Mechanical Behaviour of Annealed Cold Sprayed Cu-Ni Coating

Author: ME5 Adrian Chua, RSAF
Thesis Advisors: Andy Nieto and Troy Y. Ansell

Objective

This paper investigated the mechanical behaviour of both as-sprayed and annealed cold sprayed Cu-38Ni coatings on Cu-10Ni substrates, using pull-tests to determine coating adhesion strength, tensile testing of the cold sprayed Cu-Ni coatings on the Cu-Ni substrates to understand the overall mechanical behavior, and nanoindentation to understand the localised properties of the coating and substrate materials.

Introduction

Cold spray technology is an additive processing technology that is viable for both protective and repair applications through the deposition of metallic coatings at supersonic speed without melting the particles. Cu-Ni is particularly suited for cold spray processing due to (1) its feasibility as both a coating material and material to be repaired or protected [1], and (2) its desired characteristics of high corrosion resistance, relatively high strength, and good thermal conductivity [2].

Results

a) Anneal Effect

- Denser coating with less inter-splat porosity and finer splat microstructure was observed.
- Localised recrystallisation with sub-grain structure within splats was observed.

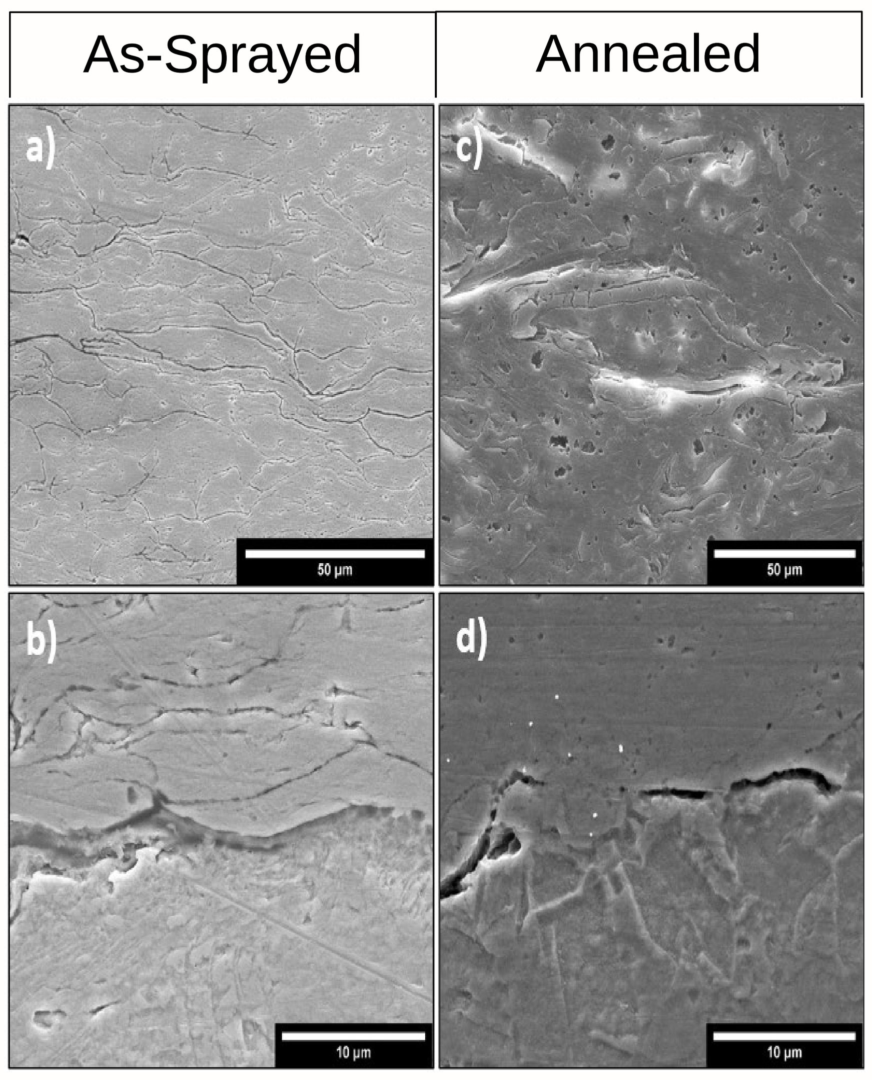

Figure 1: Scanning Electron Microscopy Comparison of Coatings' Structures

b) Adhesion Testing

- As-Sprayed. Porous interface between 1st and 2nd pass coating layers was the predominant failure point with average adhesion strength of 17.94 MPa.
- Annealed. The entire coating remained intact with average adhesion strength of 46.56 MPa.

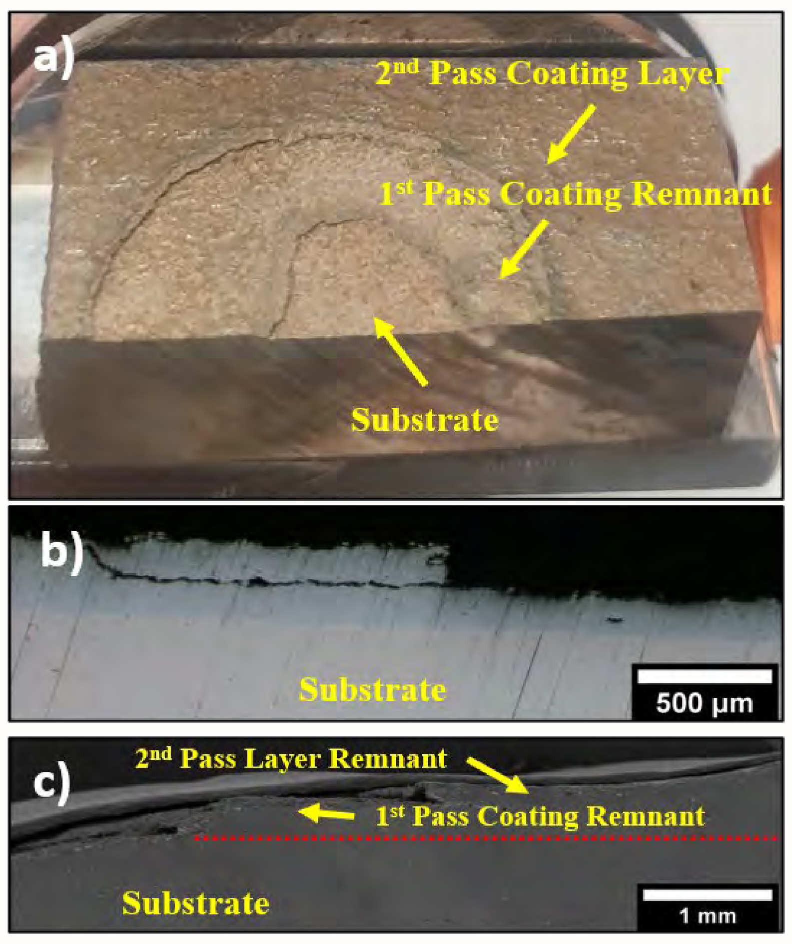

Figure 2: As-Sprayed Coating Adhesion Failure

c) Tensile Testing

- As-sprayed coating failed at single point and delaminated from substrate at ≈3.9% elongation, while annealed coating failed at multiple sites but remained adhered at ≈ 13.7% elongation.
- Cold spraying process induce hardening of the substrate to result in higher ultimate tensile strength.
- Annealing process possibly further strengthen the substrate through precipitate hardening.

Table 1: Tensile Mechanical Properties

	Elongation-to-Rupture (%)	Maximum Sustained Load (kN)	Ultimate Tensile Strength (MPa)
Substrate	63.56 ± 0.85	10.65 ± 0.08	279.63 ± 2.18
Annealed Substrate	53.65 ± 0.68	11.94 ± 0.13	313.39 ± 3.51
Coated	61.83 ± 0.91	11.62 ± 0.09	305.16 ± 2.38
Annealed Coated	50.15 ± 0.71	13.26 ± 0.17	348.15 ± 4.51

d) Nanoindentation Testing

- The intrinsic mechanical behavior of a cold sprayed coating can match that of wrought material via the appropriate annealing.
- The higher elastic modulus for both the annealed substrate and coating is attributed to the resultant denser structure.

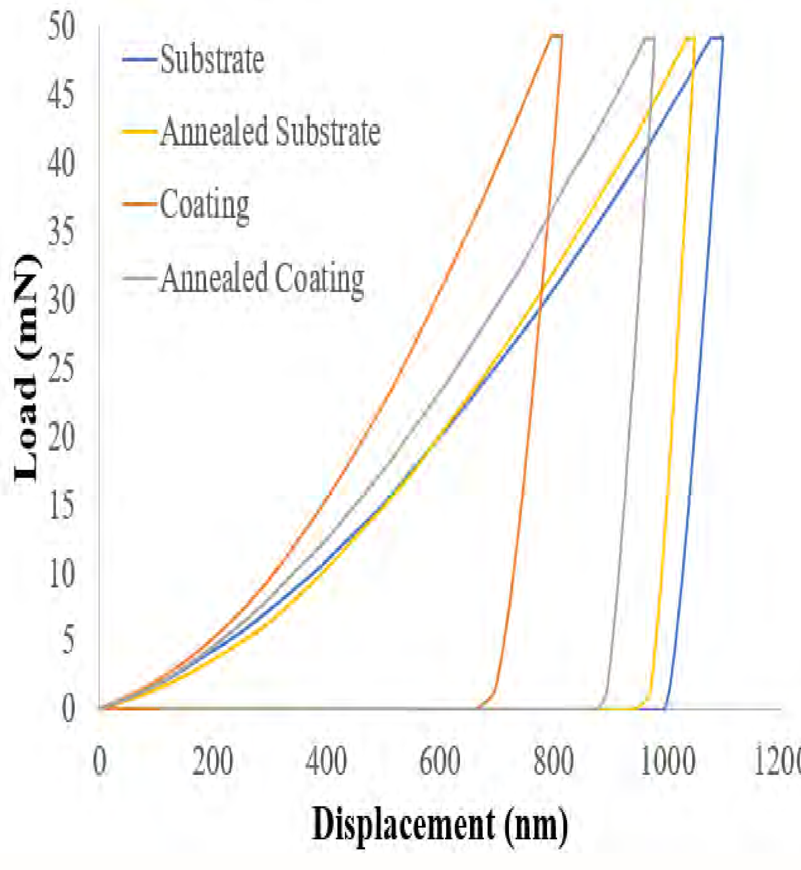

Figure 3: Characteristic Nanoindentation Load-Displacement Curves

Key Takeaways

- Annealing was able to endow the coating with both enhanced ductility and strength, by inducing solid-state diffusion within the coating that reduced porosity and bridged inter-splat cracks.
- Cold sprayed coating can have structural applications to participate in load bearing and undergo plastic deformation prior its failure, as evident by the three-fold improvement in the coating-elongation-at-failure from ≈ 3.9% to ≈ 13.7%. This suggested that the annealed coating is able to survive well beyond the yield strength of the substrate.

References

[1] H. Koivuluoto, A. Milanti, G. Bolelli, L. Lusvarghi and P. Vuoristo, High-pressure cold-sprayed Ni and Ni-Cu coatings: Improved structures and corrosion properties, Journal of Thermal Spray Technology, 2014, 23, p 98-103. https://doi-org.libproxy1.nus.edu.sg/10.1007/s11666-013-0016-7

[2] R. C. Rice, J. L. Jackson, J. Bakuckas and S. Thompson, DOT/FAA/AR-MMPDS-01 Metallic Materials Properties Development and Standardization *(MMPDS)*, National Technical Information Service, Springfield, 2003

Temasek Defence Systems Institute
NUS National University of Singapore