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Effect of strain rate on properties of superelastic NiTi thin wires

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Abstract

This study deals with the effect of strain rate on tensile and energy absorbing properties of superelastic NiTi thin wires. It also attempts to gain an understanding of the interplay of the ductile behavior, temperature and strain rate effects, energy storage and cycling. The wires are in austenite condition at room temperature and above. The strain rates imposed during testing range from 0.2 to 180%/min (i.e., 0.06–54 mm/min) corresponding to a frequency of 2.77×10^{-4} to 0.25 Hz for strain amplitudes of 6%. The corresponding frequency for 8% strain amplitude is 2.08×10^{-4} to 0.18 Hz. It is shown that NiTi SMAs exhibit ductility at both low and high strain rates. This is also true for the cold worked and heat treated conditions both below M_f and above A_f. During tensile testing the stress-induced martensite (SIM) plateau increases in length and translates upwards with increase in strain rate up to a certain value. Similarly, the onset of elastic yield stress also increases with strain rate. At high strain rates the SIM segment and elastically deformed SIM segment overlap. The SIM formation is not able to cope with the externally imposed higher strain rates. This is also the reason for the reduction of hysteresis loop at the high strain rates as observed in the cyclic tests.

The dissipated strain energy density (E_d) increases with increasing strain rate up to a certain value beyond which the E_d decreases. It is clear that the mean point of the superelastic loop shifts to the right and upwards (higher stress and higher strain region) for cyclic testing with increase in strain rates. However, it shifts to the right and downwards (lower stress/higher strain regime) for both the 6 and 8% strain amplitude cycling at constant strain rate. The stabilization of residual strain and E_d is based on the same underlying mechanism relating to SIM formation and occurs at the same numbers of cycles.

Keywords: Superelastic NiTi; Strain rate effects; Ductile behavior; Energy absorption

1. Introduction

NiTi shape memory alloys find their use in several areas such as aerospace, automobile, medical and others. This is because of their superior mechanical and functional properties compared to the other shape memory alloys. Amongst the several mechanical properties of these inherently ductile materials, the energy absorbing (damping) capacity makes them strong candidates for applications for which energy absorption is important. For these applications there is a need to understand the effect of strain rate on the energy absorption and related properties of these materials. Some efforts have been made in the past in this direction. Liu et al. [1] studied the effect of strain rate, strain amplitude and annealing condition on the martensite damping of NiTi shape memory alloy (SMA) wherein it was shown that these materials could withstand a high number of cycles without fracture under different stress modes within a large range of strain rates and at rather high strain amplitudes. DesRoches [2] investigated the strain rate effects by subjecting the NiTi SMA Wires and bars to loading frequencies of 0.025, 0.5 and 1.0 Hz at superelastic strain amplitude of 6%. Their results showed that as the test frequency increases the loading and unloading plateau stresses increase whereas the hysteresis and the hysteretic damping markedly decrease. Dolce and Cardone [3] studied the effect of loading frequency on the behavior of NiTi SMA wires in the austenite condition. They inferred that the mechanical behavior is affected when passing from very low frequency (less than or equal to 0.01 Hz) to the frequency range of 0.2–4 Hz. They recorded that when the strain rate is increased the hysteresis loops narrow and translate upwards, while the segments of the curve relevant to the phase transformation harden, thus, yielding an increase in the stress levels. The strain amplitude considered was again 6%. Brinson et al. [4] conducted in situ optical microscopy observations of NiTi SMA tensile behavior. During the loading sequences containing constant displacement holds

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