Observation and analysis of internal fatigue cracks propagating in a Ti64 alloy with or without air presence.

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Abstract

It is now well established in the scientific community that in metallic engineering materials (steel titanium, aluminium or nickel alloys) the most frequent location of fatigue crack initiation in the Very High Cycle Fatigue (VHCF) regime (i.e. very low stress amplitudes and N_failure _˜ 108 cycles and more) is the bulk of the material or its sub-surface. In steels the famous " fish-eye " is the typical feature of a fracture surface in VHCF where a central non-metallic inclusion is the reason invoked by many authors of such non-surface crack initiation. However, internal fatigue crack have also been observed without inclusion in steels (1) and in titanium alloys (2). In such cases several heterogeneities of the microstructure can explain this phenomenon (heterogeneous cyclic plastic deformation in the grains, macro zones, segregation of some chemical elements...). But the reasons why crack initiation tends to occur from the material surface instead of those internal defects when the stress amplitude is increased (i.e. for a lower number of loading cycles) are still not well understood.
Some authors claim that the environment plays a key role in this phenomenon: surface cracks initiate and propagate in air whereas the internal ones initiate and propagate in vacuum. In this later type of environment, the crack growth rates are much slower than in air but the surface is exposed during a very long time to the ambiant air in VHCF and consequently should be critical. Moreover, direct measurements of da/dN = f(ΔK) curves remain scarce in the literature because the direct observation of internal crack growth is a difficult task. That is why some authors have used fatigue tests results obtained on surface cracks propagating in high or ultra-high vacuum to discuss and simulate the environment undergone by internal fatigue cracks. But these results are debated because the local stress strain states are different between a surface small crack (plane stress) and an internal one (plane strain).

To progress in this question, an in-situ synchroton ultrasonic fatigue testing machine was used to study the propagation of internal fatigue cracks growing from an artificial sharp internal defect in a Ti-6Al4V alloy cycled at 20 kHz (3, 4). A laser vibrometer and a real-time FFT analysis were used to detect crack initiation and simultaneously an infra-red camera recorded the temperature field evolution at the specimen surface all along the fatigue tests.

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Synchrotron X-ray micro-tomography allowed us to image the internal crack propagation under load. Two sets of specimens were produced by an home made methology to introduce internal and calibrated sharp defect (5). The first one contains a central canal along the specimen axis which brings air from the laboratory to the internal notch and then to the internal crack emanating from this notch. In the second set the notches are not connected to the surface.

Systematic failures were observed with crack emanating from the internal artificial defect for the two types of specimens. The fatigue lives of the specimens with air present at the internal crack tips are significantly lower than those of the specimens with internal cracks isolated from air. For specimens containing a defect isolated from air, internal cracks propagate at a much slower rate than when the defect is connected with ambient air. The SEM observations of the fracture surfaces are in good agreement with literature for natural internal cracks in Ti-Al alloys. For the defects connected to air a supplementary region surrounding the defects appears on the fracture surface with a pronounced faceted / crystallographic aspect containing striations whereas no striation was observed on the facets of the cracks isolated from air. A detailed analysis with FIB-SEM and EBSD - TKD of the striated facets revealed that the striation marks are due to twinning.

Furthermore based on both the evolution versus time of the temperature fields at the specimen surface and the 3D internal crack growth obtained by tomography after different number of cycles, a thermomechanical finite element model was developed to identify the evolution of the heat sources located the crack tip in the reversed cyclic plastic zone. Even if the accuracy of these data is at the limit of this techniques there is a clear tendency showing that the part of the plasticity strain energy dissipated in heat is modified by the environment.

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