

Assessing the Suitability of Quality Metrics in Cold Spray

For Structural Repairs under Fatigue Loading

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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 Quality" Cold Spray Deposits



“Good” Enough for Aerospace

Cosmetic Repairs
(Geometrical Restoration)

Structural Repair



BCA
Customer
Support

SERVICE LETTER

737-SL-32-182-B

ATA: 3200-00

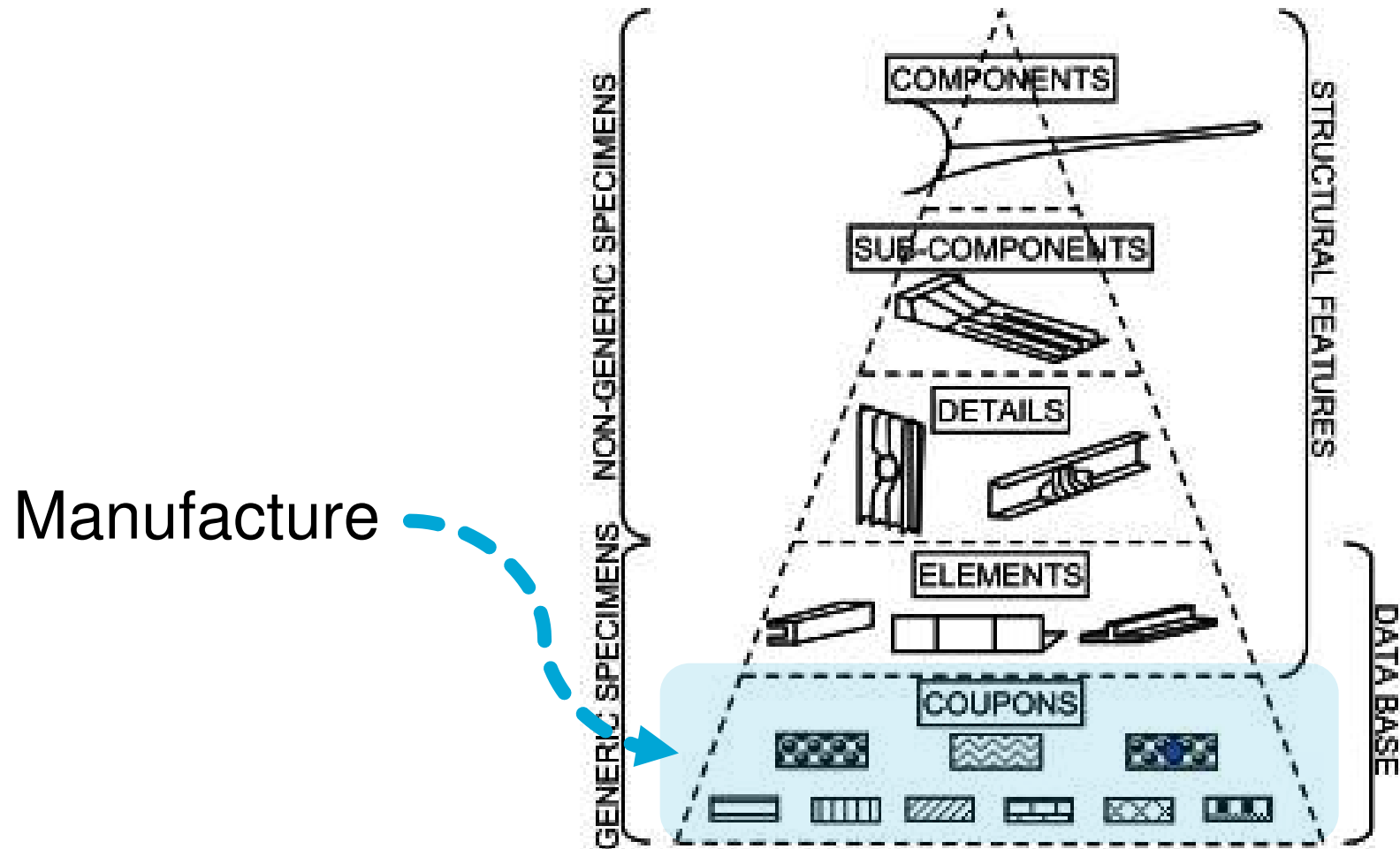
28 August 2017

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

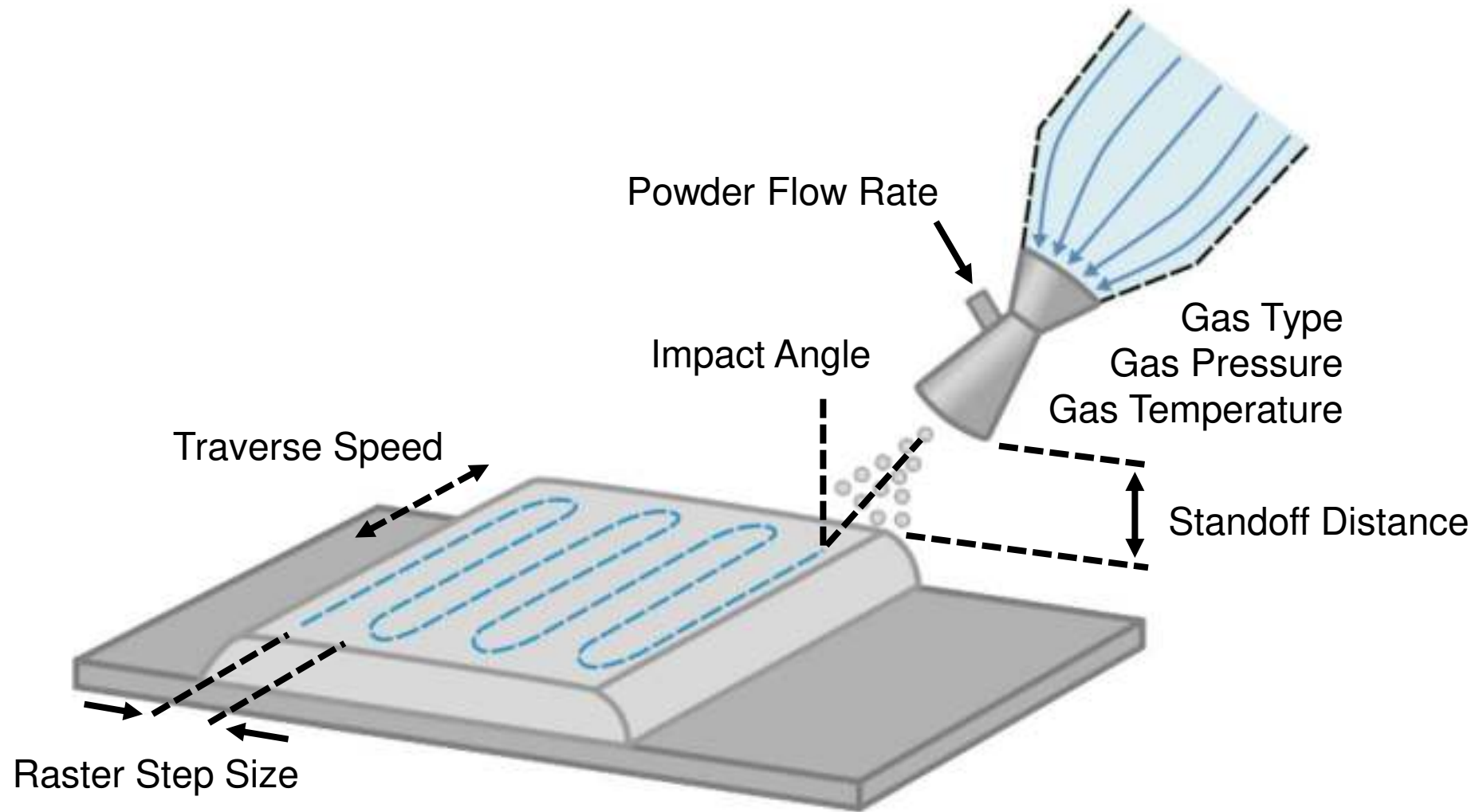


*Photos and information
courtesy of EPCOR*

“Good” Enough for Aerospace: Structural Repair



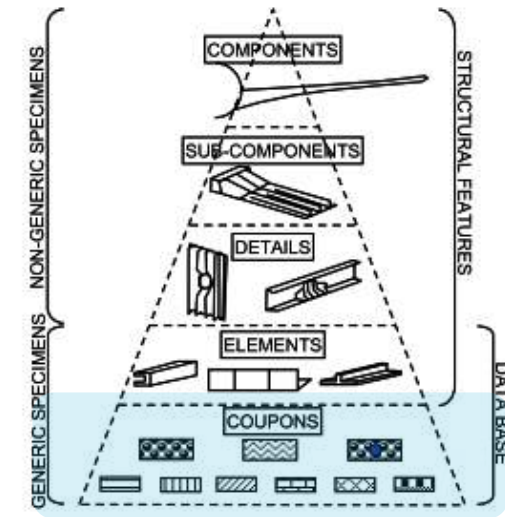
Source: FAA AC 20-107B



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



At TU Delft

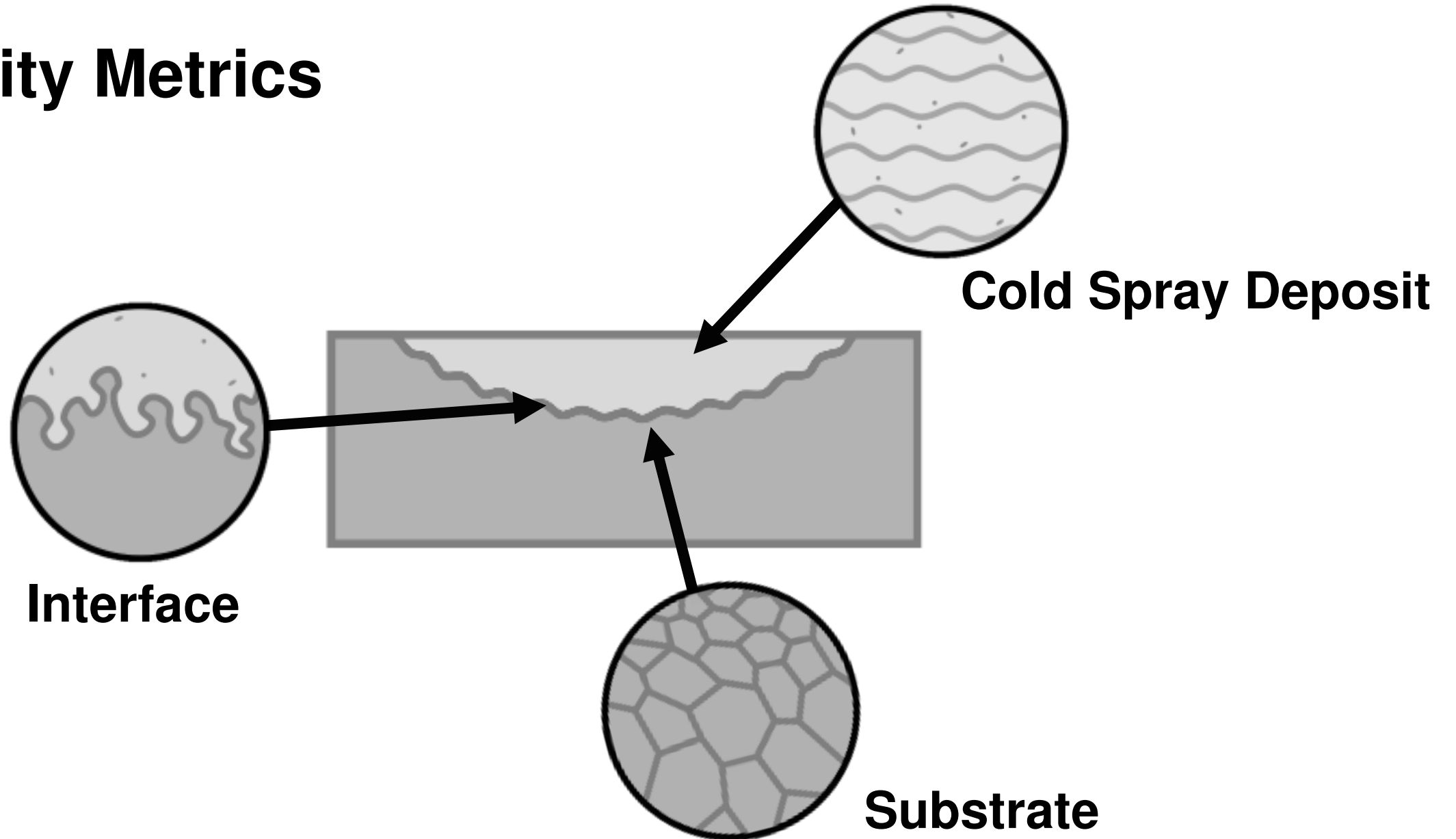


Quality Checks

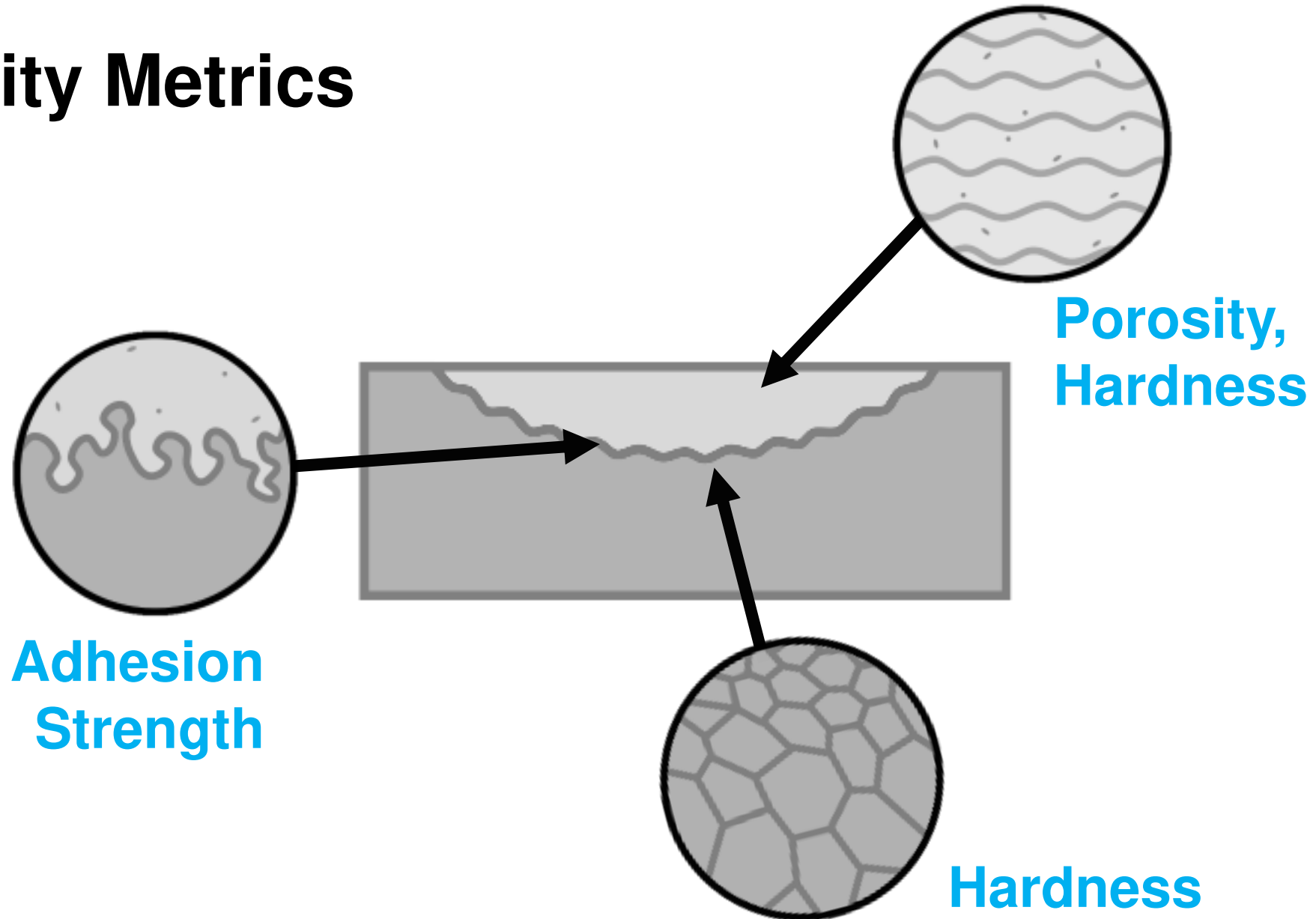


Spray settings

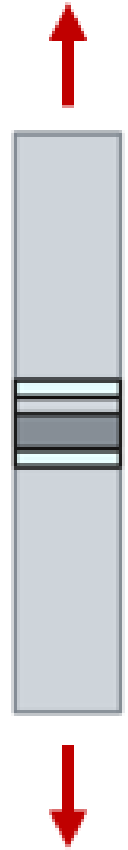
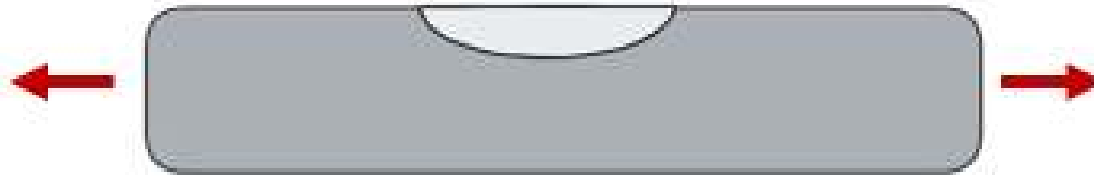
Quality Metrics

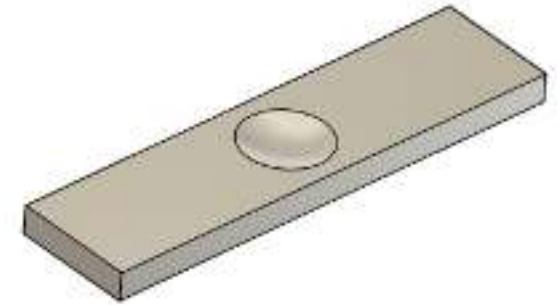
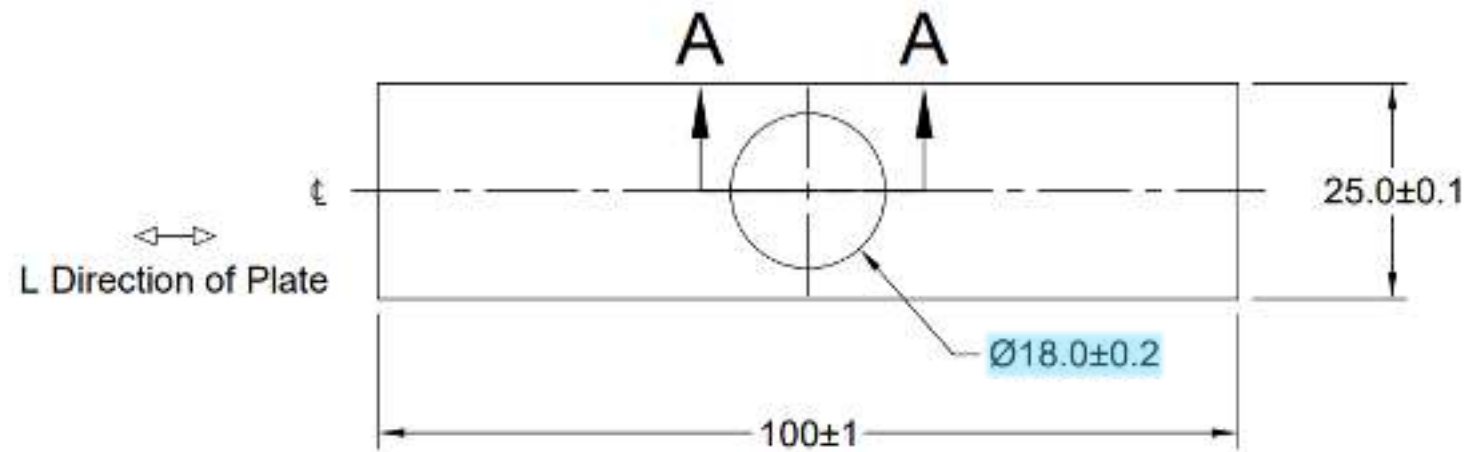


Quality Metrics

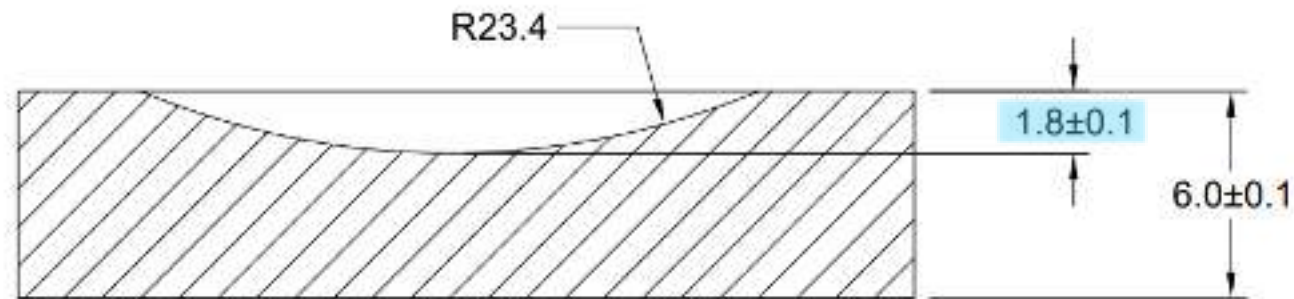


Do the quality metrics we use for
cosmetic repairs guarantee an
improvement in fatigue performance?

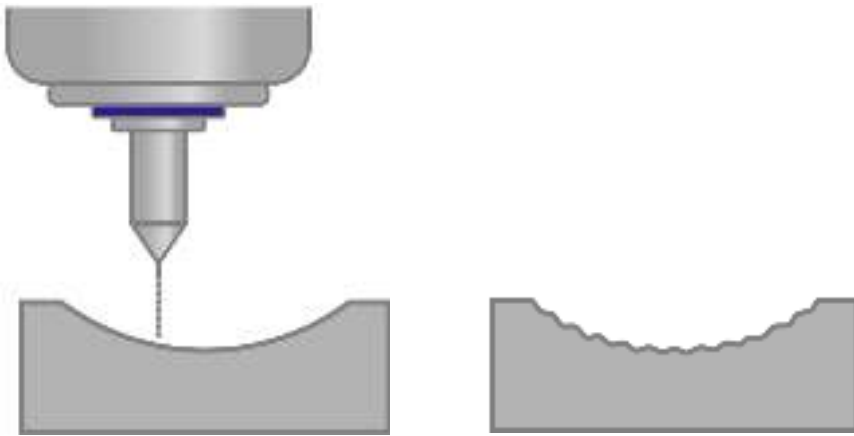




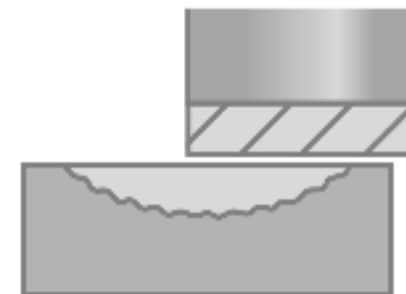
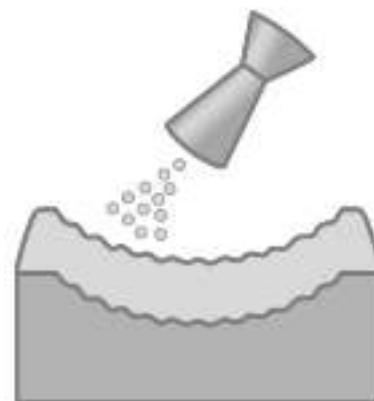
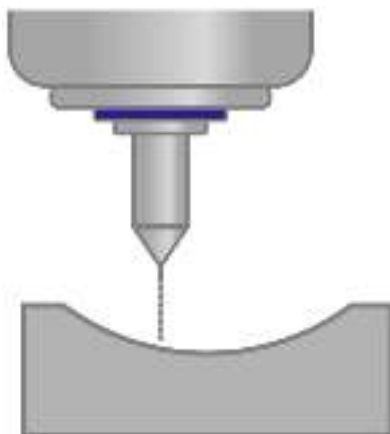
Coupon geometry is based on those used by Safe Inc. (CSAT 2024)

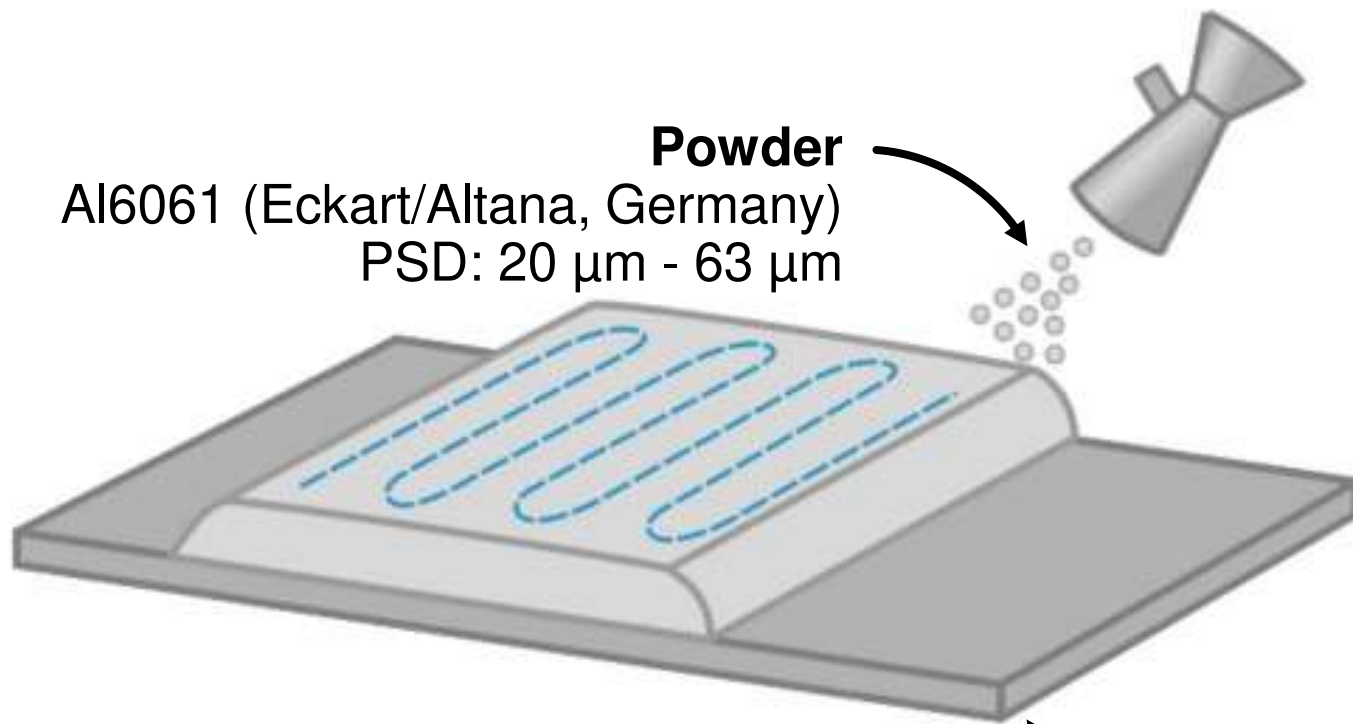


SECTION A-A
SCALE 1:0.25



Sand Blast
Scotch Brite





Powder
Al6061 (Eckart/Altana, Germany)
PSD: 20 μm - 63 μm

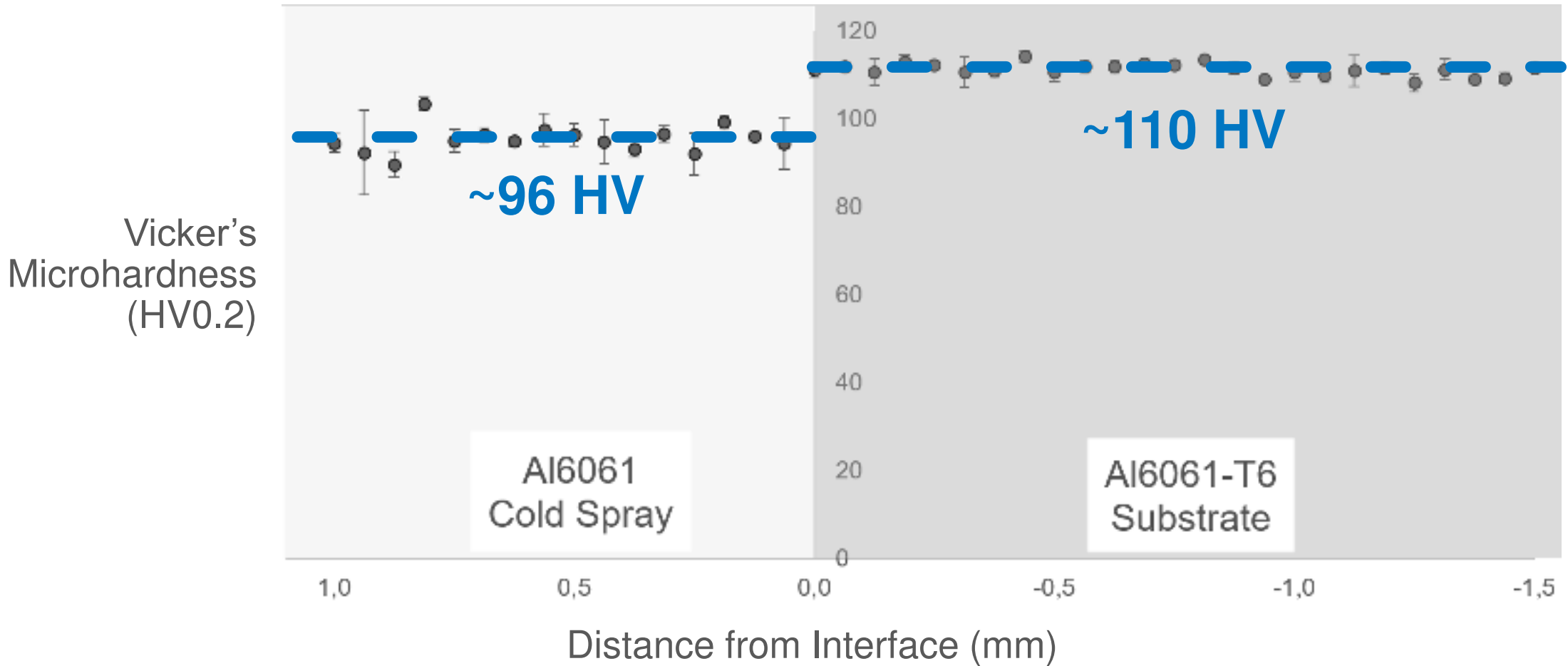
Spray Settings:

- 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

Substrate
Al6061-T6 (Salomon Metalen, the Netherlands)

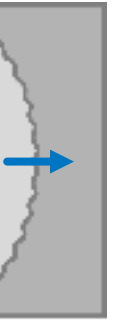
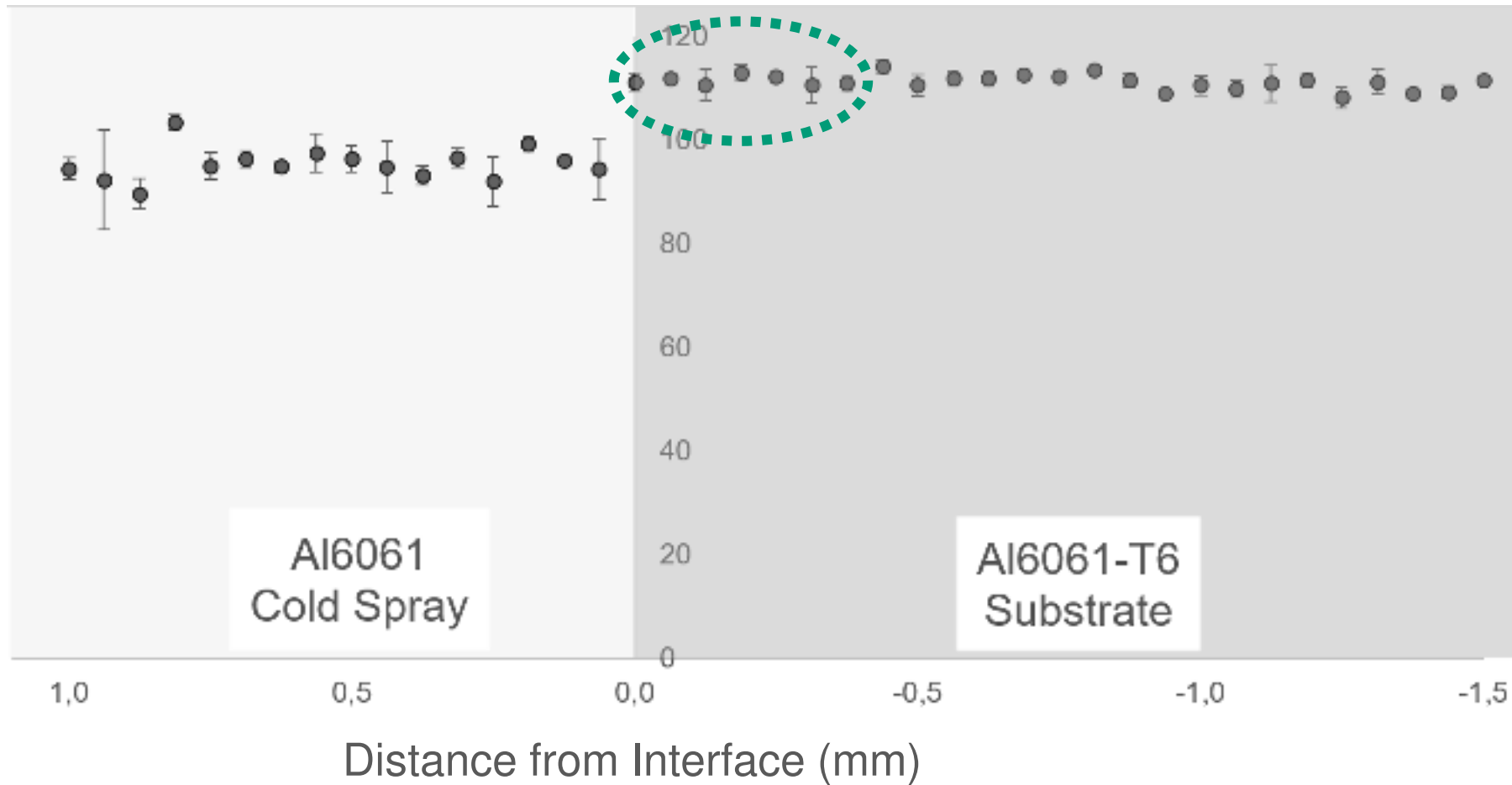
Quality Metrics – According to the Standards

ASTM E384: Hardness

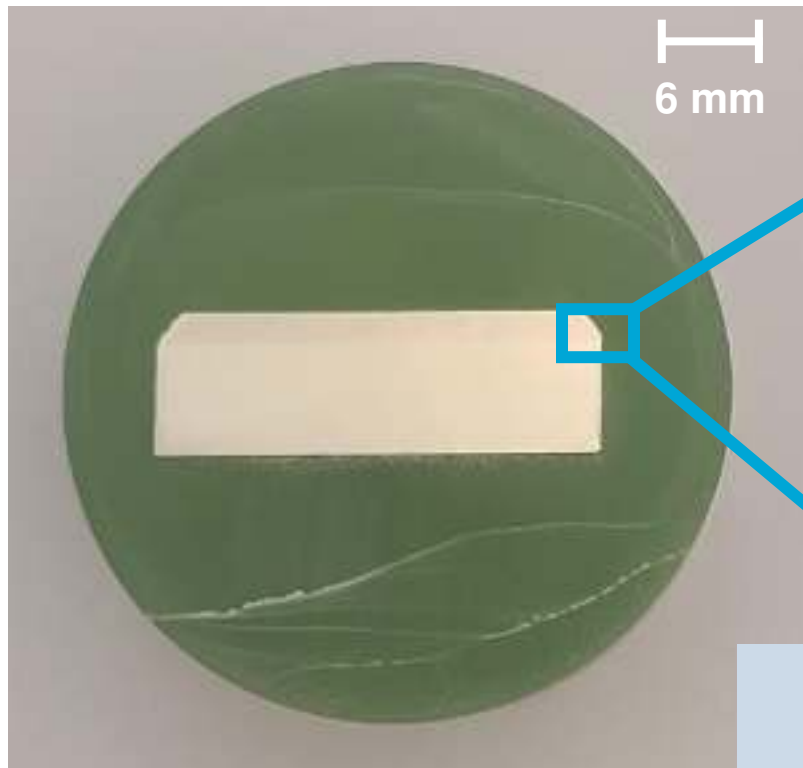


ASTM E384: Hardness

Vicker's
Microhardness
(HV0.2)



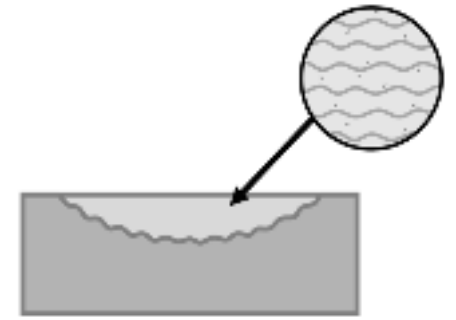
ASTM E2109: Porosity



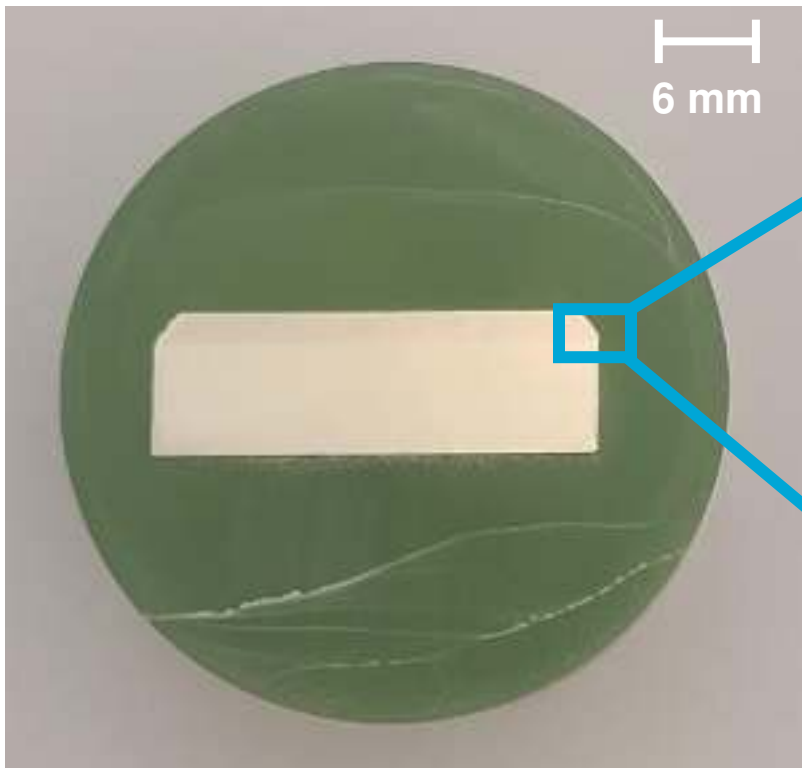
$< 0.5\%$



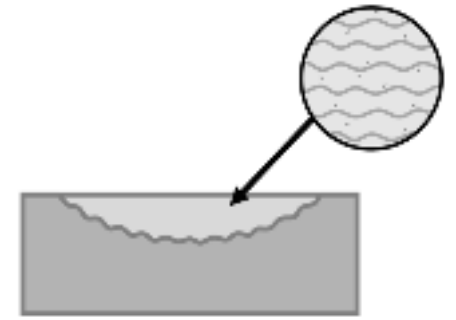
Polished



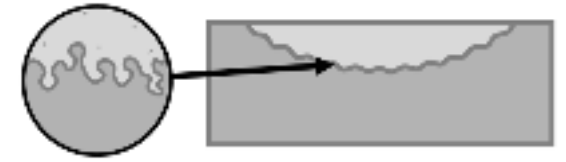
ASTM E2109: Porosity



Polished + Etched



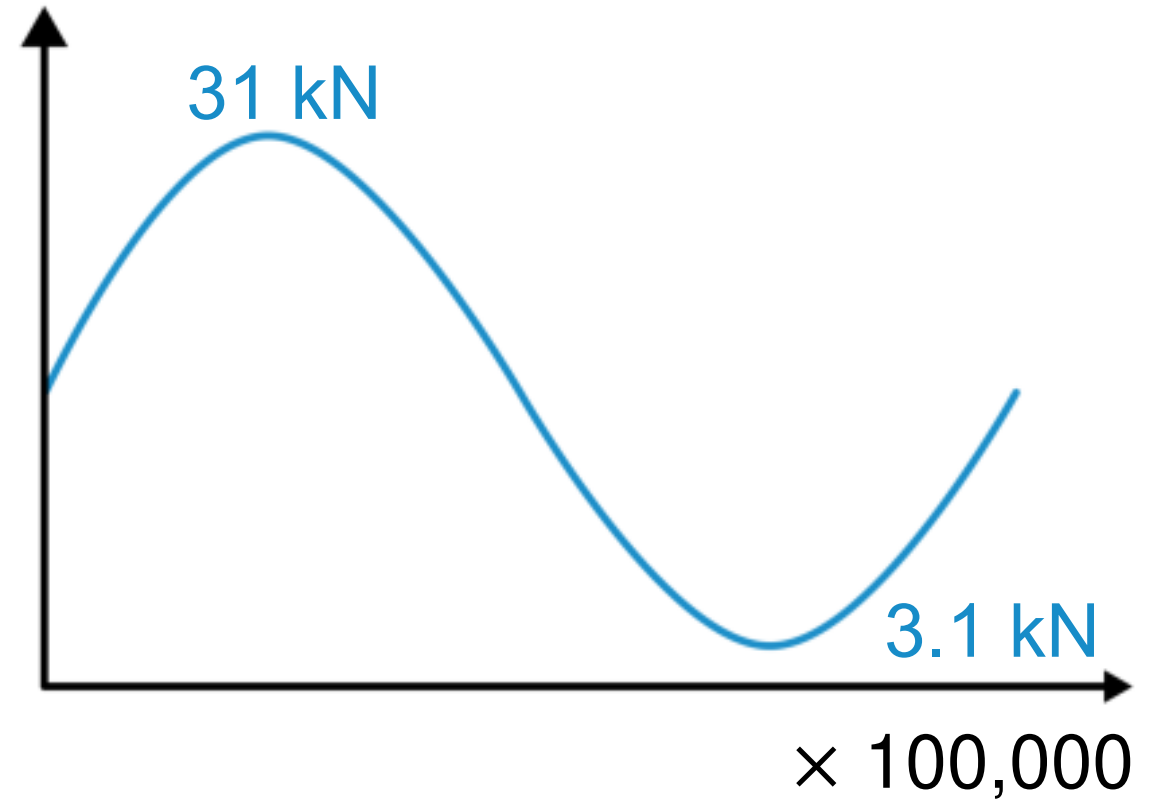
ASTM C633: Adhesion Strength

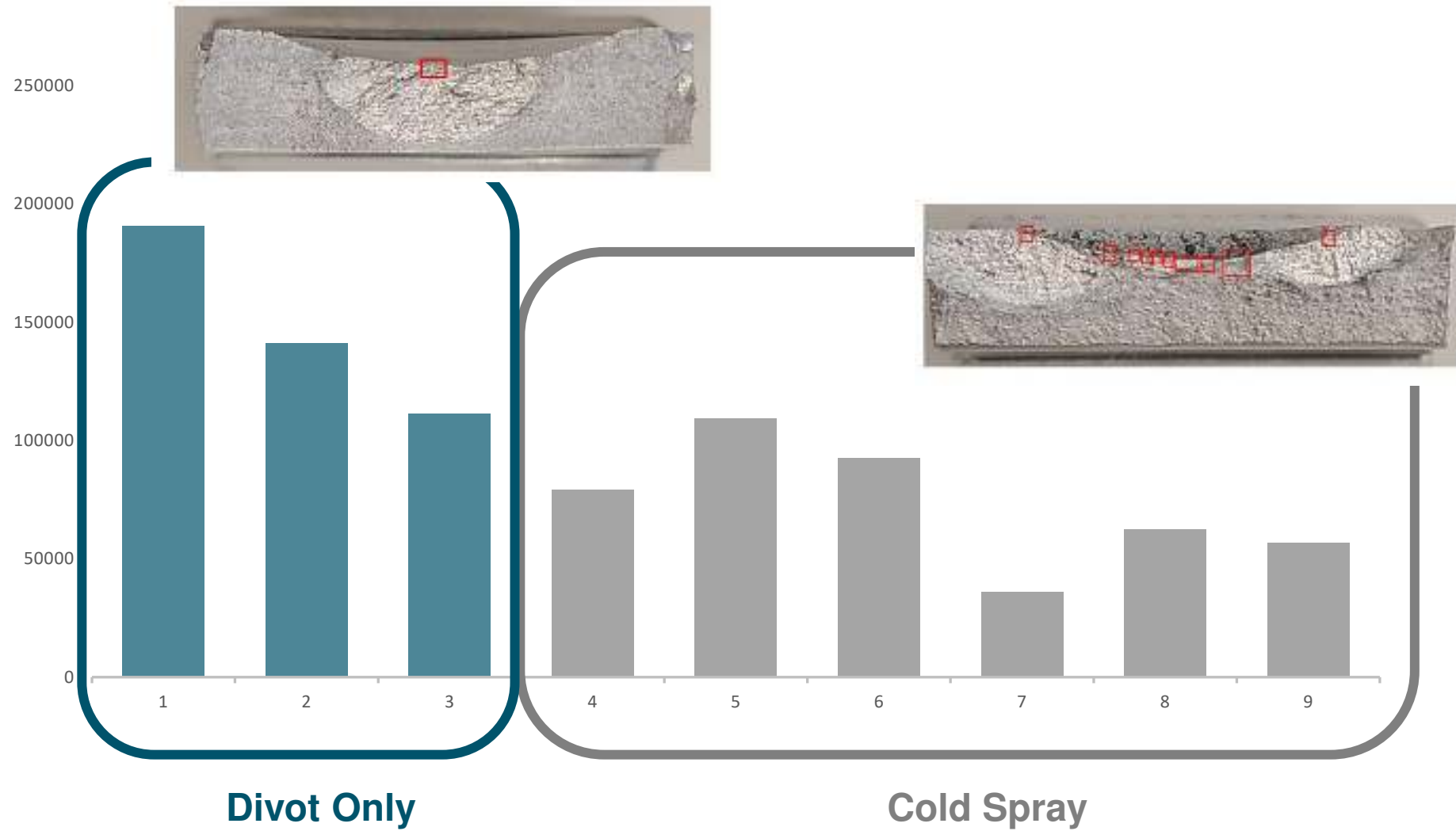


Work	Coating // Substrate	Adhesion Strength
Koh (2016)	Al6061 // Al6061	34 MPa
Koivuloto (2020)	Al6061 // Al	35 MPa
Nourian (2022)	Al6061 // Al6061	54 MPa
This work	Al6061 // Al6061-T6	27 – 52 MPa*

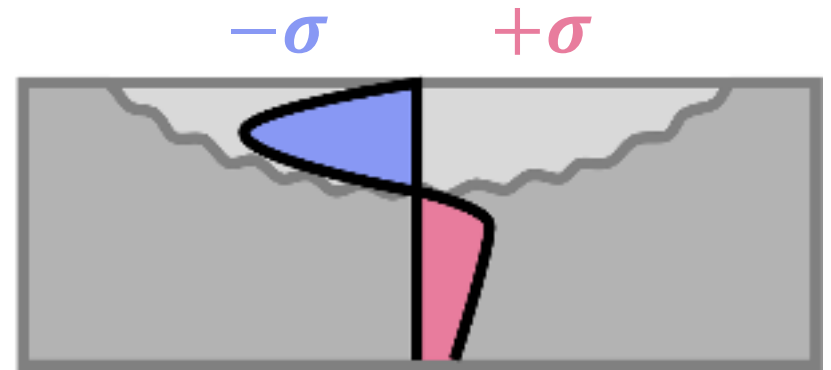
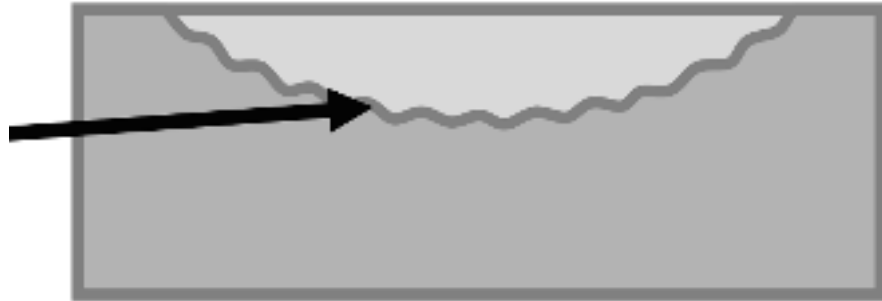
Looks good, right?

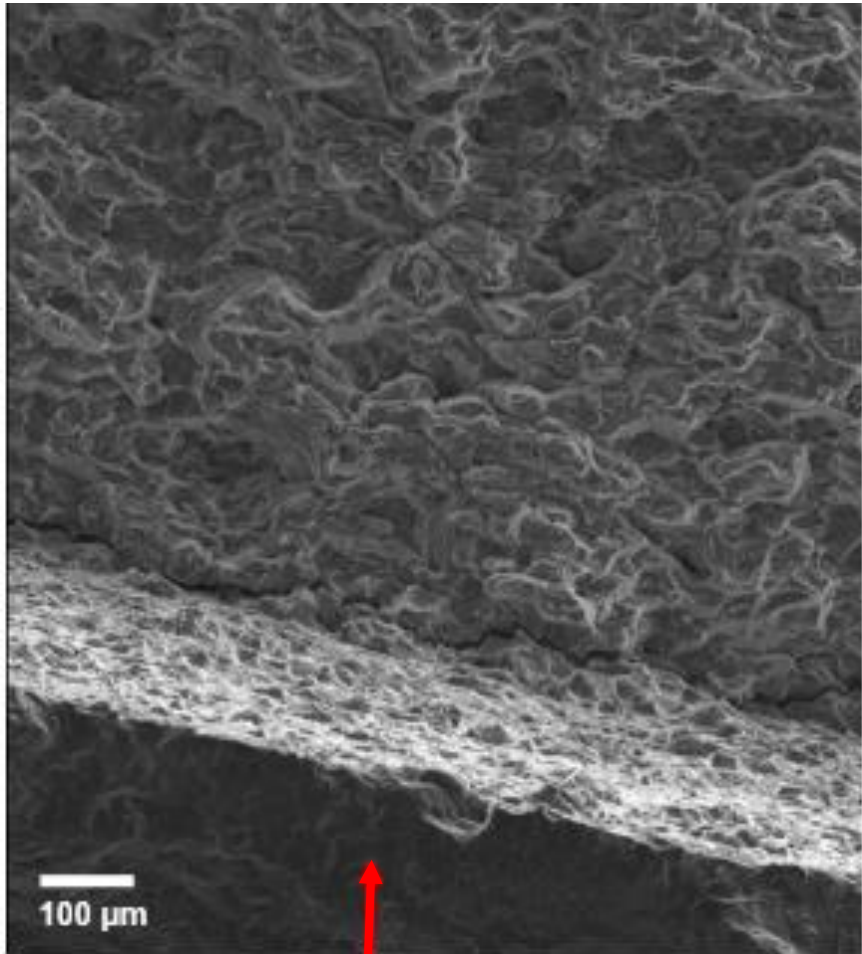
Fatigue Testing

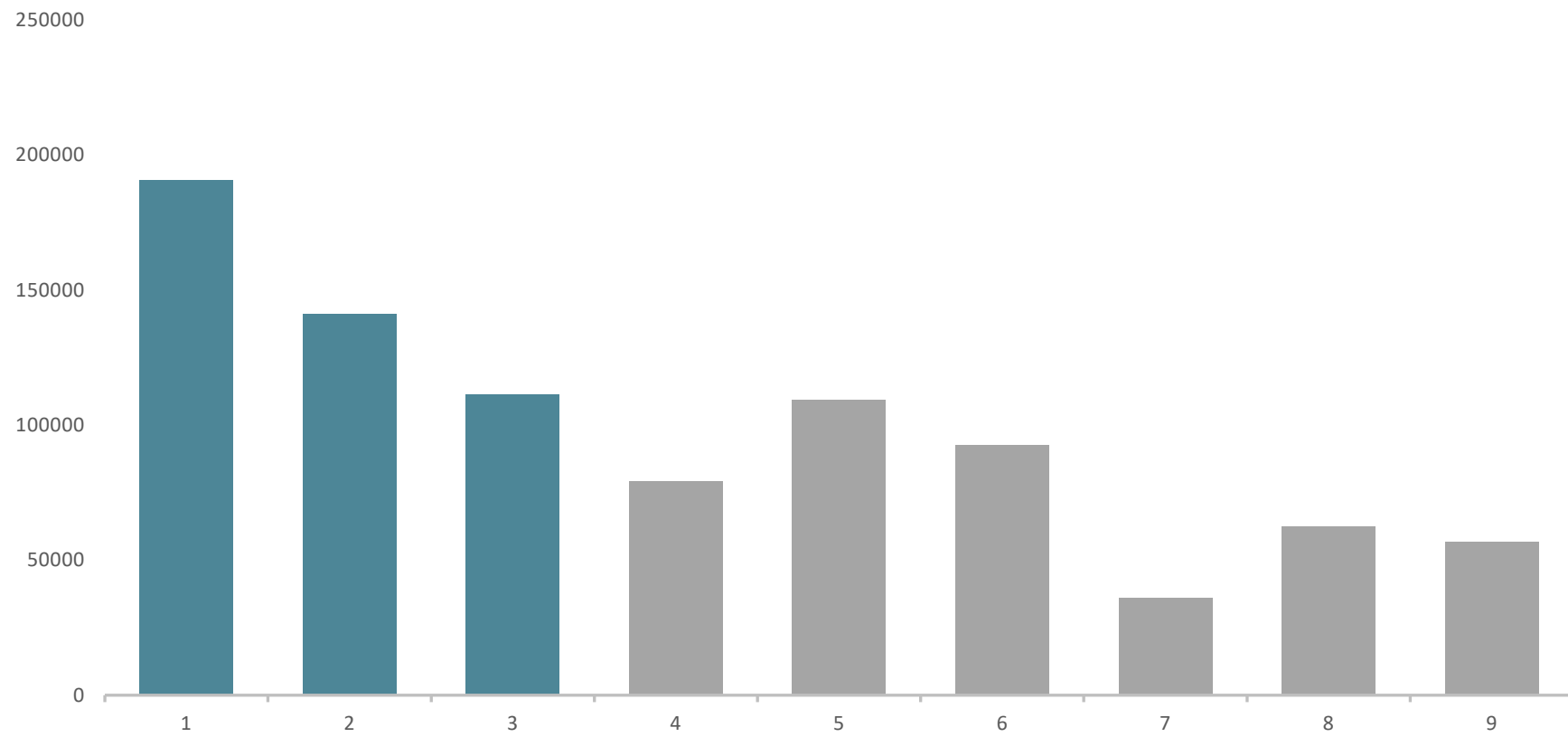


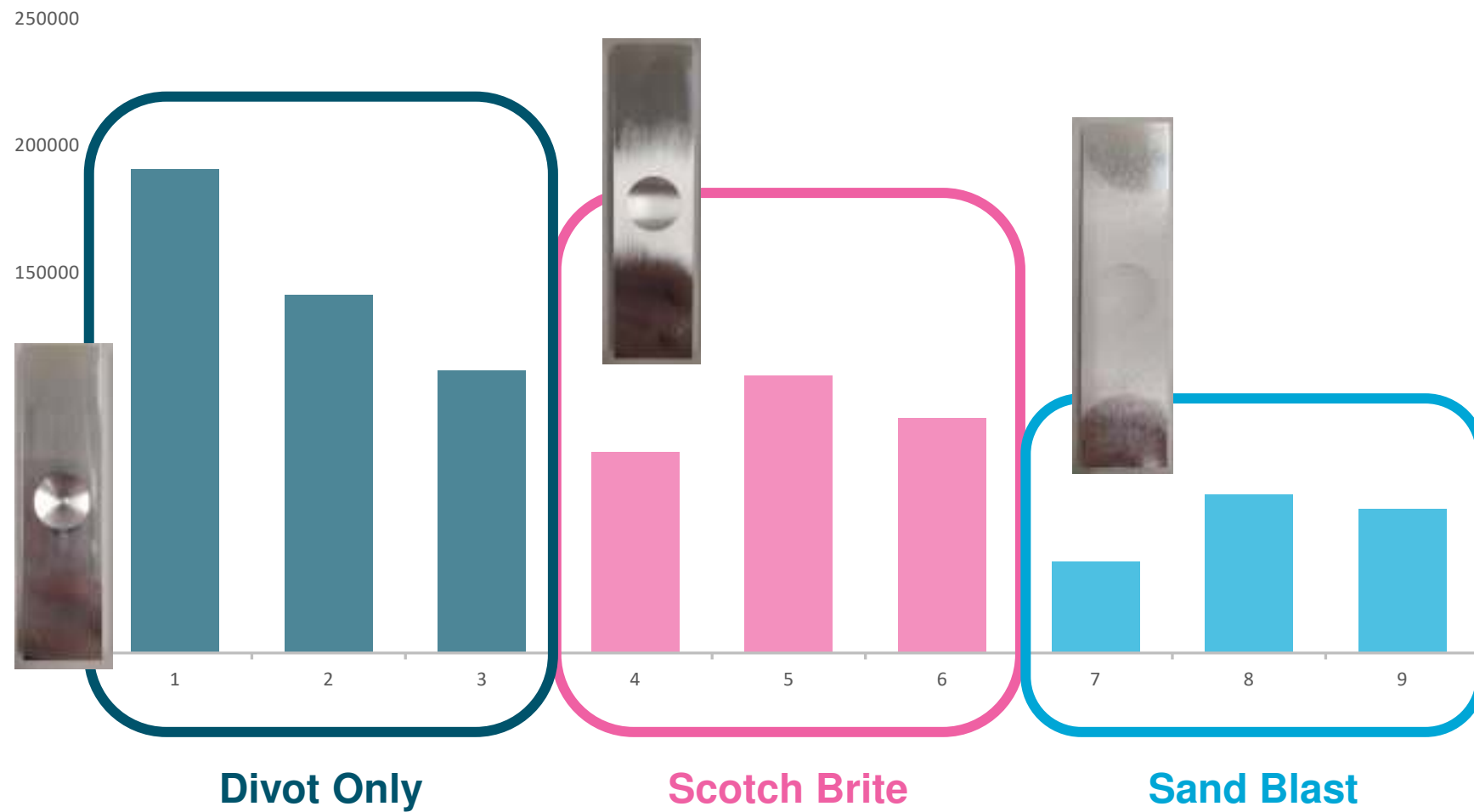


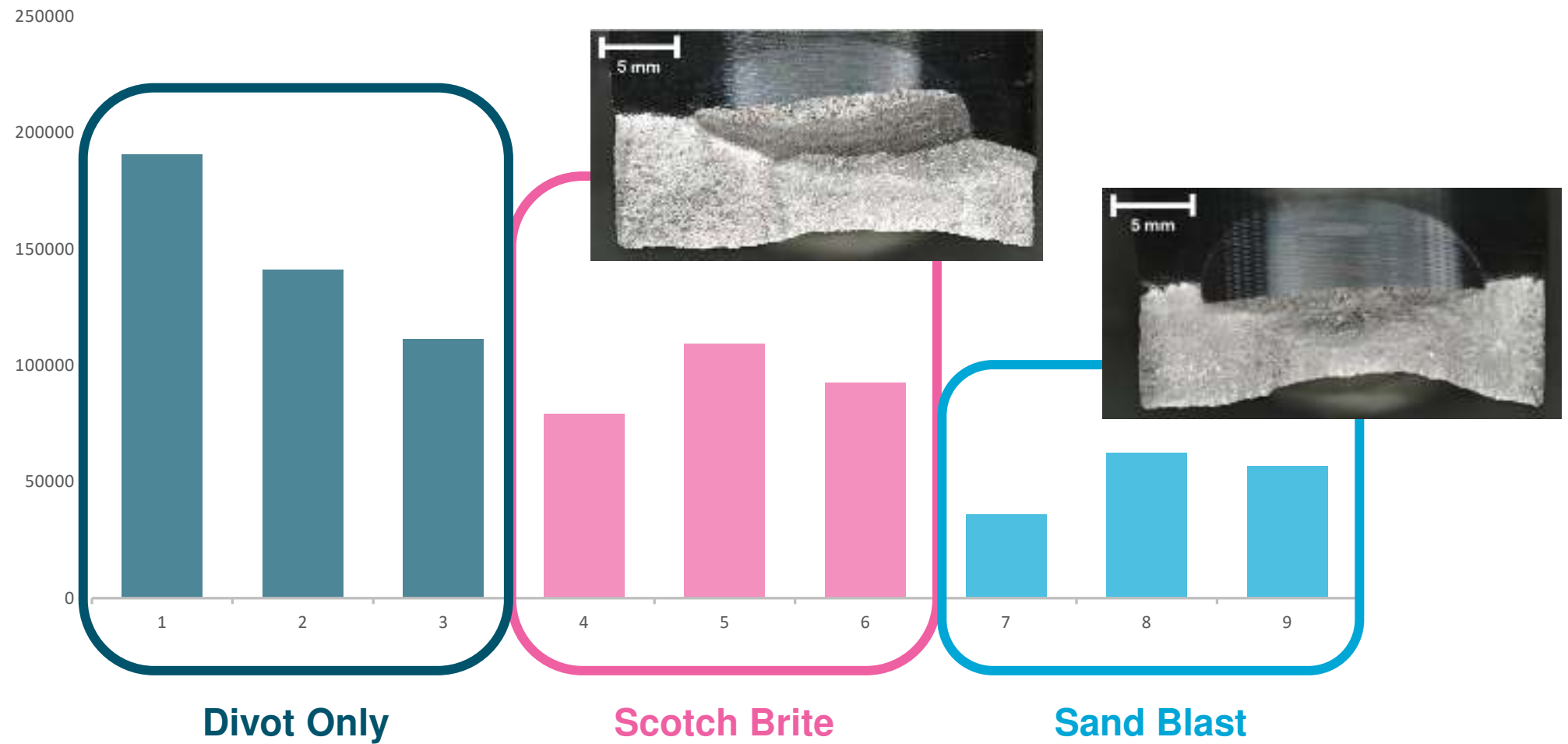
Ra











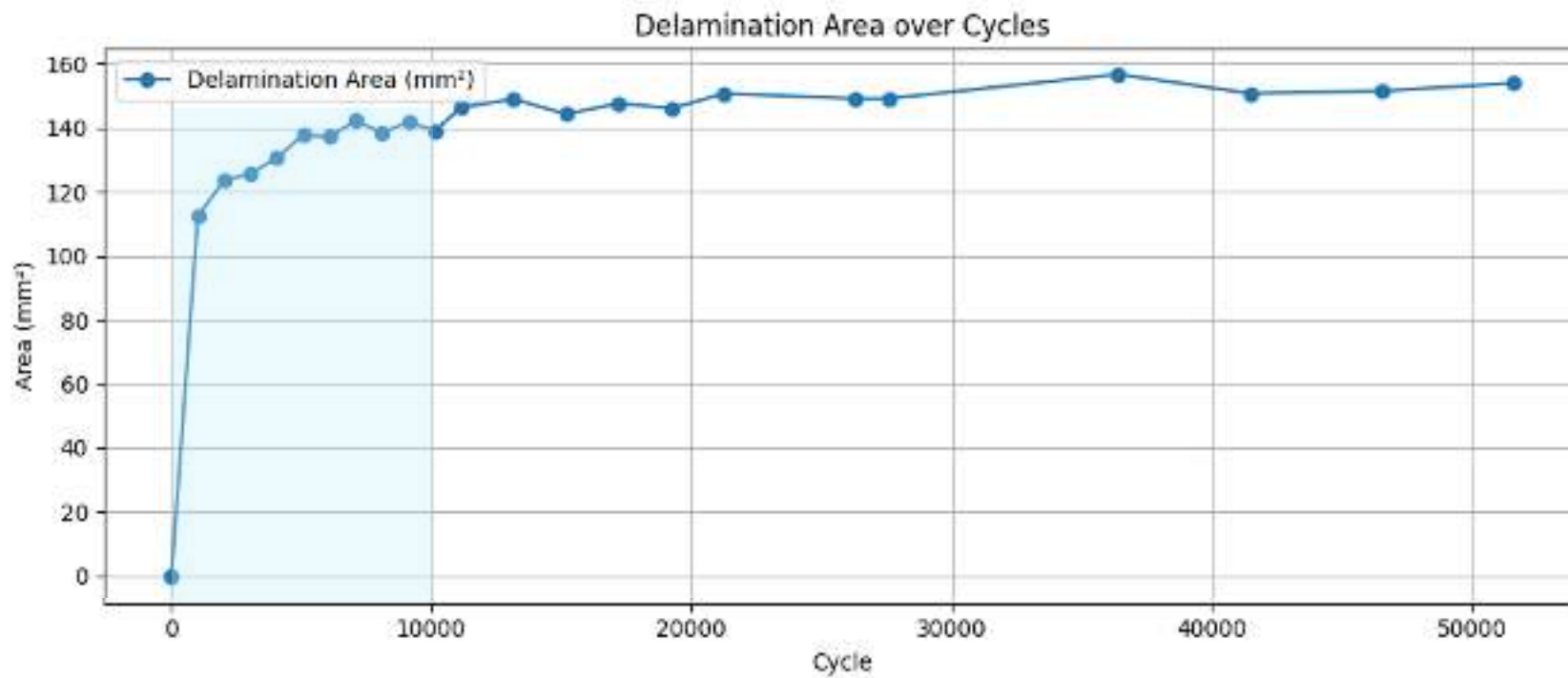
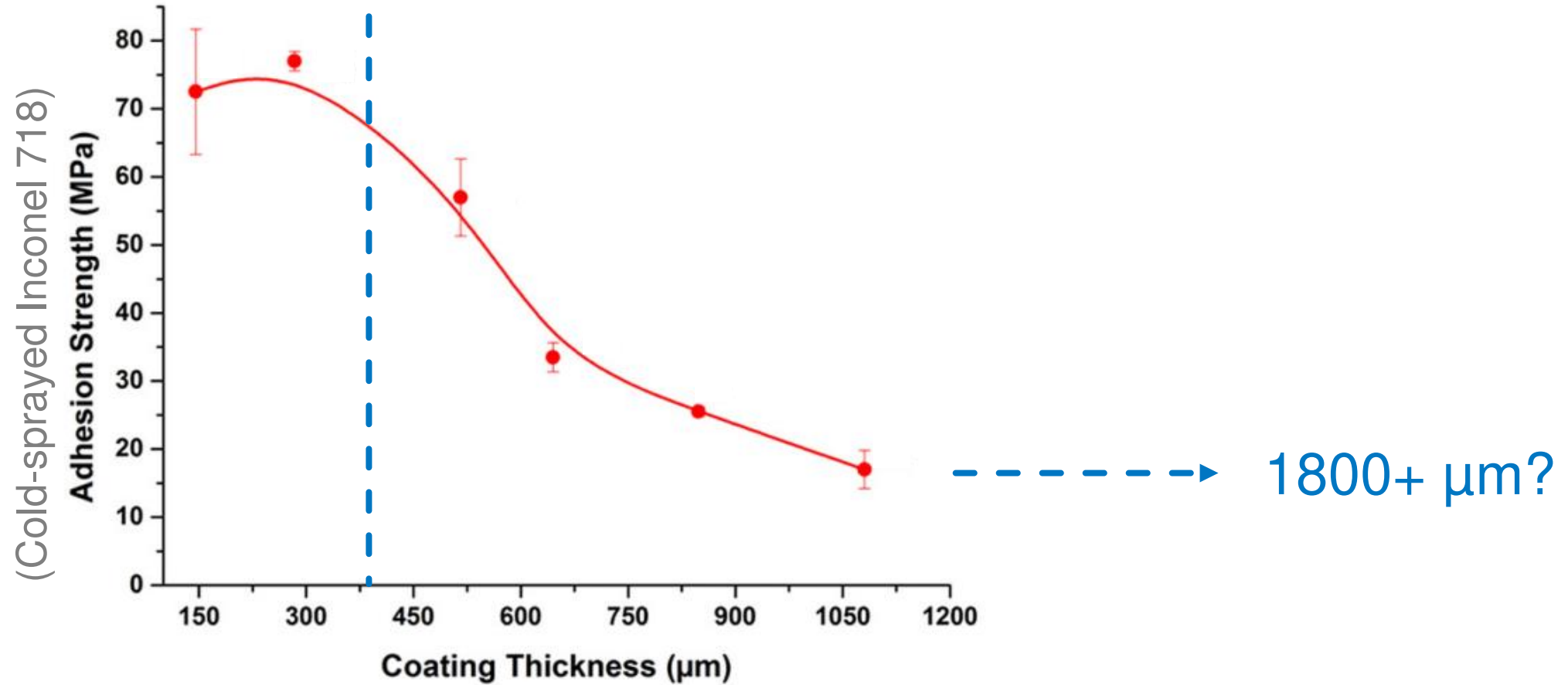


Figure courtesy of P. Dinglinger



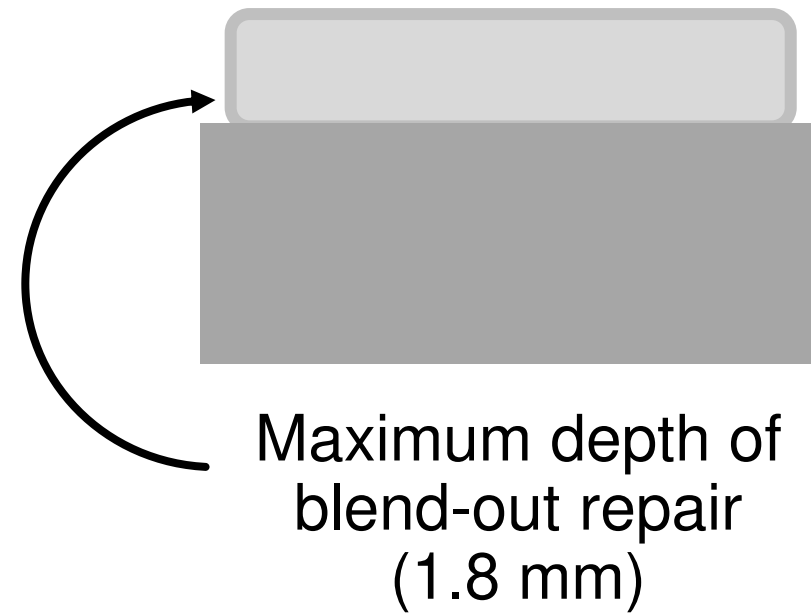
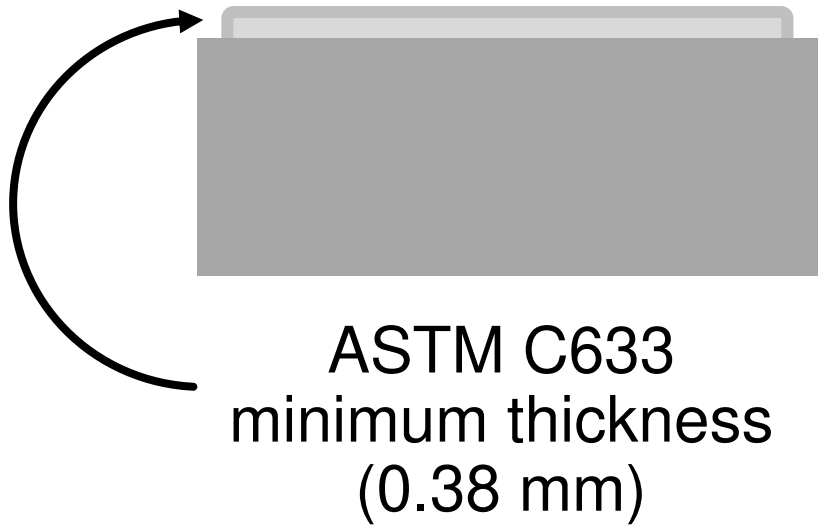
Quality Metrics – The “not-so-standard” way

Adhesion Strength for Repairs

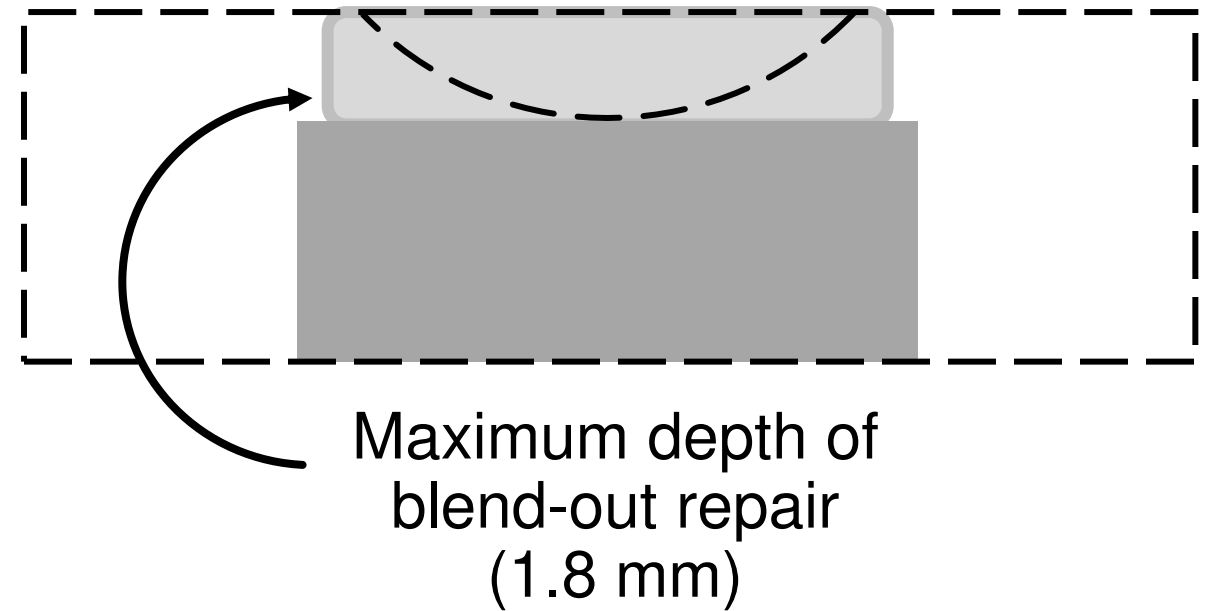
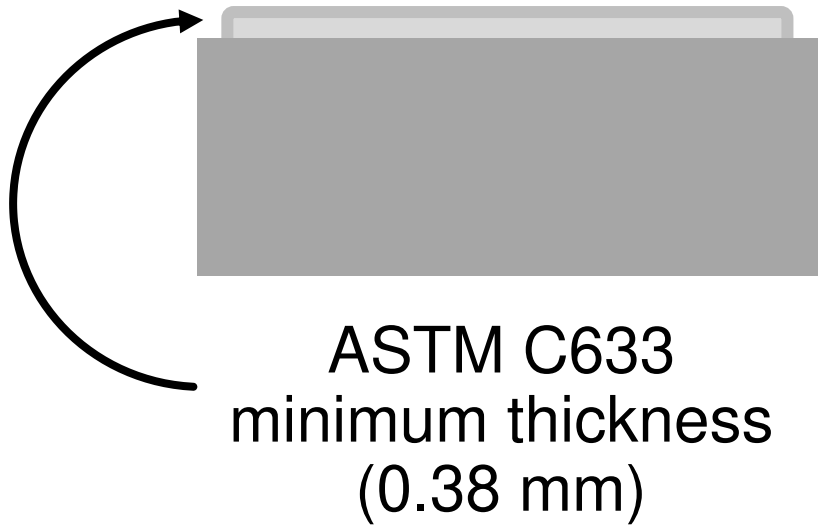


Singh et al., *Surface and Coatings Technology*, 350:64-73 (2018)

Adhesion Testing



Adhesion Testing



Adhesion Testing

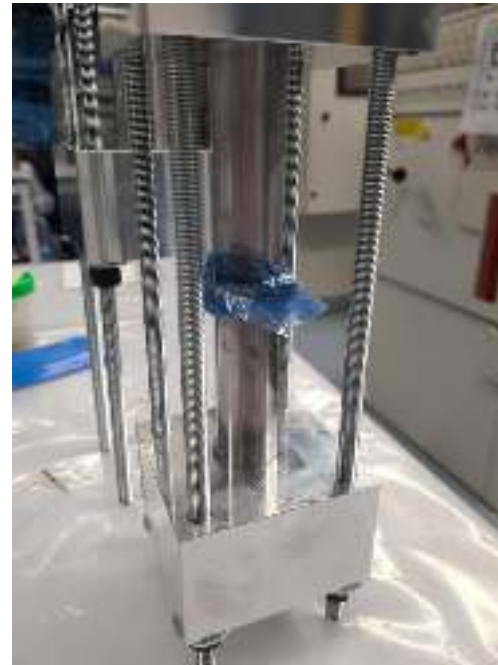
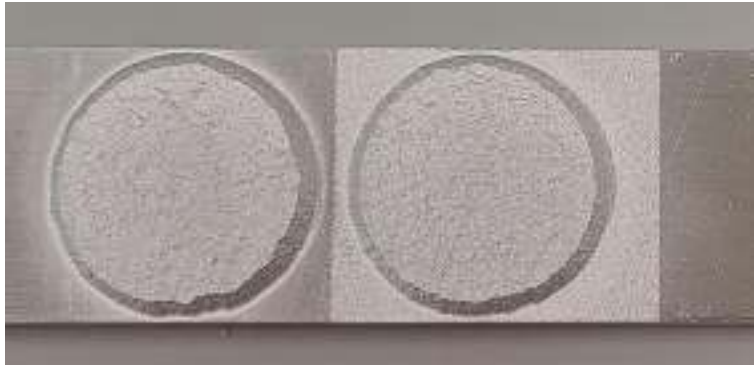


ASTM C633
minimum thickness
(0.38 mm)

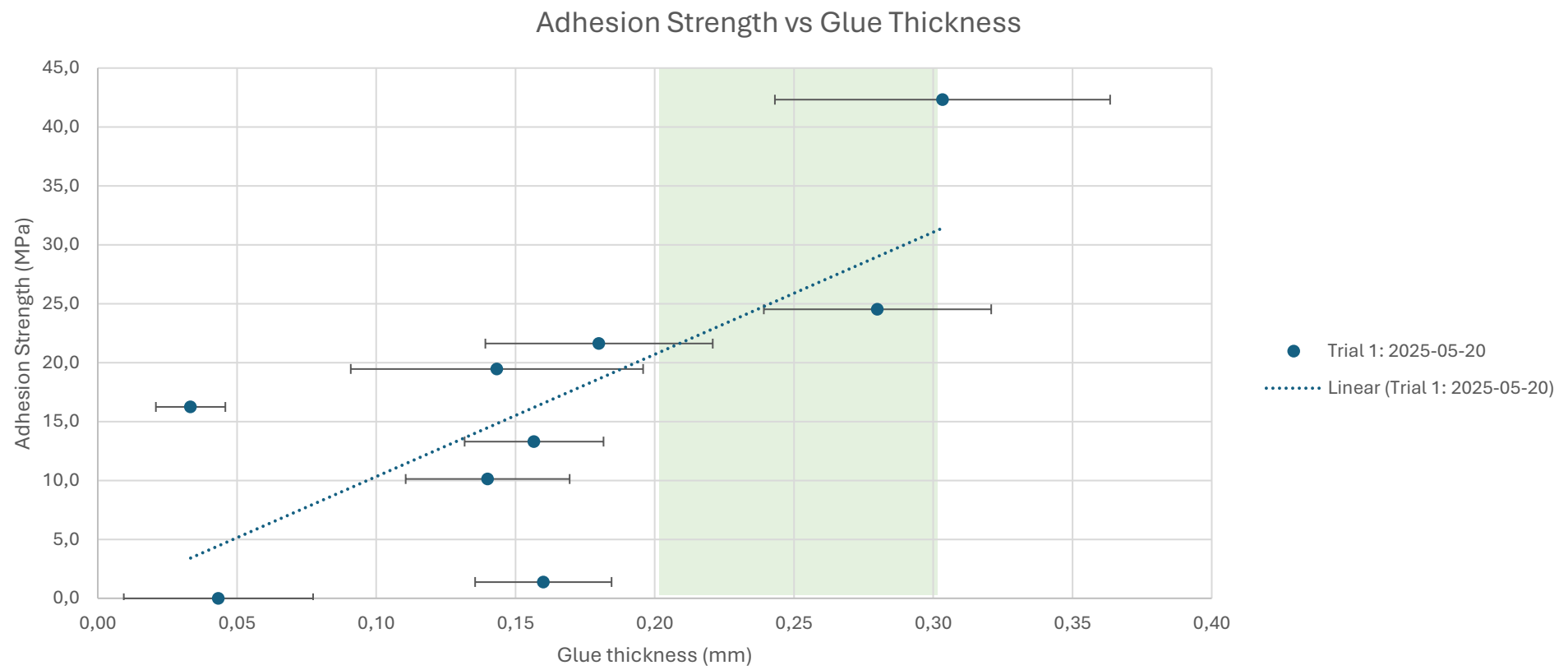


Maximum depth of
blend-out repair
(1.8 mm)

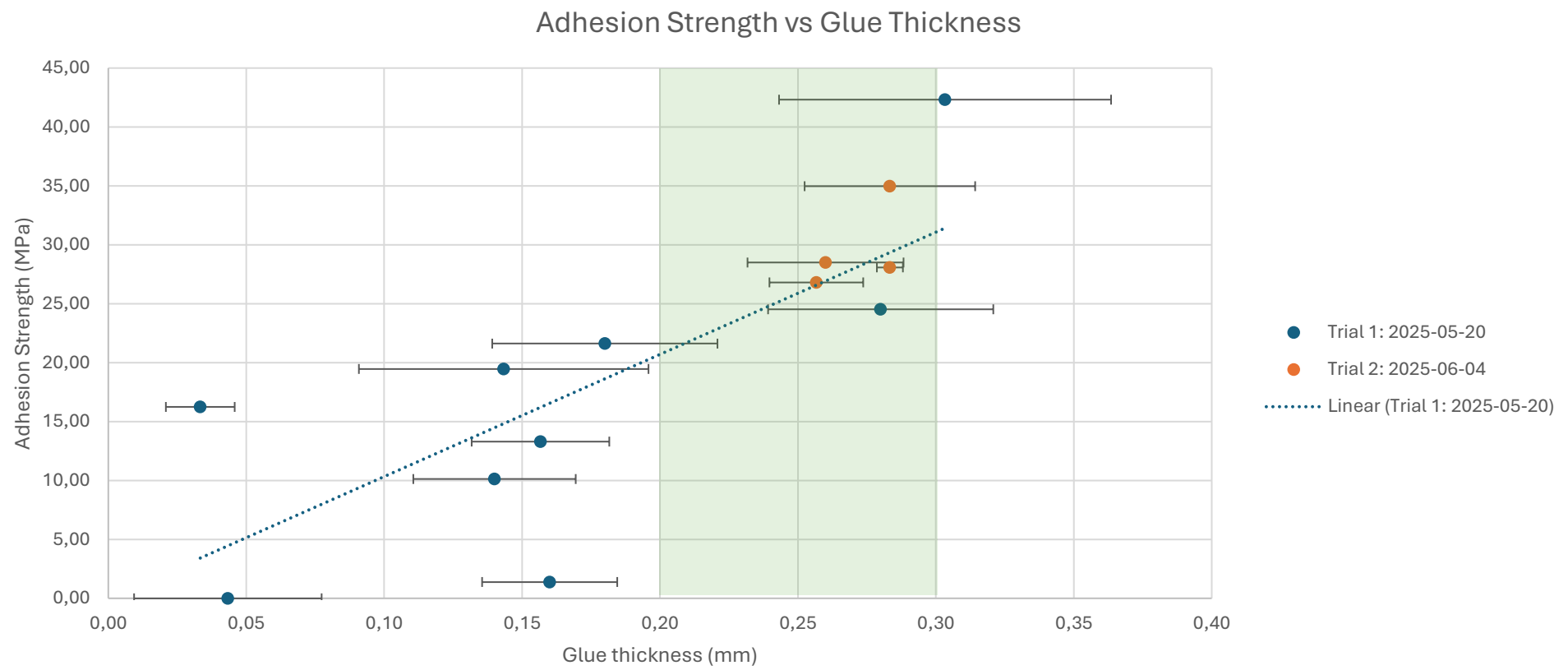
Adhesion Testing



Trial 1: May 20th 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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Thin + Sand Blast



Thick + Sand Blast



Thin + Scotch Brite



Thick + Scotch Brite

Adhesion Testing



Thin + Sand Blast



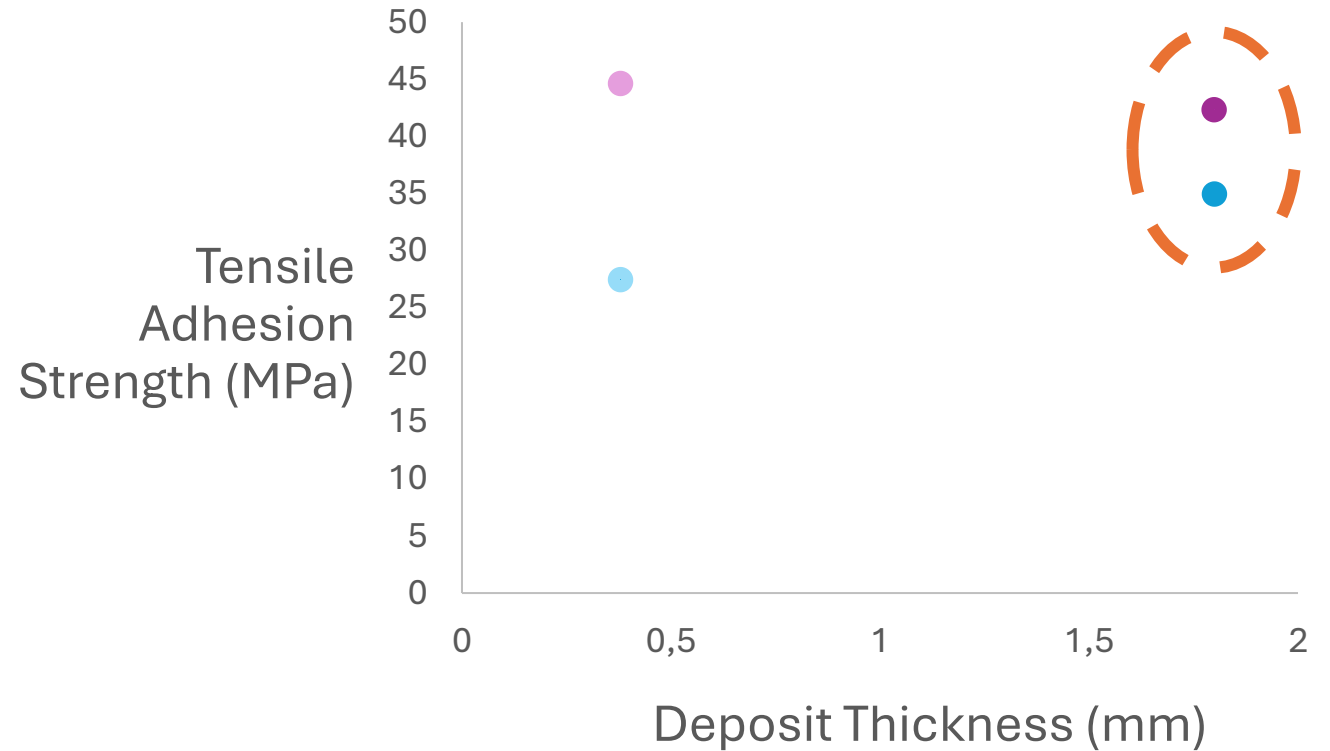
Thick + Sand Blast



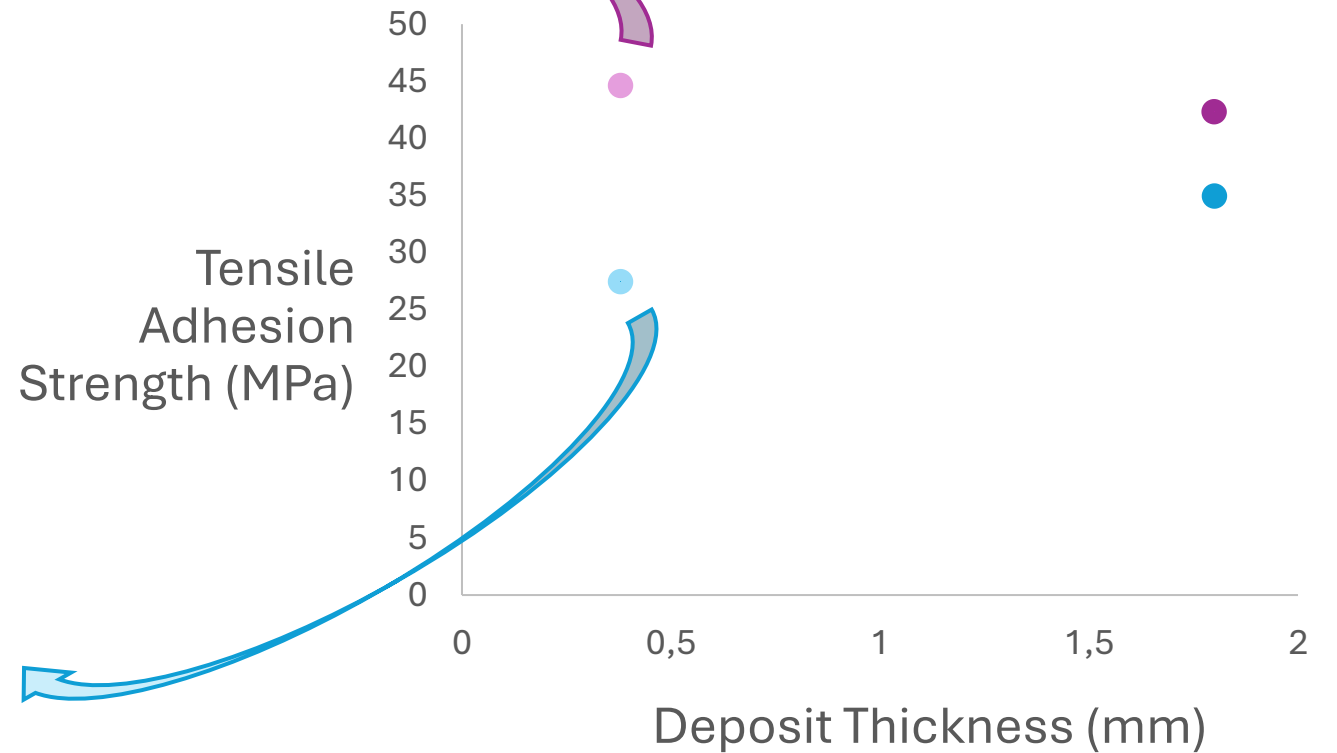
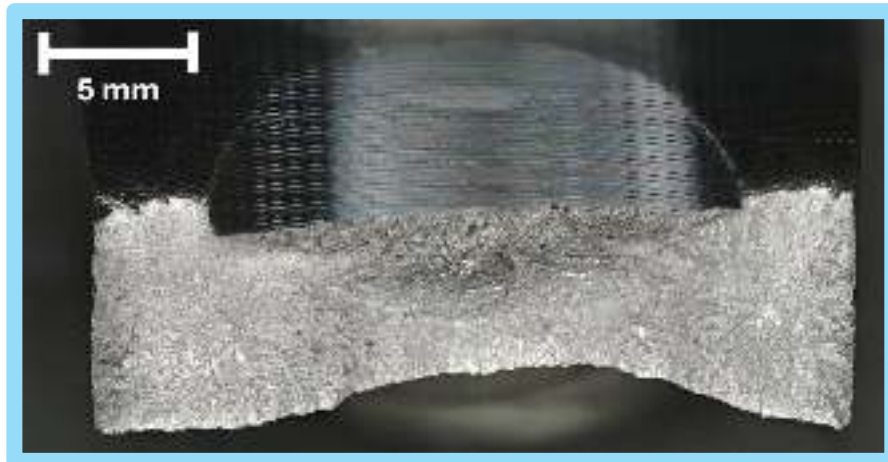
Thin + Scotch Brite



Thick + Scotch Brite



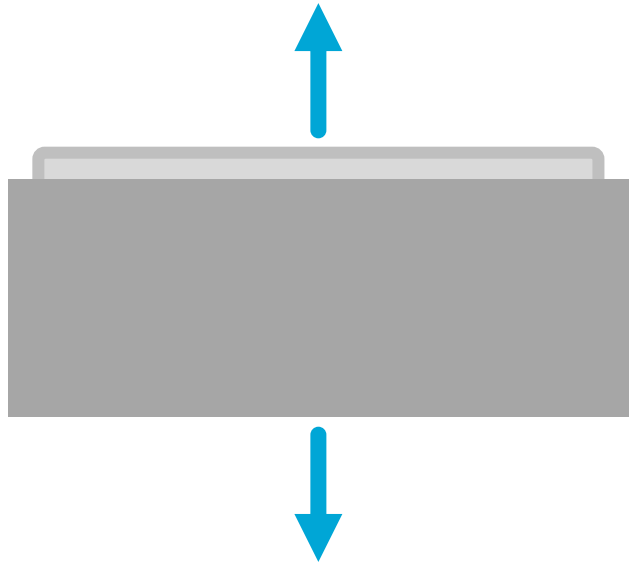
Adhesion Testing



In Conclusion

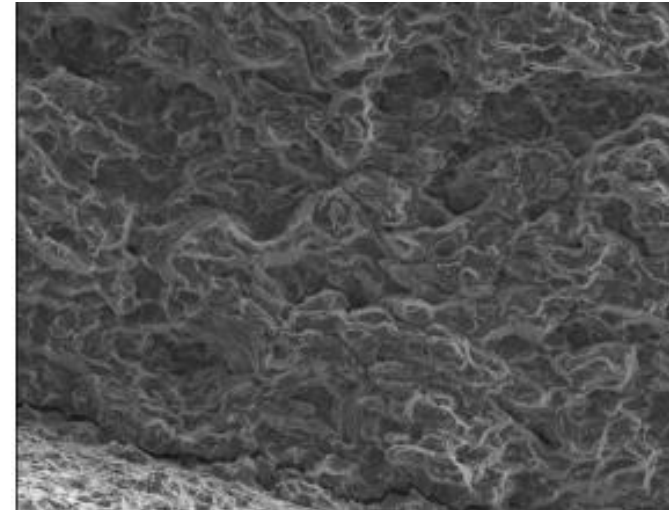
Deposits can pass all of our existing quality metrics, yet be detrimental to the fatigue performance of a repair

- 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?