Morphological and Mechanical Evaluation of Electro spun PCL/Aloe Vera Scaffolds for Wound Dressing Applications

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***Abstract*—Skin injuries frequently lead to complications such as infection, dehydration, and delayed tissue regeneration, making the development of effective wound dressings a constant challenge in biomedical research. Modern approaches aim to develop materials that actively contribute to the healing process rather than simply covering the wound. Electrospinning has emerged as a widely adopted technique for this purpose because it enables the production of fibrous scaffolds with high surface area and porosity; these structural properties are known to support cell attachment, migration, and tissue repair.**

Poly(ε-caprolactone) (PCL) is one of the most frequently used polymers in electrospun scaffolds due to its biocompatibility, biodegradability, and mechanical strength, which not only support tissue regeneration but also reduce long-term foreign body response. Moreover, it aims to offer a bio-based biodegradable solution compared to traditional disposable synthetic wound dressings. However, PCL's inherent hydrophobicity may limit cell–material interactions, which may require further modification to enhance biological performance in tissue-contact environments. To address this limitation, various strategies have been developed, including the incorporation of plant-based bioadditives. Aloe vera, in particular, has been used in wound healing formulations for its antimicrobial, anti-inflammatory, and moisture-retaining properties. Previous studies, along with our preliminary findings, indicate that Aloe vera can positively influence biological responses when integrated into polymeric systems. However, for wound dressings intended for practical use, biological benefits need to be accompanied by suitable morphological and mechanical properties, especially in the context of medical textiles where structural stability, flexibility, and durability are essential.

This study focuses on the fabrication of electrospun PCL mats containing different concentrations (2, 4, and 6%) of Aloe vera, aiming to determine how this bioadditive affects fiber morphology and mechanical behavior. The mats will be characterized using relevant techniques to evaluate changes in fiber diameter and tensile properties. By comparing the outcomes across different formulations, the study seeks to determine an optimal composition that balances mechanical integrity with the potential advantages offered by Aloe vera incorporation. The results are expected to provide valuable insights into the development of wound dressings that are not only functionally and structurally effective but also aligned with principles of biocompatibility and sustainability.

***Keywords*— Biomaterials, PCL, Aloe vera, Wound Dressing, Electrospinning.**

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I. Introduction

The performance of wound dressings depends not only on their ability to cover and protect the wound but also on their morphological and mechanical characteristics, which strongly influence stability, usability, and overall effectiveness. Parameters such as fiber diameter and surface topography regulate permeability and moisture balance, while tensile strength, elasticity, and flexibility ensure the material can resist external stresses and maintain integrity during handling [1-3]. Conventional dressings often provide only partial protection in this respect, which has motivated the development of fibrous structures with improved structural and functional properties [4]. Electrospinning has become one of the most preferred fabrication techniques for such systems. It enables the production of nanofibrous mats with controlled fiber morphology, high surface area, and interconnected porosity, which together enhance both mechanical performance and biological interactions [5]. Poly(ε-caprolactone) (PCL) is widely employed in wound dressing research due to its slow degradation rate, flexibility, and favorable mechanical properties [6]. In the literature, PCL has frequently been modified through blends and composites with natural or synthetic polymers such as chitosan, hyaluronic acid, or PVA, as well as natural extracts, underlining its versatility and broad applicability in electrospun wound dressing systems [7-9]. In recent years, natural additives have been increasingly incorporated into electrospun structures to enhance their performance, with aloe vera being a particular focus of interest. Aloe vera (AV) has been reported to promote more homogeneous, bead-free fiber morphologies and increased surface wettability in electrospun systems, while also offering antimicrobial, anti-inflammatory, and pro-regenerative effects that are highly relevant for wound healing [10]. When combined with PCL, the two materials complement each other: while PCL provides long-term structural stability and mechanical strength, aloe vera enhances surface hydrophilicity and biological activity. This combination can improve the potential of PCL–aloe vera nanofibrous systems to serve as effective wound-healing surfaces, providing both robust mechanical support and an improved wound environment [11-13].

In this study, the effect of aloe vera incorporation on the morphological and mechanical properties of electrospun PCL-based mats is examined. Morphological analysis focused on fiber diameter measurements, while tensile strength and elongation tests were conducted to evaluate mechanical

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performance. As aloe vera is a naturally derived, bio-based material, its integration into PCL scaffolds also represents a step toward developing wound dressing solutions that combine reliable structural stability with the use of bio-based resources, offering a promising design direction for future applications.

II. MATERIALS AND METHODS

A. Materials

The reinforcement phase consisted of waste cotton denim fabrics with a twill weave (132.7 g·m^{-2}) and waste polyester single jersey knitted fabrics (250 g·m^{-2}), whereas the matrix phase was obtained from PP yogurt containers (Figure 1).

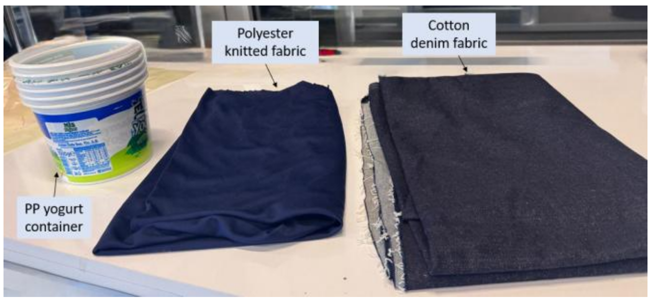

Fig. 1. Reinforcement and matrix materials used in the study.

B. Methods

Surface Fabrication

Preparation of Electrospinning Solutions

The electrospinning solutions were prepared by dissolving PCL at a fixed concentration of 8% (w/v) in a ternary solvent mixture consisting of chloroform, ethanol, and acetic acid in a weight ratio of 8:1:1. AV powder was incorporated into the polymer solution at concentrations of 2%, 4%, and 6% (w/w, relative to the weight of PCL) to investigate its influence on fiber morphology and biological performance.

The solutions were magnetically stirred at room temperature for a minimum of 4 hours to ensure complete dissolution and homogeneity. No visible phase separation or sedimentation was observed before the electrospinning process. The compositions and corresponding sample codes are listed in Table I.


Fig. 2. PP plates and fabrics used for composite laminates.

TABLE I: The sample codes of the fibrous webs

Sample Code	Polymer Concentration (%)	Aloe Vera Concentration (%)
PCL8	8	0
PCL8_AV2	8	2
PCL8_AV4	8	4
PCL8_AV6	8	6

Electrospinning Procedure

Electrospinning was performed using a custom-designed vertical electrospinning system equipped with a closed chamber (NanoSpinner NE100+, Inovenso, Türkiye). The prepared polymer solutions were loaded into 10 mL plastic syringes fitted with a stainless-steel needle (inner diameter: 0.6 mm).

The operational parameters were set as follows:

- Flow rate: 1 ± 0.5 mL/h
- Applied voltage: 11 ± 1 kV
- Needle-to-collector distance: 20 cm

Fibrous mats were collected on a flat, grounded stainless steel collector. All electrospinning processes were conducted under controlled environmental conditions:

- Ambient temperature: 13 ± 3 °C
- Relative humidity: 74 ± 8%

After collection, the fibrous webs were stored at room temperature for 24 hours

Morphological Characterization

The surface morphology of the electrospun mats was characterized using a FEI Quanta FEG 250 scanning electron microscope (SEM). Before imaging, the samples were sputter-coated with a thin layer of gold–palladium (Au–Pd) using a Quorum SC7620 coater. SEM observations were conducted at a magnification of 500× to assess surface features, and fiber diameters and wall thicknesses were quantified using ImageJ software

Mechanical Tests

The tensile properties of the planar fibrous surfaces were evaluated using a Zwick-Roell Z005 universal testing machine equipped with a 200 N load cell. Test specimens were prepared by cutting them into rectangular pieces with dimensions of 10 mm × 30 mm (width × length). Pneumatic grips were used to secure the samples without introducing stress concentrations, and the gauge length (the distance between the grips) was maintained at 5 mm. The crosshead speed was set to 10 mm/min, corresponding to the expected strain rate of the material and providing a realistic deformation condition.

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III. Results & Discussion

A. Morphological Characterization

All SEM images and fiber diameter measurements are presented in Figure I. The PCL8 sample displays continuous, bead-free fibers; however, slight irregularities in diameter can be observed along certain regions. With the incorporation of aloe vera, an apparent reduction in fiber diameter is observed, though at higher concentrations this decrease is accompanied by the appearance of slight bead formations. Overall, many samples exhibit the coexistence of both thin and thick fibers within the same structure, indicating a heterogeneous diameter distribution. Similarly, Rong et al. (2020) reported that hybrid nanofiber systems often exhibit bimodal diameter distributions, which result in morphological irregularities [14].

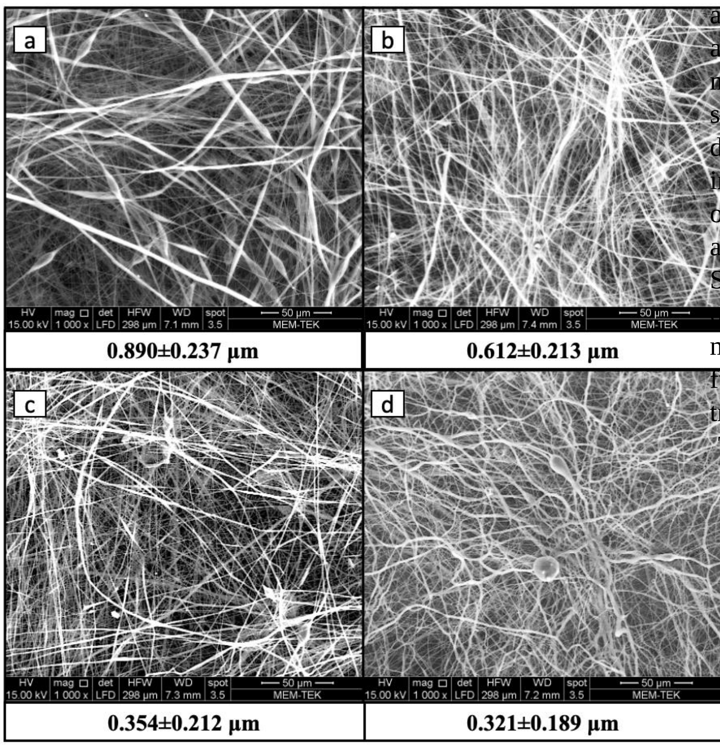

Fig I: The SEM images and fiber diameters of (a) PCL8, (b) PCL8_AV2, (c) PCL8_AV4, and (d) PCL8_AV6

The average fiber diameter of neat PCL is 0.890 ± 0.237 µm, which decreases to 0.612 ± 0.213 µm with the addition of 2% aloe vera. At a diameter of 4–6%, it is further reduced to approximately 0.3 µm. However, as the aloe vera ratio increases, the rate of reduction slows down, and localized bead formations become more apparent.

These findings are in agreement with previous studies. Dehghan et al. (2022) reported that increasing aloe vera content reduced fiber diameter while simultaneously promoting bead formation [15]. Similarly, Miguel et al. (2017) demonstrated that the addition of aloe vera to CS-PEO systems resulted in the production of finer fibers. The decrease in diameter is generally attributed to the reduction in viscosity of aloe vera-containing solutions used for nanofiber fabrication [16].

B. Mechanical Tests

The tensile test results were summarized in Table II. Neat PCL8 exhibited a tensile strength of 1.33 ± 0.12 MPa and an elongation of 294.24 ± 14.17%. With the incorporation of 2% aloe vera (PCL8_AV2), both properties improved markedly, as tensile strength increased to 1.81 ± 0.05 MPa (≈35% higher than neat PCL) and elongation rose to 374.79 ± 116.50%. This suggests that a low concentration of aloe vera has a positive influence on both the strength and ductility of the fibers.

At higher aloe vera concentrations, however, a decline in mechanical performance was observed compared to the optimum level. PCL8_AV4 showed a tensile strength of 1.54 ± 0.21 MPa and an elongation of 285.78 ± 14.54%, while PCL8_AV6 maintained a tensile strength of 1.48 ± 0.12 MPa and an elongation of 321.86 ± 8.52%. Although these values are lower than those of PCL8_AV2, they remain superior to neat PCL, suggesting that even at 4–6% incorporation, the scaffolds preserve adequate mechanical strength for wound dressing applications. These findings imply that aloe vera improves the mechanical behavior of PCL-based fibers up to an optimum concentration, beyond which reduced compatibility and local morphological irregularities may occur. Similarly, Shabannejad et al. (2020) emphasized that aloe vera at an optimum concentration had a beneficial effect on the mechanical performance of electrospun PCL/PVA scaffolds, further supporting the concentration-dependent reinforcing trend observed in our study [17].

TABLE II: Average tensile strength and elongation values of the samples

Samples	Avg. Tensile Strength (MPa)	Avg. Elongation (%)
PCL8	1.33 ± 0.12	294.24 ± 14.17
PCL8_AV2	1.81 ± 0.05	374.79 ± 116.50
PCL8_AV4	1.54 ± 0.21	285.78 ± 14.54
PCL8_AV6	1.48 ± 0.12	321.86 ± 8.52

Overall, these results indicate that the incorporation of aloe vera enhances the mechanical performance of PCL-based electrospun scaffolds in a concentration-dependent manner, with the most pronounced effect observed at lower concentrations.

IV. Conclusion

Electrospun PCL scaffolds incorporating aloe vera were fabricated and examined with respect to their morphology and mechanical performance. SEM analyses revealed that the incorporation of aloe vera led to a noticeable reduction in fiber diameter; however, at higher concentrations, this decrease was accompanied by the emergence of bead formations, indicating a concentration-dependent effect.

In terms of mechanical behavior, the addition of 2% aloe vera produced the most pronounced improvement, as both tensile strength and elongation increased compared to neat

PCL. When the aloe vera content was increased to 4–6%, the values showed a slight decline relative to the optimum level; nevertheless, they remained higher than those of neat PCL, indicating that the reinforcing influence of aloe vera can be maintained up to a particular concentration.

Taken together, these results suggest that aloe vera may serve as a functional additive in PCL-based electrospun scaffolds, contributing to both morphological and mechanical performance, particularly at lower concentrations

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