High Cycle Fatigue of Tantalum Carbide Reinforced Nickel Base Eutectics at Room Temperature

D. E. GRAHAM AND D. A. WOODFORD

The high cycle fatigue response of two advanced tantalum carbide strengthened eutectic superalloys has been determined at room temperature. Since these alloys will be coated in service, the effects of variables associated with coating processes were given special attention. Both alloys showed a well defined fatigue limit. It was concluded that the maximum stress obtained in the cycle at the fatigue limit coincided with the tensile stress at which the matrix yielded. Above this stress level cyclic deformation of the matrix resulted in fiber failure, a necessary precursor of specimen failure. Detailed observation of the sequence of events leading to fiber failure and subsequent early crack growth in the matrix over a broad range of alternating stresses confirmed that fiber fracture was the critical crack nucleation step in high cycle fatigue failure of the two alloys. It was shown that several changes in the surface condition did not affect the fatigue life of the alloys. However, when the samples were prestrained to crack the carbide fibers, they failed when cycled at alternating stresses below the fatigue limit for virgin material. A similar loss of fatigue life was observed after heat treatment of one of the alloys. Fractographic examination indicated that this degradation result from enhanced crack nucleation at sigma platelets which were present as a result of the heat treatment.

I. INTRODUCTION

Several directionally solidified eutectic superalloys are currently being assessed for use in critical gas turbine components. Prime candidates are nickel and cobalt-base eutectics reinforced with tantalum carbide fibers, called NiTaC and CoTaC respectively. One of the strongest alloys so far developed, for which creep rupture data is available, is known as NiTaC-13. Unfortunately, like other recently developed high strength derivatives of this alloy, the low Cr content results in poor resistance to oxidation and hot corrosion in a gas turbine environment.

Because of this environmental sensitivity, the successful application of these alloys is dependent on the development of compatible protective coatings. This requires a complete assessment of the effect of various types and compositions of coatings and of coating processes on mechanical properties. In particular, high cycle fatigue resistance, which is generally observed to be sensitive to surface condition, is of major concern.

In most coating processes, pre- and post-coating treatments introduce changes to the substrate which could influence fatigue life. For example, heat treatments at high temperatures (1000 to 1200°C) designed to promote diffusion between the coating and substrate and thus improve the adherence of the coating, could result in the precipitation of sigma phase. This phase is known to produce embrittlement in conventional alloys and improved phase stability compared to NiTaC-13. Unfortunately, like other recently developed high cycle fatigue superalloys has been determined at room temperature. Since these alloys will be coated in service, the effects of variables associated with coating processes were given special attention. Both alloys showed a well defined fatigue limit. It was concluded that the maximum stress obtained in the cycle at the fatigue limit coincided with the tensile stress at which the matrix yielded. Above this stress level cyclic deformation of the matrix resulted in fiber failure, a necessary precursor of specimen failure. Detailed observation of the sequence of events leading to fiber failure and subsequent early crack growth in the matrix over a broad range of alternating stresses confirmed that fiber fracture was the critical crack nucleation step in high cycle fatigue failure of the two alloys. It was shown that several changes in the surface condition did not affect the fatigue life of the alloys. However, when the samples were prestrained to crack the carbide fibers, they failed when cycled at alternating stresses below the fatigue limit for virgin material. A similar loss of fatigue life was observed after heat treatment of one of the alloys. Fractographic examination indicated that this degradation resulted from enhanced crack nucleation at sigma platelets which were present as a result of the heat treatment.

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To develop a full understanding of the effect of overlay coatings on high cycle fatigue performance, it is necessary to understand the behavior of the uncoated alloy as well as to separate the ancillary variables associated with the coating processes. This paper addresses the following questions:

1. Since substrate surfaces are usually roughened to improve coating adherence, what is the effect of various surface preparation methods on high cycle fatigue?
2. What effects do various coating process heat treatments have on high cycle fatigue?
3. What are the crack nucleation and propagation mechanisms which operate during high cycle fatigue of NiTaC alloys?

The major objective of this study was to provide a framework on which to assess the effect of coatings on these alloys. In addition, a detailed microstructural evaluation of events leading to failure was made during the room temperature testing reported here. The influence of test temperature will be described in a separate paper.

In addition to NiTaC-13, a more recently developed alloy known as NiTaC-3-116A2 was employed in this study. This latter eutectic has higher rupture strength and improved phase stability compared to NiTaC-13.

II. EXPERIMENTAL PROCEDURE

The chemical compositions of NiTaC-13 and NiTaC-3-116A2, the two materials which were studied, are presented in Table I. Starting materials were 99.98 pct Ni, 99.98 pct Al, 99.6 pct V, 99.92 pct Co, 99.51 pct Cr, 99.99 pct Ta, 99.99 pct Re, 99.999 pct C, and 99.6 pct W. These materials were melted and chill cast in vacuum, and directionally solidified at 6.4 mm/h in argon as 22 mm (for NiTaC-13) and 41 mm (for NiTaC-3-116A2) diam bars using a Bridgman furnace which typically produced a thermal gradient of 130°C/cm. Specimens for NiTaC-13 were taken from near the center of the approximately 120 mm long ingots. Specimens for NiTaC-3-116A2 were taken at two locations along the length of the 200 mm long ingot.

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Table I. Chemical Compositions of NiTaC Alloys, Wt Pct

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>V</th>
<th>Co</th>
<th>Cr</th>
<th>Re</th>
<th>W</th>
<th>Ta</th>
<th>C</th>
<th>Ni</th>
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</thead>
<tbody>
<tr>
<td>NiTaC-13</td>
<td>5.4</td>
<td>5.6</td>
<td>3.3</td>
<td>4.4</td>
<td>6.2</td>
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<td>8.1</td>
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<tr>
<td>NiTaC-3116A2</td>
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<td>3.7</td>
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<td>6.3</td>
<td>8.0</td>
<td>0.24</td>
<td>Bal.</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1—Typical NiTaC microstructures: (a) Longitudinal view of NiTaC-13, (b) Transverse view of NiTaC-13, and (c) Longitudinal view of etched NiTaC-3116A2.

Fig. 2—NiTaC-13 heat treated 100 h at 1093°C to form platelet sigma phase.

gots. The significance of this is described subsequently. Tops and bottoms of the ingots which were not aligned, as indicated by a polished longitudinal stripe, were discarded.

Typical microstructures of the directionally solidified ingots are shown in Fig. 1. The density of TaC fibers was 3.5 vol pct in NiTaC-13 and 2.5 vol pct in 3-116A2. On the basis of previous work, it has been deduced that the growth direction of both the TaC fibers and the γ' strengthened γ matrix is <100>; γ is the continuous dark phase in Fig. 1(c).

Slugs approximately 10 mm in diam and 60 mm long were electrospark discharge machined from the ingots. Five of the NiTaC-13 slugs were heat treated for 100 h at 1093°C to precipitate sigma phase. The platelet sigma which forms as a result of this heat treatment is shown in Fig. 2. Two other slugs were heat treated at 1093°C for four h to simulate a typical coating heat treatment. Following this treatment, no sigma was detected using light microscopy. All slugs were ground to the specifications indicated in Fig. 3.