A Microstructural Mechanism for Low-cycle Fatigue in Nickel-Titanium Shape Memory Alloys

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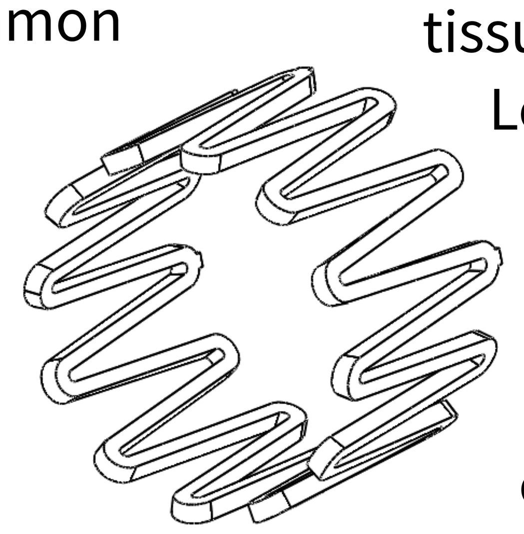
Highlights

- Low-cycle fatigue life in NiTi is inversely proportional to the martensite front motion and the number of impurity inclusions.
- The motion of martensite leads to transformation-induced slip and is deleterious.
- Inclusions provide sites for locally elevated stress.
- Based on this microstructural mechanism, we provide a phenomenological function to determine the fatigue life based on the phase transformation volume amplitude and inclusion density.

Significance of Fatigue in NiTi

NiTi = common material for implants (stents and heart valve frames).



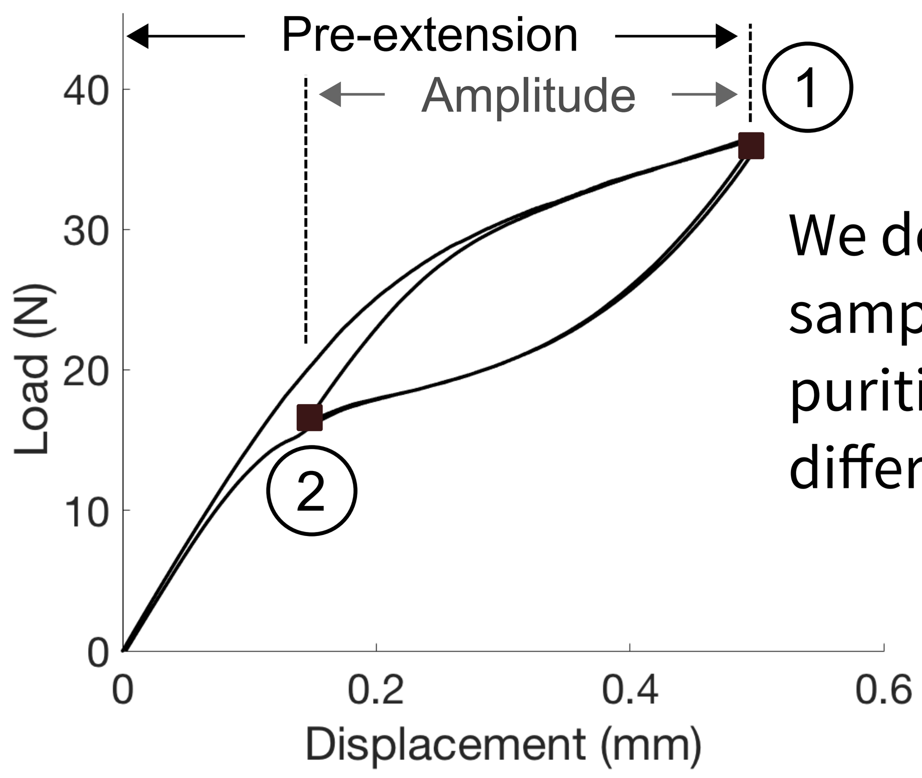
Smaller implant profile = less tissue trauma = better. Long fatigue life = even better!

Thus, it is crucial to develop new NiTi materials with lower impurity content and to better understand the mechanisms of fatigue.

Objective and Experimental Methodology

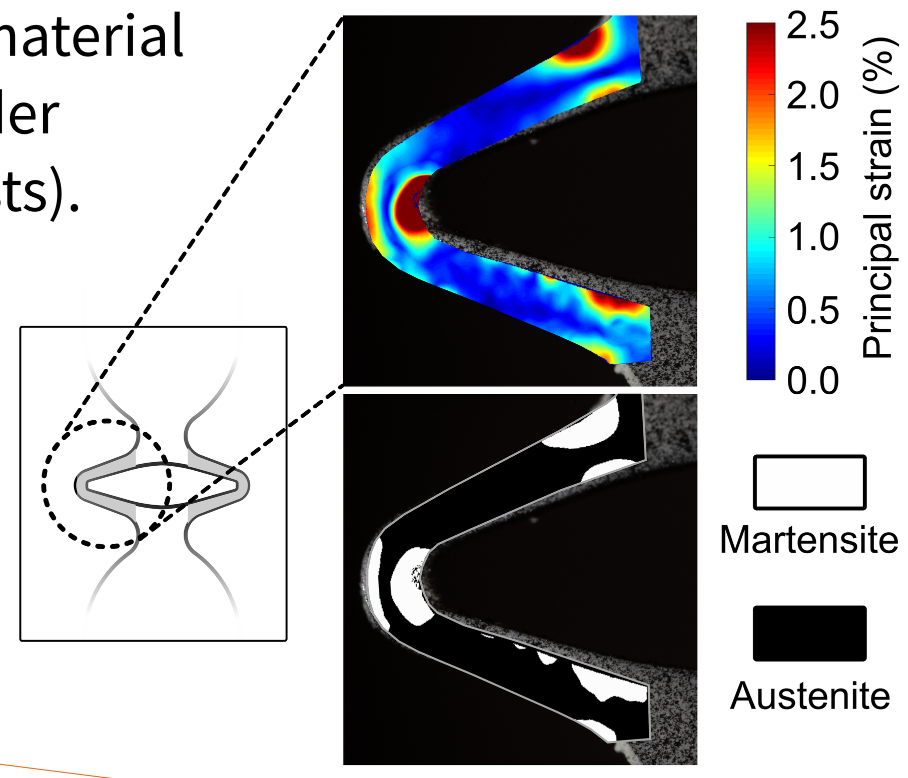
We set to prove two hypotheses

- Larger motion of martensite fronts = shorter low-cycle fatigue life in superelastically loaded NiTi.
- Transformation fronts interaction with larger/ numerous inclusions = shorter fatigue life.

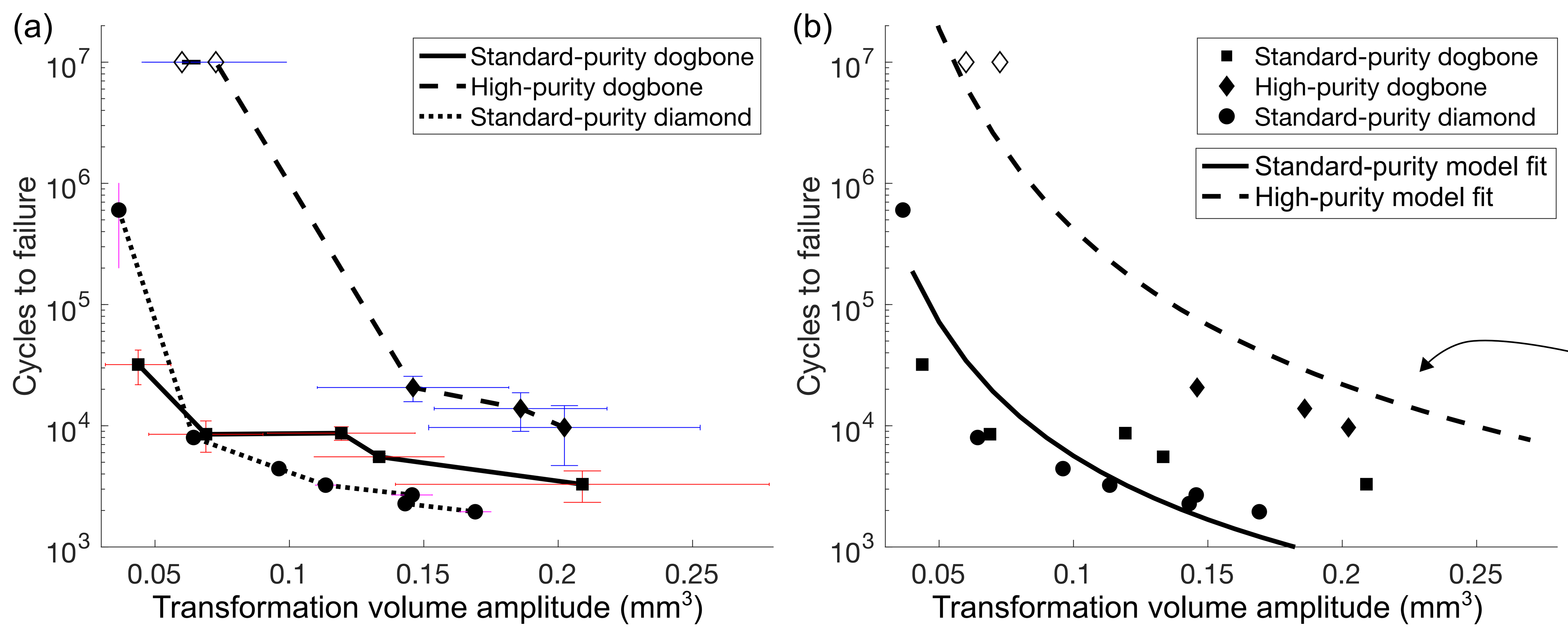


We determined cycles-to-failure for two sample types (,) and two material purities (std-purity, high-purity) under different fatigue conditions (~ 50 tests).

We determined phase transformation volume amplitude in a fatigue cycle using digital image correlation.



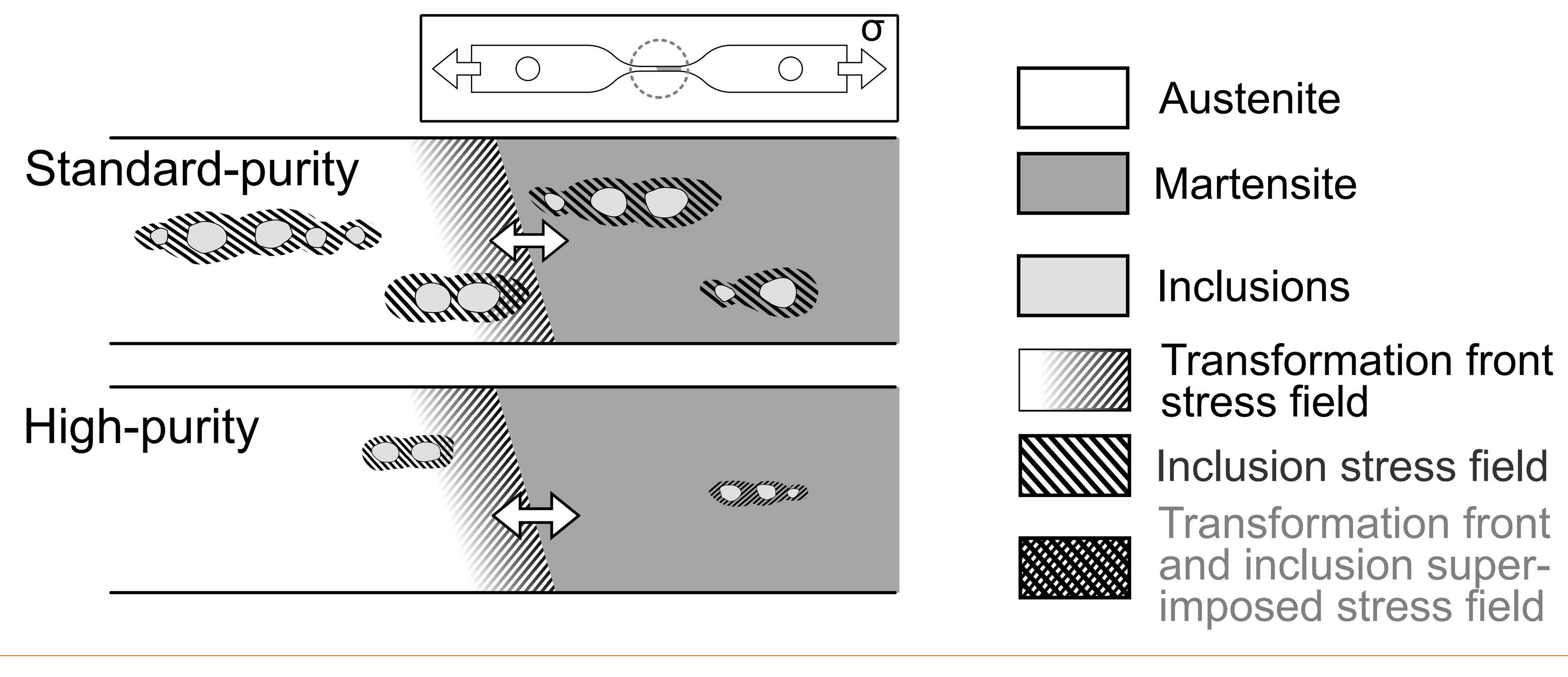
Fatigue Lifetime is Inversely Proportional to Phase Transformation Volume Amplitude and Inclusion Content



- Inverse correlation between cycles to failure and transformation amplitude is agnostic of the sample geometry (i.e., loading mode: uniaxial vs. bending).
- Fitting function is of the form: cycles to failure = *f*(extreme inclusion size, inclusion density, phase transformation volume amplitude).

The Mechanism: Fatigue = Transformation-induced Plasticity x Inclusion Stress-fields

- Larger transformation front motion = more transformation-induced plasticity.
- Inclusions harbor stress fields that interact with transformation fronts to cause larger local damage.
- Both factors above contribute to fatigue failure.
- In summary, phase transformation volume amplitude is a reasonable low-cycle fatigue indicator.
- Future effort: Mechanistic difference between low-cycle and high-cycle fatigue.



For details: Paranjape et al. Scripta Mat. (2020). Reference library: https://nitinol.com/

Stent sketch courtesy of C. Bonsignore. This work is funded by Confluent Medical.

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