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Acoustic emissions caused by fretting induced adhesion, wear and cracking

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1. Introduction

Fretting wear and fretting fatigue are damage modes caused by very small amplitude sliding (from 0 to some hundreds of microns) between contact surfaces. The former is the formation of wear particles through mainly adhesive and abrasive wear mechanisms occurring in the contact. The latter is the nucleation of surface cracks which in the presence of a bulk fatigue load can accelerate the fatigue fracture process. Detecting these damage modes may be difficult without opening the contacts and performing extensive characterization. Some research has been directed to detection of fretting induced damage using acoustic emission (AE) sensors [1–3]. Furthermore, AE-monitoring has been used to detect conventional wear and fatigue crack propagation [4,5]. This study investigates the AE-signals created by torsional fretting induced phenomena large area contacts between self-mated quenched and tempered (QT) steel specimens in dry conditions.

Fretting tests were conducted with equipment described extensively in [6]. Gross sliding tests were run with constant sliding amplitudes of 35 µm (4 tests) and 77 µm (1 test). Stable friction type tests were done with constant displacement amplitudes of 4–15 µm (5 tests). All tests used a 30 MPa contact pressure and 40 Hz loading frequency. All except one measurements were continued for 3 million load cycles (the 77 µm gross sliding test was stopped after 40 000 load cycles). Figure 1 shows how the broad band AE -sensor was attached to the moving specimen holder with a 50 N force applied with springs.

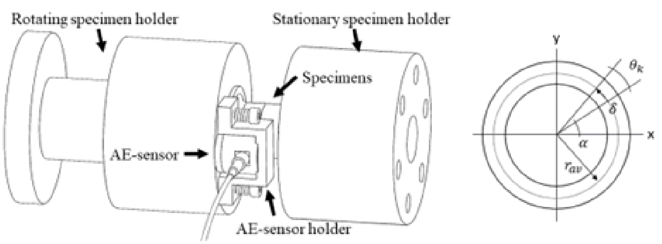

Figure 1. Left: Fretting test setup and attachment of the AE-sensor. Right: Specimen contact geometry.

2. Results

2.1. Gross sliding tests

The four repetition gross sliding tests showed similar features in their AE responses. The first AE hits (events where AE signal exceeds threshold voltage) were detected after 200 loading cycles by which time the coefficient of friction (COF) had risen close to its maximum value of around 1.2 in all tests. Typical COF evolution is shown in figure 2 where the COF peaks during early load cycles and then lowers to a steady state value. During friction peak in QT-QT contact adhesive junctions are formed. These adhesion spots experience plastic deformation and cracking in the early loading cycles and are the source of the first wear particles. The peak friction lasted up to around 10 000 load cycles after which it slowly set to around 0.8 which is typical for this material pair. After peak friction a more abrasive wear type dominates in the contact as a layer of oxidized wear particles covers the surfaces. After tests, the specimen surfaces were covered in fine oxidized powder and contained visible remnants of adhesion spots.

During peak friction, the AE amplitudes (maximum signal voltage of a hit) were low (up to around 85 dB) relative to later loading cycles (up to 105 dB). Similar evolution was noted in the AE energies with more energetic hits occurring only after peak friction. The dominant AE frequencies (highest magnitude peaks on the AE waveforms frequency spectra) at friction peak were mostly below 200 kHz with occasional high frequencies (up

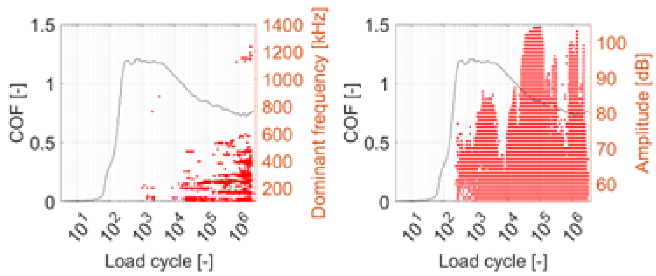

Figure 2. Dominant frequency (left) and AE amplitude (right) compared to COF in a gross sliding test.

to 1200 kHz). Dominant frequencies in the 100–200 kHz band were most common throughout all tests. After peak friction more signals with dominant frequencies of 300–600 kHz started occurring. Especially in the late parts of tests (after 100 000 load cycles), dominant frequencies of 1000–1400 kHz were also recorded. Generally the higher frequency signals had lower amplitudes than lower frequency ones. Figure 2 shows the AE amplitude and frequency evolutions during one tests.

In the shorter 77 µm gross sliding test the evolution of AE amplitudes and energies relative to friction conditions were similar to those in the repetition tests, but the recorded values were much larger and the number of hits in the recorded time was higher. The AE amplitudes around friction peak were up to 80 dB after which the highest recorded amplitudes rose to around 130 dB. It should be noted that in this test different AE recording equipment was used than in the other gross sliding tests which could affect the comparability of quantitative results, but the trends are similar to the other tests. The increased maximum amplitudes could be linked to the increased severity of fretting wear under higher sliding amplitudes. The dominant frequencies were found to be in the same ranges as in the smaller sliding amplitude tests and to follow friction evolution as earlier.

2.2. Stable friction tests

In stable friction tests the contact is mainly in stick or partial slip with very low sliding amplitudes for at least parts of the test. Therefore COF cannot de determined and the ratio of tangential and normal tractions (TR) is used instead. The average TR can be closely approximated by COF. TR stayed relatively stable in tests up to 9 µm displacement amplitude. In two 15 µm displacement amplitude tests, TR was unstable and showed a distinctive peak. After tests the smaller sliding amplitude test surfaces were relatively clear of loose wear particles and contained small adhesion spot remnants. The higher sliding amplitude test surfaces had evidence of larger scale adhesive damage concentrated mostly on their inner annuli.

In all stable friction tests much fewer AE hits were recorded than in the gross sliding tests. When sliding amplitude increased between tests, so did the number of hits and, to a lesser degree, the maximum values of AE amplitude. The AE amplitudes and dominant frequencies did not vary as much over the test durations as in the gross sliding tests, but there tended to be more hits recorded when the TR was higher. Figure 3 shows an example of this in AE data recorded from a test with a relatively stable TR (9 µm displacement amplitude). The TR peak correlates with a smaller sliding amplitude and a greater degree plastic deformation between adhesive junctions. The AE energies during peak TR also tended to be higher. Dominant frequencies in all stable friction tests were mosly between 100–300 kHz in all tests with very occasional higher frequency signals.

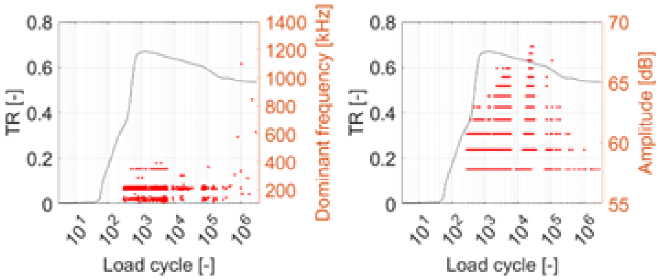

Figure 3. Dominant frequency (left) and AE amplitude (right)

3. Summary

Fretting tests with different sliding conditions were run with an adjacent AE-measurement to see the how the AE-signals correlate with the contact condition. AE amplitudes were found to increase with sliding amplitude in both gross sliding and stable friction tests. In gross sliding tests they also increased after COF had moved past its early peak corresponding with the wear type becoming more abrasive. A wide range of dominant AE frequencies was recorded. Very high dominant frequencies (1000–1400 kHz) were recorded mostly in gross sliding tests and these tended to have relatively low AE amplitudes. Based on these findings, AE-measurements could be used as indications of fretting related damage formation, and further fretting studies are required.

4. References

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