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HIGH-TEMPERATURE EDDY-CURRENT CRACK DETECTION*

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84

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ABSTRACT

A technique was developed to detect the time of cracking of samples representing atomic reactor components under high thermal gradients. An eddy current coil of tungsten-rhenium wire (W-26%Re) was wound on a specially machined boron nitride coil form. This coil has been shown to operate at temperatures up to approximately 3200°F. This temperature was reached, from ambient, in 22 seconds. Special electronic circuitry was also developed to detect the small signal change caused by the cracking but ignoring the large changes caused by the quick heating.

INTRODUCTION

The Los Alamos Scientific Laboratory is presently involved in the development of a nuclear rocket engine for deep space voyages. One of the problems involved in this venture is the development of materials which will withstand the high temperatures and temperature gradients involved, particularly near the exit (hot) end of the reactor. Of particular interest in one series of tests was the resistance to damage by high thermal gradients of certain carbon-metal carbide composite materials, e.g., NbC·C, TaC·C, NbC·TaC·C.

A test sample, 1.25-inches long and 1.5 inches in diameter, was selected. It had a large bore down the center.

The thermal gradient tests were performed in the furnace shown in Fig. 1. This furnace was heated in a closed helium atmosphere by passing current through the graphite radiator (center cylindrical object in Fig. 1). The sample was centered

within this radiator on a water-cooled probe. When the radiator was heated with 10,000 amperes of current, the exterior surface of the sample heated much more rapidly than the inner surface, producing a thermal gradient from the outside to the inside.

The temperatures inside the test specimen during the test were as much as 4000°R, with the maximum thermal gradient occurring at approximately 1700°R. The total test time was typically 30 seconds. Thermal gradients varied from 0° to 500°R with the maximum occurring at approximately 13 seconds.

The Nondestructive Testing Group (GMX-1) of LASL was asked to develop a technique that would detect when a crack occurred due to the thermal gradient.

THE EDDY-CURRENT SYSTEM

Eddy-current testing methods offered promise of working at the temperatures and gradients involved. The primary feature of the eddy-current test which made it the most amenable to this problem was the probability that a coil could be made which would withstand the temperatures involved. Also, the wires to the coil would be fairly easy to bring out of the furnace under sealed condition.

Tests were run to perfect the eddy-current techniques. These consisted of (1) cracking specimens at room temperature to determine the sensitivity and other characteristics of the electronic system, (2) running various coil designs at high temperatures to check out their material and physical properties, and (3) actual high temperature runs with specimens of graphite and of composite material.

A coil was developed on the basis of the room-temperature and high-temperature preliminary tests. The coil form was made of boron nitride and wound with tungsten-26% rhenium wire. The coil was to be placed in the large bore of the sample. The wires had to be insulated from the sample yet be as close to it as possible. No high-temperature insulating material was found which could easily be formed to the necessary shape; therefore, the wires were wound in deep slots in the boron nitride to provide standoff.

The coil design is shown in Fig. 2. The wires exit from the probe at the rear of the coil form in a relatively cool section of the furnace. From that point to the furnace exit, they are insulated with ceramic sleeves and held against the cold probe. A diagram of the assembly is shown in Fig. 3.

The impedance change effects produced by heating the coil were evaluated. It was discovered that the amplitude of the impedance at 1 MHz increased approximately 50% when the coil was heated to 3500°R. Associated with this was a phase change of 65°. The effect of a crack in the specimen was determined to be approximately a 5% change in impedance amplitude with little change in phase. Thus, an electronic system was built which could resolve a 5% change in impedance while responding to a 50% change. In addition, the phase was constantly measured so that temperature effects could be more easily separated from cracks.

A block diagram of the electronics system is shown in Fig. 4. The main feature of this system is the Hewlett Packard 3405A Vector Voltmeter. This device is capable of measuring the absolute amplitude and comparative phase of a voltage (B) in relation to a standard (A). The output is two dc voltages which are proportional to the full-scale meter readings of both

phase and amplitude. Since the signal change produced by a crack is a small step in the amplitude of the impedance, a time-differentiation system was inserted to amplify the effects of this step for easy visualization. All output was recorded on a 6-in. Honeywell Visicorder.

THE CRACK-DETECTION TESTS

Five fully instrumented, high-temperature runs were made. Figure 5 is a typical oscillograph trace from a test. The crack indication is easily visible.

Cracking occurred at approximately 500°R thermal gradient from the outside to the inside of the sample. This gradient occurred at about 1700°R. The eddy current coil failed at approximately 3600°R by brittle fracture of the leads at the point where the windings turned 90° to go through the coil form. This failure could probably have been avoided if the bends had not been so sharp. However, a redesign of the coil form was not necessary for this investigation; the failures occurred well after the crack initiation.

CONCLUSION

An eddy-current coil was developed which detected the occurrence of cracking in samples during thermal transients. The coil, a boron nitride coil form with tungsten-26% rhenium wire, was excited at 1 MHz. The typical temperature of crack occurrence was 1700°R; the coil was operational up to 3600°R. This could probably be extended by redesign of the coil form.

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Figure 1 - End view of thermal test furnace showing graphite radiator (center cylindrical object).

Figure 2 - Cutaway drawing of high temperature eddy-current probe.

Figure 3 - Diagram of sample and eddy current coil on cold probe.

Figure 4 - High temperature eddy current electronics.

Figure 5 - Typical oscillograph trace of high temperature test.

Figure 1

Figure 2

HIGH TEMPERATURE EDDY CURRENT COIL SCHEMATIC OF FURNACE SET-UP

Figure 3

BLOCK DIAGRAM OF HIGH TEMPERATURE EDDY CURRENT ELECTRONICS

Figure 4

EDDY CURRENT TRACE, HIGH TEMPERATURE RUN OF 8-10-67

Figure 5