

## DISCUSSION

*J. Polák<sup>1</sup> (written discussion)*—What is your mechanism of crack initiation assisted by carbide oxidation? Is it a formation of a notch-like geometry or does the crack grow from the oxide into the metal?

*J. L. Malpertu and L. Rémy (authors' closure)*—Your question is quite difficult to answer. In this kind of alloy primary interdendritic carbides are preferentially oxidized; however, it is not only the carbide which is oxidized at a higher rate than the dendrite material but also the interdendritic area, which has a local composition different from the average. A number of observations at the outer surface of the specimens suggest that cracks nucleate inside the carbides, and this may result from a notch-like geometry effect. Very rapidly, however, the crack grows from the outer surface into the metal and this occurs mainly in interdendritic areas, often along the carbides and not inside the carbides.

*N. Marchand<sup>2</sup> (written discussion)*—(1) Every time you make a replica you have to stop the test, wait for the specimen to cool, make the replica, heat the specimen again, wait for the temperature to stabilize, and start the test again. Are you concerned about introducing transient phenomena in your test?

(2) Your  $\Delta T(T_{\max} - T_{\min})$  is about 450°C. You also show no difference between isothermal life and TMF lives. This behavior has also been shown by some Japanese workers; in particular, they show that the difference in life between isothermal and TMF increases with increasing  $\Delta T$ . With higher  $\Delta T$  use for your tests, are you expecting to obtain the same results (i.e., a difference between  $N_{\text{iso}}$  and  $N_{\text{TMF}}$ )?

*J. L. Malpertu and L. Rémy (authors' closure)*—(1) You raise an interesting point. We carry out only interrupted thermal-mechanical fatigue tests to take replicas, and we do not have results of tests without any interruption. However, a number of experiments have been carried out under isothermal conditions, and in most cases test interruptions do not bring any alteration in the total life of the specimens. Test interruptions certainly introduce transient strains in the test, but the hysteresis stress-strain loop is stabilized within a few cycles.

(2) We have found no life difference between isothermal and thermal mechanical fatigue. Our temperature of 450°C is fairly high already, and we do not think that a higher temperature variation will give very different results. The main problem is not the temperature difference itself but rather what life criterion is used. In our case we used replicas to achieve a life criterion to 0.3 mm crack depth, one rather sensitive to initiation. A criterion to a shorter crack depth should still be better, but relevant data were not available for isothermal fatigue. If your life criterion encompasses a large part of both initiation and propagation, however, you may expect great difficulties when you compare isothermal fatigue and thermomechanical fatigue data.

*Eric Jordan<sup>3</sup> (written discussion)*—Is your radiant heating based on light bulb or furnace heating? How do you keep the shadow of the extensometer off the specimen?

*J. L. Malpertu and L. Rémy (authors' closure)*—We are aware that most people use induction heating for thermal-mechanical fatigue tests, but we have gained much experience in our labo-

<sup>1</sup>Institute of Physical Metallurgy, Czechoslovak Academy of Sciences, Brno, Czechoslovakia.

<sup>2</sup>Massachusetts Institute of Technology, Cambridge, MA 02139.

<sup>3</sup>University of Connecticut, Storrs, CT 06268.

ratory on high temperature fatigue testing using radiation furnaces. Radiation using four bulbs (power: 1500 W each bulb) enables specimens to be heated rapidly up to 1100°C (1373 K). The inner cross section of the furnace is made of four ellipses. The number of bulbs used minimizes the shadow of the extensometer on the specimen, as checked by thermocouple measurements at various specimen locations.