Ch. 15 Fretting wear

Short amplitude reciprocating sliding between contacts.
Large number of cycles.
Movement can be as short as 1 micron, due to mechanical vibration
Can be a microscopic contact within the contact area, without gross sliding
Damage is hidden in contact area.
Due to low sliding speed, lubrication is not effective in fretting prevention,
but may be effective in environmental protection

Due to pressure distribution, $p$, limiting frictional stress is not uniform.
For a tangential force $Q$, the distribution of tangential stress is $q_x$.

### Elastic Model:

$$q_x = \frac{Q}{2\pi a (a^2 - x^2)^{1/2}}$$

![Figure 15.1](image)

**Figure 15.1** Normal and tangential stress fields for Hertzian contact with and without slip.
(adapted from [5]).

![Figure 15.2](image)

**Figure 15.2** Effect of increased amplitude of fretting on fretting damage [6].

$$\frac{a'}{a} = (1 - \frac{Q}{\mu W})^{1/3}$$

where:
- $a'$ is the radius of the central unslipt region [m];
- $a$ is the contact radius [m];
- $Q$ is the superimposed tangential force [N];
- $\mu$ is the coefficient of static friction;
- $W$ is the normal load acting on the contact [N].

![Figure 15.3](image)

**Figure 15.3** Relationship between the radius of central stationary zone and oscillating tangential load (a) [7] and schematic fretting regime map (b).
Elasto-Plastic Model:

Similar to elastic model, but with area of plastic deformation

![Elasto-Plastic Model Diagram]

An analysis of a stress field during fretting revealed that plastic deformation occurs even for modest normal loads in most metals [10].

Mutual Overlap Coefficient (MOC) : Ratio of contact area of the smaller sliding member to wear track area.

Effect of amplitude and debris retention on fretting wear

![Pin motion and Wear track on the counterface]

Figure 15.6 Concept of the 'Mutual Overlap Coefficient' [13].

Effect of wear debris retention due to different MOC

![Effect of wear debris retention due to different MOC]

Figure 15.7 Wear rates of selected polymers versus temperature at low and high values of the 'Mutual Overlap Coefficient' [13].
Effect of environment on Fretting Wear

Oxidation at contacting surface cause change of chemical composition at surface

Polymerization of organic pollutant can occur at contact surface of noble metals.

Figure 15.8 Mechanism of debris entrapment in a fretting contact.

Figure 15.9 Variation of contact resistance for steel surfaces fretted first in nitrogen and then in air [18].

Figure 15.10 Mechanism of friction polymer formation in fretting electrical contacts.

Figure 15.11 SEM micrograph of the fretting contacts: a) between two crossed steel wires after 10^6 cycles, 5 N load and 25 μm fretting amplitude and b) between two ceramic surfaces after 10^6 cycles, 5 N load and 25 μm fretting amplitude.
Effect of temperature and lubricants on fretting

High temperature increases corrosion and oxidation resistant
High temperature changes material properties.

![Graph showing effect of temperature and lubricants on fretting](image)

**Figure 15.12** Effect of temperature and gas environment on fretting wear of mild steel [28].

Protective oxide layer at high temperature, and strain aging at 200°C.

**Fretting Fatigue:** Combination of fatigue due to bulk stress which cause gross alternating movement, and micro-sliding due to fretting.

![Graph showing fretting fatigue](image)

**Figure 15.14** Example of a reduction in fatigue life due to the combined effect of fatigue and fretting [40].

Fretting accelerates crack initiation.

![Diagram showing mechanism of surface microcrack initiation in fretting contacts](image)

**Figure 15.15** Mechanism of surface microcrack initiation in fretting contacts (adapted from [11]).

Fretting accentuates effect of Fatigue wear.
Fretting accelerates crack initiation.

Combined effect of corrosion and fretting to fatigue wear

Practical examples of fretting:

\[ S_n = S_a - 2 \mu P_a [1 - e^{-k \cdot l}] \]

where:
- \( S_n \) is the fretting fatigue strength [MPa];
- \( S_a \) is the fatigue strength in the absence of fretting [MPa];
- \( \mu \) is the coefficient of friction;
- \( P_a \) is the contact pressure [MPa];
- \( l \) is the fretting amplitude [\( \mu m \)];
- \( k \) is a constant. Typically \( k = 3.8 \ [\mu m]\) [19], which renders the exponential term negligible for amplitudes of slip greater than 25 [\( \mu m \)].
Controlling of fretting:
Reduce shear stress at contacting surface by part design.
Apply surface coating to reduce adhesion or oxidation
Use polymer gasket at contact as sacrificially worn material.
Introduce residual compressive stress to suppress crack initiation.

![Fretting Mechanism]

Figure 15.19 Suppression of fretting by design optimization in a press-fit shaft assembly (adapted from [S]).

Minor wear mechanisms

Melting Wear

Melting point of the least refractory material

Local temperature

Ambient temperature

Schematic illustration of the formation of molten layer.

Figure 15.20

Can have benefit in providing liquid lubrication at high sliding speed, where high temperature occurs. Ex. Ice skating, Cu-10Zn coating of gun barrel.

Reduction of friction coefficient at high sliding speed due to melting of low melting point metals.

Figure 15.21 Effect of sliding speed on the coefficient of friction measured between bismuth on steel and copper on steel combinations [S].
Mechanism of melting wear.

Beyond critical sliding speed, friction coefficient is approximated by:

$$\mu = \mu_{\text{threshold}} \left( \frac{U_{\text{threshold}}}{U_{\text{sliding}}} \right)^k$$ (15.4)

where:
- $U_{\text{threshold}}$ is the threshold speed [m/s], i.e., critical minimum value of sliding speed below which melting does not occur;
- $U_{\text{sliding}}$ is the sliding speed [m/s];
- $\mu_{\text{threshold}}$ is the friction coefficient at or below threshold speed.

Wear due to electrical discharge.

Diffusive wear: Dissolution of a high alloy surface.
**Impact wear:** Repetitive collision between opposing surfaces.

**Mechanism of impact wear:**
- Sliding due to relative movement of the surfaces accelerates wear rate.
- Figure 15.25: Repetitive stress pulses under impact wear.
- Figure 15.26: Schematic illustration of the mechanisms of impact wear.
- Figure 15.27: Sliding movements during impact wear caused by elastic deflection.