Progress Report: Adhesive-free Bond Strength Test for Cold Spray Coatings

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Materials Joining and Engineering Technologies

The challenge

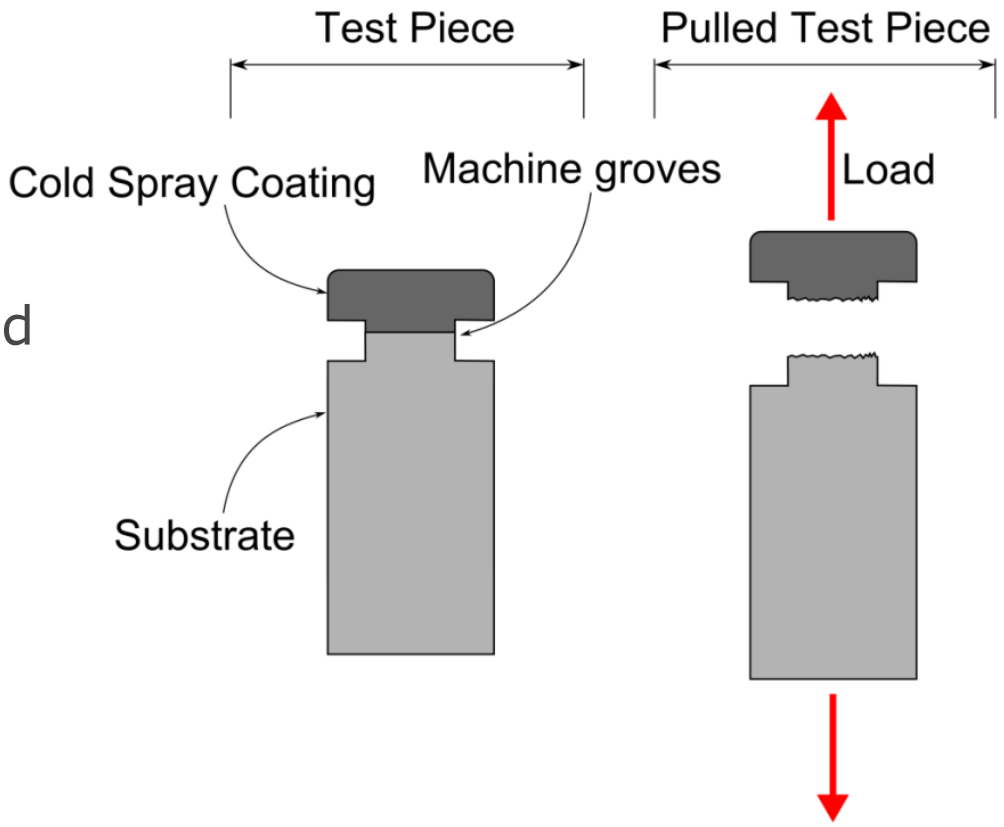
- Conventional coating bond strength tests use glues/epoxies
- Even the best epoxies typically fail at around 70-90 MPa
- Some thermal spray coatings (e.g. WC-CoCr HVOF) routinely exceed this bond strength
- As do some cold spray deposits …
- If we are to develop load-bearing cold spray repairs, we have to be able to measure the cold spray deposit's true adhesion and strength.

Possible approaches

- Modified ASTM C633 Method
- Interfacial Indentation Method (ISO 19207)
- Plug Test
- Scratch Test
- Peel Test
- Tie Bar Test

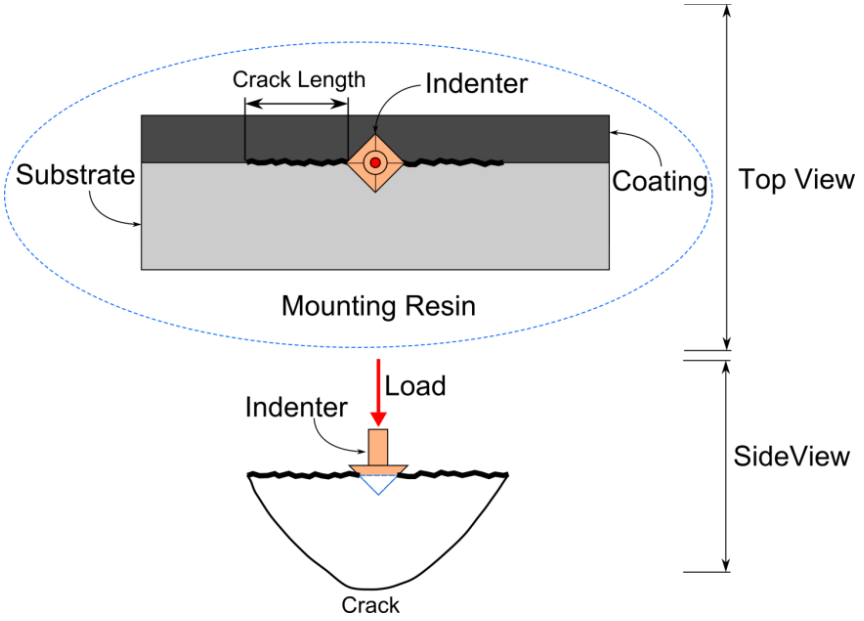
Modified ASTM C633

- Requires a very thick cold spray deposit
  - Originally proposed by Huang and Fukanuma.
  - Building up the required deposit can be costly and time-consuming
  - The machining step can introduce flaws at the interface.

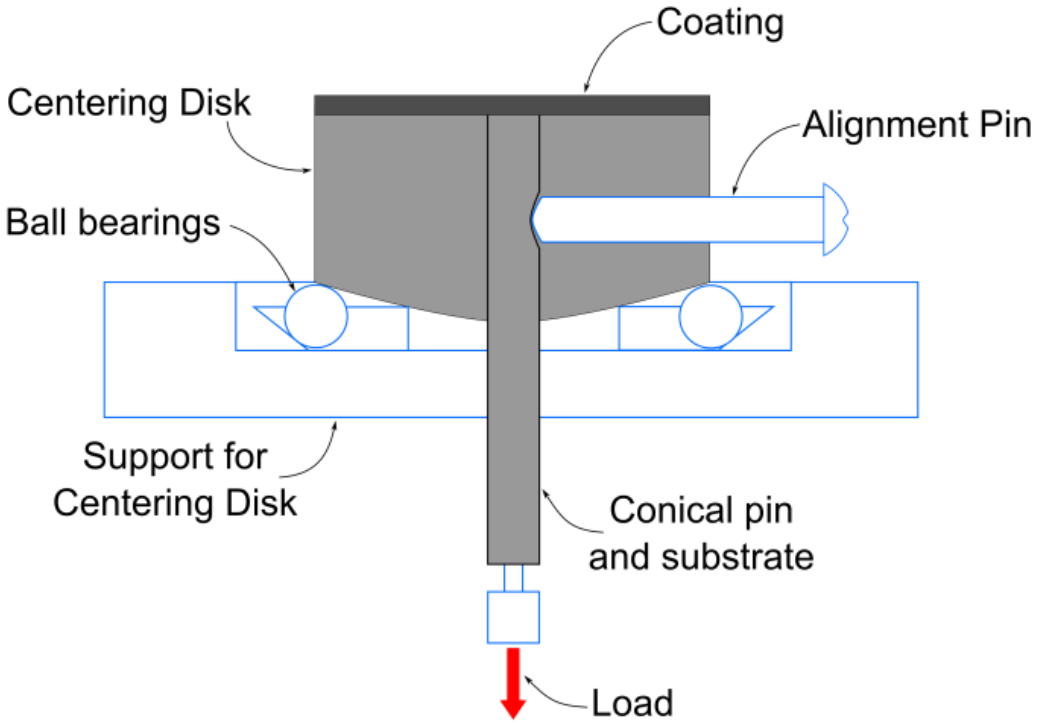


Interfacial Indentation Test

- Uses a Vickers hardness indenter at the interface
  - Observes cracking to determine “apparent interfacial toughness”
  - Requires careful metallographic preparation
  - Cracks may propagate into the coating, invalidating the test

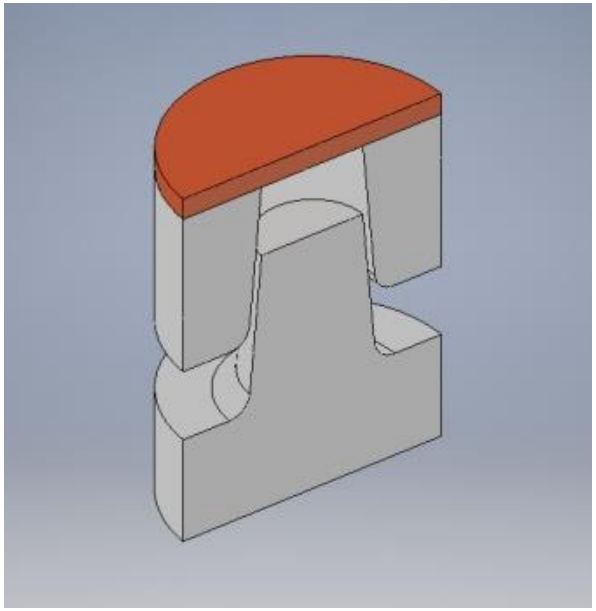


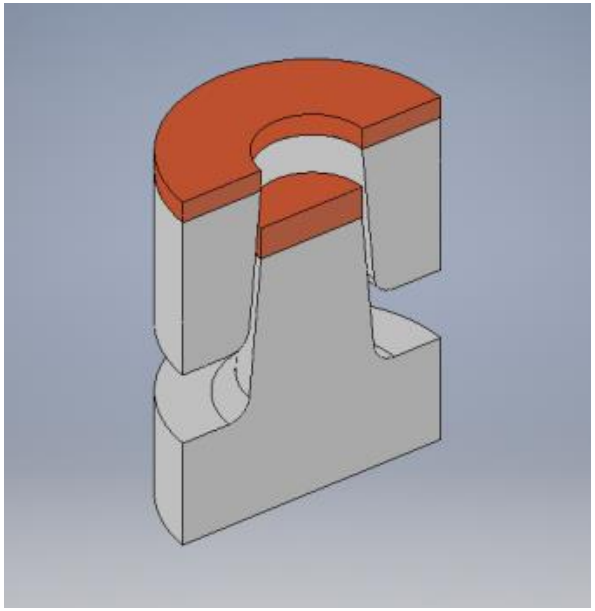
Plug Test



- Lyashenko, B. A., Rishin, V. V., Zil'berberg, V. G., & Sharivker, S. Y. (1969). Strength of adhesion between plasma-sprayed coatings and the base metal. Powder Metallurgy and Metal Ceramics, 8(4), 331-334.
- Lyashenko, B. A., Rishin, V. V., Astakhov, E. A., & Sharivker, S. Y. (1972). Investigation of the adhesion strength of coatings applied by detonation-gun flame spraying. Strength of Materials, 4(3), 287-290.

Plug Test Limitations





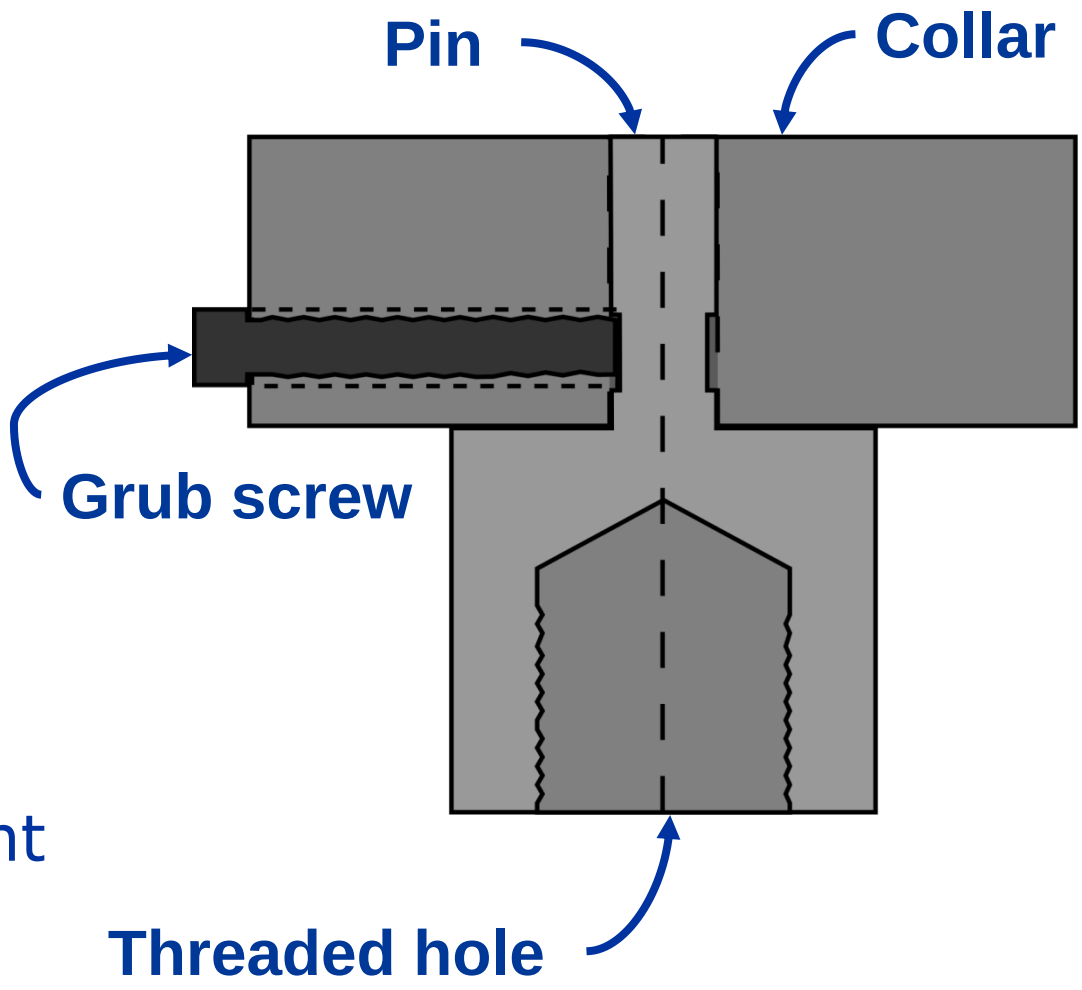
- Bond failure (left) is favoured over shear failure (right) when the cylindrical shear plane is larger, i.e.
  - if the coating is very thick
  - if the pin diameter is very small.
- Therefore, this test is not ideal for conventional thermal spray coatings (<≈300 µm) as this implies a pin diameter of ≈1-2 mm.

TWI Test

- TWI is developing a modified version of the Plug Test for cold spray deposits.
  - Designed for easy integration with conventional tensile testers.
  - The design avoids misalignment, preventing introduction of shear stresses which may affect the results.

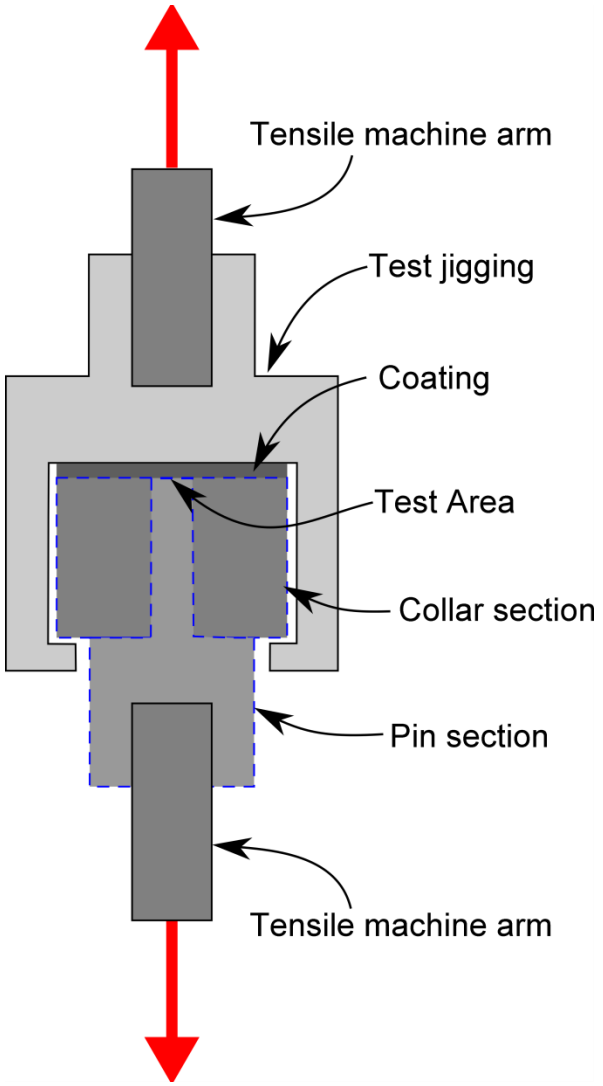
TWI Test - Prototype

- Pin diam. 5 mm
- Grub screw to prevent relative movement.
- M16 threaded base
  - Same as ASTM C633 for easy integration with existing equipment & procedures



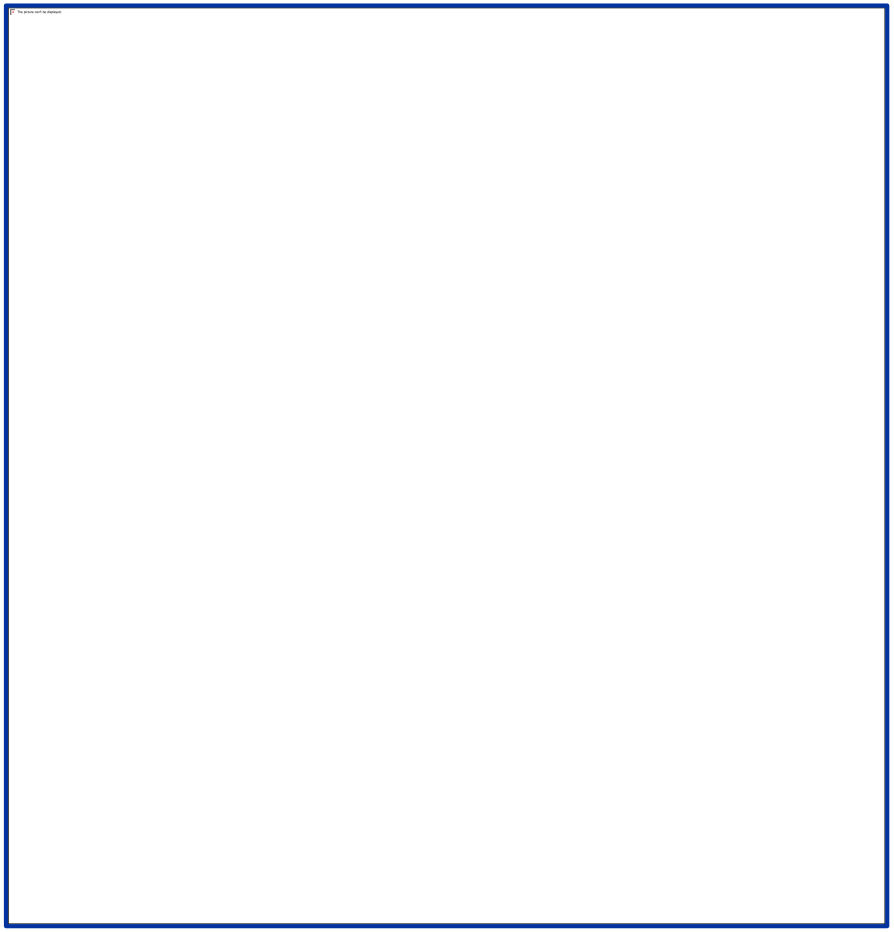
TWI Test - Prototype

- The coated pin assembly is placed in a jig
- Tensile force is applied (via the collar and threaded base) until failure occurs.
- If the coating fails adhesively the pin is removed and the coating remains intact.
- If the coating fails in shear then the bond strength is '> x MPa'.
- Mixed mode failures are presumably also possible.



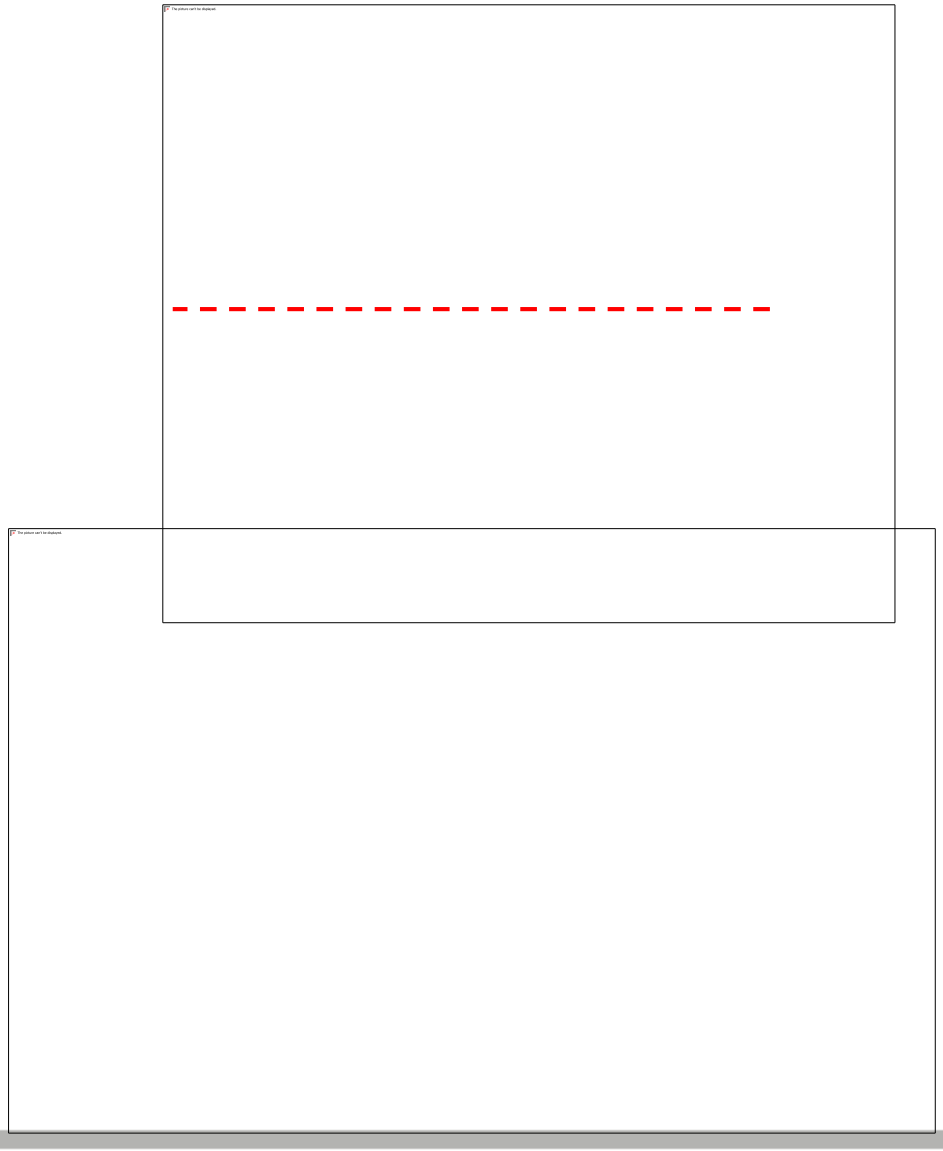
First trial: Assessment of machined assembly

- A series of assemblies were measured using 3D surface profilometry to observe any defects at the pin-collar interface.
- Assemblies were measured in three conditions:
  - As-machined
  - Ground
  - Grit blasted



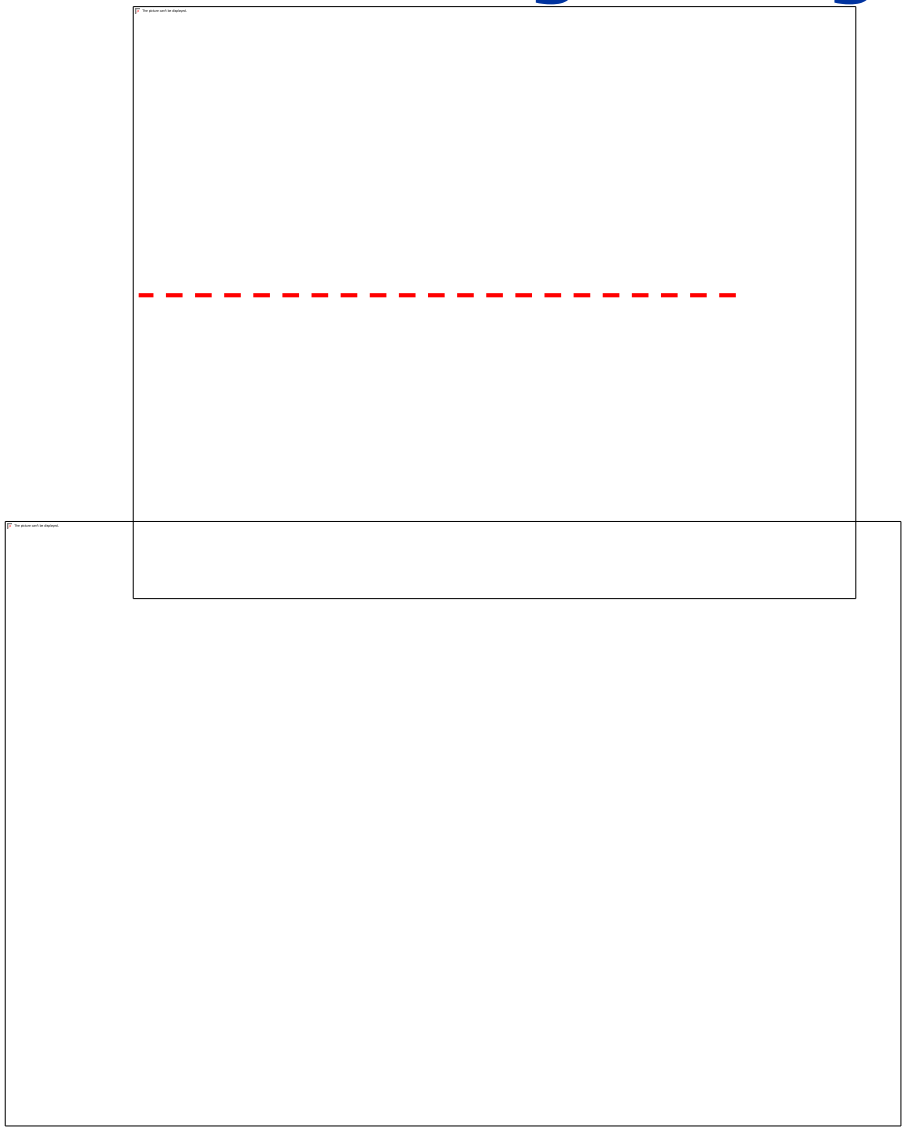
As-machined assembly

- Machined substrate assembly (pin & collar)
  - No defects observed (other than machining pip).
  - If present, they are smaller than the machining marks <5µm.
  - It’s possible that material was smeared into a defect, covering it up.
  - Other surface preparation methods may introduce new surface defects.



After grinding

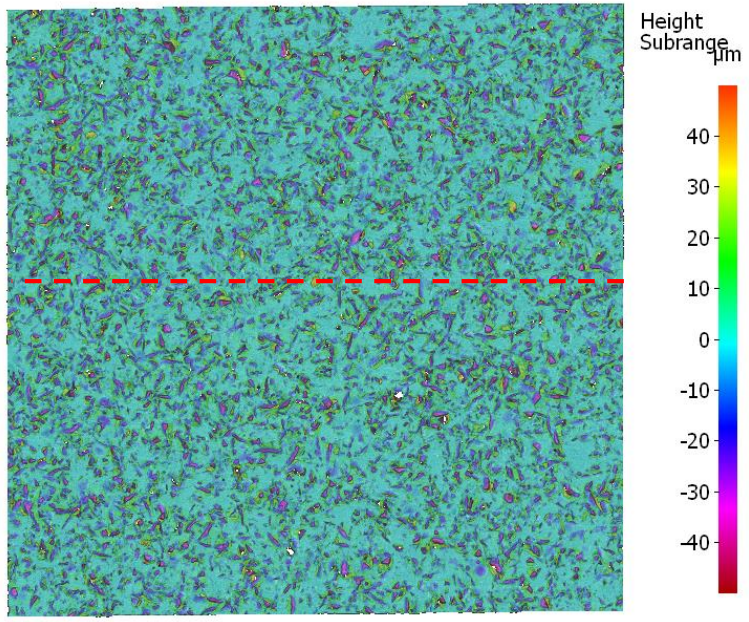
- Ground substrate assembly (pin & collar)
  - Machining pip has been removed by blasting.
  - No significant defects observed.
  - Slight pin height difference visible, <2µm.
  - Any defects are smaller than the surface roughness.



Mild steel assembly prepared using a 320 paper.

After grit blasting

- Grit blasted substrate assembly (pin & collar)
  - If present, defects are smaller than the surface roughness.

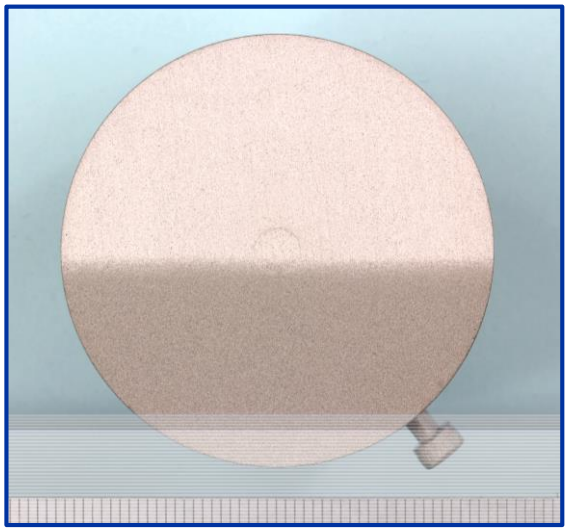


Mild steel assembly prepared using a chilled iron 24 mesh grit.

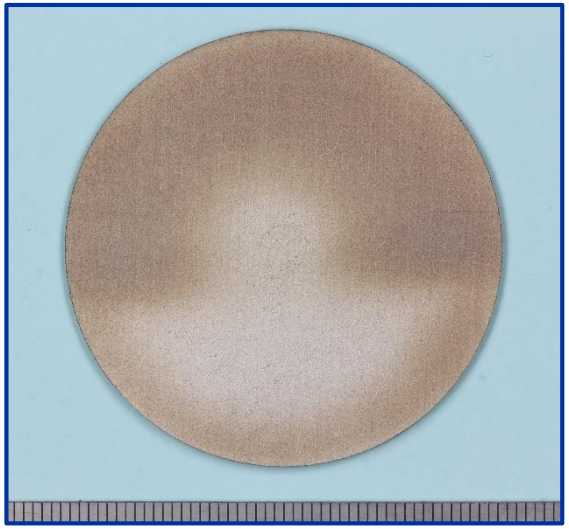
After coating

- Does the pin-collar interface cause defects during coating?
  - A coating was sprayed onto a ground assembly until it delaminated.
  - The surface of the assembly was then scanned by 3D profilometry to observe any defects.
  - The back face of the delaminated coating was also scanned to observe any defects.

Assembly



Delaminated Coating

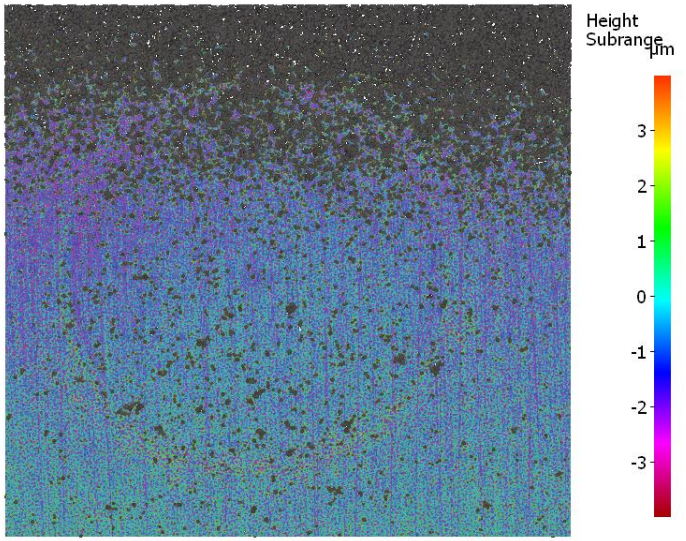


316 coating on a mild steel coupon prepared to a 320 Mesh finish

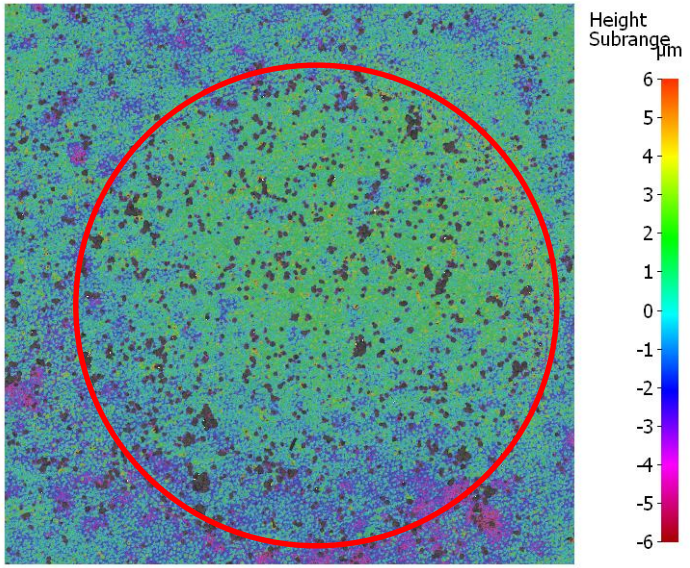
Substrate and delaminated coating

- Ground substrate assembly (pin & collar) after coating delamination.
  - Ring-like shadow visible on the substrate after coating, <5µm high (cannot be observed on a line trace).
  - No significant surface features observed on the back face of the delaminated coating
  - Design therefore appeared suitable for further trials.

Assembly



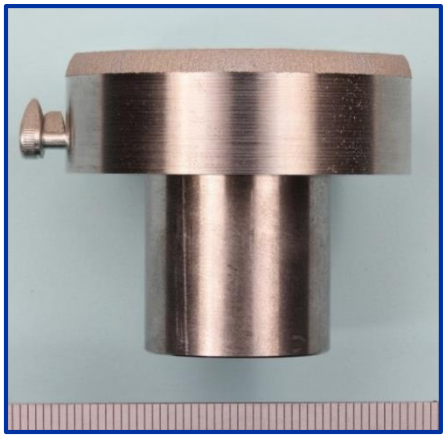
Delaminated Coating

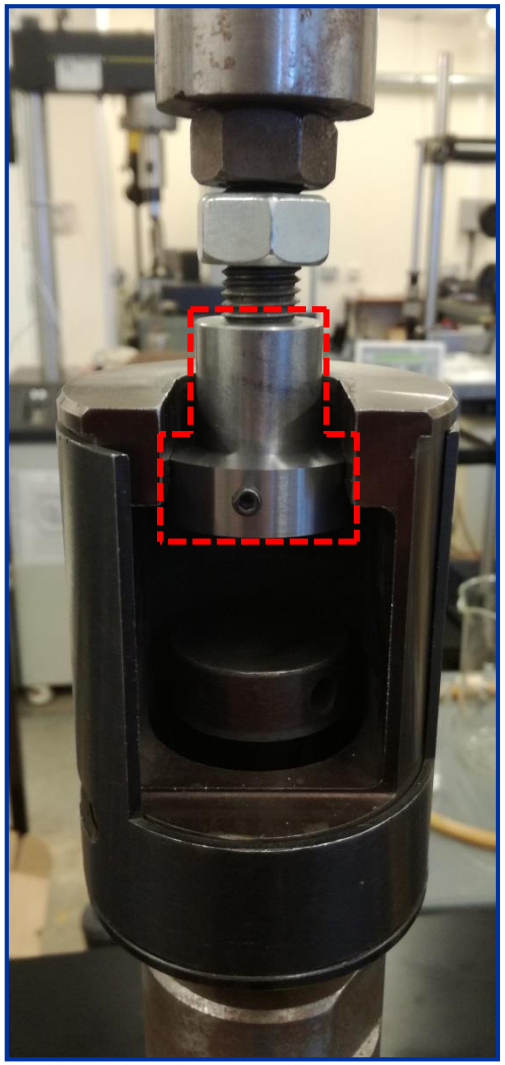


316 coating on a mild steel coupon prepared to a 320 Mesh finish

TWI Test – Initial Assessment

- 3mm AISI 316 SS coating deposited onto grit blasted mild steel.
- Coating pulled until failure.
  - Failure mode: Adhesive (bond line failure
  - Failure load: 1.179kN
  - Adhesion strength: **60 MPa**





TWI Test – Initial Assessment Summary

- No significant defects found at the pin-collar interface
  - Checked following a number of surface operations, including coating.
- Coated assembly successfully coated and pulled.
- Coating failed adhesively with an adhesion strength value that seems “not unreasonable” for such a coating.
- Basic design is therefore appropriate for further development.

What's next?

- Improvements to the design
- Changes to manufacturing process to avoid oil/grease contamination
- Testing a variety of coatings
  - TWI welcomes third party samples, provided data can be published
- Experimental assessment of force required to remove uncoated pin (correction factor).

What's next?

- Modelling of various scenarios and correlation with further experimental results
  - e.g.: How likely is it that shear plane suffers some plastic deformation hence affecting result?
  - Any stress concentrations which may affect results?
- Interchangeable pin and collar faces to reduce material usage for expensive systems such as Ti? Reuse of specimens to reduce cost?
- If results are encouraging, do further work and propose the test for standardisation.

Thank you

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