N72-29907

12

# ON THE CYCLIC STRESS-STRAIN BEHAVIOR AND LOW-CYCLE FATIGUE OF AEROSPACE MATERIALS

By J. Burbach
Krupp Forschungsinstitut, Germany

The elastic-plastic deformation behavior under cyclic stress of a number of different engineering materials was experimentally investigated with the aid of high-precision methods of measuring, some of which had been newly developed. (See refs. 1 to 4.) The report covers, in particular, experiments made with a variety of steels, the titanium alloy Ti-Al6-V4, a cobalt (tungsten) alloy, the high-temperature material Nimonic 90 and Dural (Al-Cu). The theory given – in an attempt to explain these experiments – is aimed at finding general formulas for the cyclic stress-strain behavior of engineering materials.

The experimental and theoretical investigations made can be summarily described as follows:

(1) Geometric relationships of stable mechanical hystereses at a given variation of stress or strain and normal strain-rate dependence at cyclic deformation (plain and notched specimens) (refs. 5 and 6)

(2) Accurate and direct measurement of the second-order elastic constants of polycrystals and their influence on the test result

(3) Accurate balance of elastic and plastic energy in cyclic deformation, particularly in microscopic inhomogeneous plastic deformation

(4) Spreading of Lüders bands in cyclic deformation; phenomena of strain hardening and removal of strain hardening

(5) Inverse strain-rate dependence for aluminum-copper alloys

(6) Investigations relating to cumulative damage at irregular cycling of stress.

The investigations, unfortunately, showed that cyclic stress-strain curves do not provide sufficient information for developing cumulative damage formulas that are sufficiently accurate from the physical aspect or suitable for engineering application. For this reason, it is not possible for the time being to give up practical simulation of actual material stresses with modern fatigue-testing machines.

The accuracy of the measurements made is exemplified by the cyclic stress-strain behavior of a round bar specimen with a sharp notch. (See figs. 1 and 2.) The stress – related to specimen cross-sectional area in the notch root – is plotted against the plastic deformation of the full-length specimen. It is clearly seen how the gradually propagating crack causes a "nose" in the cyclic stress-strain curves; that is, the opening and closing of the crack becomes apparent.

In figure 1, the stress given is related to the notch-root cross section. The hysteresis curves shown were written with rising values of the plastic-strain amplitude. Strain measurement was made as usual at a distance between the edges of the inductive extensometer of 40 mm; thus, the mean value of the inhomogeneous extension was obtained.

The test represented by figure 1 was continued in such a way that with (approximately) constant amplitude of plastic strain, cyclic deformation proceeded. Continuation of the test eventually led to fracture of the specimen. See figure 2.

## REFERENCES

1. Burbach, J.: A Tensile Machine With a Particularly High Spring Constant. Techn. Mitt. Krupp, Forsch.-Ber., Bd. 24, 1966, pp. 79-88.
2. Burbach, J.: The Static Tensile Test. Recent Methods of Metallurgical Investigation. Ver. Dt. Eisenhuttenleute (Dusseldorf), 1970, pp. 19-36.
3. Burbach, J.; and Vierling, P.: Experimental and Theoretical Studies of Strain Gauges, Particularly With Respect to Their Transverse Strain Sensitivity. Experimental Stress Analysis (Dusseldorf), VDI-Rep. 102, 1966, pp. 131-136.
4. Burbach, J.: Unavoidable Influences of the Loading Speed on the Indication of Load Cells. Precision Measurements With Strain Gauges for Force Measurement and Weighing (Dusseldorf), VID-Rep. 137, 1970, pp. 83-87.
5. Burbach, J.: Recent Investigations on the Plastic Behavior and Fracture Process of Hard Metals. Techn. Mitt. Krupp, Forsch.-Ber., Bd. 26, 1968, pp. 71-80.
6. Burbach, J.: Zum Zyklischen Verformungsverhalten Einiger Technisher Werkstoffe. Techn. Mitt. Krupp, Forsch.-Ber., Bd. 28, Heft 2, 1970.

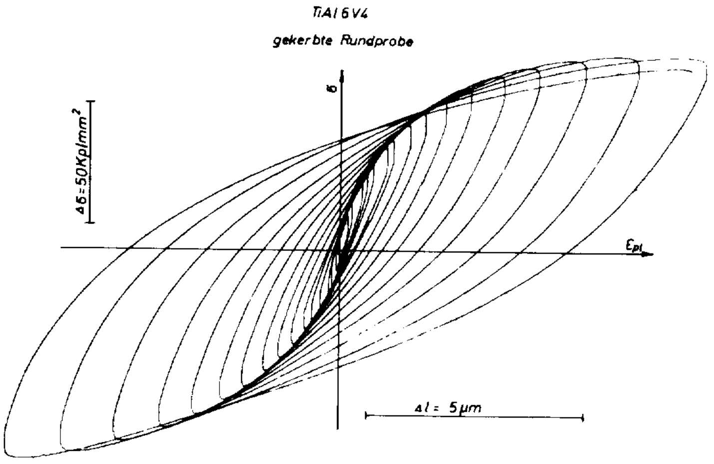

Figure 1.- Cyclic stress-strain behavior of a notched round bar specimen. Notch angle, 60°; notch-root radius, 0.15 mm; notch-root cross-sectional diameter, 3 mm; Ti-Al6-V4.

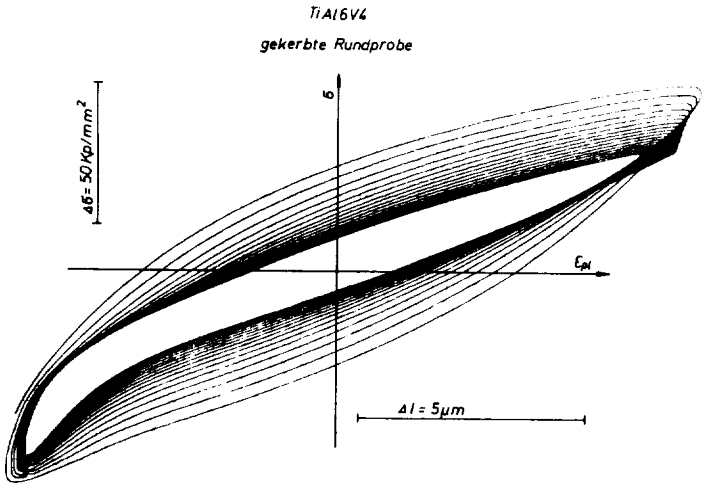

Figure 2.- Continuation of test measurements shown in figure 1 into the cracking stage. Ti-Al6-V4.