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Effect of Film Thickness on Mechanical Properties of Polyurethane Based Polymeric Films Fabricated by Doctor Blade Casting

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ABSTRACT

Polyurethane-based polymeric films are widely used in biomedical and medical device applications due to their excellent flexibility, biocompatibility, and mechanical strength. In this study, polymeric films were fabricated using an automatic film casting technique employing the doctor blade method. Films with three different thicknesses (130, 150, and 180 μm) were prepared and evaluated to investigate the influence of thickness on mechanical performance. Mechanical characterization was performed using tensile strength, tear resistance, and suture pull-out tests. The results demonstrated that film thickness significantly influenced the mechanical properties of the polymeric films. The 180 μm films exhibited superior tensile strength and tear resistance compared to thinner films, while the 130 μm films showed comparatively lower mechanical stability. Suture pull-out testing further confirmed improved retention strength with increasing film thickness. These findings suggest that optimized film thickness plays a critical role in improving the mechanical performance of polyurethane films for biomedical applications.

KEYWORDS: Polymeric films; Doctor blade casting; Film thickness; Mechanical properties; Tensile strength; Tear resistance; Suture retention strength

INTRODUCTION

Polyurethane (PU) is a versatile class of polymer widely utilized in biomedical applications due to its excellent mechanical properties, flexibility, and biocompatibility. Polyurethane-based films have found extensive applications in wound dressings, medical membranes, and cardiovascular implantable devices owing to their ability to withstand physiological stresses while maintaining structural integrity. [1-3]

The medical applications of polymeric films are highly dependent on their mechanical properties. Mechanical characteristics include the tensile strength, tear resistance, and suture retention strength which directly affect the durability, reliability of mechanical loading conditions and functional performance. The tensile strength of a polymeric film is an important property determined by its ability to stretch and deform without rupturing, and thus has fundamental importance in applications where the material may be subjected to significant mechanical stress. Additionally, Tear resistance is also an essential property for films used in medical applications, as it allows the film to resist puncturing and tearing during handling or use—both of which are critical to maintaining sterility and integrity. In addition, the suture retention strength is of interest particularly in surgical applications due to its direct influence on surgical success and patient outcome by enabling or preventing proper support for sutures. Hence, characterization and tuning of these mechanical properties are crucial for the design of polymeric films that meet the rigorous demands of medical applications, ensuring that they provide the necessary support and protection in critical healthcare scenarios. [4-6]

Among the multiple methods available for fabricating uniform polymeric films, the doctor blade casting method is mainly distinguished with respect to controllable thickness. This methodology is simple, which means it can easily be implemented on-site. Also, the reproducibility of results represents a great advantage (a low batch-to-batch variability) since similar films can easily be obtained with similar properties from different batches. This is important for applications where consistency matters. Moreover, the scalability of the doctor blade casting technique makes it an ideal choice for both laboratory-scale and industrial-scale production. This enables researchers to initially develop and optimize films at the laboratory scale before scaling up to larger production volumes without significant modifications to the fabrication process. Overall, the doctor blade casting technique is a versatile and efficient method widely used in the polymer film industry for the production of high-quality films intended for medical applications. [6-9]

The study was conducted using polyurethane-based polymeric films with thicknesses ranging from 130 to 200 μm to identify the most suitable thickness by considering both mechanical performance and ease of cutting after completion of the procedure. Based on the observed balance between mechanical and tensile strength, tear resistance, and ease of cutting, a thickness of approximately 180 μm appeared to be the most optimum.

Therefore, the primary aim and objective of the current research study was to fabricate polyurethane-based polymeric films with varying thicknesses of 130, 150, 180 and 200 μm using an automated doctor-blade casting method and to systematically evaluate their mechanical properties, including tensile

strength, tear resistance, and suture pull-out strength. The study further aimed to identify the film thickness that provides an optimum balance between mechanical integrity and ease of cutting following the procedure.

LITERATURE REVIEW

Polymeric films have gained significant attention in biomedical applications due to their tunable mechanical properties and suitability for implantable and wound-healing systems. Recent developments emphasize solvent-based and casting techniques for fabricating uniform thin films suitable for medical use. Poly-Med Inc. (2020) reported the development of polymer films fabricated via solvent processing, highlighting their application as degradable barrier layers in implantable medical devices [1].

Among polymer systems, polyurethane (PU) has emerged as a highly versatile material due to its excellent elasticity, biocompatibility, and mechanical stability. Qiu et al. (2025) provided a comprehensive review of functional polyurethane elastomers, emphasizing their structural tunability and expanding biomedical applications [2]. Similarly, Joseph et al. (2018) and Chlup et al. (2021) reported that polyurethane-based materials demonstrate favorable mechanical performance and coating stability, making them suitable for biomedical devices and tissue-contacting applications [4,6]. Further, Ma et al. (2024) investigated the fracture behavior and molecular mechanisms of polyurethane, providing insight into structure–property relationships essential for designing high-performance biomedical films [10].

In addition to material development, fabrication techniques such as solvent casting and doctor blade coating play a critical role in achieving uniform film morphology and controlled thickness. Borbolla-Jiménez et al. (2023) demonstrated the fabrication of wound-healing films using solvent casting, showing improved structural uniformity and biological performance [3]. Chede et al. (2018) compared casting methods and highlighted the influence of doctor blade techniques on membrane performance and structural consistency [7]. Furthermore, La Chance et al. (2022) demonstrated the effectiveness of doctor-blade-assisted casting in producing uniform composite coatings, reinforcing its applicability in precision biomedical film fabrication [11].

Advancements in coating and dispensing systems have further improved the scalability and uniformity of film production. Son et al. (2015) developed a doctor blade-type dispenser for roll-to-roll coating processes, enabling controlled resin deposition and improved film homogeneity [8].

Beyond fabrication, the functional properties of polymer films, including mechanical strength and elastic behavior, are critical for biomedical performance. Yan et al. (2024) investigated the thickness- and temperature-dependent elastic modulus of polymer films, demonstrating how processing conditions influence mechanical response at micro and nanoscale levels [9].

Emerging research has also explored advanced processing techniques such as 3D printing and centrifugal casting for biomedical polymer systems. Griffin et al. (2020) reviewed polyurethane-based 3D printing technologies for biomedical applications, highlighting their adaptability in tissue engineering [5]. Hwang et al. (2022) reported the fabrication of transparent biocomposite films using nanocellulose and nanochitin via centrifugal casting, demonstrating improved optical and mechanical properties [12].

Collectively, these studies highlight that polymer film performance is strongly influenced by material selection, fabrication technique, and processing conditions. Among various methods, solvent casting and doctor blade techniques remain widely used due to their simplicity, scalability, and ability to produce uniform biomedical-grade films suitable for advanced applications.

DEVICE DESCRIPTION



Figure 1: Optical image of the doctor blade-casted polyurethane film showing a smooth and uniform surface

Figure 1 presents the optical image of the polyurethane film fabricated using the doctor blade casting technique. Visual inspection revealed a continuous, smooth, and homogeneous film surface without observable cracks, pinholes, or phase separation. The uniform appearance of the film indicates effective solvent evaporation and homogeneous polymer distribution during film formation. Film thickness uniformity was ensured by maintaining a constant blade gap, controlled coating speed, and identical drying conditions throughout the fabrication process.

Materials and Preparation of Polyurethane Polymer Solution

- **Polymer selection:** Polyurethane was selected as the primary film-forming polymer, providing the desired mechanical strength and structural integrity to the final polymeric film.
- **Base polymer:** Medical-grade thermoplastic polyurethane (TPU) pellets, specifically polyether-based TPU suitable for biomedical applications, such as Carbothane AC and Carbothane PC series, were selected.
- **Solvent selection:** Commonly used TPU solvents, including tetrahydrofuran (THF), dimethylacetamide (DMAc), and methylene chloride (MC), were considered for preparation of the polymeric solution.
- **Selected solvent:** Anhydrous tetrahydrofuran (THF) was selected because of its relatively low boiling point (66 °C), which facilitates rapid solvent evaporation during film formation.
- **Moisture control:** Prior to dissolution, the TPU pellets were dehumidified to remove residual moisture, and anhydrous THF was used to minimize moisture-related effects during solution preparation and film casting.
- **Material purity:** All materials were used as received without additional purification to preserve their inherent properties and simplify the formulation process.
- **Safety precautions:** Since THF is highly flammable, all solution-preparation steps were performed inside a laminar airflow cabinet to facilitate safe handling and effective removal of solvent vapours.
- **Polymer concentration:** A 17% (w/v) polymeric solution was prepared by dissolving the medical-grade TPU pellets in anhydrous THF.
- **Dissolution procedure:** The required quantity of TPU pellets was gradually added to THF under continuous stirring to promote complete dissolution and obtain a homogeneous polymeric solution.
- **Film casting:** The resulting homogeneous TPU solution was subsequently used for polymeric film casting.
- **Overall approach:** The formulation employed commercially available medical-grade materials and a controlled solution-preparation process to obtain a homogeneous polyurethane solution suitable for fabrication of biomedical polymeric films.

Preparation of Polymeric Films

Polymeric films were prepared using an automatic film applicator based on the doctor blade casting technique. A measured volume of the polymeric (TPU) solution was poured in front of the micrometer-adjustable film applicator (Make: STECH) at one end of the glass substrate. The blade was then drawn across the substrate at a controlled speed, spreading the solution into a thin film of uniform thickness defined by the blade gap. As shown in Table 1, the wet film thickness was adjusted to obtain dry film thicknesses of 130, 150, and 180 μm . In our example, we need to achieve three dry film thicknesses, for that we have fixed wet film thickness as mentioned in below table:

Table 1: Wet Film Thickness and Corresponding Dry Film Thickness of Polyurethane Films

Polymeric Film	Wet Film Thickness (mm)	Dry Film Thickness (μm)
Film 1	1.70 ± 0.01	180 ± 10
Film 2	1.50 ± 0.01	150 ± 10
Film 3	1.35 ± 0.01	130 ± 10

After coating, the wet film on the substrate was allowed to dry in a vacuum oven. The coated plates were initially maintained under vacuum at ambient temperature for 2 h to facilitate controlled solvent evaporation. Subsequently, the temperature was increased to 50 °C and maintained for an additional 1–2 h until complete drying was achieved. After drying, the polymeric films were carefully peeled from the glass substrate and visually inspected for uniformity and surface defects.

Prior to mechanical testing, all three film specimens were conditioned according to ASTM D882 requirements at 23 ± 2 °C and $50 \pm 5\%$ relative humidity (RH) for a minimum of 40 h. Tensile, tear resistance, and suture retention tests were subsequently performed under the same environmental conditions to minimize the influence of temperature and humidity on the mechanical properties of the polyurethane films and to ensure reproducibility of the experimental results.

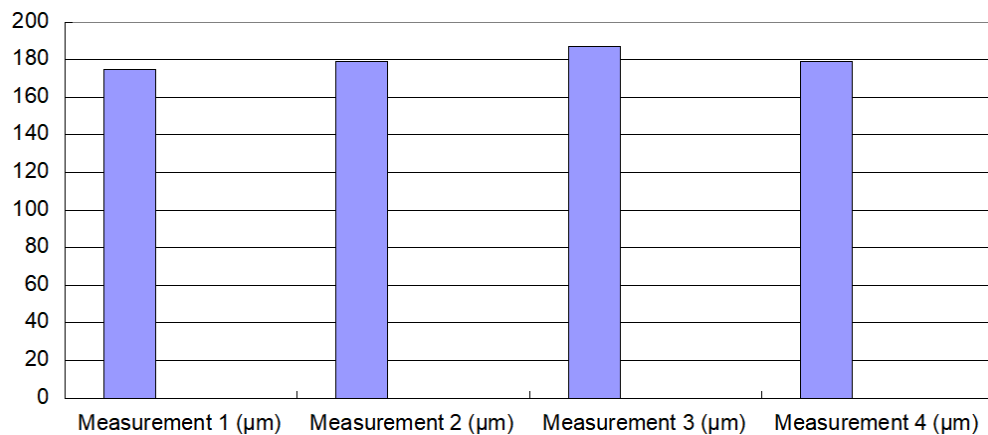
Table 2: Dry Film Thickness Measurements Using Thickness Gauge

Film Sample	Measurement 1 (μm)	Measurement 2 (μm)	Measurement 3 (μm)	Measurement 4 (μm)	Mean Thickness (μm)
Film 1	175	179	187	179	180.0 ± 5.0
Film 2	145	150	150	154	149.8 ± 3.9
Film 3	128	128	133	128	129.3 ± 2.5

The dry film thickness of each polyurethane film was measured using a calibrated thickness gauge. To ensure measurement accuracy and account for local thickness variations, three readings were taken at different locations on each film sample. The average value of the three measurements was reported as the final film thickness, while the standard deviation was calculated to evaluate thickness uniformity.

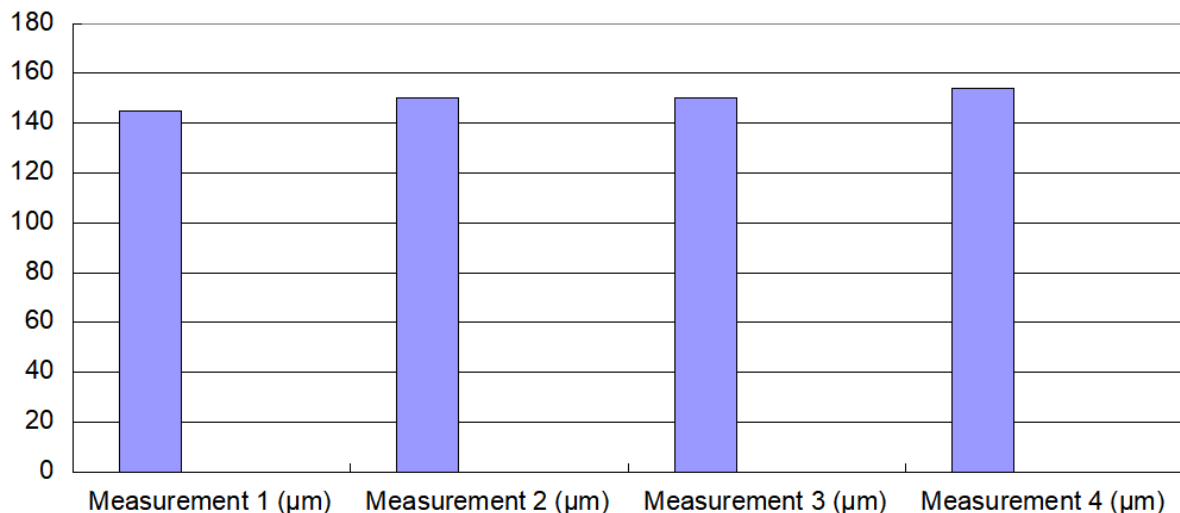
As shown in Table 2, Film 1 exhibited an average dry thickness of $180.0 \pm 5.0 \mu\text{m}$. The low standard deviation indicates good thickness consistency across the film surface. Similar measurements were performed for all film samples to ensure reliable comparison of mechanical properties with film thickness.

Film 1 Thickness Measurement

**Figure 2: Thickness measurements of Film 1 at four different locations**

As shown in above Figure 2, Film 1 exhibited a relatively uniform thickness across the four measurement locations. The recorded thickness values were approximately 175 μm , 179 μm , 187 μm , and 179 μm indicating only minor variation. This uniformity suggests that the solvent casting process provided consistent film formation with good thickness distribution. Uniform thickness is essential for maintaining consistent mechanical properties and ensuring reliable performance during subsequent tensile, tear, and suture retention testing.

Film 2 Thickness Measurement

**Figure 3: Thickness measurements of Film 2 at four different locations**

As shown in figure 3, Film 2 showed thickness values of approximately 145 μm , 150 μm , 150 μm , and 153 μm . The small difference between the three measurements indicates good thickness uniformity throughout the film. Such consistency is desirable because it minimizes experimental variability and improves the accuracy of mechanical characterization.

Film 3 Thickness Measurement

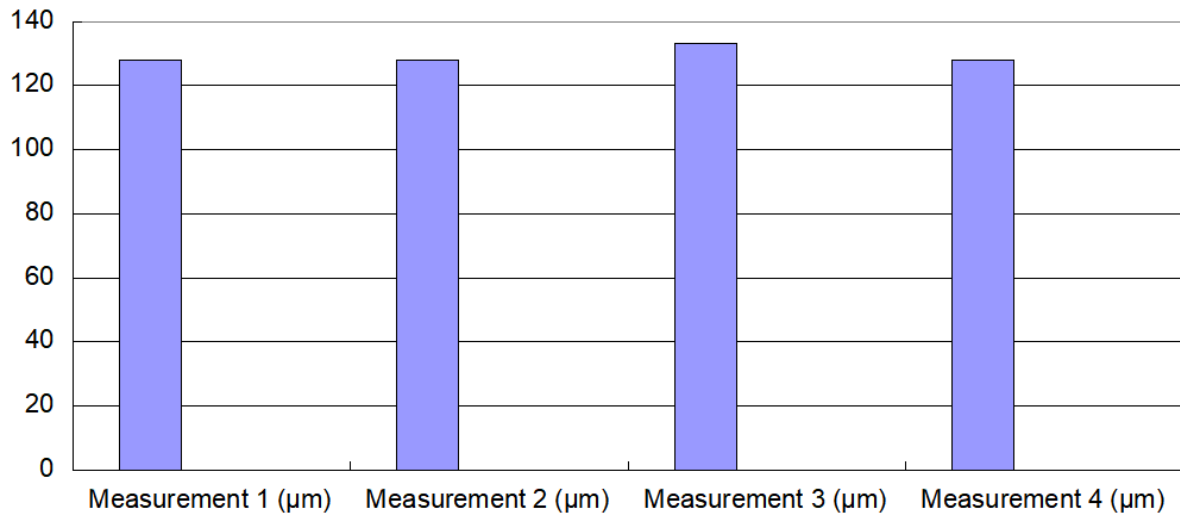


Figure 4: Thickness measurements of Film 3 at four different locations

As shown in figure 4 Film 3 exhibited thickness values of approximately 128 μm , 128 μm , 133 μm , and 135 μm . The measurements demonstrate a uniform thickness profile with only slight deviations. The consistent thickness confirms the reproducibility of the fabrication process and provides a reliable basis for comparing the mechanical performance of films with different thicknesses.

Film Characterization Methods

Thickness Measurement:

Thickness measurements were taken with a digital thickness gauge (Make: Mitutoyo) at various locations across each film (e.g. center and four corners of a 11×11 cm sample) to quantify uniformity. The average thickness was recorded for films from each method.

Tensile Mechanical Tests:

Tensile properties of the polymeric films were evaluated using a uniaxial tensile test (as per ASTM D882 for thin films). Strips of film (e.g. 5 mm wide, gauge length 20 mm) were clamped in a mechanical tester and pulled at a constant rate (e.g. 500 mm/min) until failure. From stress–strain data, the ultimate tensile strength, elongation at break, and Young’s modulus were obtained. At least 3 specimens from each film were tested to ensure reproducibility.

Suture Retention Tests:

The suture retention strength was evaluated in accordance with ISO 7198:2017 using a straight-pull test method. Rectangular test samples were prepared from the test material. A polypropylene (Prolene) suture was inserted from the test sample and passed through the material. The free ends of the suture were tied to form a loop, which was secured in the upper grip of a universal testing machine, while the test sample was clamped in the lower grip. Tensile force was applied at a crosshead speed of 50 mm/min until failure occurred by suture pull-out or material tearing. The maximum force (N) recorded at the point of failure was reported as the suture retention strength.

Tear Strength Test:

The tear strength of the polymeric films was evaluated in accordance with ASTM D1004-13 using the Graves tear method. Test specimens were prepared in a standardized Graves tear geometry, incorporating a precut slit to initiate tearing. The samples were mounted in the grips of a universal testing machine, ensuring proper alignment to avoid any lateral stresses. A tensile load was applied at a constant crosshead speed of 50 mm/min until the specimen failed by tear propagation from the precut slit. The maximum force (N) required to propagate the tear was recorded and reported as the tear strength of the material. All experiments were performed in triplicate ($n = 3$), and the results are presented as mean $\pm$ standard deviation (SD). All experimental data collected were analyzed comparatively between the three different thicknesses of the cast films. The following sections present the results and discussion of these comparisons.

RESULTS AND DISCUSSION

Effect of Thickness on Tensile Strength

The tensile test results show maximum force values of 32 N for DFT 0.13 mm, 67.06 N for DFT 0.15 mm, and 79.29 ± 2.15 N ($n = 3$) for DFT 0.18 mm polyurethane films fabricated via doctor blade casting. Thicker films exhibited progressively higher maximum force. The force at break increased markedly ($\sim 109.6\%$) with thickness increase from 0.13 mm to 0.15 mm, while a moderate increase ($\sim 18.2\%$) was observed from 0.15 mm to 0.18 mm. Overall, a substantial enhancement ($\sim 147.8\%$) was observed from 0.13 mm to 0.18 mm, indicating a non-linear relationship between film thickness and mechanical strength. As shown in Figure 5 these values indicate enhanced load-bearing capacity in thicker samples under uniaxial tension.

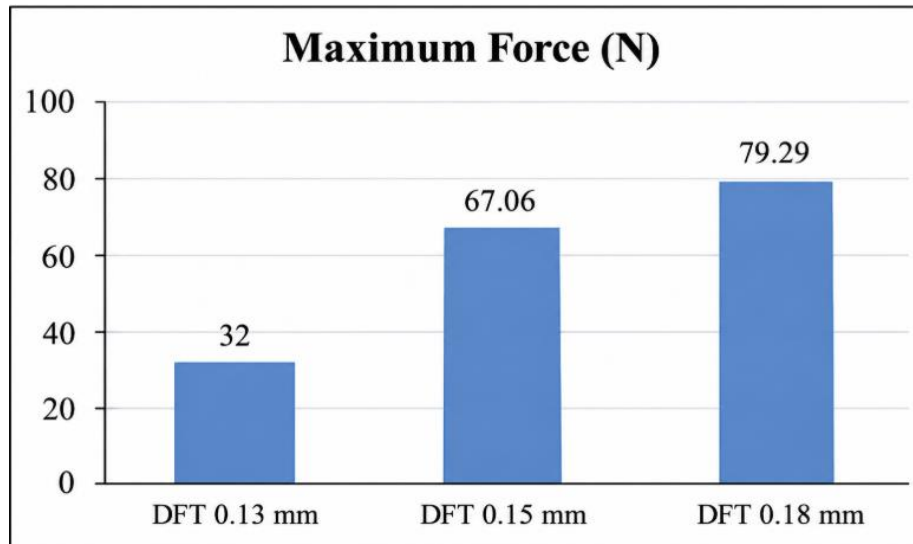


Figure 5: Tensile strength of polymeric films with varying thicknesses. (Data

Are presented as mean $\pm$ SD ($n = 3$))

The tensile stress of the PCU films increased with increasing film thickness, following a trend similar to the maximum force values. The tensile stress increased significantly from 0.42 ± 0.03 MPa for the 0.13 mm film to 0.88 ± 0.05 MPa (Megapascal) for the 0.15 mm film and further to 1.04 ± 0.04 MPa for the 0.18 mm film ($n = 3$). This corresponds to an increase of $\sim 109.5\%$ from 0.13 mm to 0.15 mm, followed by a moderate increase of $\sim 18.2\%$ from 0.15 mm to 0.18 mm, with an overall enhancement of $\sim 147.6\%$ from 0.13 mm to 0.18 mm. As shown in figure 6, the similarity in percentage increase between tensile stress and maximum force indicates a consistent scaling of mechanical strength with film thickness, suggesting uniform material behavior and effective load distribution across the cross-section.

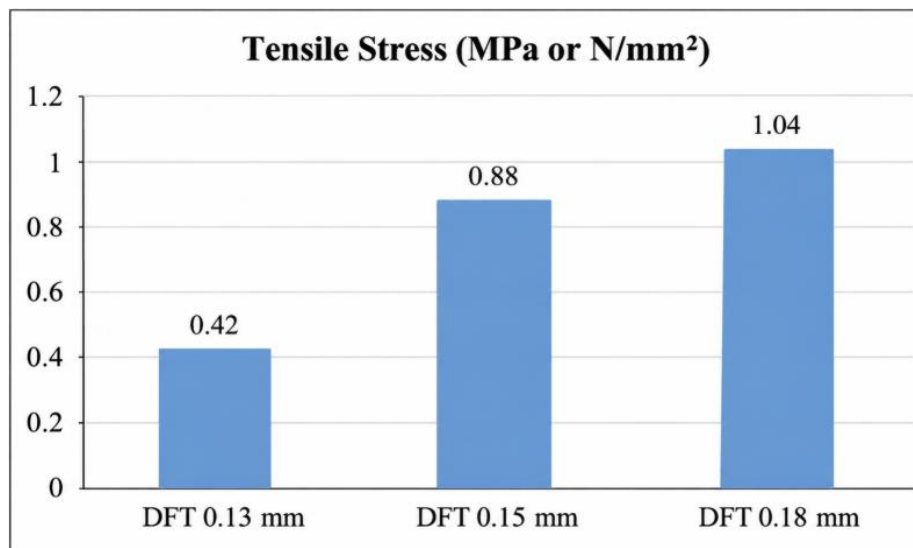


Figure 6: Influence of film thickness on tensile stress of doctor blade-casted polyurethane films

For a tensile test, the ultimate tensile strength (UTS) is calculated using:

$$\text{Tensile Strength (MPa)} = \text{Maximum Force (N)} / \text{Original Cross-sectional Area (mm}^2\text{)}$$

The tensile mechanical parameters, including film thickness, sample width, cross-sectional area, maximum force, and calculated tensile stress, are summarized in Table 3.

Table 3: Tensile mechanical parameters of polyurethane films with different thicknesses

Film Sample	Film Thickness (μm)	Sample Width (mm)	Cross-Sectional Area (mm^2)	Maximum Force (N)	Tensile Stress (MPa)
Film 1	130	5.0	0.65	32.00	0.42
Film 2	150	5.0	0.75	67.06	0.88
Film 3	180	5.0	0.90	79.29	1.04

The results demonstrate a progressive increase in tensile strength with increasing film thickness. The larger cross-sectional area of thicker films contributed to their improved load-bearing capacity and tensile performance.

The polyurethane film exhibited excellent flexibility and elastomeric behavior. The elongation at break (strain at failure) was found to be $581.49 \pm 56.04\%$, indicating the ability of the films to undergo substantial deformation before rupture. The high elongation value confirms the elastic nature of the polyurethane matrix and its capability to absorb mechanical stresses while maintaining structural integrity. In addition to enhancing tensile strength, increasing film thickness improved the overall mechanical stability and load-bearing capacity of the films while retaining adequate flexibility. These characteristics are highly desirable for biomedical applications where both strength and elasticity are essential.

Tear Resistance

The tear resistance of polymeric films increased with film thickness, as indicated by the maximum force values. The tear force increased from 12.9 N for the 0.13 mm film to 15.05 N for the 0.15 mm film and further to 16.51 N for the 0.18 mm film. This corresponds to an increase of $\sim 16.7\%$ from 0.13 mm to 0.15 mm and $\sim 9.7\%$ from 0.15 mm to 0.18 mm, with an overall enhancement of $\sim 28.0\%$ from 0.13 mm to 0.18 mm. As shown in figure 7 the gradual increase in tear force suggests improved resistance to crack propagation with increasing film thickness.

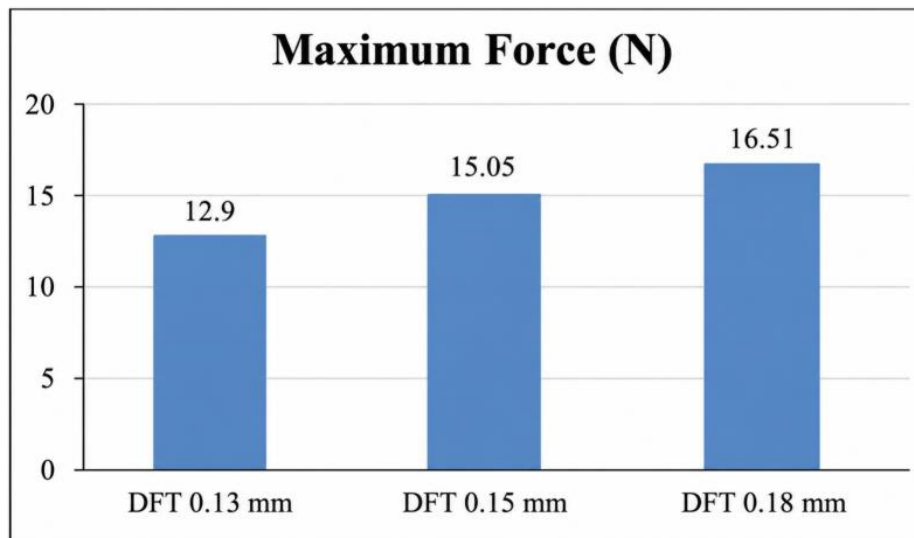


Figure 7: Tear resistance of polymeric films with varying thicknesses. Data

Are presented as mean $\pm$ SD (n = 3)

Suture Pull-Out Strength

The suture retention strength of the polymeric films increased with increasing film thickness, as indicated by the maximum pull-out force values. The force required to pull the suture increased from 6.03 N for the 0.13 mm film to 7.31 N for the 0.15 mm film and further to 9.31 N for the 0.18 mm film. This corresponds to an increase of $\sim 21.2\%$ from 0.13 mm to 0.15 mm and $\sim 27.4\%$ from 0.15 mm to 0.18 mm, with an overall enhancement of $\sim 54.4\%$ from 0.13 mm to 0.18 mm. As shown in figure 8 the increasing pull-out force indicates improved suture holding capacity with increasing film thickness, which is critical for surgical handling and fixation.

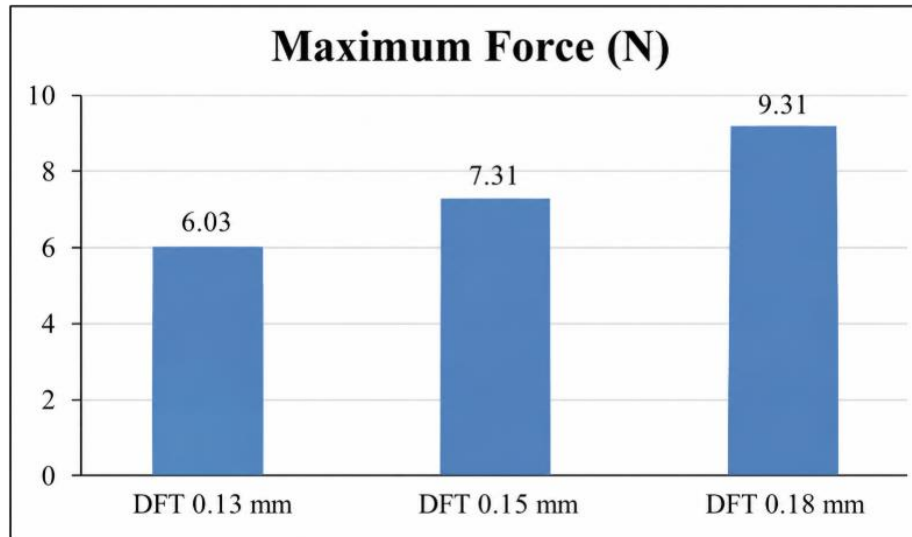


Figure 8: Suture pull-out strength of polymeric films with varying thicknesses. Data are presented as mean $\pm$ SD (n = 3)

Tensile tests on polymeric films produced by doctor blade casting show a clear correlation between film thickness and mechanical properties. Increases in maximum force, tensile stress, tear resistance, and suture pull-out strength with greater thickness demonstrate a non-linear relationship between thickness and mechanical strength.

MECHANISM DISCUSSION

The improvement in mechanical properties with increasing film thickness can be attributed to several processing- and structure-related factors. During solvent evaporation, thicker films contain a larger polymer volume, which promotes improved polymer chain packing and stronger intermolecular interactions within the polyurethane matrix. The relatively slower solvent removal from thicker films facilitates better molecular organization and reduces the likelihood of micro void formation. Furthermore, thicker films provide a larger cross-sectional area for stress distribution, resulting in improved tensile strength, tear resistance, and suture retention strength. Residual stresses generated during film drying are also expected to be lower relative to the overall film thickness, contributing to enhanced structural stability. Consequently, the 180 μ m films exhibited superior mechanical performance compared with the 130 μ m and 150 μ m films. These findings indicate that film thickness plays a critical role in determining the microstructure and mechanical behavior of doctor blade-casted polyurethane films.

CONCLUSION

The present study demonstrated that increasing polymeric film thickness improved tensile strength, tear resistance, and suture retention properties. Among the investigated samples, the 180 μ m films exhibited superior mechanical performance compared to the 130 μ m and 150 μ m films, indicating enhanced structural integrity and load-bearing capacity. The findings suggest that film thickness is a critical parameter in optimizing the mechanical durability and reliability of polyurethane films for biomedical applications. Further studies investigating the influence of environmental conditions, long-term stability, and alternative fabrication techniques may provide additional insight into the real-world performance of these materials. The optical observations further confirmed the formation of smooth and uniform films through the doctor blade casting process.

COI (Conflict of Interest):

All the authors are an employee of Meril Medical Innovations Private Limited, Vapi, Gujarat – India and have no conflict of interest related to this study.

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