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13. ABSTRACT (Maximum 200 words)

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Dayton, Ohio 45435

Mechanical Systems Engineering
Materials Science and Engineering
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FINAL TECHNICAL REPORT

To

Air Force Office of Scientific Research
AFOSR/NE
Building 410
Bolling AFB DC 20332-6448

Attn: Dr. Alan Rosenstein

Grant No. AFOSR-85-0078 (URIP)

Title: Processing Science: Characterizing Flow Behavior of High Temperature Structural Materials

Period: 1 January 1985 to 30 April 1986

Principal Investigator: Joseph F. Thomas, Jr., Ph.D.
Professor,
Materials Science and Engineering

ABSTRACT

This grant provided for the purchase of a high temperature vacuum and controlled atmosphere furnace system. A Brew model 1052 was acquired, with a temperature capability of 1650°C. The furnace chamber has been mounted in the load frame of a servo-hydraulic mechanical tester with high load capacity and stroke rate capability. Together these comprise a unique test facility for determining the mechanical behavior and processing characteristics of high temperature structural materials. This test facility is currently in full operation at Wright State University.

1. Equipment Purchased with Grant Funds

The high temperature vacuum and controlled atmosphere furnace system purchased under this grant was a Brew Model 1052 obtained from the Brew Division of Thermal Technology, Inc., 90 Airport Road, Concord, NH 03301. The total cost of this furnace was $115,570. An additional $339 was spent to visit Brew to inspect the furnace prior to delivery.

The Brew unit has a "clamshell" design consisting of a double-walled, water-jacketed stainless steel chamber with an inner cylindrical water-traced copper shell. It is resistance heated using tungsten mesh elements with six molybdenum radiation shields. The SCR power supply is capable of supplying 40 kVA to the elements. Connection to the testing machine is made with water-cooled stainless steel pushrods sealed with flexible stainless steel bellows. The current configuration allows temperatures to 1650°C (3000°F) whereas sufficient power is available for 2000°C if a combination of tungsten and molybenum shields is used. A more detailed list of components follows:

- Type 304 stainless steel double-walled rectangular vacuum chamber measuring 16" wide by 18" high by 10" deep. Chamber and hinged front door have four water-cooled copper power feedthroughs and four thermocouple ports. There is a 1" sight glass with movable shield to view the center of the hot zone.

- A water-cooled copper heater shell supports the tungsten mesh heating elements and both vertical and top and bottom horizontal molybdenum shields. The hot zone size is 5" diameter by 12" high. One-half of the shell is mounted in the chamber and one-half is mounted on the hinged front door. An extra set of elements and shields has also been obtained since these are very fragile.

- The SCR-controlled power supply and furnace transformer operate at 480 volts, 3 phase, up to 60 kVA. This provides a minimum 40 kVA to the tungsten mesh elements. The operating temperature specification was 1650°C in vacuum or inert gas; we are able to reach this temperature at approximately 20 kVA operating in vacuum.

- The temperature controller is a Research Incorporated Micristar model 828. It has two channels, is programmable with 50 program steps, and provides both digital and analog outputs.

- A total of three tungsten-5% rhenium / tungsten-26% rhenium molybdenum-sheathed thermocouples were obtained for furnace control and specimen temperature measurement.

- The furnace chamber has support brackets to mount on the bed of an MTS 311.31 220 kip testing machine. Connection to the actuator and load cell are with water-cooled 17-4 PH condition 900 stainless steel 3" diameter push rods. The vacuum seals from the push rods to the chamber are by flexible stainless steel bellows. The lower bellows allows 4" linear travel, while the upper bellows is stationary and used for alignment. Two APD-1 POCO graphite push rods, 3" diameter by approximately 8" long, for connection to the water-cooled push rods, were supplied for initial testing.

- o The major components of the vacuum system include: Varian VHS-6, 2400 l/s, 6" oil diffusion pump; Alcatel 2033 27 CFM mechanical pump; Varian 336 6" water-cooled baffle; VRC 6" air-operated high vacuum valve; air-operated roughing and foreline valves; electro-pneumatic valve control panel; and Fredericks combination single-station cold cathode Type 7B2 ionization guage and two-station thermocouple guage. The vacuum system is designed for 1 x 10^{-6} torr which has been easily reached.

The decision to purchase the Brew furnace resulted after two rounds of competitive bids. The only other bidder was Centorr, Inc., Suncook, NH. Brew was the lowest bidder in both rounds, but their quotes involved some features considered undesirable. Extensive negotiation resulted in obtaining the desired features within budget, including water-jacketed (vs. traced) chamber construction, sufficient power for future operation to 2000°C (60 vs. 30 kVA), a programmable temperature controller, and semi-automatic vacuum valves.

2. High Temperature Mechanical Test Facility

The Brew model 1052 vacuum and controlled atmosphere furnace is installed as part of a high temperature mechanical test facility. The testing machine is an MTS servohydraulic tester model 810 with 220 kip 4-post load frame, 10 gpm hydraulic pump with accumulators, actuator capable of 10" stroke, dual servovalves for high and low rate operation, and standard electronic controls and function generator. The hydraulic system has been designed to provide for a stroke rate of 10 in/sec, over a 1" stroke, at a load of 110 kips. The MTS servohydraulic tester has been supplied by the AFWAL Materials Laboroatory.

Two important requirements for the testing system involve programmable stroke profiles and high speed data acquisition. The former is obtained using an IBM PC along with a Data Translation DT 2801 analog and digital I/O system. Programs have been written to provide command signals for constant true strain rate compression at a variety of strain rates from 10^{-4} s^{-1} to 30 s^{-1}. Constant true strain rate compression requires an exponentially decreasing stroke rate such that the ratio of velocity to instantaneous specimen height remains constant during the test.

Data acquisition is currently being performed using a Nicolet model 3091 digital storage oscilloscope. This is a two channel instrument which allows display of load-time and stroke-time simultaneously for a test. For storage, each channel accumulates 4000 data points at 12 bit resolution with sampling times variable from 1 microsecond per point to 200 seconds per point. Thus, the maximum sampling rate is 1 MHz. After a test, the digital data is transferred to the IBM PC and analyzed to produce true stress vs. true strain. As a further step, the data files can be sent by telephone lines to the Wright State Engineering VAX. Using data from a matrix of true stress - true strain tests for various strain rates and temperatures, we then use ISSCO DISPLA to create contour and 3-d plots, e.g. flow stress vs. strain rate and temperature.

The Nicolet oscilloscope and Data Translation I/O boards have been obtained using grant funds supplied by the General Electric Co. Aircraft Engine Business Group.

2.1. Summary of Operating Capabilities

The Brew 1052 furnace and MTS 810 tester, along with computer hardware for control and data acquisition combine to provide a high temperature mechanical test facility with the following unique set of capabilities:

- Maximum temperature of 1650°C (3000°F). Higher temperatures up to 2000°C (3630°F) are possible if tungsten shields are installed.
- Vacuum to 10^{-6} torr or inert atmosphere operation.
- Large hot zone size: 5 inches diameter by 12 inches long.
- Load capacity of 200 kilopounds static.
- Load capacity of 100 kilopounds at a stroke rate of 10 inches per second.
- Maximum stroke rate of 15 inches per second. This allows a strain rate of 30 s^{-1} for a 0.5 inch high compression specimen.
- Maximum stroke of 4 inches.
- Ram movement controllable by a microcomputer or MTS function generator.
- Digital data acquisition over a wide range of sampling rates from 1 point per microsecond to 1 point per 200 seconds.

2.2. Installation and Status

The Brew 1052 furnace was delivered to Wright State University during December, 1985. It was installed in the Engineering and Mathematical Sciences building during January - March, 1986. The entire mechanical test facility was operational April 16, 1986. The initial project involved determination of the flow stress vs. temperature and strain rate for a nickel base alloy using constant true strain rate compression tests under the sponsorship of the General Electric Co. Sample results for flow stress at a temperature of 1135°C (2075°F) for strain rates from 10^{-3} s^{-1} to 10 s^{-1} are shown in Figure 1.

3. Research in Progress

3.1. Background

In the design of metal forming processes, it is important to know the response of materials to the processing conditions. In particular, knowledge of the effect of deformation rate and temperature on flow stress, deformation mechanisms, and resulting microstructure and properties of the workpiece is required. This can be achieved by conducting compression tests at constant true strain rate over a sufficiently large range of temperature and strain rate for a particular material. Data from these tests are presented in the form of empirical constitutive equations that relate the flow stress to temperature and strain rate. Further analysis using these constitutive equations along with microstructural examination of the test specimens allows identification of possible deformation mechanisms. For example, results can be presented in the form of 3-D and contour maps of flow stress and strain rate sensitivity. These are processing maps which identify domains in strain-rate temperature space where different mechanisms operate. The boundaries of these domains represent constraints on the processing parameters during metal forming and can be used to control the microstructure and properties of the product. This procedure, known as dynamic material modeling, has been developed by H. L. Gegel et al. at the AFWAL Materials Laboratory.

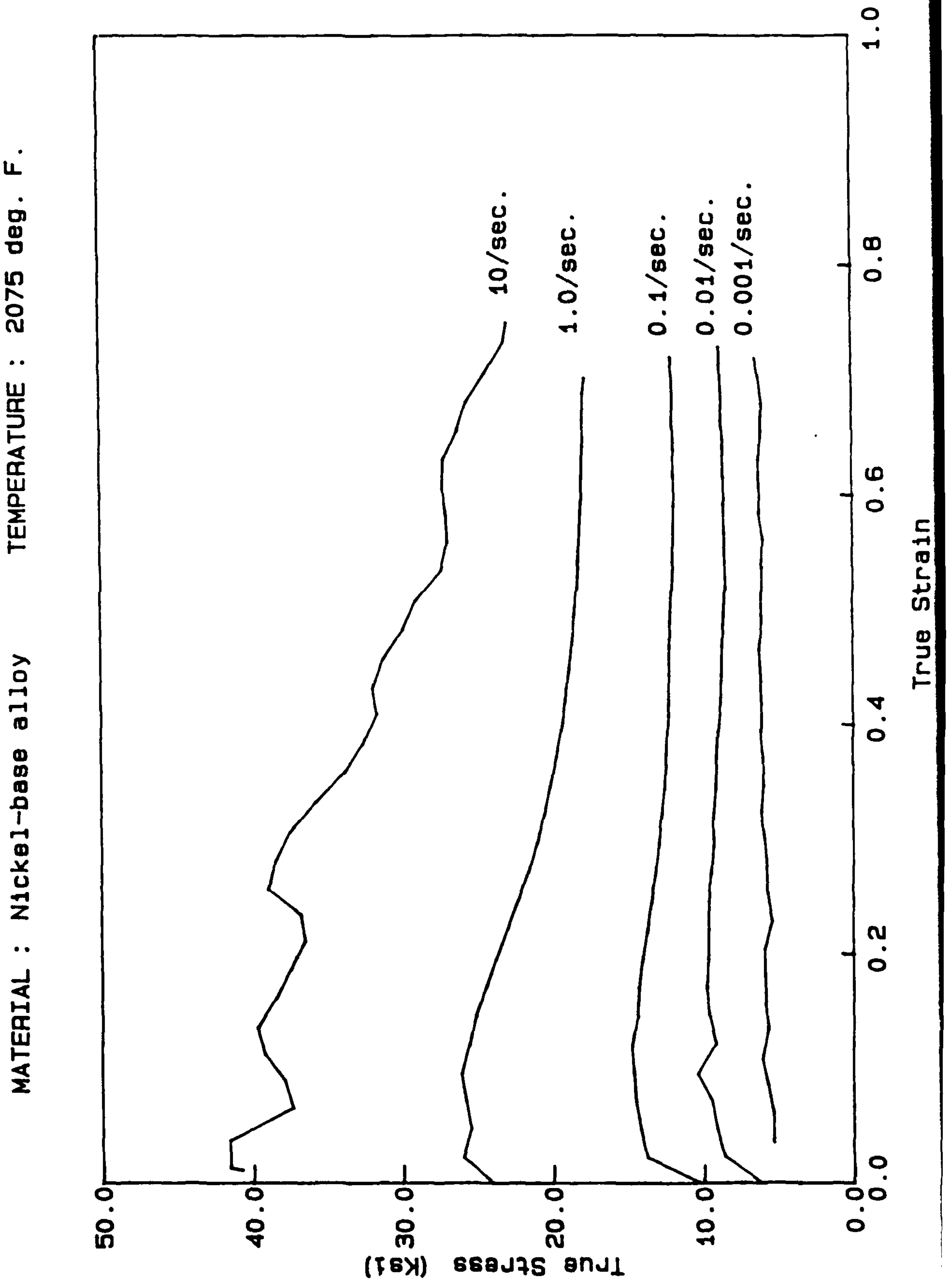
3.2 Research Projects

Currently, nickle-base superalloys and titanium alloys of various processing history are being identified for characterization. For each material, approximately 40 compression tests utilizing specimens about 0.75 in. high by 0.5 in. diameter will be conducted over a constant true strain rate range of 10^{-3} s^{-1} to 30 s^{-1} and over a temperature range suitable for each class of alloy. The compression test data is corrected for temperature rise during deformation, and isothermal constitutive equations and processing maps at different strains are determined. Metallography of selected specimens is conducted to study the microstructure resulting from various processing conditions for comparison to the processing maps.

This research has been supported by a grant of $24,000 from the General Electric Co. Aircraft Engine Business Group. In addition, several separately funded testing programs for specific alloys are also in progress. Concurrently, a program supported by the AFWAL Materials Laboratory to be funded as a subcontract through Westinghouse Electric Co. has been negotiated and is expected to run for twelve months from June or July, 1986 at a level of $123,000.

With this funding, we are able to support a research assistant professor for operation of the High Temperature Mechanical Test Facility. Dr. Raghavan Srinivasan has been in this position since December, 1985, and has done an excellent job bringing the facility into operation very rapidly. In addition, we are supporting a technician part-time and employ two students for metallography and data analysis.

Figure 1



MATERIAL : Nickel-base alloy
TEMPERATURE : 2075 deg. F.
10/sec.
1.0/sec.
0.1/sec.
0.01/sec.
0.001/sec.
True Strain
True Stress (Ksi)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
10.0
20.0
30.0
40.0
50.0