SODIUM JACKET
FOR TEMPERATURE EQUALIZATION

Leo E. Chulos

September 1968

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INTRODUCTION

The selection of materials for elevated temperature service and the prediction of component service life at elevated temperatures requires exacting measurement of creep or time-dependent deformation behavior of materials under load. The creep properties are considerably more dependent upon temperatures than on load, thus requiring not only a uniform temperature along the length and throughout the cross section of the test specimen but also a minimum variation about a prescribed temperature during the test.

ASTM recommended test procedures (E 139-66T) suggest that the temperature difference along the length of the specimen be not more than ± 3 F° for test temperatures to 1800 °F. Some investigators feel that this is too great, and the variations should not exceed $\pm 1 \frac{1}{2}$ F°.

Many commercially available tube furnaces, whether of single or multiple heating zone design, will not meet the above criteria. The maximum plateau region of the temperature profile provided by single zone furnaces is somewhat limited. In some furnaces, an up or down movement of 1/16 in. about a central point will cause a temperature variation of 15 to 20 F° about the top, center, and bottom of a standard specimen. After the furnace has been positioned with respect to the test specimen, there still remains the problem of controlling the convective air currents through the furnace along the specimen train. This problem can be partially solved by placing insulation at the top and bottom of the furnace liner channel around the specimen train, but as the furnace is brought to temperature or as the ambient temperature changes, constant adjustment is necessary to maintain an acceptable temperature variation. Thus the time required to attain an initial temperature equalization is extreme.

Furnace adjustment to the proper temperature balance has taken as long as four days. After temperature equalization is attained, nearly constant operator attendance is required to maintain acceptable temperature limits. Unattended operations for times greater than two hours produce temperature variations that are in excess of ASTM recommended limits. What is required is a means to maintain an elevated temperature zone of sufficient uniformity and extent to meet or exceed ASTM recommended limits.

SOLUTION AND DESCRIPTION

A sodium-filled furnace liner or jacket was designed, fabricated, and used to provide the necessary dependability and temperature stabilization at an economical price. The jacket is composed of two concentric lengths of stainless steel tubing from commercially available standard tubing. The tubes are selected to provide an annulus of 1/4 in. or larger, which is filled with sodium. The outer diameter of the outer tube is selected to fit the furnace process channel, and the inner diameter of the inner tube is selected to accommodate the specimen train. Stainless steel flanges, 1/4 in. thick, are welded at the top and bottom of the two tubes. The top flange fits the inner diameter of the inner tube and has a 1 in. radius extension beyond the outer tube to support the jacket when it is lowered into the furnace process channel. The overall length of the jacket is dependent on the length of the furnace, but should be approximately 3 in. shorter than the furnace.

Two, 1/4 in. stainless steel tubes, 3 in. long, are welded into the upper flange, 180° apart to act as sodium fill and vent ports to the jacket annulus. One, 1/4 in. stainless steel tube, 3 in. long, is welded into the bottom flange to act as a sodium drain (see Figures 1 and 2).

The jacket is first evacuated to a pressure of about 2×10^{-5} torr, and then filled with high-purity sodium (less than 50 ppm oxide) to a level 3 in. from the top to provide a

Neg PNL-0680814

FIGURE 1. Sodium Jacket

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FIGURE 2. Sodium Jacket Cross Section

gap for thermal expansion. The sodium is allowed to freeze, and then the jacket is evacuated again and back-filled with high purity (99.99%) helium to a gage vacuum of 20 in. of mercury. Adjustment of the sodium level to within 3 in. of the top and bottom of the furnace conserves heat loss out of the furnace and maintains a relatively flat temperature profile within the temperature-controlled zone.

TESTING

The jacket was placed in a tube furnace (Engelhard), and a specimen train was inserted with a control thermocouple at the center of the specimen. Additional thermocouples were attached at the specimen grips in contact with the bottom and top of the specimen button-heads. High-temperature insulation was placed around the specimen train at the bottom and top openings of the furnace. A minus 30 in. mercury, plus 15 psi pressure gage was attached to the jacket vent tube to measure pressure variations. The furnace heater was tapped to provide three-zone heating capabilities for optimum temperature control, and the heater set point was 1200 °F. While at temperature, a temperature profile of the sodium jacket was obtained by raising and lowering the furnace about the center point of the specimen. Separate tests were performed with the heater tapped for multiple-zone and single-zone heating.

RESULTS

It was noted that as the control thermocouple temperature began to rise, the top and bottom thermocouples lagged by about 20 °F. However, the top and bottom thermocouples approached the temperature of the control thermocouple at higher temperatures. Within 3 min of reaching the 1200 °F control temperature, all thermocouples were isothermal and remained so for the duration of the test (60 hr). To achieve this isothermal condition, the insulation was left undisturbed,

the settings on the variacs for the three heating zones were not changed, and the furnace was left in its original vertical position. With other furnace arrangements these items required considerable maneuvering before a comparable isothermal condition could be achieved.

The pressure gage indicated a pressure of 4.2 psig maximum at 1200 °F, but dropped to a pressure of 3.2 in. of mercury when isothermal conditions were established. When the test was ended, the heater was de-energized, and the temperature was allowed to drop to room temperature, at which time the pressure gage again registered about 20 in. of mercury.

A temperature profile constructed by raising and lowering the furnace, with the heaters tapped for three-zone heating, indicated isothermal readings on all three thermocouples for a furnace travel of 2 in. Thus, only an approximate centering of the furnace was necessary to obtain isothermal conditions across the length of the specimen (see Figure 3). With the furnace tapped for single zone heating, the furnace was still able to travel over a 1 1/2 in. span while maintaining isothermal conditions (see Figure 4).

In previous creep stress tests without a sodium jacket, the specimen often ruptured next to the hotter button-head. In the test conducted in the sodium jacket, the specimen ruptured in the center, which is indicative of a correct temperature profile.

CONCLUSIONS

When the sodium-filled jacket described above was used, there was no operator time required for equalizing the temperatures along the gage section of a specimen after the desired set-point temperature was reached. Furthermore, the operator time needed to maintain equalized temperatures during the test was reduced to zero. Measured temperature differences along the gage section were well inside the ASTM recommended limits for creep testing.

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FIGURE 3. Preset for 3-Zone Heat Control
Operating Temperature: 1300 °F

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FIGURE 4. Preset for use as Single Zone Furnace
Operating Temperature: 1300 °F

Stainless steel in air at 1200 °F will corrode at the rate of about 0.010 in. per year (ASM Metals Handbook, Vol. 1, 8th Edition, p. 598), thus ensuring a jacket lifetime of many years. In the event of a jacket rupture, the sodium leakage will be small because of the very low internal pressure. The jacket is easily and inexpensively built, is rugged, and has no moving parts. When not in use, the sodium jacket can be safely stored as an ordinary stainless steel part.

Sodium-filled jackets have been in use for four months at temperatures of 1000 and 1200 °F. One jacket has completed 10 creep tests with a total heater time of 2516 hr; another has completed 7 tests with a total heater time of 1066 hr. All of the tests conducted have produced excellent well defined data.

The monetary saving derived from reduced operator attendance time is considerable. A low-cost single-wound furnace employing a sodium jacket will provide a constant temperature profile along a 2 in. specimen length. Similar sodium jackets could be constructed in a variety of shapes and sizes, including a split jacket to accommodate a clam-shell type furnace.

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