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Microstructure and Mechanical Property Heterogeneity in Directed Energy Deposition (DED) Austenitic Stainless Steel

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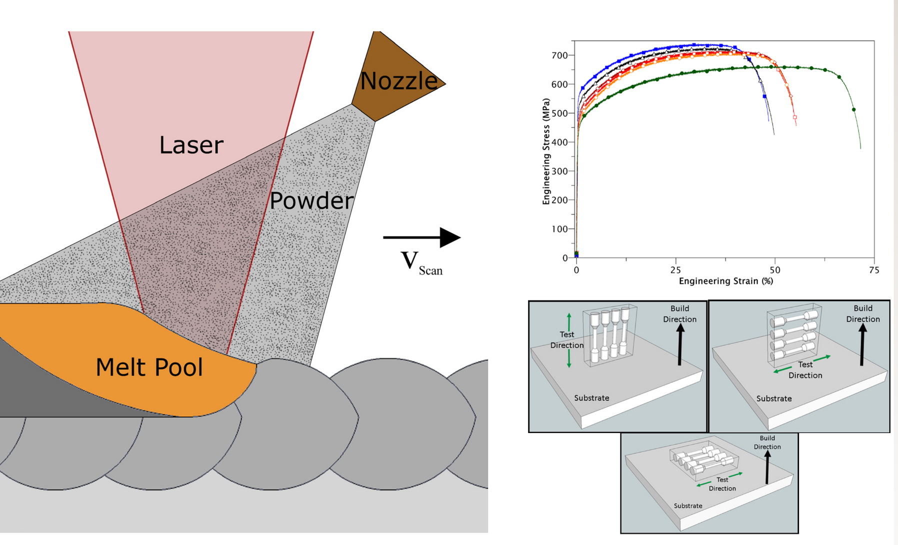

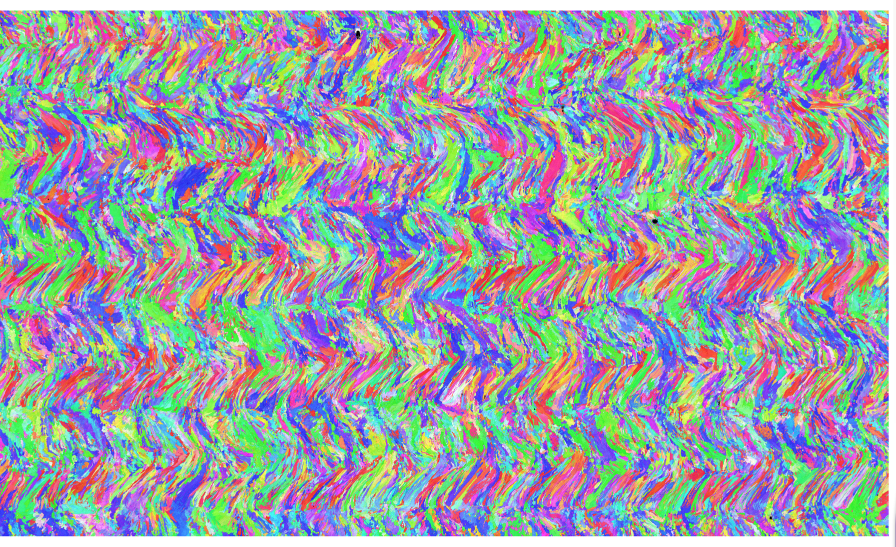

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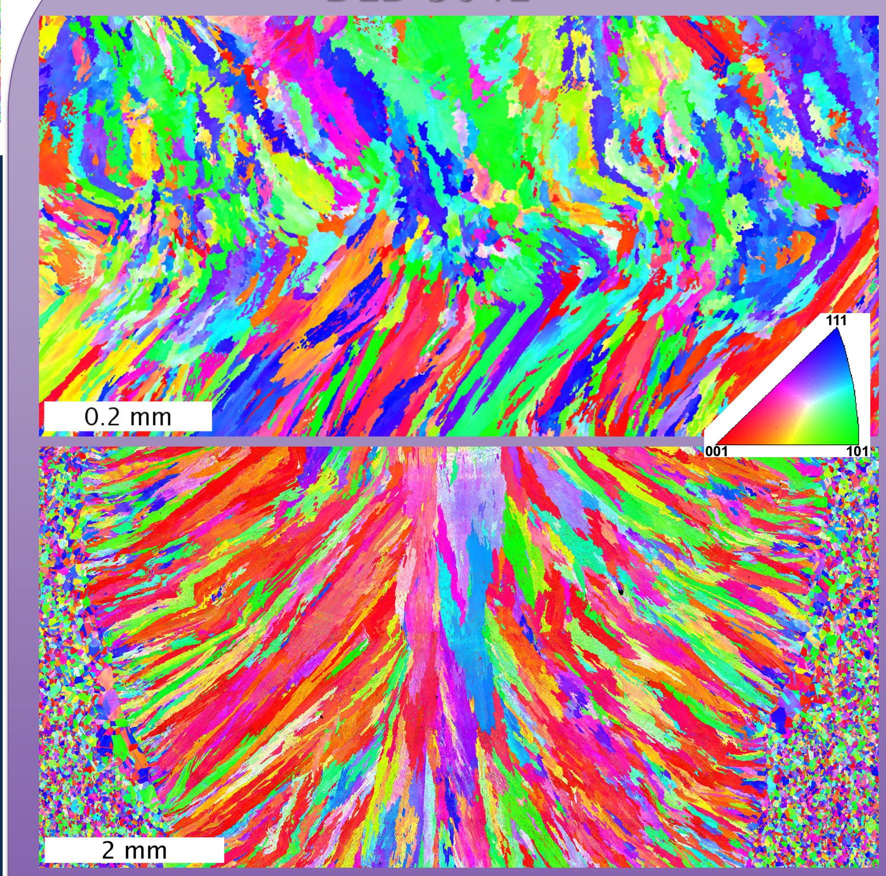
Localized melting, rapid cooling, and extensive thermal cycling occur during directed energy deposition (DED) processes and give rise to spatially varying thermal histories that affect local microstructures and mechanical properties in as-deposited materials. The homogeneity of microstructural features in as-deposited DED 304L was evaluated through electron backscattered diffraction, scanning electron microscopy, transmission electron microscopy, and electron probe microanalysis. Tensile properties were determined for three distinct combinations of build geometry and specimen orientation. Mechanical properties of the as-deposited DED 304L are comparable to conventional forged materials, with yield strengths ranging from 438-553 MPa and tensile elongations between 50-70%. By relating the spatial distribution of microstructural characteristics and mechanical properties, we show that heterogeneous fine-scale microstructures are responsible for differences in mechanical behavior.

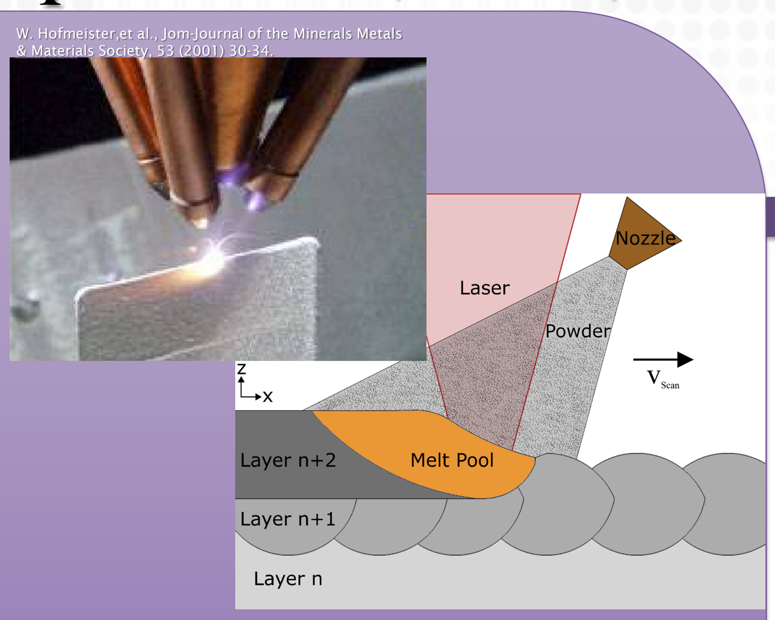
Directed Energy Deposition (DED)

DED 304L



308L/304L Weld

W. Hofmeister et al., Jom-Journal of the Minerals Metals & Materials Society 53 (2001) 30-34.



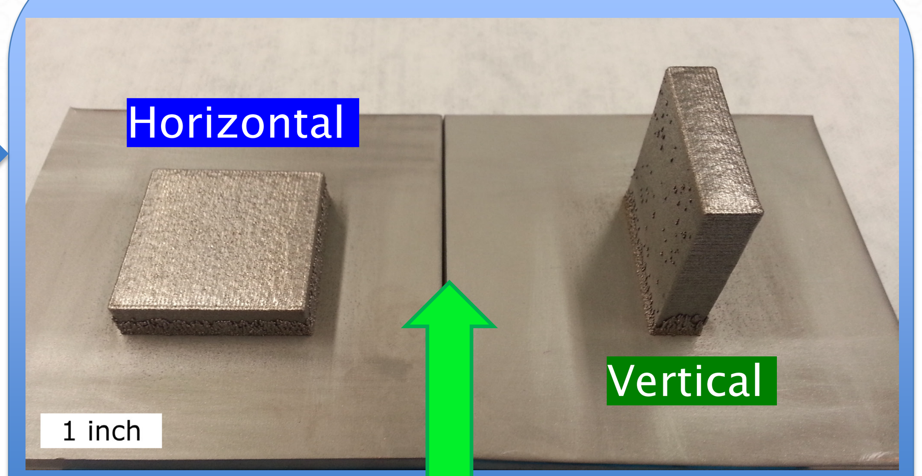
- Analogous to welding
  - Localized melting
  - Rapid heating/cooling cycles
- Complex thermo-mechanical states evolve in materials
- Shaping process and materials properties are coupled

How does build geometry influence mechanical properties?

What is the effect of specimen location and orientation on mechanical properties?

How are differences in properties related to microstructural heterogeneity?

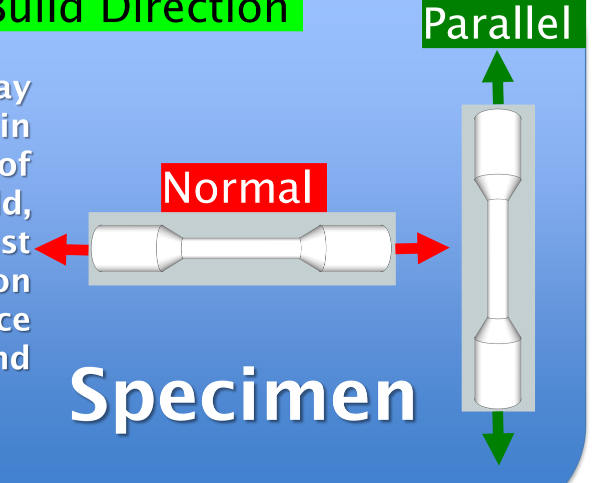
Experimental Variables



Build

Build Direction

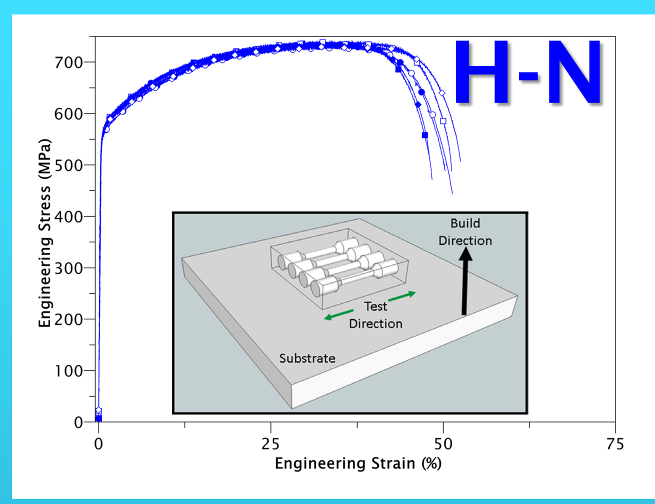
Differences in properties may develop due to differences in build geometry, the location of a test specimen within a build, or the orientation of a test specimen. The build direction is used to define the reference frame for the builds and specimens.

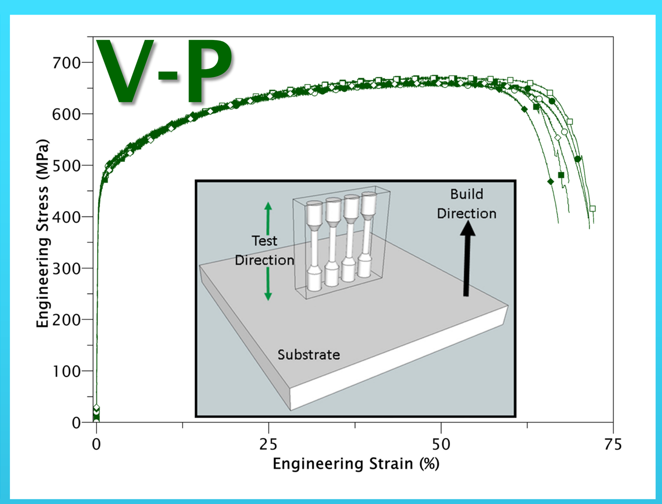


Specimen

Tensile Properties

Build Orientation





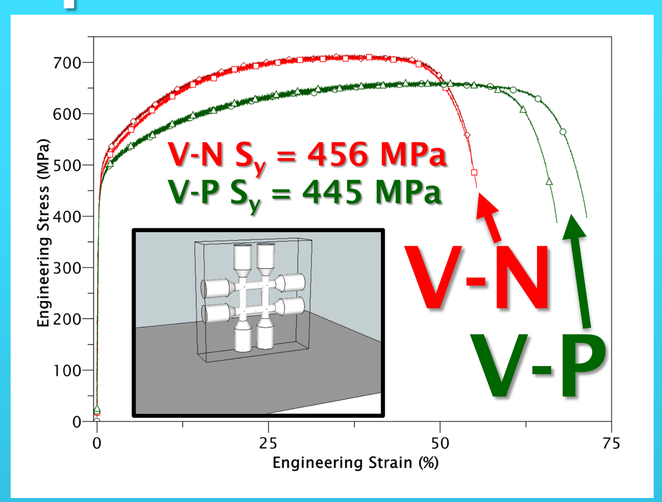
Condition	S_y (MPa)	S_u (Mpa)	El_t (%)
H-N	553 ± 3	734 ± 5	50 ± 2
V-N	470 ± 34	714 ± 8	53 ± 3
V-P	438 ± 7	664 ± 5	70 ± 2
Forged [1]	452	674	68

[1] H. Jackson, et al., Metallurgical and Materials Transactions: A 47(8) (2016) 4334-4350.

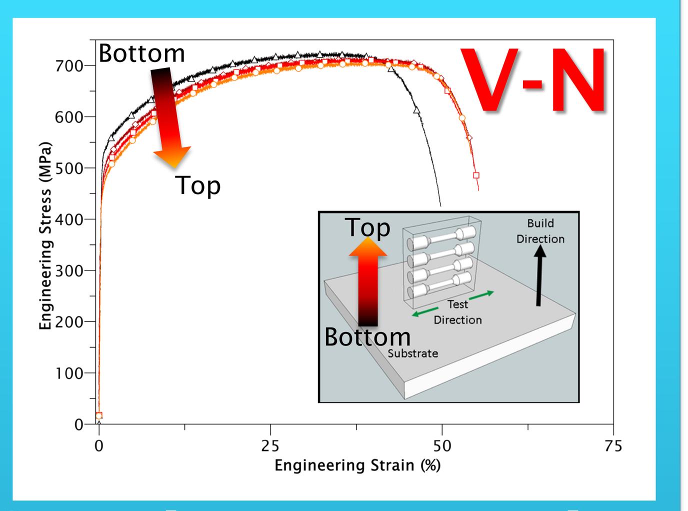
Build orientation significantly influences tensile properties likely due to the influence of geometry on thermal dissipation and material constraint during DED processing.

Despite build and specimen effects, DED tensile properties are comparable to conventional forged materials.

Specimen Orientation

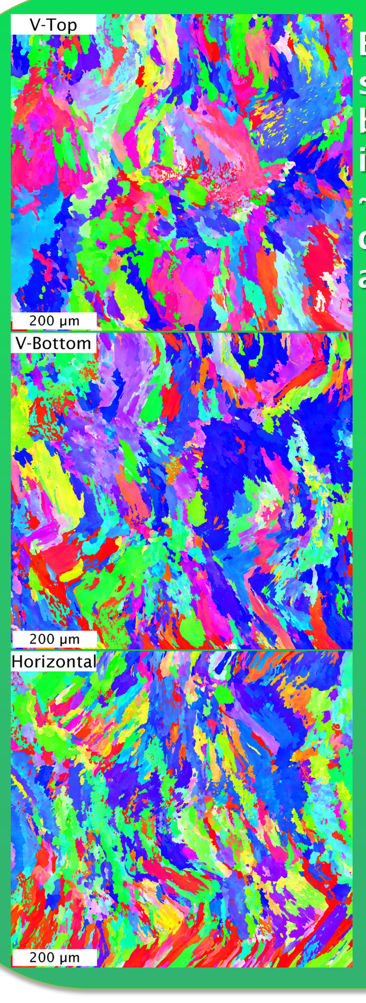


Specimen orientation has little effect on properties, particularly yield strength, of materials with similar thermal histories. Conversely, a gradient in yield strength exists with specimen location distance from the substrate due to the evolution of thermo-mechanical states experienced by the materials.



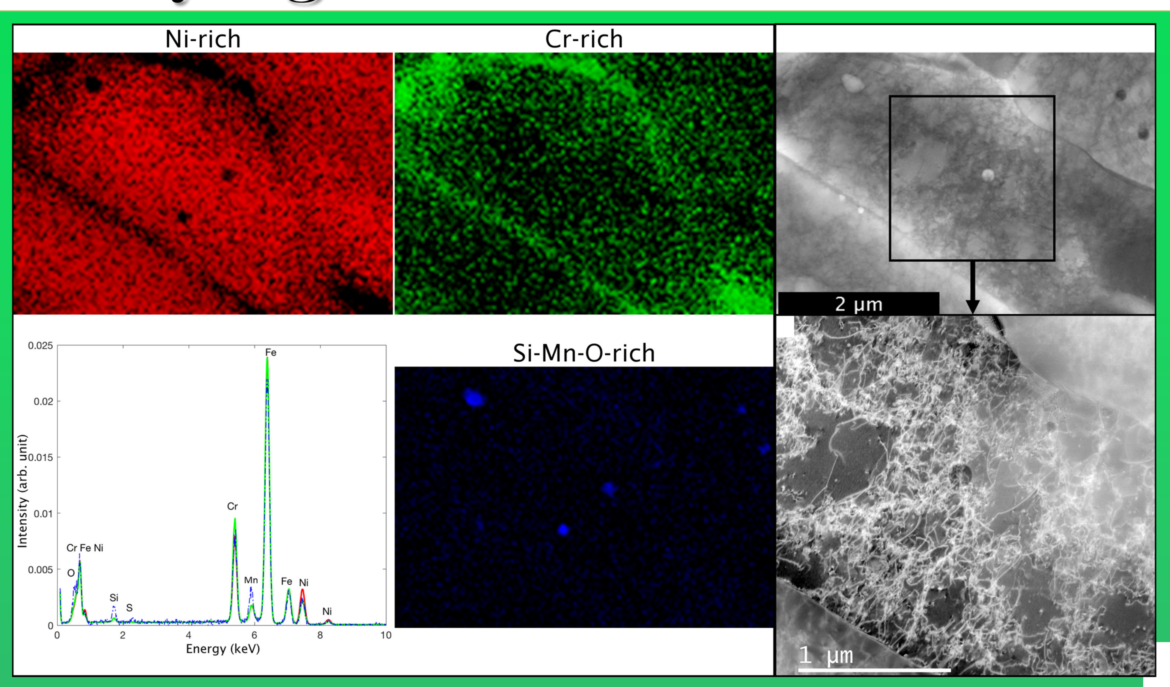
Specimen Location

Spatially Varying Microstructures

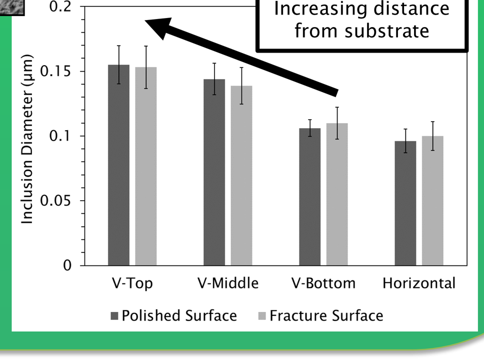


Equivalent circle diameter grain size measured by electron backscattered diffraction (EBSD) in the DED 304L is found to be ~10 μm, showing little dependence on build orientation and location in the vertical build.

Composition of the bulk DED 304L does not exhibit significant dependence on build orientation or location within the vertical build; however, the materials do possess slightly elevated nitrogen and oxygen concentrations.



The differences observed in tensile properties can be attributed to fine-scale microstructural heterogeneity in the dislocation substructure, the chemical and phase modulations associated with the solidification structure, and oxide inclusions; all of which evolve with the variation of thermo-mechanical states during the deposition process and depend on the build geometry.



		Composition (wt%)										
Processing	Grade	Fe	Cr	Ni	Mn	Si	Mo	C	N	O	P	S
Gas Atomized	304L	Bal.	19.4	10.0	1.49	0.54	0.03	0.015	0.091	0.019	0.007	0.007
V-DED Top	304L	Bal.	19.5	10.0	1.45	0.55	0.04	0.010	0.082	0.018	0.008	0.007
V-DED Bottom	304L	Bal.	19.3	10.0	1.44	0.55	0.04	0.011	0.082	0.018	0.010	0.007
H-DED	304L	Bal.	19.3	10.0	1.46	0.55	0.04	0.011	0.082	0.019	0.008	0.007

Conclusions: Differences in tensile properties are attributed to spatially varying microstructures that develop with the complex thermo-mechanical states evolved in DED materials and are dependent upon the process definition. Little difference is observed in tensile properties when comparing build volumes that experience similar thermal histories and material constraint conditions. Although DED tensile properties are comparable to those of conventional forged materials, the significant differences in properties caused by build geometry highlight the need for more robust design tools to predict the spatial evolution of microstructure and associated materials properties.

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