

Review Article: Evaluation of Micro Catheter Tubing Strength and Advantages in Medical Applications

Kothwala Dr. Deveshkumar, Patel Jayendra and *Patel Aniket

Meril Medical innovation Pvt. Ltd., Bilakhia House, Survey No. 135/139, Muktanand Marg,
Chala, Vapi - 396191, Gujarat, India

A B S T R A C T

Microcatheters serve as essential instruments in less-invasive medical procedures, enabling precise treatment across various specialties, including peripheral cardiovascular surgery, neurology, cardiology, and oncology. A vital consideration in determining procedural safety, reliability, and clinical effectiveness is the mechanical strength of these devices—specifically, their tensile strength.

This study investigates the tensile strength of various microcatheter tube polymers, including silicone, polyethylene, polyvinyl chloride (PVC), and medical-grade polyamide, by conducting standardized mechanical testing in accordance with ISO 10555-1 and ASTM D638 standards. The key mechanical properties—such as Young's modulus, elongation at break, and maximum tensile strength—were evaluated under controlled environmental conditions using a universal tensile testing machine.

Significant performance diversity is demonstrated by the results, underscoring the significance of component selection in maximizing catheter strength, flexibility, and durability. These findings provide critical insights for manufacturers aiming to enhance microcatheter design—ensuring compliance with medical device standards while improving clinical outcomes. Future work will explore advanced biomaterials and in vivo testing to further refine catheter performance.

Introduction

Micro catheters are vital tools in modern minimally invasive medical interventions, particularly in neurology, cardiology, and oncology. Their small diameters and exceptional flexibility enable navigation through complex vascular pathways inaccessible to larger catheters, facilitating precise diagnostic and therapeutic procedures. Ensuring the mechanical integrity of micro catheters is critical for patient safety and procedural success.

According to ISO 10555-1 standards, the tensile properties of catheter bodies and the joint strength of connectors and hubs must be rigorously evaluated using a universal tensile testing machine (ISO 10555-1) [4]. This standard mandates evaluation of key mechanical parameters such as maximum tensile strength, elongation at break, and Young's modulus to determine material performance under stress and strain conditions.

The present review synthesizes current knowledge on the tensile strength evaluation of micro catheter tubing made from various polymers, focusing on the methodology, testing instruments, and implications for medical device manufacturing.

Materials and Methods for Tensile Testing

Material Composition and Sample Preparation

Micro catheter tubing materials tested typically include polyethylene, PVC, silicone, and advanced polymers such as medical-grade polyamide. Each polymer exhibits unique mechanical properties affecting catheter performance. For example, silicone is known for high flexibility and elongation, while polyethylene offers superior tensile strength (Merz, 2021) [1].

Sample preparation involves strict control of dimensions and surface treatment to avoid variability in tensile test results. Specimens are conditioned at physiological temperature ($\sim 37^{\circ}\text{C}$) to replicate in-vivo conditions. Uniform testing procedures following ASTM D638 ensure consistency (ASTM D638-14) [6].

Universal Tensile Testing Procedure

Testing employs a universal tensile testing machine (UTM) equipped with pneumatic grips to prevent specimen slippage during elongation (Instron 3400 Series recommended) [4]. Gradually increasing tensile loads are applied until specimen failure, while measuring elongation and force.

- **Maximum Tensile Strength:** The highest stress sustained before failure.
- **Elongation at Break:** Measure of ductility.
- **Young's Modulus:** Indicates stiffness.

Environmental factors such as temperature and humidity are controlled to avoid confounding influences on material behavior.

Results and Discussion

Material Performance Comparison

Results from tensile tests reveal significant variability among polymers:

- **Silicone** demonstrates high elongation at break, reflecting superior flexibility, advantageous in navigating tortuous vascular routes.
- **Polyethylene** exhibits higher tensile strength, making it suitable for applications demanding load-bearing capacity.
- **PVC** and **Medical-grade polyamide** provide intermediate performance, balancing strength and flexibility.

Stress-strain curves illustrate these differences clearly, with materials displaying distinct yield points and failure modes [5].

Clinical Implications of Mechanical Properties

The mechanical properties directly impact micro catheter performance in clinical use. Flexibility facilitates navigation and reduces vessel trauma, while tensile strength ensures catheter integrity under mechanical stresses during deployment (Sandell, 2023) [3]. Hydrophilic coatings and

radiopaque markers further enhance catheter maneuverability and imaging visibility, respectively, enabling precision interventions.

Applications of Micro Catheters

- **Neurointervention:** Deliver coils or stents to treat cerebral aneurysms and embolize arteriovenous malformations (Merz, 2021) [1].
- **Cardiology:** Navigate narrowed coronary arteries for stent or balloon placement.
- **Oncology:** Targeted chemoembolization to minimize systemic drug exposure.
- **Peripheral Vascular and Urology:** Embolization and access to small vessels and urinary pathways.

The advantages of micro catheters include minimally invasive procedures, high precision, and reduced patient risk, promoting faster recovery (Sandell, 2023) [3].

Testing Instruments and Software

Leading universal testing machines used in this domain include ZwickRoell 8050 and Test Resources 220 Series, capable of applying forces up to 10 kN, suitable for catheter tubing testing [2]. Common software platforms for data acquisition and analysis include ZwickRoell TestXpert II, Instron Bluehill, and MTS Test Suite, enabling comprehensive evaluation compliant with international standards.

Challenges and Future Perspectives

- **Technical Skill:** High operator expertise required for device navigation.
- **Device Compatibility:** Need for integrated compatibility with guide wires and embolic agents.
- **Cost:** High production costs limit accessibility.

Future research should explore bioresorbable polymers and conduct in-vivo evaluations post tensile testing to simulate real-world clinical scenarios (Li et al., 2008) [2].

Conclusion

Universal tensile testing of micro catheter tubing is indispensable for ensuring the mechanical integrity and safety of these critical medical devices. Understanding material-specific tensile properties guides manufacturers in optimizing catheter design to enhance durability and patient safety, aligning with ISO 10555-1 and ASTM standards.

The study reaffirms that material selection is paramount—silicone's flexibility complements polyethylene's strength for diverse clinical needs. Continued innovation and rigorous testing protocols will advance catheter technology, supporting minimally invasive interventions with improved outcomes.

References

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