ELECTROSPINNING-BASED PCL FIBRE COATINGS ON METALLIC MESHES FOR BIOMIMETIC SURFACE ENGINEERING

Bartłomiej Boruchowski*[1], Roksana Kurpanik[1], Karol Gryń[1], Barbara Szaraniec[1]

[1] AGH University of Krakow,
Faculty of Materials Science and Ceramics,
Department of Biomaterials and Composites,
al. A. Mickiewicza 30, 30-059 Krakow, Poland
* e-mail: bborucho@agh.edu.pl

Abstract

Electrospinning represents a versatile technique for the fabrication of micro – and nanofibrous structures that mimic the architecture of biological tissues. In this study, electrospinning was employed as a surface engineering method to functionalize metallic mesh substrates intended for potential biomaterial surface engineering applications. Steel meshes with varying geometries and opening sizes were coated with polycaprolactone (PCL) fibres using three solution variants: pure PCL, PCL modified with Tween 80 surfactant, and a hybrid system combining both fibre types. The influence of surfactant incorporation on fibre morphology, wettability, and surface energy was investigated. Microscopic observations confirmed the formation of continuous fibrous coatings across all mesh geometries, despite local variations in fibre density arising from substrate conductivity and electrostatic deposition effects. The addition of Tween 80 enabled a controlled transition from hydrophobic to superhydrophilic surface behaviour, while the hybrid coating exhibited heterogeneous wettability characteristics. Mechanical testing demonstrated that the fibrous coatings preserved structural continuity under large deformations exceeding 100% elongation. The deformation behaviour was governed by fibre reorientation and network adaptation rather than coating failure, indicating favourable mechanical compatibility between the fibrous layer and the metallic substrate. These results demonstrate that electrospinning can be effectively applied to fabricate mechanically stable fibrous coatings with tunable surface properties on metallic mesh structures.

Keywords: *Electrospinning, Polycaprolactone (PCL), Metallic meshes, Fibrous coatings, Biomimetic surfaces*

Introduction

In regenerative medicine, spatial implants designed as three-dimensional scaffolds or two-dimensional meshes are widely used for tissue reconstruction and functional restoration [1,2]. Scaffolds fabricated from resorbable polymers and ceramics have demonstrated significant potential in bone, cartilage, and soft tissue engineering applications [3,4]. However, their clinical applicability is often limited to small defects and regions subjected to relatively low mechanical loads. In cases requiring higher mechanical stability, particularly for large tissue defects, metallic scaffolds provide a more reliable solution due to their superior strength, structural durability, and load-bearing capacity [5].

Despite their favourable mechanical performance, metallic biomaterials frequently exhibit limited bioactivity and suboptimal interactions with biological environments. To address these limitations, biomimetic design strategies have been developed, aiming to replicate structural and functional characteristics of natural tissues [2,4]. Such scaffolds are often characterized by hierarchical organization or porosity gradients that enable improved biological integration [5]. Further enhancement of these systems can be achieved through surface modification, particularly by introducing fibrous polymeric layers that mimic the architecture of the extracellular matrix (ECM).

Fibrous coatings play an important role in regulating material–tissue interactions. Nanofibrous networks may provide favourable conditions for cell attachment, proliferation, and tissue regeneration while simultaneously acting as protective barriers or functional interfaces controlling fluid transport [6,7]. Additionally, modification of physicochemical surface properties, including wettability and surface energy, allows tailoring of biomaterials to specific biomedical functions [1].

Among metallic biomaterials, both biostable and resorbable systems are currently employed in medical applications. Biostable materials include medical steels, titanium, and their alloys, whereas resorbable metals are primarily based on magnesium [8]. Metallic mesh-based devices are commonly used in clinical practice, including cardiovascular stents, urological stents, occlusion systems, and embolic protection devices [8–10]. In many such applications, metallic substrates are combined with polymeric components to enhance biological performance and functional adaptability.

Polymeric modifications of metallic implants can be introduced in various forms, including continuous films, woven structures, and nonwoven fibrous layers (FIG. 1).

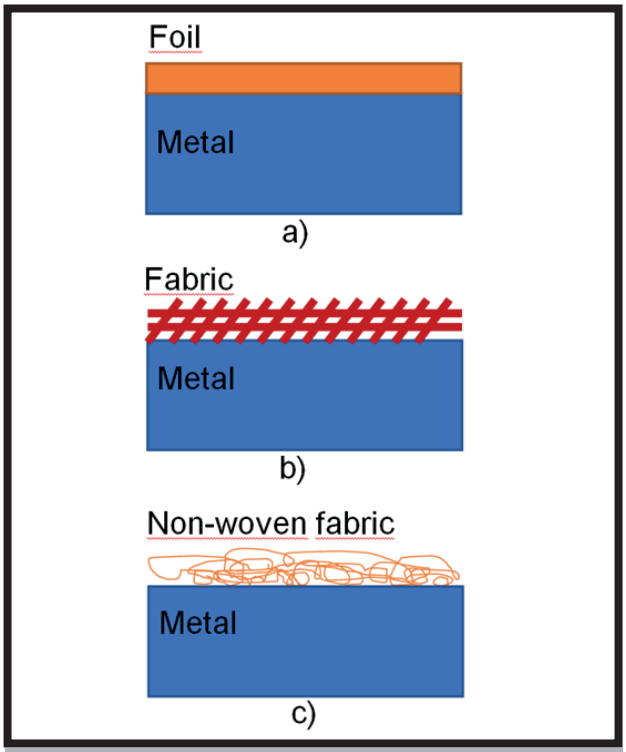

FIG. 1. Types of polymer layers applied on implants.

[Engineering of Biomaterials 174 (2026) 07]

doi:10.34821/eng.biomat.174.2026.07

Submitted: 2026-03-13, Accepted: 2026-04-21, Published: 2026-04-24

Copyright © 2026 by the authors. Some rights reserved.
Except otherwise noted, this work is licensed under
https://creativecommons.org/licenses/by/4.0

Among these approaches, nonwoven fibrous coatings offer distinct advantages. Due to their loose and deformable microstructure, fibrous networks can accommodate large deformations through fibre reorientation, straightening, and inter-fibre sliding [11,12]. Unlike continuous polymer films, which may undergo brittle failure, fibrous coatings demonstrate improved mechanical compliance and damage tolerance, making them particularly suitable for dynamically loaded biomedical systems.

Electrospinning has emerged as a versatile technique for the fabrication of micro – and nanofibrous structures with controlled morphology and surface characteristics [1,13]. The method enables precise modulation of fibre diameter, orientation, and physicochemical behaviour, which is essential for biomimetic material design. Polycaprolactone (PCL) is widely employed in electrospinning due to its biocompatibility, biodegradability, and favourable mechanical properties [6,11]. Importantly, the physicochemical properties of electrospun PCL fibres can be tailored through the incorporation of functional additives.

Surface wettability represents a critical parameter governing biological interactions at the biomaterial–tissue interface. Hydrophilic surfaces are generally associated with enhanced protein adsorption and improved cellular responses, whereas hydrophobic surfaces may provide barrier-type functionalities [1,6]. Surfactants such as Tween 80 are frequently applied to modify interfacial properties of polymer systems. Their amphiphilic molecular structure enables reduction of surface tension and controlled alteration of surface energy, leading to significant changes in wettability behaviour.

Although electrospinning of modified polymeric membranes has been extensively studied, the behaviour of surfactant-modified fibrous coatings directly deposited onto conductive metallic mesh substrates remains insufficiently explored. In particular, the interplay between electrostatic deposition mechanisms, fibre morphology, surface wettability, and mechanical performance requires further investigation.

Therefore, the present study examines the feasibility of using electrospinning as a coating technique for metallic meshes intended for potential biomedical applications. Steel meshes of varying geometries were functionalized using three fibrous systems: hydrophobic PCL fibres, hydrophilic PCL/Tween fibres, and hybrid coatings combining both fibre types, resulting in heterogeneous surface wettability. The study focuses on analysing fibre morphology, wettability modification, surface energy, and mechanical behaviour under large deformation conditions.

Materials and methods

Materials

The research material consisted of hybrid systems in which fibrous polymer coatings based on polycaprolactone (PCL, Mn = 80 kDa, Sigma-Aldrich) were deposited onto stainless steel mesh substrates with different geometries.

Three types of meshes were used as substrates for electrospinning:

- a woven stainless steel mesh with square openings (2 × 2 mm) manufactured from AISI 304 wire with a diameter of 0.40 mm (Lun Fix Sp. z o.o., Poland),
- a rolled cut-drawn stainless steel mesh with rhomboidal openings (7 × 3.5 mm) manufactured from a metal strip with a thickness of 0.4 mm,
- a cut-drawn stainless steel mesh with rhomboidal openings (14 × 7 mm) manufactured from a metal strip with a thickness of 0.7 mm.

All meshes were used in the as-received industrial condition and served as conductive collectors during the electrospinning process (FIG. 2).

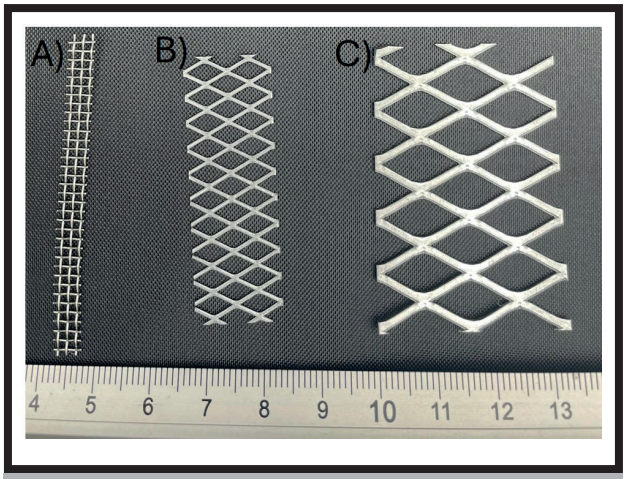

FIG. 2. Metal meshes constituting substrates for spun PCL fibers. A) woven mesh made of wire Φ=0,40 mm with a square mesh shape of 2 × 2 mm; B) rolled cut-drawn mesh made of a strip of thickness b=0,4 mm with a rhomboidal mesh shape (7 × 3.5 mm); C) cut-drawn mesh made of a strip of thickness b=0,7 mm with a rhomboidal mesh shape (14 × 7 mm).

Preparation of Spinning Solutions

Electrospinning solutions were prepared by dissolving polycaprolactone (PCL) in a binary solvent system consisting of dichloromethane (DCM, POCH) and dimethylformamide (DMF, POCH) at a volume ratio of 7:3 (v/v). The polymer was gradually introduced into the solvent mixture under continuous magnetic stirring at room temperature (~25 °C). The solutions were stirred for 24 h to ensure complete dissolution and formation of a homogeneous solution.

The prepared solution was transferred into a 10 mL polypropylene syringe fitted with a stainless steel needle (19 G).

Three solution variants were prepared:

Variant I – 10% (w/v) PCL in DCM/DMF (7:3 v/v)

Variant II – 10% (w/v) PCL in DCM/DMF (7:3 v/v) with 0.1% (v/v) Tween 80

Variant III – Hybrid system consisting of Variant I and Variant II solutions supplied simultaneously from two separate syringes.

The non-ionic surfactant Tween 80 (Sigma-Aldrich) was introduced to modify the physicochemical properties of the electrospun fibres, particularly their surface wettability.

Substrate Preparation

Before electrospinning, the steel meshes were degreased in ethyl alcohol to remove surface contaminants.

Degreasing was intentionally selected as a minimal surface preparation method to avoid altering the mesh geometry, surface roughness, or mechanical behaviour, which could influence fibre deposition mechanisms and deformation behaviour during mechanical testing.

Electrospinning Process

Electrospinning was performed under controlled environmental conditions. The polymer solution was delivered using a syringe pump through a 19 G needle positioned at a fixed distance of 15 cm from the collector. A high voltage of 18 kV was applied between the needle and the grounded collector.

TABLE 1. Electrospinning parameters.

Variant	Needle-collector distance [cm]	Current voltage [kV]	Feed speed [mL/h]	Humidity [%]	Temperature °C
I	15	18	3	~45	~25
II	15	18	3	~43	~25
III	15	18	3 (PCL) 1 (PCL+Tween 80)	~43	~25

The mesh substrates were mounted on a grounded rotating drum collector operating at a rotational speed of 600 rpm in order to obtain randomly oriented fibrous layers. The electrospinning deposition time was approximately 15 min.

For the hybrid system (Variant III), two syringes were used simultaneously, supplying the PCL solution and the PCL/Tween solution at flow rates of 3 mL/h and 1 mL/h, respectively. This configuration enabled concurrent electrospinning of hydrophobic PCL fibres and hydrophilic PCL/Tween fibres, resulting in the formation of a hybrid fibrous nonwoven structure.

Each solution variant was electrospun onto the three mesh types, yielding a total of nine systems differing in substrate geometry and coating composition. The process parameters are summarized in TABLE 1.

Hybrid Coating Fabrication

Hybrid fibrous coatings (Variant III) can be produced using either sequential or simultaneous electrospinning techniques. In the present study, a parallel needle configuration was employed, allowing simultaneous deposition of two fibre populations with different surface properties (FIG. 3).

This approach resulted in a hybrid nonwoven fabric characterized by heterogeneous wettability behaviour arising from the coexistence of hydrophobic PCL fibres and hydrophilic PCL/Tween fibres.

Microscopic Observations

Microscopic observations of the electrospun coatings were performed using a digital optical microscope (Keyence VHX-900F) at magnifications ranging from 20× to 200×, and a scanning electron microscope (SEM, NOVA NANOSEM 200) at 5000× magnification.

The analyses were conducted to evaluate:

- coating continuity
- fibre morphology
- fibre distribution within mesh openings

Fibre diameter measurements were carried out based on SEM micrographs. For each coating variant, measurements were performed on a minimum of 100 fibres using image analysis software. The obtained datasets were statistically analysed and presented as fibre diameter distribution histograms.

Mean fibre diameter values and standard deviations were calculated for each coating variant.

Wettability and Surface Energy

Surface wettability of the electrospun coatings was evaluated using the sessile drop method. Contact angle measurements were performed using a Krüss DSA 25 goniometer by depositing 1 µL droplets of deionized water onto the sample surface. Measurements were conducted at room temperature. For each coating variant, measurements were performed at multiple locations on the sample surface (n = 10) in order to account for possible local heterogeneity of the fibrous coatings. The reported contact angle values represent the mean values with corresponding standard deviations. Surface free energy of the coatings was determined using the Owens–Wendt method based on contact angle measurements performed with two test liquids: deionized water (polar liquid) and diiodomethane (dispersive liquid).

Mechanical Properties

Mechanical behaviour of the mesh–coating systems was investigated using a universal testing machine (Zwick Roell Retroline 1435). Static uniaxial tensile tests were conducted under displacement-controlled conditions at a crosshead speed of 10 mm/min. Because the mechanical response of the system is dominated by the metallic mesh substrate, the primary objective of the mechanical testing was to evaluate the deformation behaviour of the fibrous coating and its structural integrity during large deformation of the mesh.

During testing the following were recorded:

- stress–elongation relationship of the mesh–coating system
- deformation behaviour of the fibrous coating
- coating continuity and adhesion to the substrate.

Failure and deformation mechanisms were further analysed by post-test microscopic observations.

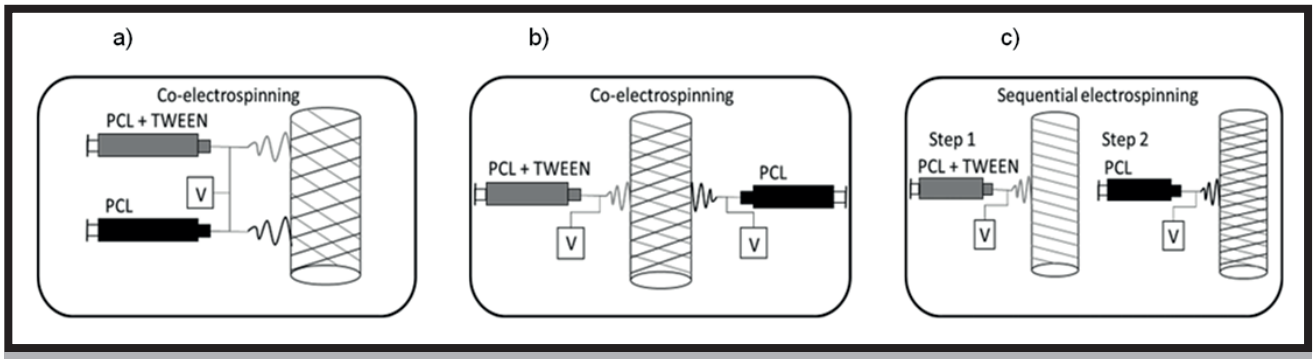

FIG. 3. Schematic diagram of electrospinning from two polymer solutions. a) co-electrospinning with two parallel needles; B) co-electrospinning with the collector positioned between two needles; c) co-electrospinning with sequential spinning.

Results

Morphology and Coating Continuity

Microscopic observations revealed that all electrospun coatings formed continuous fibrous layers on the metallic mesh substrates, irrespective of mesh geometry and opening size (FIGs. 4–6).

However, the fibre distribution within the mesh openings was non-uniform. This effect was particularly pronounced for meshes with large openings (FIG. 4A), where increased fibre accumulation was observed near the metallic elements. In contrast, the fibre density within the central regions of the openings was lower.

This deposition behaviour can be attributed to electrostatic effects associated with the high electrical conductivity

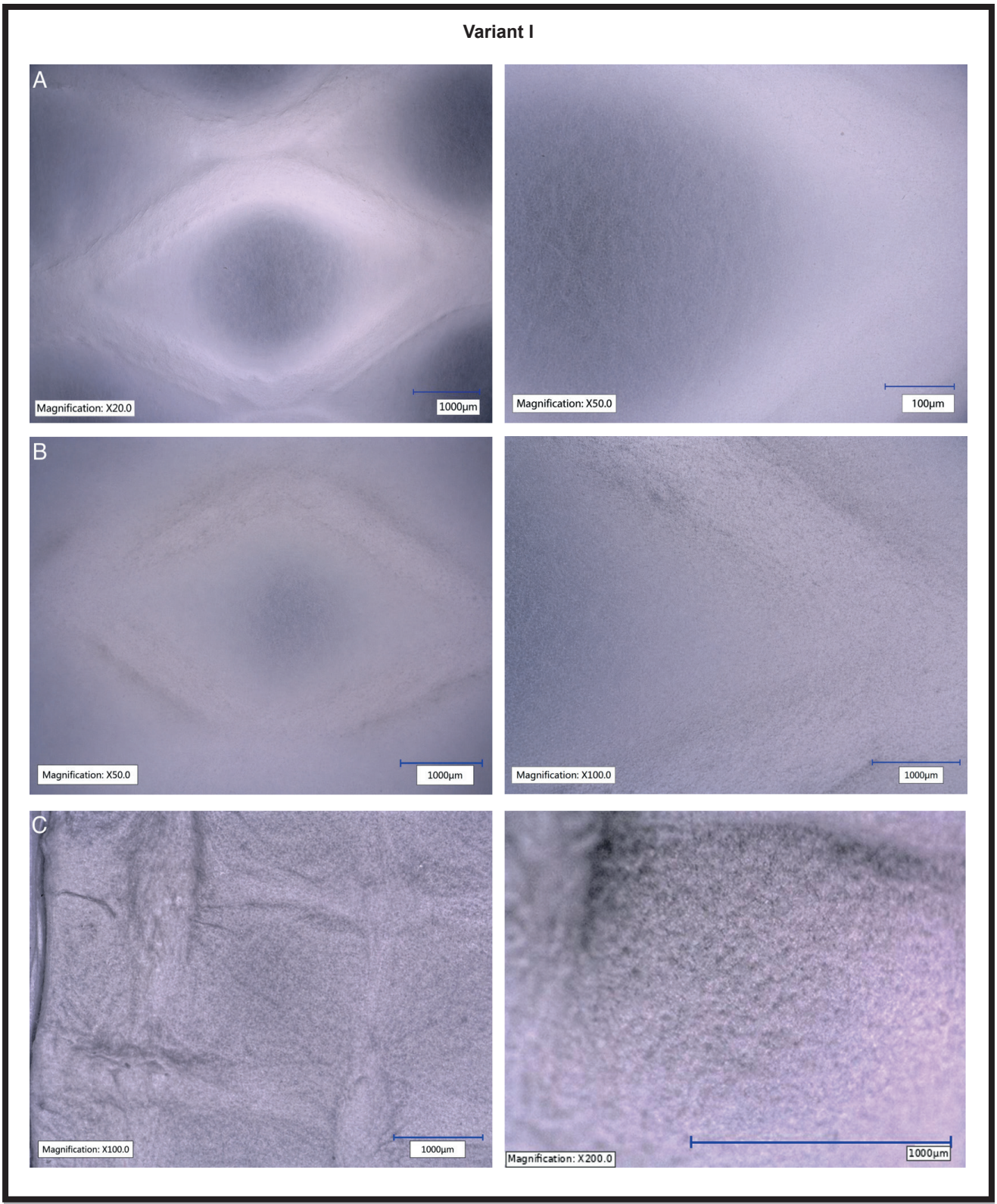

FIG. 4. Optical microscopy images (Keyence VHX-900F) of steel mesh substrates coated with electrospun polycaprolactone (PCL) fibres (Variant I). Images correspond to meshes with (A) large openings (14 × 7 mm), (B) medium openings (7 × 3.5 mm), and (C) small openings (2 × 2 mm). Magnification: 50×, 100×, 200×.

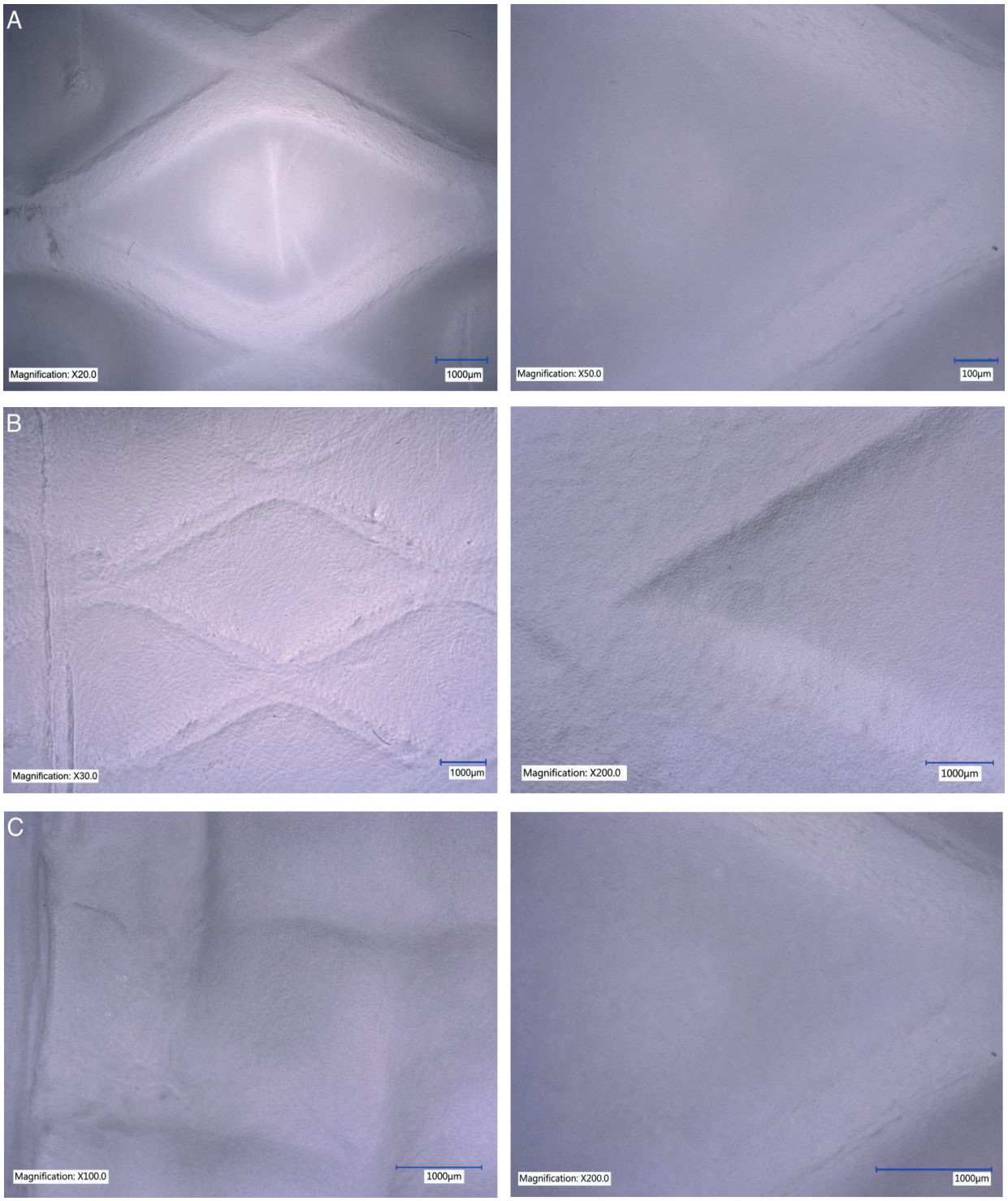

FIG. 5. Optical microscopy images (Keyence VHX-900F) of steel mesh substrates coated with electrospun polycaprolactone fibres modified with Tween 80 surfactant (Variant II). Images correspond to meshes with (A) large openings (14 × 7 mm), (B) medium openings (7 × 3.5 mm), and (C) small openings (2 × 2 mm). Magnification: 20×, 30×, 50×, 100×, 200×.

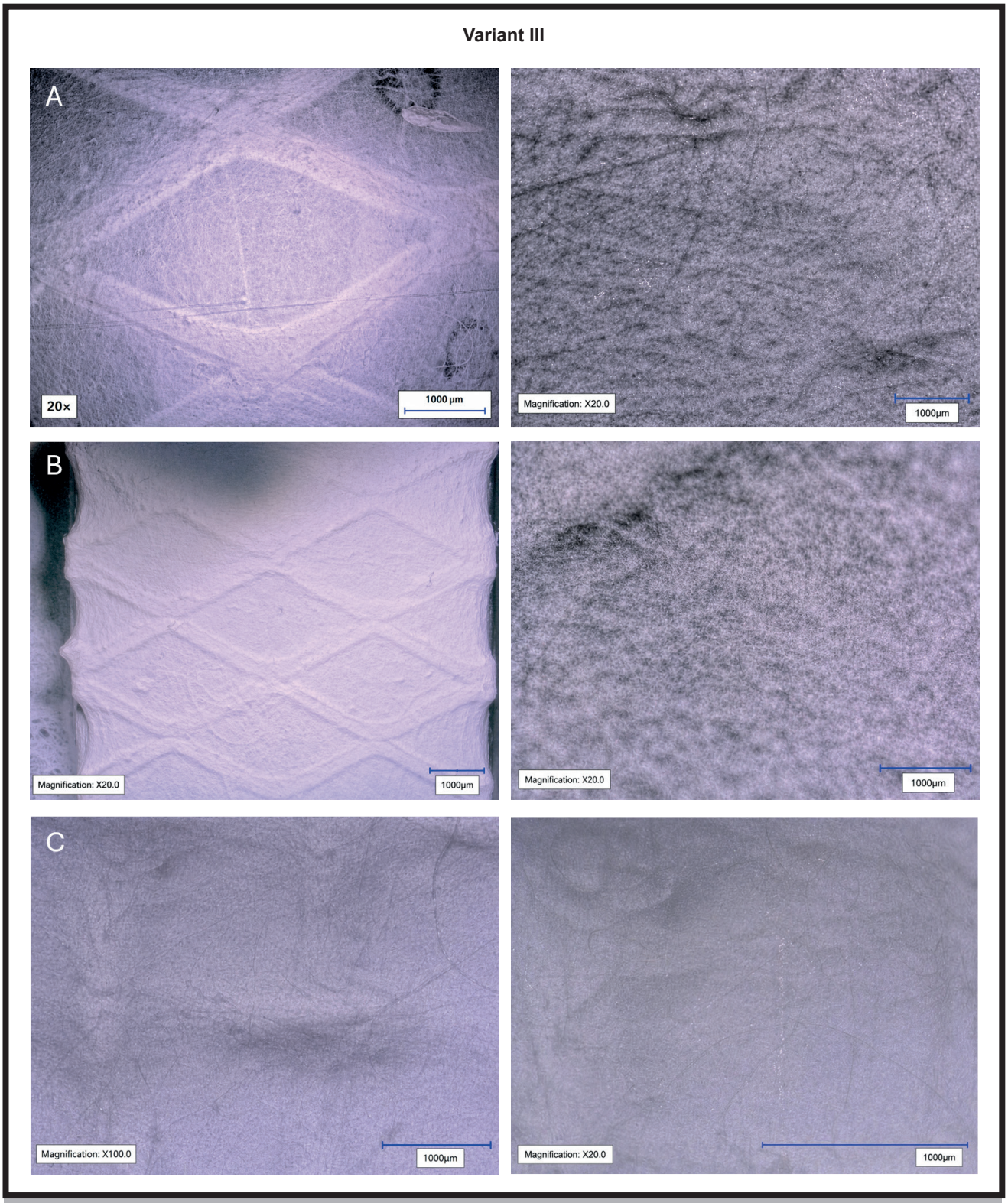

FIG. 6. Optical microscopy images (Keyence VHX-900F) of steel mesh substrates coated with hybrid electrospun fibres consisting of polycaprolactone (PCL) and polycaprolactone modified with Tween 80 (Variant III). Images correspond to meshes with (A) large openings (14 × 7 mm), (B) medium openings (7 × 3.5 mm), and (C) small openings (2 × 2 mm). Magnification: 20×, 100×, 200×.

of the steel substrate. The conductive elements locally intensified the electric field, promoting preferential fibre attraction toward the metal framework. Additionally, differences in effective deposition distance between conductive wires and the collector plane may have contributed to the observed fibre density gradients.

Fibre Diameter Distribution

SEM analysis confirmed that all coating variants consisted of micro- and nanometric fibres with unimodal diameter distributions (FIG. 7).

The fibre diameter distributions were unimodal for all investigated variants. The measured diameter ranges were:

- Variant I (PCL): 0.45–1.1 µm
- Variant II (PCL/Tween): 0.19–1.8 µm
- Variant III (Hybrid): 0.16–1.8 µm

Despite the incorporation of the surfactant, no substantial qualitative differences in fibre morphology were observed. All systems produced uniform fibres without visible beads or structural defects. The presence of Tween 80 slightly broadened the diameter distribution, which may be associated with changes in the physicochemical properties of the spinning solution, particularly surface tension and solution conductivity.

Wettability and Surface Energy

Wettability measurements revealed significant differences between the coating variants. Variant I exhibited hydrophobic behaviour with a contact angle of 130 ± 3.5°. In contrast, Variant II displayed superhydrophilic characteristics, with contact angles below 10°, indicating rapid spreading and absorption of water droplets.

The hybrid coating (Variant III) demonstrated heterogeneous wettability behaviour. Regions of high and low wettability were observed within the same sample (FIG. 8), corresponding to the coexistence of hydrophilic (PCL/Tween) and hydrophobic (PCL) fibres within the hybrid fibrous structure.

Time-dependent observations further indicated that droplet spreading and absorption kinetics for Variant III were slower than those observed for Variant II, reflecting the mixed surface character of the hybrid coating.

Surface free energy analysis revealed an increase from 43 mJ/m² for Variant I to approximately 74 mJ/m² for coatings containing the surfactant (Variants II and III). In the case of the hybrid system, this value should be interpreted as an effective surface energy influenced by locally dominant hydrophilic fibre domains.

Mechanical Behaviour under Tensile Deformation

Mechanical testing demonstrated that the mesh–coating systems maintained structural integrity during large tensile deformation. During uniaxial stretching, both the metallic mesh and the electrospun fibrous coating underwent substantial deformation exceeding 100%. As expected, the mesh openings were significantly elongated and the fibre arrangement within the nonwoven layer changed due to progressive fibre reorientation along the loading direction (FIG. 9).

Despite these large deformations, the fibrous coating remained attached to the metallic substrate and no delamination or coating detachment was observed (FIG. 10). The deformation behaviour of the coating was primarily governed by fibre straightening, reorientation, and sliding within the fibrous network rather than by fibre fracture. These observations indicate favourable mechanical compatibility between the electrospun coating and the deformable metallic mesh substrate.

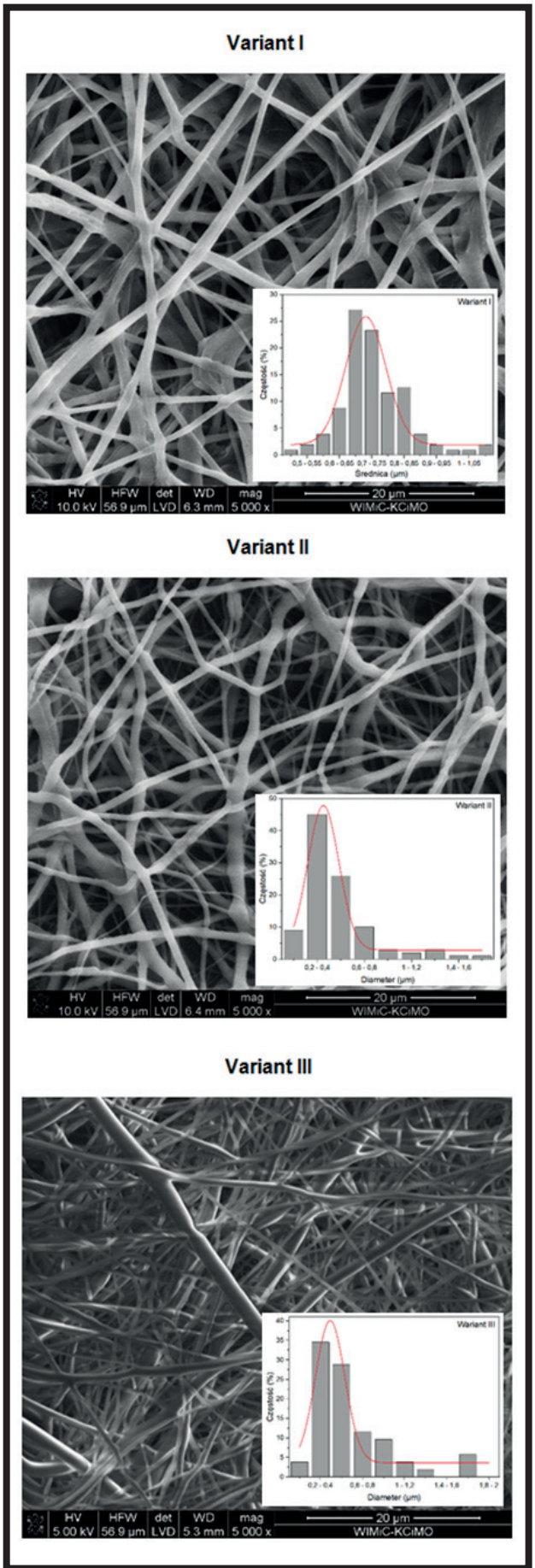

FIG. 7. SEM micrographs (NOVA NANOSEM 200) of electrospun fibrous coatings obtained for (Variant I) PCL, (Variant II) PCL/Tween 80, and (Variant III) hybrid PCL–PCL/Tween systems. Magnification: 5000×. Corresponding fibre diameter distributions are shown.

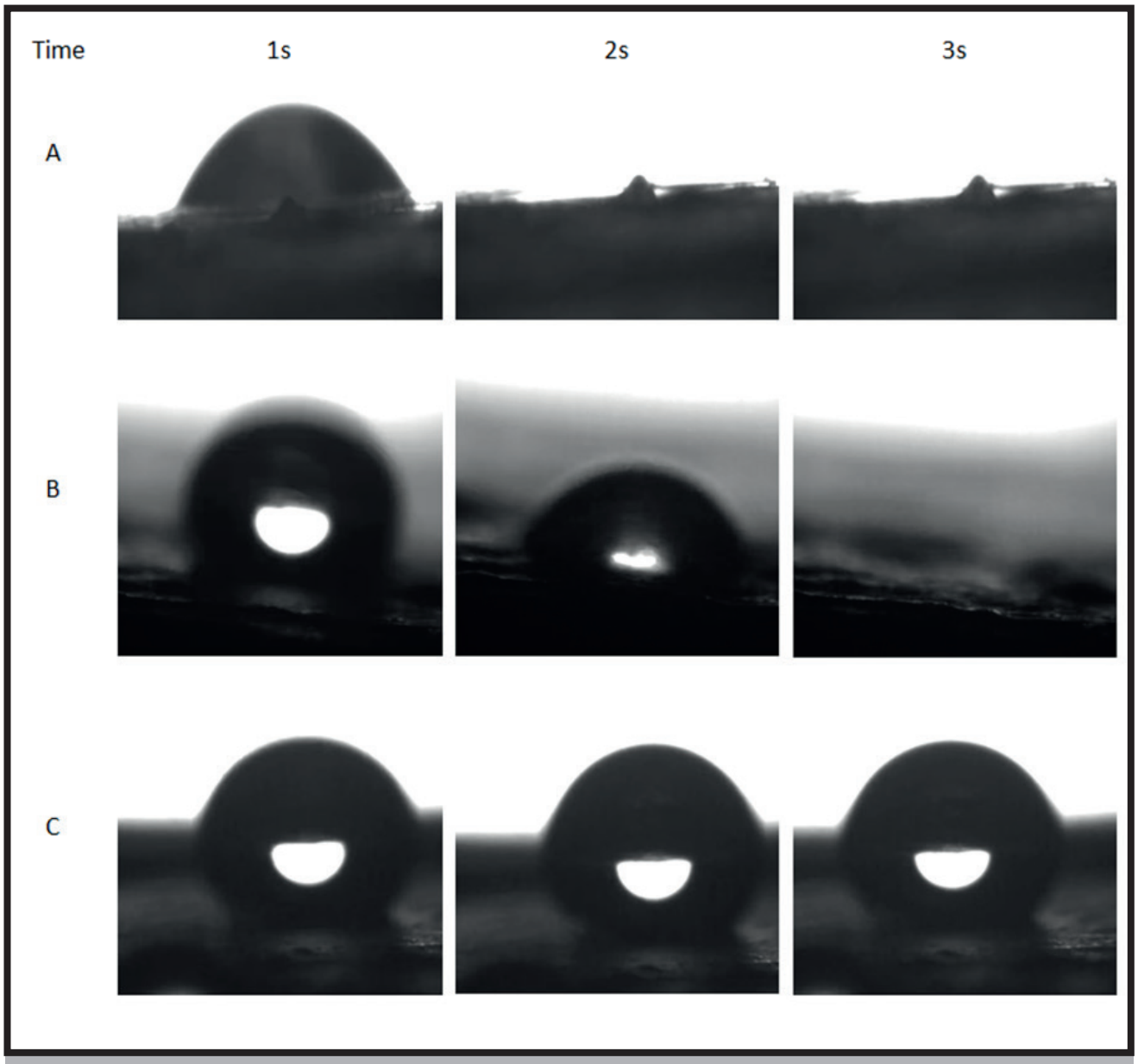

FIG. 8. Time-dependent wettability behaviour of the hybrid fibrous coating (Variant III). Optical images show the evolution of water droplet spreading at selected regions of the sample characterized by (A) high wettability, (B) intermediate wettability, and (C) low wettability.

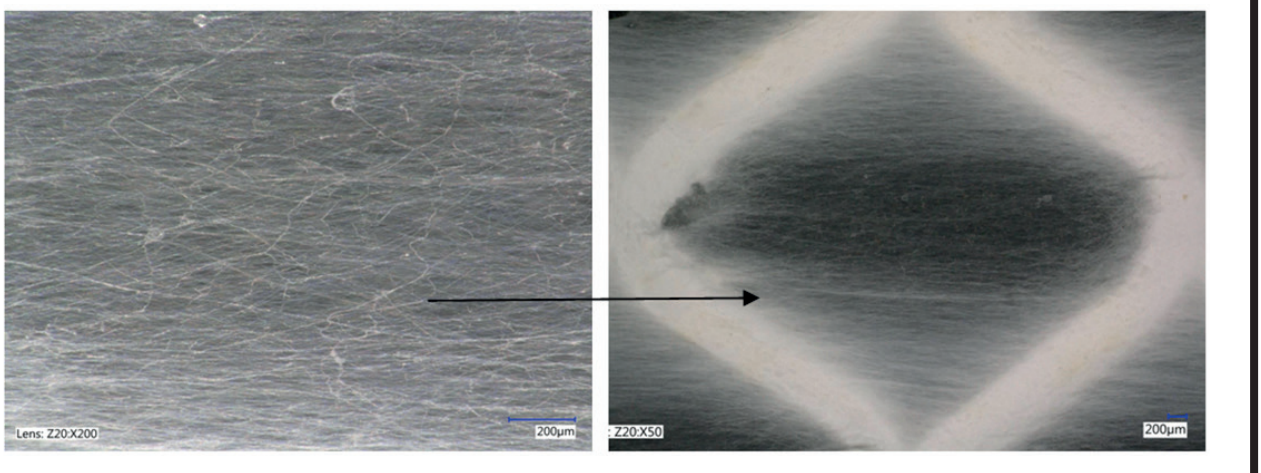

FIG. 9. Optical microscopy image of electrospun polycaprolactone fibres (Variant I) within a mesh opening after uniaxial tensile deformation exceeding 100% elongation. Fibre reorientation along the loading direction is visible.

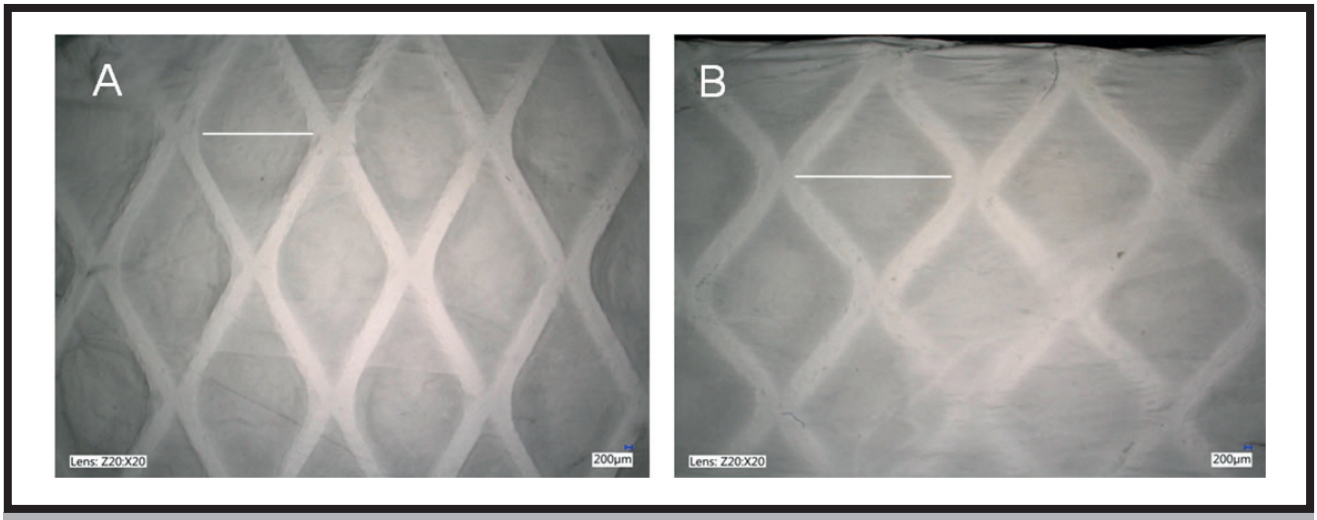

FIG. 10. Optical microscopy images of steel mesh coated with hybrid electrospun fibres (Variant III): (A) before tensile testing and (B) after uniaxial deformation corresponding to 40% elongation. The coating maintained structural continuity with no evidence of delamination.

Discussion

The obtained results confirm that electrospinning is an effective technique for the fabrication of continuous fibrous coatings on metallic mesh substrates with varying geometries. The successful deposition of structurally coherent and defect-free fibrous layers demonstrates the adaptability of the electrospinning process to conductive collectors characterized by complex architectures.

Fibre Deposition Behaviour

Microscopic observations revealed non-uniform fibre distribution, particularly within meshes exhibiting large openings. This deposition behaviour can be attributed to electrostatic effects associated with the high electrical conductivity of the steel substrate. Conductive elements locally intensified the electric field, resulting in preferential fibre deposition near the metallic framework.

Such fibre accumulation mechanisms are consistent with electrospinning phenomena widely described in the literature, where electric field gradients strongly influence fibre trajectory and deposition behaviour [1,13]. Additionally, differences in effective deposition distance between conductive mesh elements and the collector plane may further contribute to the observed fibre density variations.

Effect of Surfactant on Physicochemical Properties

The incorporation of Tween 80 significantly altered the wettability characteristics of the electrospun fibres. The transition from hydrophobic behaviour (Variant I) to superhydrophilic response (Variant II) can be explained by the amphiphilic nature of surfactant molecules, which increase surface polarity and modify interfacial energy.

This behaviour is consistent with previously reported effects of physicochemical surface modification in electrospun polymeric systems [1,6]. Importantly, despite pronounced changes in wettability and surface energy, no substantial alterations in fibre morphology were observed. This suggests that the surfactant primarily influenced surface-related phenomena rather than significantly modifying the bulk rheological properties of the spinning solutions.

The hybrid coating (Variant III) exhibited heterogeneous wettability behaviour, reflecting the coexistence of fibres with distinct surface energies. Such domain-like surface structures may be advantageous in applications requiring spatially differentiated surface interactions with liquids or biological environments.

Mechanical Response and Deformation Mechanisms

Mechanical testing demonstrated that the fibrous coatings preserved structural continuity under large deformations exceeding 100% elongation. Unlike continuous polymer films, fibrous networks deform through mechanisms including fibre straightening, reorientation, and inter-fibre sliding.

Such deformation mechanisms are characteristic of fibrous materials and have been widely reported for electrospun coatings applied to metallic substrates [11,12]. These structural adaptation mechanisms enable effective stress redistribution within the fibrous network while preventing catastrophic coating failure.

The observed fibre alignment along the loading direction confirms that mechanical response was primarily governed by network reorganization rather than coating damage.

The absence of coating delamination suggests sufficiently strong physical interaction between fibres and the metallic substrate. Although no dedicated adhesion tests were conducted, the preservation of coating integrity during large deformation indicates favourable mechanical compatibility between the coating and the mesh substrate.

Implications for Biomimetic Scaffold Design

The ability to tailor surface wettability without compromising mechanical stability represents an important advantage of electrospun coatings. Surface hydrophilicity plays a significant role in biomaterial performance, influencing protein adsorption, cell attachment, and tissue integration [1,6].

Furthermore, the fibrous morphology obtained via electrospinning resembles extracellular matrix-like architectures commonly used in biomimetic scaffold design [6,13]. When combined with mechanically robust metallic substrates, such systems may provide a promising platform for hybrid biomaterial structures integrating mechanical stability with tunable surface properties.

Study Limitations

The primary objective of this study was to evaluate the interaction between the metallic mesh and the electrospun fibrous layer, particularly the ability of the coating to follow plastic deformation of the metal substrate without delamination and without damage to the fibrous structure. Therefore, the analysis focused mainly on observing the

behaviour of the mesh–coating system under large mechanical deformation.

The study did not include biological analyses, quantitative adhesion measurements, or detailed chemical surface characterization. These aspects will be addressed in future work, particularly in the context of potential biomedical applications.

Conclusions

The present study demonstrates the feasibility of using electrospinning as a method for functional modification of metallic mesh substrates. Based on the obtained results, the following conclusions can be drawn:

- Electrospinning enabled the formation of continuous nano- and microfibrous polymer coatings on metallic meshes with different geometries, including meshes with relatively large openings, confirming the adaptability of the process to conductive collectors with complex architectures.
- The electrospun fibrous layers were able to accommodate large plastic deformation of the metallic mesh substrate. The coating maintained structural continuity without delamination and without visible damage to the fibrous network.
- Incorporation of the surfactant (Tween 80) allowed controlled modification of surface wettability, enabling the transition from hydrophobic to superhydrophilic behaviour.
- Hybrid electrospinning of PCL and PCL/Tween fibres resulted in coatings exhibiting heterogeneous wettability behaviour, reflecting the coexistence of fibres with different surface characteristics.
- The obtained mesh–fibre systems demonstrate favourable mechanical compatibility between the electrospun coating and the deformable metallic substrate, which may be advantageous for surface functionalization of metallic biomaterials.

These results provide a basis for further research on electrospun coatings applied to advanced metallic biomaterials, including shape memory alloys (SMA), where large elastic deformation requires high mechanical compatibility between the substrate and the functional coating.

Acknowledgments

This research was commissioned by CardioCare Sp. z o.o. and co-financed under the Regional Operational Program of the Lesser Poland Voivodeship 2014–2020 (Project No. RPMP.01.02.01-12-0059/19).

References

[1] R. Kurpanik, E. Stodolak-Zych: Chemical and physical modifications of electrospun fibers as a method to stimulate tissue regeneration – minireview. *Engineering of Biomaterials* 159 (2021) 31-41

[2] A. Golchin, S. Farzaneh, B. Porjabbar, F. Sadegian, M. Estaji, P. Ranjbarvan, M. Kanafimahbob, J. Ranjbari, N. Salehi-Nik, S. Hosseinzadeh: Regenerative Medicine Under the Control of 3D Scaffolds: Current State and Progress of Tissue Scaffolds. *Current Stem Cell Research & Therapy* 16(2) (2021) 209-229

[3] B. Dhandayuthapani, Y. Yoshida,T. Maekawa, D.S. Kumar: Polymeric Scaffolds in Tissue Engineering Application: A Review. *International Journal of Polymer Science* (2011) 1-19

[4] J. M. Grasman, M. J. Zayas, R. L. Page, G. D. Pins: Biomimetic scaffolds for regeneration of volumetric muscle loss in skeletal muscle injuries. *Acta Biomaterialia* 25 (2015) 2-15

[5] H. Chen, Y. Liu, Ch. Wang, A. Zhang, B. Chen, Q. Han, J. Wang: Design and properties of biomimetic irregular scaffolds for bone tissue engineering. *Computers in Biology and Medicine* 130 (2021) 104241

[6] E. Stodolak-Zych, A. Łuszcz, E. Menaszek, A. Ścisłowska-Czarencka: Resorbable polymer membranes for medical applications. *Journal of Biomimetics, Biomaterials & Tissue Engineering* 19 (2014) 99-108

[7] E. Stodolak-Zych, E. Menaszek, A. Twardy, A. Ścisłowska-Czarnecka, M. Boguń, B. Kolesińska: Synthetic extracellular matrix as a substrate for regenerative medicine. *Engineering of Biomaterials* 152 (2019) 10-15

[8] H. Yang, F. Zhang, J Qian, J. Chen, J. Ge: Restenosis in Magmaris Stents Due to Significant Collapse. JACC: *Cardiovascular Interventions* 11(10) (2018), e77-e78

[9] J.-W. Park, A. Bethencourt, H. Sievert, G. Santoro, B. Meier, K. Walsh, J. R. Lopez-Minguez, D. Meerkin, M. Valdés, O. Ormerod, B. Leithäuser: Left Atrial Appendage Closure With Amplatzer Cardiac Plug in Atrial Fibrillation: Initial European Experience. *Catheterization and Cardiovascular Interventions* 77 (2011) 700–706

[10] S. D. Sheth, R. P. Giugliano: Coronary artery stents: advances in technology. *Current Cardiology Reports* 17(3) (2015) 83–91

[11] M. Khandaker, S.Riahinezhad, F. Sultana, T. Morris, R. Wolf, M. Vaughan: Effect of Collagen-Polycaprolactone Nanofibers Matrix Coating on the In Vitro Cytocompatibility and In Vivo Bone Responses of Titanium. *Journal of Medical and Biological Engineering* 38 (2018), 197-210

[12] M. Khandaker, S.Riahinezhad, W. R. Williams, R. Wolf: Microgroove and Collagen-poly(ε-caprolactone) Nanofiber Mesh Coating Improves the Mechanical Stability and Osseointegration of Titanium Implants. *Nanomaterials* 7(6) (2017) 145

[13] J. Xing, M. Zhang, X. Liu, Ch. Wang, N. Xu,D. Xing: Multi-material electrospinning: from methods to biomedical applications. *Materials Today Bio* 21 (2023) 100710