Assessing the Suitability of Quality Metrics in Cold Spray: For Structural Repairs under Fatigue Loading [PPT]

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Assessing the Suitability of Quality Metrics in Cold Spray

For Structural Repairs under Fatigue Loading

Mary Patrick, John-Alan Pascoe, Calvin Rans,
René Alderliesten

26-6-2025 – Cold Spray Club

Acknowledgements

The work presented was supported by the Dutch Research Council Open Technology Programme 'CSAR' (grant no: 20434), EPCOR, and Pascal Dinglinger (University of Bremen).

Ice Breaker

What does a “good quality” cold spray deposit mean to you?

“Good” Enough for Aerospace

Cosmetic Repairs
(Geometrical Restoration)

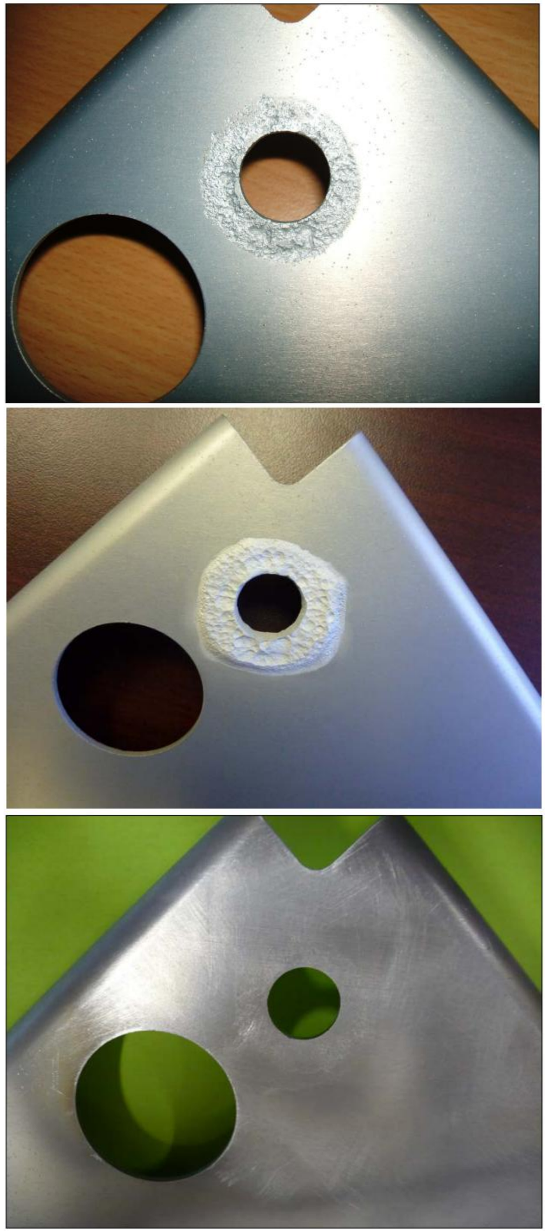
Structural Repair

BCA
Customer
Support

SERVICE LETTER

737-SL-32-182-B
ATA: 3200-00
28 August 2017

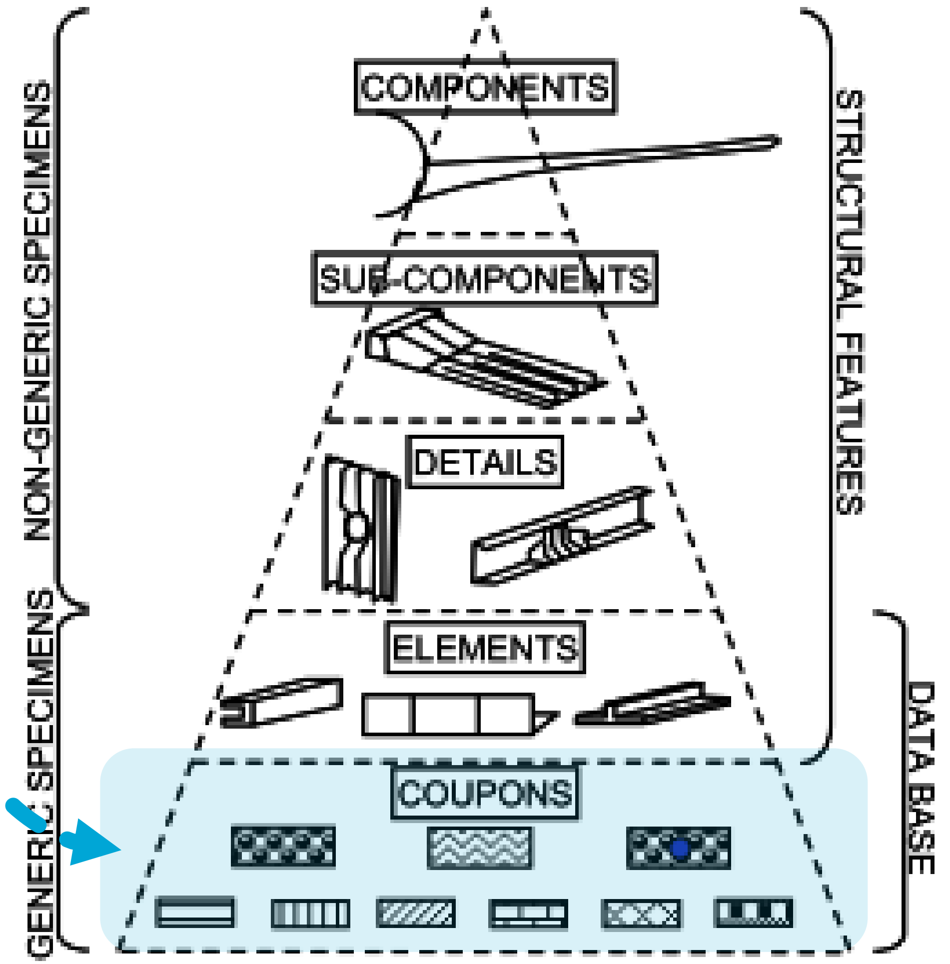
SUBJECT: COLD SPRAY REPAIR OF P/N 287A6115 MLG WIRE BUNDLE SUPPORT BRACKET



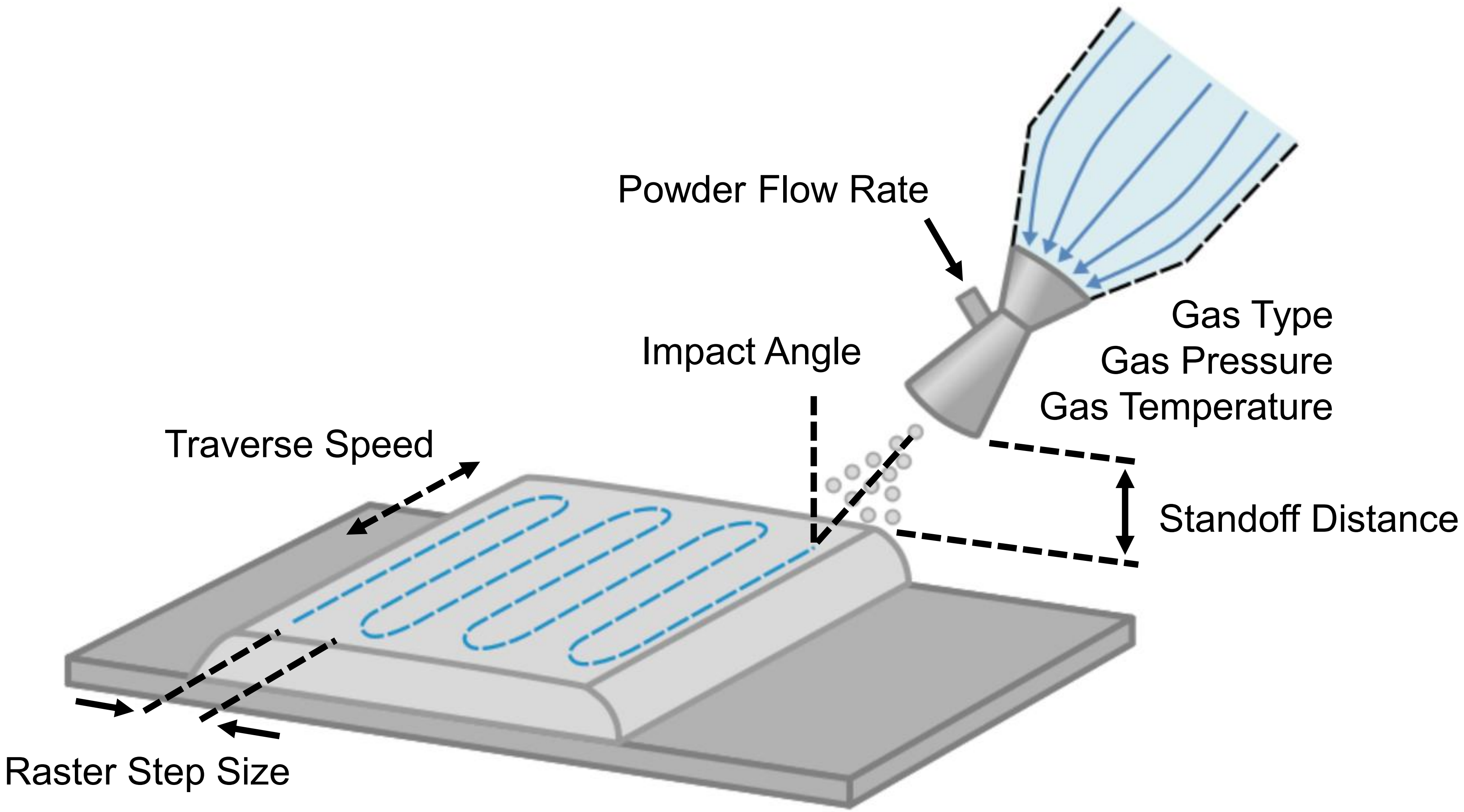
Photos and information courtesy of EPCOR

“Good” Enough for Aerospace: Structural Repair

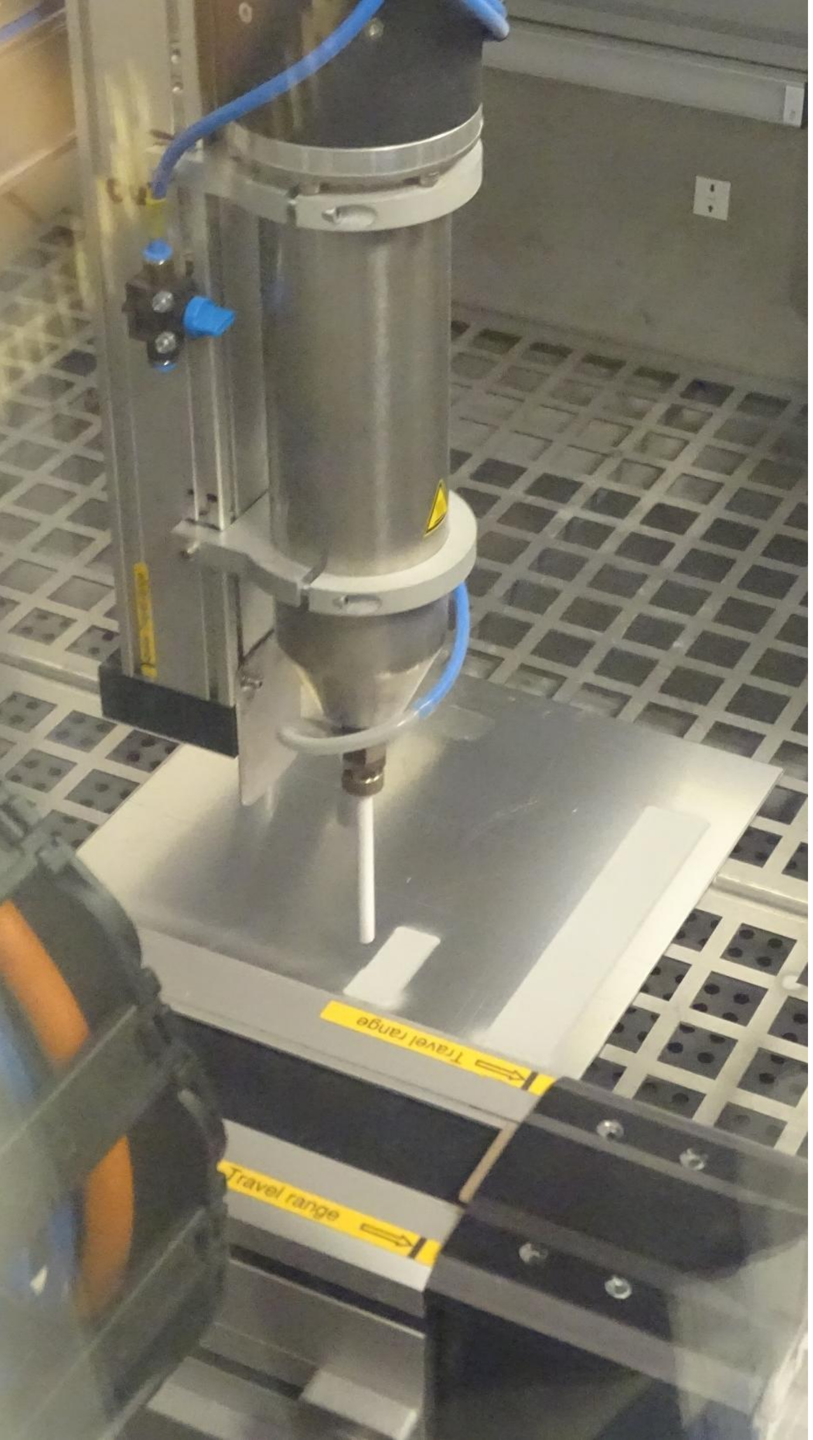
Manufacture



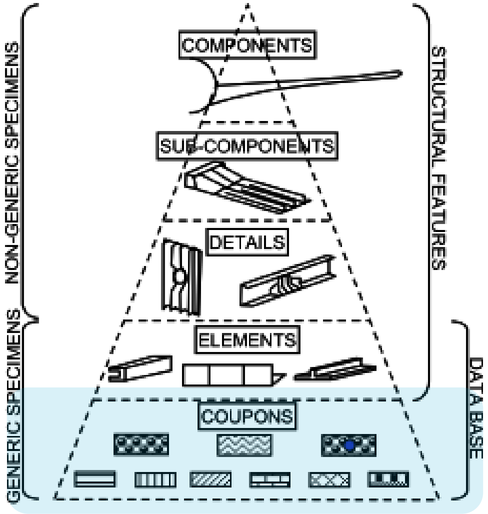
Source: FAA AC 20-107B



Adapted from Yin et al., *Additive Manufacturing,* 21:628-650 (2018)



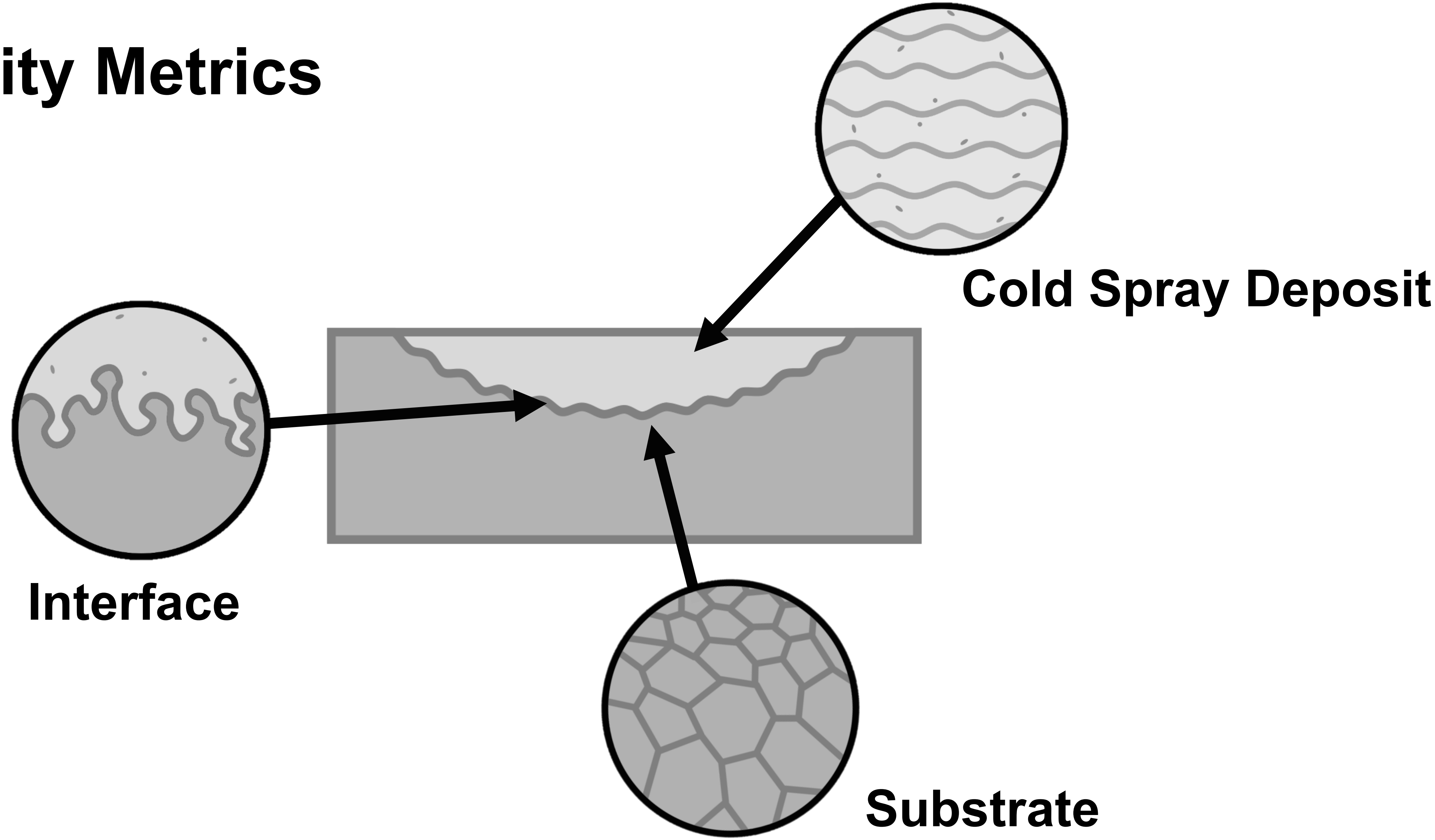
At TU Delft



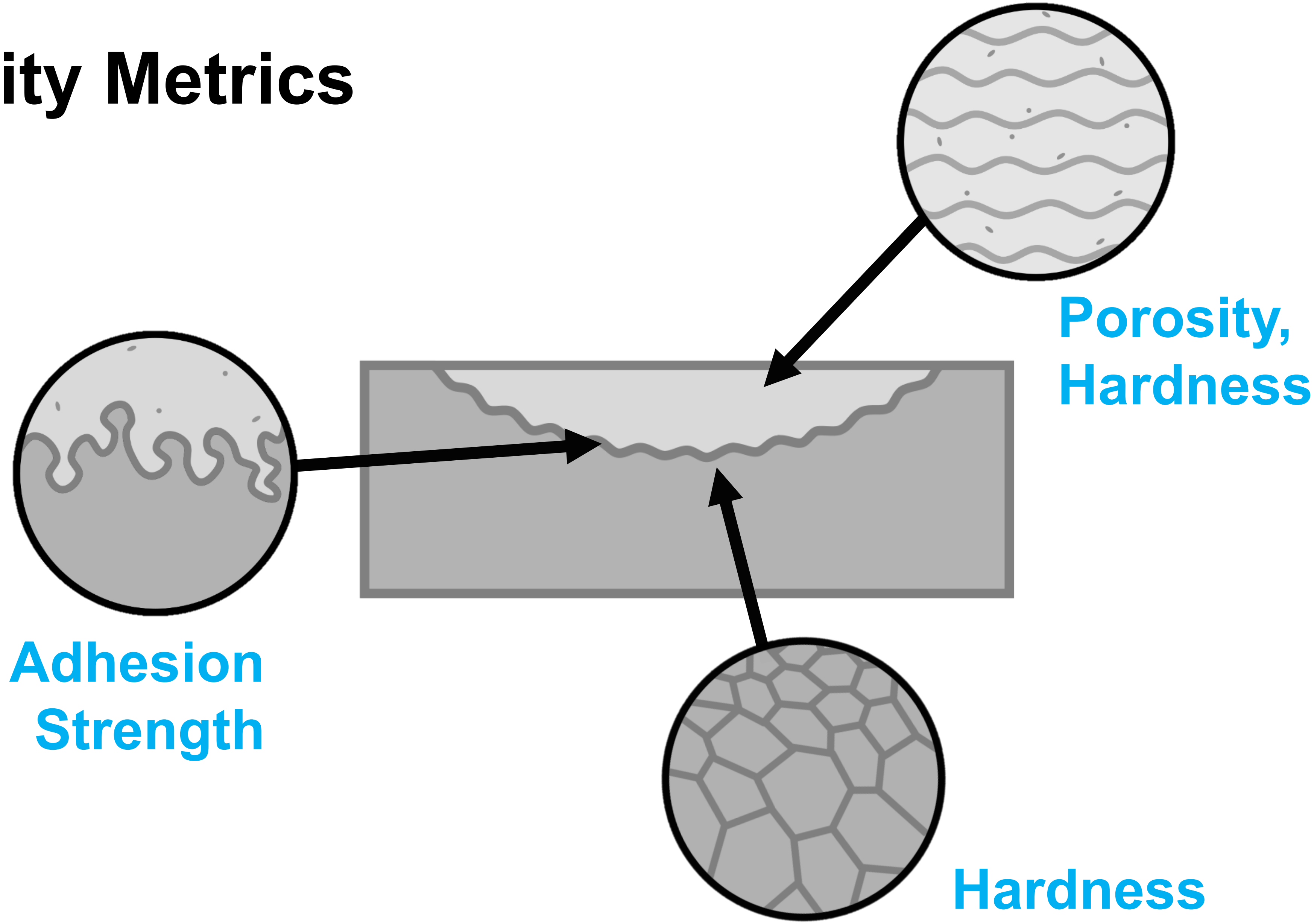
Spray settings

Quality Checks

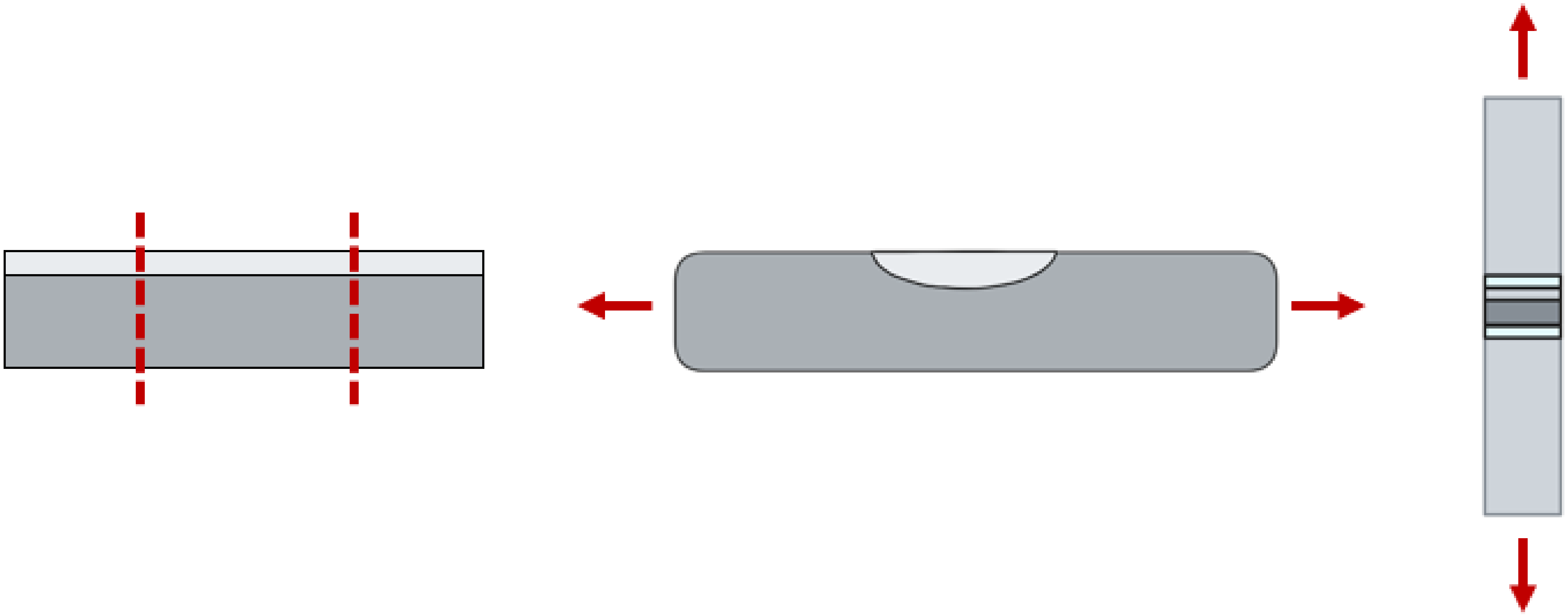
Quality Metrics

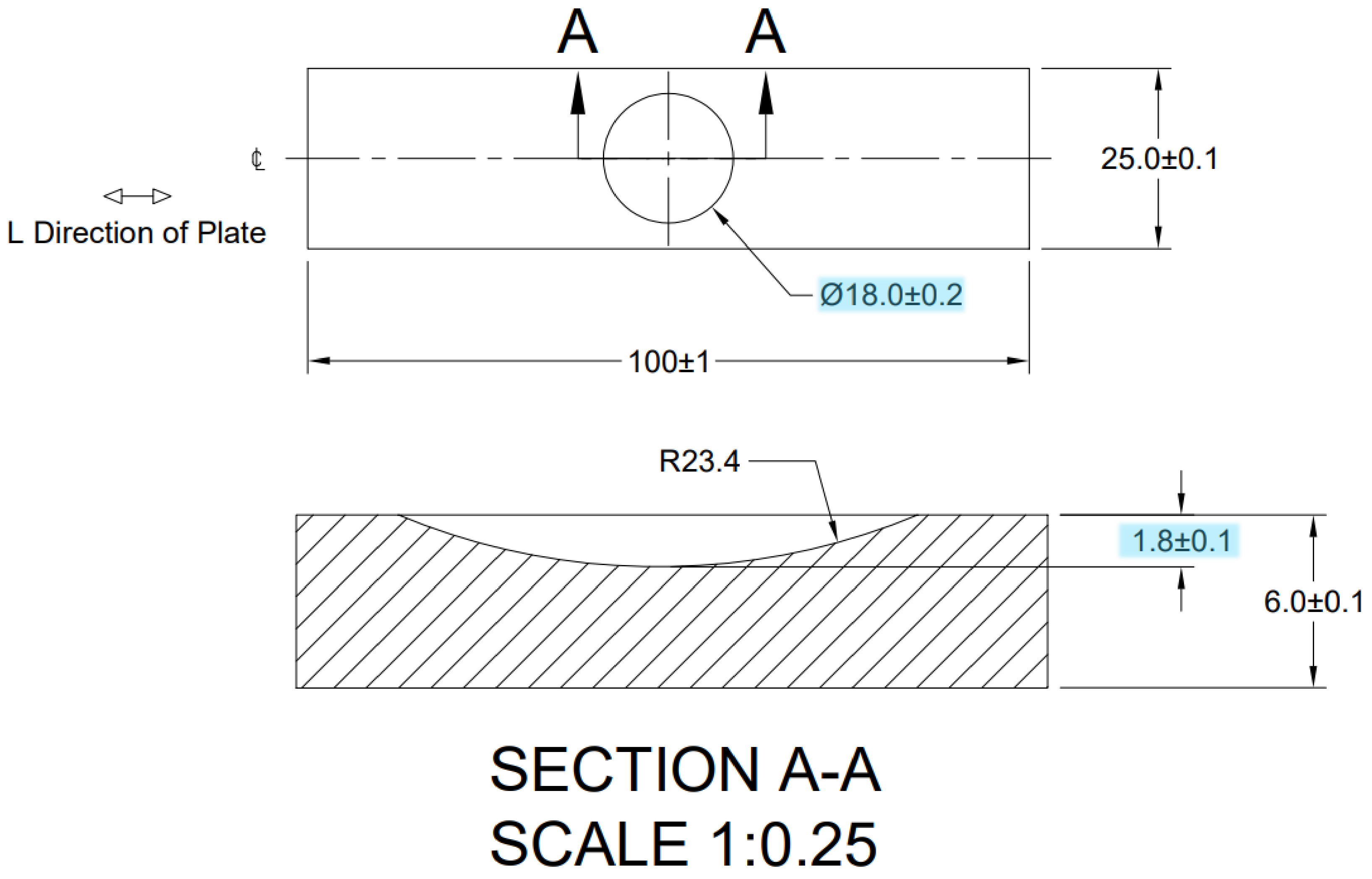


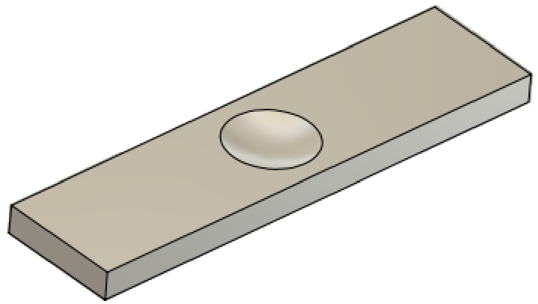
Quality Metrics



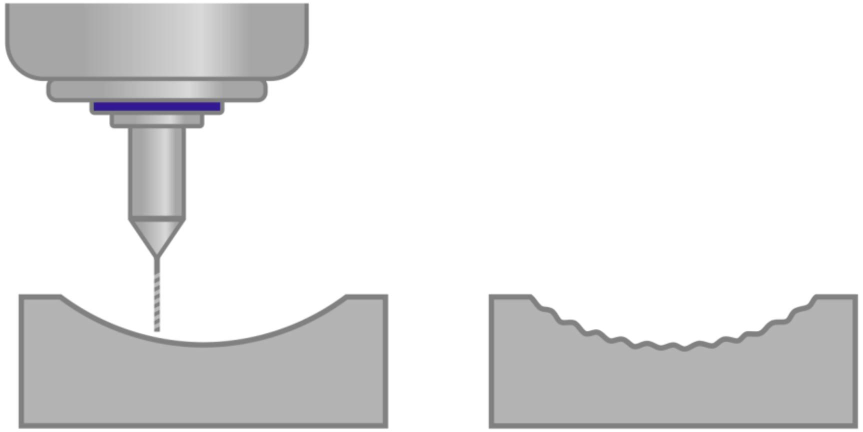
Do the quality metrics we use for cosmetic repairs guarantee an improvement in fatigue performance?

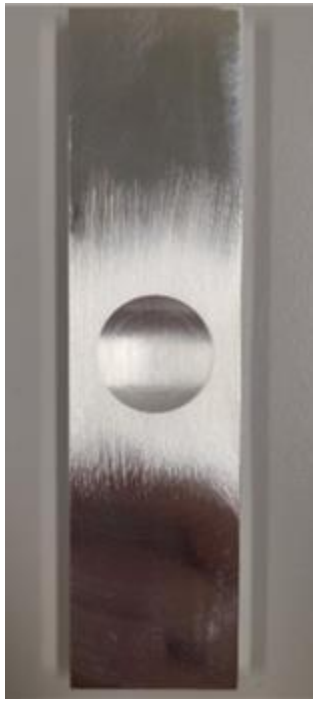






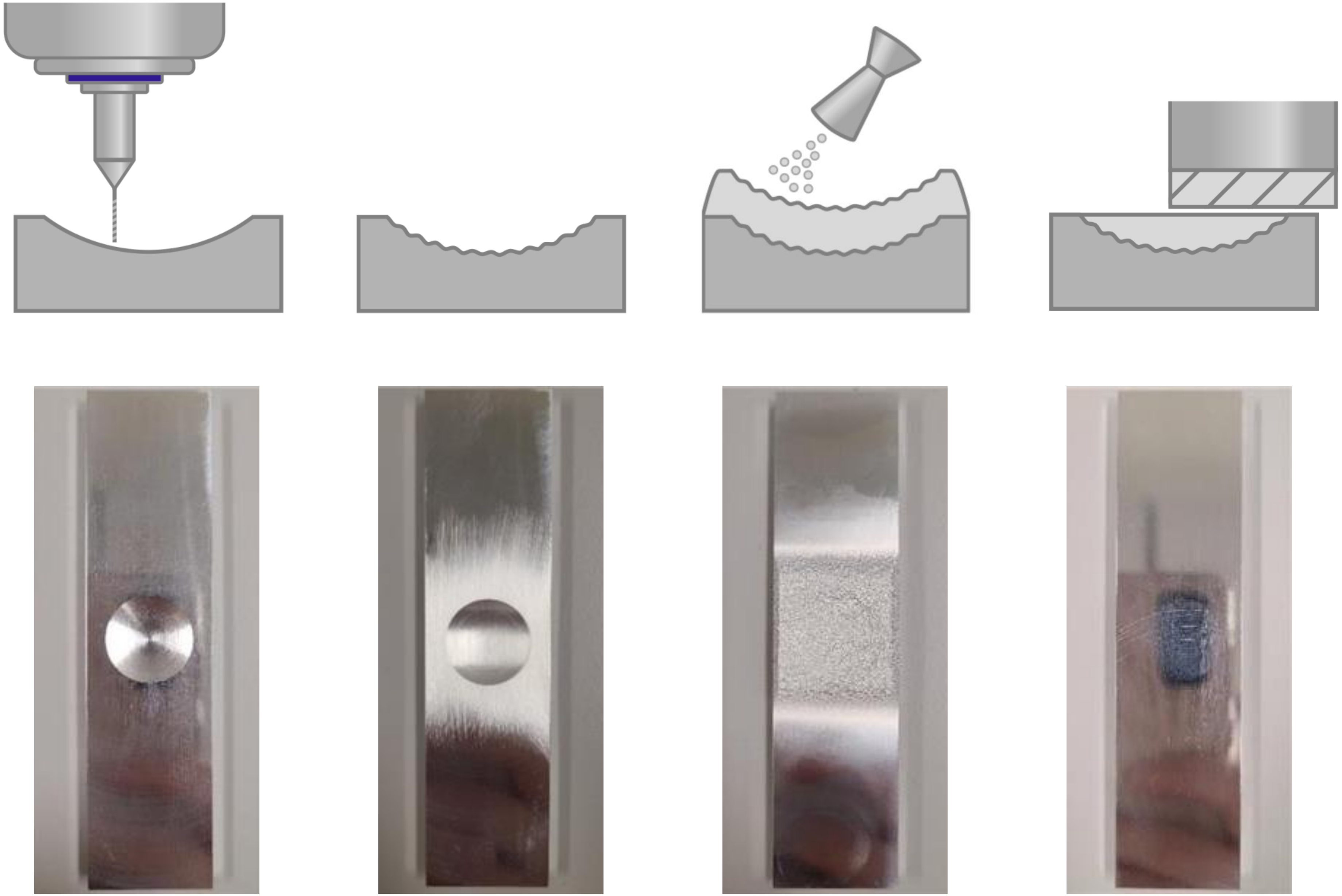
Coupon geometry is based on those used by Safe Inc. (CSAT 2024)

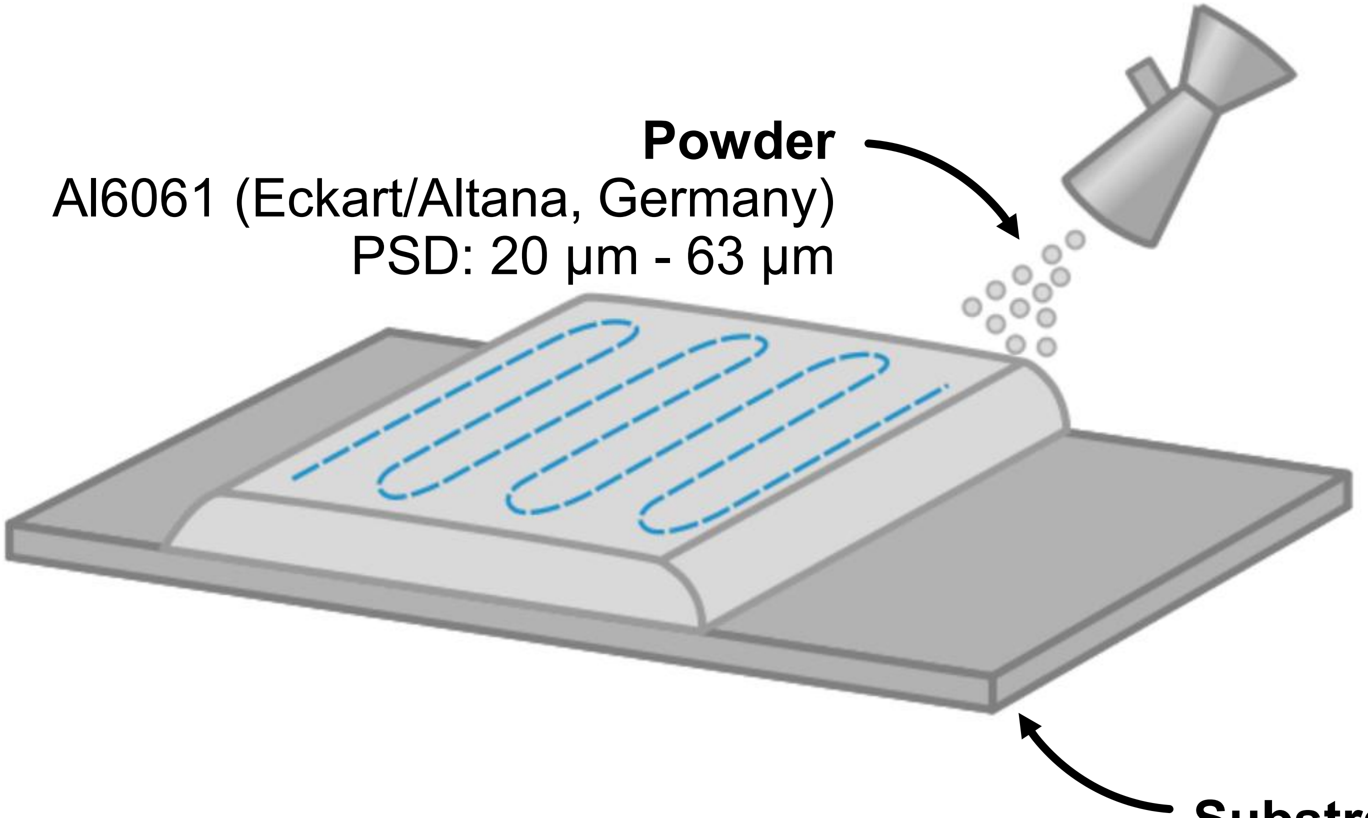




Sand Blast

Scotch Brite



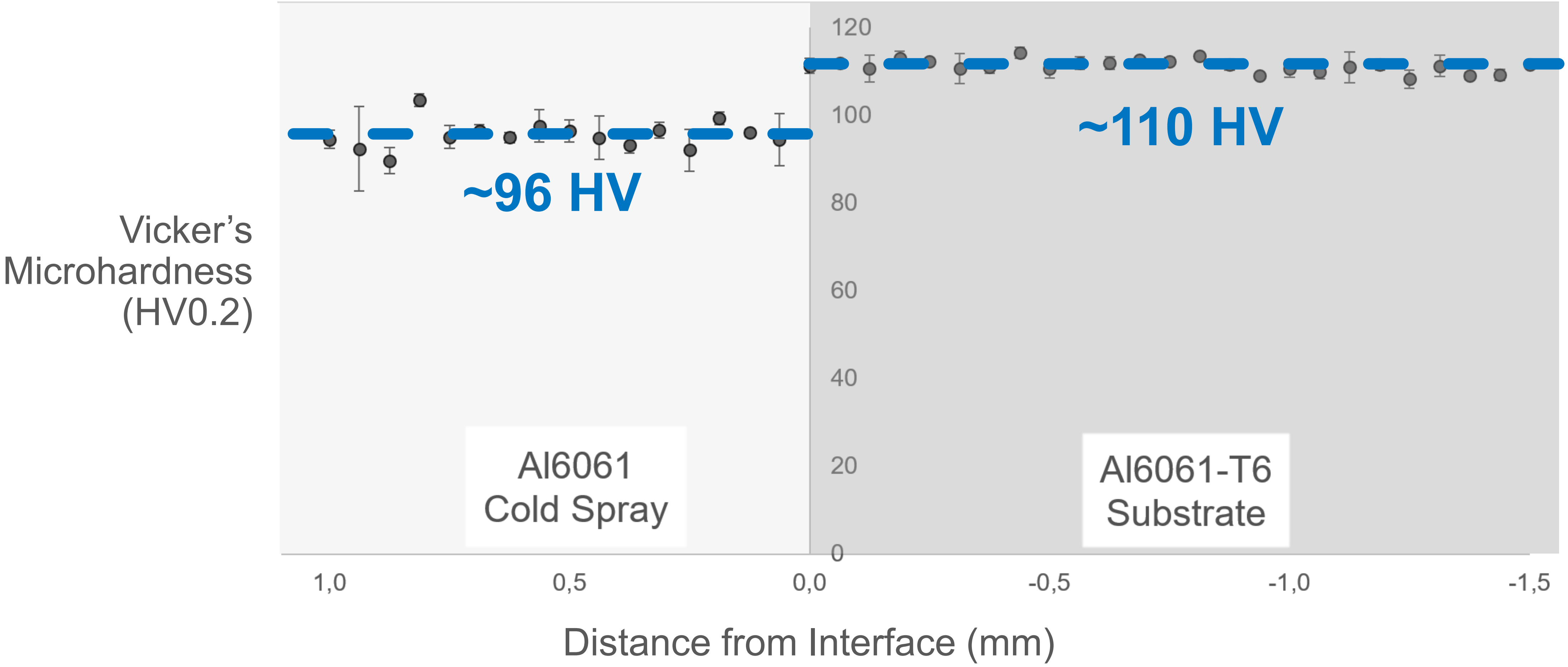


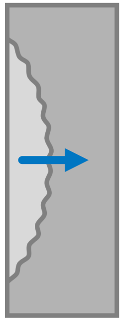
Spray Settings:

- Pressure: 20 bar
- Gas: Nitrogen
- Nozzle Temperature: 600 °C
- Nozzle Traverse Speed: 20 mm/s
- Standoff Distance: 20 mm
- Average Particle Velocity: 550-720 m/s
- Number of Layers per Coupon: 5

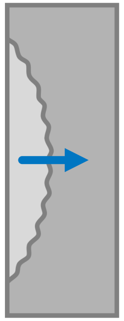
Quality Metrics – According to the Standards

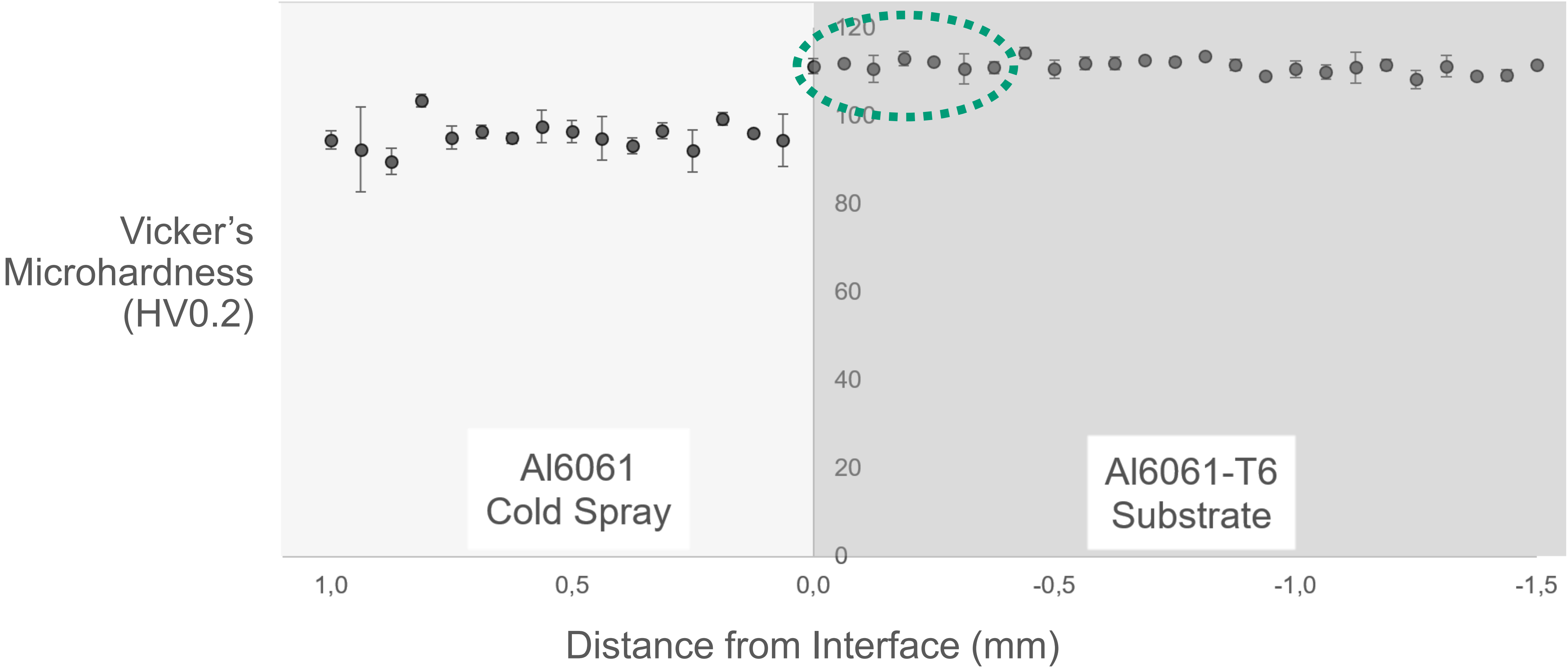
ASTM E384: Hardness



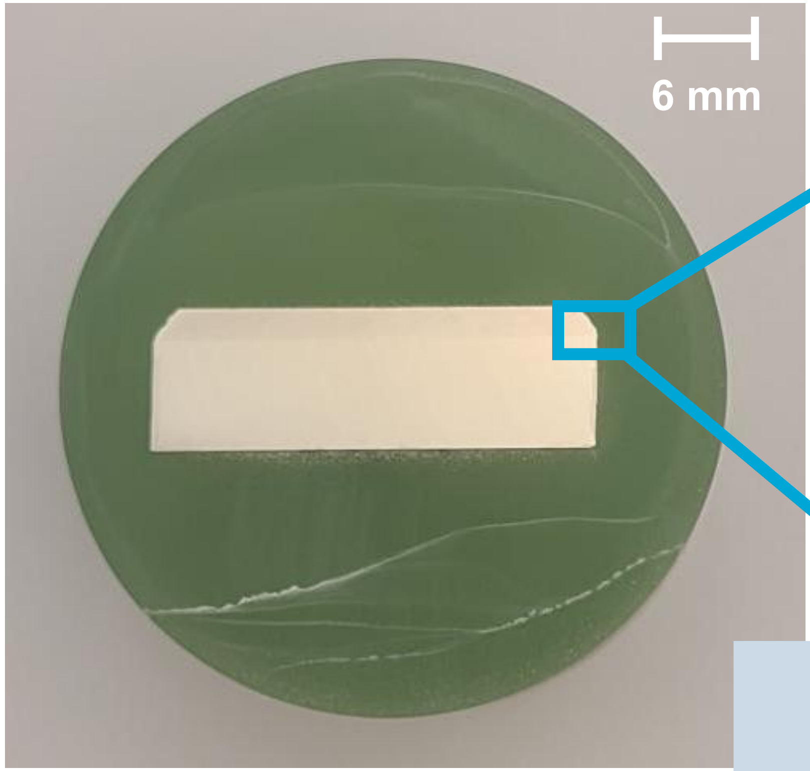


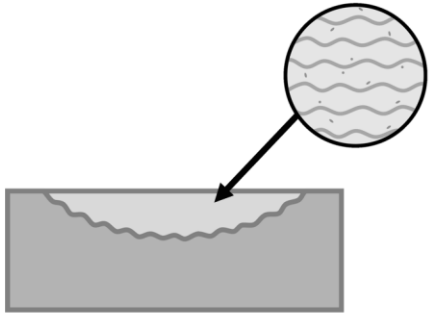
ASTM E384: Hardness





ASTM E2109: Porosity

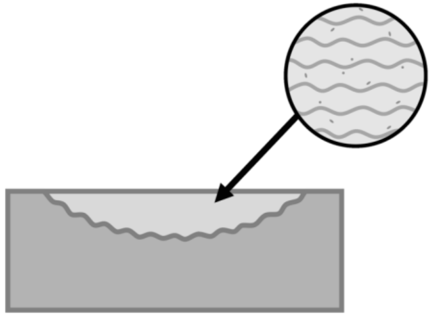


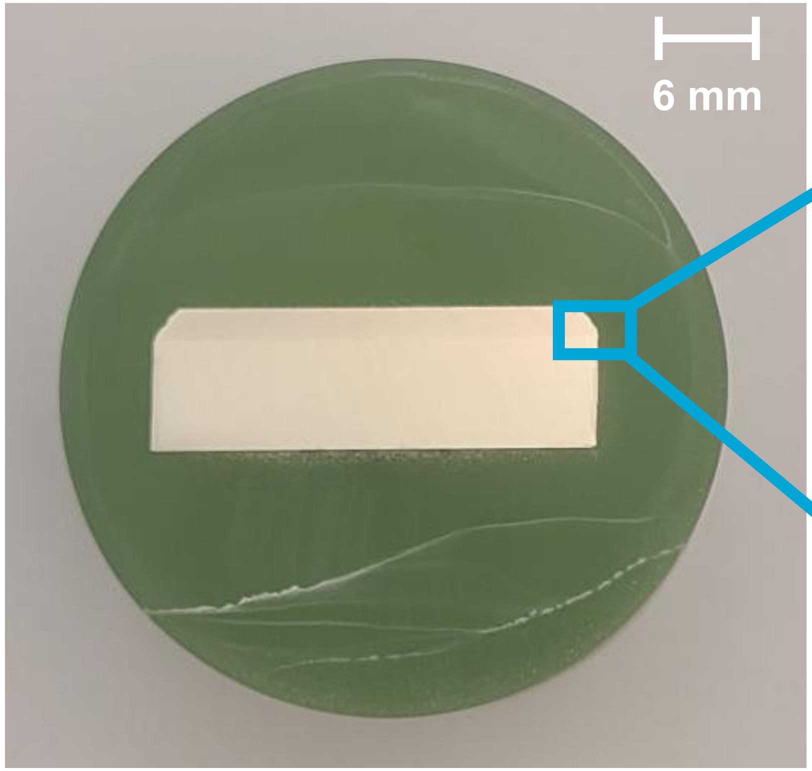


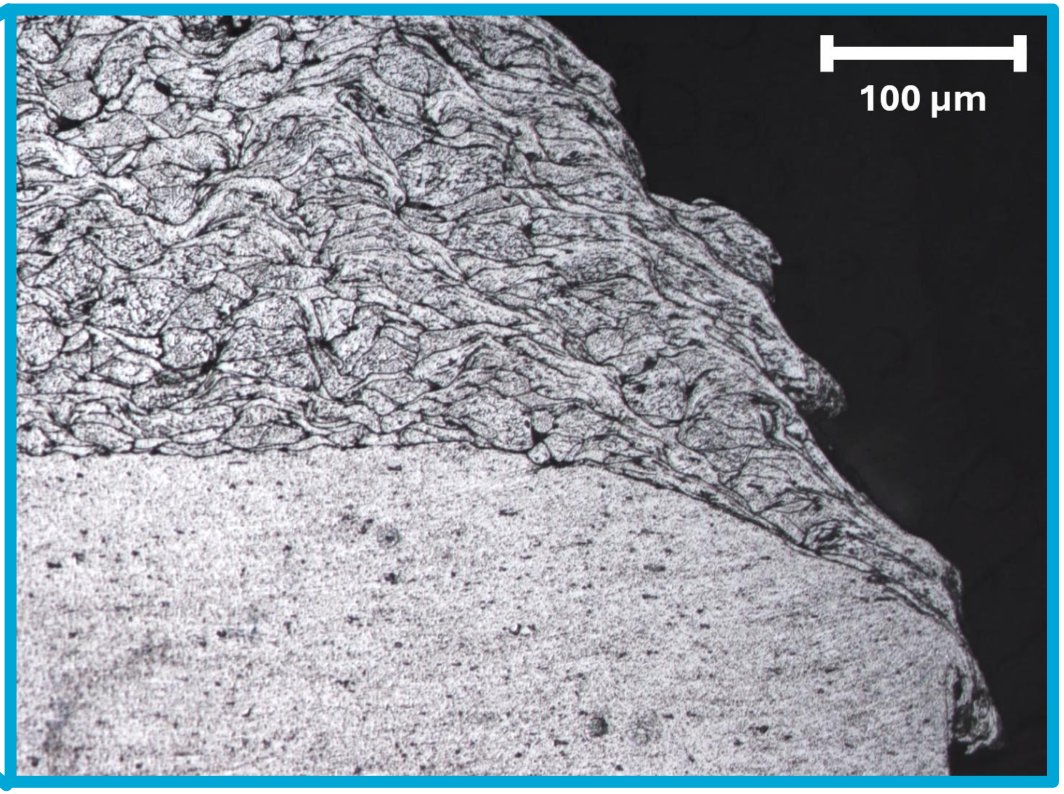
< 0.5%

Polished

ASTM E2109: Porosity

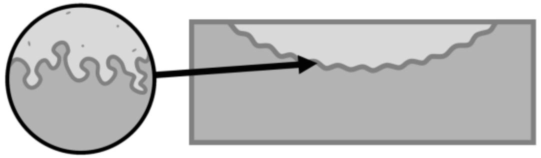






Polished + Etched

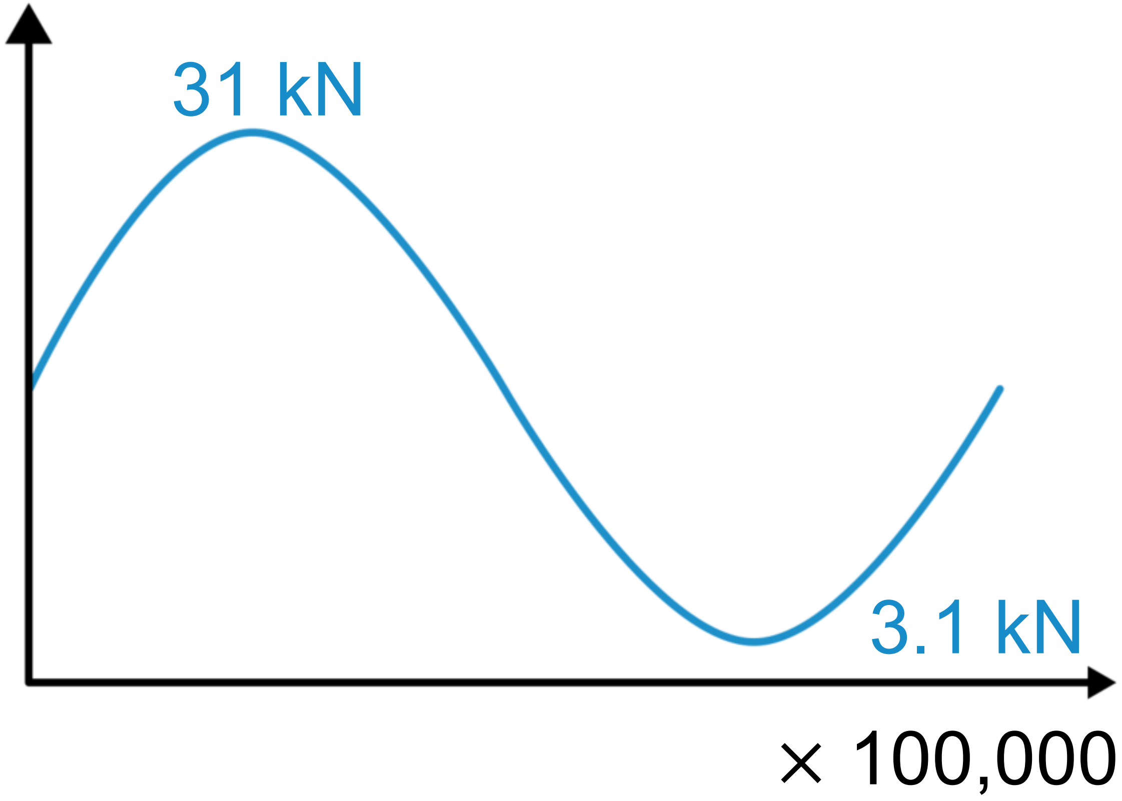
ASTM C633: Adhesion Strength

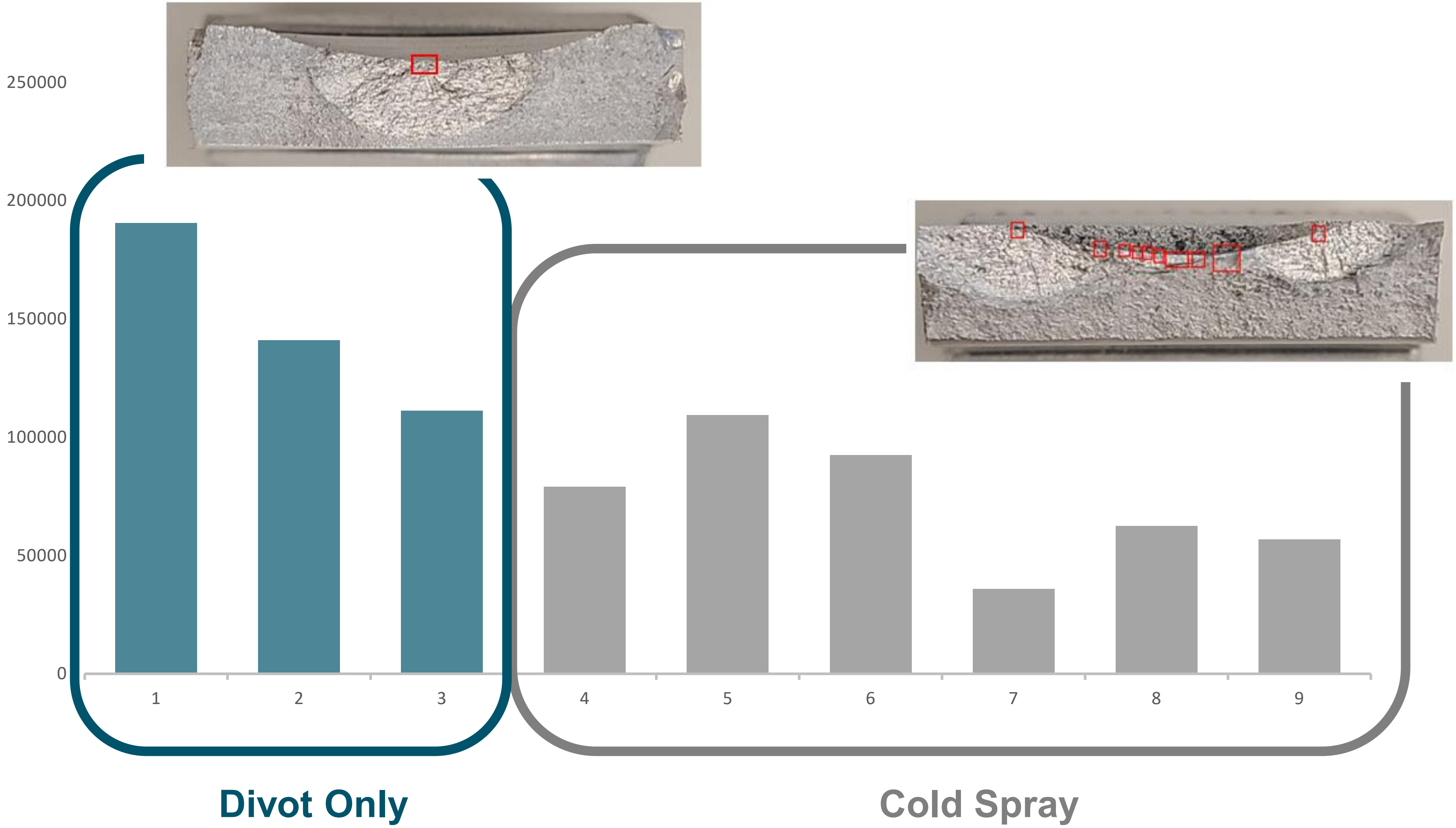


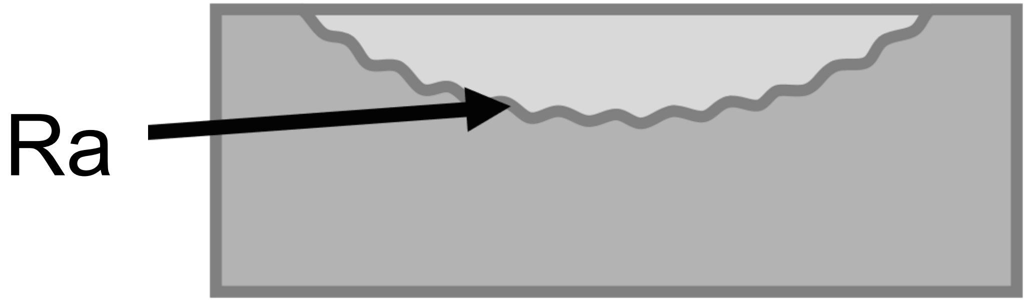
Work	Coating // Substrate	Adhesion Strength
Koh (2016)	Al6061 // Al6061	34 MPa
Koivuloto (2020)	Al6061 // Al	35 MPa
Nourian (2022)	Al6061 // Al6061	54 MPa
This work	**Al6061 // Al6061-T6**	**27 – 52 MPa***

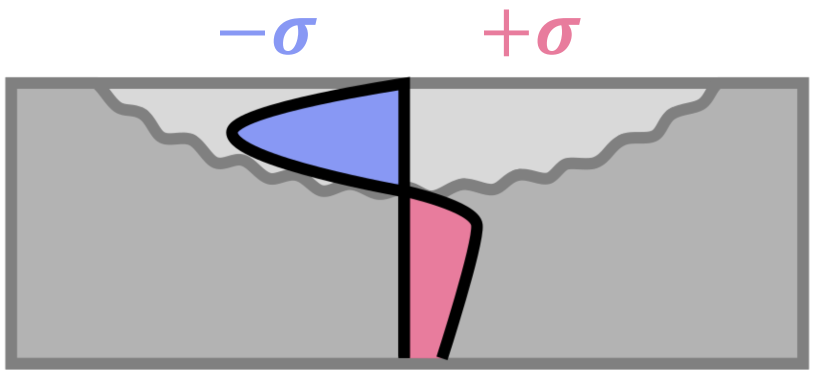
Looks good, right?

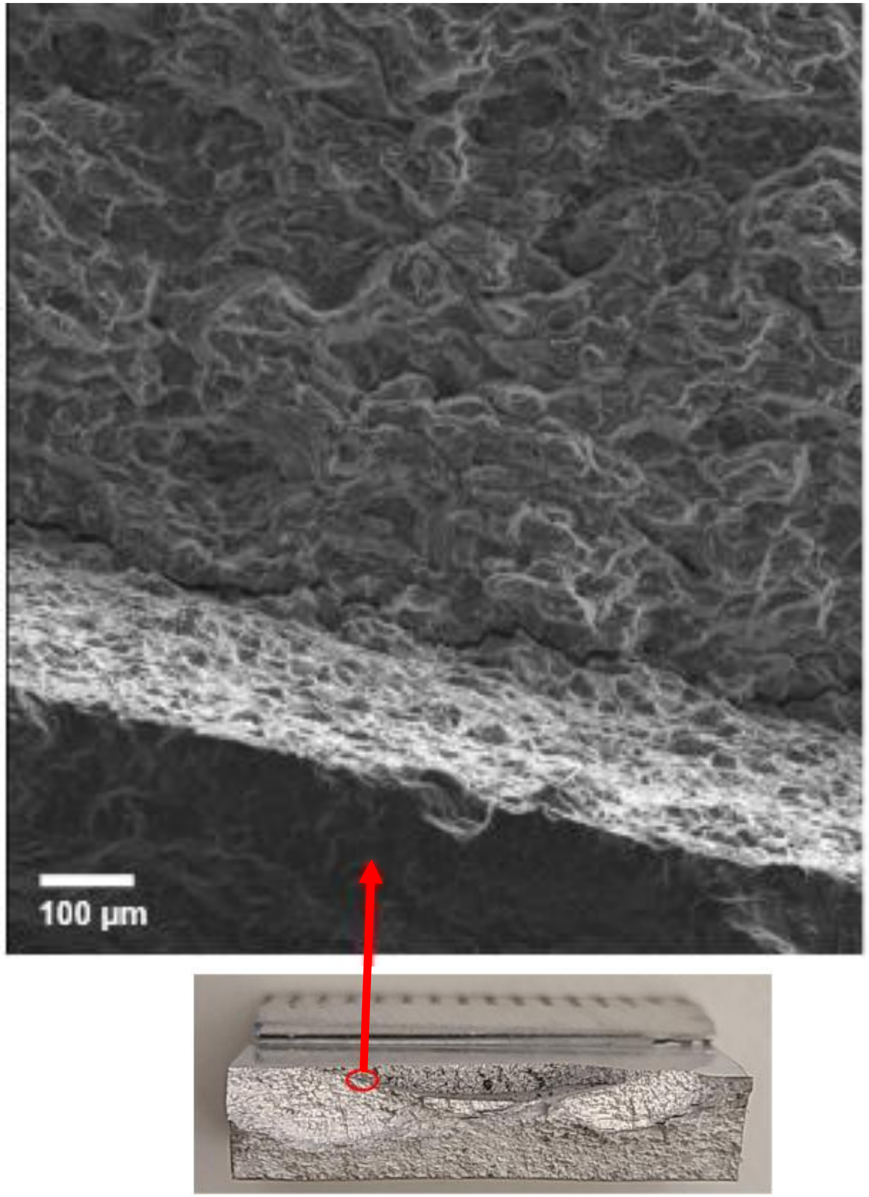
Fatigue Testing



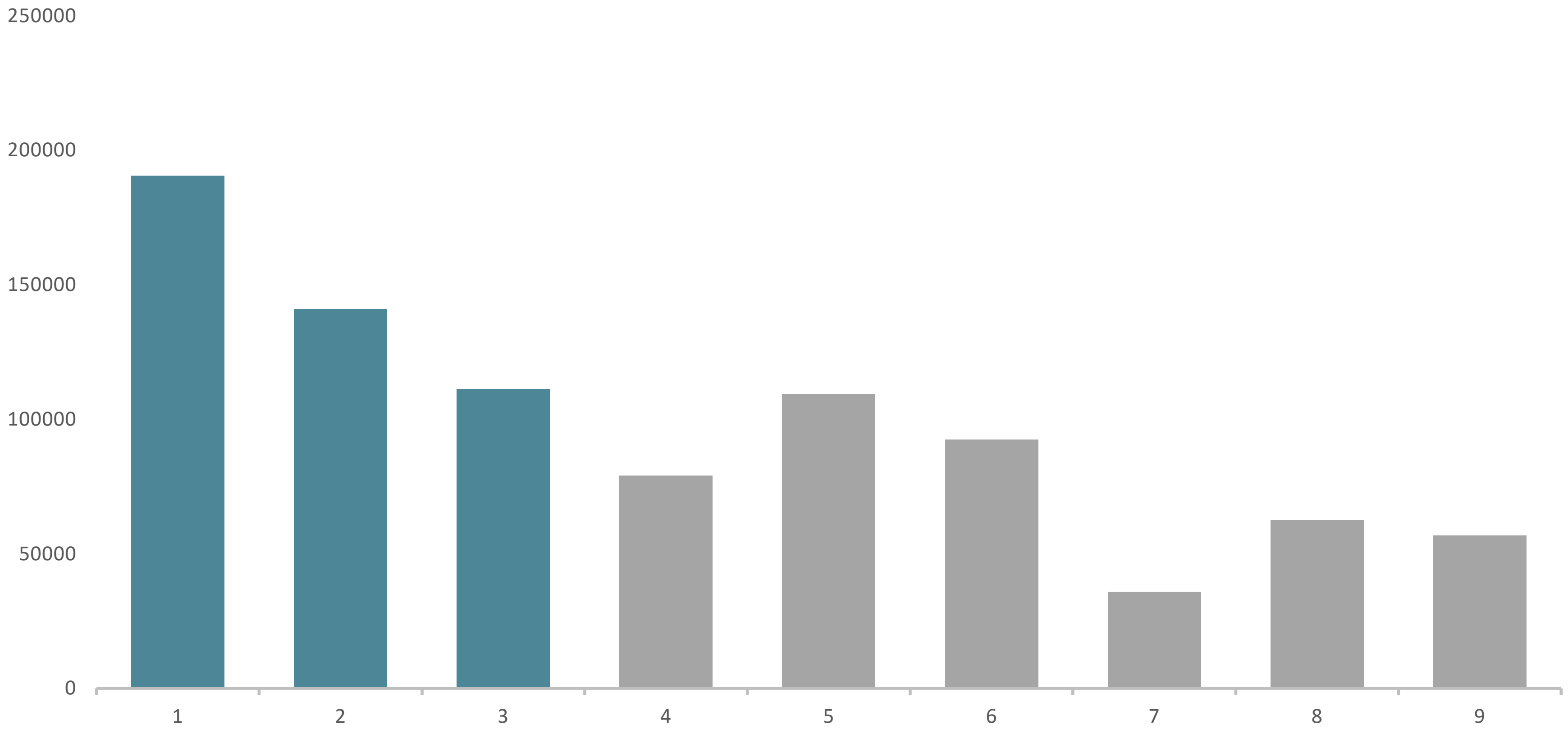

250000
200000
150000
100000
50000
0
1
2
3
4
5
6
7
8
9
Divot Only
Cold Spray


Ra


$-\sigma$
$+\sigma$


100 µm


50
µm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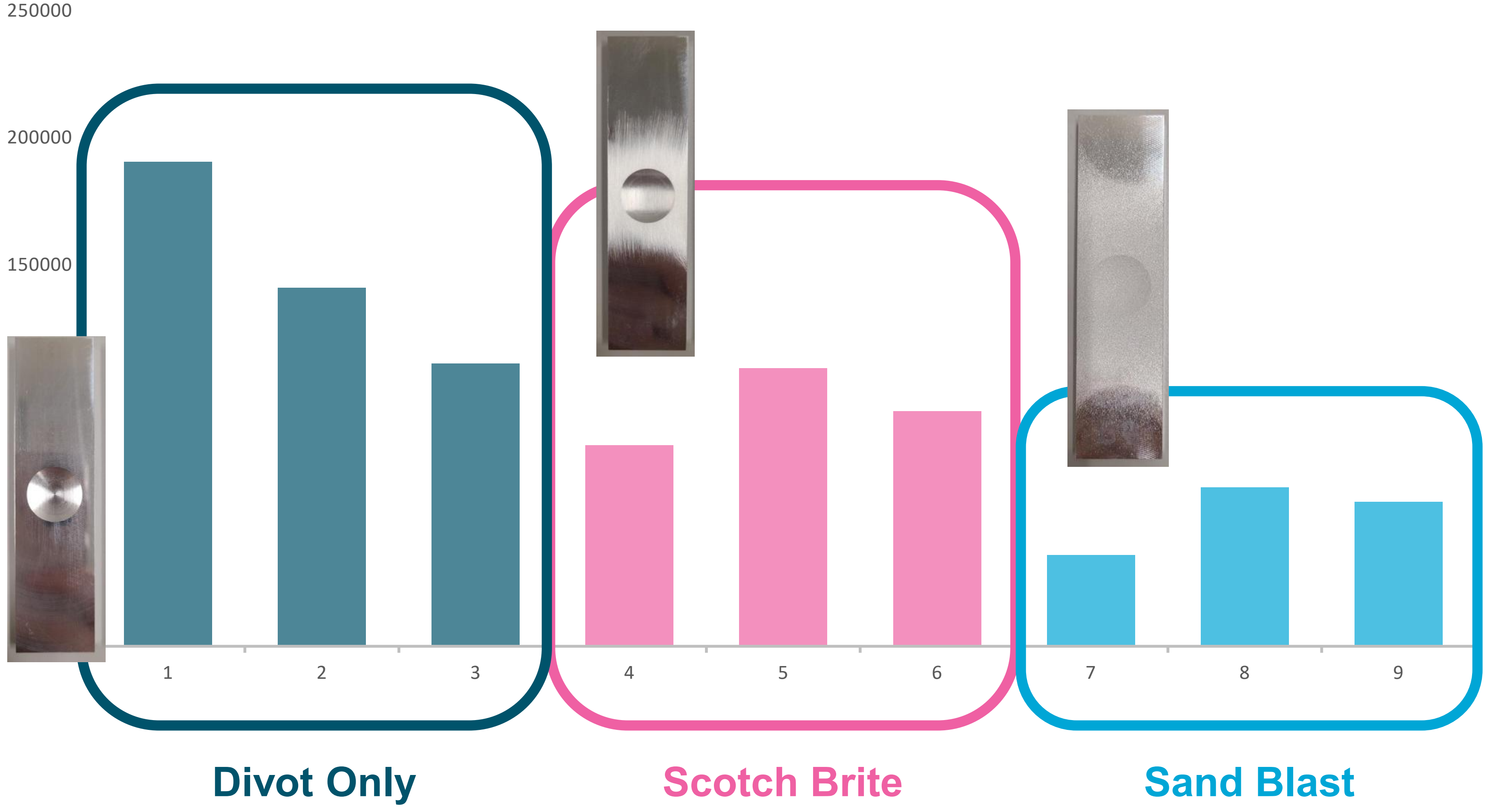
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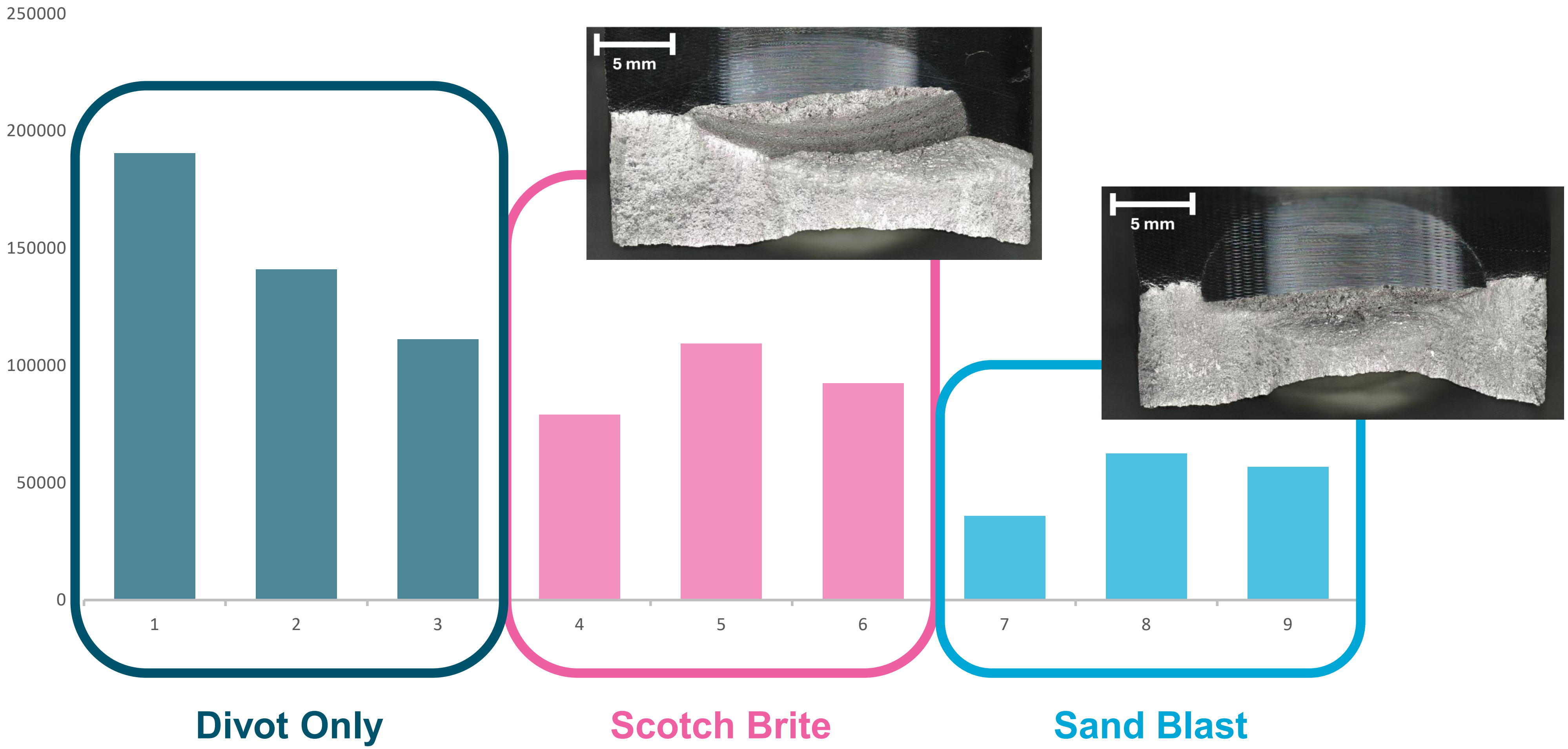
9
Divot Only
Scotch Brite
Sand Blast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8
9
5 mm
5 mm
Divot Only
Scotch Brite
Sand Blast

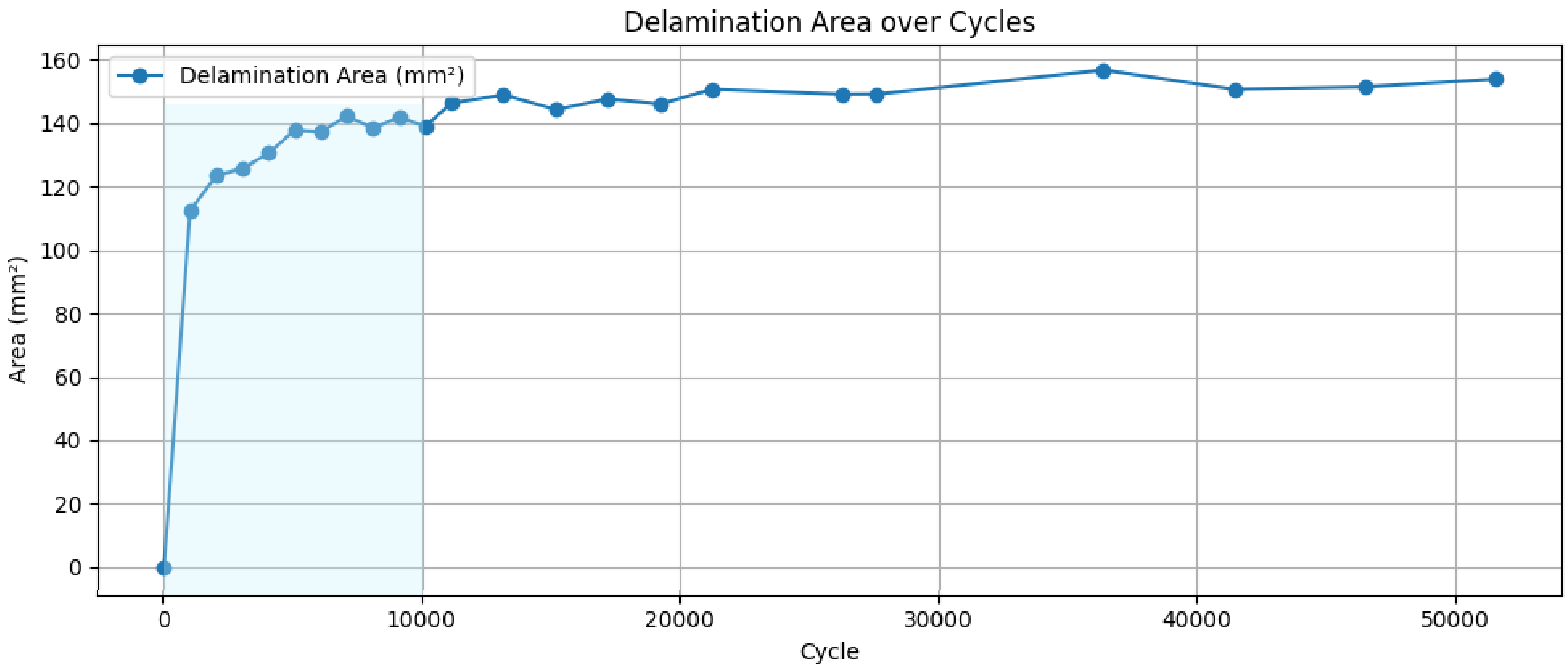
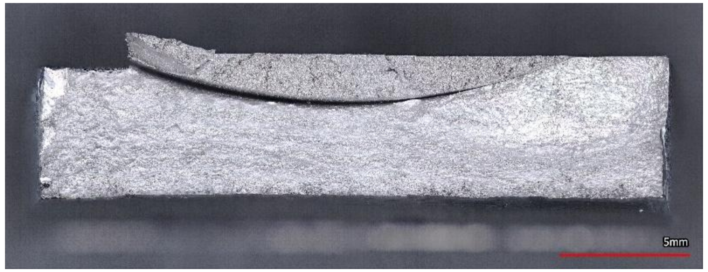
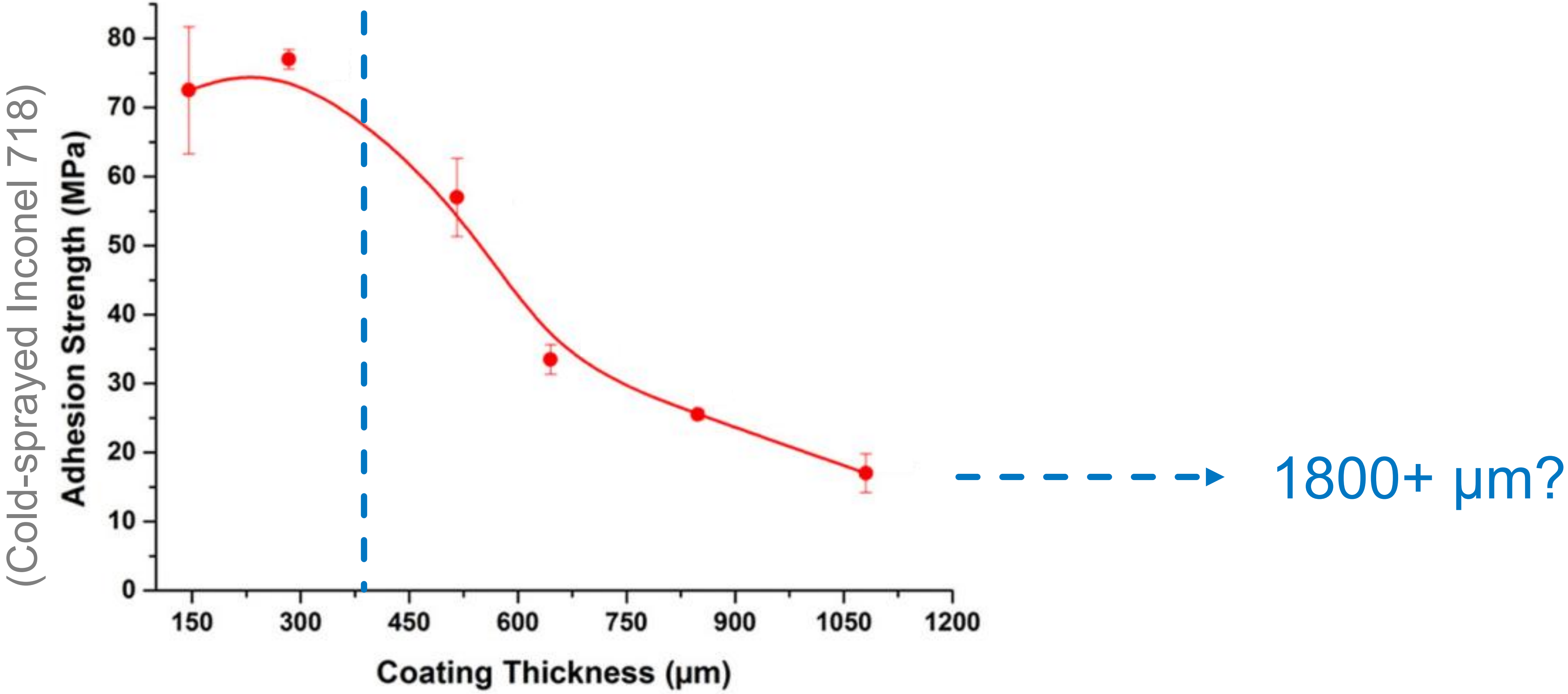


Figure courtesy of P. Dinglinger



Quality Metrics –
The “not-so-standard” way

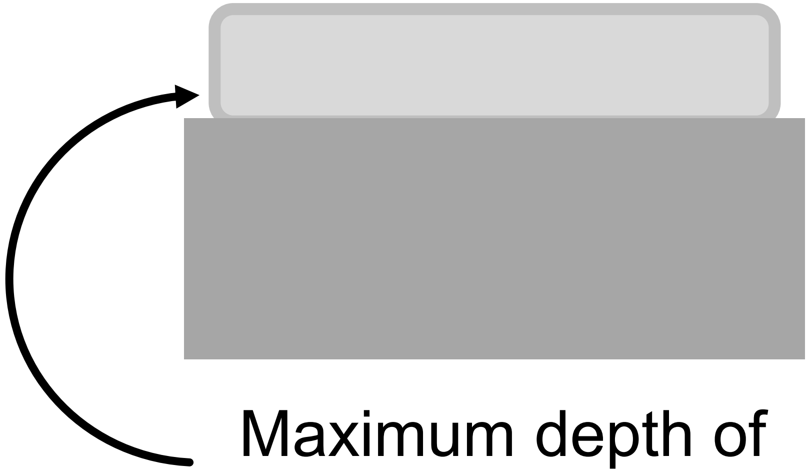
Adhesion Strength for Repairs



Singh et al., *Surface and Coatings Technology*, 350:64-73 (2018)

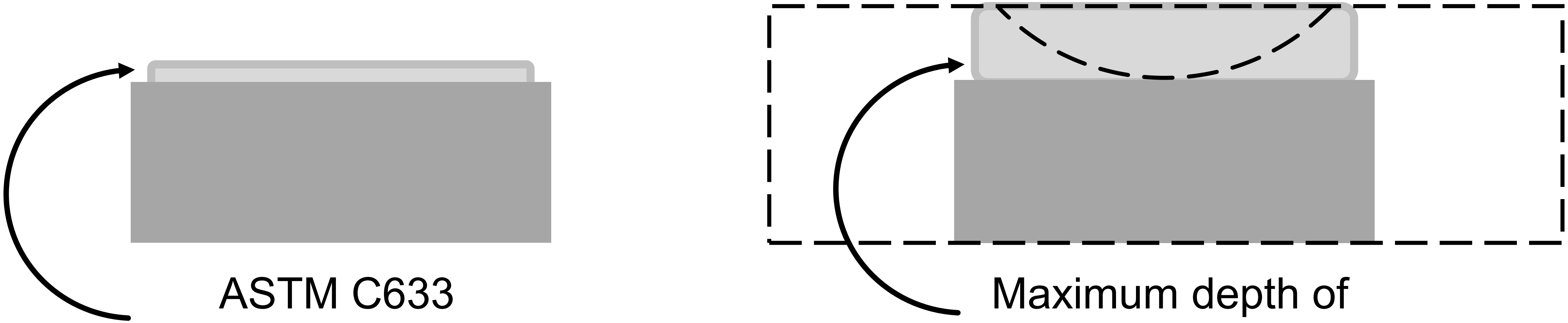
Adhesion Testing

ASTM C633
minimum thickness
(0.38 mm)



Maximum depth of
blend-out repair
(1.8 mm)

Adhesion Testing



ASTM C633
minimum thickness
(0.38 mm)

Maximum depth of
blend-out repair
(1.8 mm)

Adhesion Testing

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Maximum depth of
blend-out repair
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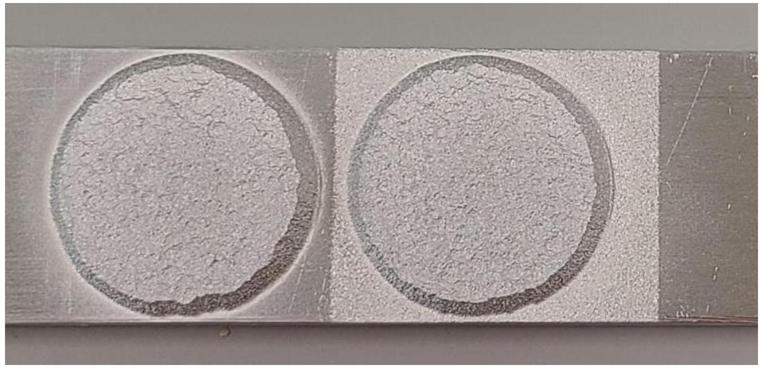
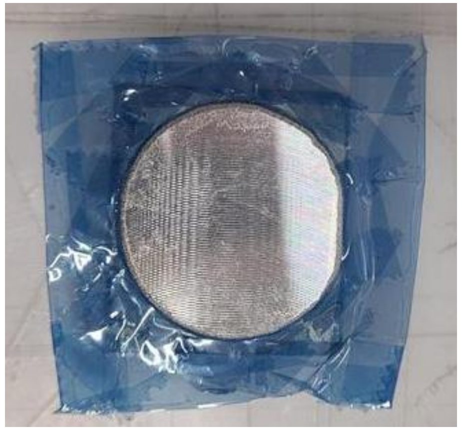
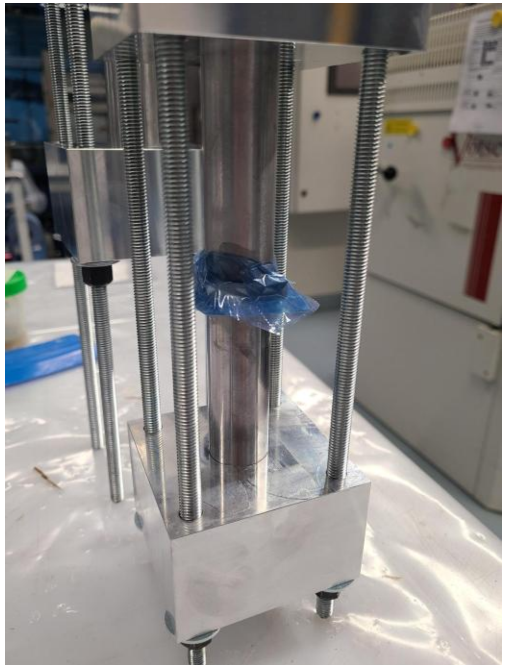
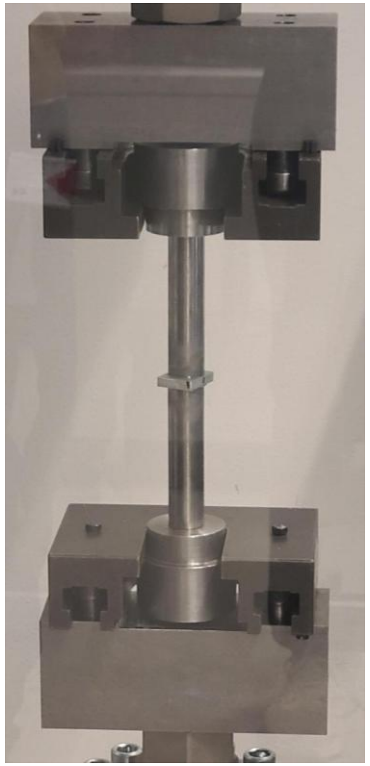
Adhesion Testing

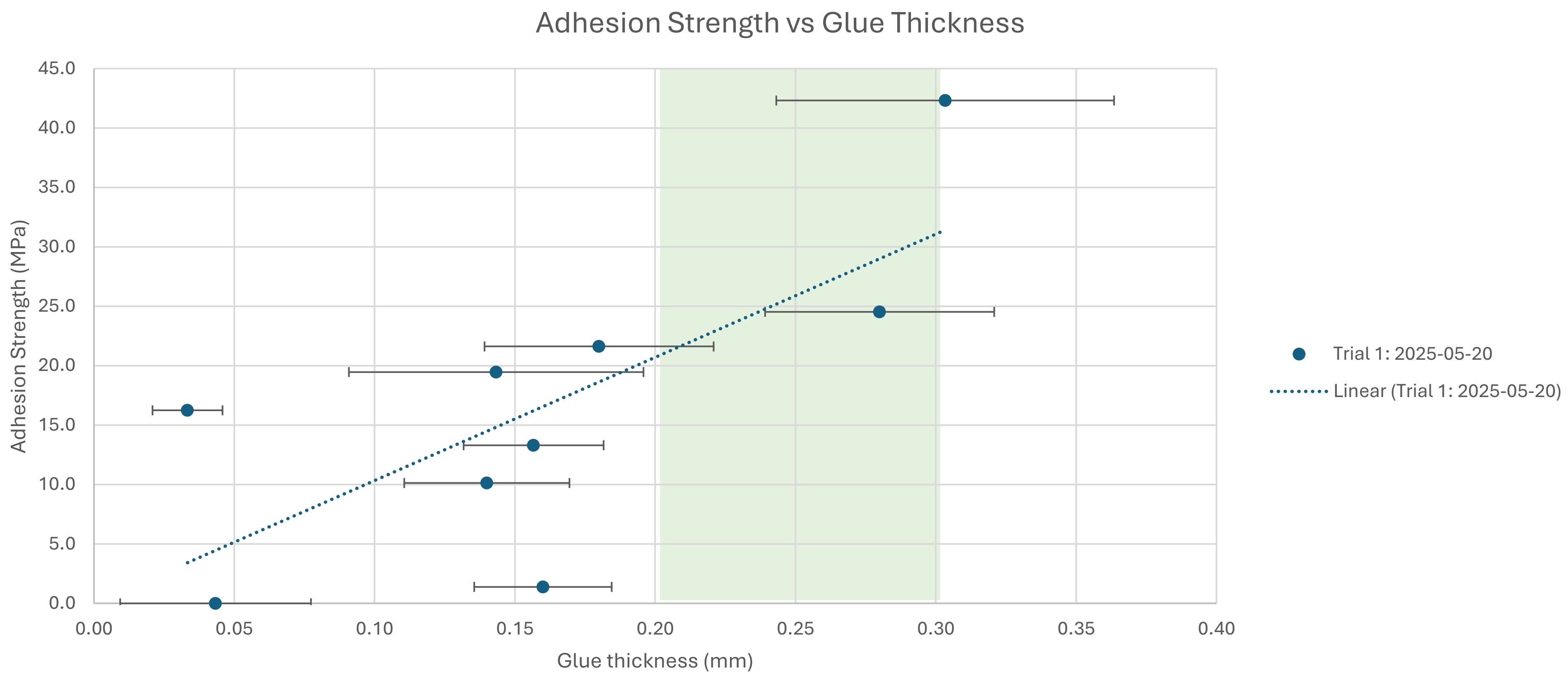




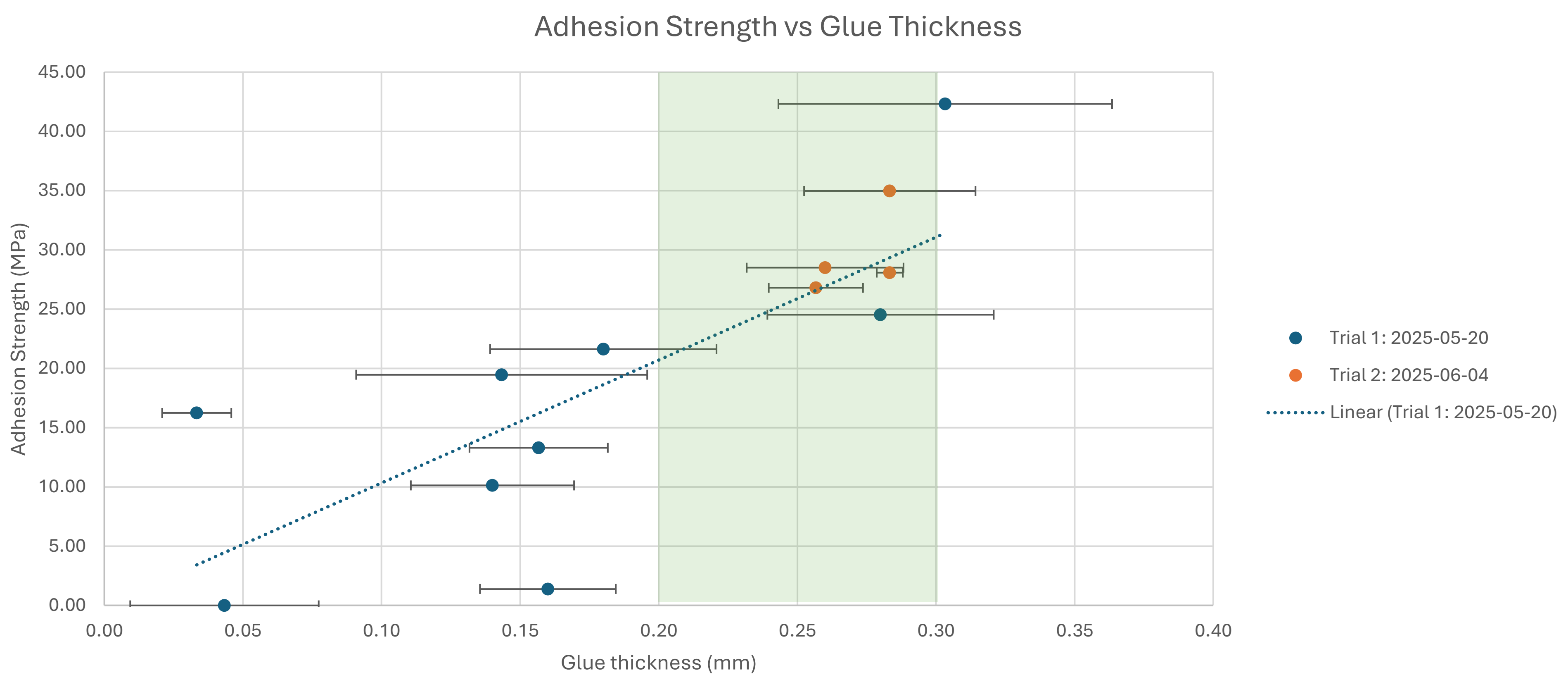




Trial 1: May 20^{th} 2025



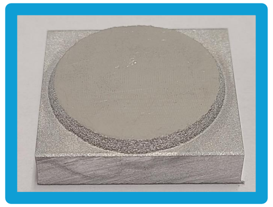
Trial 2: June 4th 2025



Adhesion Testing

Adhesion Strength (MPa)	Test Failure Type
28,1	Glue
1,4	Glue
13,3	Glue
26,8	CS Interface
16,2	Glue
28,5	Glue
35,0	Glue
0,0	Glue
37,7	CS Interface*
51,5	CS Interface & Glue (Mixed)
19,5	Glue
24,5	Glue
42,3	Glue
10,1	Glue
21,6	Glue
28,9	Glue

Thin + Sand Blast



Thick + Sand Blast

Thin + Scotch Brite

Thick + Scotch Brite

Adhesion Testing

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28,1	**Glue**
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28,5	Glue
35,0	**Glue**
0,0	Glue
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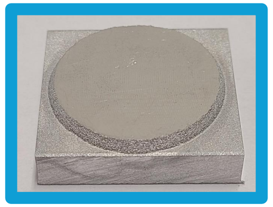
51,5	**CS Interface & Glue (Mixed)**
19,5	Glue
24,5	Glue
42,3	**Glue**
10,1	Glue
21,6	Glue
28,9	Glue

Thin + Sand Blast



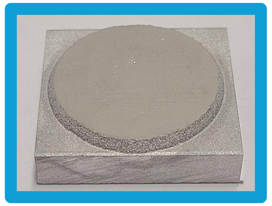
Thick + Sand Blast

Thin + Scotch Brite

Thick + Scotch Brite

Adhesion Testing

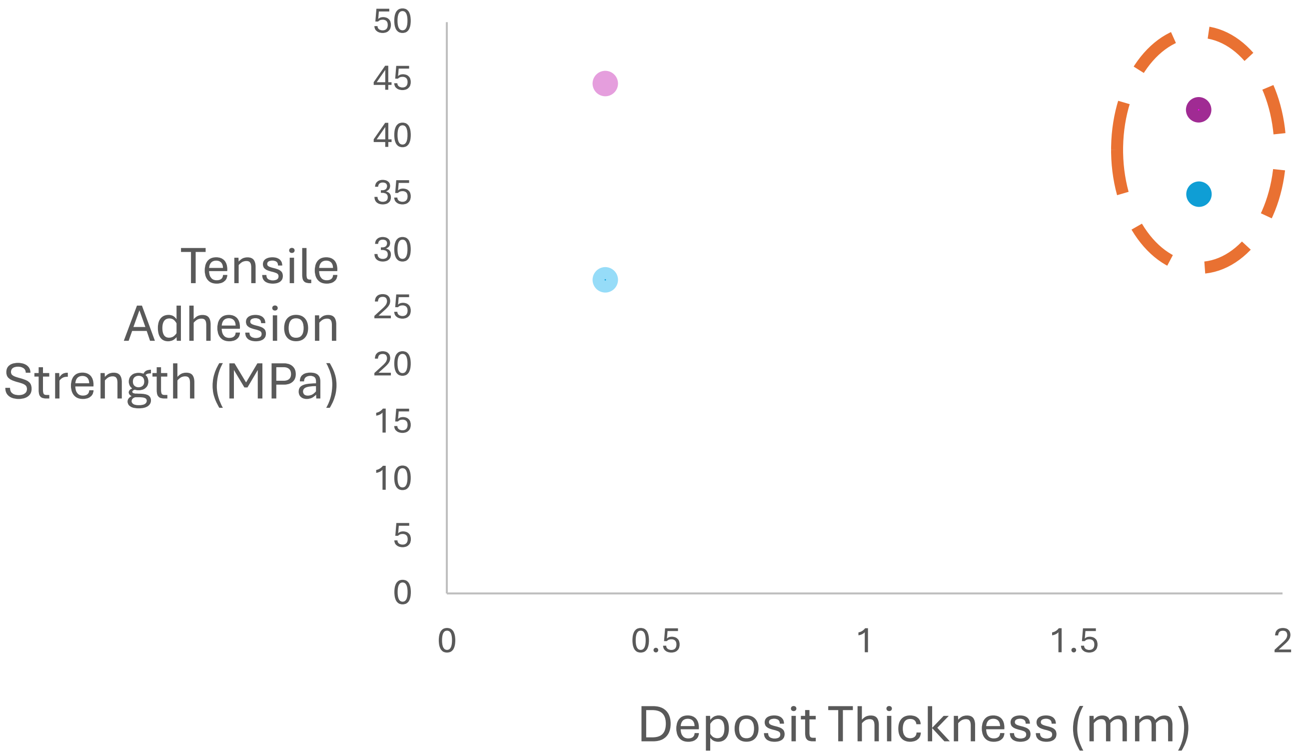
Thin + Sand Blast



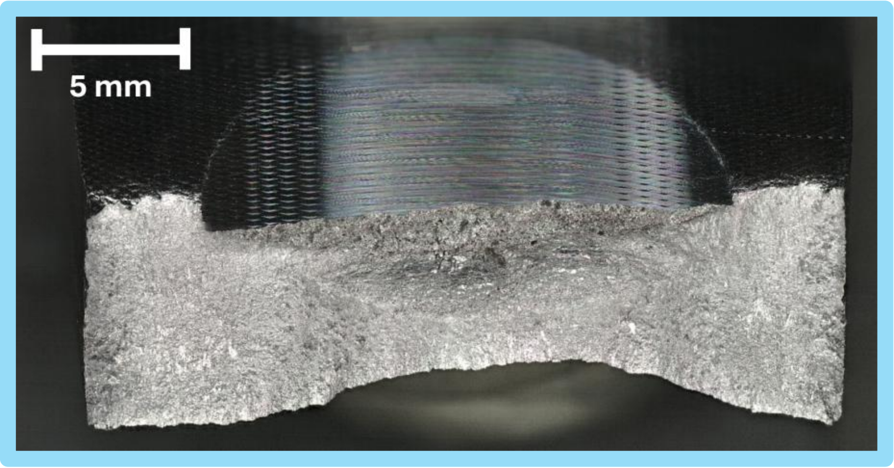
Thick + Sand Blast

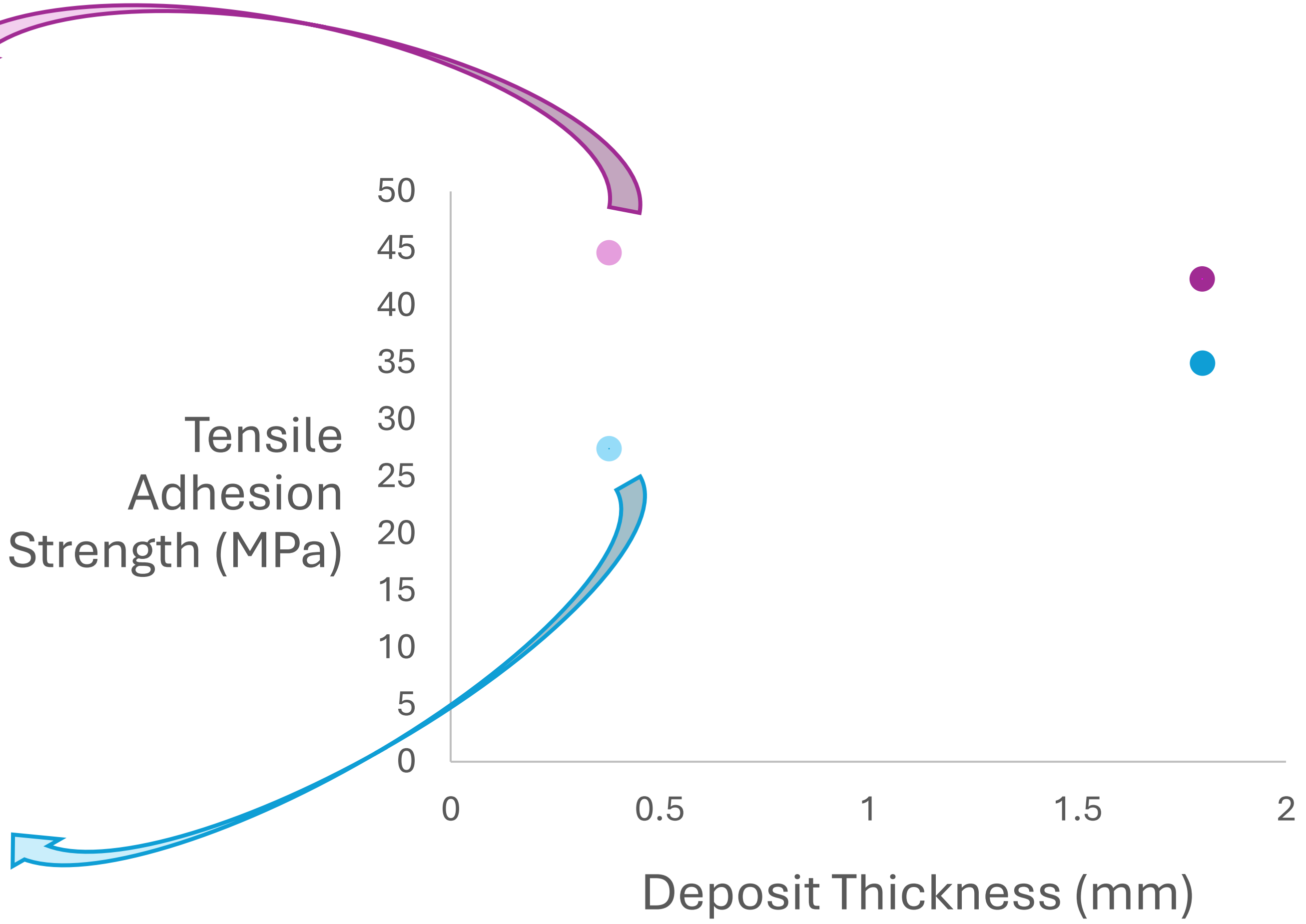
Thin + Scotch Brite

Thick + Scotch Brite



Adhesion Testing

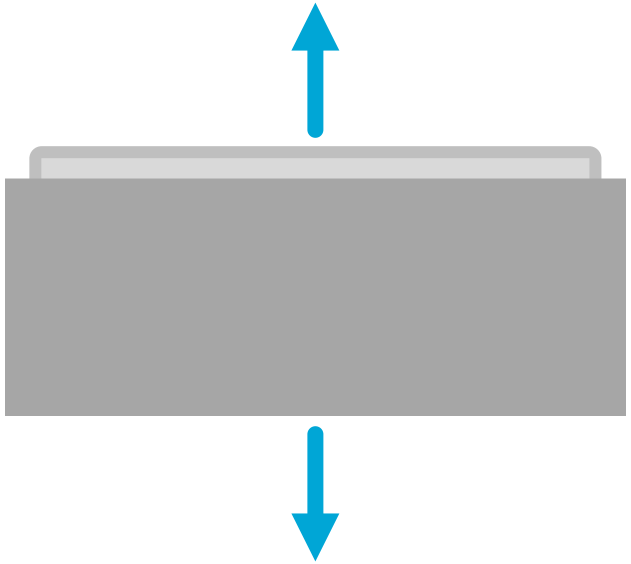




In Conclusion

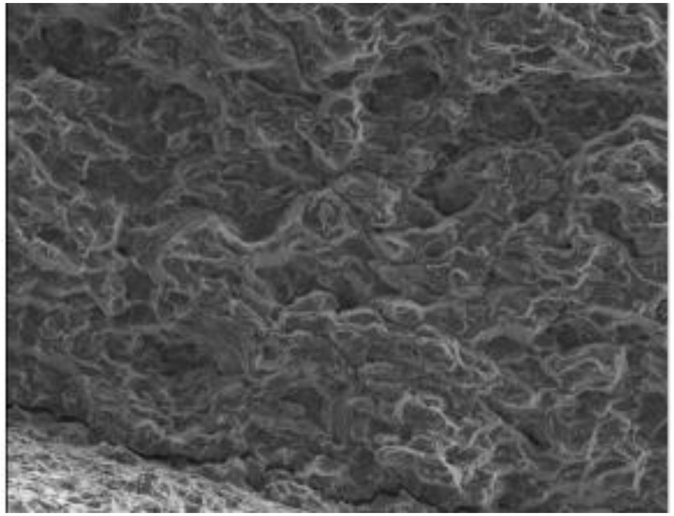
Deposits can pass all of our existing quality metrics, yet be detrimental to the fatigue performance of a repair

- Tensile Adhesion Strength -> Repairs



Deposits can pass all of our existing quality metrics, yet be detrimental to the fatigue performance of a repair

- Tensile Adhesion Strength -> Repairs
- Coating Density != Good Particle Cohesion (in fatigue)



How do we effectively guarantee improved fatigue performance without fatigue testing every time?

How do we effectively guarantee improved fatigue performance without fatigue testing every time?

M.A.Patrick@tudelft.nl

Questions?

References

Dorman, S. G., Rausch, J., & Ausherman, M. (2024). *Evaluation of cold spray for aircraft repair*. Presented at the Cold Spray Action Team (CSAT) meeting.

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Yin, S., Cavaliere, P., Aldwell, B., Jenkins, R., Liao, H., Li, W., & Lupoi, R. (2018). Cold Spray Additive Manufacturing and Repair: Fundamentals and Applications. *Additive Manufacturing*, *21*, 628–650. https://doi.org/10.1016/j.addma.2018.04.017