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The Mechanisms of Ductile Fracture

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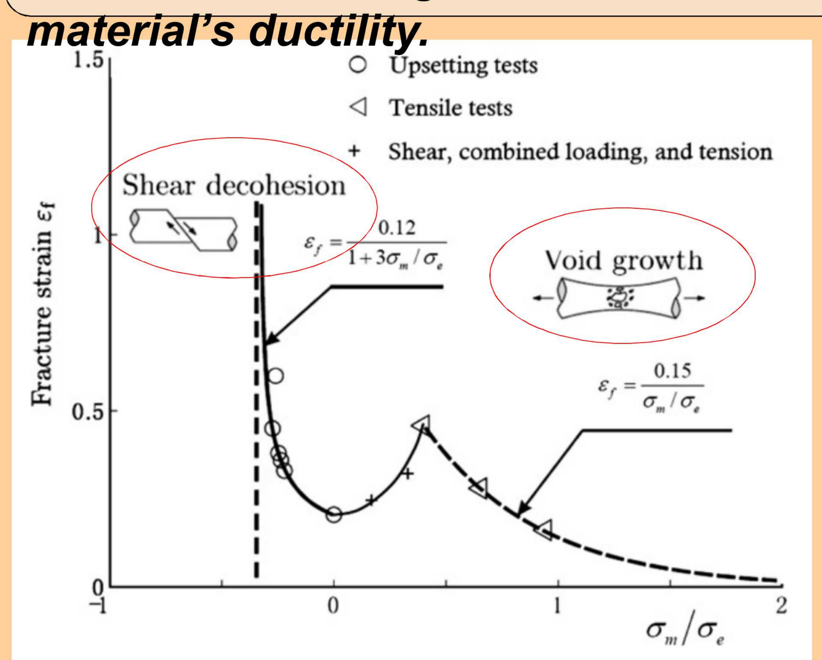
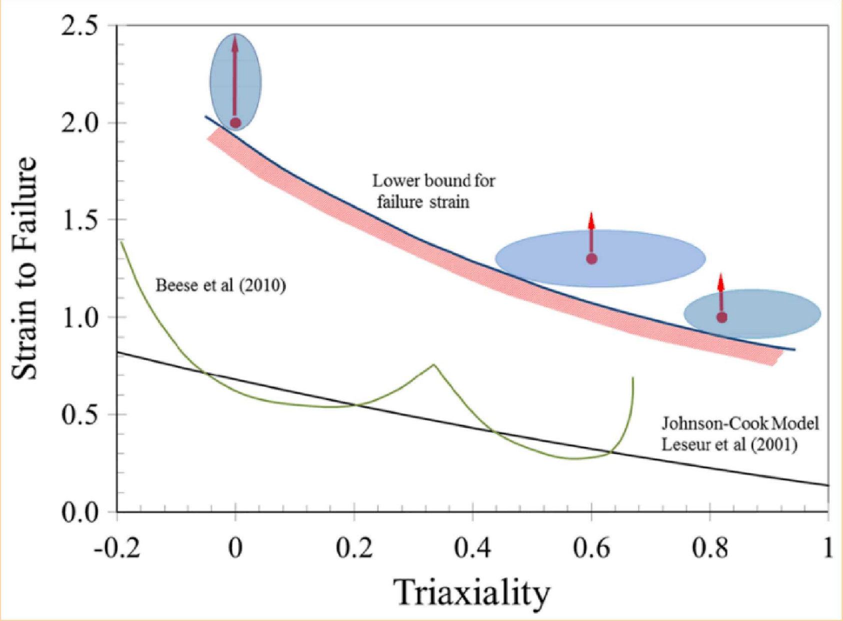
The relationship between stress state and ductility

Current models of ductile fracture assume that ductility depends on stress state. The two rupture mechanisms that are generally considered are void nucleation, growth, and coalescence (for tensile-dominated loading), and shear-localization and void coalescence (for shear-dominated loading). Current constitutive models have thus focused on predicting the competition between these mechanisms based on the stress state and the material's strain-hardening capacity. ***However, there is now strong evidence that stress-state alone does not determine a material's ductility.***



Nahshon, J., and Hutchinson. *Europe. J. Mech A/Solids*, 2008



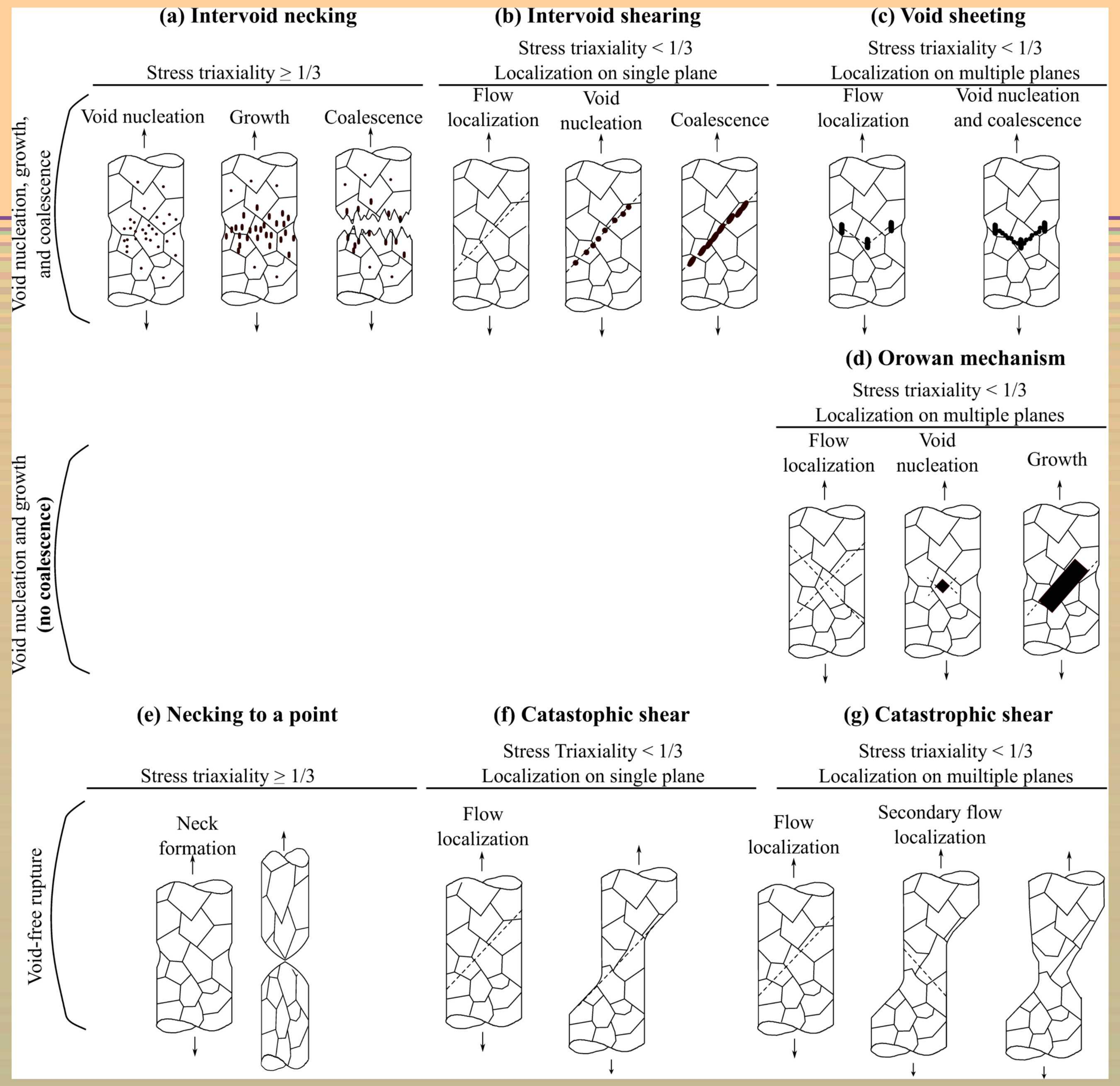
Ghahremaninezhad.A., and K. Ravi-Chandar., Int. J. Frac., 2013

Hypothesis

Departing from nearly all prior studies of ductile fracture, in the present study we propose that:

1. As many as seven different mechanisms can control fracture, and that
2. These mechanisms are not necessarily independent or exclusive, but can work in sequence during the rupture process.

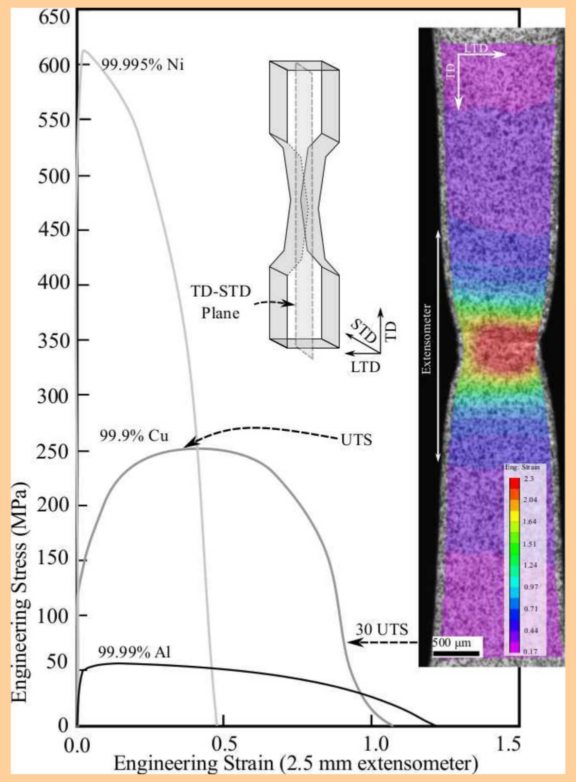
A postulated taxonomy of failure mechanisms



At least seven different failure mechanisms have been observed in different materials. However, all but intervoid necking and intervoid shearing have largely been ignored. Thus, there is no understanding of:

1. ***How these mechanisms interact with one another, and***
2. ***The microstructural features and selection***

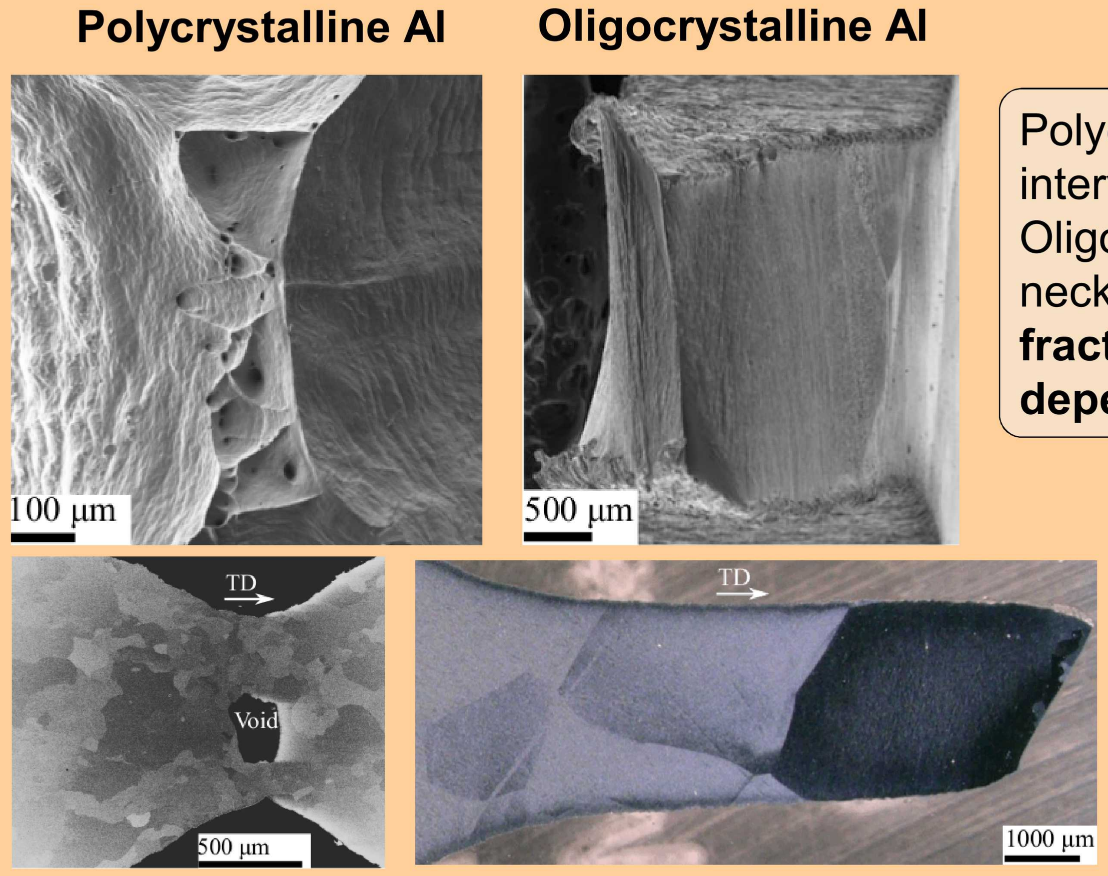
Methods: interrupted tensile tests of three high-purity FCC metals



The fracture process was examined in high-purity aluminum (Al), copper (Cu), and nickel (Ni)

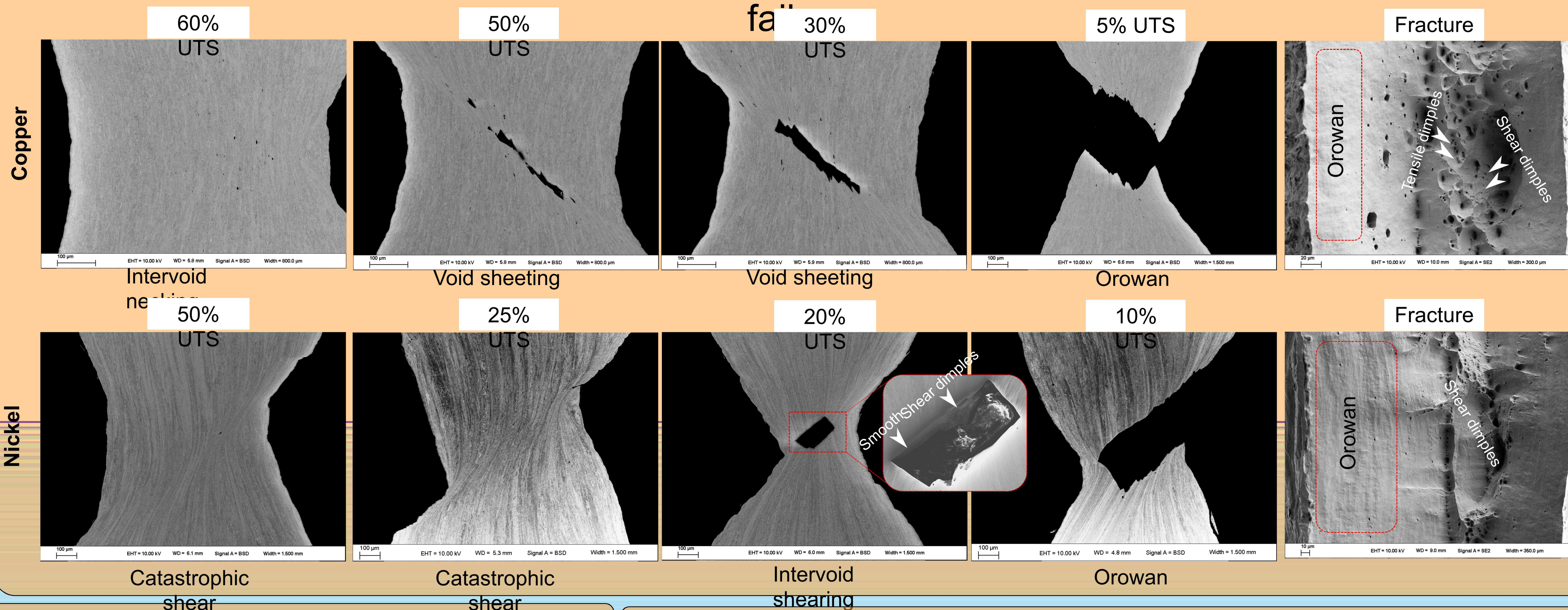
Damage accumulation was characterized by interrupting tensile tests of different specimens of each material at predetermined percentages of the UTS. Specimens were subsequently ground and polished to the midplane to characterize the progression of damage

Aluminum: mechanism depends on grain size

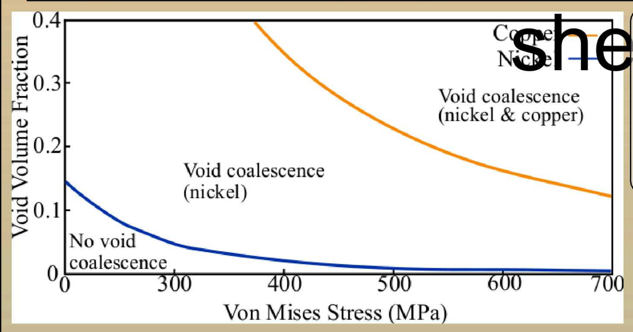


Polycrystalline Al failed by intervoid necking while Oligocrystalline Al failed by necking ot a point. **The fracture mechanism in Al depended on grain size.**

Copper and Nickel: a series of mechanisms worked together in a stepwise manner to cause failure



Intervoid shearing *vs.* Void sheeting



Is coalescence nucleation limited (intervoid shearing) or growth limited (void shearing)? This competition is controlled by the material's strain hardening capacity

$$m\left(\frac{A}{\bar{\sigma}}\right)^{1/m} = VN_v$$

Teirlinck, D., *et al. Acta Metallurgica* (1988)

VN_v: *void volume fraction*
m, A: strain-hardening constants
$\bar{\sigma}$: von Mises stress

Conclusions

- We generally think of fracture as being controlled by exclusively one mechanism and that the dominant mechanism depends on the stress state. The reality is that fracture is more of a relay race. Multiple mechanisms can combine in a stepwise manner to cause failure.
- The competition between these mechanisms depends on the distribution of void nucleation sites and the material's strain-hardening capacity
- **Accurate fracture predictions must capture the complex interplay between different fracture mechanisms, material properties, and the microstructure.**

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