Interfacial Microstructure and Mechanical Properties of 316L/17-4PH Dissimilar Stainless Steels Joints Fabricated by Coaxial Wire Directed Energy Deposition

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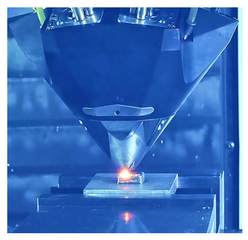
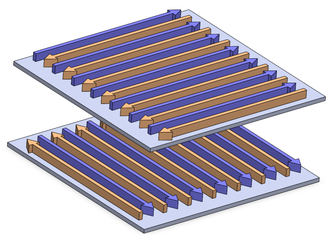
1. Motivation

- Multi-material additive manufacturing enables tailored, location-dependent properties within a single component.
- Pairing 316 L and 17-4PH offers a pathway to combine the ductility/corrosion resistance of 316L with the higher strength of 17-4PH.
- Key challenge: understand how compositional mixing during coaxial wire DED controls interface formation, phase evolution, and mechanical integrity.

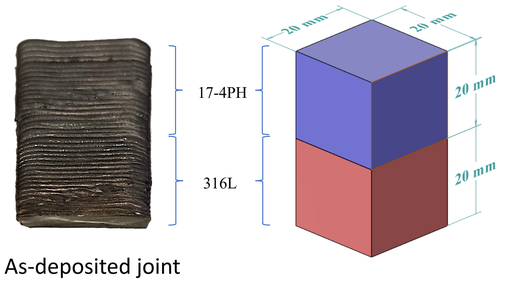
2. Experimental Approach



Coaxial WL-DED



Bilinear scanning with 90° Interlayer

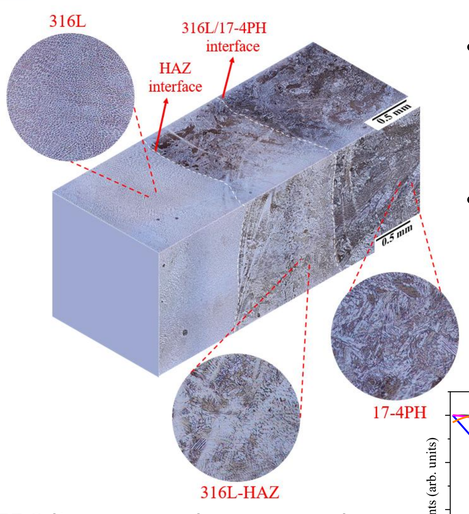


As-deposited joint

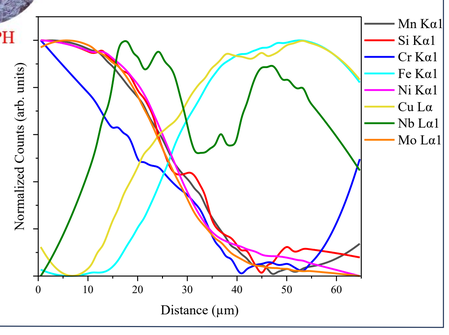
- Meltio M450 coaxial WL-DED; 6 concentric lasers.
- Feedstock: 1 mm 316L and 17-4PH wires
- Build geometry: 20 x 20 x 40 mm; 316L / 17-4PH
- Print parameters: 800 W, 546 mm/min, bilinear scan, 90° interlayer rotation, Ar shielding.
- Characterization: optical microscopy, SEM/EDS, EBSD, TEM, nanoindentation, tensile testing.

Fabricate (Coaxial WL-DED) → **Characterize** (microstructure & mechanics) → **Correlate** (Composition, phase & mechanics)

3. Interface Morphology & Composition

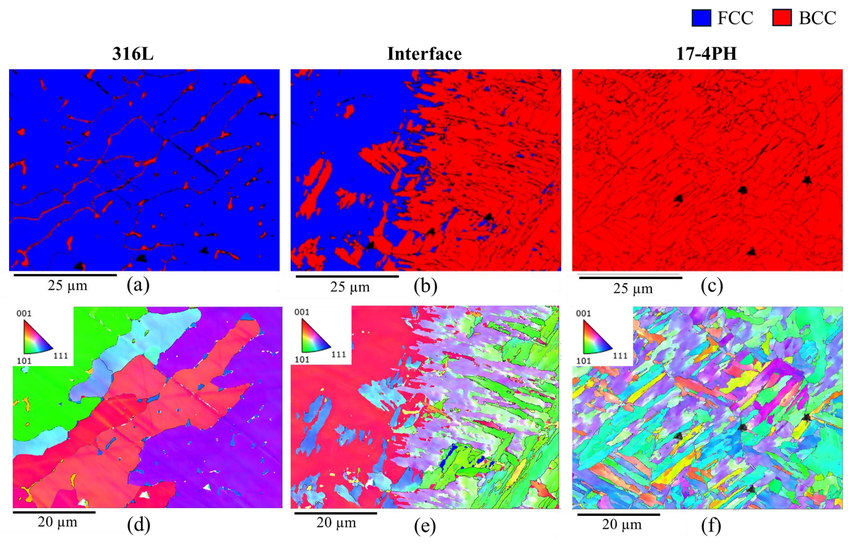


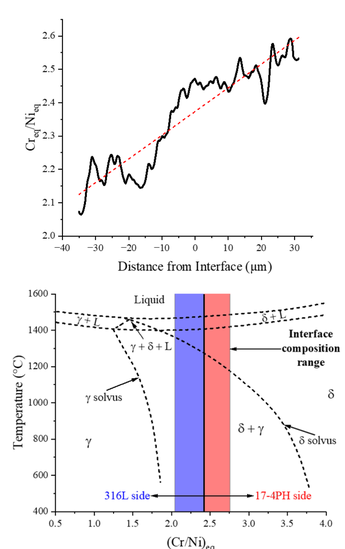
- Continuous metallurgical bond with no visible cracking, porosity, or lack-of-fusion defects.
- A distinct heat-affected zone (HAZ) develops on the 316L side of the interface.



- EDS line scans show smooth compositional gradients across a ~50 μm transition zone, rather than an abrupt change in chemistry.

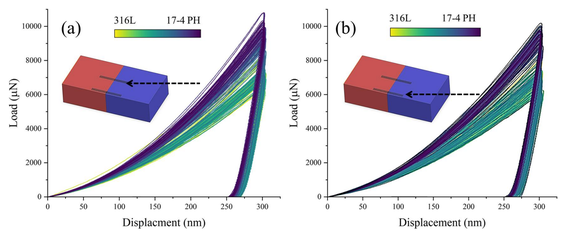
4. Phase Evolution Across the Interface

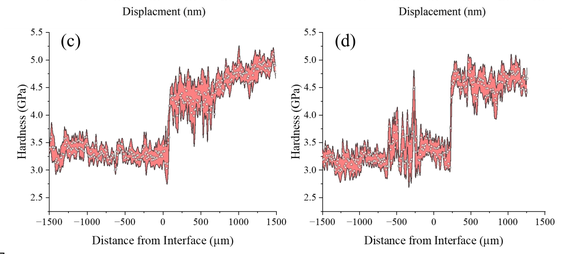


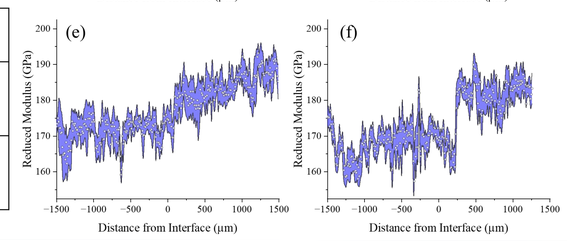


- 316 L is predominantly FCC, with localized BCC/δ-ferrite along grain and sub grain boundaries. The interfacial region contains a mixed FCC + BCC microstructure, while 17-4PH is predominantly BCC.
- Cr_{eq}/Ni_{eq} increases from ~2.04 on the 316L side to ~2.6 on the 17-4PH side, placing the interface in the γ + δ transition regime.
- Rapid solidification limits completion of the δ → γ transformation, promoting retention of BCC phases near the interface.

5. Local Mechanical Response



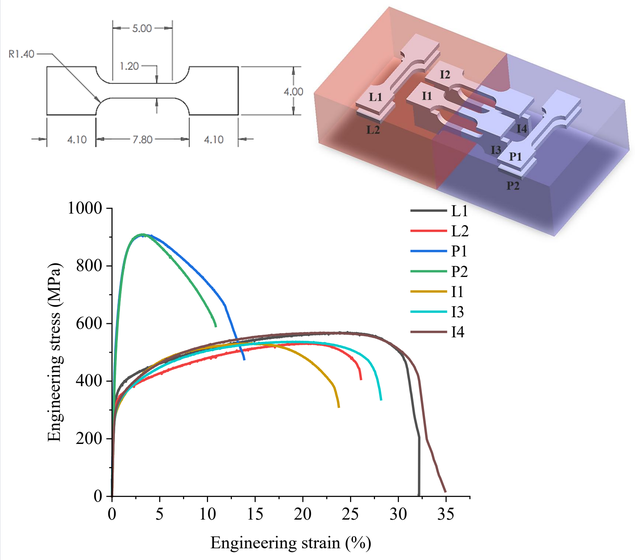


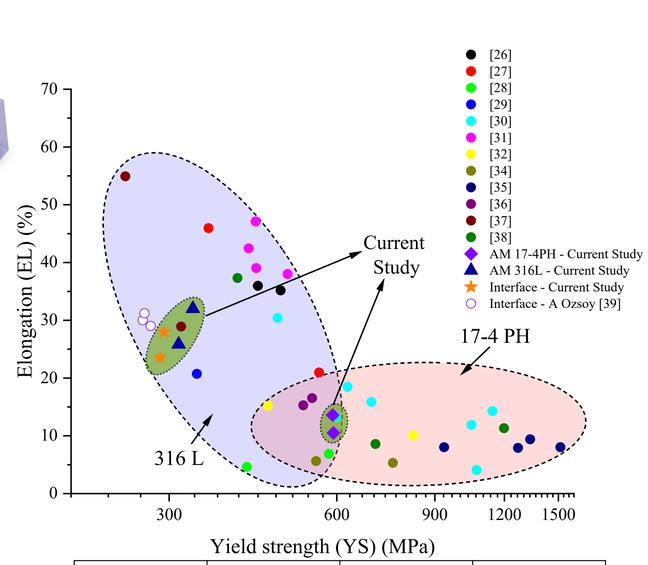


- Hardness and modulus increase from 316 L → 17-4PH, consistent with the FCC → BCC phase transition.
- The center shows a more gradual property transition, while the edge exhibits a sharper change.

Property	316L	17-4PH
Hardness	3.0–3.75 GPa	4.5–5.0 GPa
Reduced modulus	160–180 GPa	180–195 GPa

6. Bulk Tensile Response

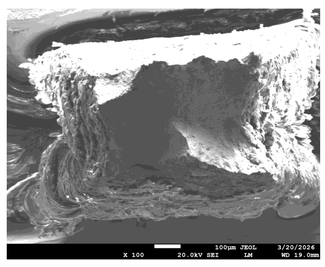


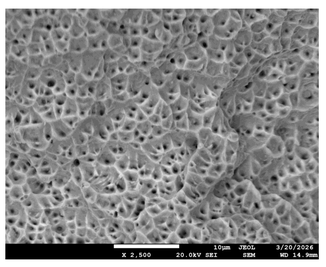


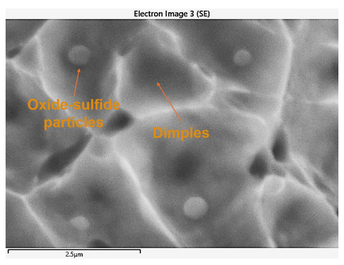
- Interface specimens retain 316L-like strength and ductility, despite spanning the dissimilar joint.
- Most importantly, failure occurs away from the interface, primarily within the 316L HAZ, confirming a mechanically robust bond.

Material	YS (MPa)	UTS (MPa)	TE (%)
316L	312–331	531–567	25.8–32.0
Interface	289–308	530–567	23.5–31.9
17-4PH	590–592	~908	10.5–13.6

7. Fracture Mechanism







- Fracture is predominantly ductile, characterized by micro-void nucleation, growth, and coalescence.
- Interface specimens exhibit a high density of fine dimples, indicating heterogeneous void nucleation.
- Oxide-sulfide inclusions frequently observed at dimple centers, identifying them as preferential void-nucleation sites.

8. Key Conclusions & Future Direction

- Coaxial wire DED produced a mechanically robust 316L/17-4PH joint, with a confined compositional and phase transition across the interface and failure occurring away from the bonded region.
- Future work will explore dissimilar-material pairs relevant to advanced fission and fusion reactors, with emphasis on designing and controlling robust graded interfaces.
- The next step is to determine how these joints perform under high-temperature and irradiation environments, including the stability of the interface, microstructure, and mechanical properties.

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