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The Effect of Carbon-Based Surfaces on the Development and Structure of Marine Cyanobacterial Biofilms

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| Background

Marine biofouling is a natural and spontaneous process by which submerged structures are colonized by marine organisms[1]

can be responsible for

Economic and ecological problems including changes in the physicochemical properties of the surfaces, leading to their rapid deterioration and corrosion[2]

frequently associated with

The **adhesion** and **biofilm formation** by microfoulers such as cyanobacteria[3] - one of the **first steps** of marine biofouling

The **development** of **novel** and **environmentally friendly antibiofilm strategies**, such as the manufacture of innovative nanocomposite coatings, is **required**

among different nanocomposites

Carbon nanotubes (CNTs)

have been widely used due to their **mechanical strength**, **structural stability**, and **antimicrobial** and **anti-adhesive activities**[4]

This work aimed to (i) **produce** and **characterize CNT-based surfaces**, and (ii) **evaluate** their **antifouling performance** against marine cyanobacterial biofilms under conditions that mimic marine environments

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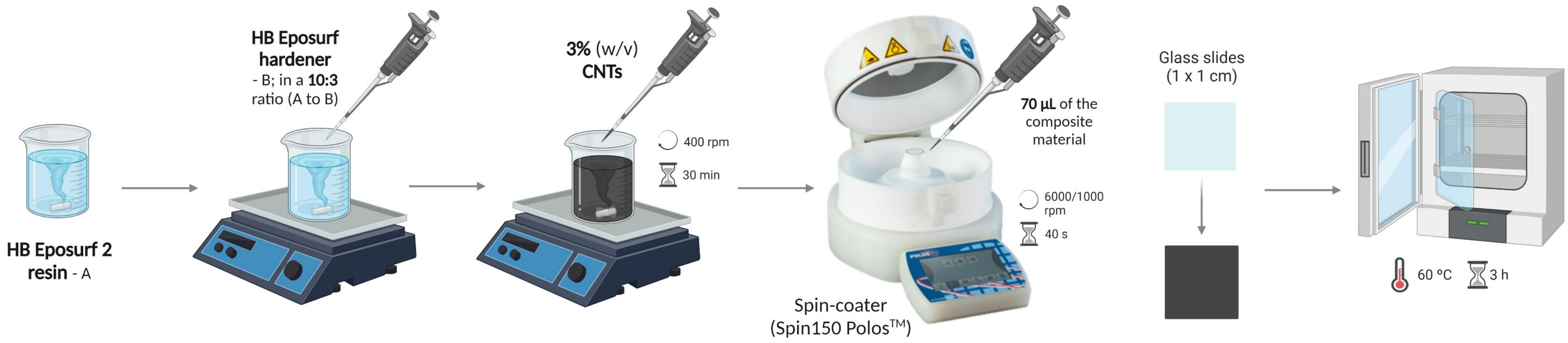
Material and Methods

Surface Preparation and Characterization

- Control surfaces: **glass** and glass coated with **epoxy resin;** CNT composite: epoxy resin with **3%** (w/v) **Multi-Walled CNTs**
- CNT surfaces: produced by spin coating and analyzed by Scanning Electron Microscopy (SEM)



Biofilm Assays

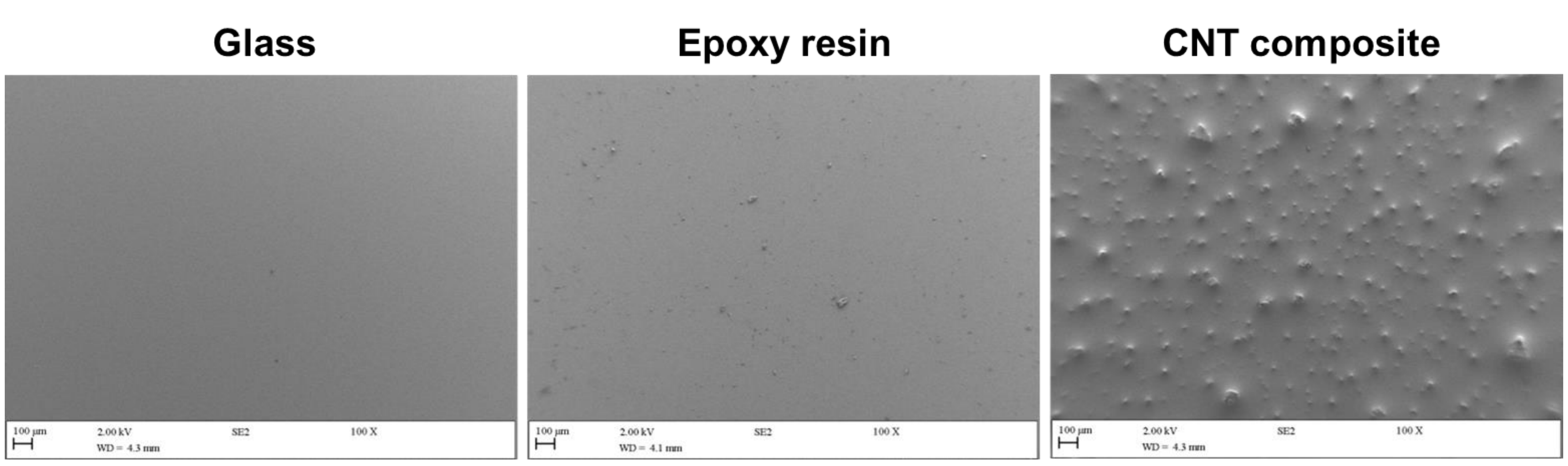
Biofilm Formation

- Filamentous cyanobacterial strain:
  ***Nodosilinea* cf. *nodulosa* LEGE 10377**
- 12 well-plates for **49 days** at **25 ˚C**
- Shear rate of **50 s^{-1}**; **14 h light/10 h dark** cycles

Biofilm Analysis

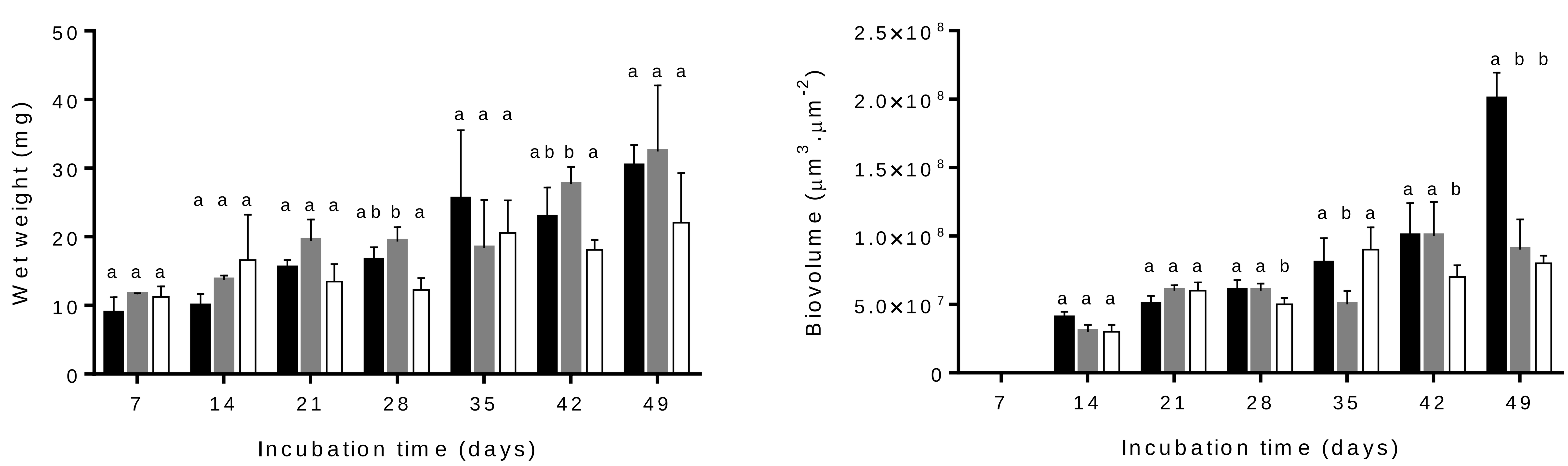
- **SEM** – Morphology
- **Wet weight**
- **Optical Coherence Tomography (OCT)**
  Biovolume, thickness, porosity, structure

Results



SEM images of glass, epoxy resin, and CNT surfaces. Magnification = 100×; scale bar = 100 µm.

The **CNT composite** had the **roughest** and most **heterogeneous** surface, presenting CNT **agglomerates**



Wet weight and biovolume of *Nodosilinea* cf. *nodulosa* LEGE 10377 biofilms developed on different surfaces (glass - black, epoxy resin - grey, CNT composite - white).

Biofilm wet weight and **biovolume** gradually **increased over time,** revealing that this cyanobacteria is a **good biofilm former**

CNT-modified surfaces can **delay biofilm development,** presenting a **greater antifouling effect** on the **maturation stage**

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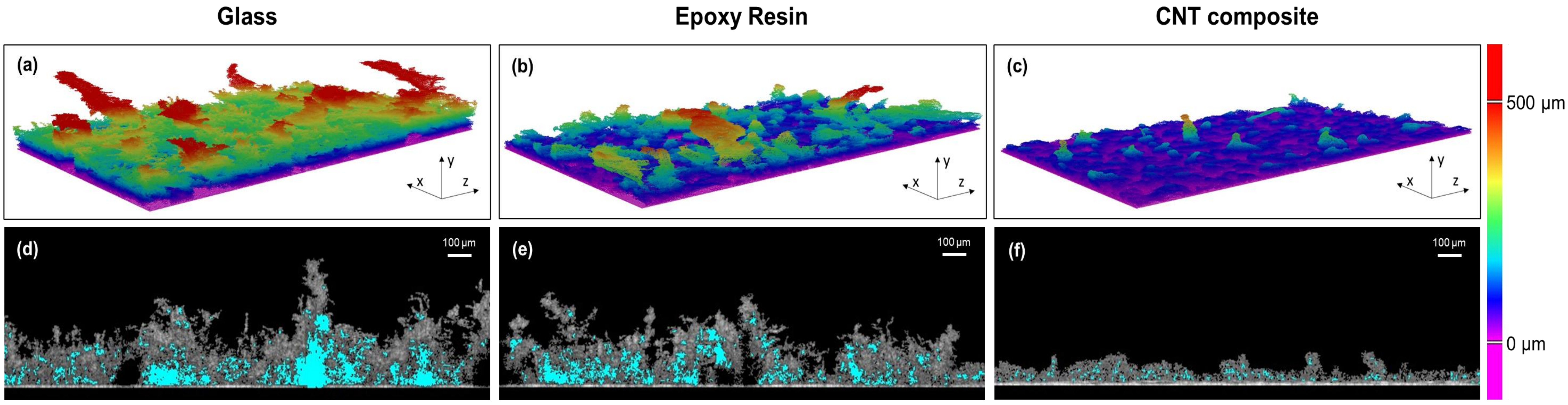
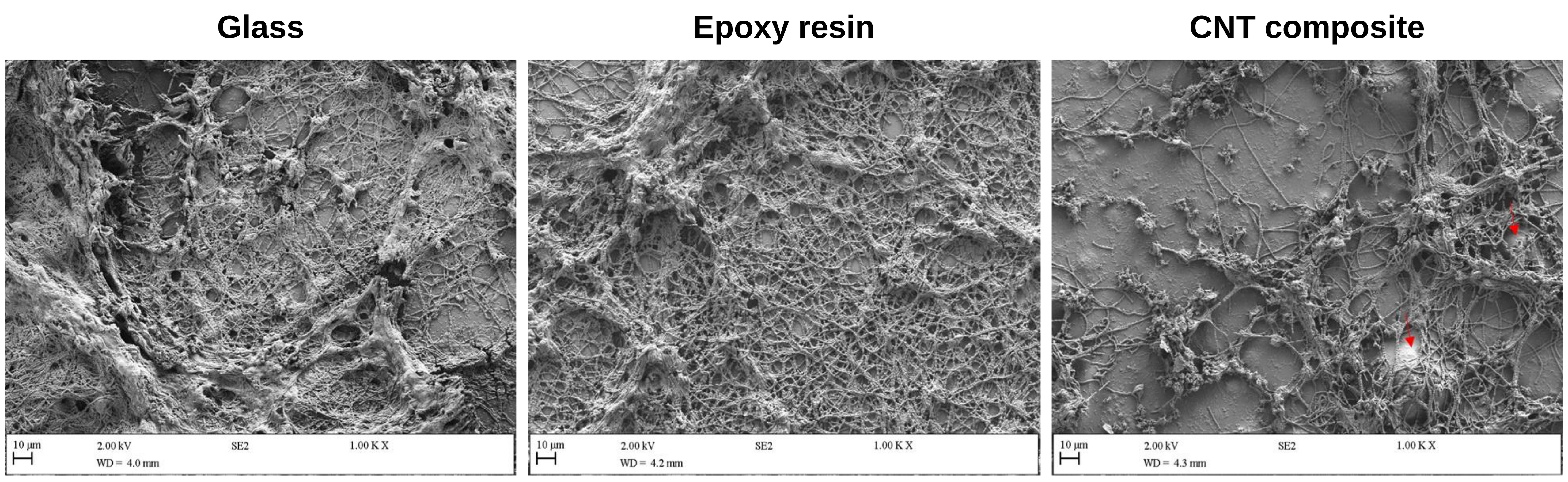
Results



Representative 3D (**a-c**) and 2D cross-sectional (**d-f**) OCT images of *Nodosilinea* cf. *nodulosa* LEGE 10377 biofilms on controls and CNT composite after 49 days. The empty spaces in 2D biofilm structures (**d-f**) are filled in blue (scale bar = 100 µm).

Visible differences in **biofilm structures:** while those formed on **control surfaces** had more **prominent** and **irregular structures,** biofilms developed on **CNT composite** were **flatter** and more **homogeneous**

Biofilms formed on **CNT-based surfaces** showed **lower thickness**, **percentage** and **mean size** values of **empty spaces** compared to glass and epoxy resin surfaces



SEM images of *Nodosilinea* cf. *nodulosa* LEGE 10377 biofilms formed on glass, epoxy resin, and CNT composite after 49 days. The red arrows indicate clusters of CNTs. Magnification = 1000×; scale bar = 10 µm.

While **biofilms** formed on the **control surfaces** showed **dense filamentous networks**, biofilms developed on **CNT-based surfaces** presented **lower-density cell aggregates**

Conclusions

- **CNT-based surfaces** showed an **antifouling activity** against *Nodosilinea* cf. *nodulosa* LEGE 10377.
- **Biofilms** formed on CNT surfaces presented more **homogeneous**, **flatter**, **less porous**, and **tightly packed** structures compared to those formed on control surfaces.
- The **incorporation of carbon nanotubes into polymeric matrices** showed to be a **promising approach** to **delay cyanobacterial biofilm development** and **reduce biofouling consequences**.

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Acknowledgments

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