The Role of Powder Characteristics on the Strength and Ductility of Cold Sprayed Refractory Metal Deposits

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INTRODUCTION

The underlying mechanisms by which feedstock powder properties can influence the mechanical behavior of refractory metal cold sprayed (CS) deposits were studied through a combination of micro-mechanical tests and high-resolution characterization.

Two deposits were produced from feedstock powders 1 and 2. The two powders differed in the concentrations of interstitial oxygen and hydrogen impurities introduced during processing, and particle size distributions (PSD). Feedstock 1 contained a higher H content and a wider PSD than feedstock 2. Preliminary work (Fig. 1) revealed that the two deposits respond very differently under 3-point bending experiments. The causes for the very different mechanical behaviors in these coatings were investigated.

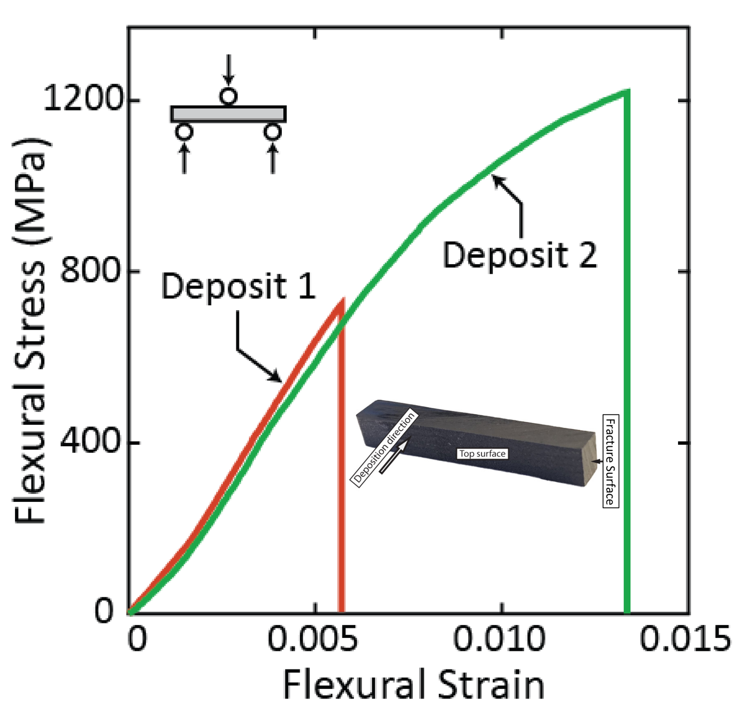


Fig. 1. 3-point bend test data for the two deposits.

MOLECULAR SIMULATIONS

MD simulations were run to understand if the presence of H in the present range can cause embrittlement of the lattice.

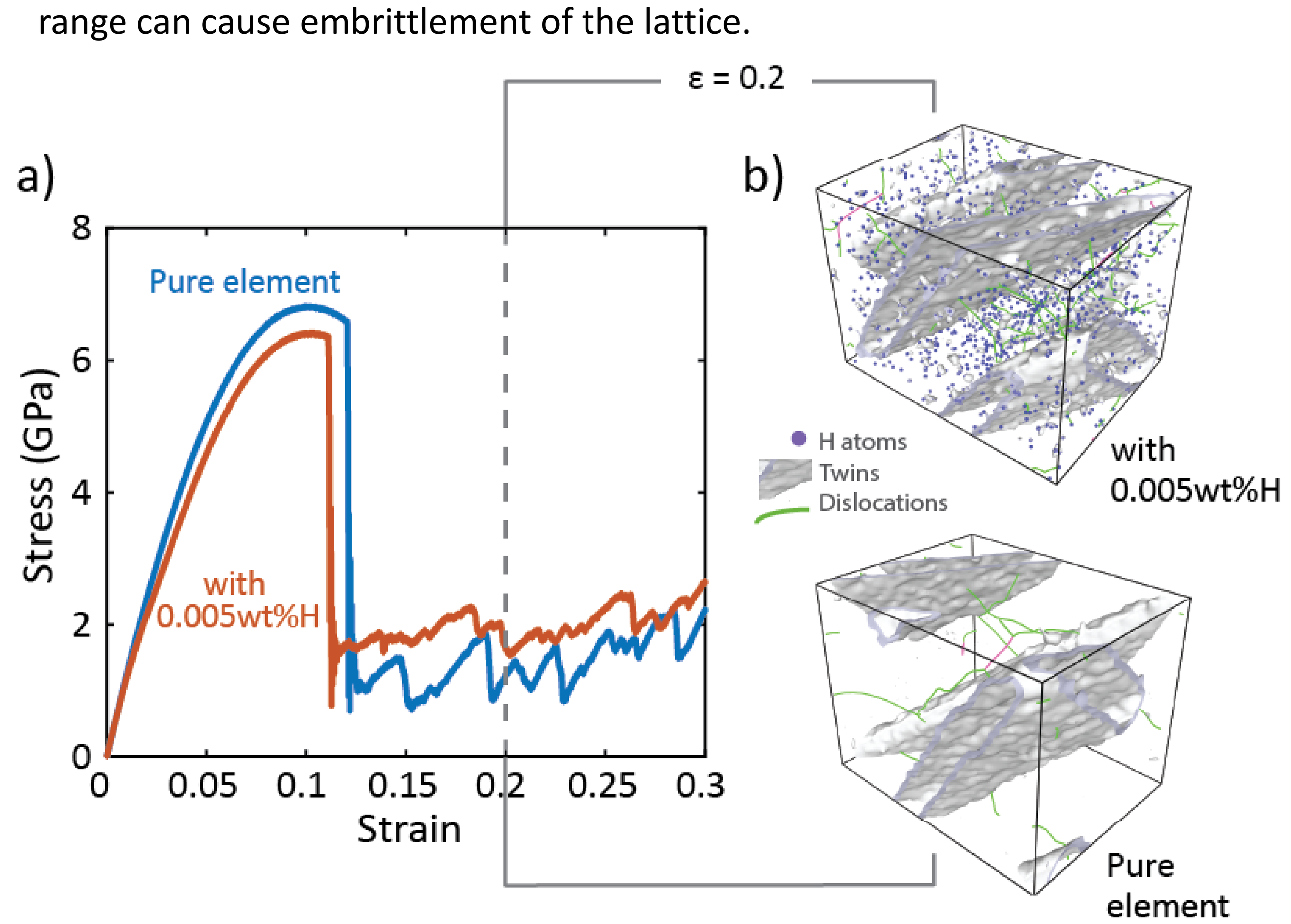


Fig. 2. (a) Stress-strain curve of uniaxial tensile loading of lattices along [1 0 0] direction obtained from MD simulations, and (b) snapshots of the evolution of deformation at a strain of 0.2. H atoms were randomly distributed in the T-sites, and simulations were done at a strain rate of 10^8 s^{-1}.

MICROSTRUCTURE

Elongated and fine grain structures were observed near the inter-splat boundaries. The grain structure coarsened traversing from the inter-splat boundary region to the interior domain of an impacting particle. Deposit 1 showed higher porosity, and larger regions with coarse grain structure compared to deposit 2.

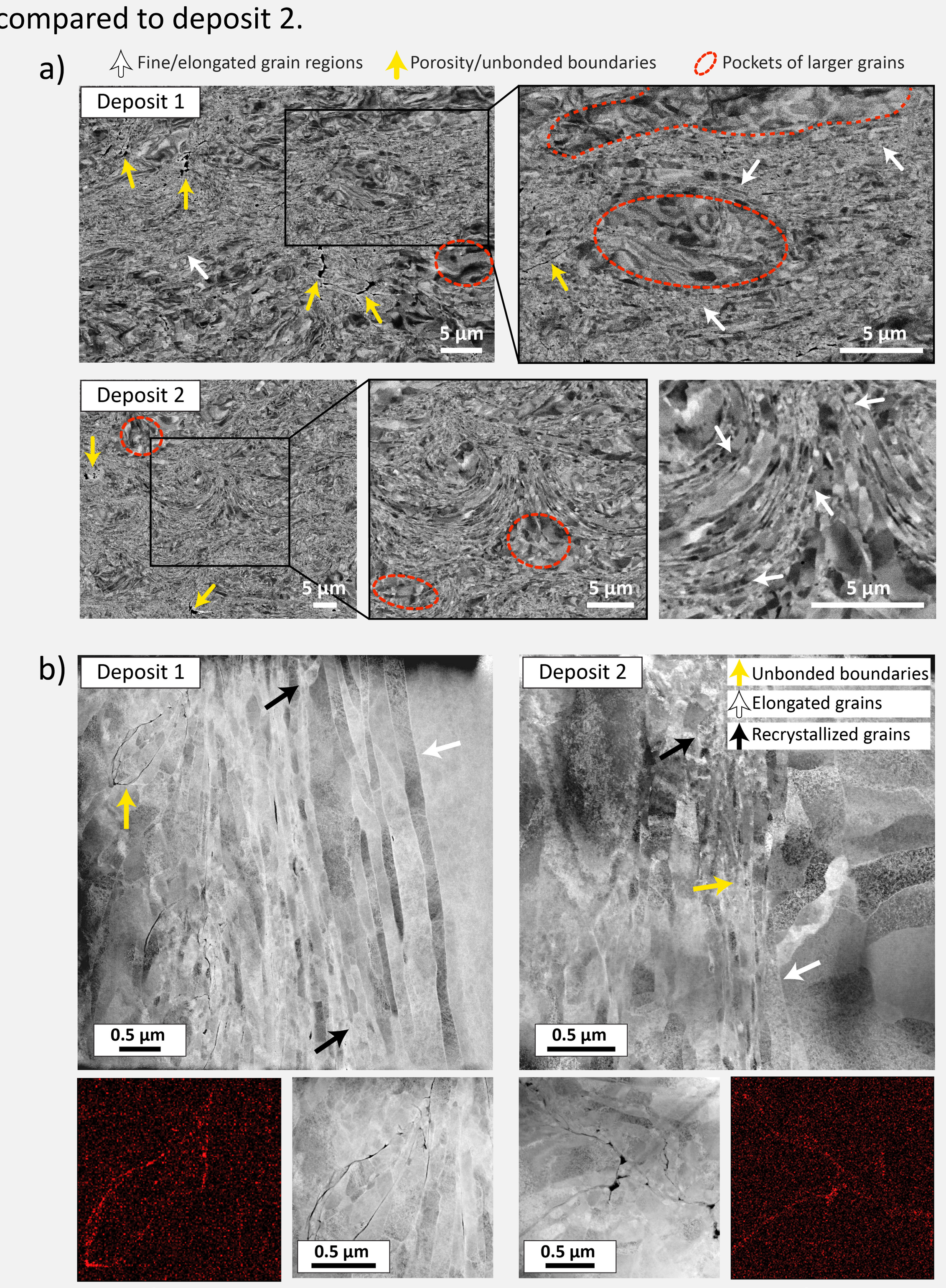


Fig. 3. (a) BSE micrographs of cross-sections of the deposits, (b) Microstructural features observed via DF-STEM in the inter-splat boundary regions, (c) High magnification DF-STEM images of unbonded areas with corresponding EDS maps showing segregation of oxygen to inter-splat boundaries.

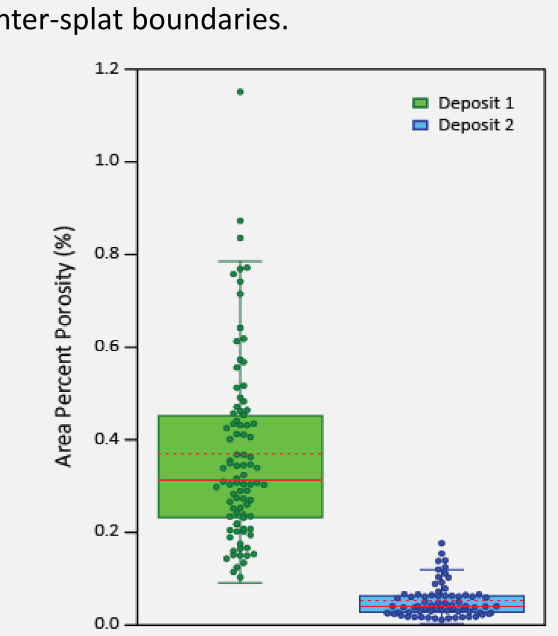


Fig. 4. Area percentage porosity of deposits. The solid red and dashed red horizontal lines inside the boxes show the median, and mean values, respectively. The upper and lower values of the boxes are the medians of the upper and lower halves of the data. Lower and upper whiskers represent the minimum and maximum values that are not outliers, with outliers indicated by the data points beyond the whiskers.

MECHANICAL TESTS

METHOD

Samples with aspect ratio of 2:1 were extracted from CS deposits via a focused ion beam (FIB) lathe milling procedure. Tests were done at a constant strain rate of 10^{-3} s^{-1}.

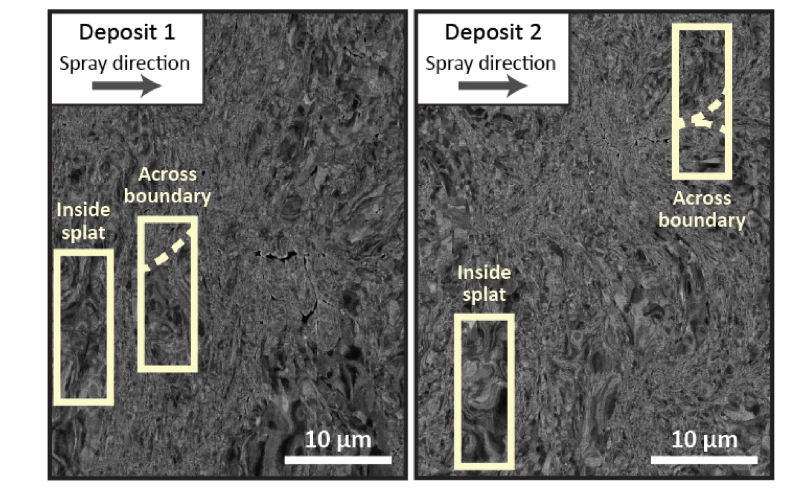


Fig. 5. Locations of interest for micromechanical tests.

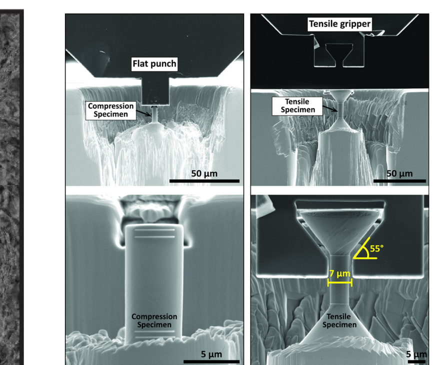


Fig. 6. SEM micrographs of the flat punch and gripper used for micro-mechanical tests.

RESULTS

- Both powders show similarly ductile behavior.
- Slip bands formed, and failures occurred along the inter-splat boundaries in deposit samples.
- Strength and ductility are dependent on the microstructure and the defect structure. Low ductility was observed in tensile samples with a crossing inter-splat boundary. Higher strength was seen where the grain structure was finer with a higher degree of deformation during the cold spray processing.
- Premature brittle failure was observed in the sample with a non-fully bonded inter-splat boundary going across the gauge.

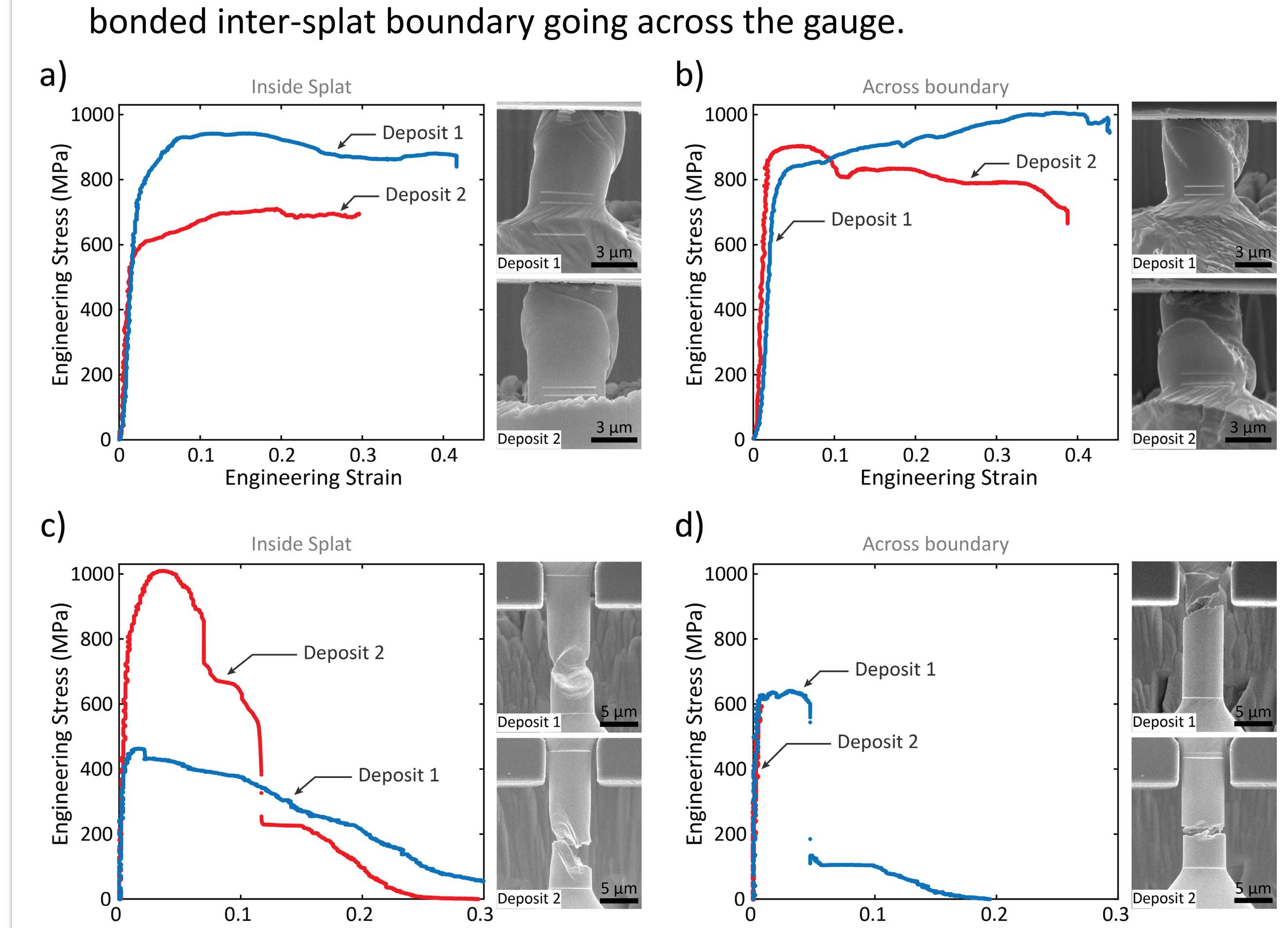


Fig. 7. Stress-strain curves for; (a) and (b) micro-compression, (c) and (d) micro-tension tests of the two deposits. SEM micrographs show the specimens at the end of the tests.

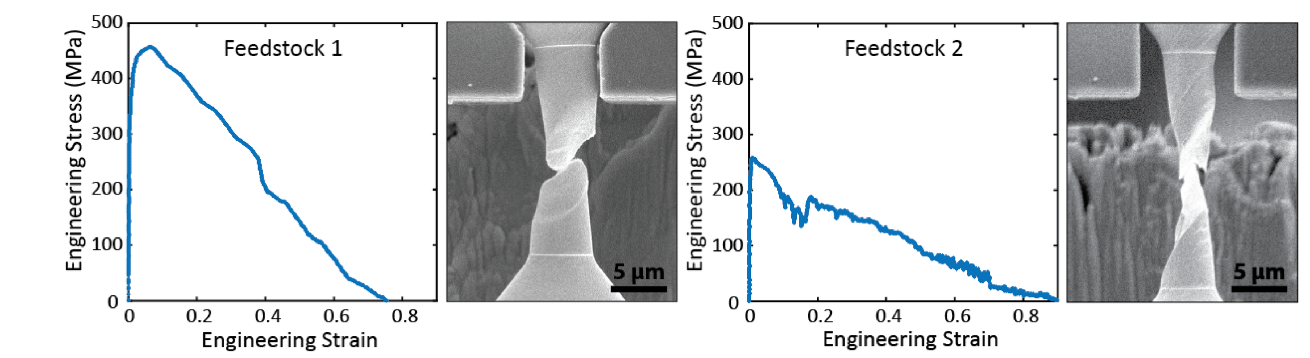


Fig. 8. Stress-strain curves from micro-tensile tests. SEM micrographs at the end of the test from individual feedstock powder particles are also shown.

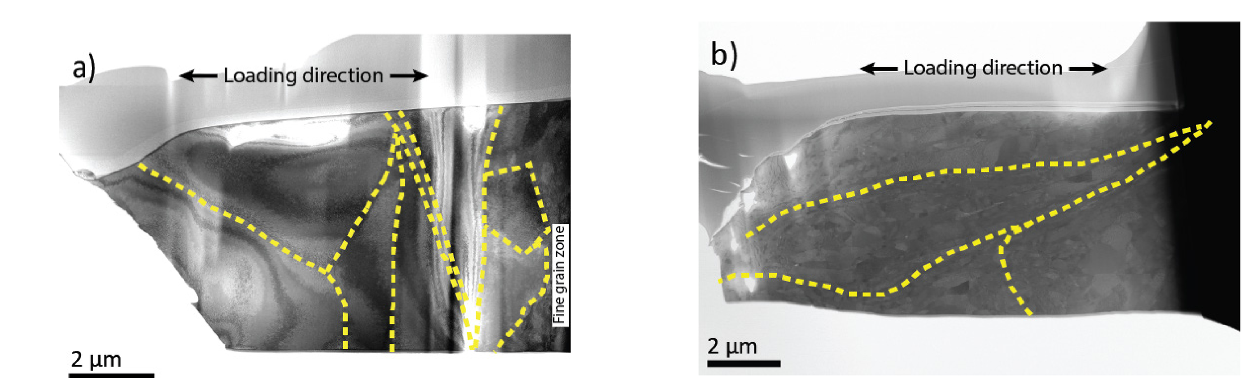
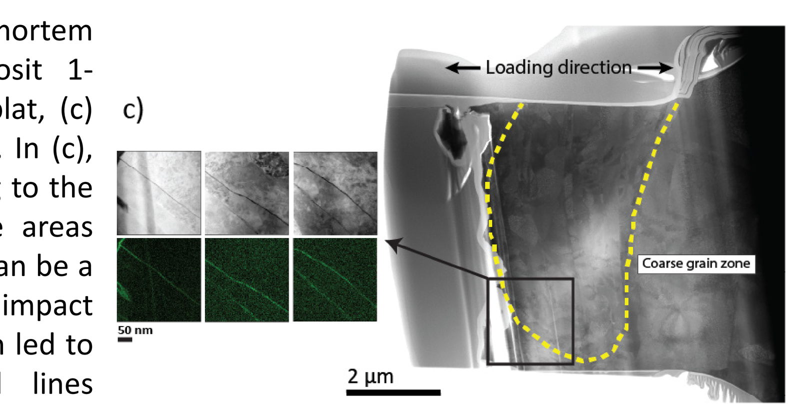


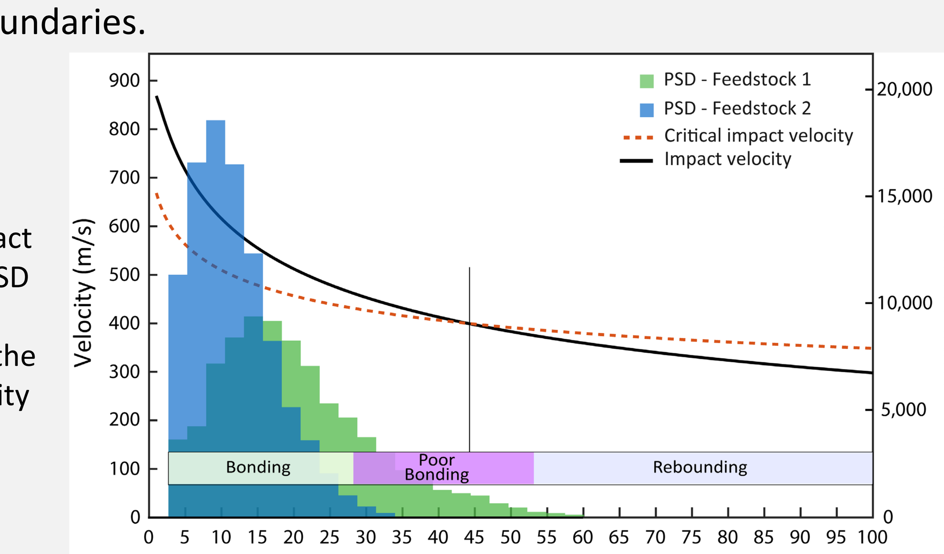
Fig. 9. STEM micrographs of post-mortem micro-tensile specimens: (a) deposit 1-inside splat, (b) deposit 2-inside splat, (c) deposit 2-with inter-splat boundary. In (c), EDS maps of some openings leading to the fracture surface are shown. These areas show segregation of oxygen which can be a sign of an unbroken oxide upon impact during the cold spray process, which led to an unbonded boundary. Dashed lines represent inter-splat boundaries.



CONCLUSION

Particle size distribution of the feedstock powder is the defining factor in the formation of defect networks and determination of mechanical behavior of refractory element CS deposits. Larger particles are accelerated below the critical impact velocity, resulting in imperfect metallurgical bonding and higher porosity at the inter-splat boundaries.

Fig. 10. Effect of the particle size and distribution on the impact velocity and bonding. PSD for feedstock 1 and feedstock 2 along with the calculated impact velocity curves, and highlighted ranges for bonding and rebounding are shown.



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