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Enhanced mixing efficiency for a novel 3D Tesla micromixer for Newtonian and non-Newtonian fluids

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The Significance of Study

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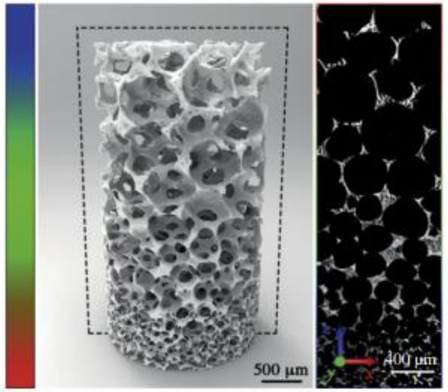
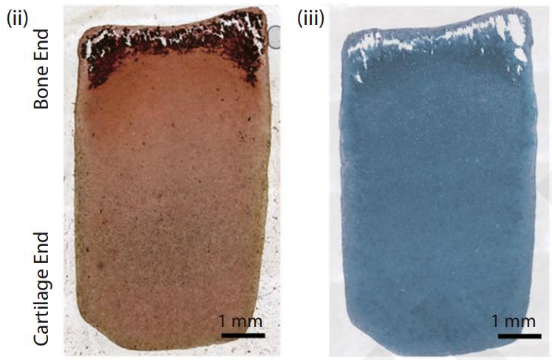
Gradient printing in biomedical field

Gradient in Structural properties



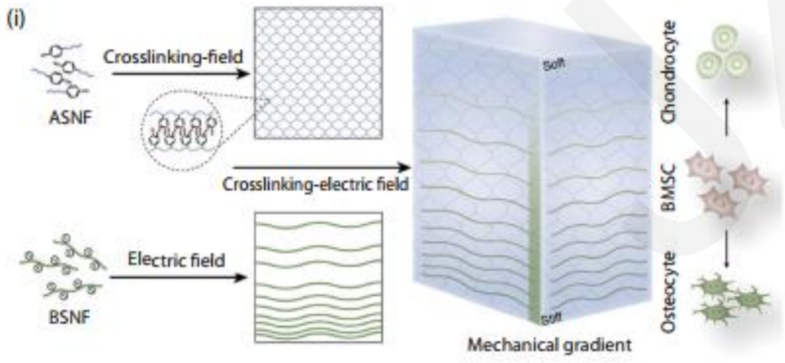
Costantini et al. 2019

Gradient in composition



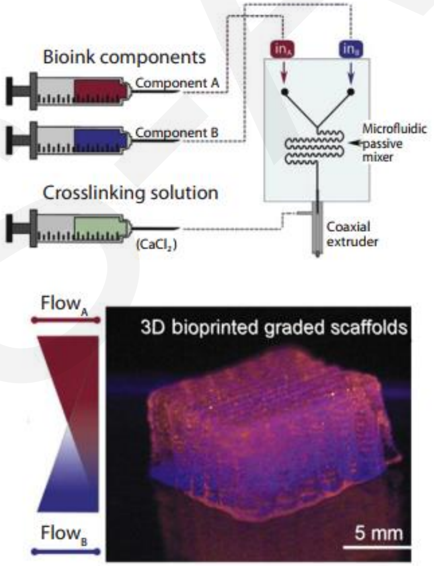
Li, C. et al. 2019

Gradient in physical properties

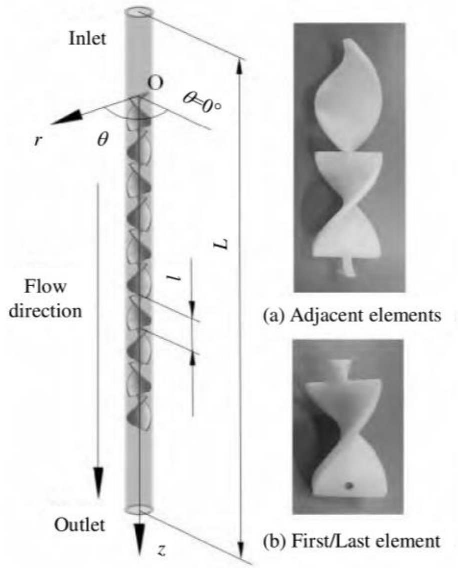


Xu, G. et al. 2020

Current micromixers



Idaszek, J. et al. 2019



Zhang, J. et al. 2022

Traditional micromixer for extrusion-based 3D printing often faces the limitations in mixing efficiency, which can lead to inhomogeneities of printed bioactive structure and risks such as channel blockages.

Unique Structure of Tesla Micromixer

Innovative Points of This Paper

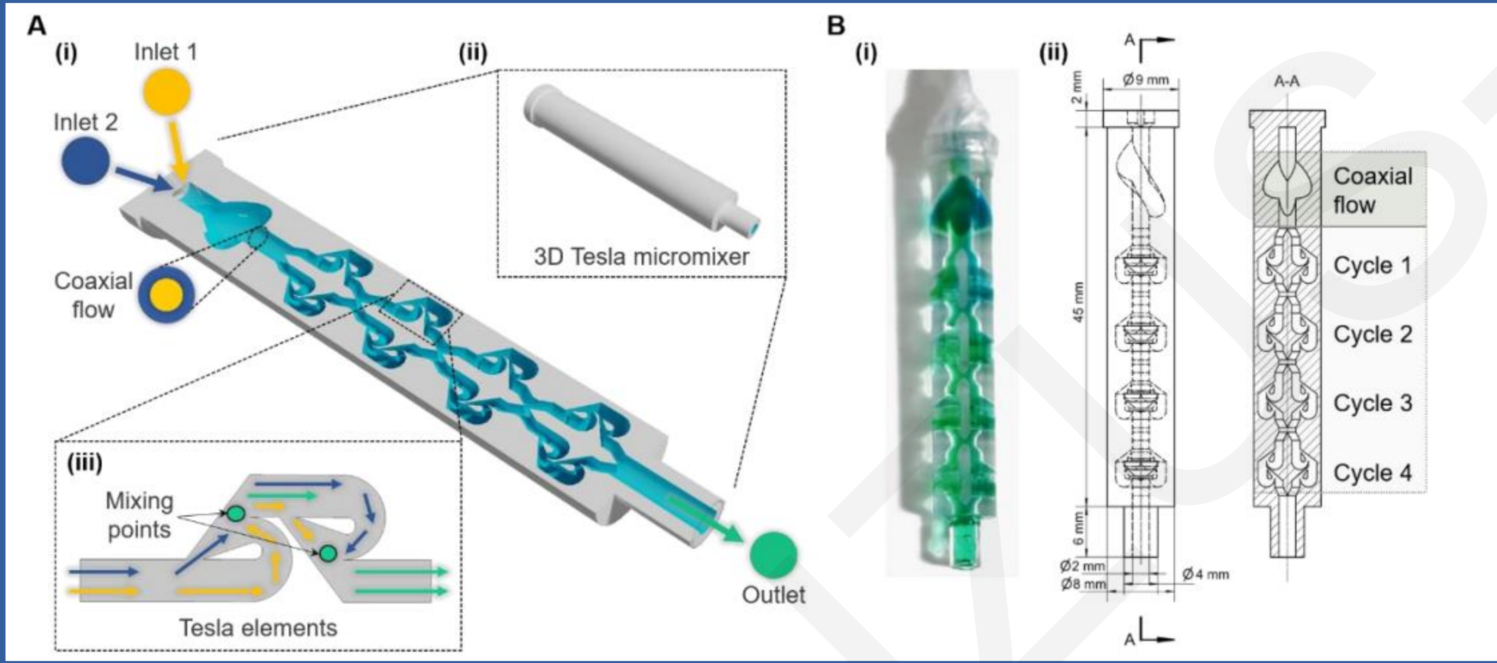


Fig.1: Overview of the Tesla micromixer design and operational flow dynamics

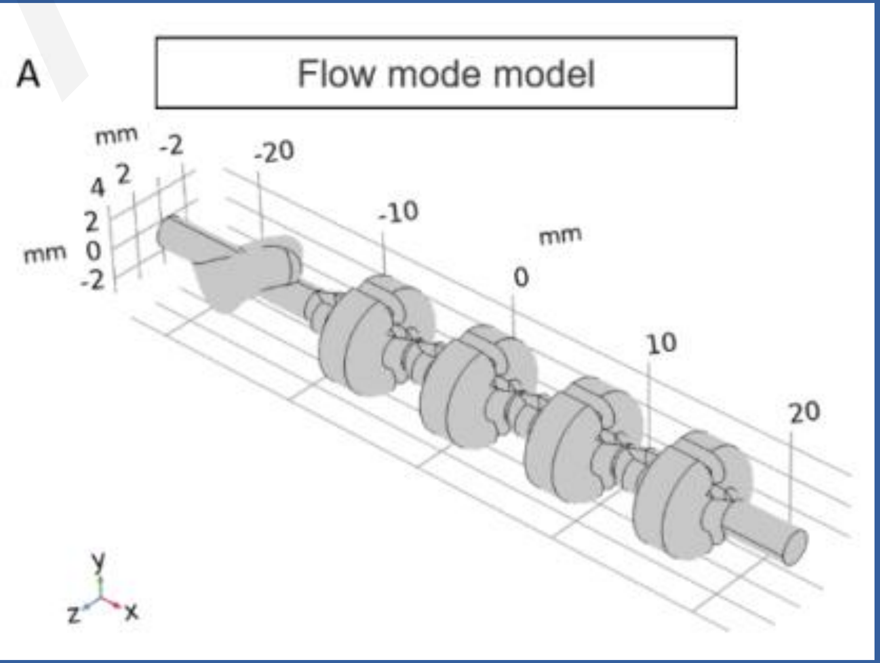


Fig.2: CFD simulation model

In this study, we introduce a novel micromixer design based on Tesla valve, which has heightened ability to achieve superior mixing efficiency with fewer mixing cycles.

Boundary Conditions and Governing equations

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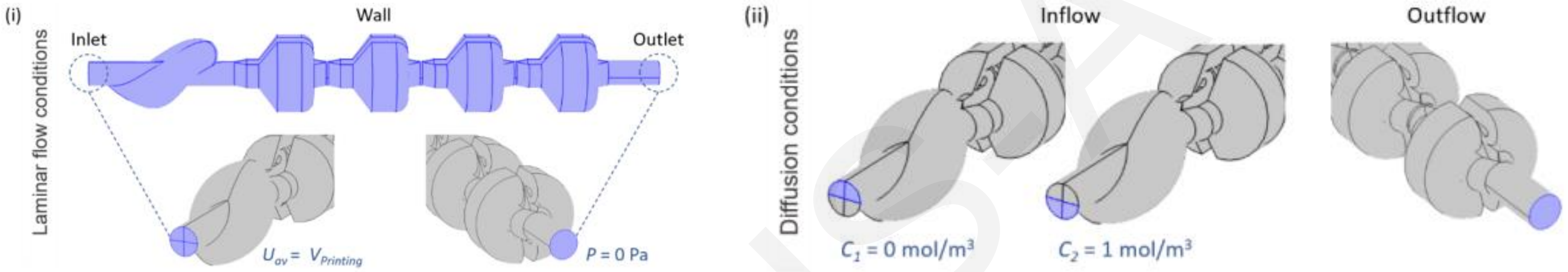
Boundary conditions



Governing equations

$$2\boldsymbol{u} \cdot \nabla c = D\nabla^2 c \qquad (1)$$

$$\begin{cases} \boldsymbol{u} = \boldsymbol{u}_0, & on\ \Gamma_{inlet} \\ \boldsymbol{u} = \boldsymbol{0}, & on\ \Gamma_{wall} \\ p = \boldsymbol{0}, & on\ \Gamma_{outlet} \\ \boldsymbol{c} = \boldsymbol{c}_0, & on\ \Gamma_{inlet} \end{cases} \qquad (2)$$

$$\mu = K\dot{\gamma}^{n-1} \qquad (3)$$

$$Re_N = \frac{\rho U L}{u_\infty} \qquad (4)$$

$$Re_{PL} = \frac{\rho U^{2-n} L^n}{\frac{K}{8}(\frac{6N+2}{n})^n} \qquad (5)$$

$$Pe = \frac{UL}{D} \qquad (6)$$

$$U_{PL} = \frac{nL}{2(3n+1)} \times (\frac{\tau_W}{K})^{1/n} \qquad (7)$$

$$Pe_{PL} = \frac{nL^2}{2(3n+1)D} \times (\frac{\tau_W}{K})^{1/n} \qquad (8)$$

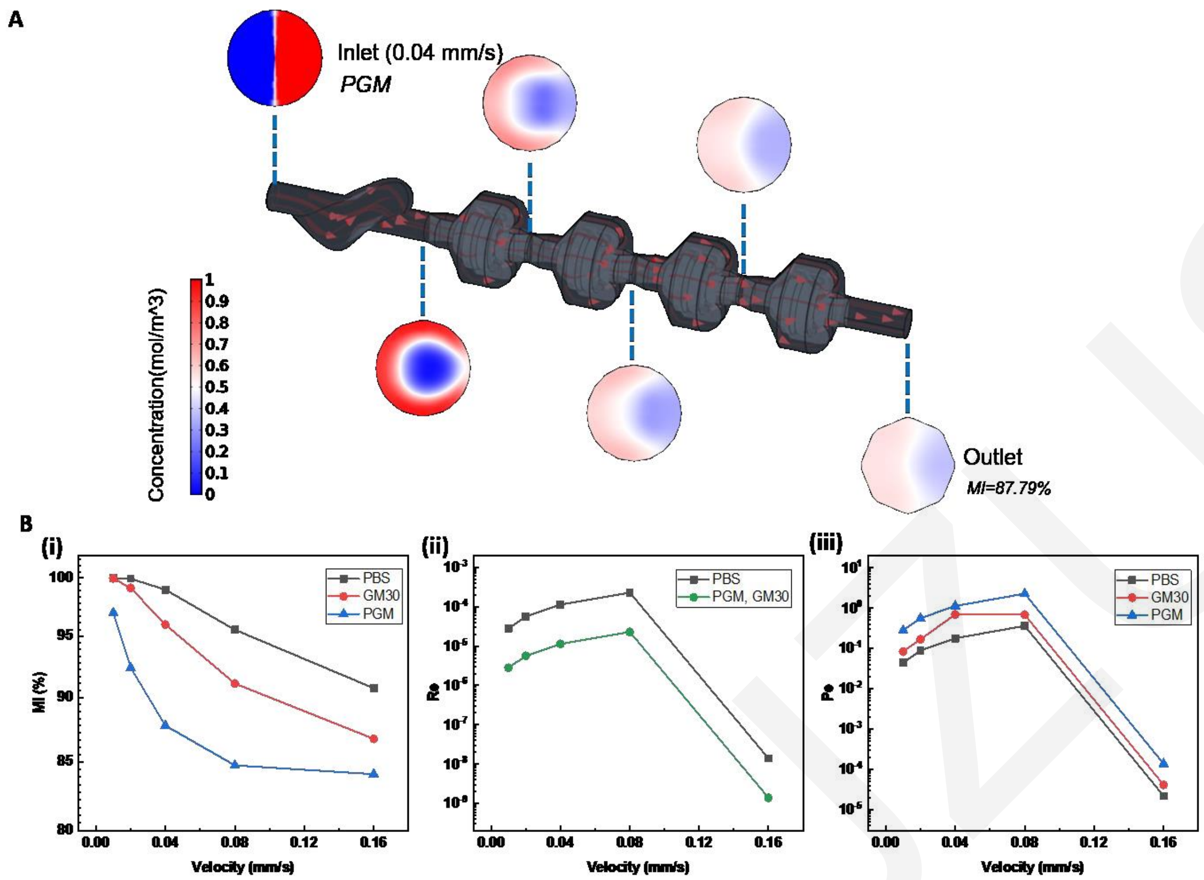
$$M.I = \sqrt{\frac{\sigma^2}{\sigma_{max}^2}} \qquad (9)$$

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(c_i - \bar{c})^2 \qquad (10)$$

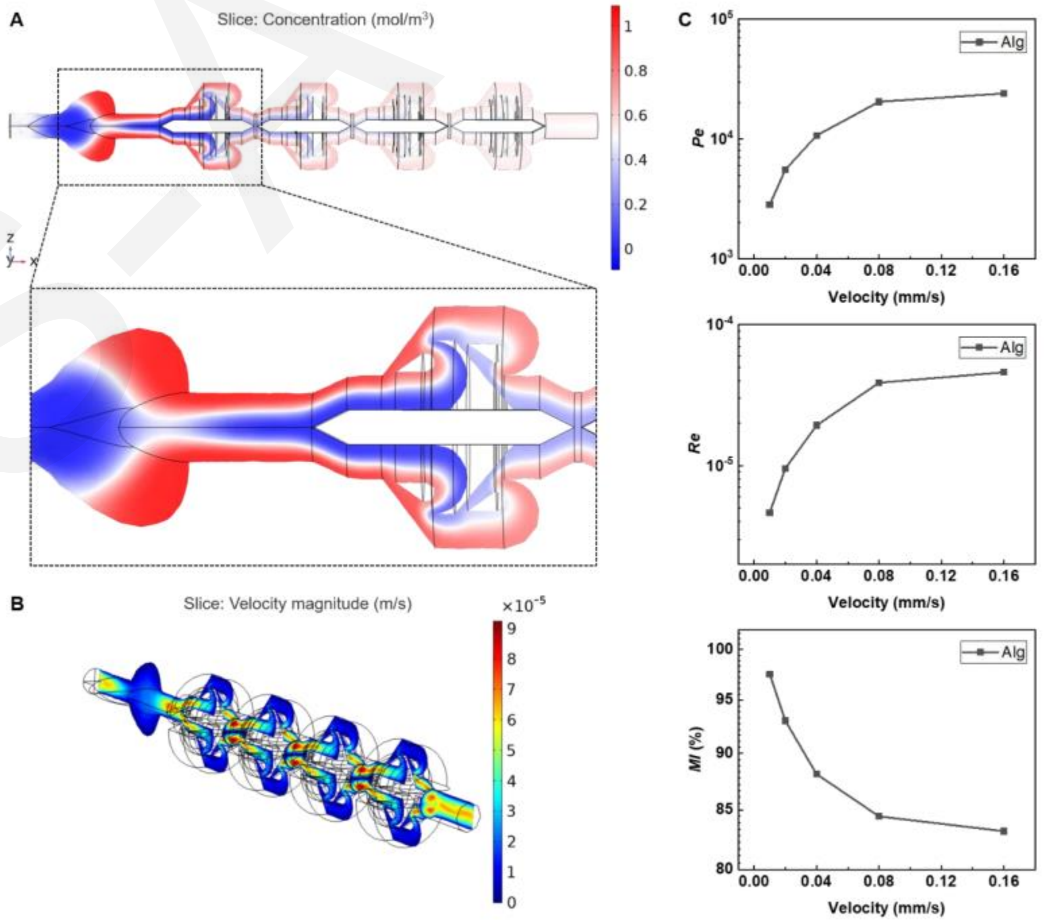
$$\sigma_{max}^2 = \bar{c}(1 - \bar{c}) \qquad (11)$$

CFD Simulation for Newtonian and non-Newtonian Fluids

Newtonian fluids



non-Newtonian fluids



Though CFD simulation, the Tesla micromixer is validated to adapt to both Newtonian and non-Newtonian Fluids which have distinct viscocities and diffusion coefficients. All result reveal a optimal velocity for thorough mixing with a high efficiency.

Experimental Assessment of 3D Tesla Micromixer for Extrusion 3D Printing Applications

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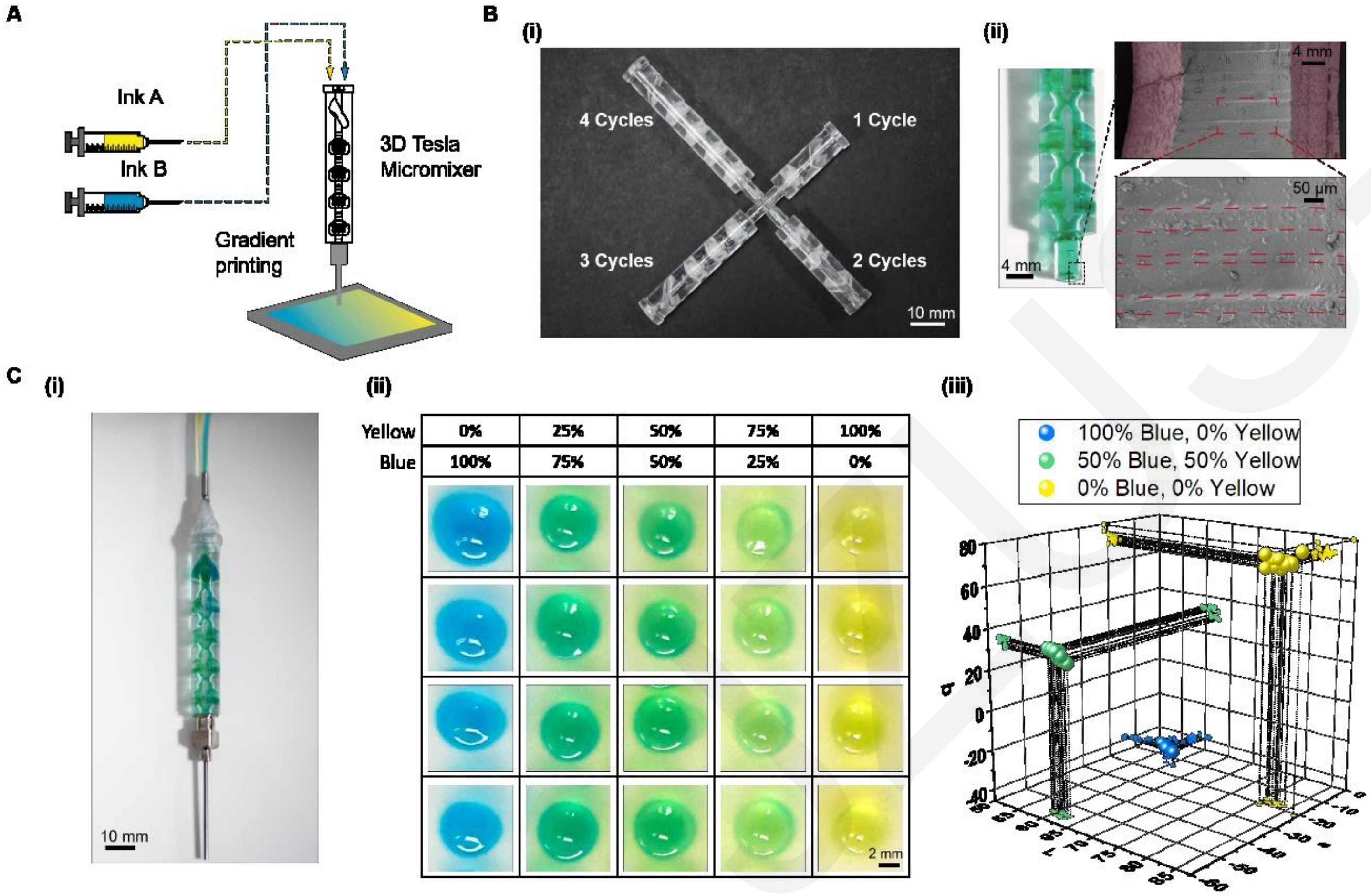

Fig.7: Multifaceted analysis of gradient droplet generation using a Tesla micromixer.

The superior mixing capabilities highlights the potential of this micromixer in the bioprinting applications, which is capable of reliably producing homogenously mixed hydrogels.

Conclusions

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- The novel micromixer design demonstrates an enhanced capability to achieve a high mixing efficiency with a reduced number of cycles, which is a crucial advancement for bioprinting of complex tissue structures

- Through rigorous CFD simulations and experimental validation, a more profound cognizance of the dynamics within the micromixer was established, leading to efficient blending of hydro-gels with remarkable reproducibility

- The superior mixing capabilities and wide range of adaptation demonstrated by the 3D Tesla micromixer highlight its potential as an essential component in the bioprinting arsenal, capable of reliably producing homogenously mixed bioinks of different materials