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Fatigue strength of VDSiCr spring steel under cyclic torsion and cyclic axial loading at different load ratios in the VHCF regime

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1. Materials and method

Ultrasonic fatigue tests are performed with VDSiCr spring steel under cyclic torsion loading. Based on earlier investigations [1, 2] a test-setup was developed for applying static mean torque, to allow torsion testing at load ratios R = 0.1, 0.35 and 0.5, respectively. VDSiCr spring steel is used for coil springs, which are cycled at positive load ratios in the very high cycle fatigue (VHCF) regime during service. The material is patented and oil quenched. Specimens are machined from wires of 8 mm diameter with a circular reduction of cross section in the centre to a diameter of 4 mm. Shot peening of the surface produces conditions similar to the practical application with surface compression stresses of about 700 MPa. Ultrasonic cyclic torsion tests are compared to ultrasonic cyclic axial loading tests at load ratios R = −1, 0.1 and 0.5.

Specimens must vibrate in resonance at ultrasonic frequency in ultrasonic fatigue testing. Due to the different wavelengths of axial and torsional waves, specimen dimensions must be different. The inner sections of both specimens, where fatigue cracks are initiated, however have the same shape. Due to the stress gradient and the shorter wavelength of shear waves compared with longitudinal waves, the stressed volumes (i.e. stress amplitude greater 95% of nominal stress) are 36.0 mm^3 in cyclic axial tests and solely 0.83 mm^3 in cyclic torsion tests.

Ultrasonic equipment used to control both tests is similar. However, different vibration gauges and ultrasonic converters are used. Cyclic load is applied in a pulse-pause-sequence to avoid specimen heating. Superimposed static torques (in cyclic torsion tests) or forces (in cyclic axial tests) are introduced at vibration nodes in both test setups.

2. Results and discussion

Figure 1 shows the fatigue data for axial loading at load ratios R = −1, R = 0.1 and R = 0.5, and for torsional loading at load ratios R=0.1, 0.35 and 0.5 up to 10^{10} cycles or 5×10^9 cycles, respectively.

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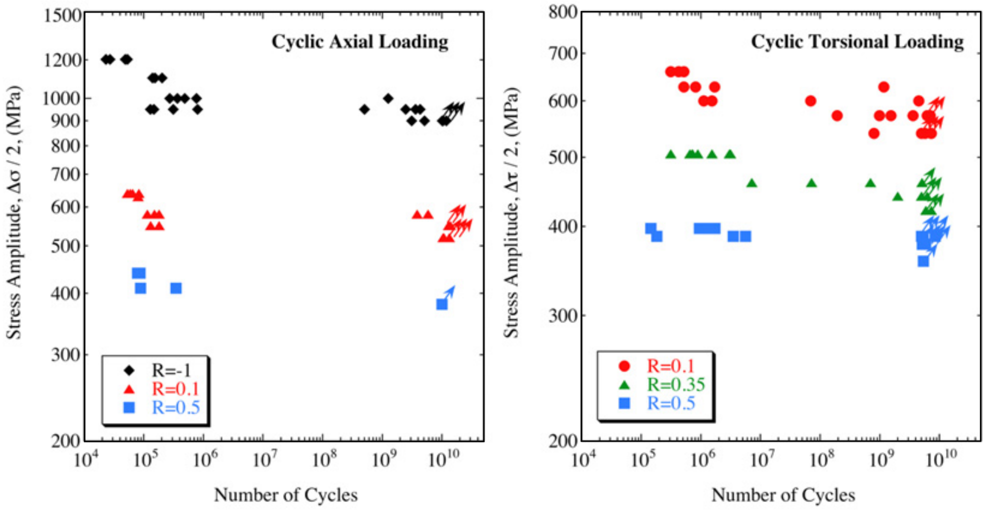

Figure 1. Fatigue lifetimes of VDSiCr spring steel at different load ratios for cyclic axial (left) and torsional loading (right).

In axial loading experiments failures occurred exclusively from the surface for lifetimes below 10^6 cycles, whereas for lifetimes greater than 10^8, cracks always originated from the specimen's interior. Cracks in the interior initiated either at inclusions or in the matrix. No failures occurred between 10^6 and 10^8 cycles. The picture is different for torsional loading experiments. While crack initiation still occurs from the surface for early failures, it is also found occasionally for lifetimes greater than 10^8 cycles. However, interior crack initiation above 10^8 cycles only appeared in the matrix. The relatively high purity of the material combined with a much smaller testing volume compared to axial specimen causes that no cracks originate from inclusions in torsional tests.

The von Mises yield criterion suggests a ratio of $\Delta\tau_{en}/\Delta\sigma_{en} = 0.58$ between the endurance limit for cyclic torsion and axial loading for soft materials. The presently investigated spring steel with high residual surface stresses, however, behaves more like a brittle than a ductile material. The crack is initiated perpendicular to the maximum principal stress for both loading conditions (i.e. 90° to specimen's length axis in cyclic axial loading tests and 45° inclined to the specimen's length axis in cyclic torsional loading tests). A ratio of $\Delta\tau_{en}/\Delta\sigma_{en} > 0.9$ is found in tests at positive load ratios.

3. Conclusions and outlook

For the first time the feasibility of ultrasonic cyclic torsion tests for positive load ratios is demonstrated. Fatigue life of VDSiCr spring steel is investigated at cycling frequency of about 20 kHz under cyclic torsion and cyclic axial loading at different load ratios in the VHCF regime. A distinct difference in the occurrence of failures from the interior is found, caused by the large difference in testing volume between specimens for axial and torsion loading tests. Comparison of cyclic torsion and cyclic axial VHCF behaviour is possible using a critical plane approach and considering residual stresses.

References

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