ELEVATED TEMPERATURE CAVITATION IN CREEP AND SUPERPLASTICITY OF Ti-6Al-4V ALLOY

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Microstructural aspects of elevated temperature deformation have been investigated in a Ti-6Al-4V alloy. The occurrence of both grain growth and dynamic grain refinement during the deformation process was noted. The relationship between grain boundary sliding, leading to stresses at triple points, accommodation processes and cavitation is discussed. It is shown that cavities nucleate and grow below 850°C. Above 950°C cavity nucleation is almost non-existent due to the high volume fraction of the soft deformable β phase in the microstructure.

SUPERPLASTICITY IN Ti-6Al-4V ALLOY

Elevated temperature superplastic forming of Ti-6Al-4V alloy allows the manufacture of airframe components to a more cost effective design with savings in materials and labor intensive machining costs, and with the possibility of obtaining large geometrically complicated shapes in one step. Until recently it was assumed that this alloy did not cavitate during deformation at elevated temperature. However, cavitation has now been observed below 850°C[1],[2]. The present paper reports results of an investigation of cavitation in Ti-6Al-4V alloy using SEM and TEM work in conjuction with elevated temperature mechanical deformation.

EXPERIMENTAL PROCEDURE AND RESULTS

Tensile specimens (5μm grain size) were tested at 750, 800 and 850°C at strain rates of 5 x 10^{-6}, 10^{-5}, 2 x 10^{-5}, 5 x 10^{-5} and 10^{-4} s^{-1}. This combination of temperatures and strain rates allowed the experimental results to fall in region II of superplastic deformation. The specimens were tested in an MTS machine interfaced with a computer and a digital data acquisition system. The computer was programmed to run the test either at constant strain rates or at differential strain rates (either in an incremental on decremental mode). During the constant strain rate tests, deformation was terminated at various preprogramed strains and the specimen was quenched by pre-cooled argon gas in order to preserve the elevated temperature microstructure. The microstructure was investigated by scanning (SEM) and transmission (TEM) electron microscopy.

Typical stress-strain curves for deformation at 800°C are shown in Fig. 1. It is evident that at lower strain rates the curves show strain hardening. This hardening is associated with grain growth of both alpha and beta phases which was clearly revealed in SEM micrographs. At higher strain rates (10^{-4} and 5 x 10^{-5} s^{-1}), the curves show evidence of strain softening which is due to dynamic refinement of grain size as shown in Fig. 2. The value of strain rate sensitivity m, given by $\sigma = k\dot{\varepsilon}^m$, where σ and $\dot{\varepsilon}$ are the stress and strain rate, respectively, was calculated at selected temperatures using the incremental and decremental strain-rate technique. The value of the strain-rate sensitivity parameter was found to be approximately 0.52 which is close to the value of 0.5 often associated with superplastic deformation.

One of the dominant microstructural processes in elevated temperature deformation of fine grained materials is grain boundary sliding. The chief consequence of this sliding is to produce stress concentrations at grain boundary triple points and at other grain boundary irregularities. This stress concentration needs to be accommodated in order to prevent the opening up of cracks in these grain boundary regions. The two most important accommodation mechanisms are: diffusion processes and/or dislocation-related processes. In general, earlier experimental results indicate that the overall level of cavitation increases with an increase in both strain and grain size, and with a decrease in temperature.[3].

Two types of cavities were observed after a true strain of 1.2 (which is less than the fracture strain) at a strain rate of 10^{-4} s^{-1}. The first type, generally seen at 750°C, usually nucleates on α/α boundaries. However, as the cavities grow they frequently inpinge on β grains. Fig. 3 shows a cavity associated with an α/β boundary but growing into the α grain. The second type of cavity was observed at 850°C. These cavities were usually located at triple point grain or phase boundaries between alpha and beta phases (Fig. 4). These elliptical cavities have a major axis of 1 to 2 microns. Often multiple cavities can be observed in close proximity to each other as in Fig. 5. In this two-phase alloy the body centered cubic (bcc) β phase is more deformable than the close packed hexagonal (cph) α phase. The diffusivity of Ti in the β phase is also two orders of magnitude higher then that in the α phase[2]. Hence the absence of cavitation at temperatures higher than 900°C is possibly due to a large amount of a

highly deformable phase (in this case β phase) which can accommodate grain boundary sliding, analogous to the behavior of α/β brasses containing a large volume fraction of bcc β phase[4]. At lower temperatures (750 or 850°C) cavities open up between two α grains or at triple points between α and β phases due to insufficient accommodation of stresses arising from grain boundary sliding. Preliminary results suggest that these cavities continue to grow by a plasticity-induced hole-growth process leading to final failure.

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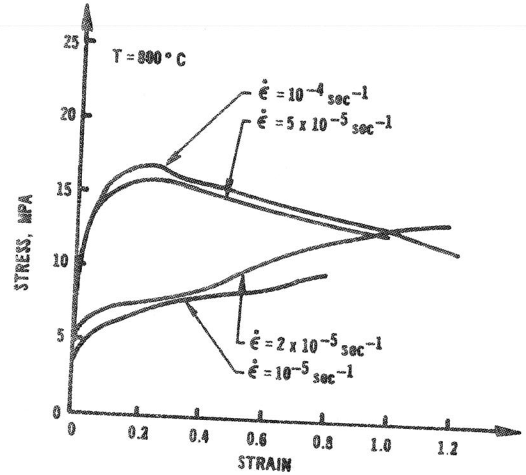

Fig. 1. Stress-strain curves at 800°C. The faster strain-rates show strain softening whereas the slower ones exhibit strain hardening.

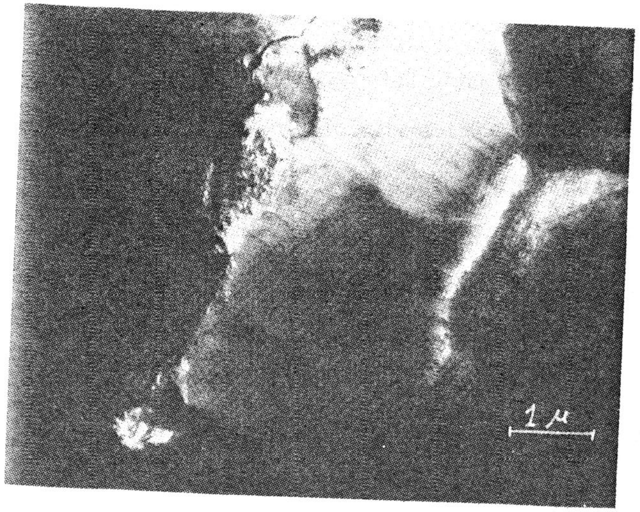

Fig. 2. Dynamic grain refinement at 750°C, $\dot{\varepsilon}=10^{-4}$ sec^{-1} (TEM).

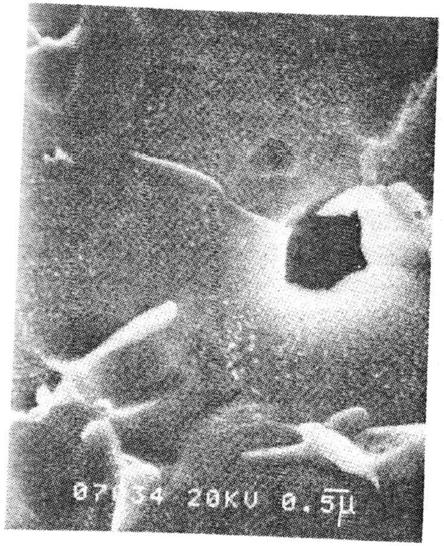

Fig. 3. Cavity inbetween 'α' and β grains at 750°C, $\dot{\varepsilon}=10^{-4}$ sec^{-1}, true strain, $\varepsilon=1.2$ (SEM).

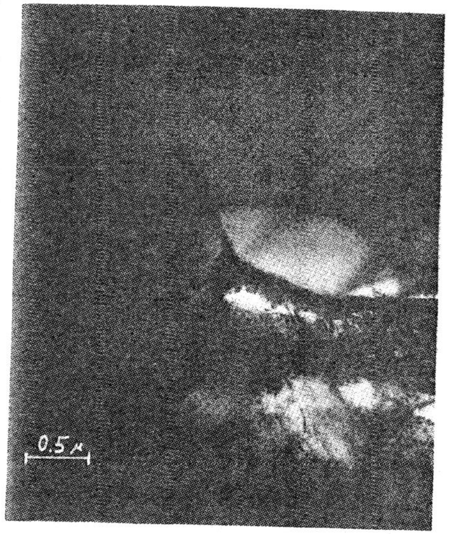

Fig. 4. A single cavity located at a triple point at 800°C, $\dot{\varepsilon}=10^{-4}$ sec^{-1}, $\varepsilon=1.2$ (TEM).

Fig. 5. Multiple cavities at a triple point at 800°C, 10^{-4} sec^{-1}, $\varepsilon = 1.2$ (TEM).