Beyond Nickel-Based Superalloys II   Proceedings

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Towards nanoindentation at application-relevant temperatures – A study on CMSX-4 alloy and amdry-386 bond coat

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Towards Indentation at Operational Temperatures

A Study on CMSX-4 and Amdry-386 Bond Coat

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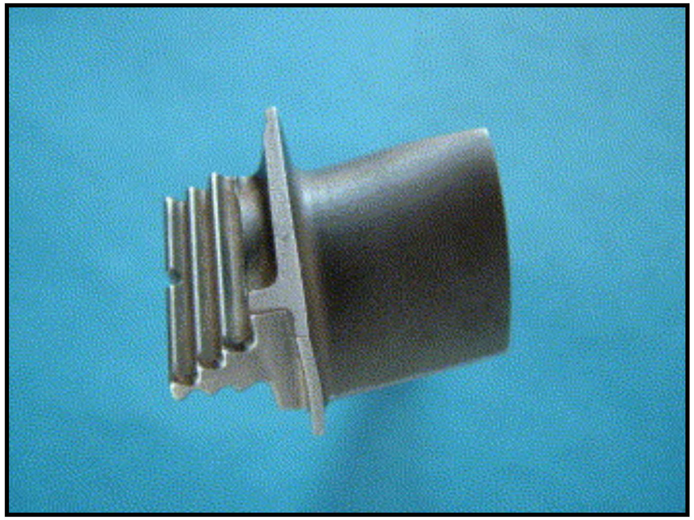
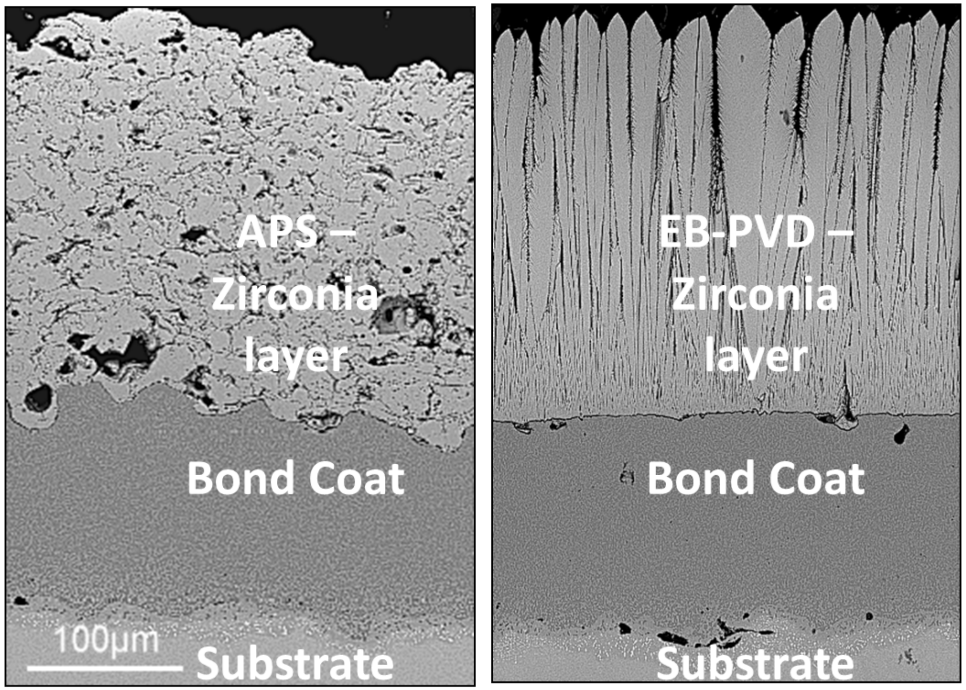


Carter, http://dx.doi.org/10.1016/j.engfailanal.2004.07.004

Motivation



Galetz1, http://dx.doi.org/10.5772/61141

Investigate MCrAlY bond coats

- Typically ~300µm thick layers
- Used for oxidation/corrosion resistance
- Some recent research for turbine sealing to increase efficiency and for blade repair

Use CMSX-4 as reference

- Well-studied deformation mechanisms

Hit 1000˚C

- Demonstrate applicability of nanoindentation near turbine operating temperatures

Experimental Details

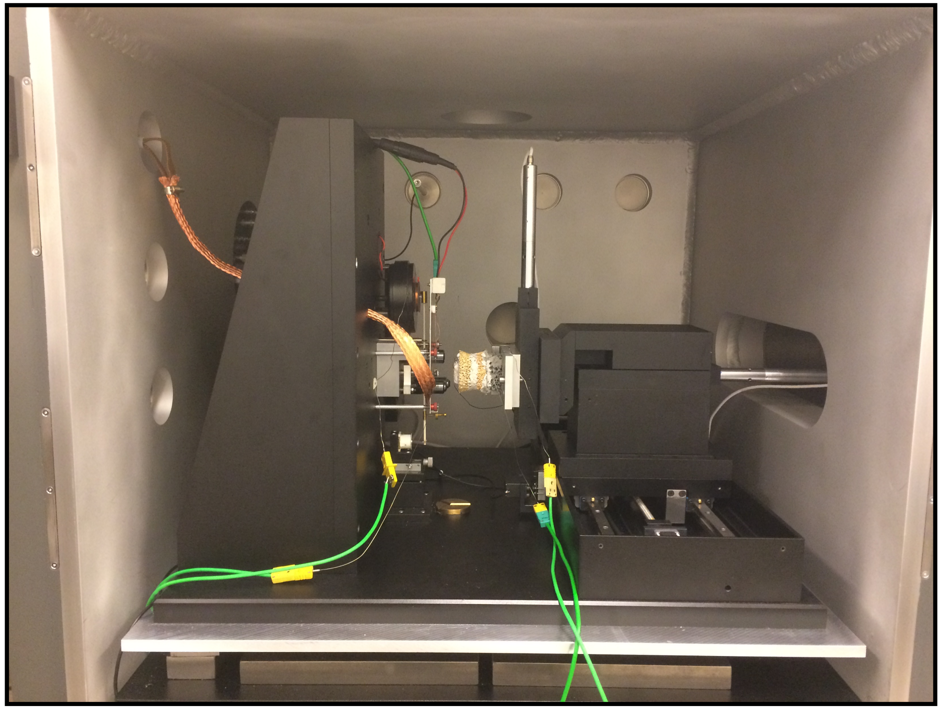
CMSX-4 single crystal [100] orientation

(Ni-9Co-6.5Cr-6.5Ta-6W-5.6Al-1Ti-0.6Mo-3Re-0.1Hf)

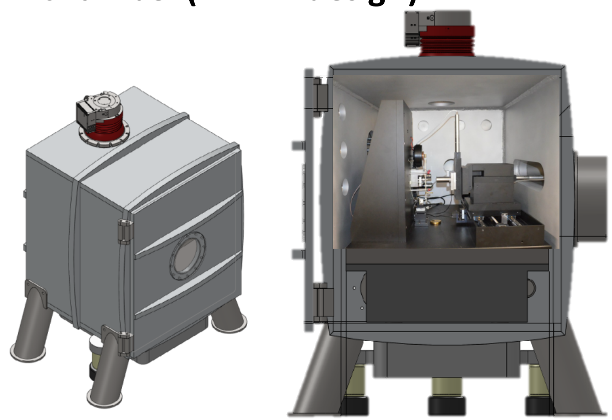
Amdry 386 Bondcoat (Ni-Co-Cr-Al-Y)

YSZ Topcoat

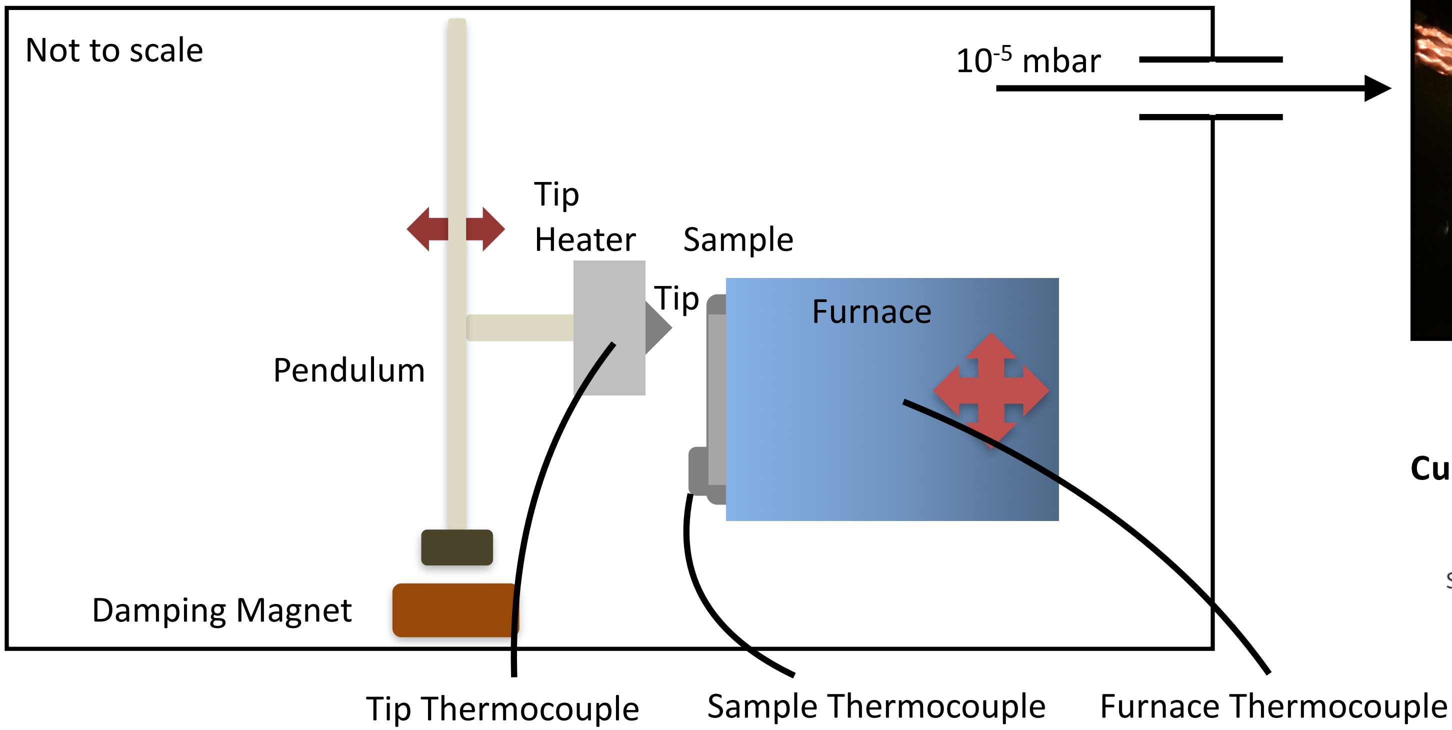
Supplied by R. Vaßen,FZJ

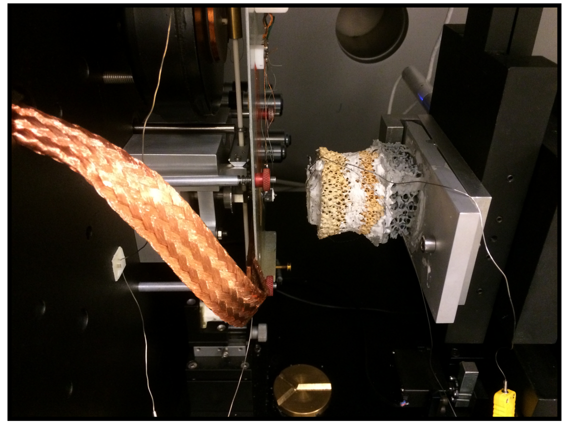


Vacuum chamber (RWTH-design)



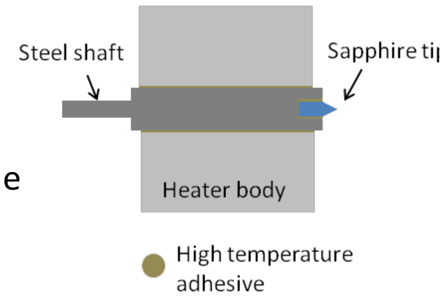
Experimental Details



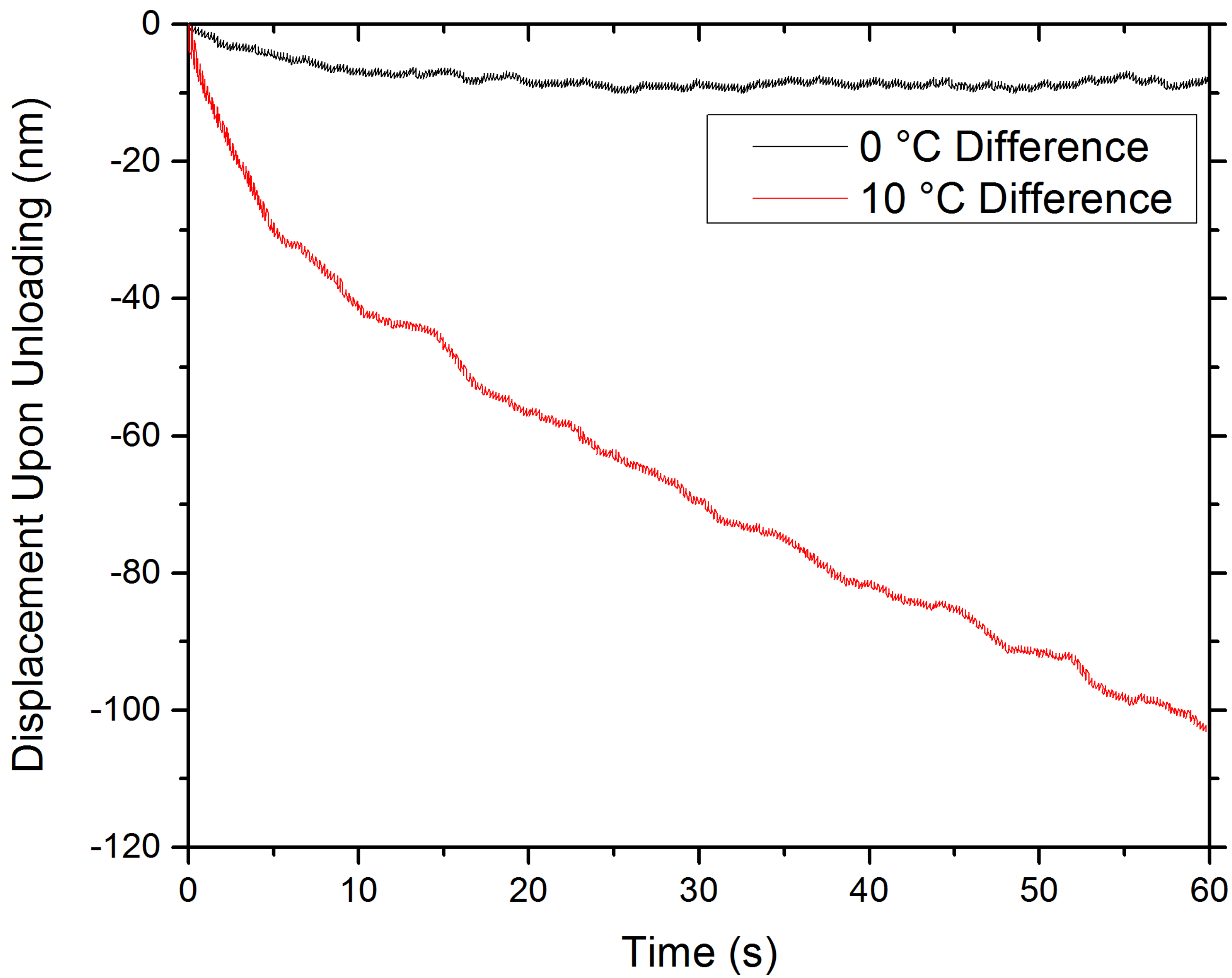


Custom-built compression tip

(with Synton-MDP, CH)



Problems: Thermal Drift

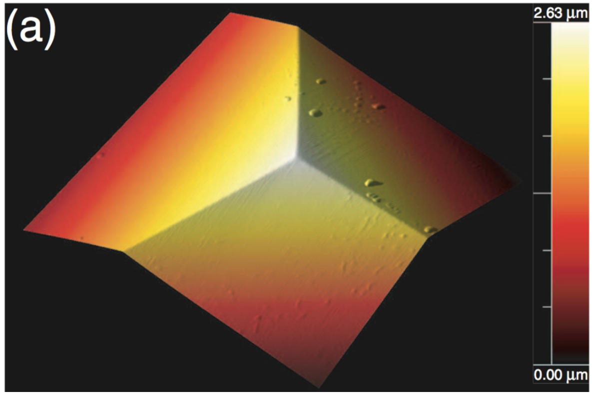


Thermocouples not positioned exactly at tip-sample interface

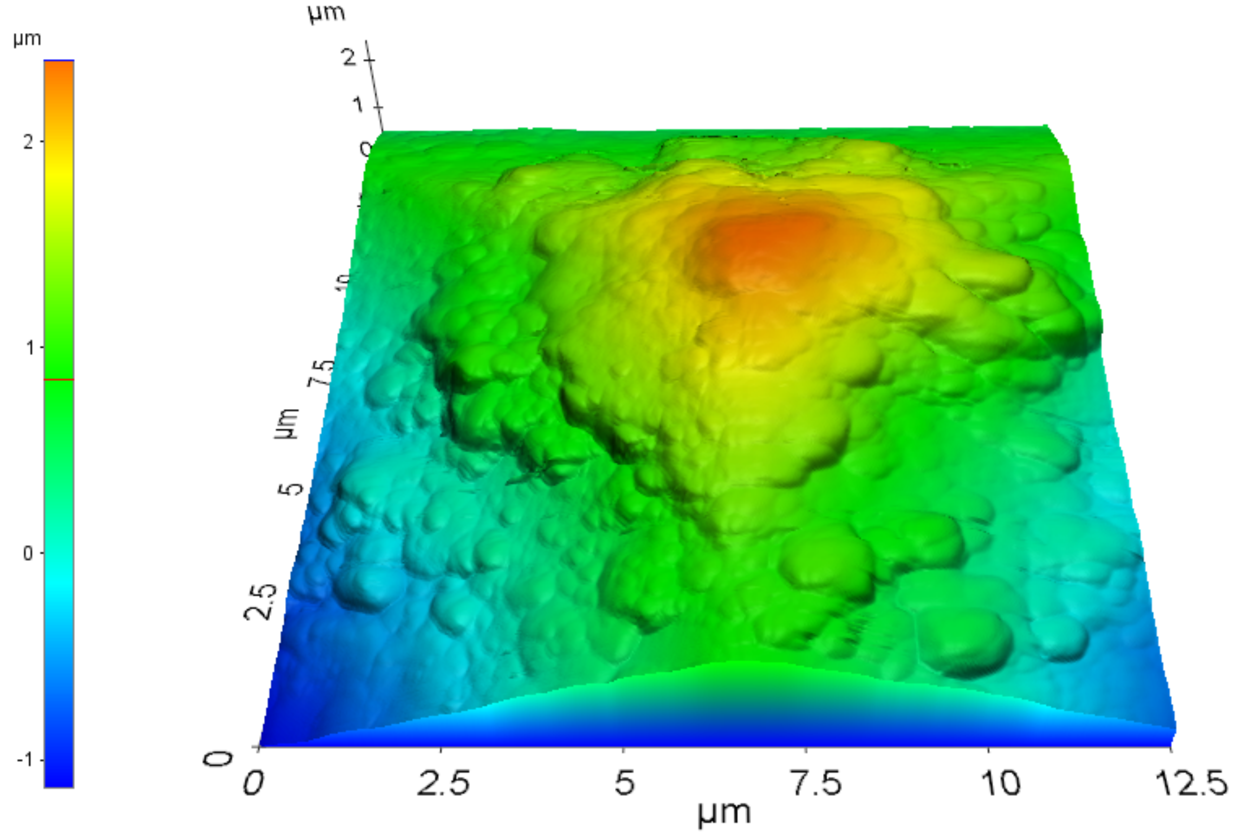
Therefore, `tuning' of the contact temperatures is required

Poorly-optimised thermal contact leads to high levels of thermal drift and unreliable data

Problems: Tip Wear



Wheeler, http://dx.doi.org/10.1063/1.4824710



AFM scan of sapphire tip after indentation at 1000˚C

Huge amount of deposition / chemical reaction

Limits the number of tests that can be performed

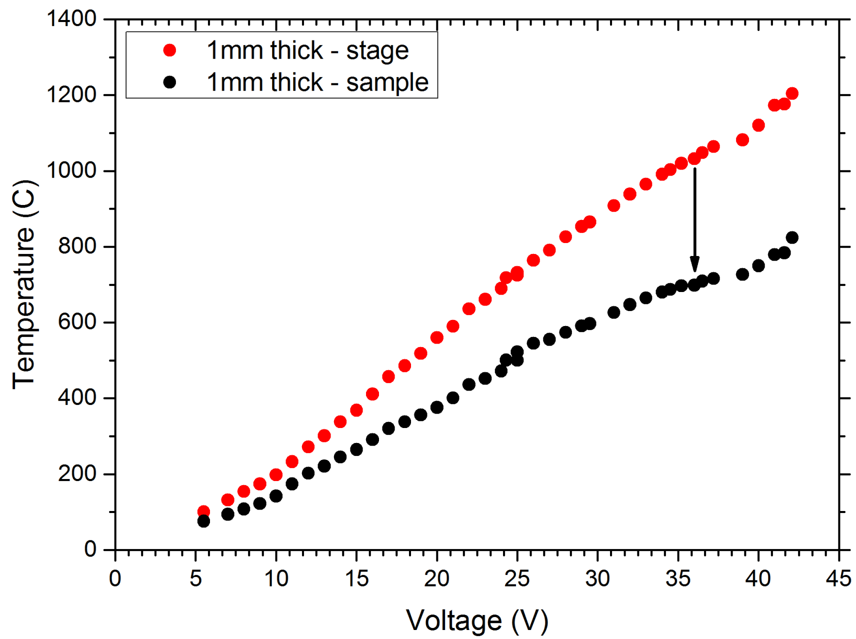
Problems: Temperature

	Thermal Conductivity (W/m.K)
Cu	400
Al	200
Mg	160
CMSX-4	9

Sample Thickness for 400˚C:

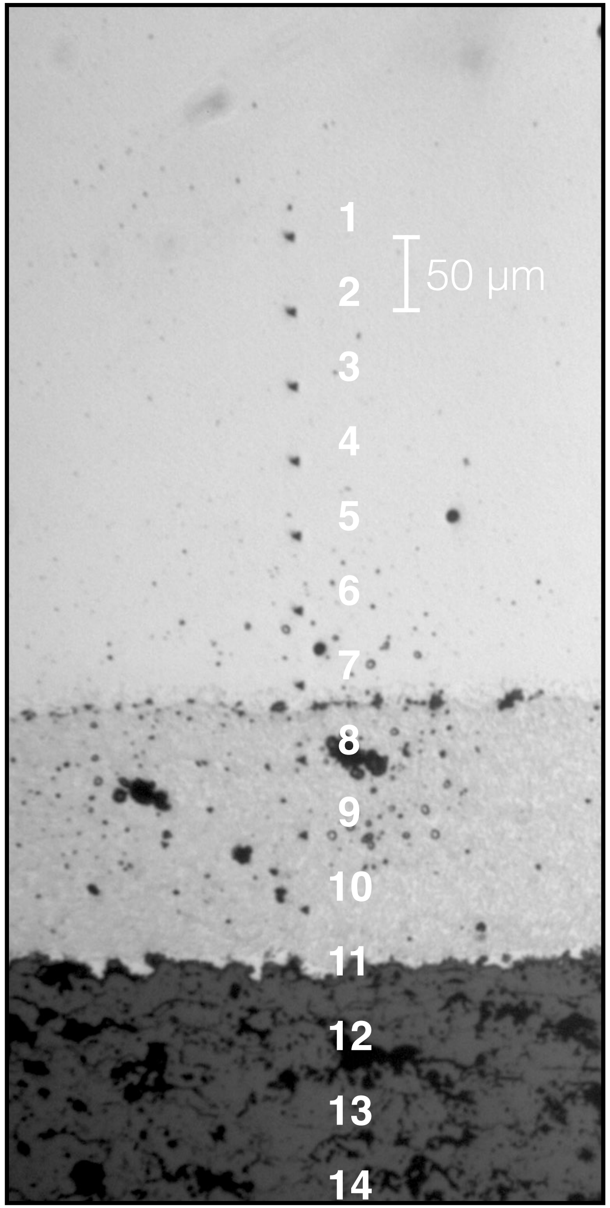
3 mm: T_{stage} = 710˚C

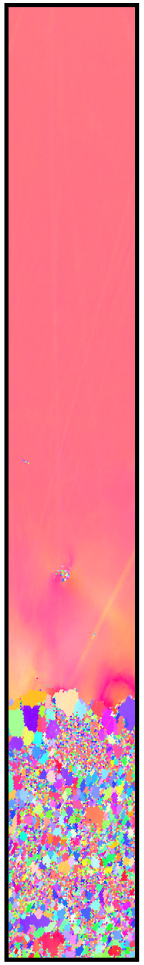
1 mm: T_{stage} = 590˚C



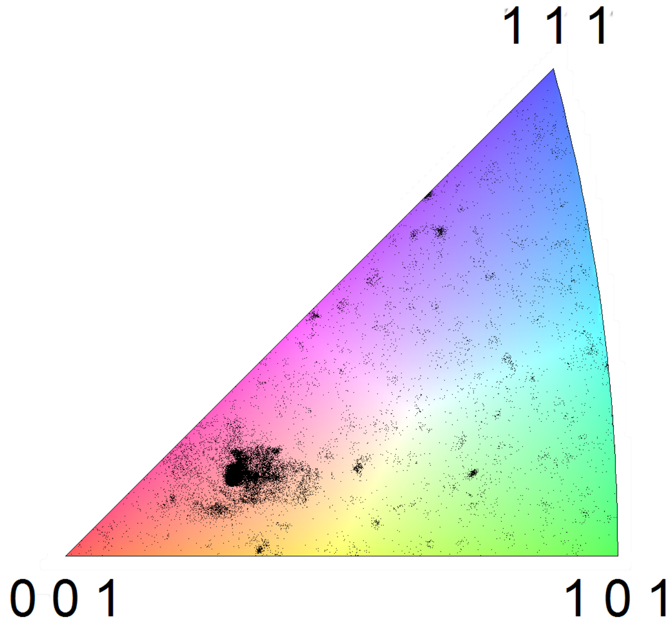
Low thermal conductivity of CMSX-4 means samples must be made extremely thin (~250 µm) for 1000˚C indentation

Results: Initial Tests





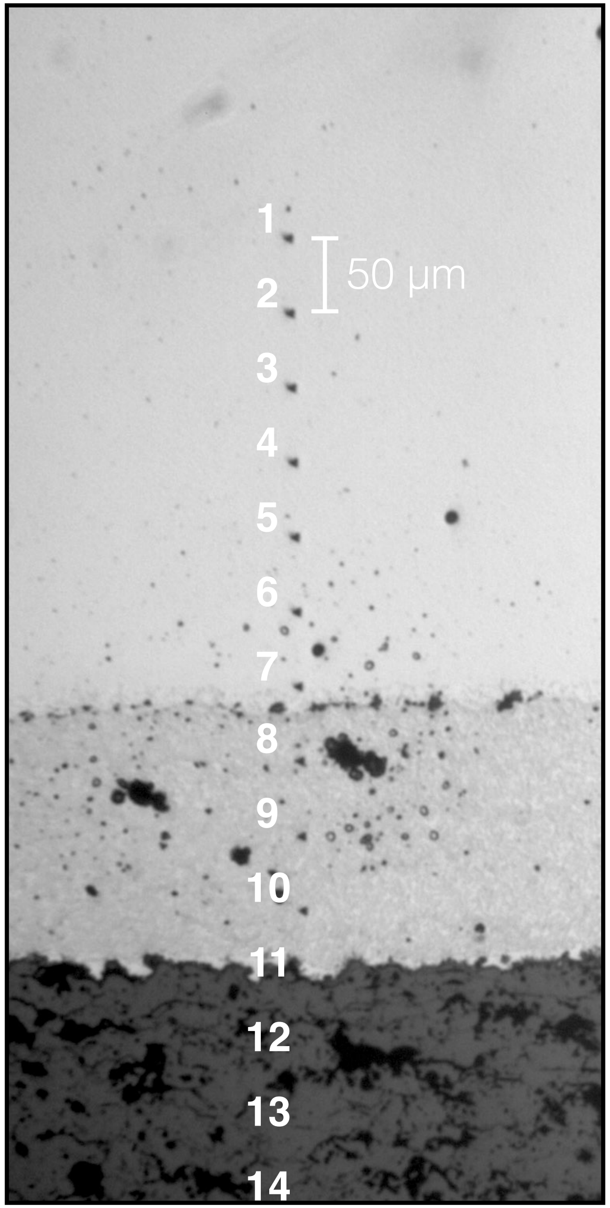
[001]

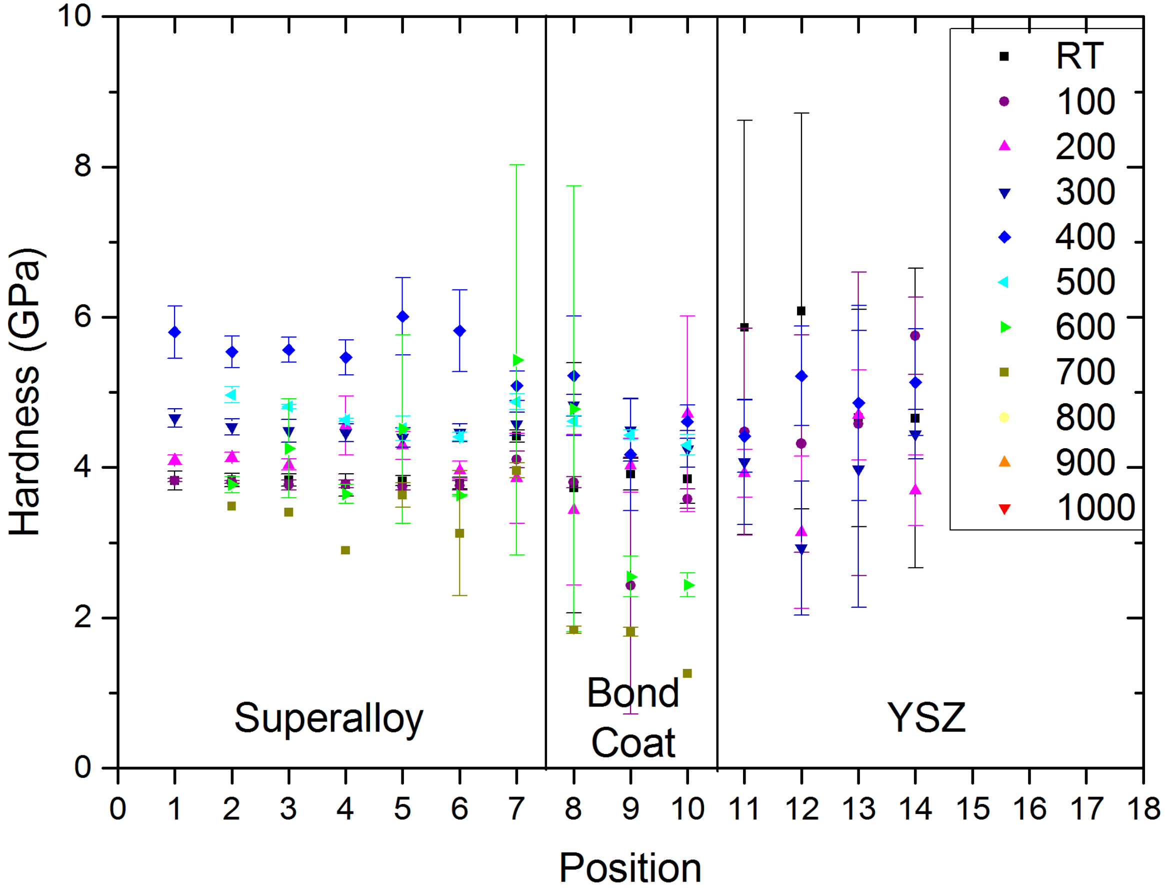


EBSD shows CMSX-4 close to [001]

Amdry-386 consists of fine, equiaxed grains with no overall texture

Results: Initial Tests



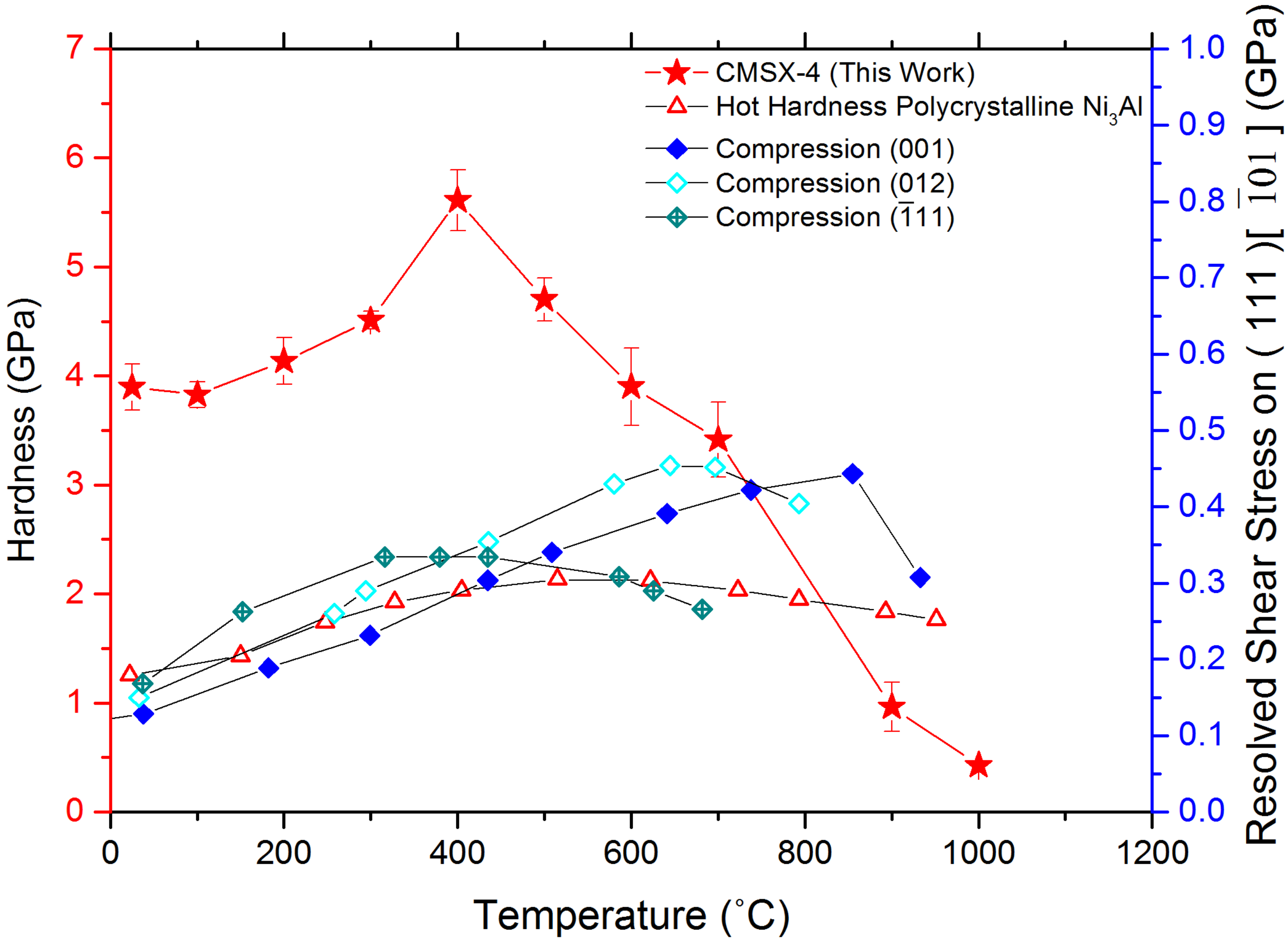


1µm indent depth, 2mN/s load, 30s hold, 5mN/s unload

First tests showed no variation with position

Porosity of TBC makes testing unrepresentative

Results: CMSX-4

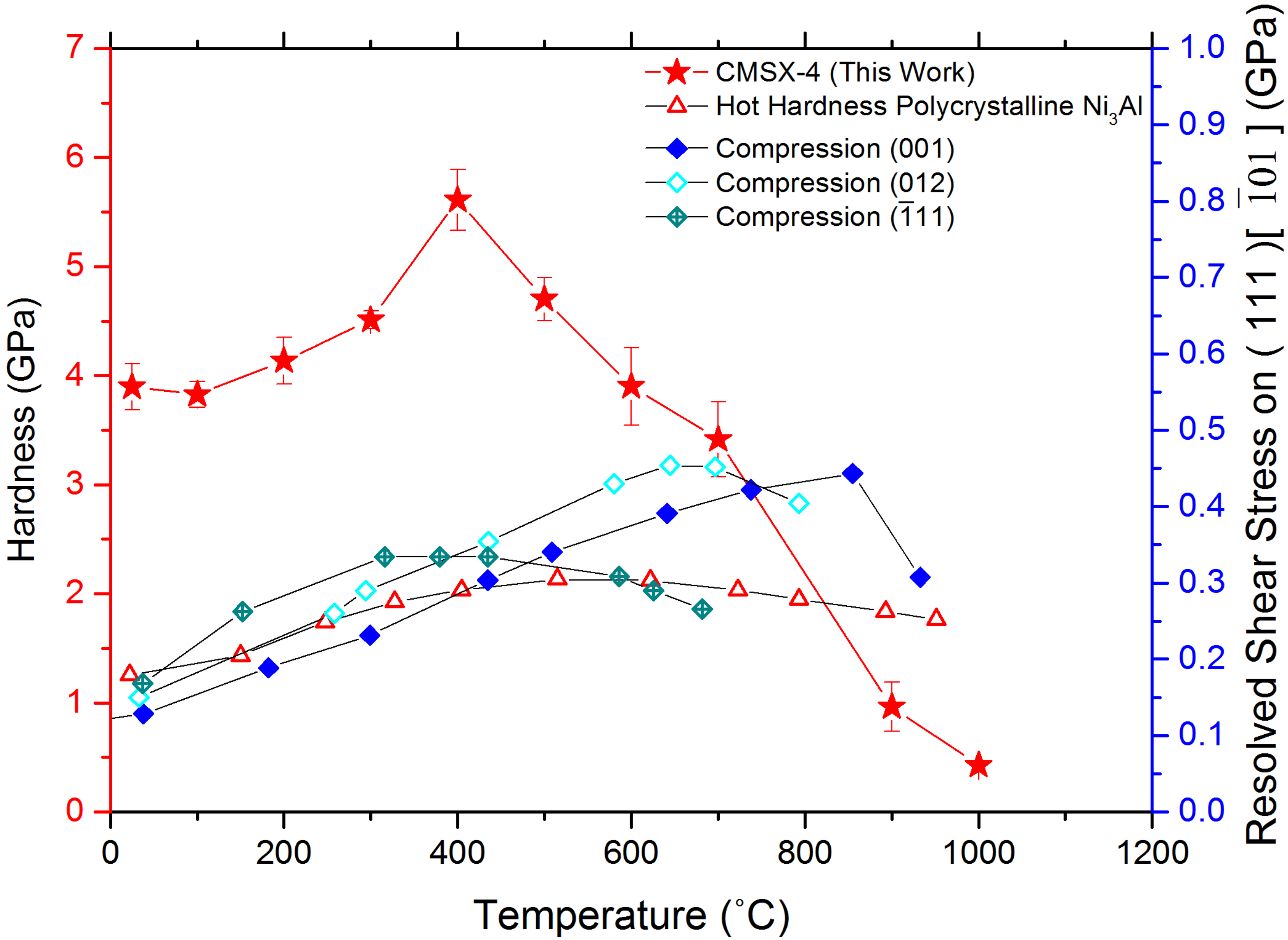


<400˚C - Pre-Peak

High strains and complex stress state under a Berkovich indenter activates many slip systems

We observe a comparable peak hardness temperature to macro-indentation and $(\bar{1}11)$ tensile data

Results: CMSX-4



>400˚C - Post-Peak

We observe a rapid drop-off in hardness. In tensile-testing, this is attributed to free cross-slip of dislocations

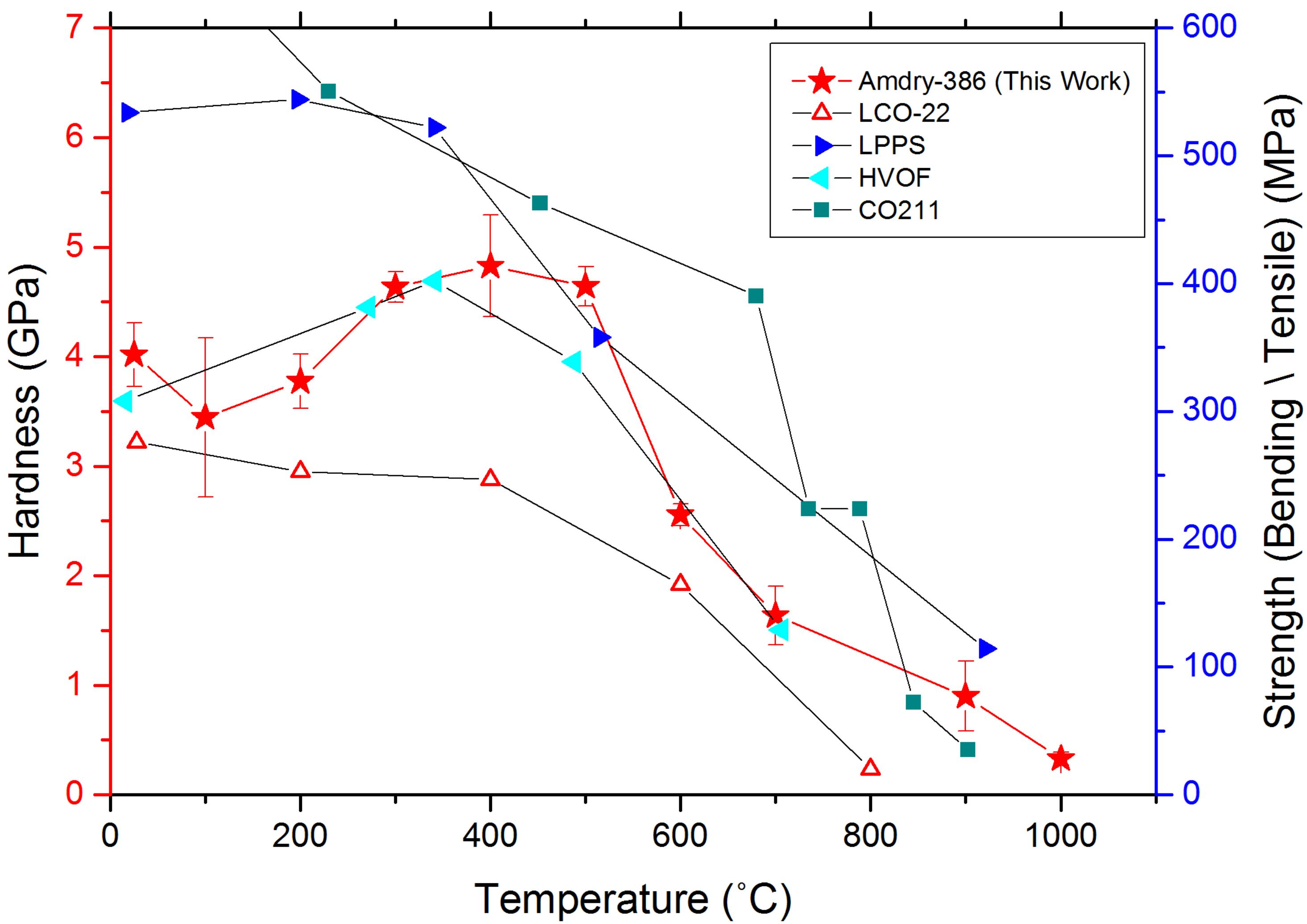
Enthalpy of super-dislocation unlocking:

$$H_u = {}^0H_u - \sigma V^*$$

Hirsch, http://dx.doi.org/10.1080/01418619208201539

High stresses in nanoindentation drive cross-slip, so the influence of other orientations is not seen

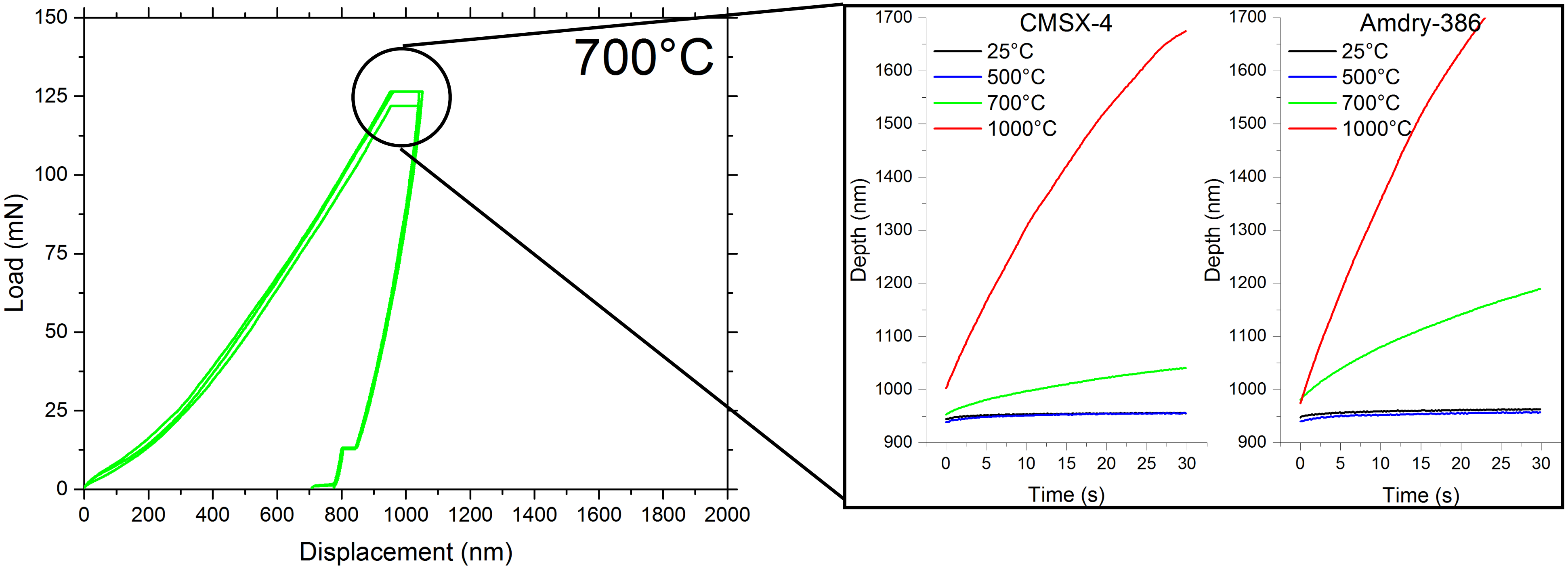
Results: Amdry-386



Bond Coat Data

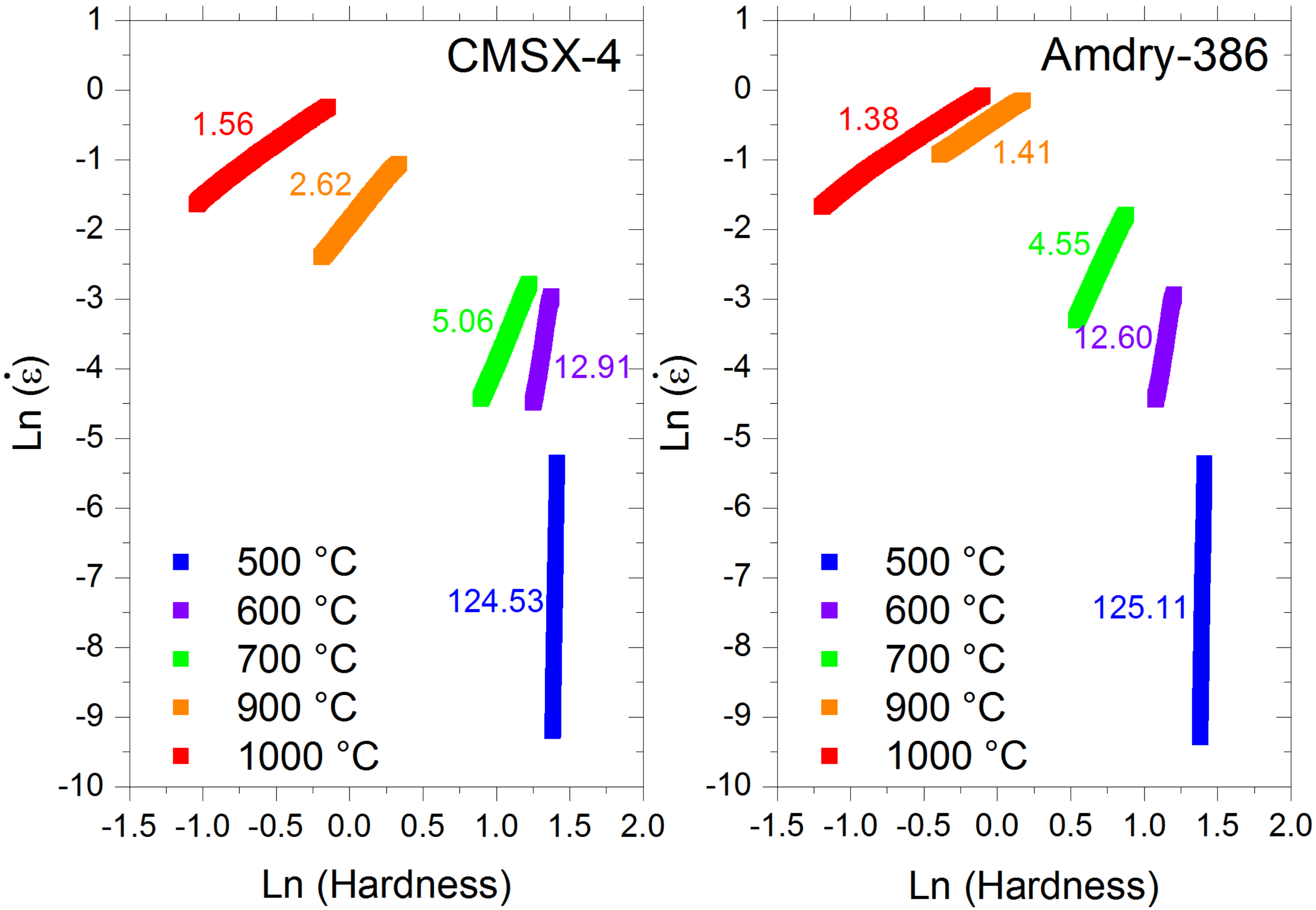
- Little literature data with which to compare
- Both literature hardness (LCO-22) and bending strength (LPPS\HVOF) drop off at 400-500˚C
- HVOF-sprayed CoNiCrAlY shows increasing strength with temperature

Results: Creep



30 second dwell period at peak load extracted to determine creep parameters

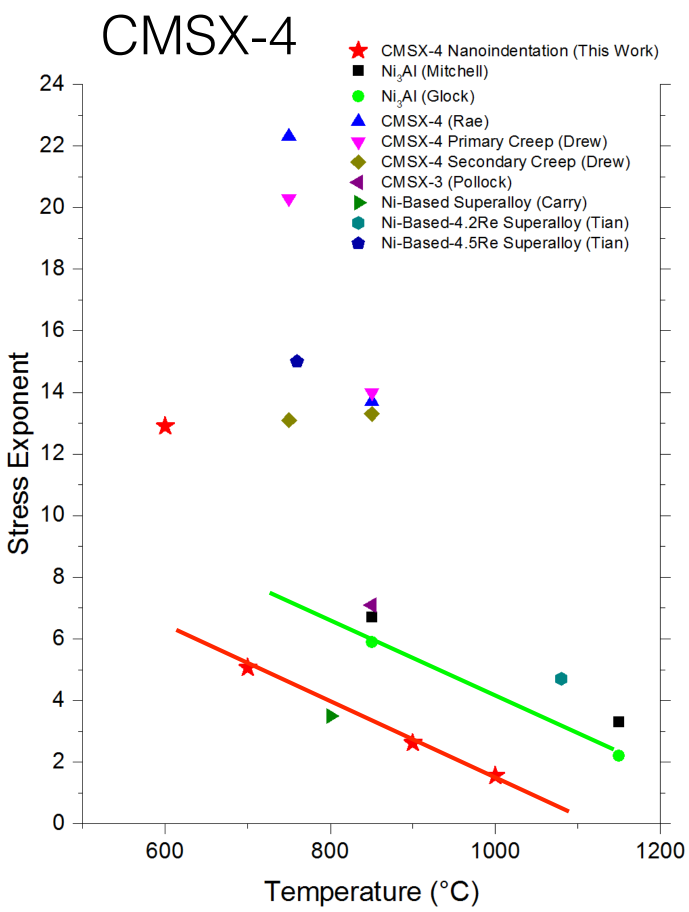
Results: Creep Exponent

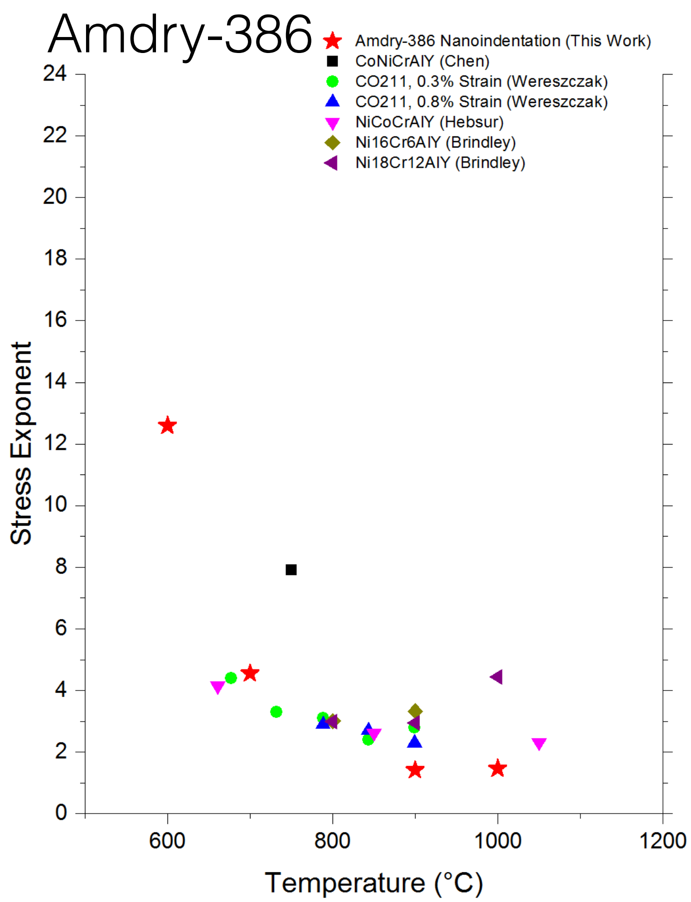


Creep strain rate

$$\dot{\epsilon} = A\sigma^n$$

Results: Creep Exponent





CMSX-4 creep exponents slightly different in magnitude, but temperature-dependence is well captured
All literature data is from tensile testing - again likely that the high stresses, strains and complex stress state affecting data

Extremely close match in Amdry-386 in both magnitude and temperature-dependence

Summary & Future Work

- CMSX-4 and an Amdry-386 bond coat were tested up to 1000˚C
- In CMSX-4, the peak hardness is at 400˚C, in contrast to uniaxial tests peaking at 800˚C. This is likely due to the complex stress state and work hardening in nanoindentation. In creep tests, the same variation in *n* with temperature is seen.
- In the MCrAlY bond coat, the measured data matches well to the limited literature data in both hardness and stress exponent.
- This suggests high-temperature nanoindentation may be a powerful tool to characterise these coatings and provide valuable inputs for material, model and process optimisations.

Future Work:

1. More bond coats
2. Longer creep tests
3. Maybe superalloy replacements, depending on anisotropy of deformation

Thank you for your attention