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Deformation Behavior of Screen Mesh in Screen Printing and Its Effect on Printing Results

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Outline

- Introduction
- Experiment
- Simulation
- Conclusions

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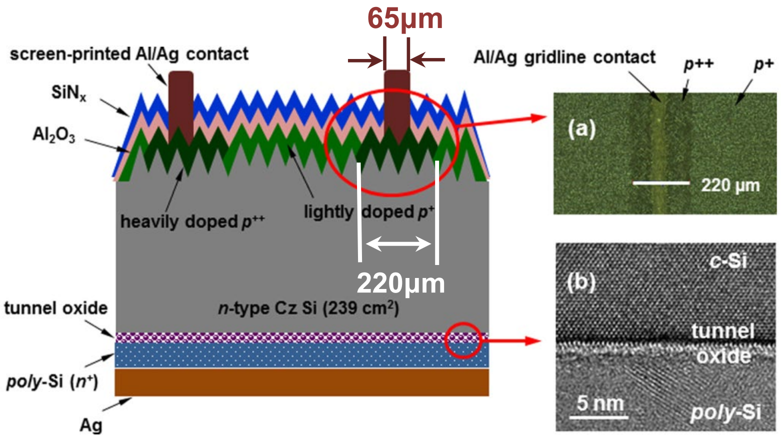
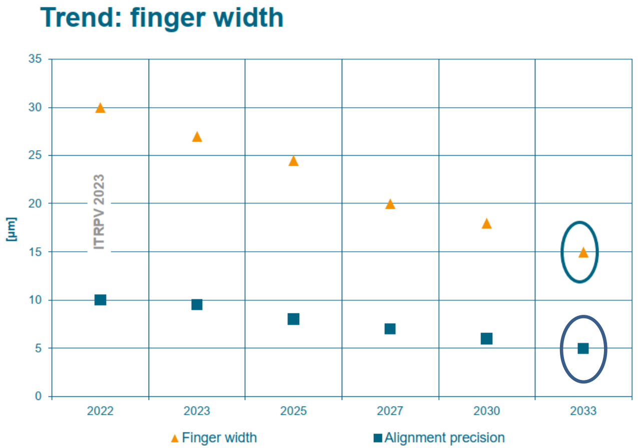
Positioning accuracy in screen printing



Y. Tao,et al, “High-efficiency selective boron emitter formed by wet chemical etch-back for n-type screen-printed Si solar cells” Appl. Phys. Lett. 110, p.021101 (2017)



ITRPV 14th edition, March 2023 key findings & report presentation

Need accurate metallization onto selective emitter

Finer finger 15μm & Alignment precision 5μm @ 2033

Positioning accuracy in screen printing is an essential key to improving the performance of silicon solar cells.

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Factors affecting positioning accuracy of screen printing

- Environmental conditions
  – temperature & humidity

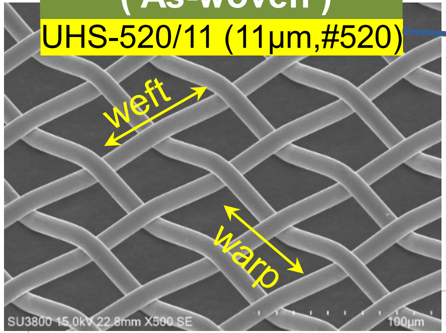
- Mechanical accuracy of printing equipment
  - vision system for the alignment mechanism
  - mechanical positioning of printing system

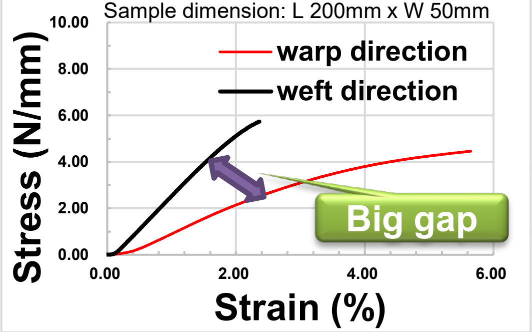
- Uniformity of mechanical properties of the screen

We focus on mesh deformation during printing, which causes misalignment of metallization.

How to make the mechanical properties of mesh uniform

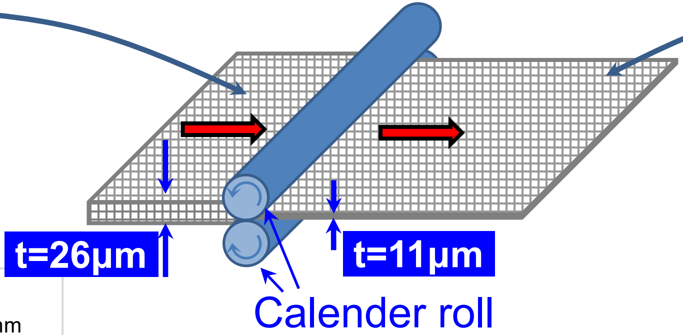
Non-calendered (As-woven)





Stress – Strain curve of UHS 520/11
Non-calendered(As-woven) mesh (t=26μm)

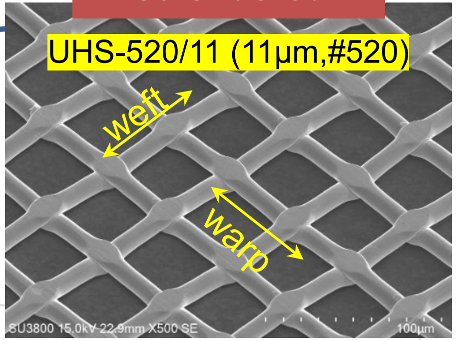
Calendering

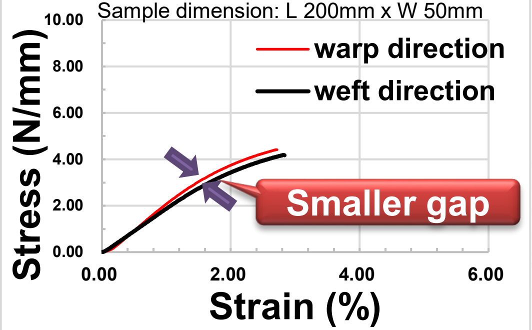


To improve the homogeneity of the mechanical properties of the mesh

The warp direction and weft one aligned to have the same mechanical properties

Calendered





Stress – Strain curve of UHS 520/11
Calendered mesh (t=11μm)

Motivation

- This study aims to analyze;
  - The printed positioning accuracy of screen printing experiments and simulations conducted under the same conditions to investigate the effect of screen mesh deformation
  - **The effect of calendering process**

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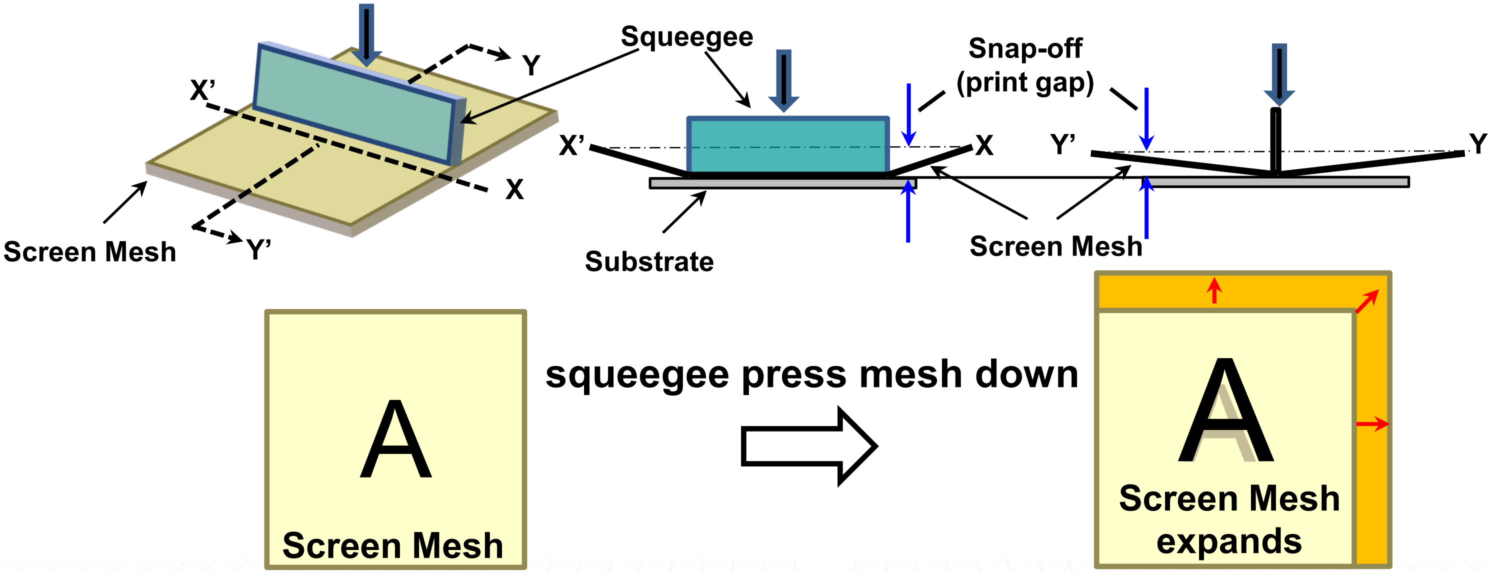
Screen printing experiments

- Screen mesh
  - UHS-520/11 (11μm,#520)
    - Non-calendered, t=26μm
    - Calendered, t=11μm
  - Mesh bias angle: 22.5 degrees
  - Mesh on-screen frame: Direct-stretching
- Screen printing parameters
  - Print speed: 50mm/sec
  - Printing pressure: 45.3N
  - Squeegee length: 170mm
  - Print gap: 1.3mm

Screen mesh behavior in screen printing

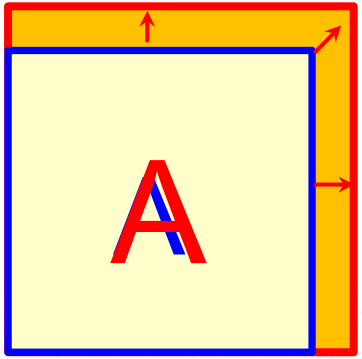


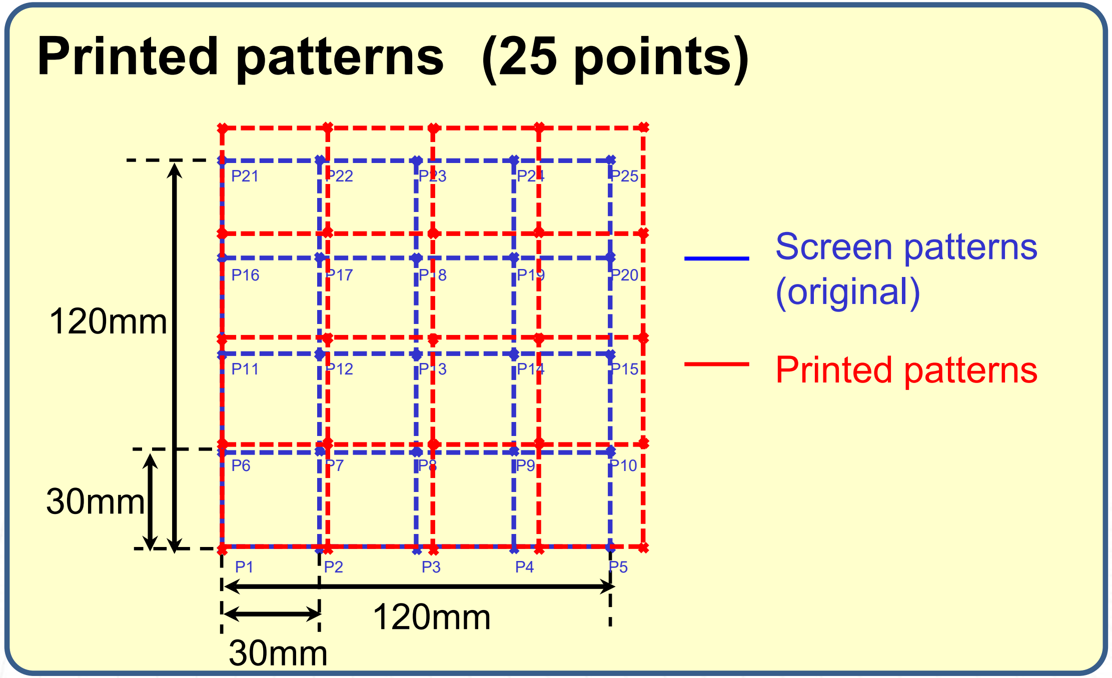
A screen mesh is deformed as a squeegee presses down

Patterns printed on a substrate become larger than an original ones on the screen

Image of screen and printed patterns

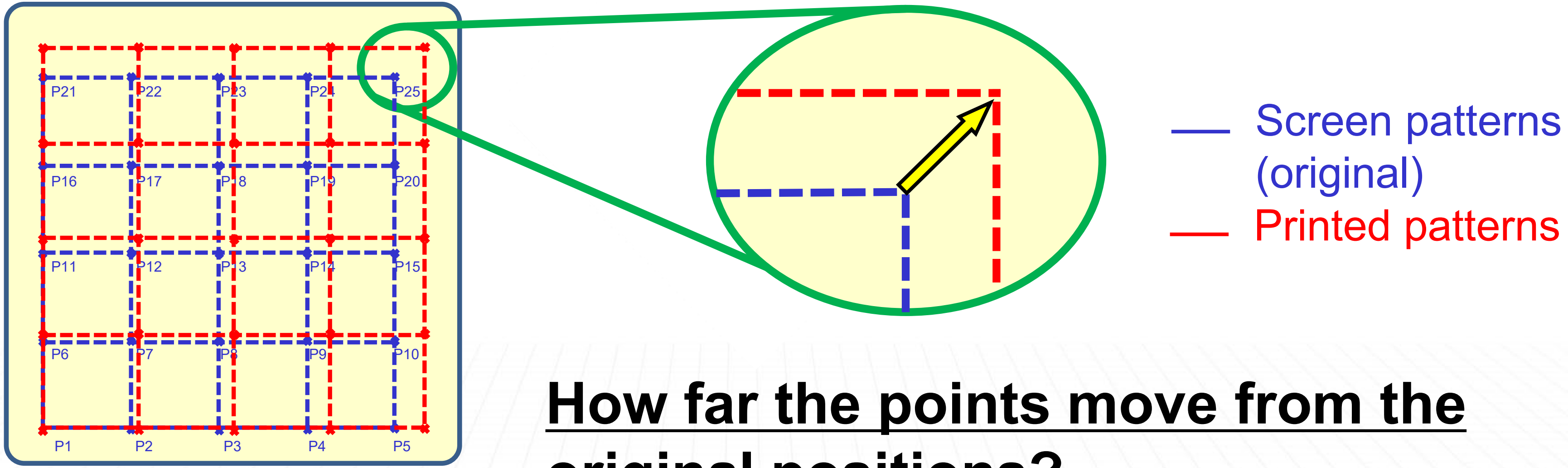
Pattern printed on a substrate is expanded and deformed





Definition of “Displacement”

Displacement = |Printed – Screen|

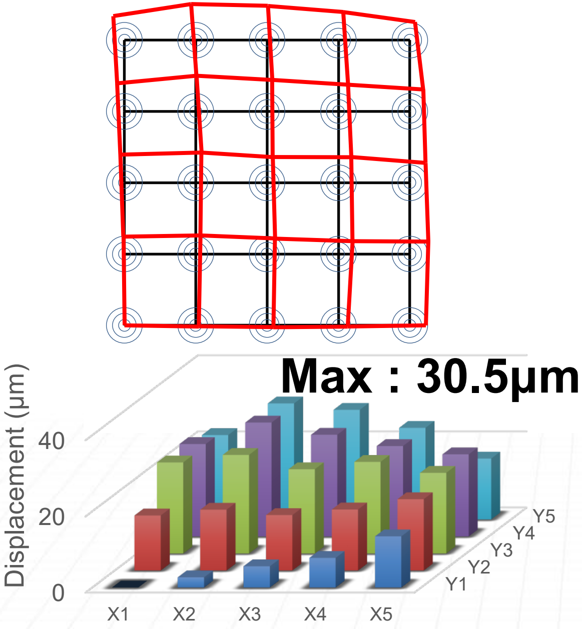


How far the points move from the original positions?

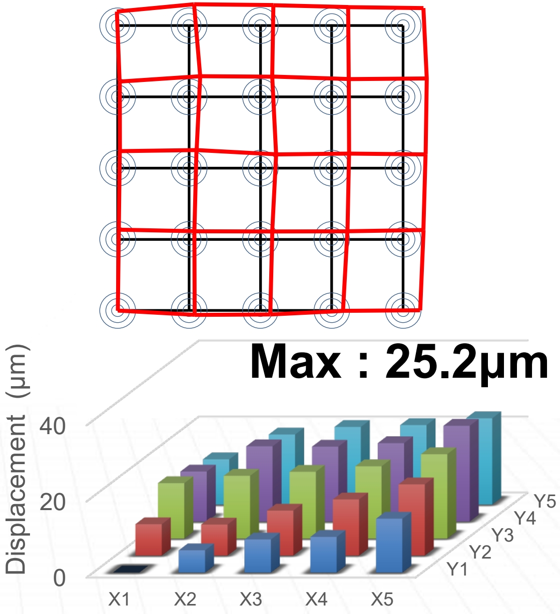
Results - Displacement

The non-calendered mesh is more deformed than the calendered one.

Non-calendered



Calendered



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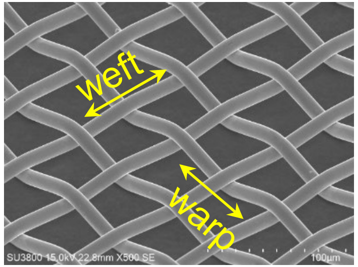
Simulation – FEM analysis

- Mesh : <u>**Orthotropic material**</u>
  - warp and weft
- Stress(σ)/Strain(ε) relationship equation for orthotropic materials



$$\begin{pmatrix} \varepsilon_T \\ \varepsilon_L \\ \varepsilon_{TL} \end{pmatrix} = \begin{bmatrix} 1/E_T & -\nu_{LT}/E_L & 0 \\ -\nu_{LT}/E_L & 1/E_L & 0 \\ 0 & 0 & 1/G_{LT} \end{bmatrix} \begin{pmatrix} \sigma_T \\ \sigma_L \\ \tau_{TL} \end{pmatrix}$$

(T=x, L=y)
ε: Strain
σ: Stress
τ: Shearing stress
ν: Poisson's ratio
E: Modulus of longitudinal elasticity
G: Shearing modulus

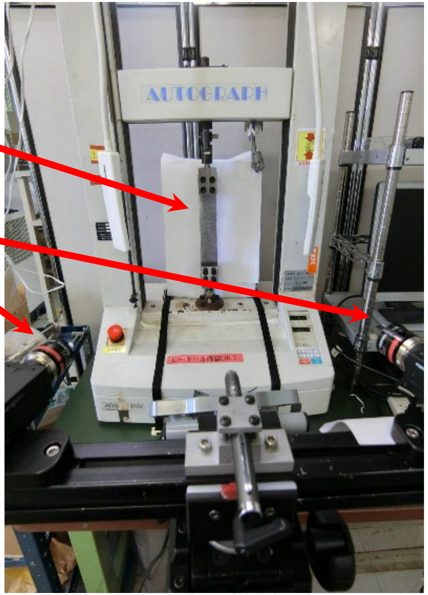
- E, v, and G can be obtained by tensile tests in the warp, weft, and 45-degree directions of the mesh.

Tensile test of mesh

The in-plane stress-strain curves of the meshes in the direction of warp, weft, and 45degree were measured by the "image correlation method"

Test sample

Cameras

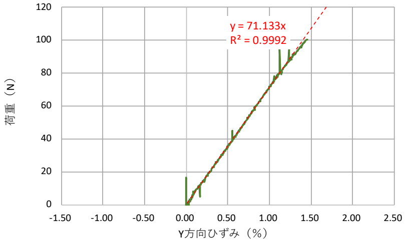


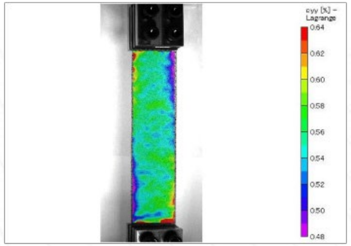
Test specimen

UHS-520/11 (11μm,#520), 6 pieces (without emulsion)

a) Non-calendered mesh (t=26μm) x 3 directions (0°, 45°, 90°)

b) calendered mesh (t=11μm) x 3 directions (0°, 45°, 90°)





Caluculated E, ν, and G

The following parameters are calculated from the results of tensile tests of the meshes

	$E_{L(0°)}$ *1 (MPa)	$E_{T(90°)}$ *1 (MPa)	ν_{LT} (-)	G_{LT} *2 (MPa)
Non-calendered	**139.48**	**268.08**	**0.1892**	**0.1131**
Calendered	**272.94**	**235.42**	**0.2952**	**0.8339**

*1 Elastic modulus per width of 1mm

*2 G_{LT} is calculated from the following equation

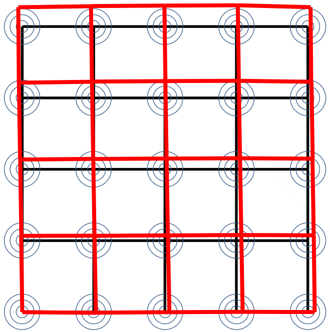
$$\frac{1}{G_{LT}} = \frac{4}{E_{45°}} - \left(\frac{1}{E_L} + \frac{1}{E_T} - \frac{2\nu_{LT}}{E_L}\right)$$

The coordinate of each point of the deformed pattern is simulated by FEM analysis using these values on the mesh.

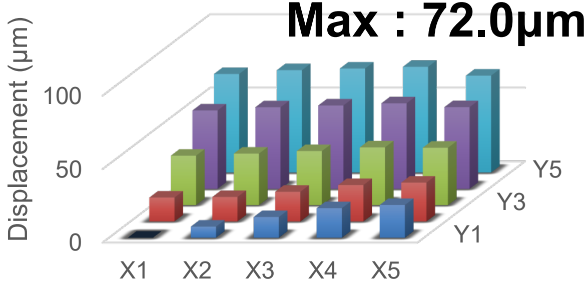
Simulation results - Displacement

The non-calendered mesh is more deformed than the calendered one.

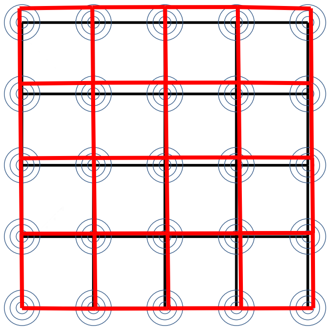
Non-calendered



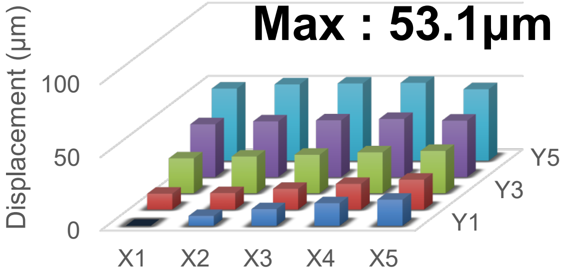
Max : 72.0μm



Calendered



Max : 53.1μm



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Summary of results

Quantitative analysis of the mechanical behavior of the non-calendered and calendered mesh samples revealed a significantly higher degree of deformation in the former. The calendering process can improve the mechanical uniformity of the as-woven mesh.

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	Displacement (μm)	
	Non-calendered	Calendered
Printing result	30.5 >	25.2
Simulation	72.0 >	53.1

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Conclusions

1. Based on the experiments, the calendered mesh shows less pattern deformation compared to the non-calendered one. This is because calendering aligns the warp and weft at the stress-strain curve.

2. The simulation demonstrates a similar trend to the experiment, but its magnitude is greater than that observed in the experiment.

3. To make a comparison with the results of other experimental conditions, further improvements are required for the simulation.

Thank you for your attention