

Elevated Temperature Mechanical Testing of Metals[†]

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Standard servo-controlled hydraulic mechanical test systems have been modified to conduct elevated temperature, strain controlled creep-fatigue tests. These modifications include the design of special grips, the use of quartz rod extensometry, and the use of induction heating. In addition, digital computer control and data acquisition allow greater test flexibility and more precise data analysis and interpretation.

Introduction

The mechanical testing systems and procedures described in this paper have been developed and refined to conduct elevated temperature, fully reversed strain controlled cyclic tests. In addition, these test systems are capable of performing all of the standard tensile tests. The need for this and similar (Slot et al., 1969) mechanical test systems has grown out of the structural design needs in such areas as advanced nuclear reactors, solar central receivers, and fusion devices. In all of these cases, piping components and pressure vessels must be resistant to failure from thermal fatigue. This is in addition to the traditional concerns of creep strength and tensile strength. Historical experience in chemical processing plants and fossil-fired power plants showed that failure of pressure containing components resulted from the effects of the environment (corrosion), of a high-pressure transient (tensile failure), or of steady-state operation for long time at high temperatures (creep rupture).

The current elevated temperature applications mentioned earlier also include a significant number of thermal cycles to and from the operating temperatures. The superposition of this cyclic component with the steady-state operation has been termed "creep-fatigue". These two aspects of the service history combine in synergistic form to produce failures that are neither pure creep nor pure fatigue (Conway et al. 1975). In order to design so that pressure-containing components do not fail by this creep-fatigue interaction mechanism, extensive testing must be conducted. Oak Ridge National Laboratory and several other laboratories (ORNL, 1982) have conducted extensive test programs on type 304 and type 316 stainless steel and on 2¹/₄Cr-1Mo steel in support of the Clinch River Breeder Reactor design.

Figure 1 shows the types of programmed signals which are used to control strain history during testing. The combination of the cycling and the hold periods at the peak strain values simulates the effect of service cycling of the power plant component. Although the cycling of the actual components is driven by thermal transients, the laboratory tests are most often conducted isothermally. Most often the strain histories given in Figure 1 are generated by a function generator used in conjunction with a feedback controlled servo-hydraulic test machine. The load and strain signals monitored during testing are usually plotted with an x-y recorder. A typical stress-strain hysteresis

loop taken from a creep-fatigue test is shown in Figure 2.

Several similar test systems are used for all testing in the high-temperature mechanical properties laboratory. However, techniques for elevated temperature mechanical testing vary with the material being tested. Temperature (up to 1300 K) must remain constant and be uniform within the gage length of the specimen. The specimen must be rigidly mounted to allow axial motion only. An accurate and sensitive method of strain measurement is needed to provide a clean signal at low strain levels. This report describes the techniques necessary to adapt standard equipment to meet these rearrangements.

Test Equipment

A. MTS Hydraulic, Closed-Loop System: Standard Components. The basic requirements of reversed loading elevated temperature fatigue testing are met with standard closed-loop MTS hydraulic system components. Figure 3 shows one of the test systems used in this laboratory. (See Appendix for names and addresses of manufacturers of equipment.) Two-post test frames with servo-actuated, push-pull rams are used with hydraulic pressure supplied by external pumps. An MTS 442 controller (with ac and dc conditioners and associated modules for servo-control) monitors stroke, strain, and load and provides feedback in the desired mode of operation. An MTS 410 digital function generator provides the test program any control mode. Additional computer control and 24-h data acquisition are possible with an MTS 433 computer interface along with the DEC PDP 11/34 computer.

Load, stroke, and strain voltages are monitored continuously with digital voltmeters during tests. A Sandia designed interlock circuit is used in addition to the MTS limit detectors to monitor temperature, flow of cooling water, and RF generator operation. An Elgar uninterruptable power source provides power for safely shutting down the equipment in the event of utility power failure. This enables 24 h testing while observing proper precautions in case of specimen failure or equipment malfunction.

B. Specimen and Grip Design. Grips used for reversed load testing, unlike those used for tensile testing, must rigidly support the specimen ends to prevent any deflection or bending stresses in the gage when the specimen is compressed. Specimens are button ended with a straight sided or hour-glass gage section machined to close tolerances. Split collet grips are used to rigidly fix the specimen and avoid any backlash in the load train. The grip assembly provided by MTS is shown in Figure 4. All surfaces which are perpendicular to the load train are held to close tolerances, typically less than 0.0005 in. The MTS-supplied water-cooled fixtures adequately cool the load train components and protect the load cell, but the collet grips as supplied became too hot during testing and

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