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Gigacycle Fatigue Crack Initiation in Cr-Mo Prealloy Sintered Steel

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Abstract

Crack initiation and short crack propagation was studied on the polished notched surfaces of Cr-Mo prealloy sintered steels with 7.35 g.cm^{-3} sintered density. An ultrasonic resonance test system operating in push-pull mode at 20 kHz and R=-1 was used. It showed that crack initiation took place in several places, small cracks growing oriented to the local pore structure rather than to stress orientation. Their growth rate is markedly higher than the corresponding one of long cracks. Finally, several microcracks join to form a dominant crack.

Keywords : sintered steels, fatigue; short cracks, crack initiation

1. Introduction

Powder metallurgy manufacturing is increasingly being used for fatigue loaded components, in particular in automotive engines and transmissions. The fatigue behaviour is therefore of critical importance (e.g. [1]). Since engine components have to sustain loading cycle numbers easily exceeding 10E8, ultra high cycle fatigue testing is necessary, and also the early stages of the fatigue process, i.e. fatigue crack initiation and short crack propagation, are of high interest [2-6], since at very high loading cycle numbers any propagating crack will sooner or later result in final fracture of the component.

For fatigue loaded components, high density is a main requirement since the fatigue endurance strength depends strongly on the density/porosity for all sintered steels [7, 8]. In this work, fatigue crack initiation and short crack propagation was studied of a high density Cr-Mo prealloyed sintered steel, this material being particularly attractive for high performance PM precision parts.

2. Experimental and Results

The test specimens were manufactured from prealloyed steel powder Fe-1.5%Cr-0.2%Mo (Astaloy CrL, Höganäs AB) with addition of 0.6% natural graphite. The powder mix was compacted by high velocity compaction (HVC) to fatigue test specimens (ISO 3928) with a green density of about 7.35 g.cm^{-3} and then sintered for 1 h at 1250°C in N_2-H_2 atmosphere, resulting in a microstructure consisting mainly of upper bainite with some fine pearlite. The sintered specimens were then machined to a slightly thinner gauge section by milling with a sharp hard metal tool and turning a thread on one end; then the gauge section was longitudinally ground and the edges slightly rounded. A semicircular notch with 1mm radius was made in the center of the gauge length, in order to reduce the area on the specimen surface to be scanned by SEM under high magnification and to provoke crack initiation there. The surface in the root of the notch was electropolished. The stress on the root of the notch was measured with miniature strain gauges.

In this study, an ultra high frequency fatigue testing system was employed in which specimens are subjected to sinusoidal push-pull loading (R=-1) at a test frequency of 20 kHz. Details of the test method are described in [9]. Because of the peculiarities of a resonance system, only the strain amplitude is amenable to measurement by means of strain gauge. For virtually elastic strain amplitudes the stress amplitudes can be calculated by use of the experimentally determined values of the dynamic Young's modulus [9, 10].

The fatigue crack initiation and the growth of microscopically small fatigue cracks were studied as follows. The notched test specimen was screwed into the tester on one end and was cyclically loaded at the stress amplitude of 50% the fatigue limit of the respective smooth specimen of 270 MPa. The load was then stepwise increased in small increments until crack initiation or growth occurred. After consecutive short growth intervals, cycling was repeated. Crack initiation and propagation were observed by SEM, and also the number of visible cracks was counted in regular intervals as precisely as possible.

It showed that cracks are initiated at pores, as might be expected. It is also visible that in this early stage of crack initiation at low loading stress, the microcracks are oriented virtually in all directions if adjacent pores can be joined by them. This indicates that the crack initiation is sensitive mainly to the microstructure, which here means the local pore structure, of the materials rather than to the direction of the applied stress. The cracks observed here are all small cracks, defined as cracks with a length <150 μm since this is the diameter of the largest powder particles. With increasing stress amplitude and loading cycle number, the cracks oriented parallel to the stress axis stop, and some microcracks oriented perpendicular to the stress axis join to form a main crack.

For a given test run the number of cracks observed in the investigated area are plotted as a function of the loading cycle numbers for different stress amplitudes as shown in Fig.1. Here it can be observed that in the early stage of crack initiation, the number of small cracks increases with increasing loading cycles and stress amplitude. After several 10E8 cycles at moderate stress amplitude, some of them stop, some of them grow and mostly coalesce, therefore at the highest stress amplitude the number of cracks decreases.

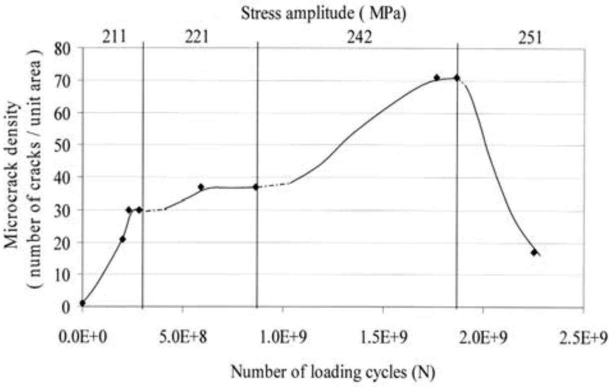

Fig. 1. Number of small cracks as a function of loading cycles and stress amplitude

These findings indicate that initiation and early growth of small cracks is primarily sensitive to the microstructure of materials rather than loading direction. Here, at the early stage of crack initiation the number of small cracks depends not only on the material and loading parameters, but also on the number of loading cycles, during protracted loading more cracks being generated. If cyclic loading is further continued, and especially at higher amplitudes, the fatigue cracks become more sensitive to the loading direction. Some cracks oriented parallel to the stress axis stop, and some microcracks oriented perpendicular to the stress axis join to form one larger crack. It has however been found that even joining of several initial cracks does not necessarily result in a propagating crack, e.g. one crack with l = 211 μm being observed to be nonpropagating at 251 MPa stress level. This result confirms the findings by [10, 11] that short cracks tend to grow at lower stress intensity amplitudes than long ones, i.e. the surprising effect can happen that several short cracks grow and merge into one long crack which then stops.

3. Summary

The experiments have shown that ultrasonic resonance fatigue testing is well suited to study the fatigue crack initiation and early crack propagation in sintered steels, high loading cycle numbers being attained at reasonably short times. Interrupting the fatigue testing in regular intervals and studying the loaded surface is a laborious task but is feasible if crack initiation is concentrated in a small area by suitably selecting the specimen geometry. The tests revealed that in the initiation stage, crack formation is controlled mainly by the microstructure, i.e. the local pore geometry, the stress direction being of secondary relevance. Only after extended testing, and especially at higher stress amplitudes, the stress direction becomes relevant, those cracks oriented perpendicularly to the applined stress growing and coalescing to long cracks, which however are necessarily all propagating.

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