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Predictive Approaches to Enhance the Fatigue Assessment of Ni-Ti Biomedical Devices

Nickel-Titanium (Ni-Ti) shape memory alloys are the top choice for designing self-expanding cardiovascular devices for minimally invasive surgeries, thanks to their superelastic behavior related to stress-induced phase transformation. The long-term reliability of these devices remains a critical issue, especially for peripheral stents and heart valves subjected to millions of load cycles due to body movements. This work investigates complementary predictive approaches to enhance the fatigue assessment of Ni-Ti biomedical devices, considering surrogate multi-wire samples. Uniaxial fatigue tests were carried out to evaluate the fatigue life at several mean and alternate strains, followed by fracture surface analysis, providing a statistical distribution of material defects.
A fracture mechanics-based predictive approach was first implemented, assuming crack propagation from defects up to fracture. Fatigue crack growth tests on Ni-Ti notched samples were conducted, adopting the energetic cyclic J-integral parameter as driving force to calibrate a proper crack growth law [2]. Conservative fatigue life predictions matching the experimental trend were obtained for multi-wire samples, neglecting the crack nucleation phase.
A more sophisticated phase-field model of fracture was developed by coupling a SMA constitutive model [3] with a gradient damage model [4. After model calibration, multi-wire fatigue tests were simulated, exploiting the inherent structure of the model accounting for fatigue effects, analyzing both the homogeneous and the localized response. Promising life predictions were obtained, capturing the experimental outcomes and gaining insights into the peculiar material behavior in the damage zone. Future efforts will allow to establish an integrated predictive tool to enhance SMA device reliability.

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