The Ruhr Fellows and their supervisors

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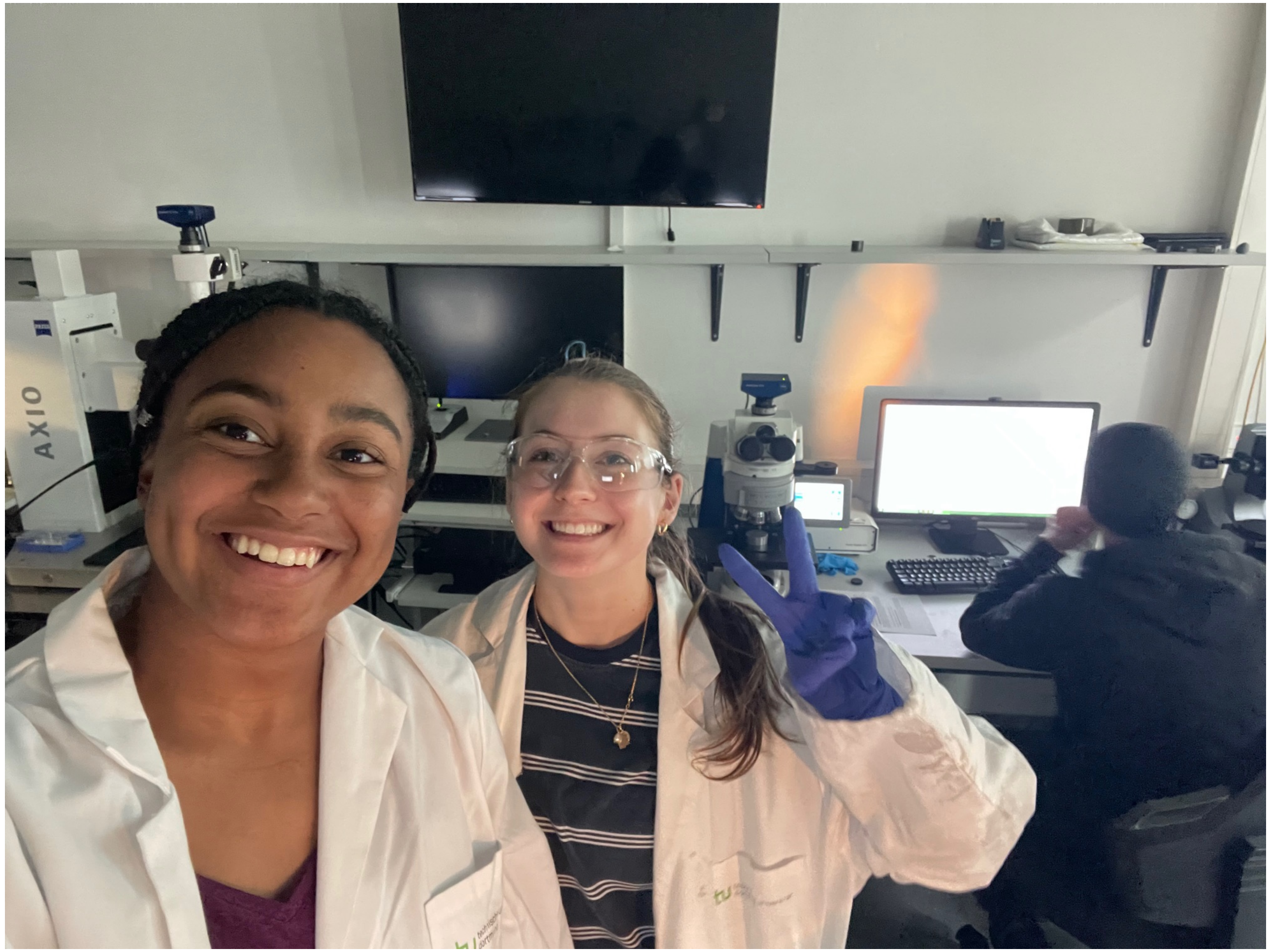

Me and Lexy measuring the surface hardness of our samples

The 3 IUL fellows

technische universität
dortmund

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Lightweight Components

Analyzing the effect of different process parameters of ball-burnishing on the mechanical properties of additively manufactured flat sheet

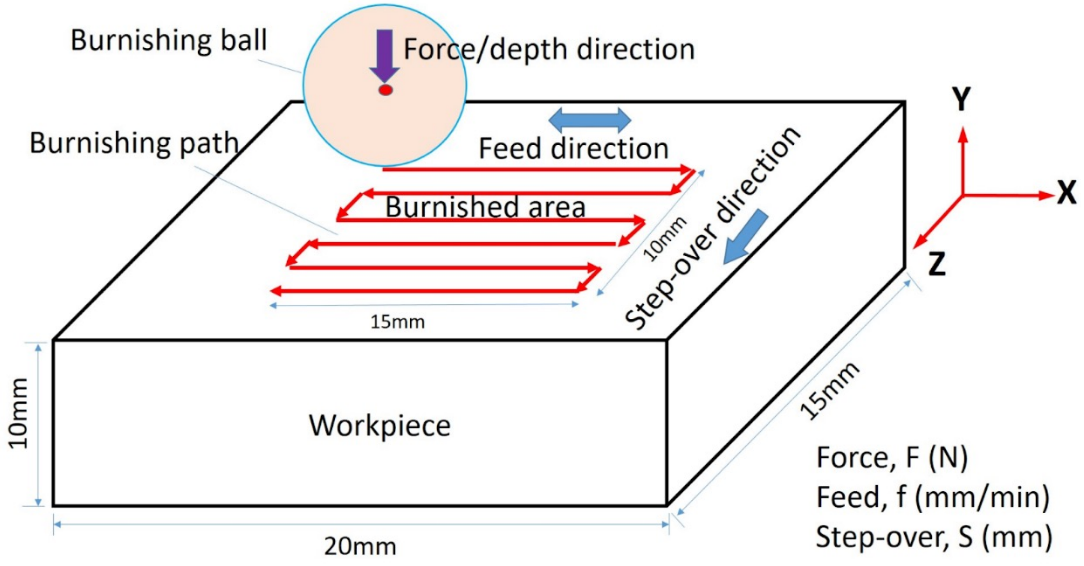
Lael Ayala,
Harvard College c/o 2026,
22.07.2024

AGENDA

- Introduction
- Literature Review
- Surface Roughness
- Residual Stresses
- Hardness
- Tensile strength
- Length and Thickness
- Conclusion

INTRODUCTION

- Laser Powder Bed Fusion (LPBF) needs extensive post processing such as ball burnishing in order to smooth surface roughness
- Ball Burnishing requires a round tool to impact a surface and flatten any metal peaks giving the object a shiny look
- **Burnishing Parameters:** Pressure, step over size, tool path
- **Properties Measured:** surface roughness, surface hardness, tensile strength, and residual stress of LPBF flat sheets



(Quelle:)

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(Quelle:)

PRESSURE

S. No.	1	2	3	4	5
Burn. Force, kgf.	8	25	42	60	85
Hardness, HRB.	66	68	70	69.75	69.25

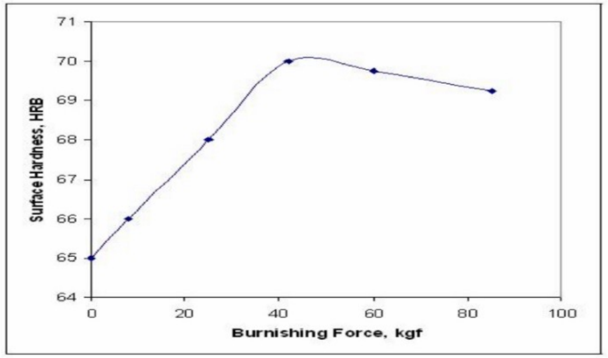
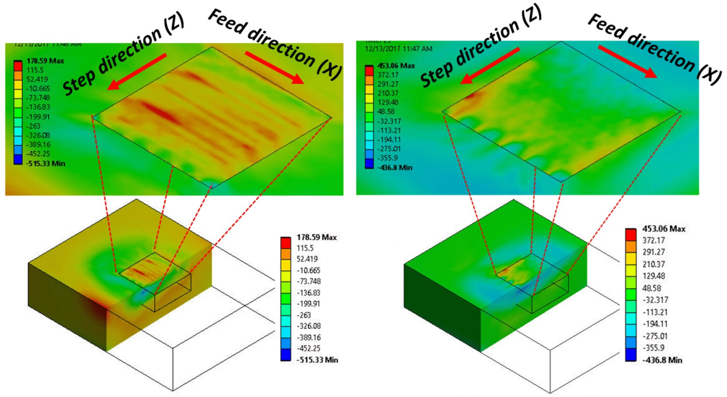


Figure 1: Surface Hardness varying with Burnishing Force [2]

As burnishing pressure increases, surface roughness decreases[1].

However, as burnishing force increases, surface hardness of steel increases, but then starts to decrease[2]

As burnishing force increases,
residual stress increases in both the X and Z directions [3]



(a) Residual stress along X (b) Residual stress along Z

Figure 2: Diagram of residual stresses[3]

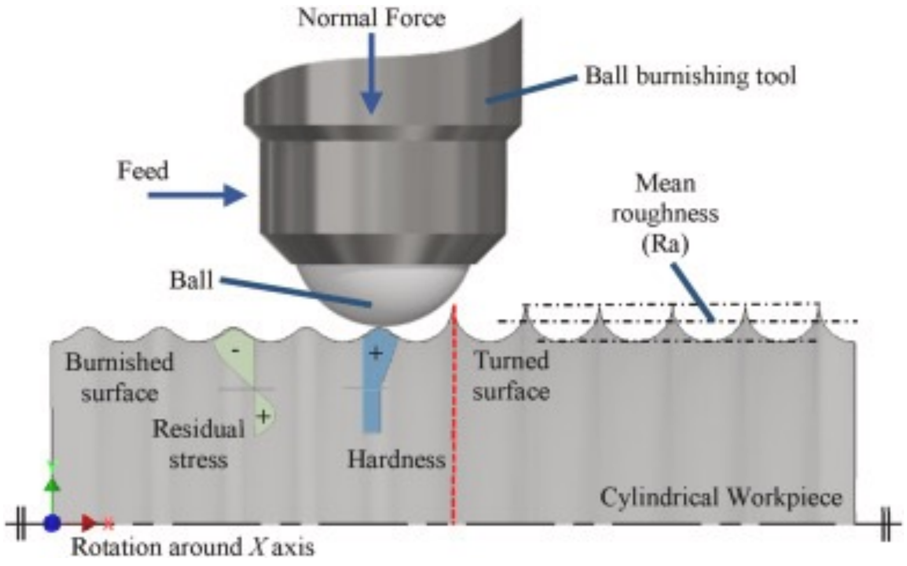
	Ultimate stress (Mpa)	Energy at fracture (J)	Elongation at fracture (%)
Unburnished	121.24±1	14.6	8.70±0,03
Burnished: 50 N–800 rpm–0.05 mm/rev	115.11±1	15.23	9.60±0,03
Burnished: 100 N–400 rpm–0.1 mm/rev	115.19±1	16.8	12,04±0,03
Burnished: 200 N–400 rpm–0.1 mm/rev	125.16±1	21.01	12.94±0,03

Figure 3: How different burnishing forces affects elongation at fracture on aluminum 1050A[4]

An increase in burnishing force, improves ductility [4]

(Quelle:)

STEP OVER/ HATCHING DISTANCE



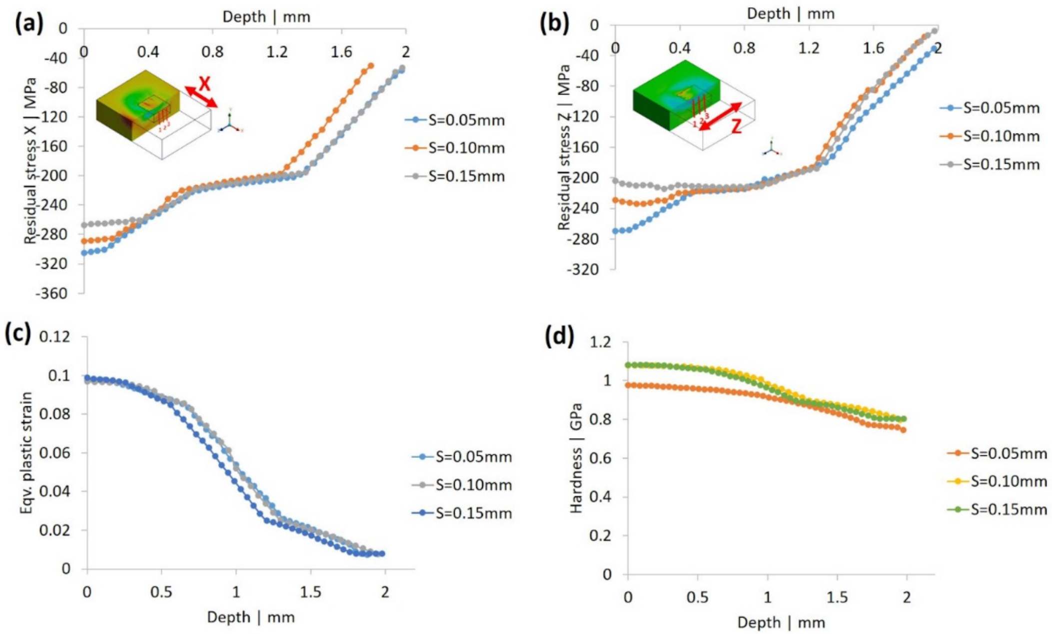


Figure 4: Effect of burnishing step-over on (a) residual stress along X (feed direction); (b) residual stress along Z (step-over direction); (c) plastic strain and (d) hardness at F = 1650 N, f = 300 mm/min [3].

Increasing step over distance, increases surface roughness [5]

Increasing the step over also increases the residual stresses and surface hardness [3]

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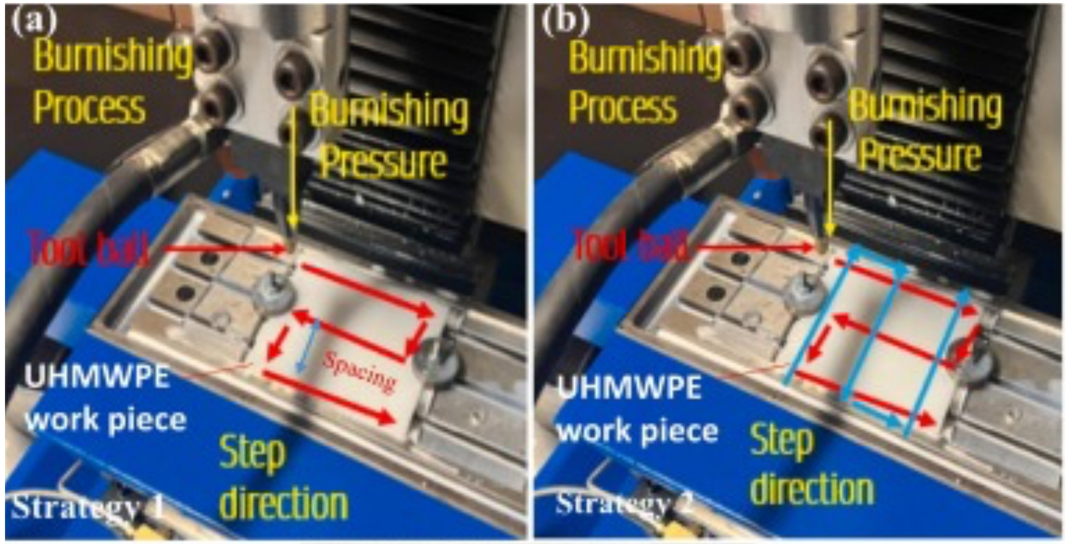
Tool Path Pattern



Single Parallel and Cross Parallel resulted in a reduction in surface roughness by up to 46 % and 70 % at 131 bar respectively [1].

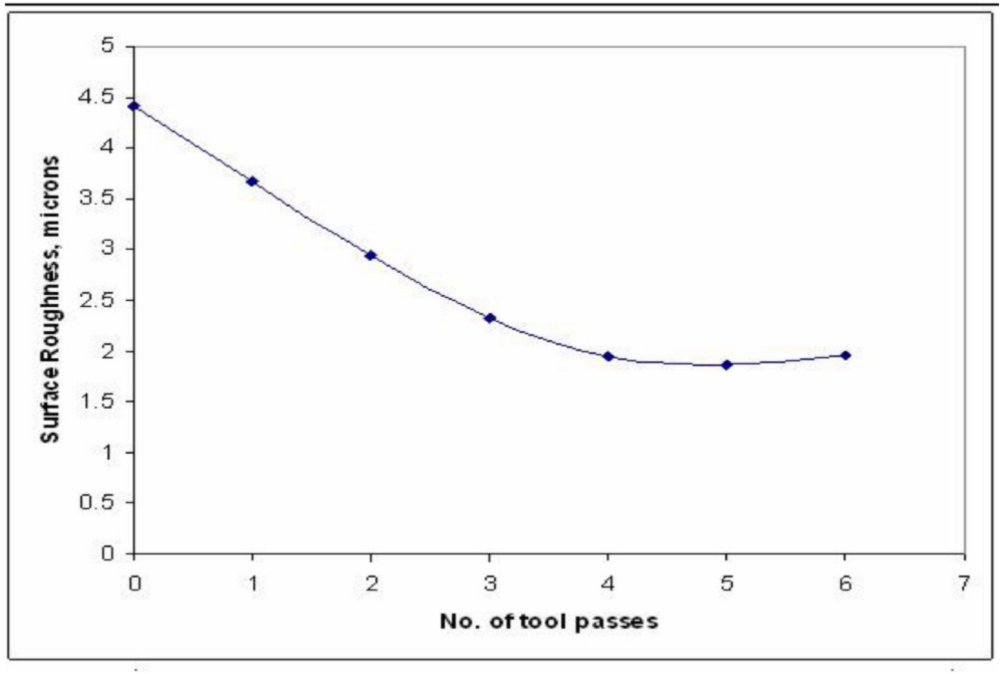


Figure 5 : Variation of surface roughness with number of burnishing passes

Burnishing with 2 passes instead of 1 can increase tensile and yield strength by 3 %[6]

Increasing No. of tool paths can decrease surface roughness to an extent, before it starts increasing[2]

(Quelle:)

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CITATIONS

[1] Li, T., Uddin M., Steven's G.,(2024) Effect of ball burnishing on surface roughness, wettability, mechanical integrity and antifouling resistance of Uhmwpe. *Surface and Coatings Technology*, 476, https://doi.org/10.1016/j.surfcoat.2023.130237

[2] Malleswara Rao J. N., Chenna Kesava Reddy A., Rama Rao P. V., (2011) The Effect of Roller Burnishing on Surface Hardness and Surface Roughness on Mild Steel Specimens. *International Journal of Applied Engineering Research.* 1(4), 777-785.

[3] Uddin M., Hall C., Hooper R.,Charrault E., Murphy P., Santos V., (2018), Finite Element Analysis of Surface Integrity in Deep Ball-Burnishing of a Biodegradable AZ31B Mg Alloy. *Metals.* 8(2) 136-154

[4] Gharbi F., Sghaier S., Hamdi H. & Benameur T, (2012), Ductility Improvement Of Aluminum 1050A Rolled Sheet By A Newly Designed Ball Burnishing Tool Device, *J Adv Manuf Technol*, 56.

[5] Stöckmann R., Putz M., (2019) Modelling of Surface Formation Mechanism During Burnishing of Aluminium. *17th CIRP Conference on Modelling of Machining Operations*. 82. pp 450-454

[6] Ravikanth Raju P. , Chinna Maddaiah K., Anjineyulu. K, (2017) Investigation on the Influence of Ball Burnishing Parameters on Mechanical Properties of Al-Bn Composites. *IJAET*. 10(2), 175-184

(Quelle:)

Methodology

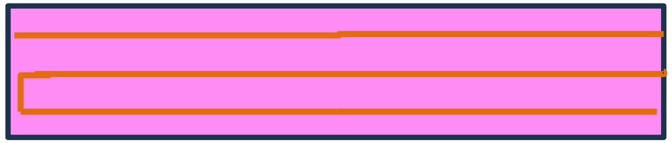
Machine	Lasertec 65 3D hybrid (DMG Mori)
Tool	HG19 and HG13(some)
Pressure [bar]	100, 200
Hatching distance [mm]	0.2, 0.6
Strategy	Along the tensile specimen (*Strategy I*), perpendicular to the tensile specimen (*Strategy II*)
Speed [mm/min]	500

Coding format:

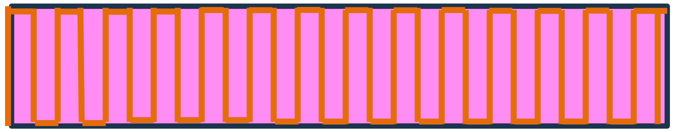
Pressure - Hatching distance - Strategy – Repetition

Example: 100-02-I-1

Strategy I



Strategy II



Total: 34 samples. HG19:24. HG13:7. Unburnished: 3
For each setup. 3x
Number of the experiments: 3 x 2 x 2 x 2 = 24 HG19 samples

Length, width, thickness: 110 mm, 25 mm, 3.04mm

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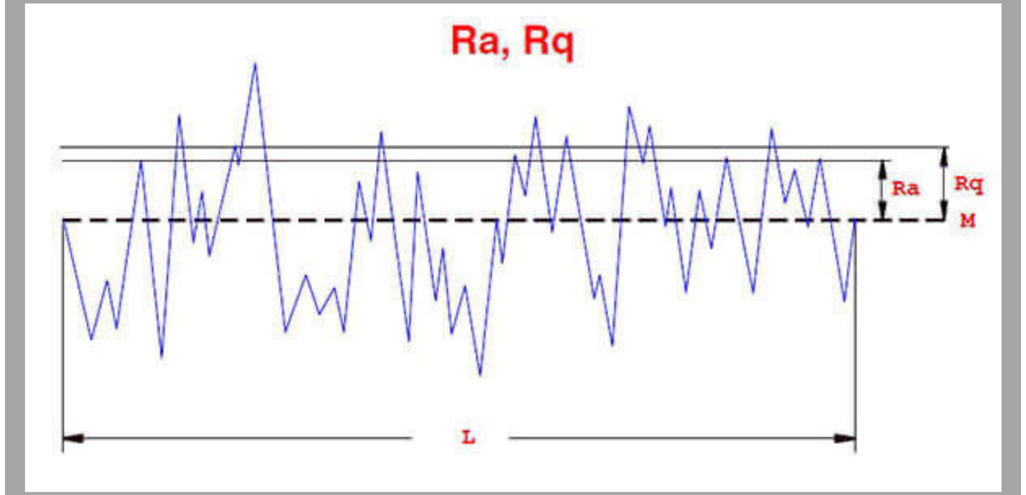
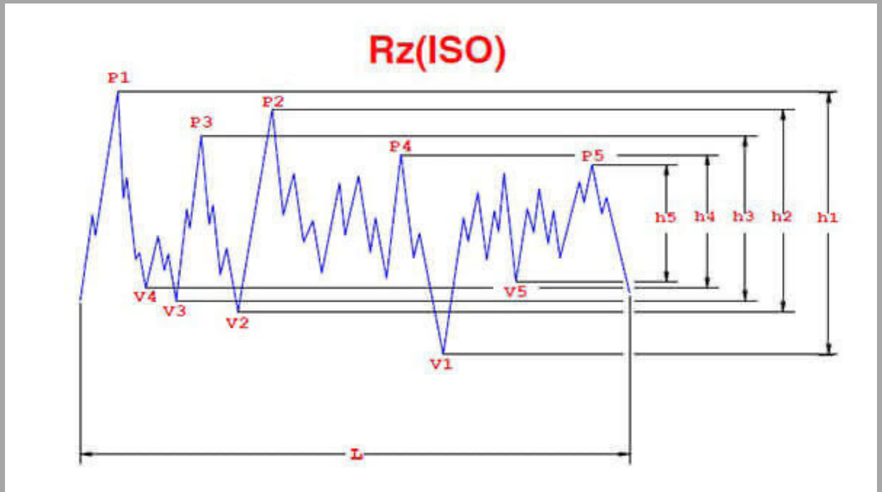
(Quelle:)

2D Surface Roughness

Ra is the average of the absolute value of profile heights over the evaluation



Rz is the average value of the five highest peaks and the five deepest values within the evaluation length.



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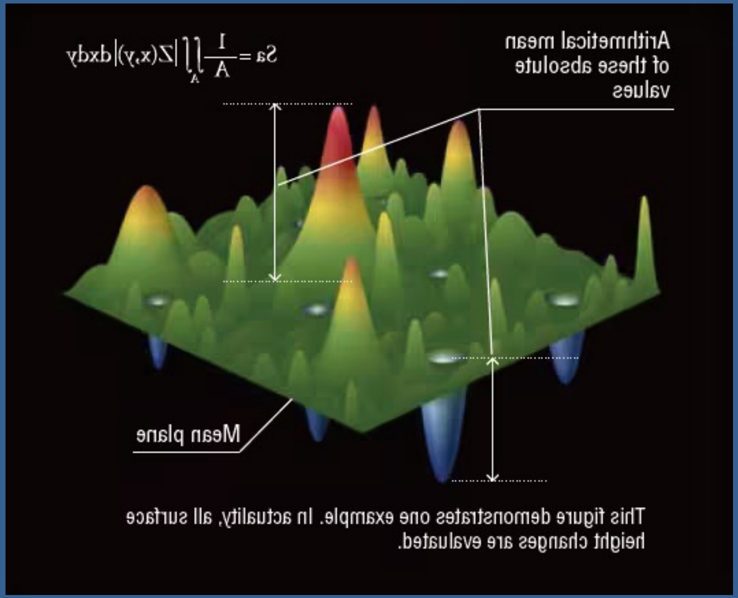
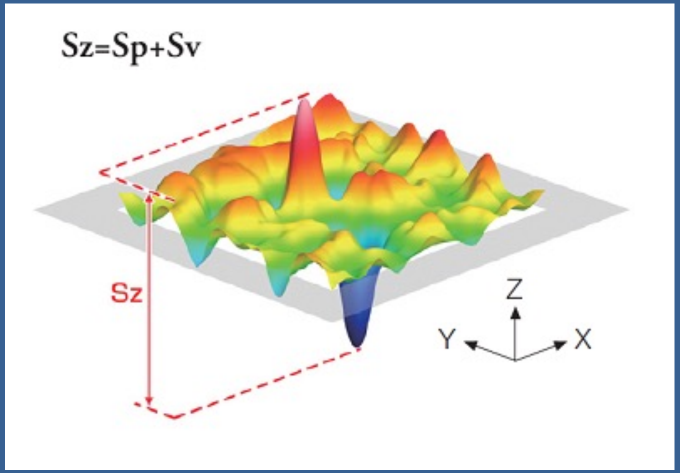
3D Surface Roughness

Sa is the difference in height of each point compared to the arithmetical mean of the surface.



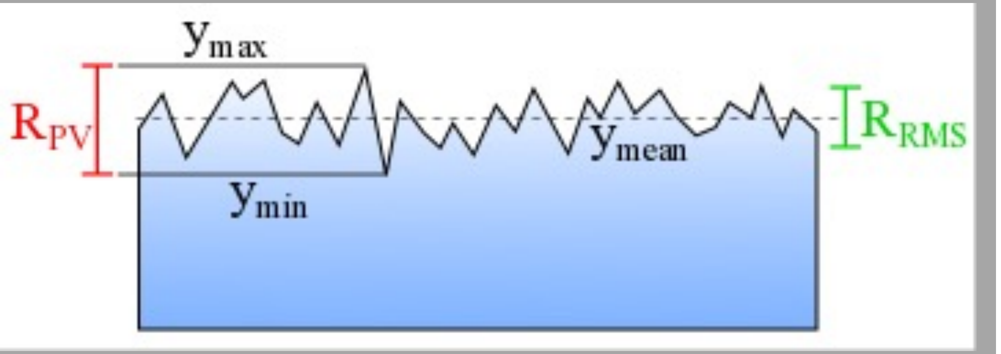
Sz is defined as the sum of the largest peak height value and the largest pit depth value within the defined area.



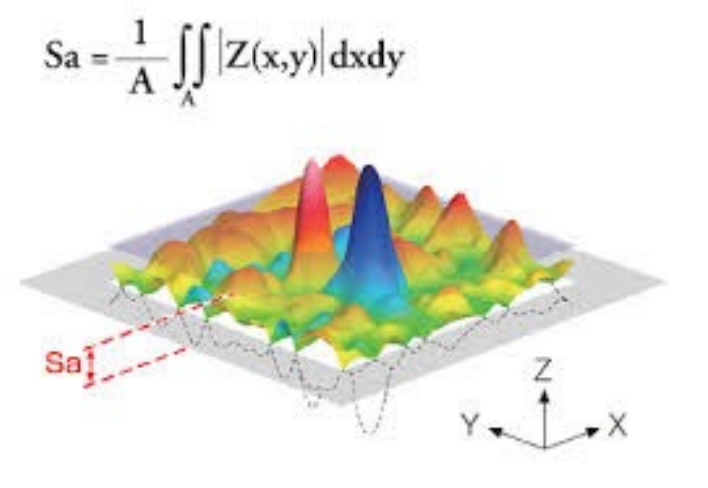
Surface Roughness – Definitions and Methodology

Ra vs Sa

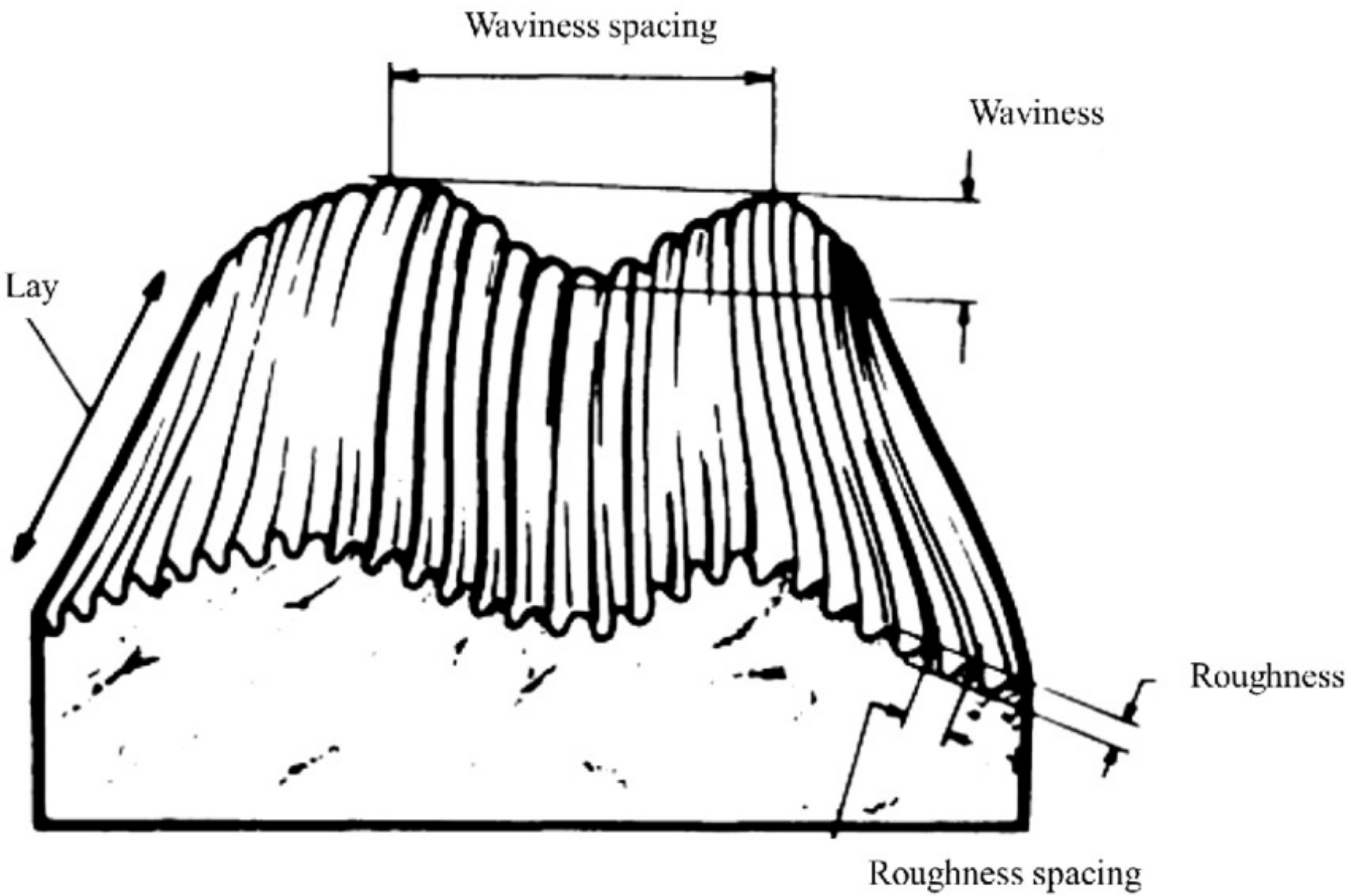
Ra is the average of the surface heights along the measurement trace



Sa is the average roughness over an area

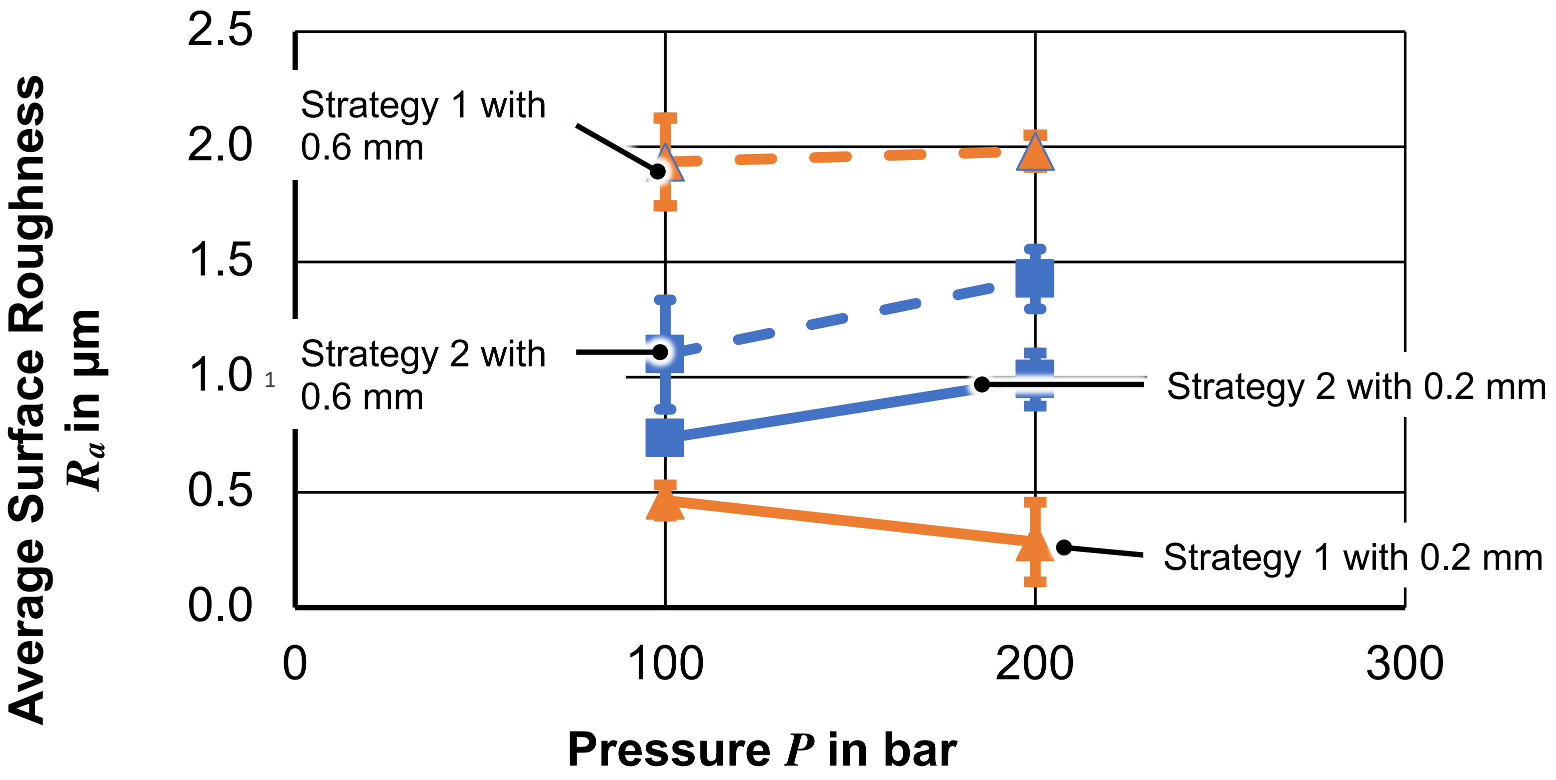


Surface Roughness – Definitions and Methodology

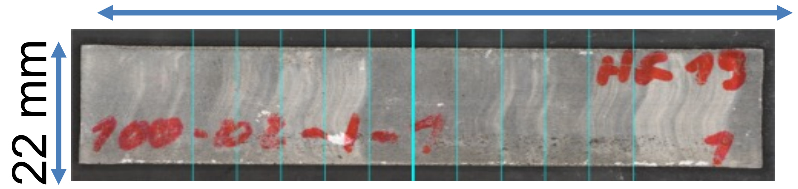


Waviness refers to uneven surfaces that appear periodically at longer intervals than the roughness

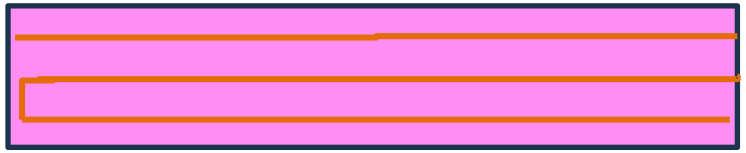
2D Surface Roughness – Ra Vertical



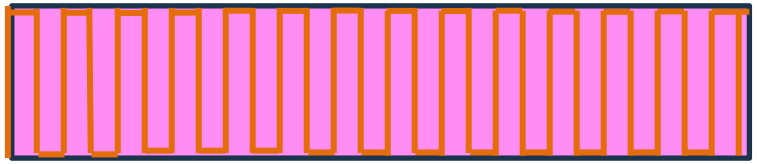
Vertical Multiline Roughness



Strategy I



Strategy II



- When running your finger up and down, strategy 1 will feel rougher because you are going against the cut.
- 0.6mm will also feel rougher because of the larger step over

As printed	
R_a (µm)	R_z (µm)
10.95 ± 0.89	92.65 ± 10.57

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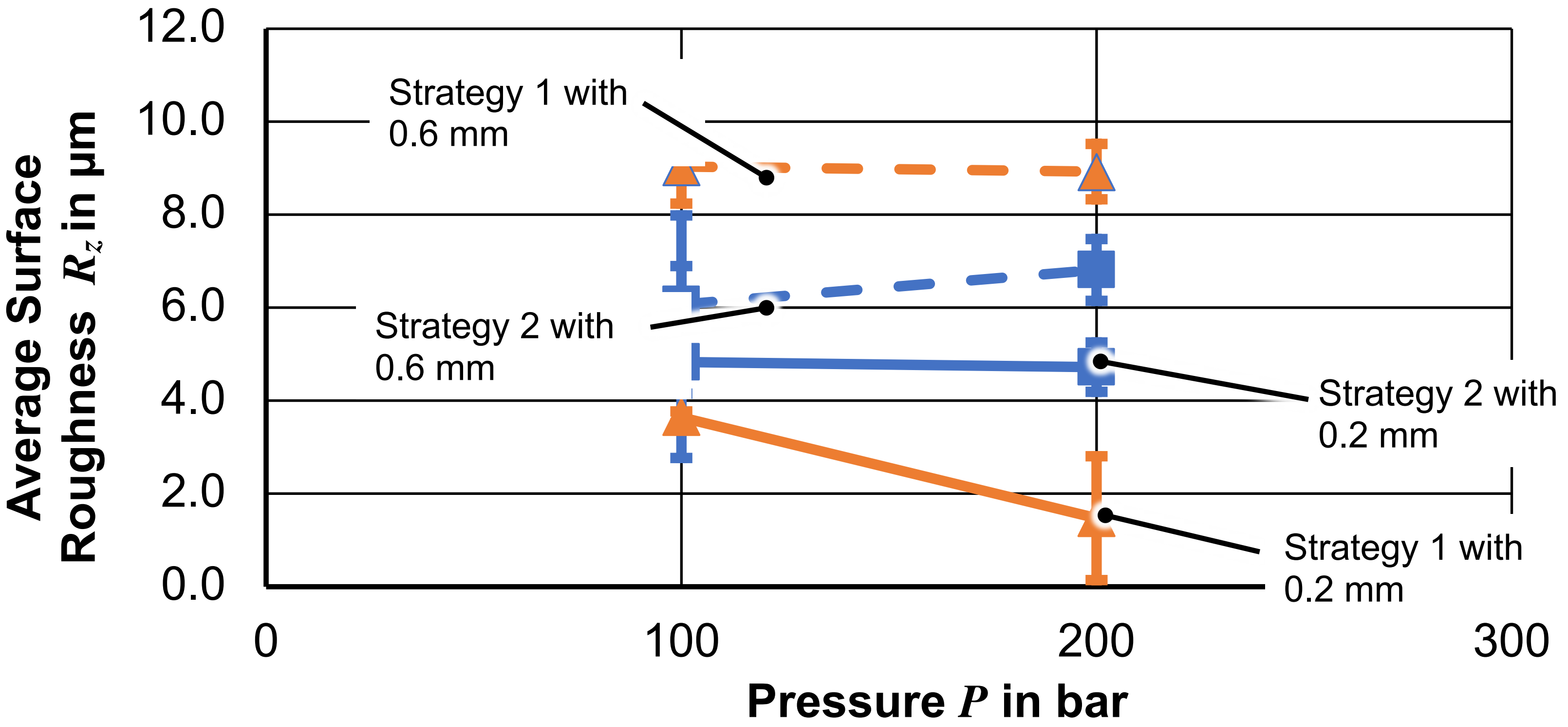
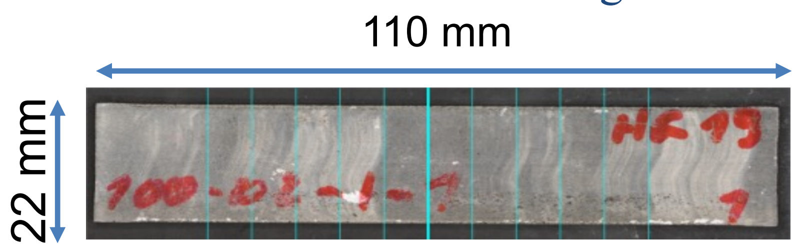
2D Surface Roughness – Rz Vertical

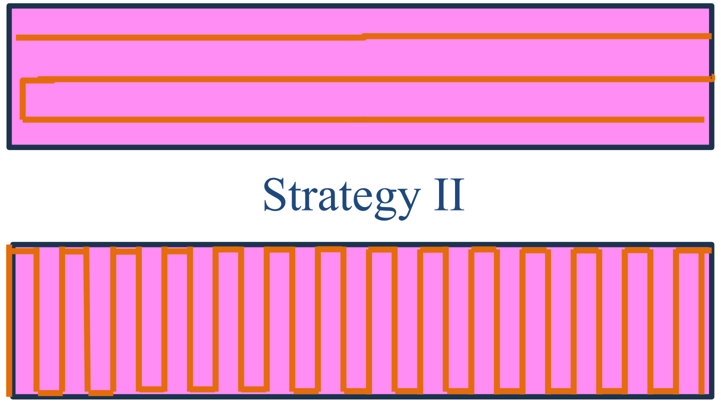


Vertical Multiline Roughness



Strategy I

Strategy II



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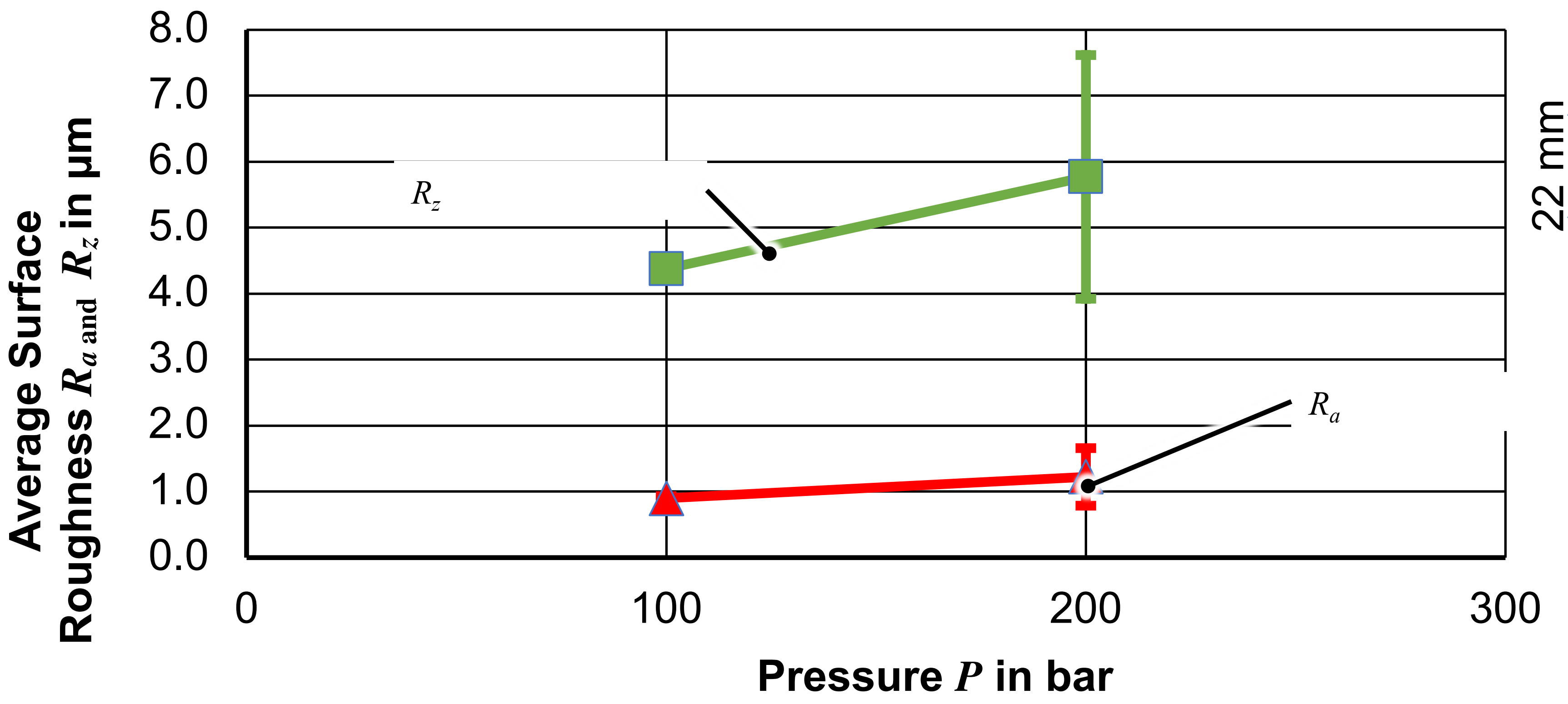
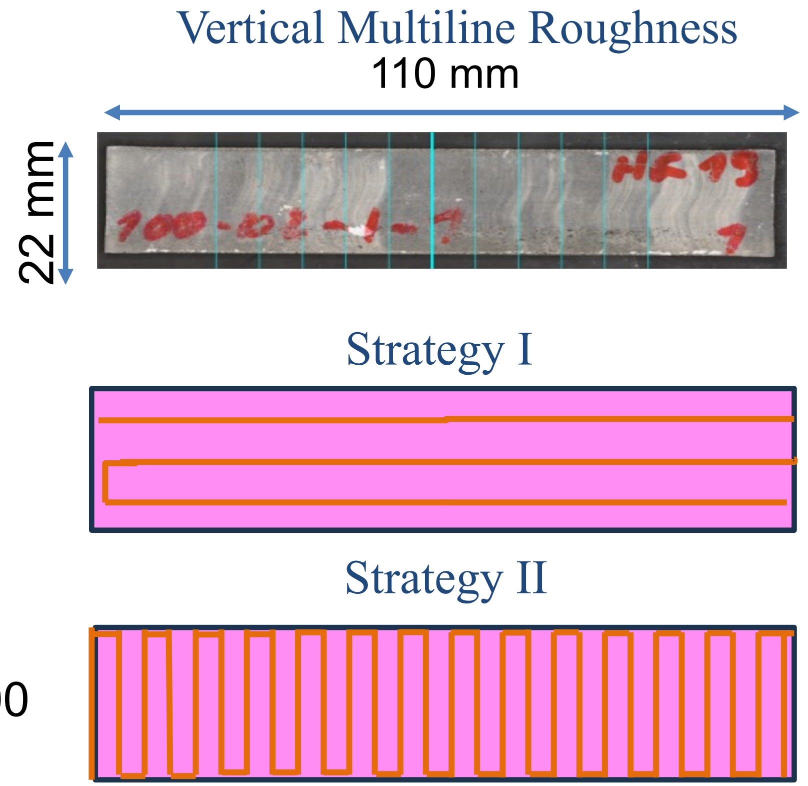
2D Surface Roughness – HG13 tool Ra and Rz Vertical





As printed	
R_a (µm)	R_z (µm)
10.95 ±0.89	92.65 ±10.57

- Samples burnished with the HG13 tool were burnished using strategy 1 with .2mm step over

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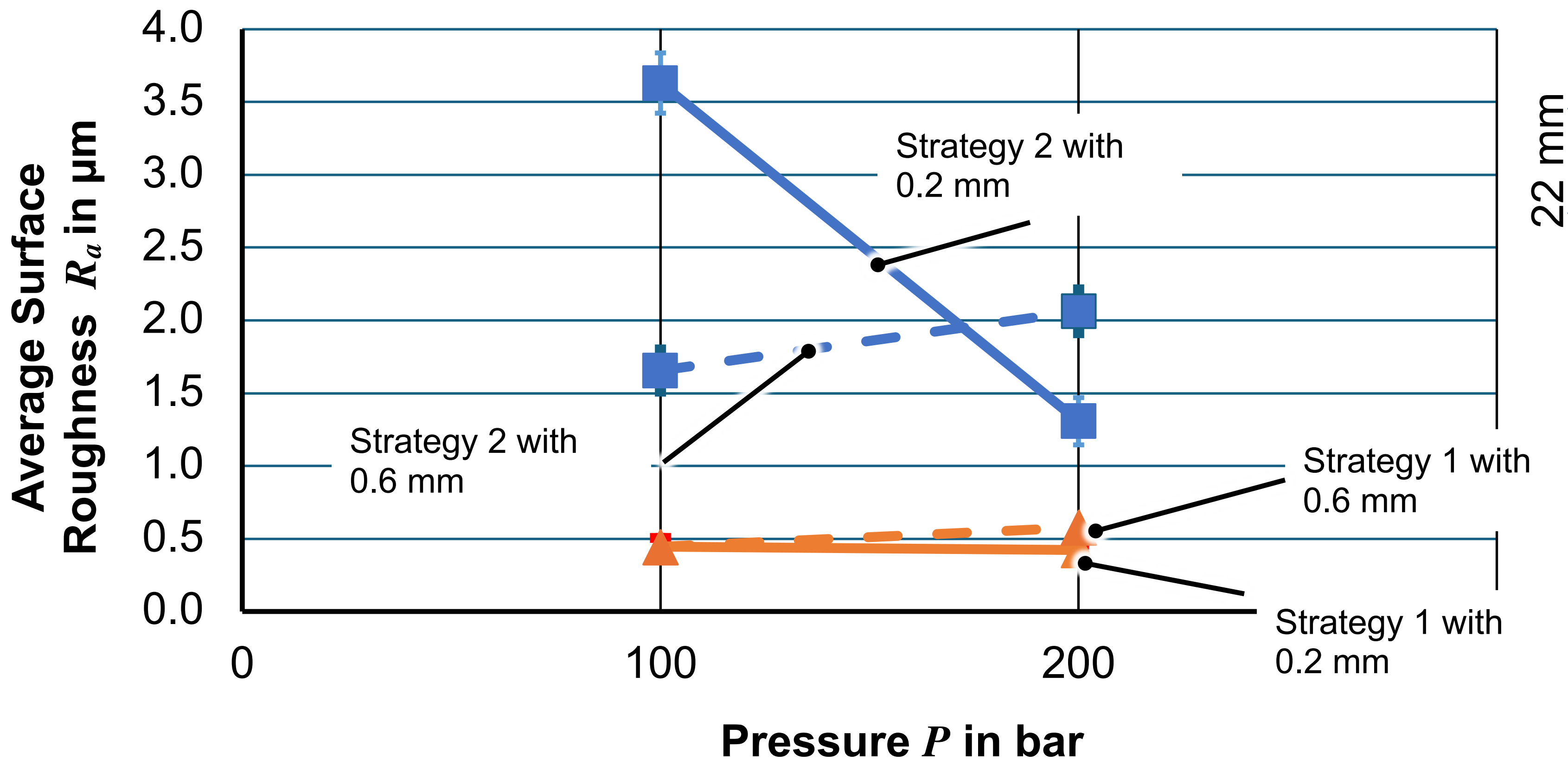
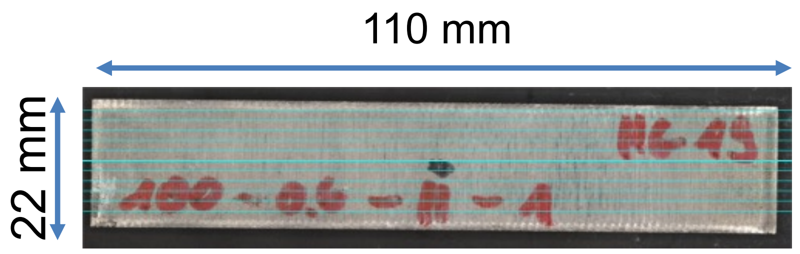
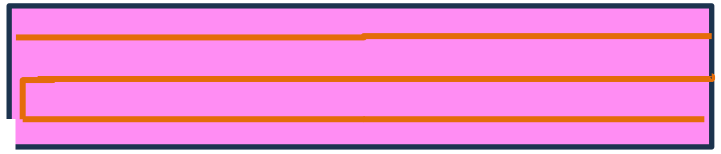
2D Surface Roughness – Ra Horizontal



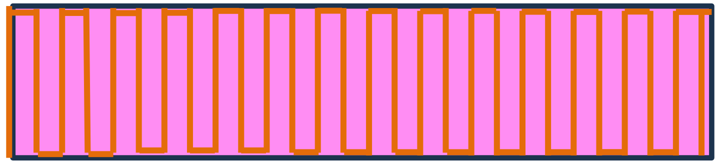
Horizontal Multiline Roughness



Strategy I



Strategy II



As printed	
R_a (µm)	R_z (µm)
6.06 ± .440	32.92 ±2.85

- When running your finger left to right , strategy 2 will feel rougher because you are going against the cut.
- 0.6mm will also feel rougher because of the larger step over

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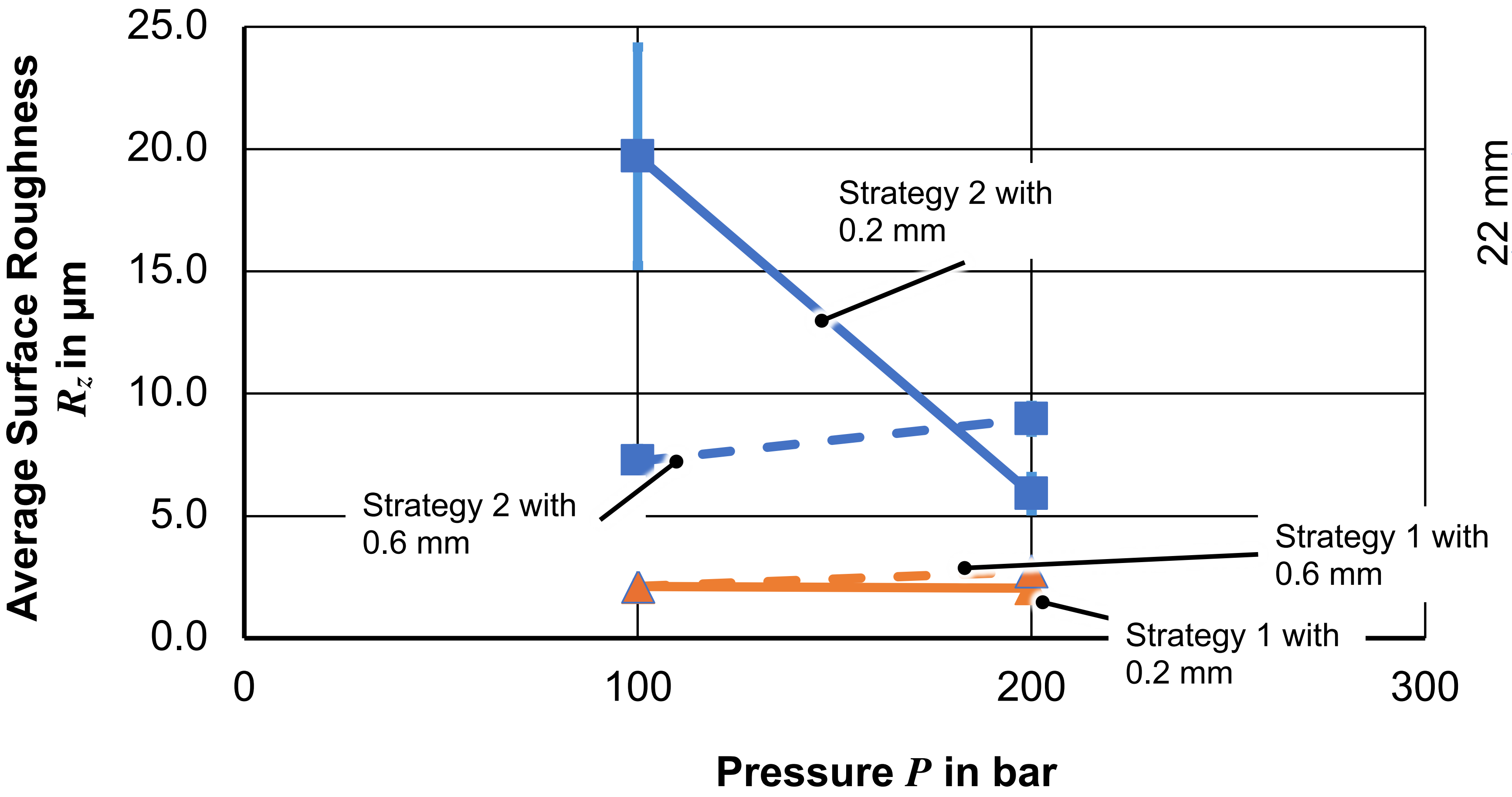
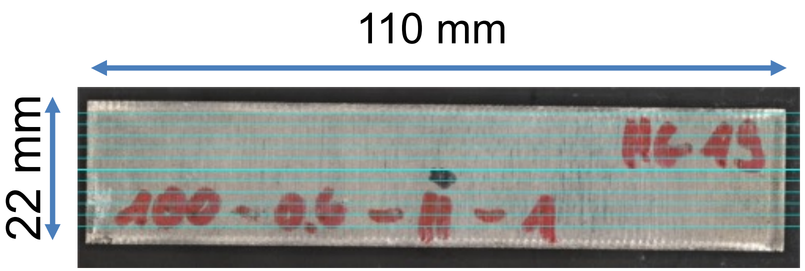
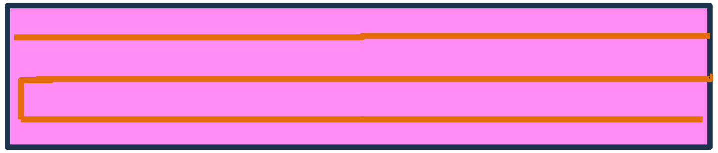
2D Surface Roughness – Rz Horizontal



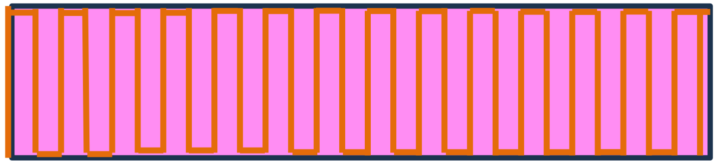
Horizontal Multiline Roughness



Strategy I



Strategy II



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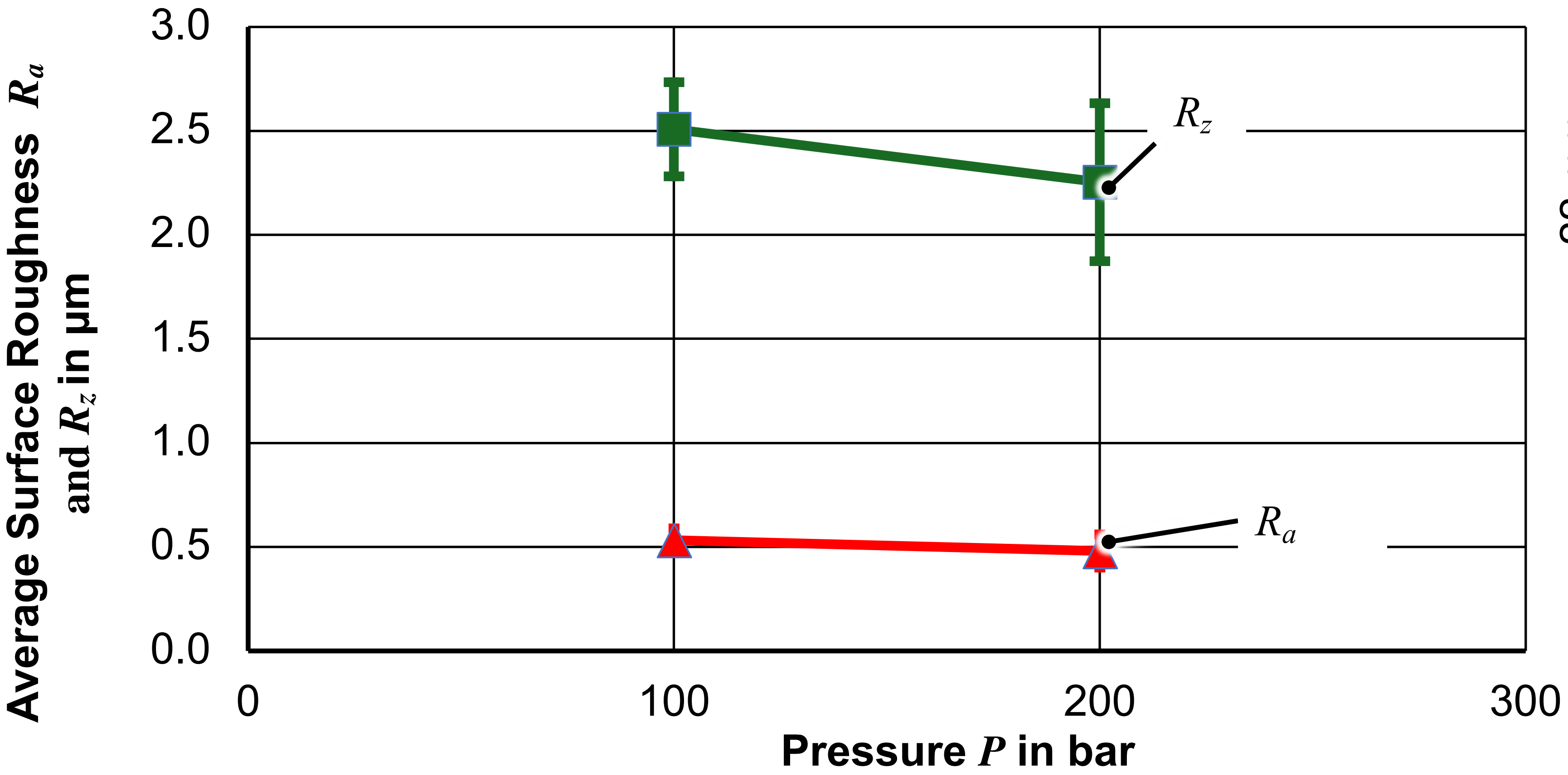
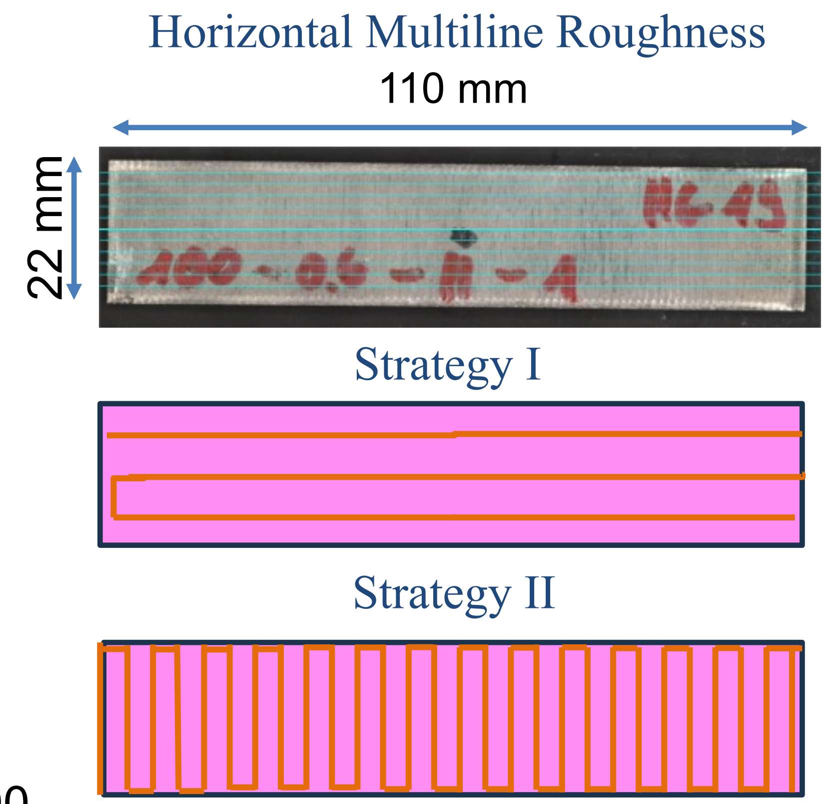
2D Surface Roughness – HG13 tool Ra and Rz Horizontal





As printed	
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6.06 ± .440	32.92 ±2.85

- Samples burnished with the HG13 tool were burnished using strategy 1 with .2mm step over

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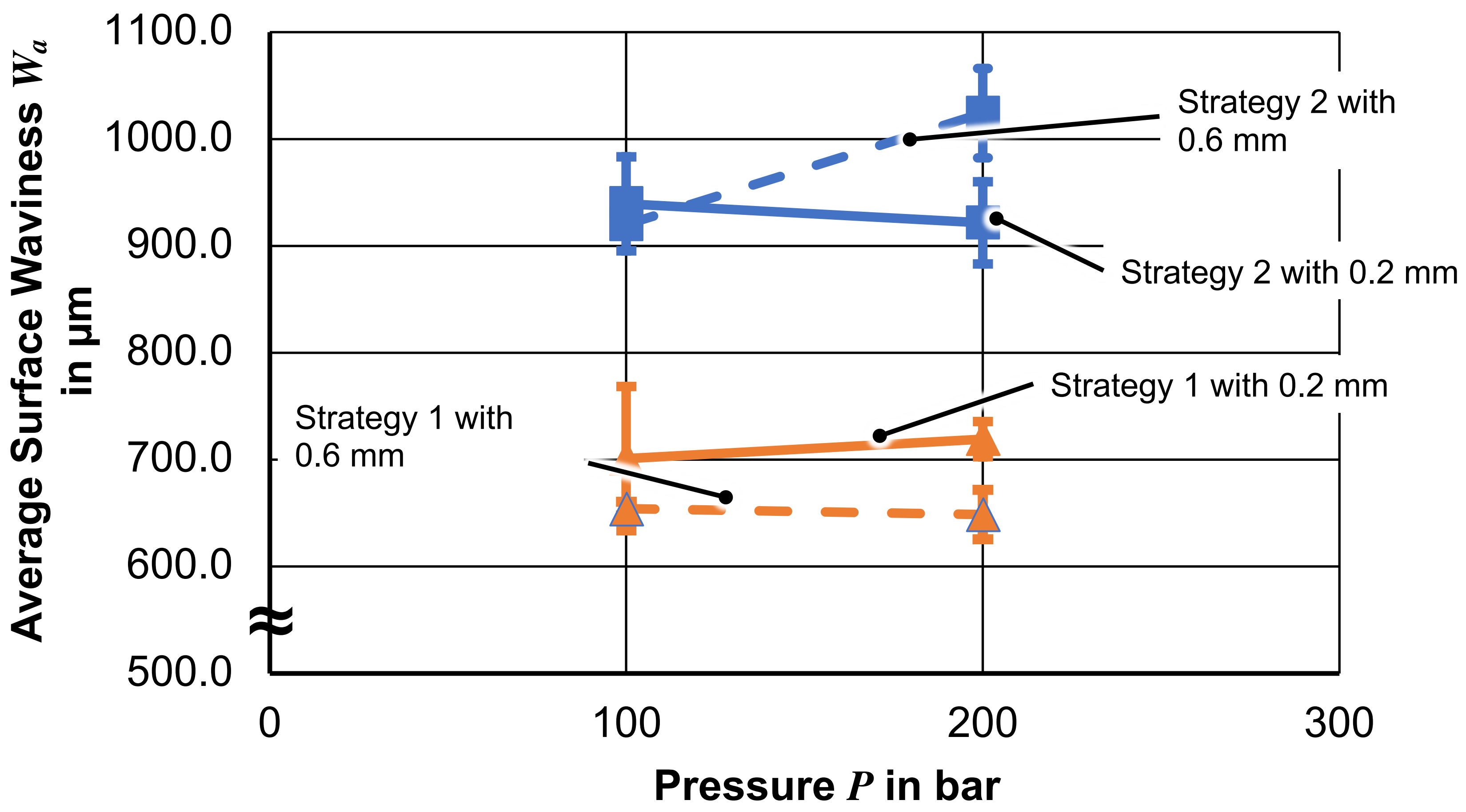
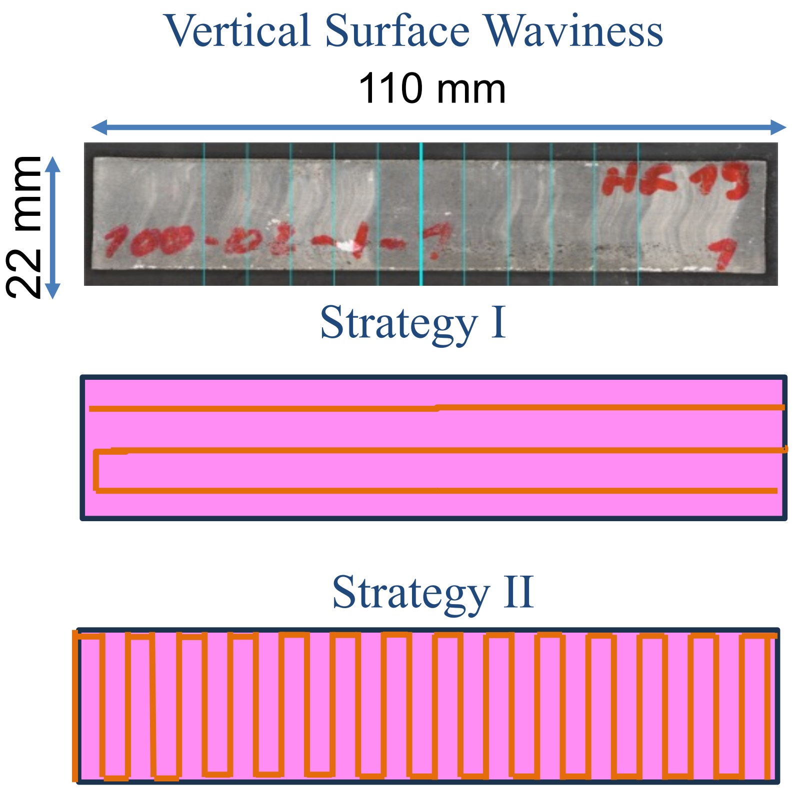
2D Surface Waviness– W_a Vertical





As printed

$W_a = 471.73 \pm 7.28$ (µm)

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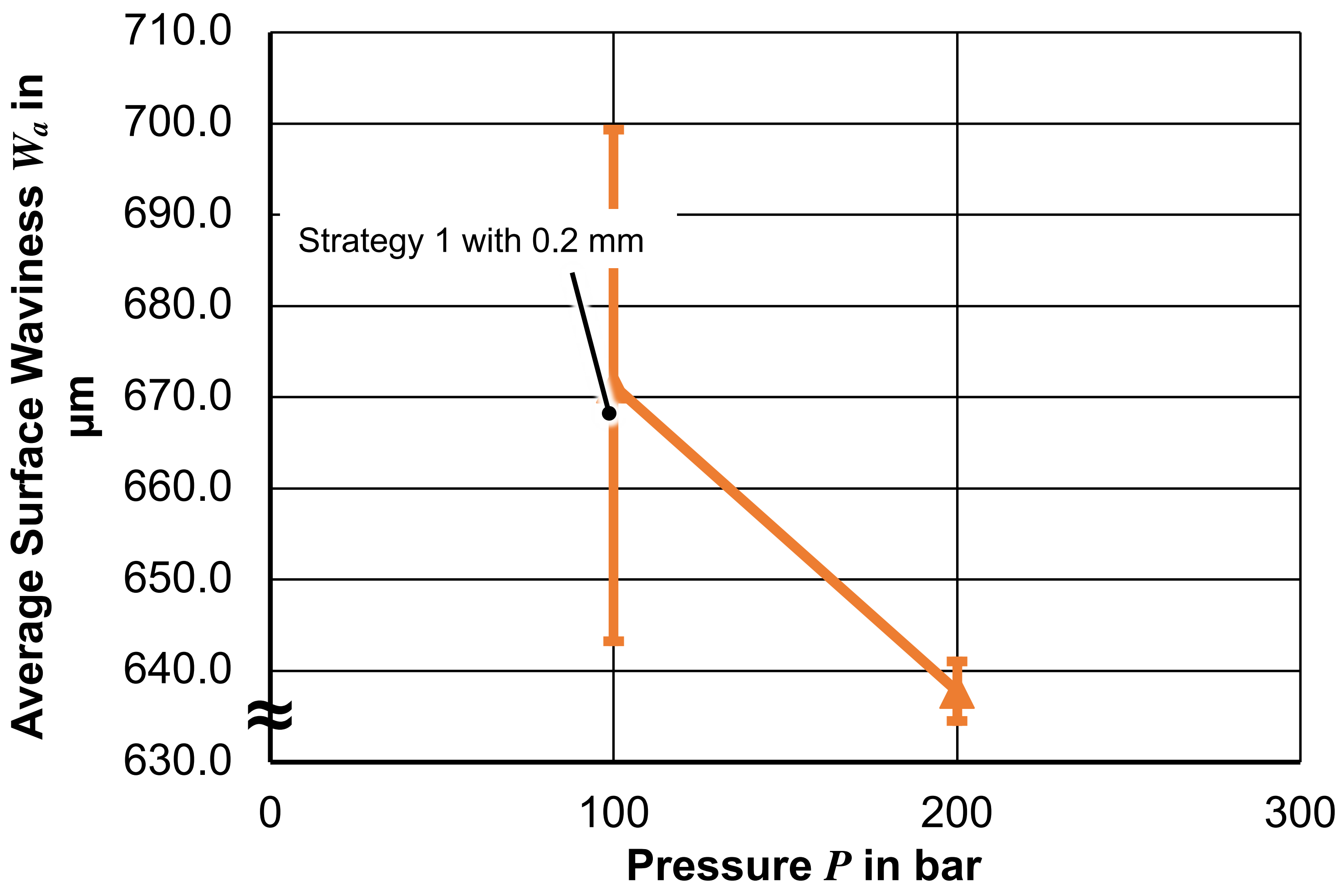
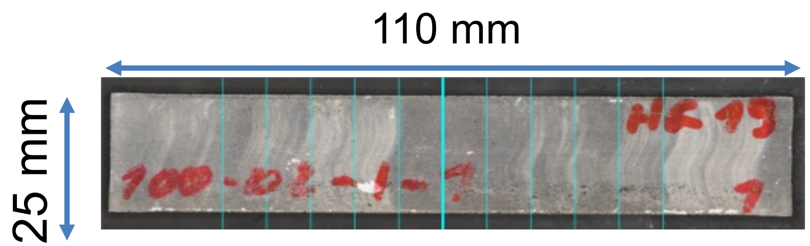
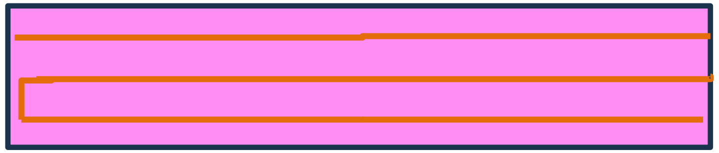
2D Surface Waviness– HG13 tool Wa Vertical



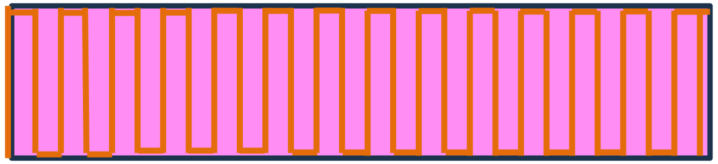
Vertical Surface Waviness



Strategy I



Strategy II



As printed

$W_a = 471.73 \pm 7.28$ (µm)

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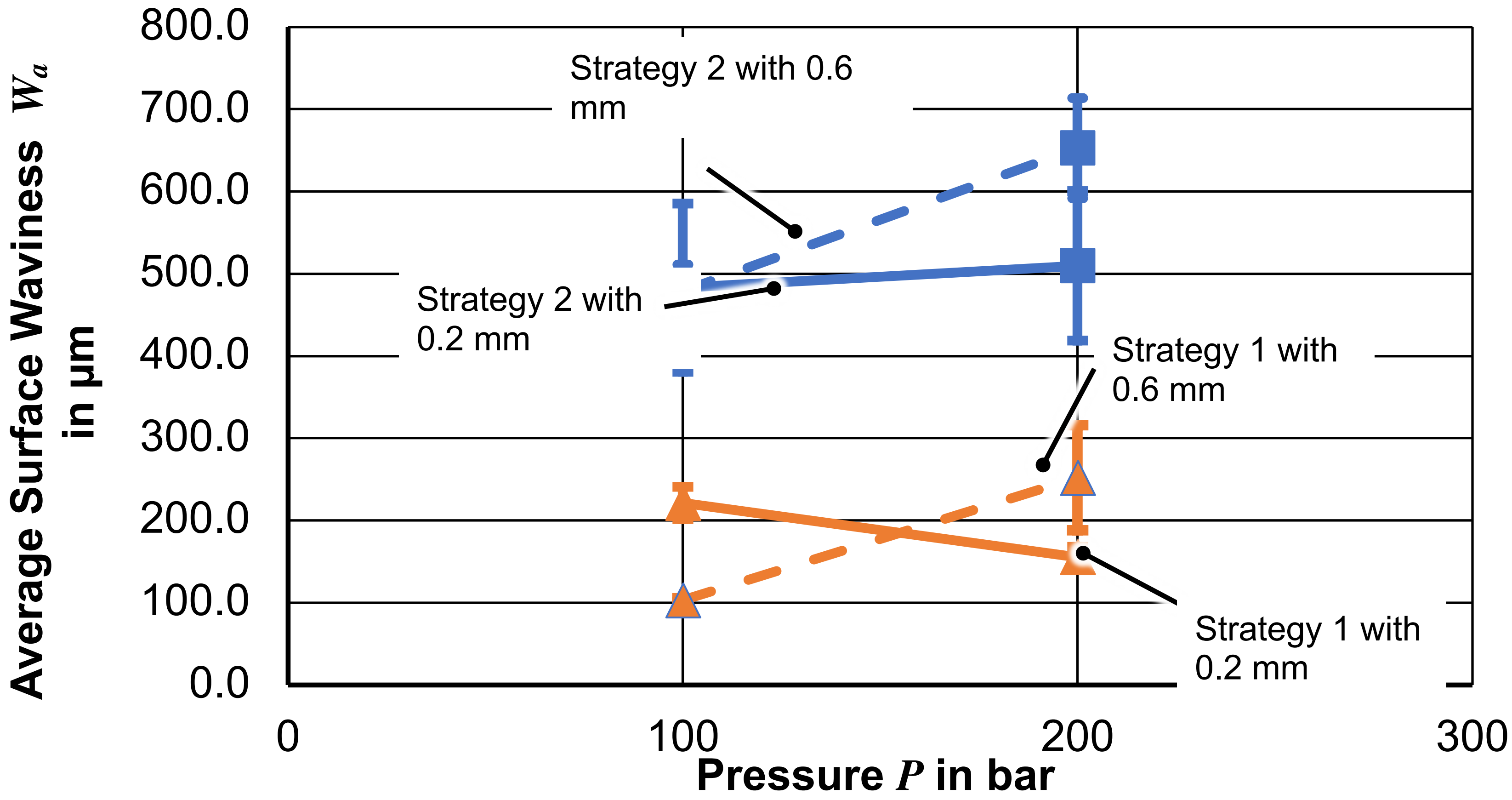
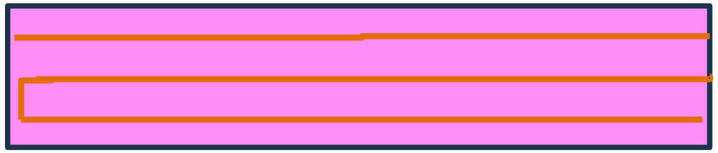
2D Surface Waviness– W_a Horizontal

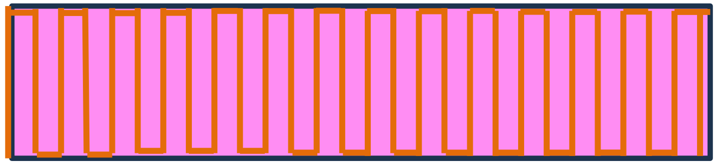


Horizontal Surface Waviness

Strategy I



Strategy II



Strategy 2 has shorter wavelengths thus more waviness

As printed
$W_a = 70.33 \pm 3.05$ (µm)

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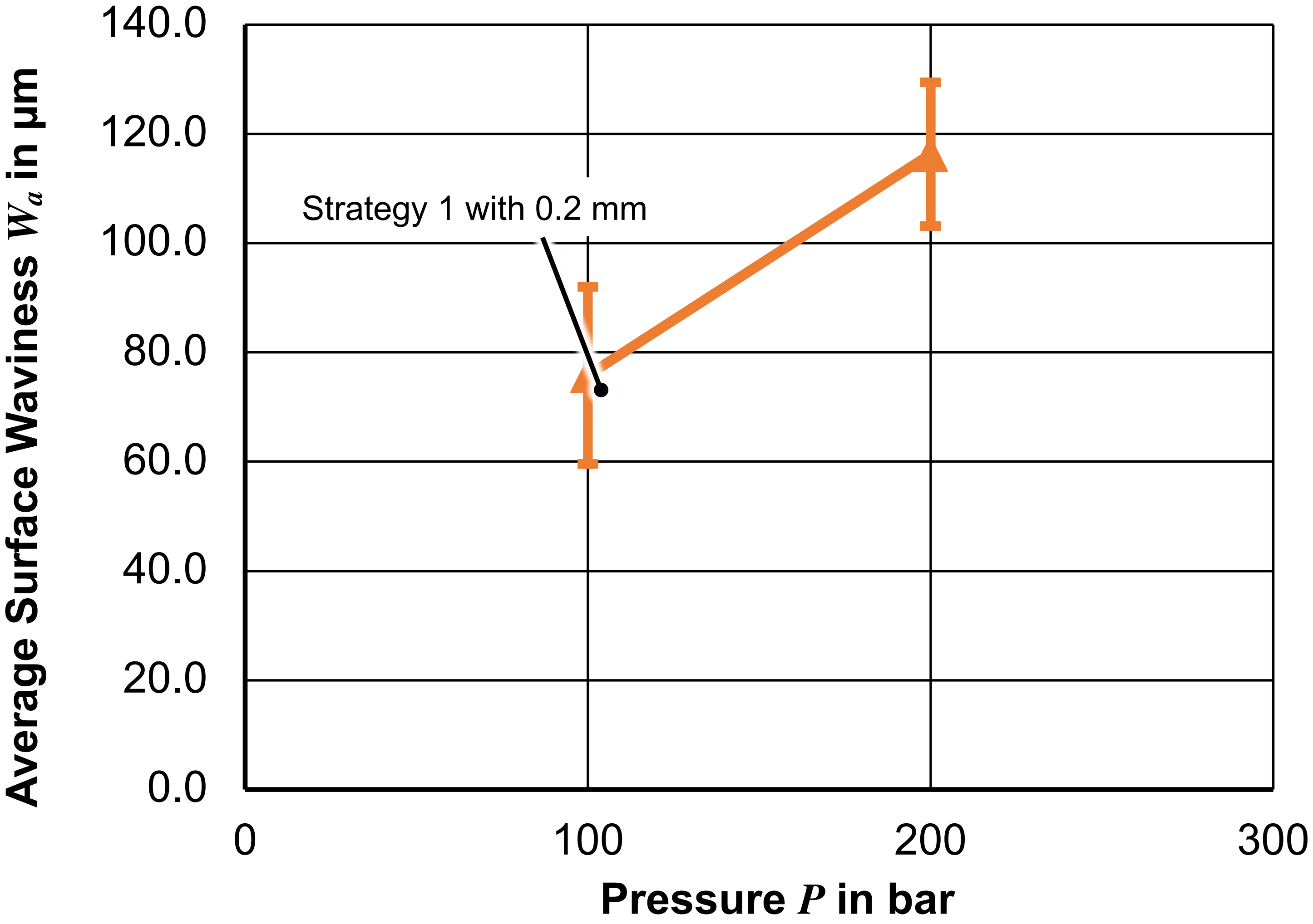
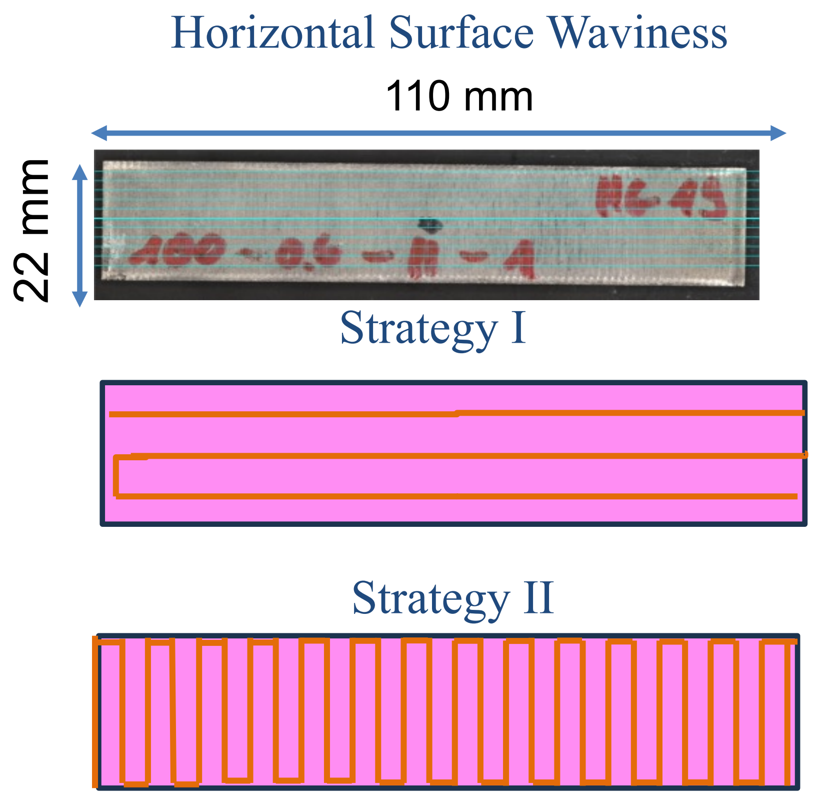
2D Surface Waviness– HG13 tool W_a Horizontal





As printed

$W_a = 70.33 \pm 3.05$ (µm)

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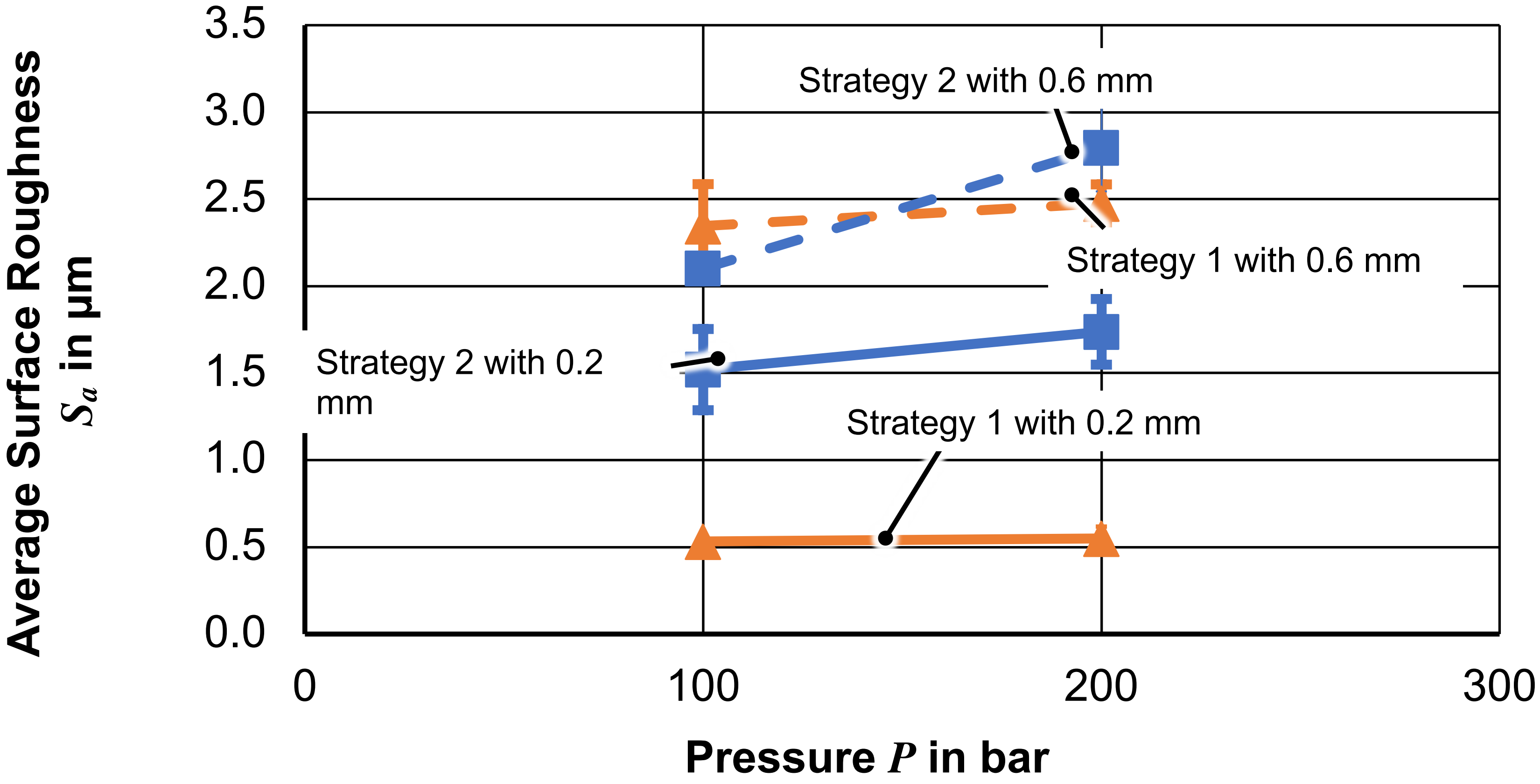
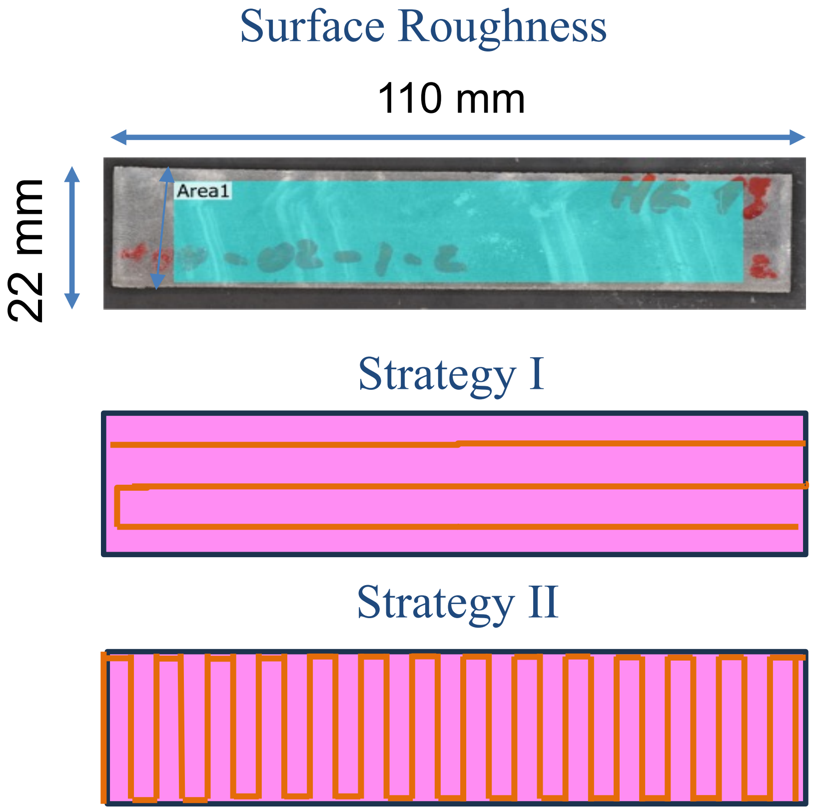
3D Surface Roughness – S_a





- 0.6 mm step-over has a higher surface roughness
- Strategy 2 has a higher surface roughness because the wavelengths are shorter.

As printed	
S_a (µm)	S_z (µm)
6.74 ± 0.34	227.41 ± 31.4

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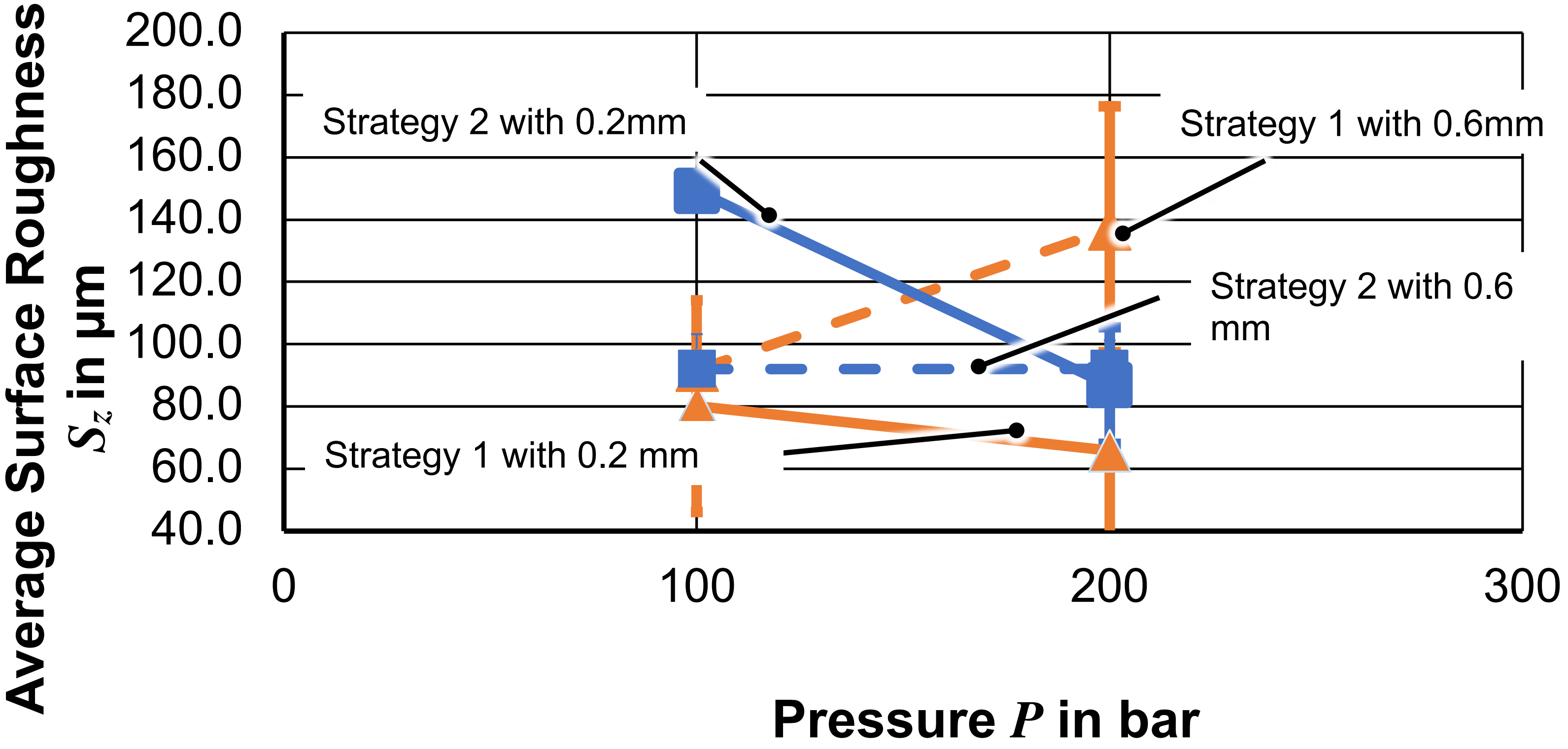
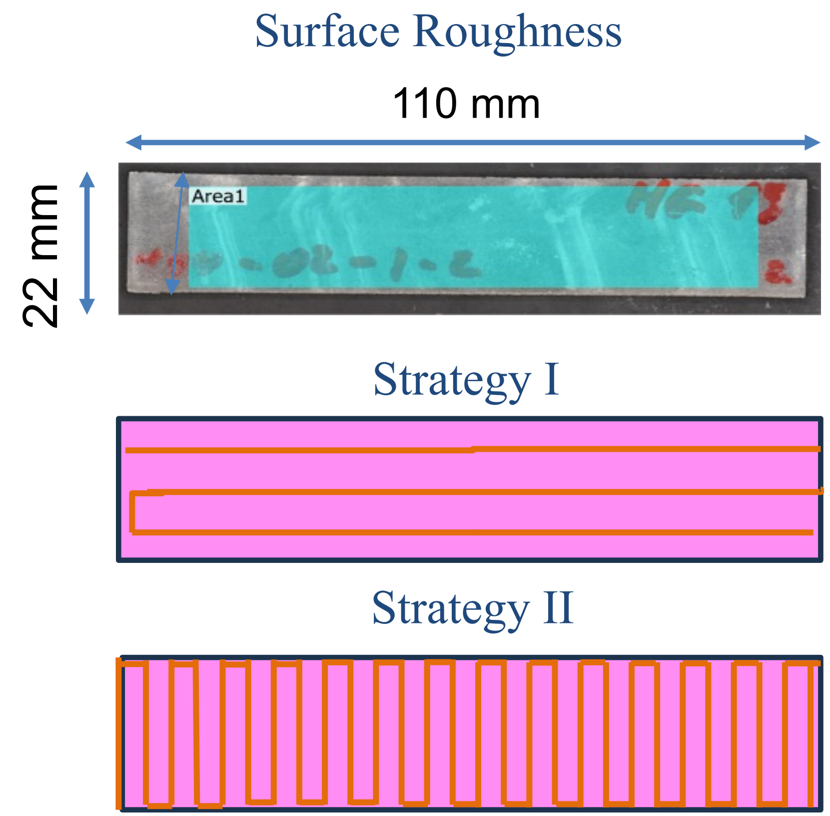
3D Surface Roughness – S_z





- For 0.2mm step over as pressure increases, surface roughness S_z decreases
- For 0.6mm step over s pressure increases, so does S_z

As printed	
S_a (µm)	S_z (µm)
6.74 ± 0.34	227.41 ± 31.4

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- Introduction
- Literature Review
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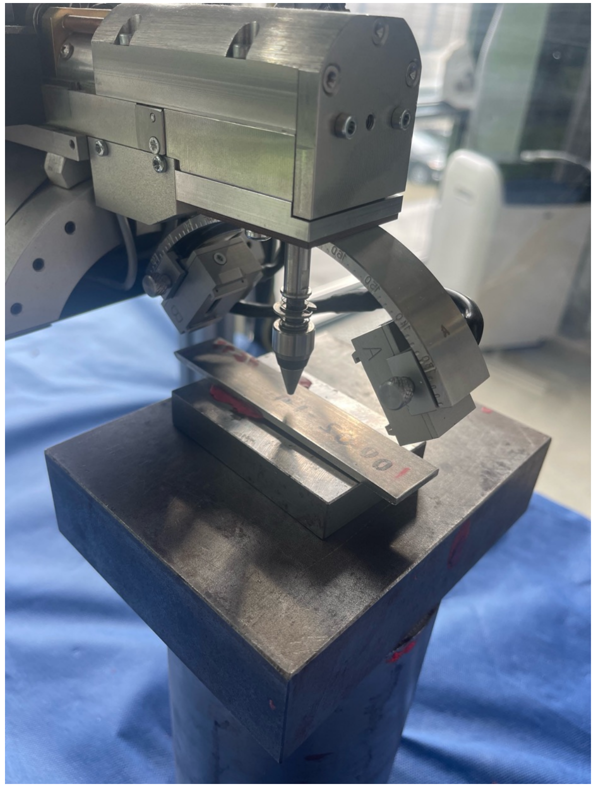
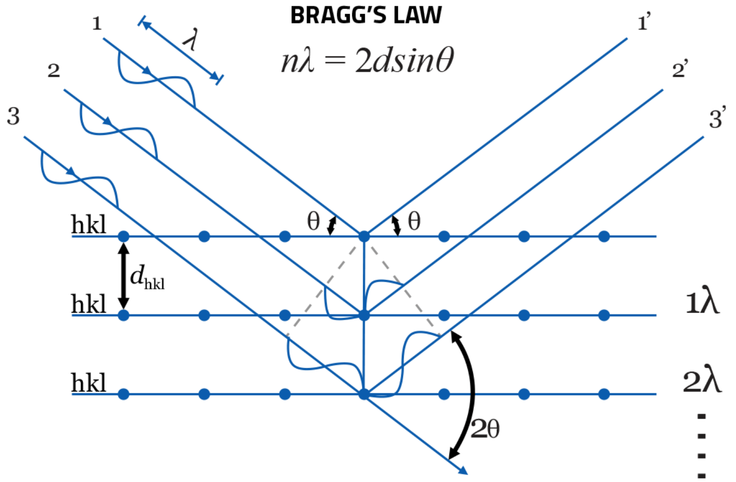
Residual Stresses- Definition and Methodology



0 degrees



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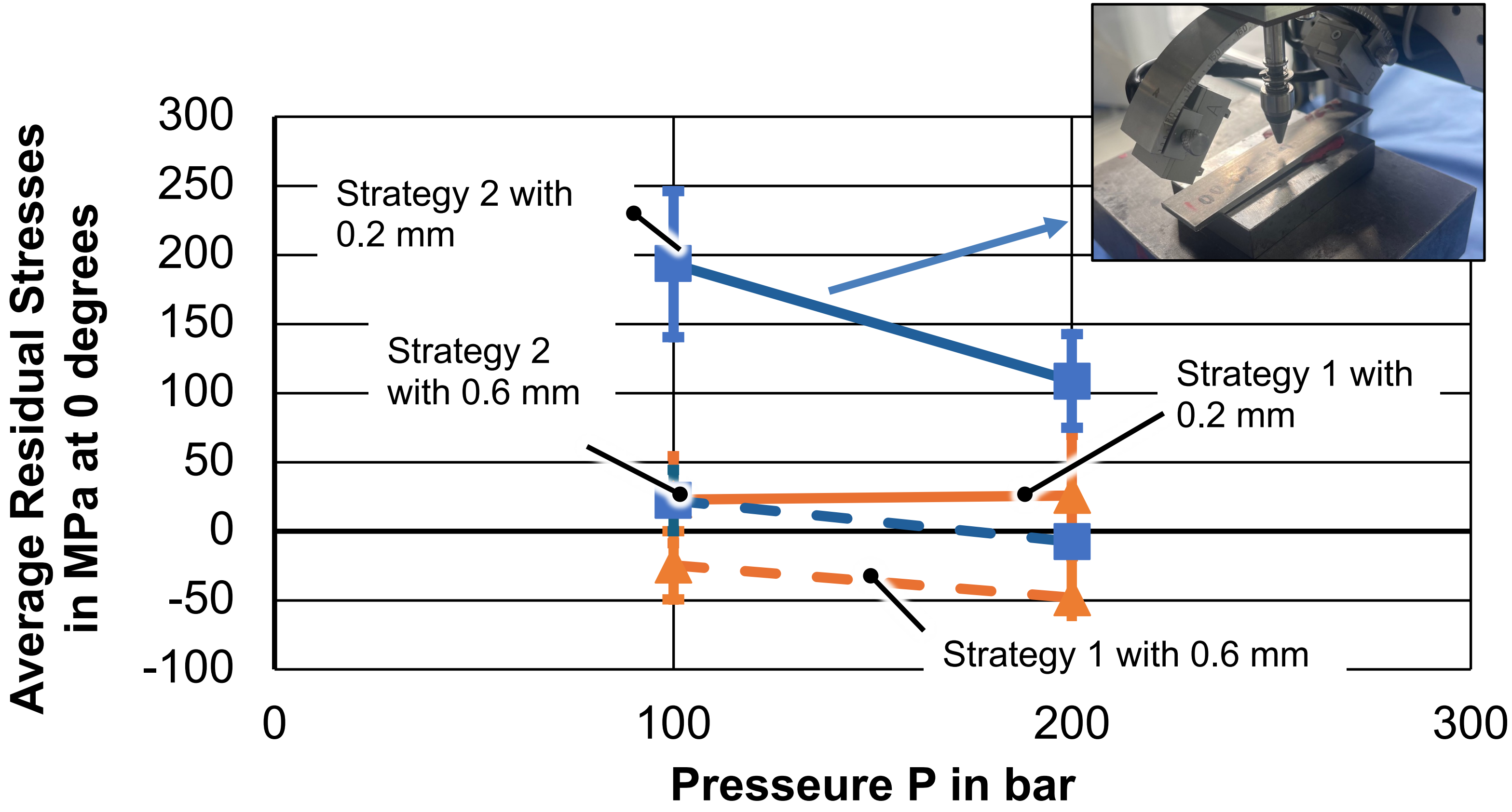
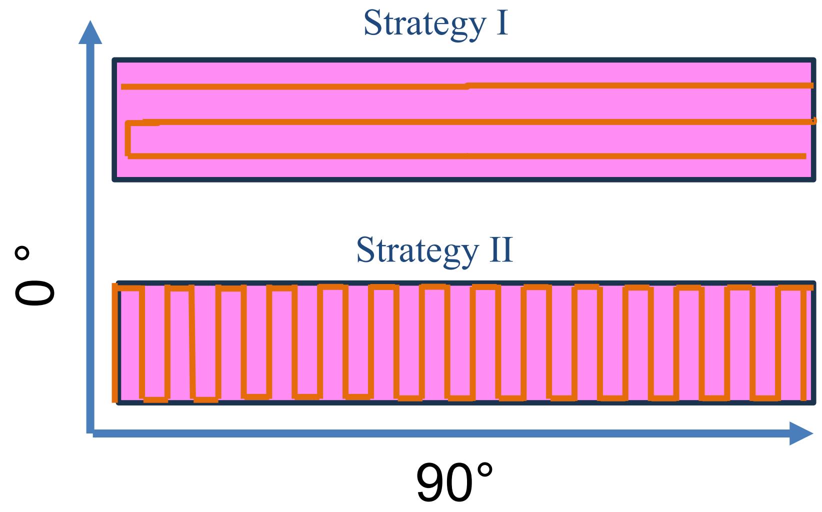
Residual Stresses – 0 degrees





As printed	
0° (MPa)	**90° (MPa)**
108.4 ± 17.5	12.8 ± 16.6

- 0.2mm step-over is is in tension rather than compression because those specimens were more bent than the others. I measured the stress at the top of the arch.

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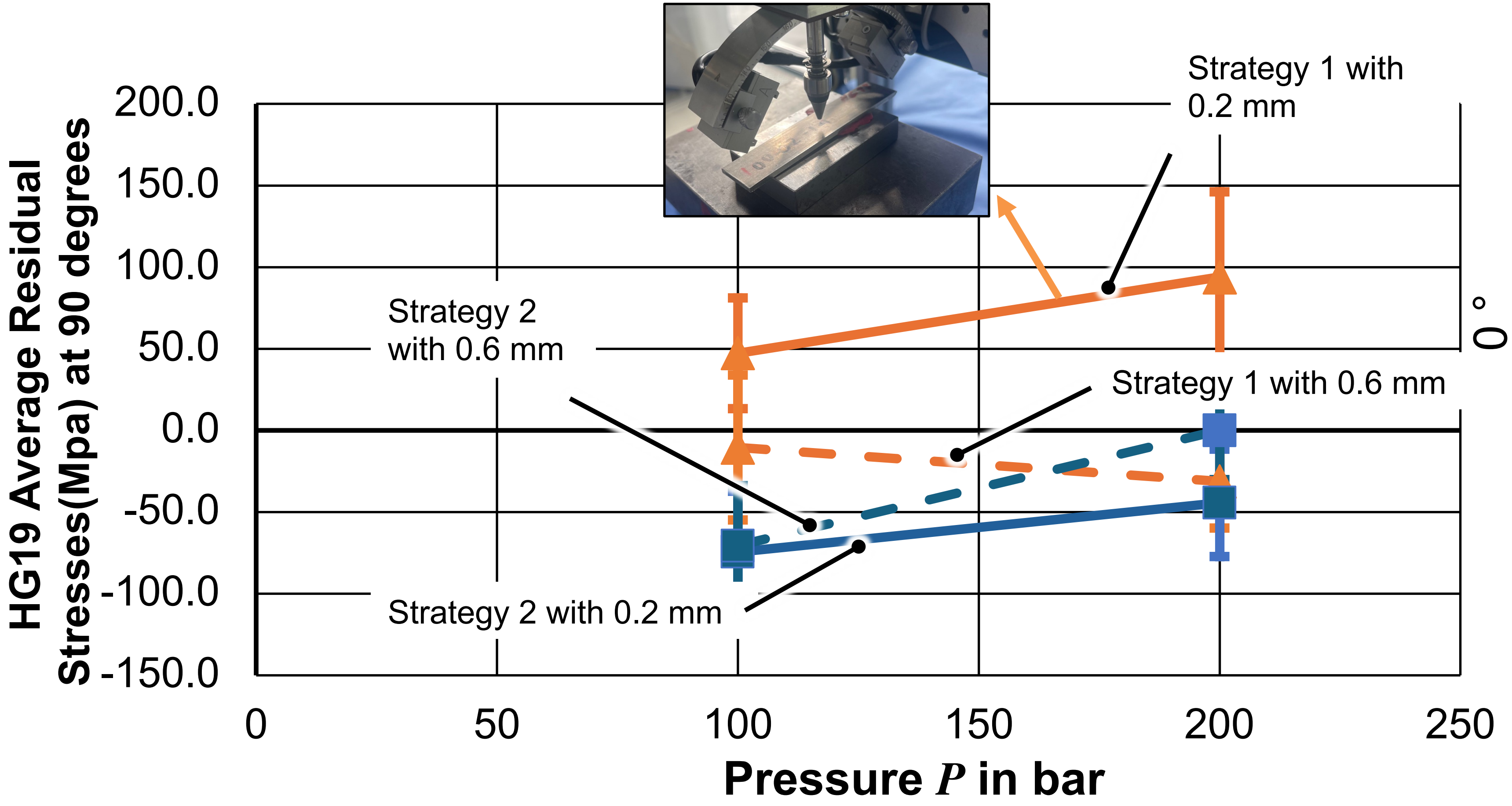
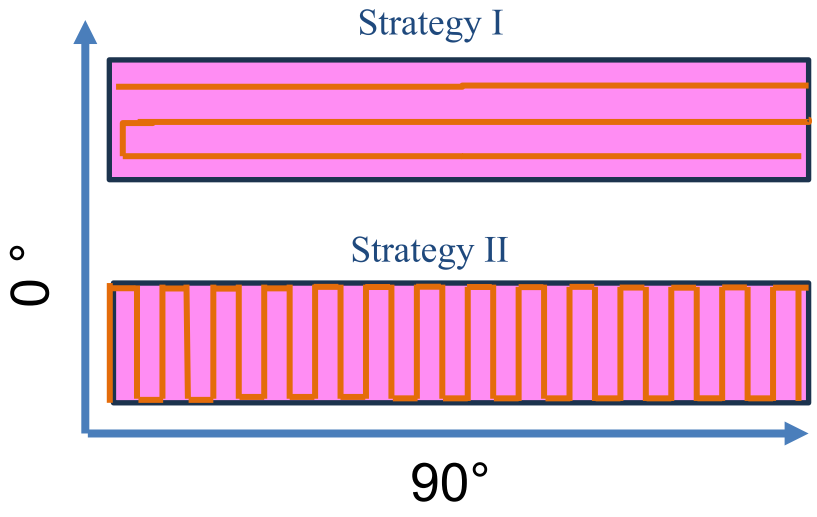
Residual Stresses – 90 degrees





As printed	
0° (MPa)	90° (MPa)
108.4 ± 17.5	12.8 ± 16.6

- Strategy 1 has greater tension because the stress is along the burnishing path

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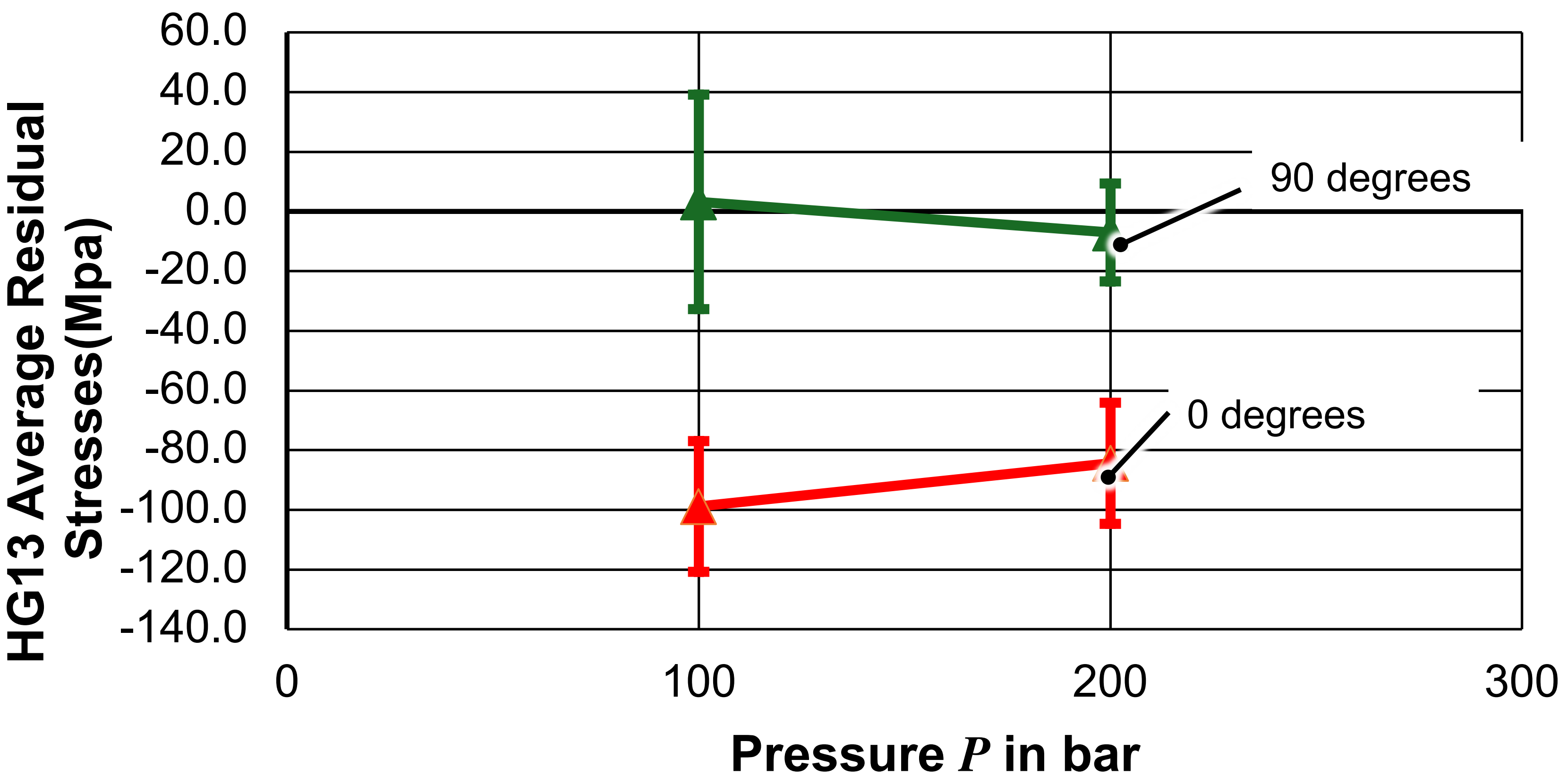
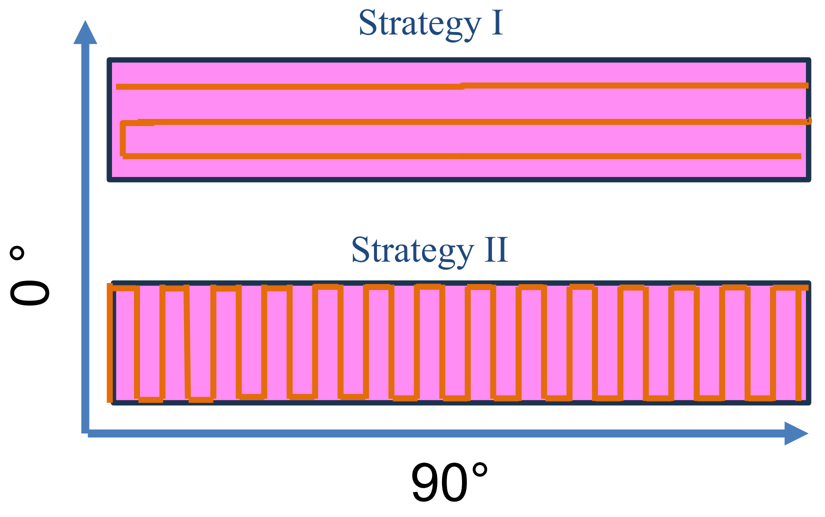
Residual Stresses – 0 and 90 degrees HG13 tool





As printed	
0° (MPa)	**90° (MPa)**
108.4 ± 17.5	12.8 ± 16.6

- For the HG13 tool, the samples were only burnished using strategy 1 with 0.2mm step over.
- Once again, at 90 degrees the residual stresses were higher because it was along the tool path

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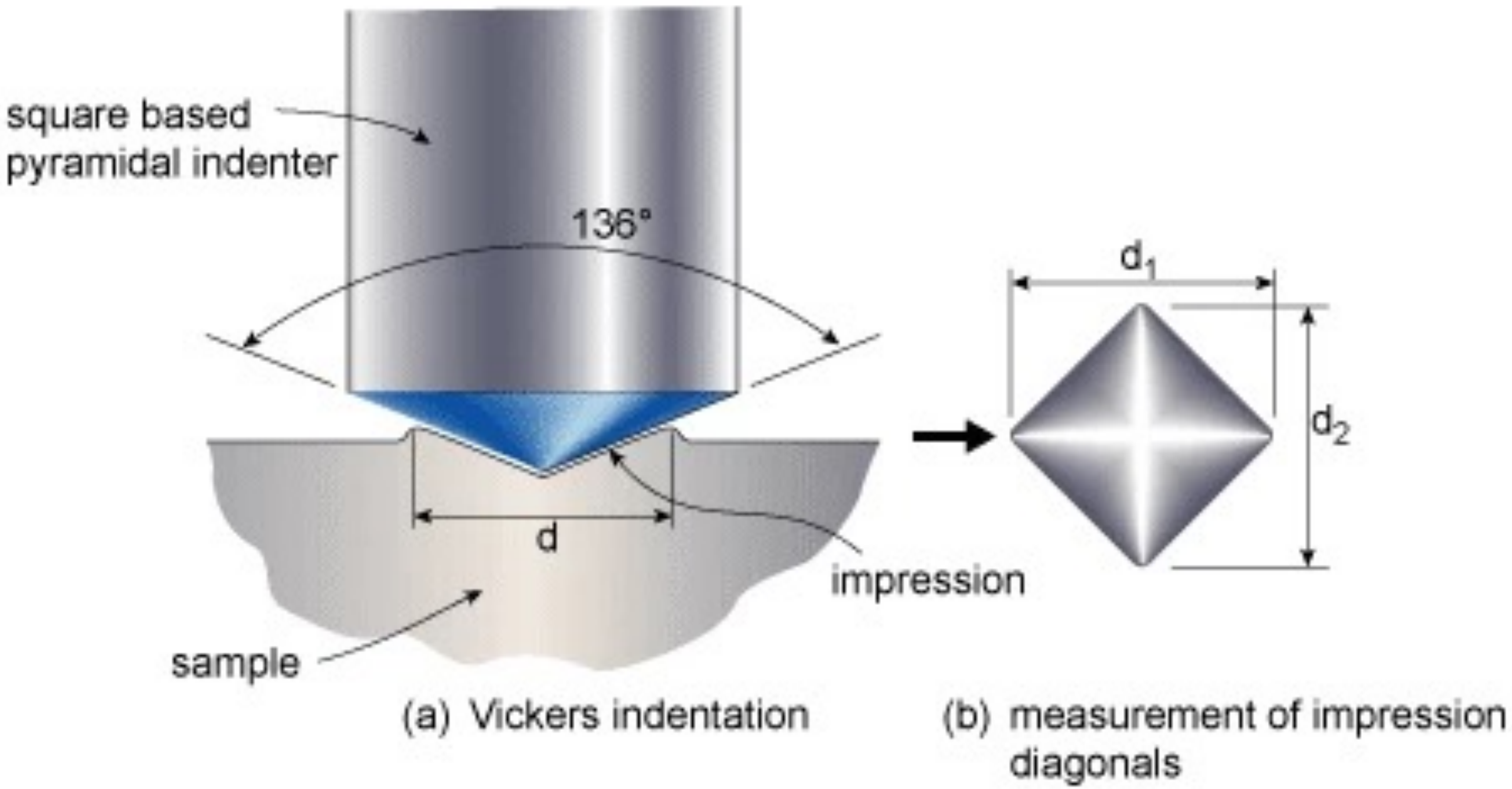
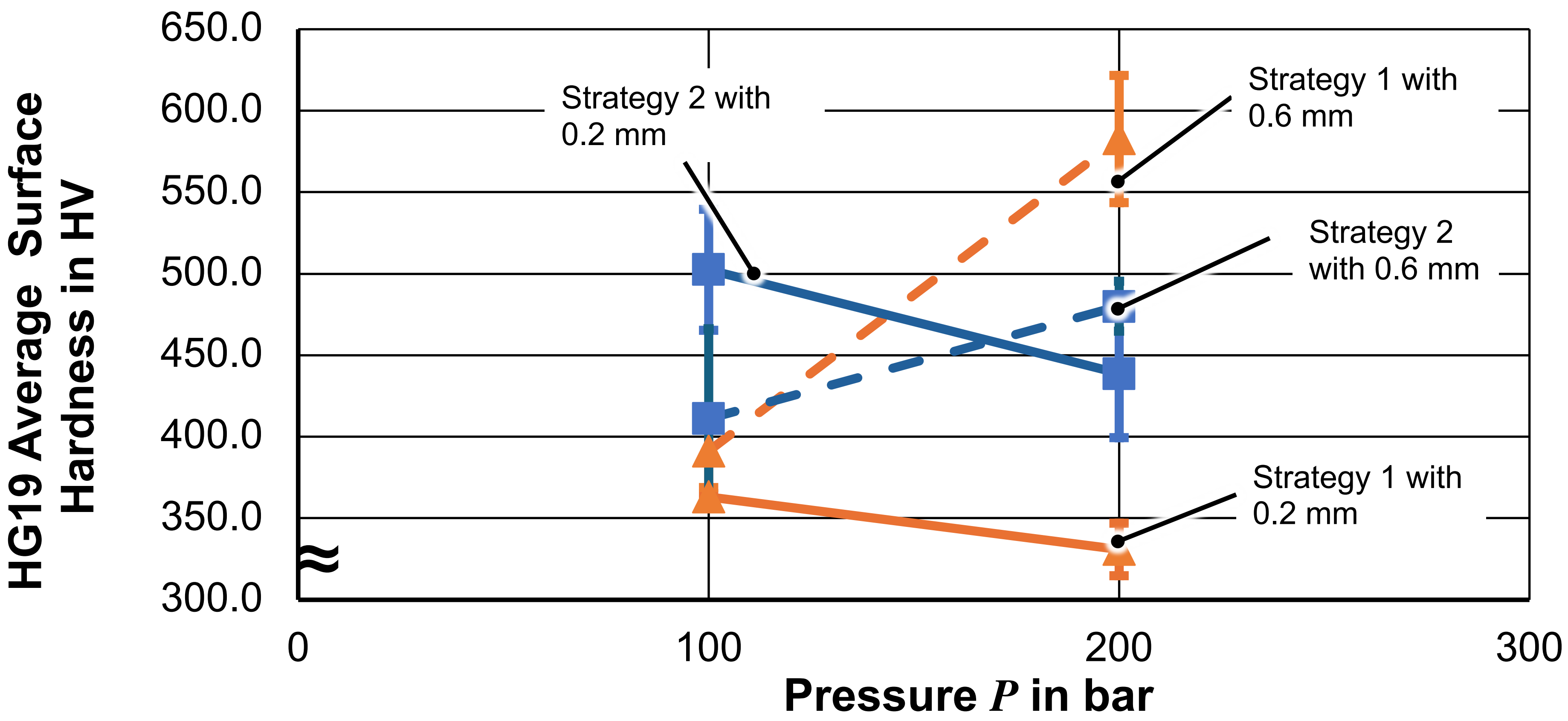
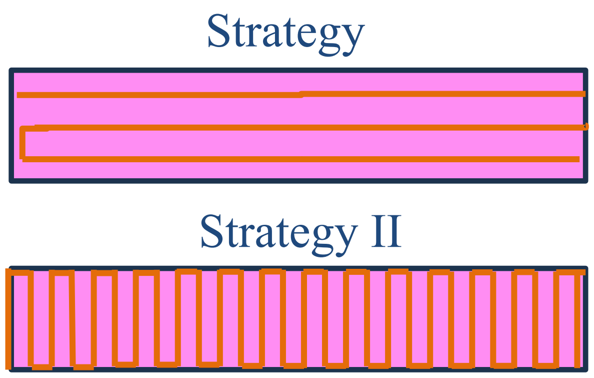
(Quelle:)

Hardness – Methodology







As printed
493.2 $\pm$65.29 HV

- A larger step over is correlated to increased hardness. This is consistent with literature

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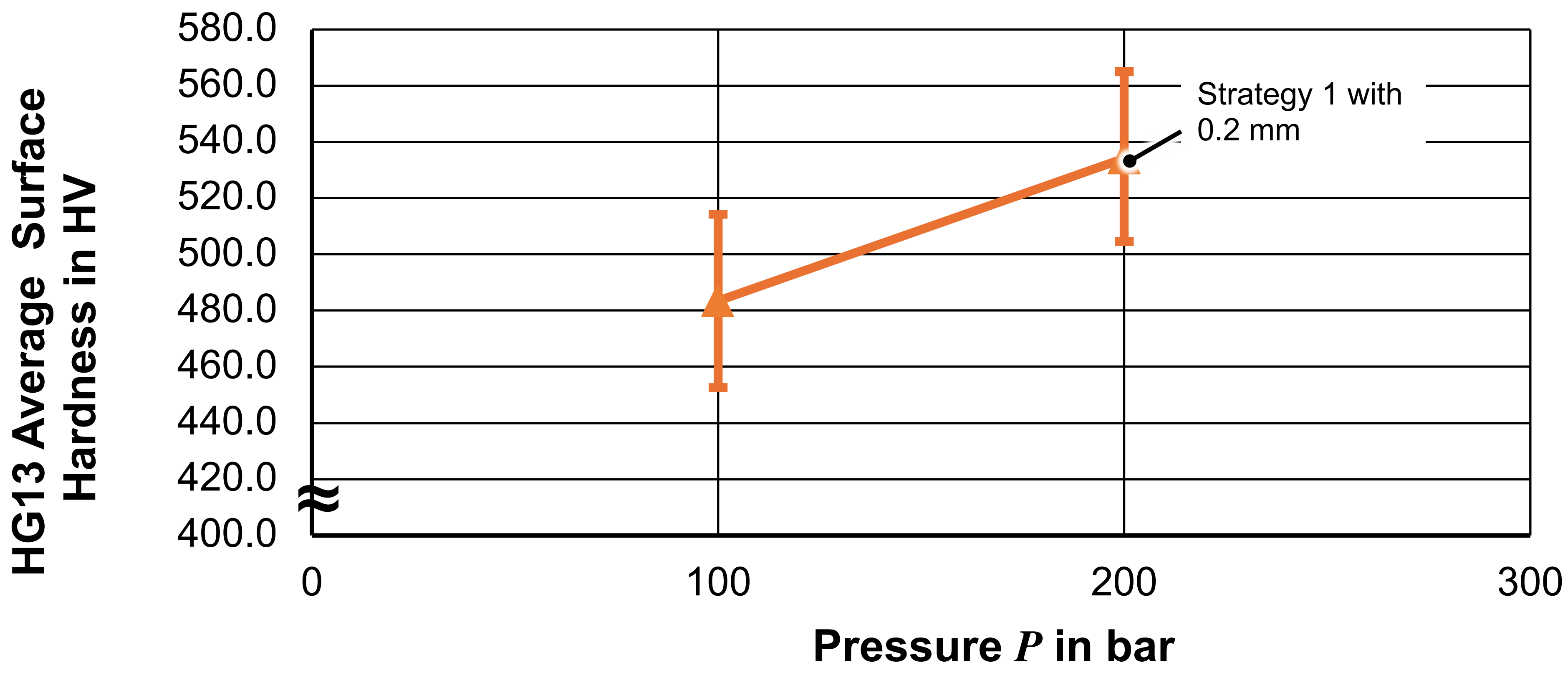
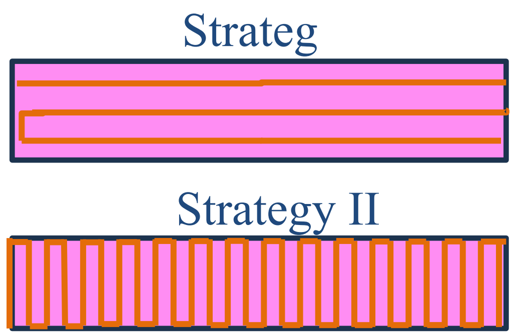
Hardness-HG13 tool





As printed
493.2 ± 65.29 HV

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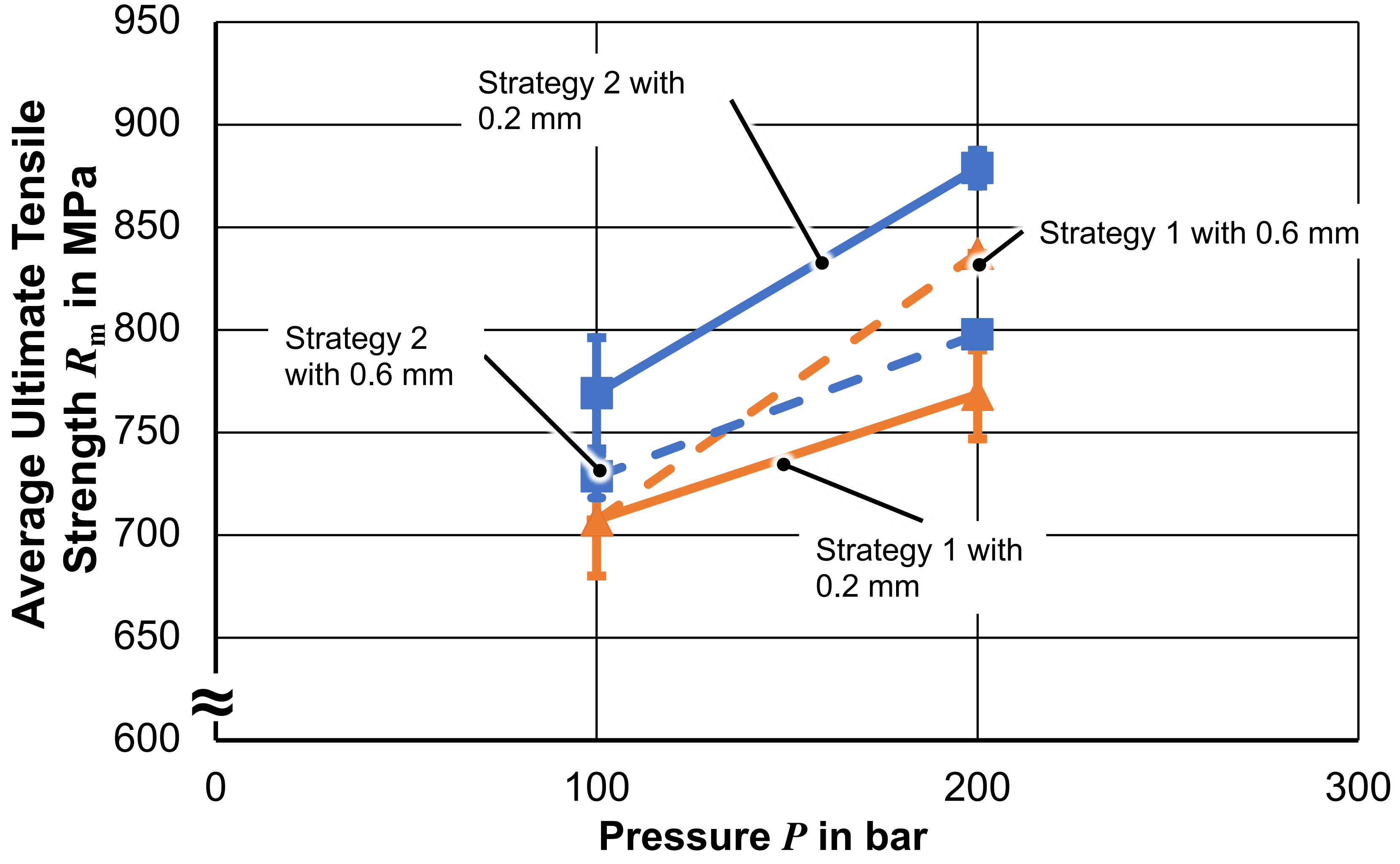
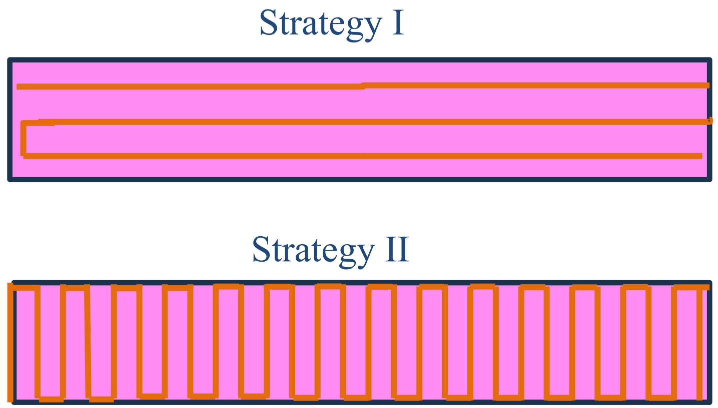
(Quelle:)

Tensile Test Results – Ultimate Tensile Strength





As printed
$R_m = 637.5 \pm 11.08$ MPa

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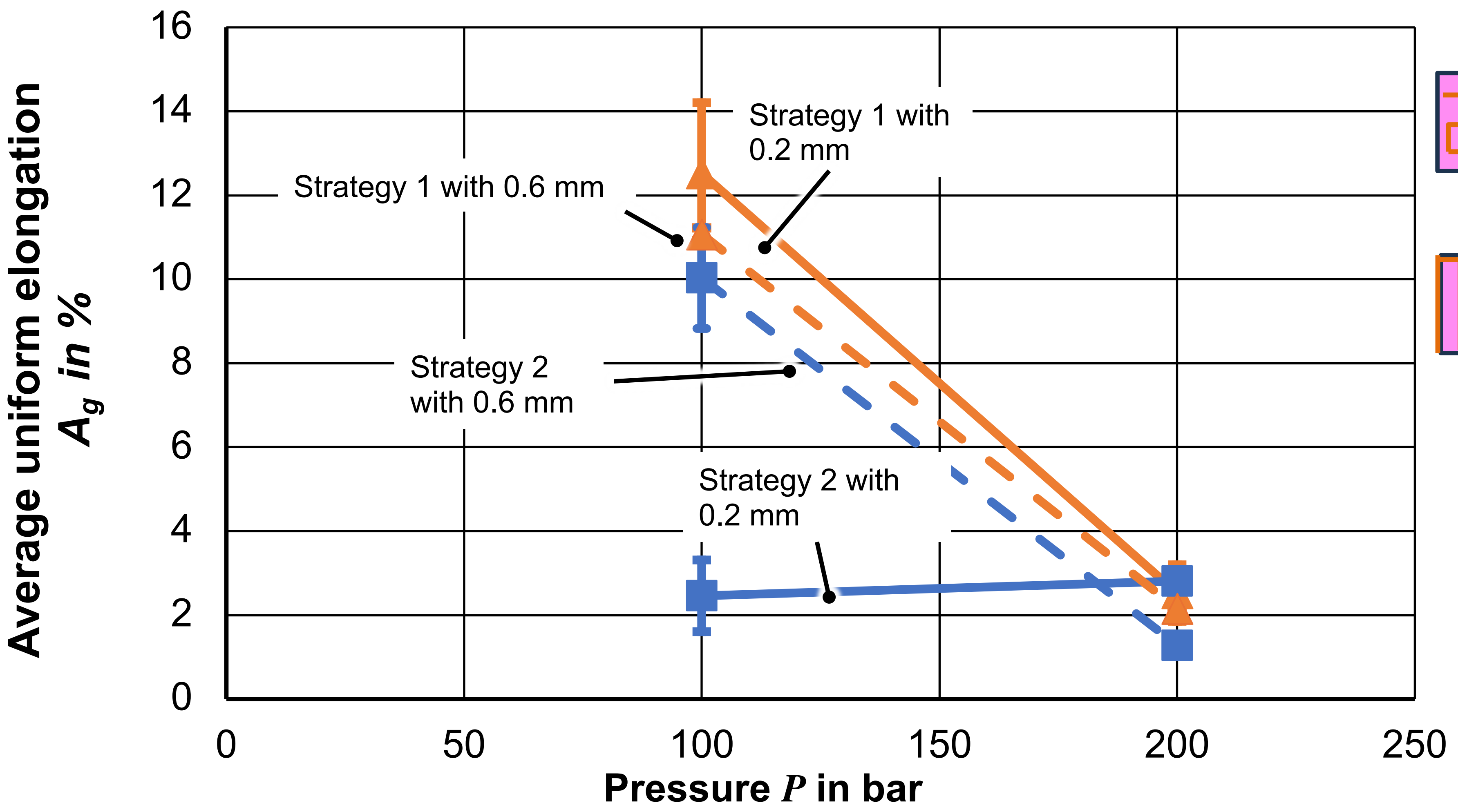
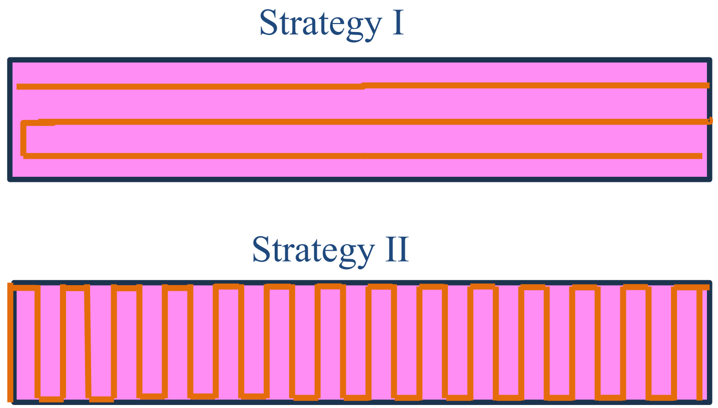
Tensile Test Results – A_g





As printed
$A_g = 21.1 \pm 0.84$ %

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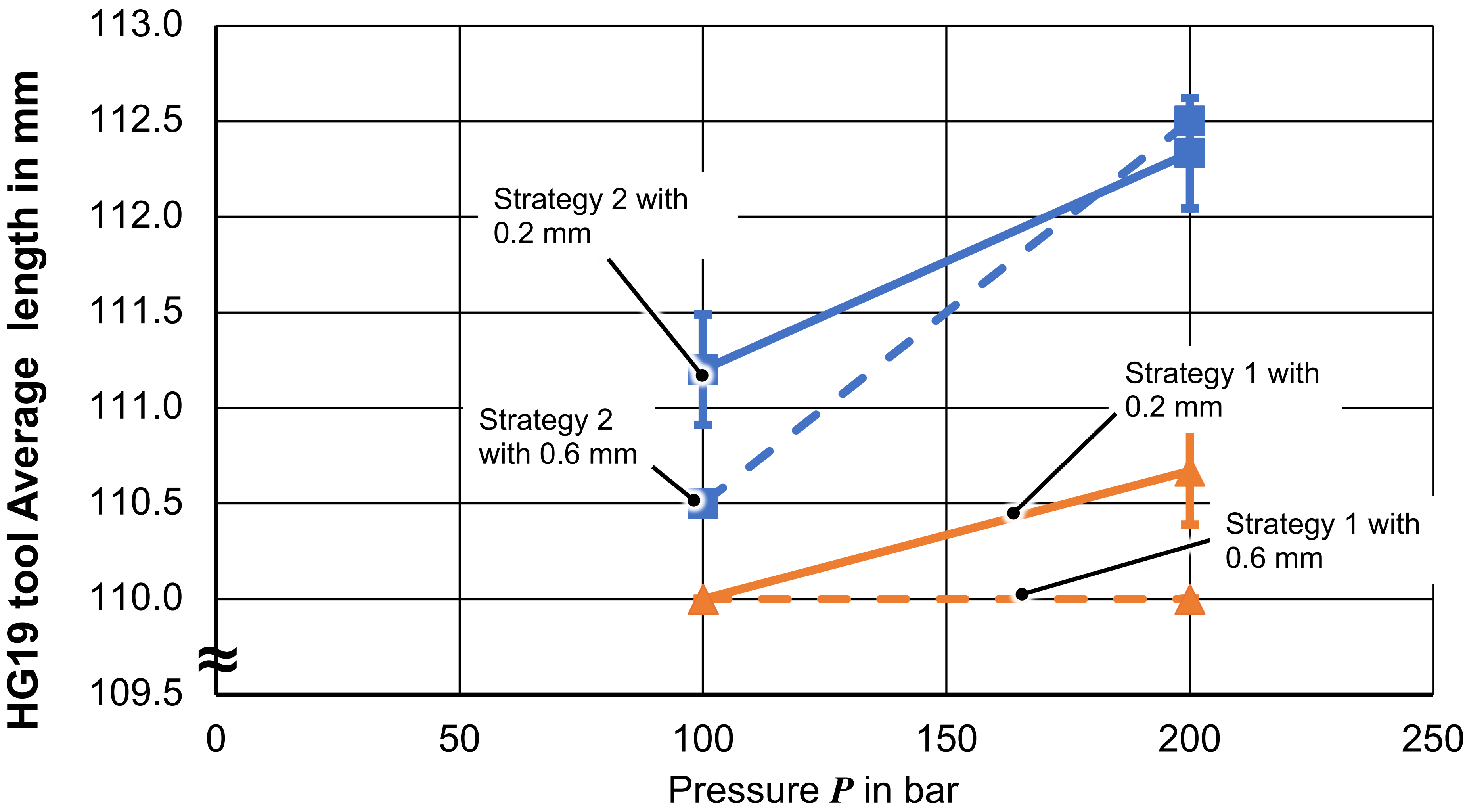
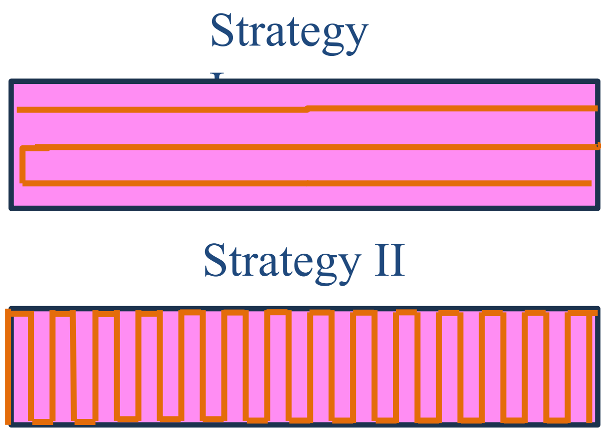
Length-HG19 tool





As printed
109 $\pm$0.3 mm

- Length usually increases with an increase in pressure

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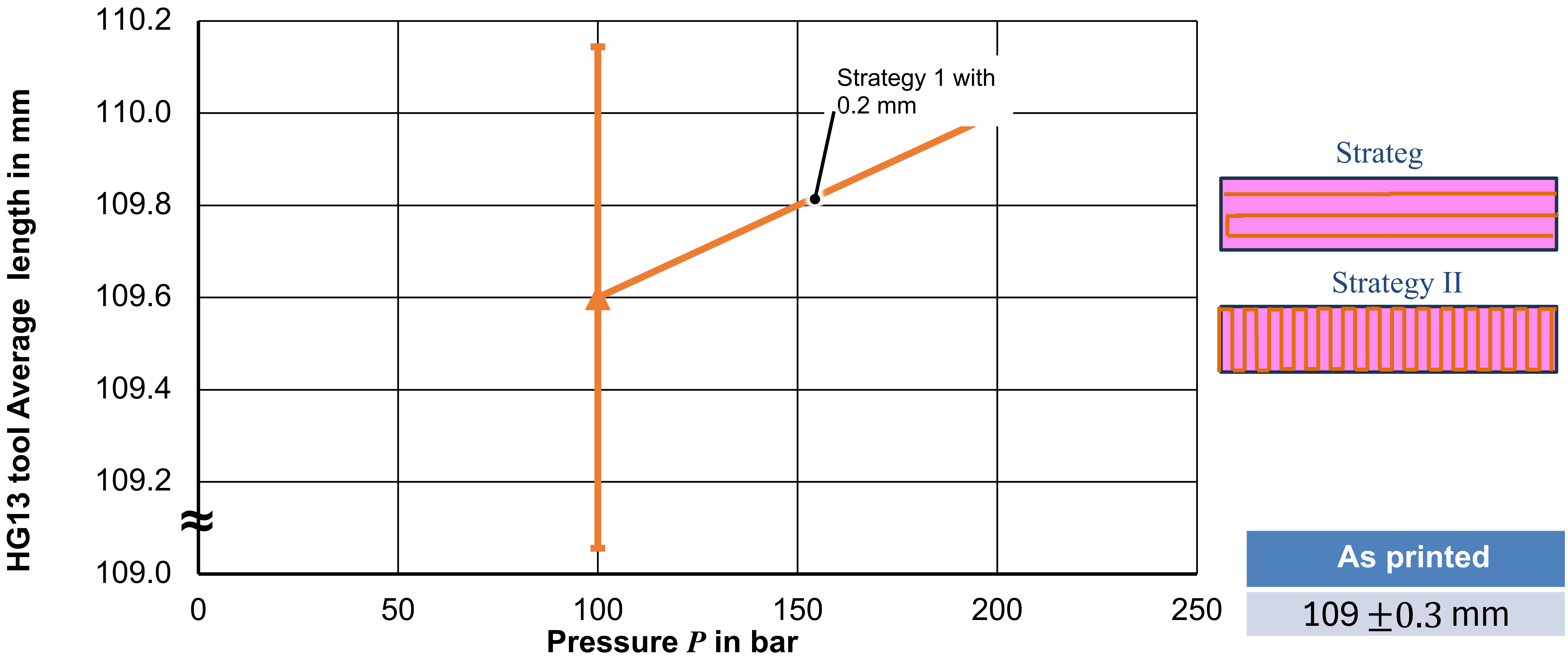
Length-HG13 tool



As printed
109 $\pm$0.3 mm

- Length usually increases with an increase in pressure

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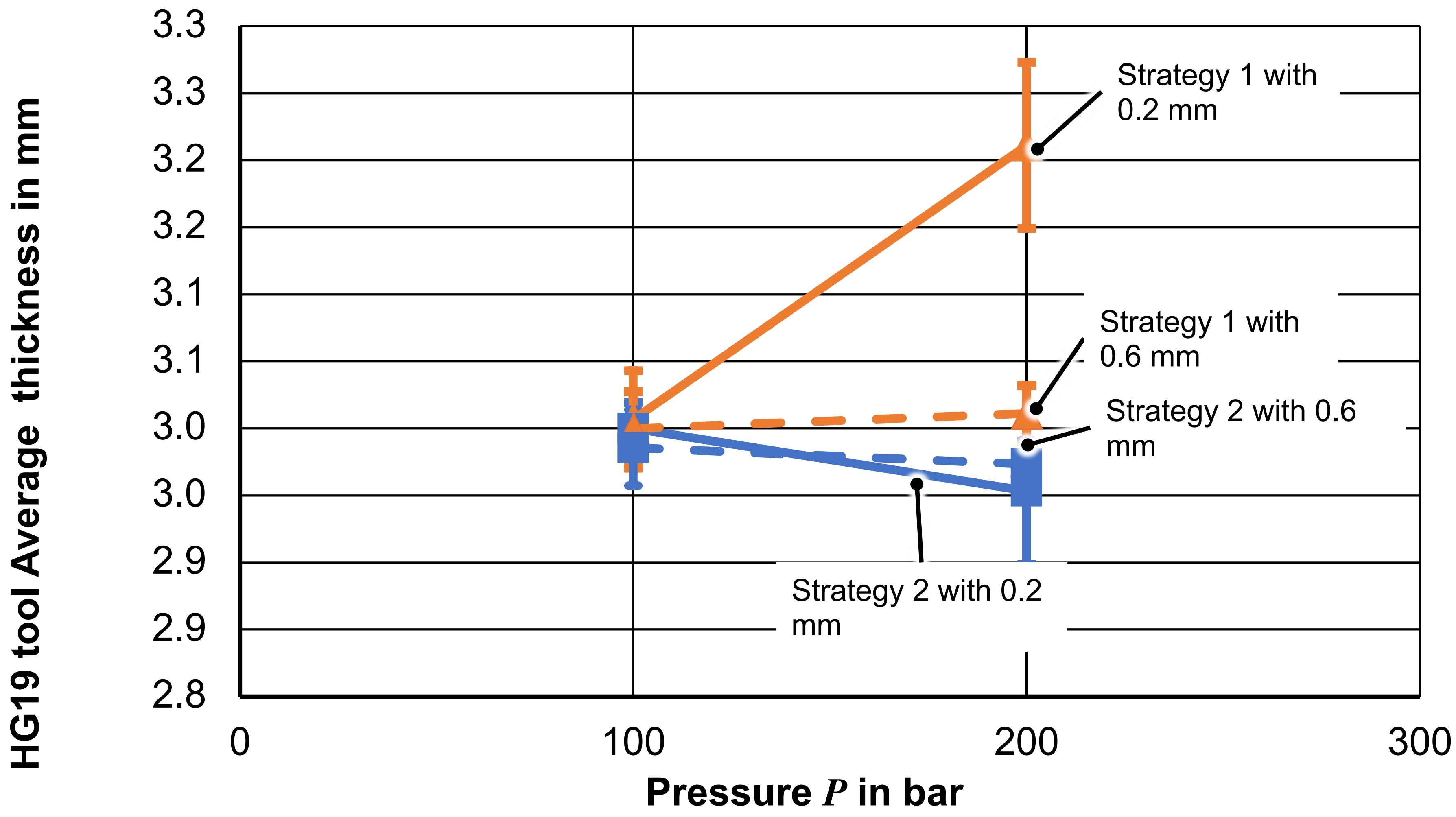
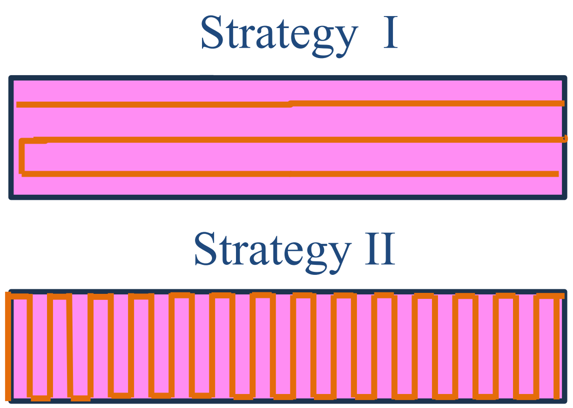
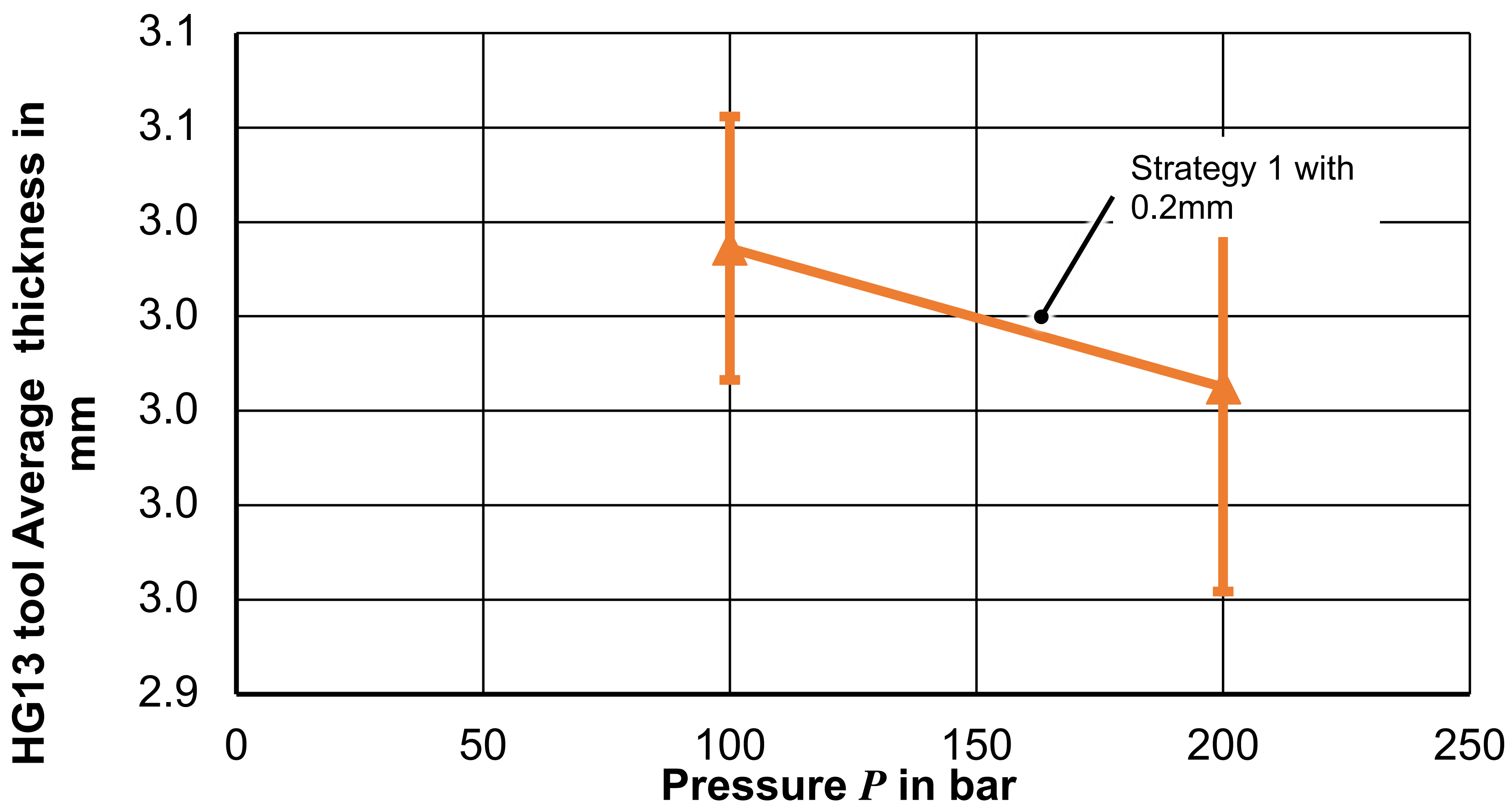
Thickness-HG19 tool

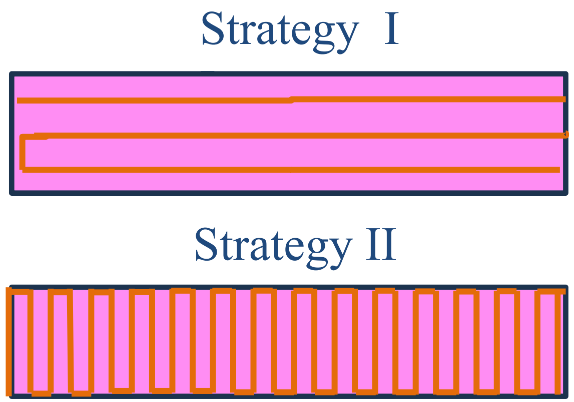




As printed
3.04 ±0.02 mm

Thickness-HG13 tool





As printed
3.04 ± 0.02 mm

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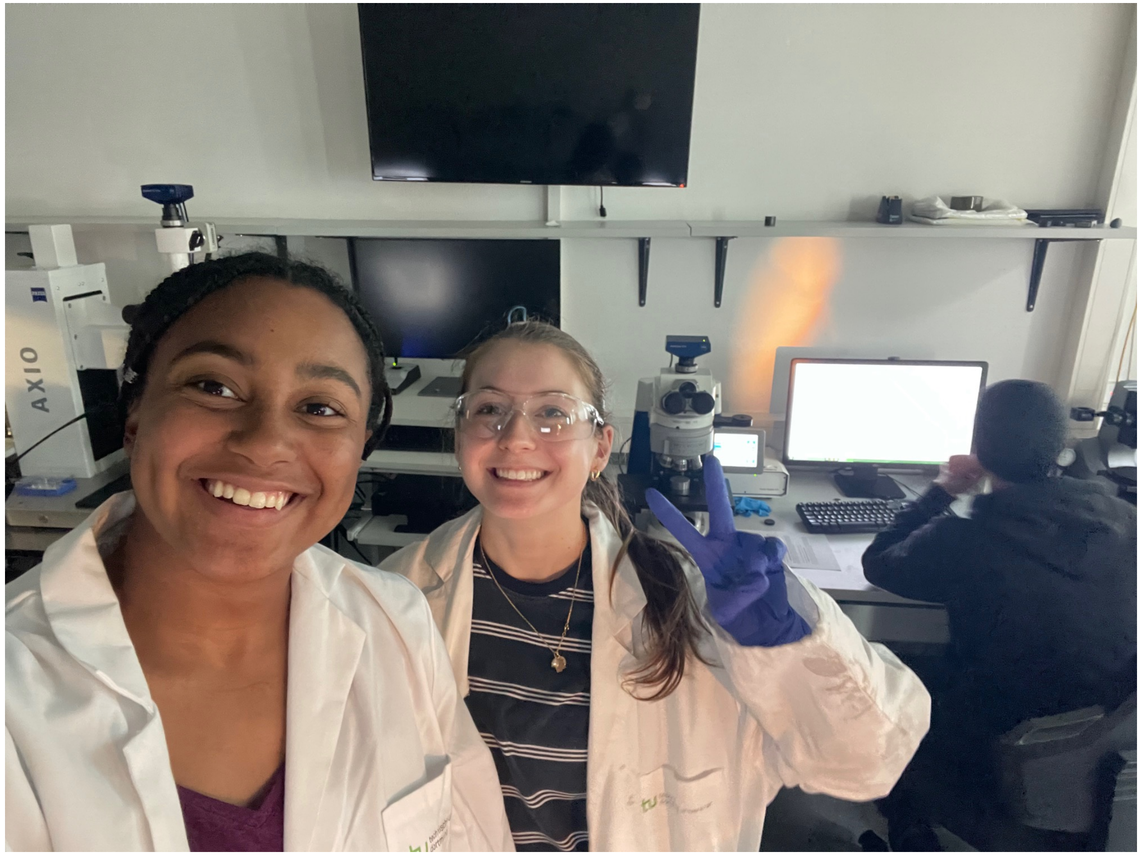
(Quelle:)

Concluding Remarks

- Thank you to my supervisor: Hamed Dardaei
- It was my first time doing experimental work
- I will carry what I've learned at the IUL to the rest of my academic and professional career



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Thank you for your attention.