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Development of the Z Specimen for Tensile-Tensile, Tensile-Compression, Compression-Compression Wire Testing

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A new wire test specimen was developed as part of the Safe Technology consortium project to produce a nitinol algorithm for the fe-safe™ fatigue postprocessor. The requirements for the design were permit tensile and compressive loading, accommodate data collection of strains from ±0.1 to 6% at high-frequency cycling. The requirements for the wire were inexpensive, stable, consistent, and commercially available. The requirements for the processing were incorporate deformation and multiple anneal cycles to simulate manufacturing methods associated with vascular stent production. The final design was 0.508 mm (0.020 in.) diameter wire formed in a two-stage process to produce a Z-shaped specimen. The final part met all requirements for testing. Subsequently, a second specimen, Z3, and a straight wire specimen were produced to supply additional data to the consortium.

Keywords biomaterials, mechanical testing, nonferrous metals

1. Introduction

Medical device engineers have struggled with unexplained early fatigue fractures of superelastic nitinol. Fatigue data have been reported by many sources (Ref 1-5) without substantial damage curve assessment (DCA). A consortium of medical device and analysis software companies has joined in a program to address this area by developing and testing new specimens for DCA.

2. Development of the Z and Z3 Wire Specimen

The requirements for a wire specimen were inexpensive, stable, consistent, widely available, and able to produce data in tensile-tensile, tensile-compression, and compression-compression modes in high cycle multi-specimen fatigue equipment.

The specimen design would incorporate deformation and multiple anneal cycles to simulate manufacturing methods. The Z1 and Z3 designs use a 1.75 mm centerline radius and 3 mm centerline radius, respectively (see Fig. 1). The final designs started with an as-drawn 0.508 mm (0.020 in.) diameter superelastic wire, vendor supplied data: 44.5% cold work, A_f 13.4 °C (DSC), upper plateau stress 579.16 MPa (84,000 psi), 14.6% elongation to break. Sequential parts from a single wire lot were formed into "Z" shapes by heat setting the parts in machined grooves in steel dies during two forming steps with a 500 °C salt bath annealing for 5 min after each step (see Fig. 2).

3. Testing

The straight wire has been characterized by convention tensile testing of a 10 in. gage length by the wire vendor (see Fig. 3). Subsequent tensile characterization was performed on samples that had been annealed twice in a 500 °C salt bath while constrained in a straight groove steel fixture (see Fig. 4).

Thirteen sets of specimens for each Z design were fatigued in tension by a displacement controlled protocol on a multi-specimen fatigue test system at room temperature. The displacement values were predicted from FEA which used the stress strain data estimated from the first fatigue cycle of the double annealed wire. Sample size for each set was five. The ranges were chosen to compare data from low cycle/high strain to high cycle/low strain regimes. Test frequency was 20 Hz. The test range was 0.5-4.0% mean strain and 0.75-3.0% alternating strain (see Fig. 5, 6).

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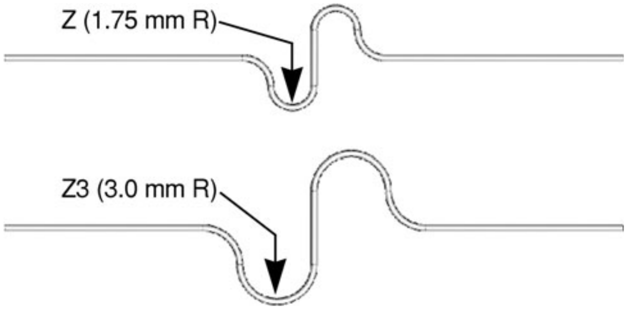

Fig. 1 Z and Z3 specimen designs

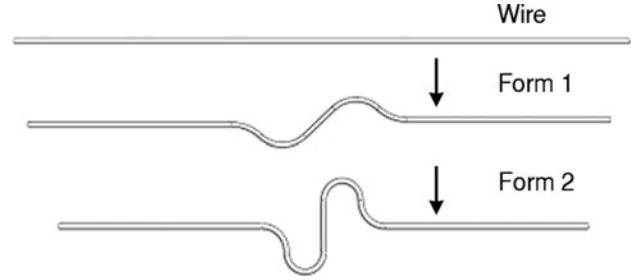

Fig. 2 Z specimen two-stage wire forming sequence

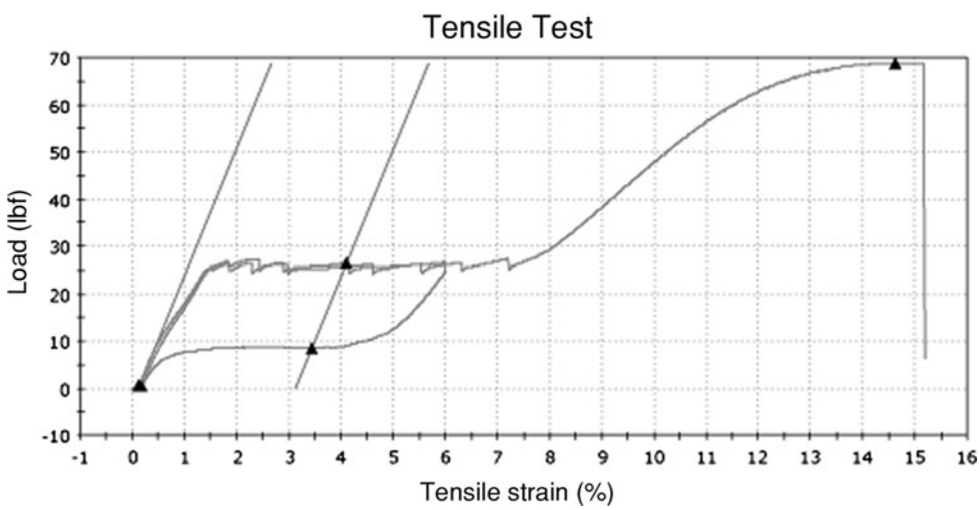

Fig. 3 Tensile properties ''as drawn''

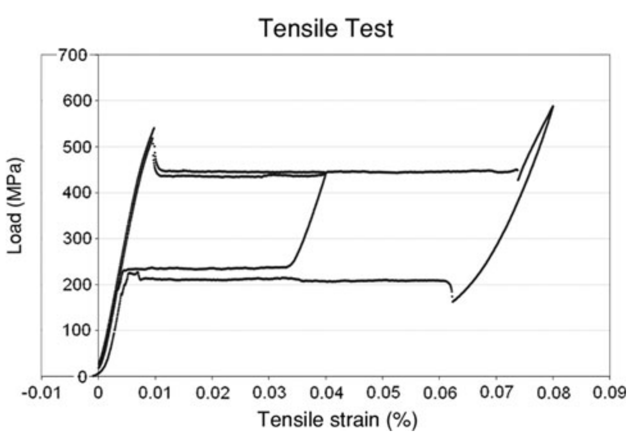

Fig. 4 Tensile properties after 2× annealing at 500 °C in a straight fixture

4. Summary and Conclusions

The Z specimens have been successfully tested up to 10^6 cycles across a strain range of 0.5-4.0% mean and 0.5-3.0% alternating. Experimental results show a tight grouping of data across the test range until bimodal separation occurs at low alternating strain of 0.5-0.75%. Preliminary DCA analysis could detect the change in bend radius between the two designs. Therefore, the specimens are satisfactory for generating fatigue data for further DCA investigation by the consortium.

Acknowledgment

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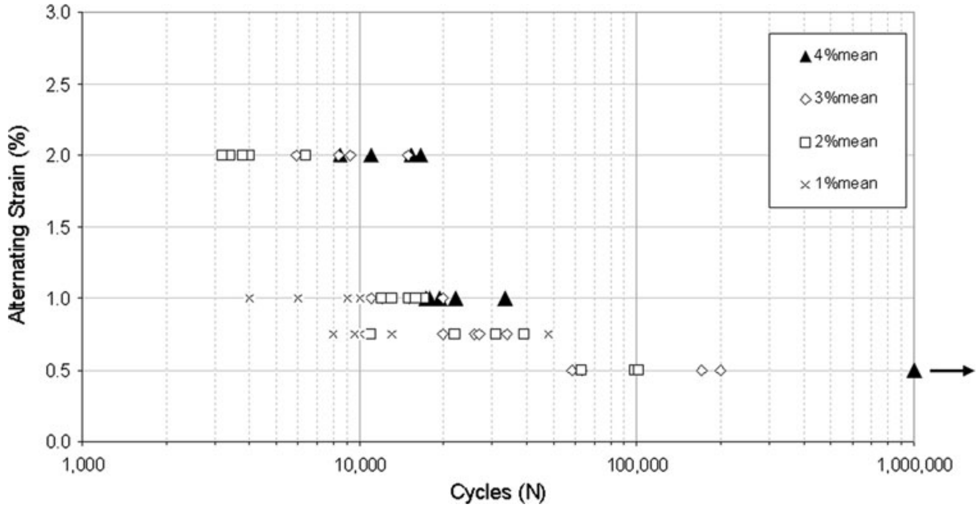

Fig. 5 Z specimen fatigue performance at room temperature

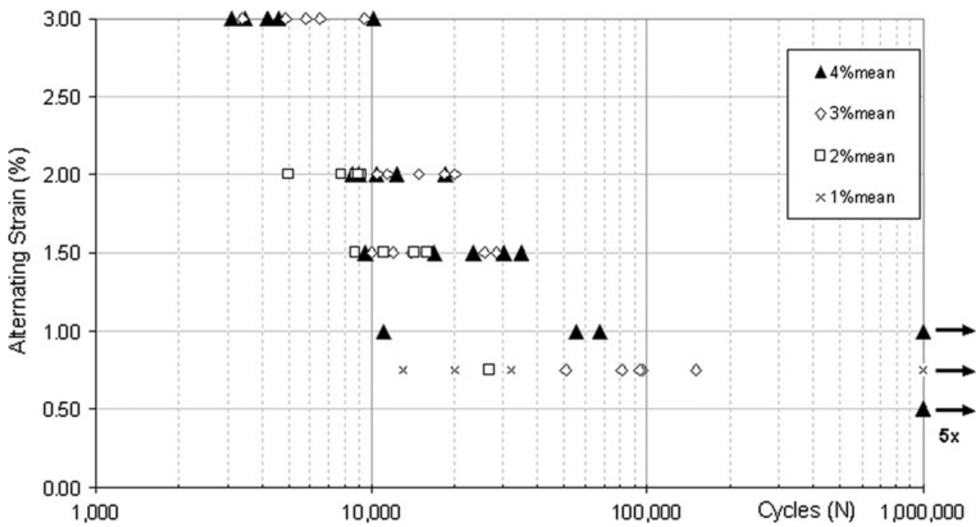

Fig. 6 Z3 specimen fatigue performance at room temperature

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