The 12th edition of the Metallization and Interconnection Workshop for Crystalline Solar Cells - October 23rd and 24th, 2024

Screen-printed Pattern Positioning Accuracy Affected by the Mechanical Properties of Screen Mesh

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Outline

- Introduction
- Methods
    - Experiments & Simulations
- Results
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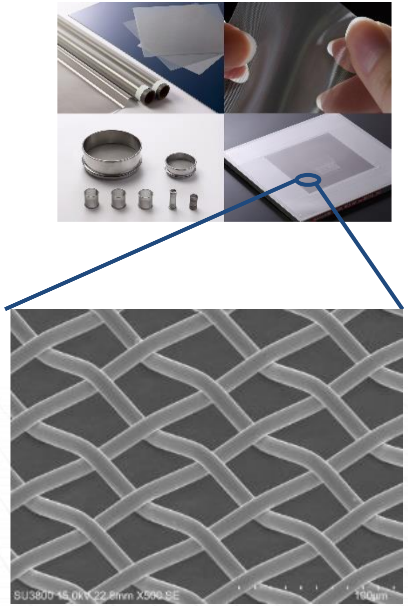
ASADA MESH CO., LTD.

Kagoshima Plant, Japan

Headquarters, Osaka, Japan

Suzhou Plant, China

Products for screen printing



https://asadamesh-global.com/en/

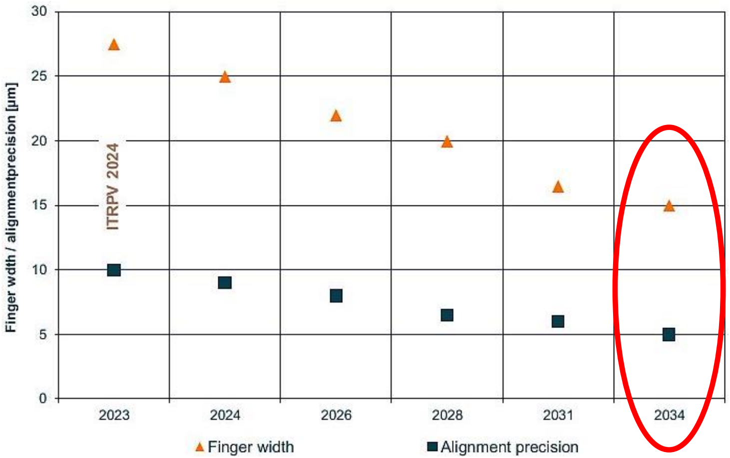
Positioning accuracy in screen printing

Selective emitters

Misaligned finger electrodes

Contact resistance ⤴
Recombination ⤴

Required accurate metallization

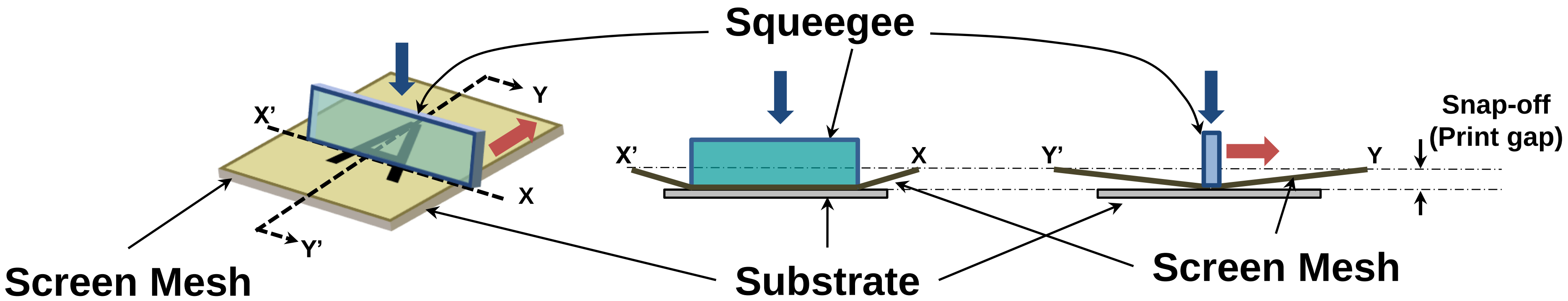


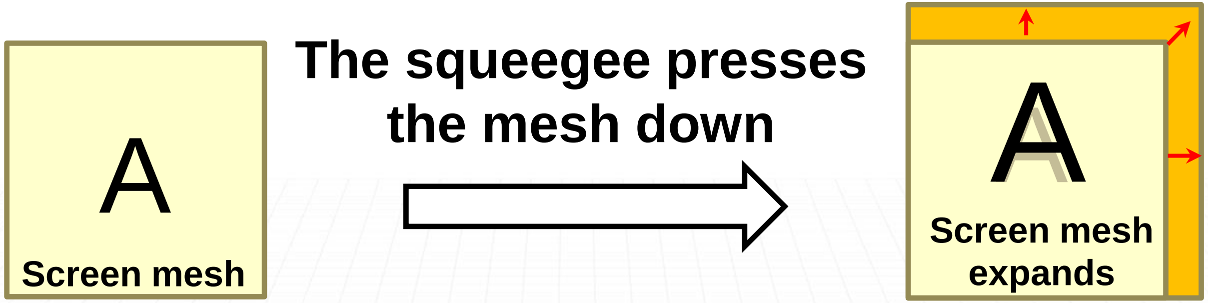
VDMA, International Technology Roadmap for Photovoltaics (ITRPV) 2023 Results. https://www.vdma.org/viewer/-/v2article/render/93952448, 2024 (accessed 17 September 2024).

The improvement of Finer finger 15 µm
&
Alignment precision 5 µm by 2034

High positioning accuracy in screen printing is essential for improving the performance of silicon solar cells.

A cause of the reduced positioning accuracy





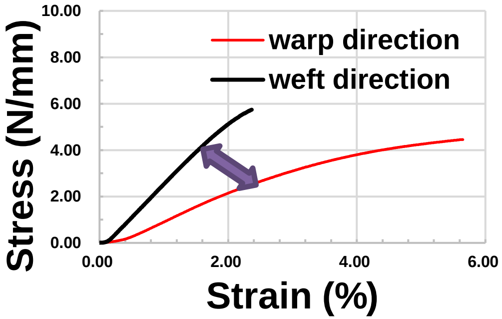
The deformations directly impact the positioning accuracy of printed patterns.

Findings from the previous study presented at the 11th MIW(2023)

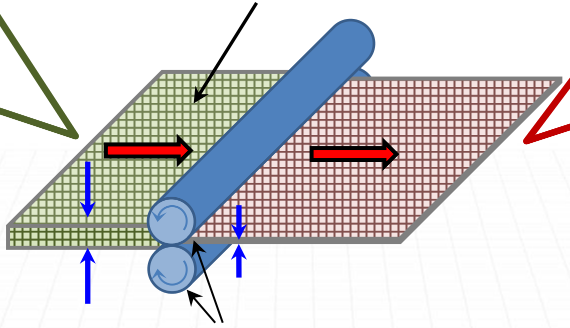
The mechanical properties of screen meshes affect the positioning accuracy in screen printing.

Calendering process

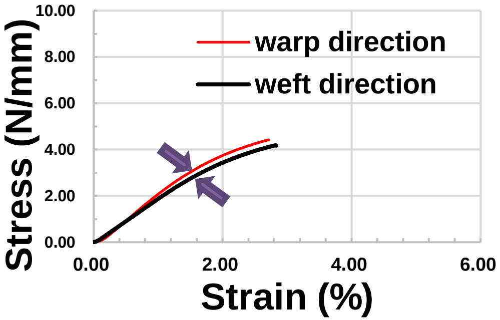
Non calendered



Non-uniform



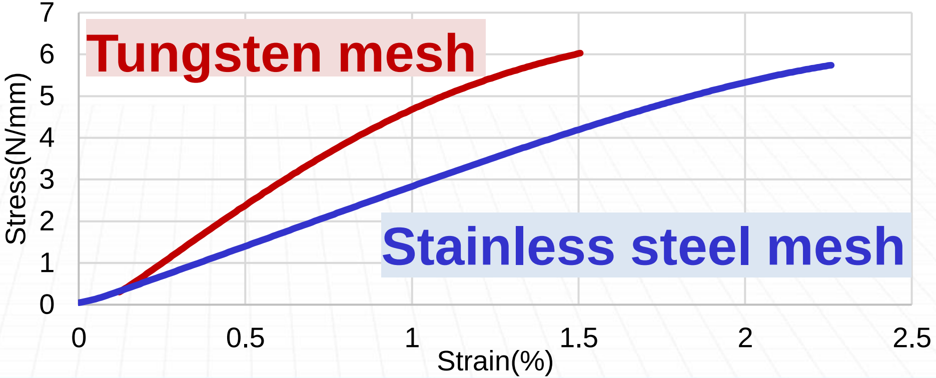
Calendered



Uniform

Aim of the study

- **To compare how a tungsten mesh, which has a different <u>mechanical property</u> from a stainless steel mesh, affects the positioning accuracy of screen printing**
  - **The stress – strain curve of a tungsten mesh is steeper than that of stainless steel mesh.**



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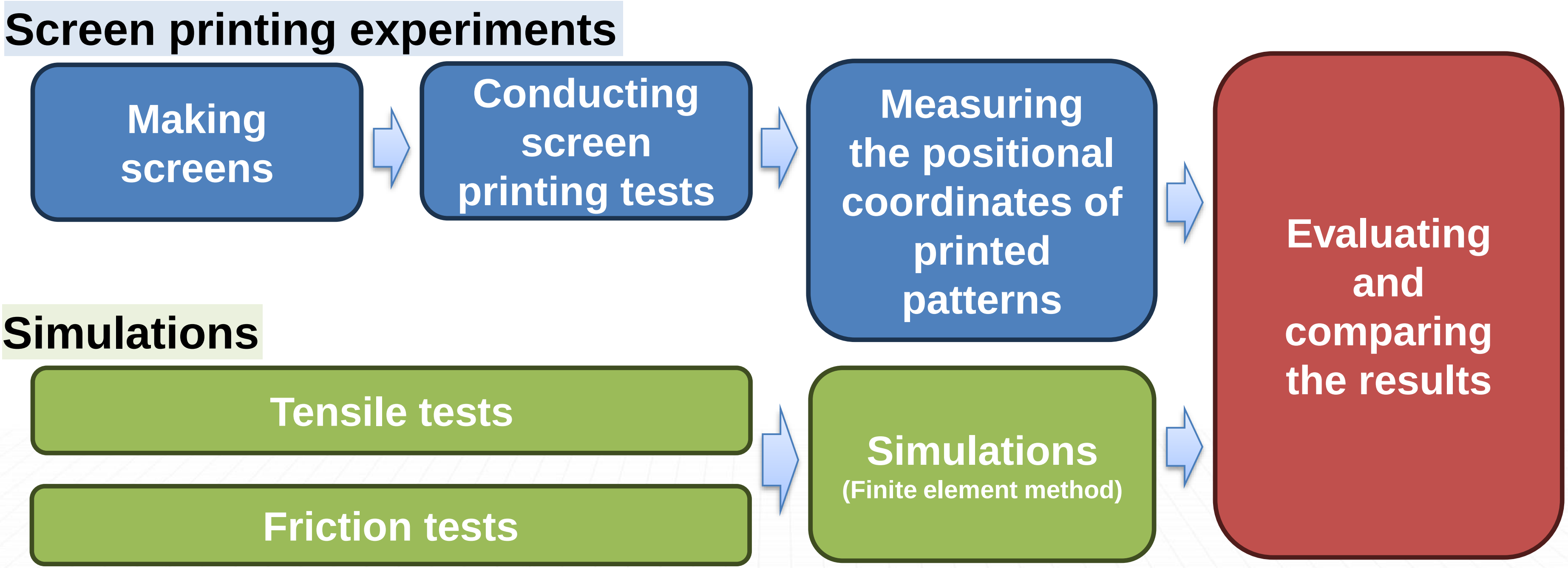
Flow of the experiments and simulations



Screen printing experiments

Making screens

Conducting screen printing tests

Measuring the positional coordinates of printed patterns

Simulations

Tensile tests

Friction tests

Simulations
(Finite element method)

Evaluating and comparing the results

Screen meshes

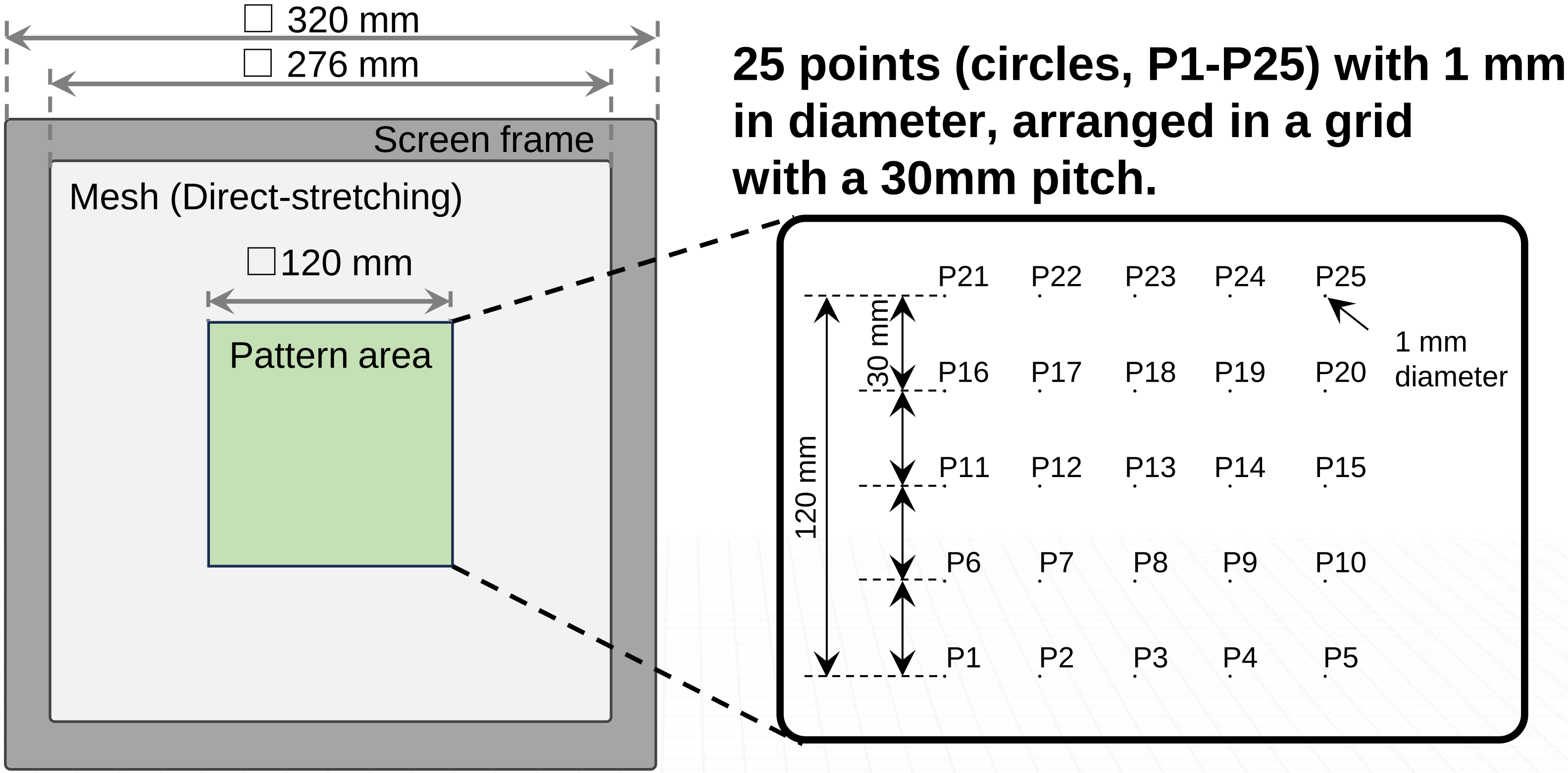
Two types of meshes with the same mesh counts and wire diameter

Screen mesh	Stainless steel mesh[*1]		Tungsten mesh[*2]	
	Non-calendered t=26 µm	Calendered t=11 µm	Non-calendered t=28-30 µm	Calendered t=11 µm
Mesh counts per inch	520			
Wire diameter	11 µm			
Bias angle	22.5 degrees			

[*1] UHS-520/11
[*2] SHS-T-520/11
Both manufactured by Asada Mesh Co., Ltd.

Screen overview

25 points (circles, P1-P25) with 1 mm in diameter, arranged in a grid with a 30mm pitch.



Screen printing conditions

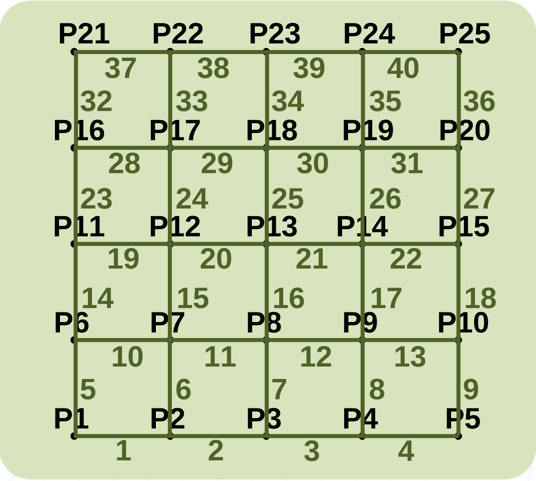
Screen printing parameters	
Snap-off (Print gap)	**1.3 mm**
Printing speed	**50 mm/sec**
Squeegee width	**170 mm**
Squeegee pressure (at the squeegee width)	**45.3 N/170mm**

These conditions were applied to screen printing experiments and simulations.

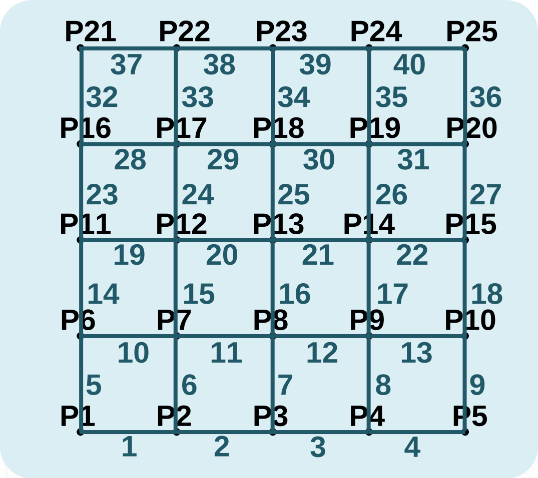
Evaluation Method

Each group of 25 points forms 40 virtual lines.

Patterns on screen

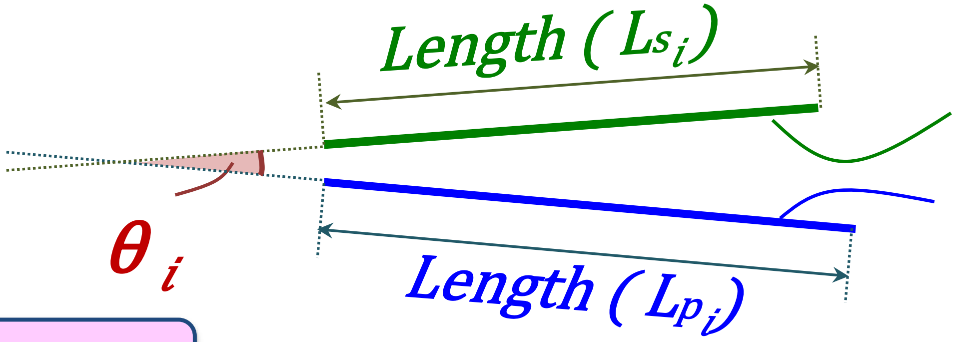


Patterns on substrate



The difference between the lines on the screen and the corresponding lines on the substrate was evaluated, for all the 40 virtual lines.

Distortion index 1 & Distortion index 2



Line # i on the screen

Line # i on the printed substrate

i = 1 - 40

Length

<u>Distortion index 1</u> = The average of | Ls_i - Lp_i |

Angle

<u>Distortion index 2</u> = The average of | θ_i |

What do the indices values indicate?

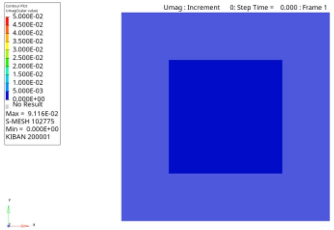
A smaller index value

The less mesh deformation

The better positioning accuracy

Simulations – Finite Element Method (FEM)

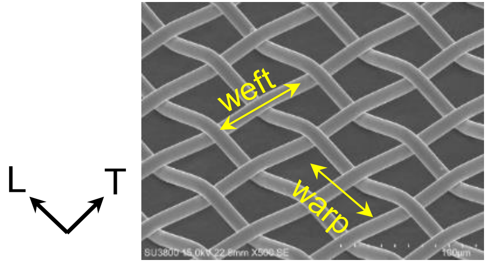
- What was simulated?
  - The screen mesh deformation as the squeegee moves across the mesh



- Mesh : **Orthotropic material**
  - The constitutive equation for orthotropic materials

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

ε: Strain
σ: Stress
τ: Shear stress
ν: Poisson's ratio
E: Young's modulus
G: Shear modulus



  - E, ν, and G were obtained from the tensile tests in the warp, weft, and 45-degree directions of the meshes.
- The friction coefficients between the mesh and the squeegee, were obtained through the friction tests.

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Results of the tensile tests and friction tests

		$E_{L(0^\circ)}$ *1 (MPa)	$E_{T(90^\circ)}$ *2 (MPa)	ν_{LT} (-)	G_{LT} *3 (MPa)	μ *4 (-)
Stainless steel mesh UHS-520/11	N	139	268	0.19	0.11	0.33
	C	273	235	0.30	0.83	0.30
Tungsten mesh SHS-T-520/11	N	181	590	0.14	0.12	Not measured*5
	C	403	326	0.21	1.25	Not measured*5

N : Non calendered mesh
C : Calendered mesh

*1 Young modulus per width of 1mm in the warp direction
*2 Young modulus per width of 1mm in the weft direction
*3 calculated from the following equation
*4 Dynamic friction coefficient
*5 The values of stainless steel mesh were used in the simulation.

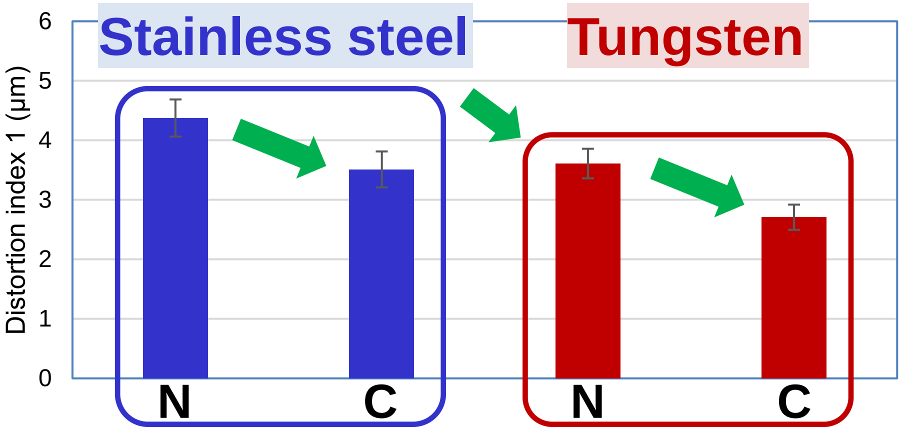
$$\frac{1}{G_{LT}} = \frac{4}{E_{45^\circ}} - \left(\frac{1}{E_L} + \frac{1}{E_T} - \frac{2\nu_{LT}}{E_L}\right)$$

The coordinates of the 25 points on the screen mesh altered by the squeegee's movement were simulated by the FEM analysis using these values.

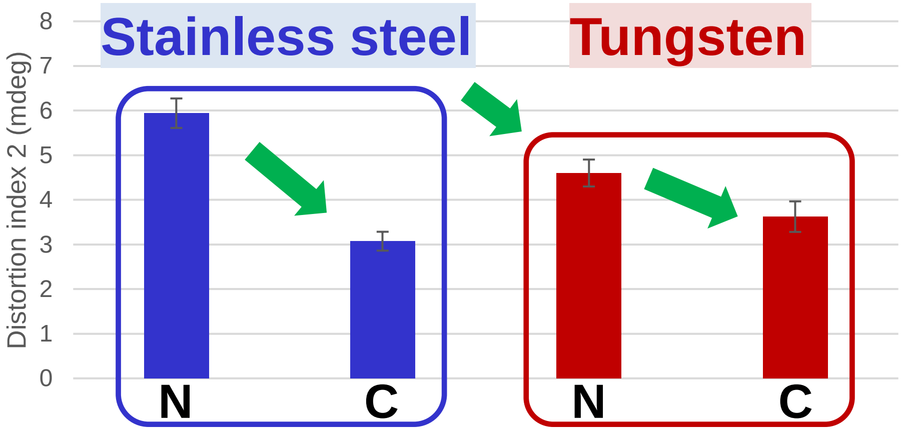
Printing results

N : Non calendered mesh

C : Calendered mesh



Distortion index 1
(Length)

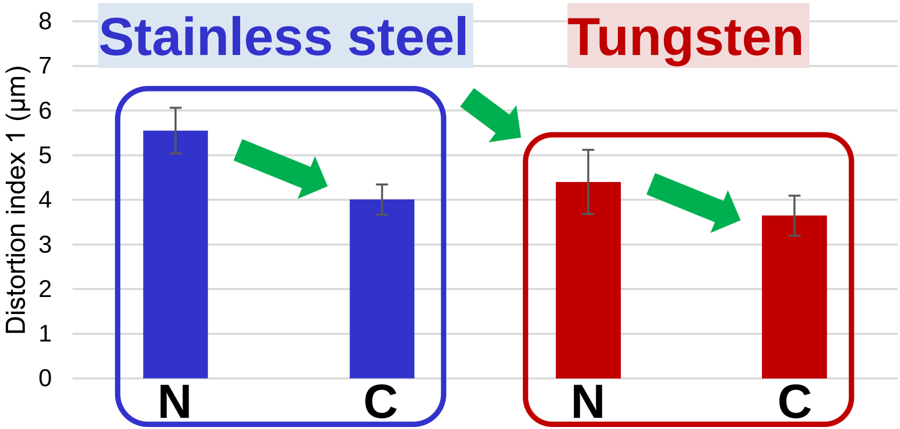


Distortion index 2
(Angle)

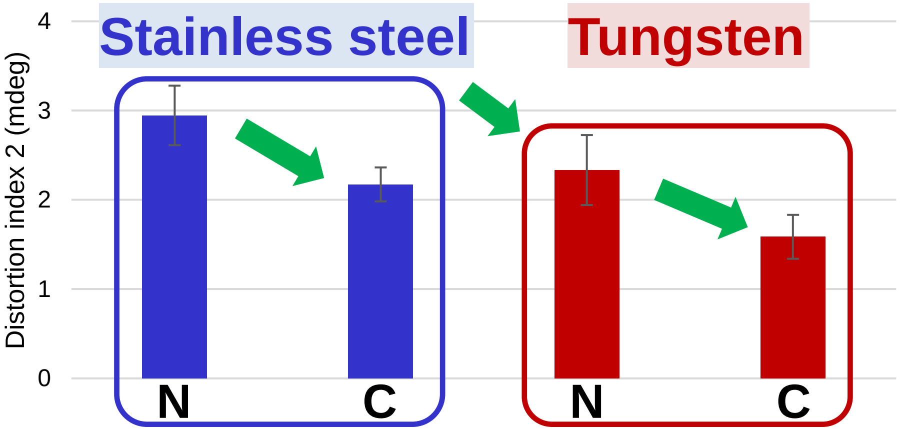
- **The tungsten meshes deformed less than the stainless steel meshes.**
- **The calendering process is effective in reducing the pattern distortion.**

Simulation results

N : Non calendered mesh
C : Calendered mesh



Distortion index 1
(Length)

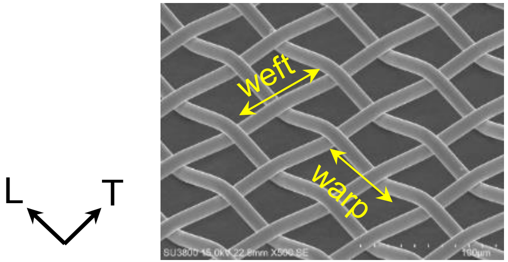


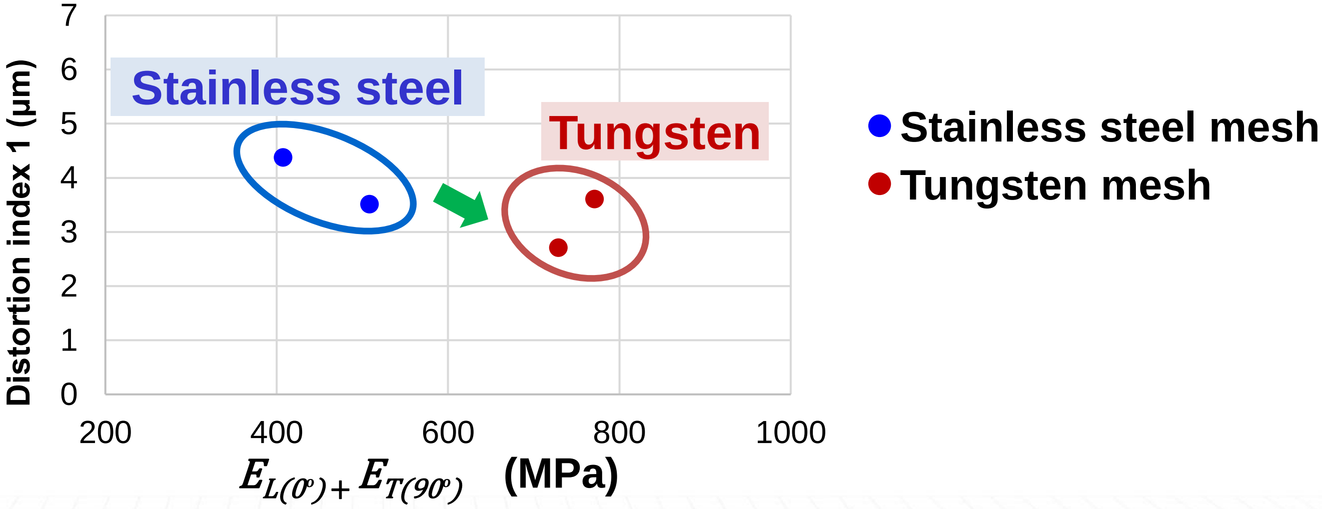
Distortion index 2
(Angle)

These simulation results followed the same qualitative trends as the actual printing results.

The relation between the pattern distortion and the mechanical properties

Distortion index 1
(Length)



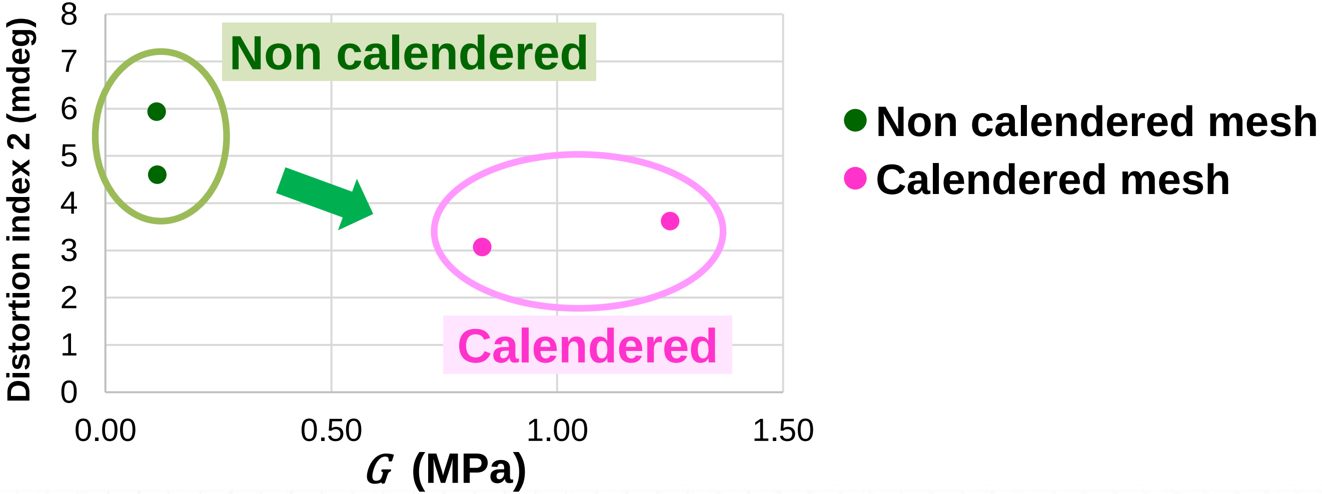


- Tungsten meshes with larger *E* (Young's modulus) than stainless steel meshes showed less Distortion index 1.

➡ The variations in the mechanical properties of the screen mesh material can affect screen-printed pattern positioning accuracy.

The relation between the pattern distortion and the mechanical properties

Distortion index 2
(Angle)



- Calendered meshes with larger *G*(shear modulus) than non calendered meshes showed less Distortion index 2.

➡ The calendering process can improve screen-printed pattern positioning accuracy.

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Conclusions

- **The variations in the mechanical properties of the mesh material can affect the positioning accuracy.**
  - Materials with larger E are more advantageous.
- **The calendering process can improve positioning accuracy.**
  - Calendered meshes with larger G are more advantageous.
- **Our FEM analysis has shown that it is possible to predict the positioning accuracy based on these mechanical properties.**

Thank you for your attention