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Non-idealities in fretting contacts

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Summary. There is direct link between non-idealities in fretting wear, friction and fretting fatigue, especially in the case of adhesion spots. Friction is not a constant and varies as a function of load cycles and non-Coulomb friction may occur. Fretting wear may lead to material transfer, resulting in tangential fretting scar interactions, and in the long run, wear debris is entrapped and cumulated in the interface. Fatigue failure can occur at low nominal stress amplitudes due to non-Coulomb effects. Novel tools are required in component design to fully capture these non-ideal phenomena.

Key words: fretting, friction, fretting wear, fretting fatigue

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Description

Fretting stands for the action of small amplitude reciprocating surface sliding, causing fretting wear and fretting fatigue. Slip amplitude is orders of magnitude smaller than the size of the contact, especially in engineering applications where large flat-on-flat contacts are common and sliding is typically undesired condition. The appearance and severity of fretting fatigue is dependent on stress field but also essentially on tribological features, such as friction and wear, which may generate surface micro-cracks and accelerate the initial stages of fatigue. Damage may appear below the pure fatigue based stress limits inside the contact that cannot be inspected visually without opening the joint [2, 14]. Modelling of contacts is largely based on simple assumptions considering friction, wear and geometry [11].

This study investigates fretting induced non-idealities in wear, friction and fatigue cracking, observed with quenched and tempered steel specimens in self contact (34CrNiMo6+QT, abbreviated as QT-steel). Result obtained using three different kinds of fretting apparatuses with different contact and loading types [4, 5, 8, 9].

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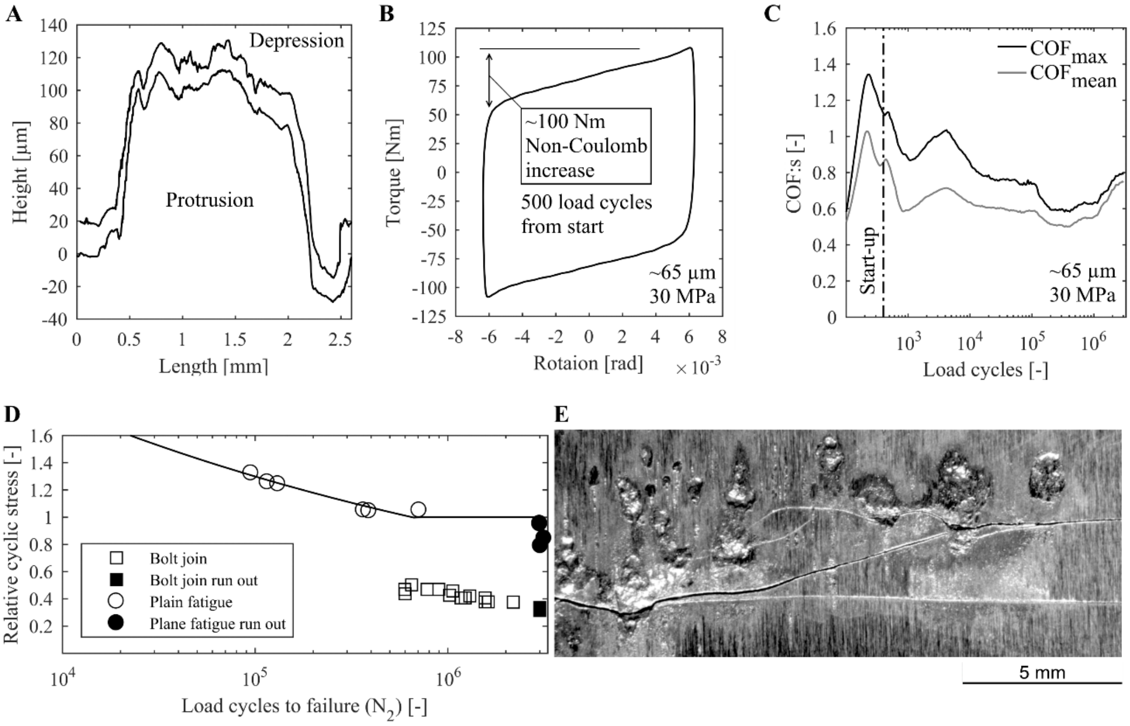

Figure 1. A) Material transfer spot profiles, B) non-Coulomb fretting loop, C) coefficients of friction, D) SN-curves and E) fatigue cracks at adhesion spots (re-printed from [3]). All measured using QT-steel fretting contacts.

Non-idealities in fretting wear

Commonly, ideal Archard wear law is assumed as a first estimate for wear, assuming that wear rate is directly proportional to sliding distance and normal load, and that wear particles simply disappear from the interface. This is often poor assumption in fretting contacts where active wear mechanisms change as fretting damage progress. Initially, wear can be adhesive, causing material transfer, and at latter stages of fretting wear particles tend to get entrapped in the interface leading to more abrasive wear conditions due to rubbing action of oxidized and work hardened metallic 3rd particles [2, 14]. Wear particles are also generated from highly work hardened top surface layer [13]

Fretting of QT-steel surfaces lead to adhesive wear and material transfer during the first few thousands of load cycles and up to few-millimetre-sized material transfer spots were identified [4, 5, 6, 10]. Surface profiles of the related protrusions and depressions have shown high degree of conformity, leading to tangential interlocking (Fig. 1A).

As the fretting load cycles continues to build up, wear particles are generated, entrapped and cumulated between the surfaces, and they start to take role in friction and wear behaviour due to velocity accommodation in third bodies [1]. At this stage, wear behaviour is strongly governed by ejection of wear debris, rather than forces and displacements. Experiments made with QT-steel contact showed that manual removal of entrapped wear debris lead to considerable increase in total wear [7].

Non-idealities in fretting induced friction

Typically, Amonton/Coulomb coefficient of friction (COF) is assumed in fretting calculations [2, 10, 11]; however, measurements have shown that this is not always accurate due to so-called 'non-Coulomb friction' [5, 6, 12]. COF can be calculated from the ratio of tangential force amplitude and normal load (COF_{max}) and from frictional energy dissipation (COF_{mean}) [5, 6]. During non-Coulomb fretting load cycle, the tangential load increases during gross sliding achieving its maximum value when the fretting movement reaches its extreme location (Fig. 1B). This kind of behaviour has been explained by the tangential fretting scar interactions which introduces inclined sliding conditions [6, 12]. COF_{max} can be significantly greater than COF_{mean}, if non-Coulomb friction prevails. It follows that the interlocked protrusions and depressions carry larger proportion of the tangential and normal loads; therefore, the material transfer spots are under high stresses in comparison to nominal stress levels assuming ideal contact geometry [6].

With QT-steel fretting contact, values of both COF:s evolve as a function of load cycles. During first few thousands of load cycles both COF:s peak to high values and then gradually reduce and stabilize. In stable conditions, frictional behaviour is close to ideal classic Amonton/Coulomb-friction (Fig. 1C). This behaviour can be explained at least partially by velocity accommodation in entrapped oxide third bodies. [5, 7]

Non-idealities in fretting fatigue

Dimensioning of fatigue prone components is often done using measured SN-curves. In case of QT-steel, a component can be designed to last for finite or infinite amount of load cycles. Notches and other sources of stress concentrations, such as fretting, make dimensioning more demanding; however, such conditions may be solved using fracture mechanics and stochastic approaches. Experiments made with sharp edged - and rounded contact geometries have demonstrated that fretting fatigue behavior, characterized by steep stress gradient and limited fretting wear, can be predicted using theory of critical distances and multi-axial fatigue criterion [9]. Fretting fatigue experiments with bolted joint were analysed using FEM, assuming ideal flat contact and it was observed that the fatigue limit was considerably lower than in the case of plain fatigue (Fig. 1D) [10]. Furthermore, the path of growing cracks were influenced by the location of the adhesion spots indicating the stresses near those locations are sufficiently high to have considerable impact on the crack nucleation and on the path of crack growth (Fig. 1E). Fretting can bring about fatigue related phenomena, which are not captured sufficiently if one assume ideal Amonton/Coulomb friction and ideal flat surfaces.

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