers and consumers. It can be marketed to forensic labs and regulatory agencies for authenticity verification.

4. Research & Education

The affordable, 3D-printed design makes the microscope accessible for academic institutions, textile R&D labs, and training centers. It encourages innovation in fiber science, nano fiber research, and protective textile development.

Market Value Potential

1. Cost Advantage

Being 3D-printed with PLA material, the novel textile microscope is significantly cheaper than conventional branded microscopes like Olympus Magnus. Its portability and ease of handling add value for industries needing rapid, field-level testing.

2. Target Market Segments

The microscope can serve various sectors including the textile and apparel industry, pharmaceutical and medical device industry, educational institutions, and forensic and regulatory agencies.

3. Commercial Positioning

It can be marketed as a cost-effective alternative to Olympus Magnus for routine textile analysis. Its unique portability and emergency testing capability provide differentiation in competitive markets. The potential for scaling production via 3D printing makes it attractive for startups and small laboratories.

3. CONCLUSIONS

The novel textile microscope bridges affordability with functionality, making it highly applicable across textiles, healthcare, education, and forensic industries. Its market value lies in being a portable, low-cost, yet reliable alternative to established microscopes, with strong potential for adoption in both developing and advanced industrial settings.

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