Mode III stable crack propagation of specimens containg shallow micronotches and submitted to out phase multiaxial loading

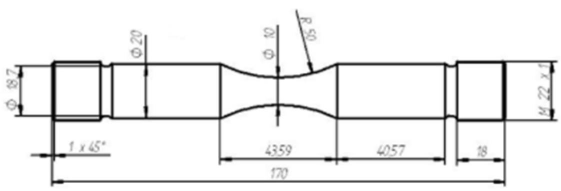
G. Tarantino

INTRODUCTION

Many engineering components under rolling contact fatigue loadings (i.e. gears, bearings, rails and etc.) exhibit mode III crack propagation. Since the fatigue failures of the mechanical components previously mentioned inevitably result in costly engineering damage/loss and down-time, it is of some importance to deep inside the mode III fatigue crack behaviour. Fundamental understanding of the mechanics of shear crack grow is necessary in the formulation of multiaxial fatigue crack growth laws.
Mode III fatigue crack behaviour have been investigated by some researchers: however almost all mode III crack growth studies, considered a circumferentially notched cylindrical crack growth specimens [1] submitted to torsional loading. Tschegg experiments [2] revealed that there is a critical applied stress intensity factor value under which mode III crack propagation is no more stable, resulting in a mode I branching. The reason of the unstable mode III crack growth can be attributed to the frictional effect. Moreover Nayeb-Hashemi et al [3] observed that a superimposed static axial load on the fatigue in torsion can promote stable mode III crack growth, since it reduces the sliding mode crack growth effect.
Nevertheless few experiments have been performed in order to investigate the mode III crack growth behaviour under multiaxial fatigue loading. The aim of the present work is to present a new experimental method in order to promote mode III co-planar crack propagation under mixed-mode loading conditions: out of phase fatigue tests were carried out in specimens containing shallow micro defects of different sizes. OOP tests have been done in order to better investigate the effect of a superimposed cyclic compression on the stable co-planar crack growth as well as the role of friction under mixed mode I+ III loading condition.

MULTIAXIAL FATIGUE TEST WITH SHALLOW DEFECTS

Multiaxial fatigue tests were carried out on pre-cracked micro-notched hourglass bearing steel specimens. Three defect sizes, expressed in terms of Murakami's √area parameter, equal to 631 μm, 314 μm and 221 μm have been considered. The geometry of the specimens and micro-notches adopted are presented in Fig. 1.



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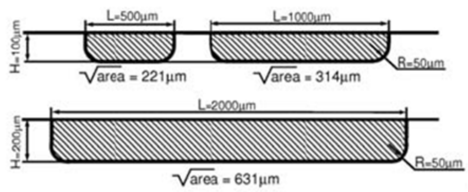


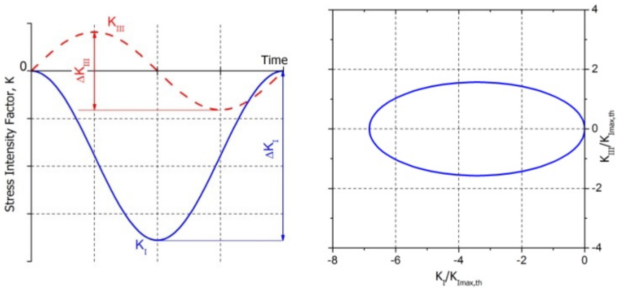
(b)

Figure 1: Out-of phase fatigue tests: a) bearing steel specimen geometry, b) micro-notches used

In order to promote co-planar crack propagation, a preliminary Mode I fatigue test pre-cracking procedure was adopted.

Pre-cracking procedure induced small non-propagating cracks at the bottom of the notch with a depth of approximately 20 μm. All specimens were observed under SEM for verifying the success of pre-cracking procedure (if not successful the Mode I loading was repeated).

Multiaxial fatigue tests were conducted in force/torque control by means of a MTS 809 Axial Torsional System. In order to simulate the most detrimental subsurface stress in rolling contact fatigue problems, the adopted loading path is characterized by an axial force always in compression and shifted on 90° degrees relatively to the torsional cycle, moreover the ratio between the normal mean stress and shear stress amplitude is approximately equal to 1.5 (typical for subsurface position where τ_{max} is present) (Fig. 2).



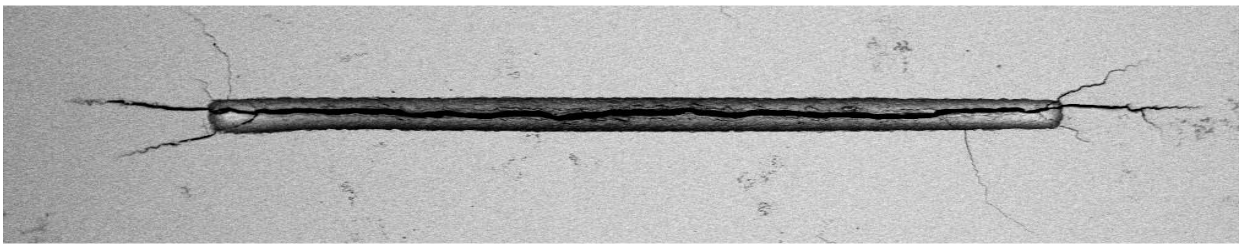
a) b)

Figure 2: Load pattern scheme adopted for fatigue testing: a) in terms of stress intensity factor, b) normalized by $K_{Imax,th}$

The main idea of the experimental onset is to run fatigue tests decreasing the load from one specimen to another till no fatigue crack growth will occur. During the fatigue tests an optical microscope Leica system permitted to control surface mixed-mode crack advance continuously during the test. After the fatigue test, cryogenic static rupture with further examination by SEM permitted to estimate in side propagation type and its order. After the tests all the specimens were examined under SEM in order to observe the specimen surface and, after static criogenic rupture, the fracture surface.

MULTIAXIAL FATIGUE TEST RESULTS

The results of the multiaxial fatigue tests show that the out-of-phase scheme of loading promotes Mode III co-planar crack growth, since it was possible to obtain continuous Mode III propagation at ΔK_{III} levels much lower than Mode I threshold, and inhibits the development of Mode I kinked cracks. In particular, it is possible to observe that in the tests where $\Delta K_{III}<\Delta K_{I,th}$ no appreciable surface growth could be observed (Figure 3), while in all tests at $\Delta K_{III}>\Delta K_{I,th}$ there is the development of mode I tilted cracks along the crack front (Figure 4) [4].



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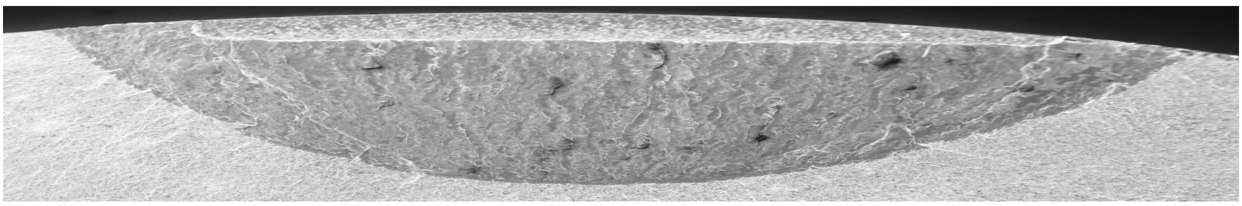
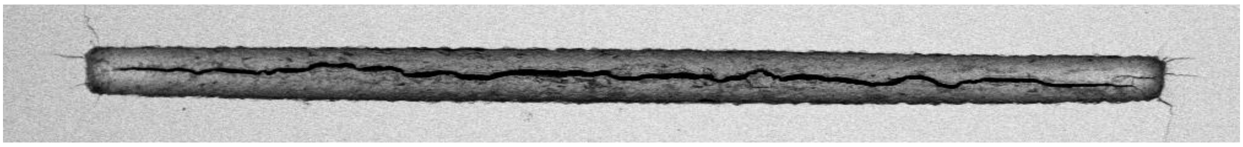


b)

Figure 3: OOP fatigue test fractography; specimen tested at $\Delta K_{III}=\Delta K_{th,I}$ test interrupted at $N_f= 1.2\cdot10^5$ cycles:
a) specimen surface; b) 90°tilted view, coplanar Mode III crack, 1060μm deep.



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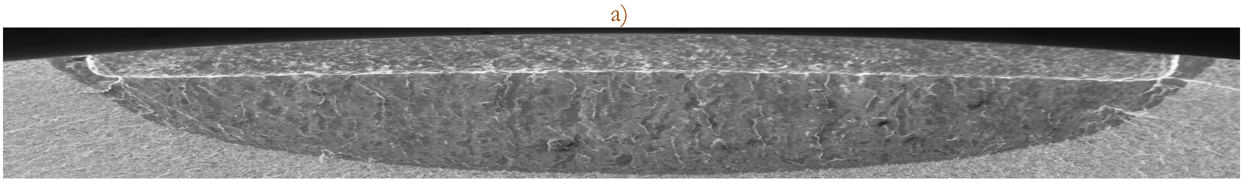

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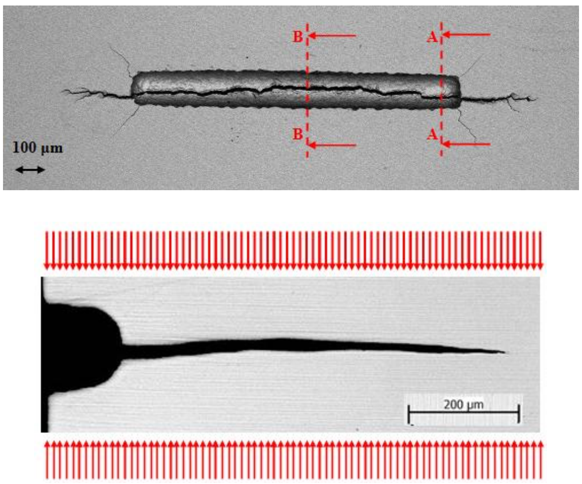
Figure 4: OOP fatigue test fractography; specimen tested at ΔK_{III}=0.85$\Delta K_{th,I}$ test interrupted at N_f= 1.2·10^5 cycles: a) specimen surface; b) 90°tilted view, coplanar Mode III crack, 573µm deep.

DISCUSSION

It can be assessed from OOP fatigue tests carried out on both a gear and a bearing steel that the adopted novel experimental procedure, under loading condition of subsurface RCF, is able to promote shear coplanar Mode III propagation, which is faster than the mixed-mode (I+II) surface propagation. However, the superposition of compression onto an alternating shear should lead to an increase of dissipation with a reduction of crack driving force respect to simple shear. On the other hand the experimentally observed crack rubbing/deformation could promote shear propagation since it prevents the friction of the crack faces. The following analysis can confirm this intuitive explanation: if the experimentally observed crack surface profile of a central section of an OOP specimen is submitted to the maximum value of the compressive loading cycle, Fig. 5, it can be observed that only the 3 % of the crack surface profile is in contact.



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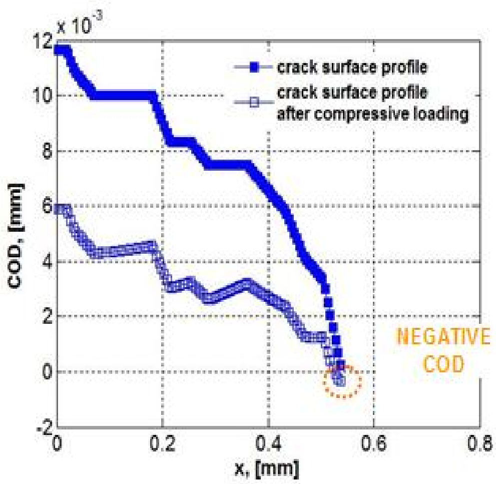

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Figure 5: a) OOP fatigue specimen tested at ΔK_{III}=0.8$\Delta K_{th,I}$ central area section, b) crack opening displacements

The crack opening displacements have been computed by the weight function method. Since only the 3% of the crack surface profile is in contact, sliding phenomena are strongly reduced and the friction role is reduced.

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