STP942-EB/Jan. 1988

DISCUSSION

G. R. Halford[1] *(written discussion)*—You have shown that a compressive hold time is more damaging than a tensile hold time for IN 625. Have you examined your specimens to determine if there are observable differences in the failure mechanisms for these two types of cycles? In particular, could you observe differences in the oxidation cracking on the specimen surface?

T. Bui-Quoc et al. (authors' closure)—Attempts were made to examine the fractured surfaces of some specimens. Unfortunately, the chemical solutions used to remove the oxide layer also affected the material surface, so that no useful information could be obtained in relation to crack propagation mechanisms. The question of differences in the oxidation cracking on the specimen surface has not been addressed yet, but we plan to study a few failed specimens in the near future.

C. T. Sims[2] *(written discussion)*—Your fatigue-creep study was conducted at 650°C (1200°F) and 815°C (1500°F) for extended times. You stated that the material was not inspected metallographically, either before or after testing, for either of the two temperature variables.

According to my experience, IN 625 is a (truly) unstable material. Above temperatures on the order of 650 to 725°C (1200 to 1300°F) the alloy commences to precipitate quantities of plate-shaped phases, usually emanating from grain boundaries. The plates are principally eta-phase (NI_3Cb, Mo), but Laves and mu also occur. These phases remove strengthening elements from solution, promote initiation of cracks, and assist directly in crack propagation under load, sharply reducing creep and rupture properties. Accordingly, it is obvious that your test results at 815°C (1500°F) ("tension hold times—at 815°C—had (significant) effects on cyclic life; compressive hold times also had a damaging effect on the fatigue life—very pronounced for low strain levels at 815°C; - etc.") were directly caused by the precipitation of quantities of eta, Laves, and perhaps mu. There are private corporate documents and ASTM documents that warn against the use of IN 625 under these conditions because of degeneration of the alloy.

In short, the failure of the authors to acquire rudimentary knowledge about IN 625 and the failure of the study to conduct simple metallographic analysis of the test material have resulted in a body of data which has most questionable value as presented. If published in the present state, it becomes a most misleading document, since the paper tacitly assumes the material tested at 650°C (1200°F) was more or less the same as that tested at 816°C (1500°F). This work is an example of the errors generated when mechanists conduct studies without the guidance essential from qualified metallurgists.

I suggest the authors approach a metallurgical group competent to reframe the information obtained into its correct context. So handled, the work may become of some value; for instance, it may show the deleterious effect of plate-phase precipitation in more mechanical detail than currently in the literature. Also, of course, it gives data for IN 625 at 650°C (1200°F) which *may* be usable industrially, *assuming no plate phases formed.*

T. Bui-Quoc et al. (authors' closure)—Dr. Sims has provided metallurgical information which may help to explain the significant effect of hold times on the cyclic life of IN 625 at elevated temperatures. The additional phase formation at a high temperature would be expected to lead to a sharp reduction in creep-rupture properties of the material, and this is reflected in the relative fatigue-creep strengths at the two temperatures considered, as noted in the paper.

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It should be pointed out that the main objective of the paper is to quantitatively evaluate the mechanical performance of IN 625 under creep-fatigue loading conditions at 650 and 815°C. This assessment is achieved by looking at, on the one hand, the reduction of the cyclic life at 815°C with respect to that at 650°C under continuous cycling (without hold times) and, on the other hand, the additional reduction of this life due to different hold-time periods at each temperature considered. Since the metallurgical changes are reflected by an overall modification in mechanical properties, the reduction of the creep-fatigue strength has been assessed using the fatigue (continuous cycling) and the creep-rupture properties *at the temperature considered*. With these considerations, the proposed predictive model takes into account, at least partially, the microstructural change effects.

Regarding the relevance of the results reported in the paper, there has recently been an expression of industrial interest for the fatigue-creep properties of IN 625 at the temperatures studied.