Corrosion and Fretting Corrosion. A Glossary.

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Mechanically initiated interface deterioration (wear and fretting)

Wear is defined as surface damage characterized by progressive loss of material due to relative motion between opposing surfaces.[4]

Fretting is defined as: „A special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force" (ASM Handbook on Fatigue and Fracture).
Several authors have analyzed the necessary magnitude of motion needed to create this phenomenon and it has generally been defined as being very low, between 1 and 100 µm.[5,6] Given the magnitude of loading in the body, all modular junctions of prostheses are susceptible to fretting.

Chemical initiated interface deterioration (corrosion and crevice corrosion)

Corrosion in the engineer's definition is the visible destruction of a structure and, in final consequence, the loss of function, while for a chemist it is an irreversible surface reaction of a material with its environment in a way that the material is consumed and its dissolved species become part of the environment. It is described as a surface degradation due to electrochemical interactions producing metallic ions and salts[7] and applies only to metallic materials. Only noble metals like gold have a surface which is self-protecting from corrosion, while all other metals and alloys in air spontaneously rely on a reaction with oxygen, forming a more or less protective (passivation) oxide layer, shown in **Figure 1**.

Any violation of this oxide film will lead to immediate corrosion (ion flow) until the film is formed again.[8]
The time to rebuild a protective oxide layer again is called repassivation time. It is dependent on the metal composition and the availability of oxygen and takes only milliseconds [9], for Ti6Al4V about 60 ms10.

Classification of corrosion phenomena

Eight distinct forms of corrosion have been defined

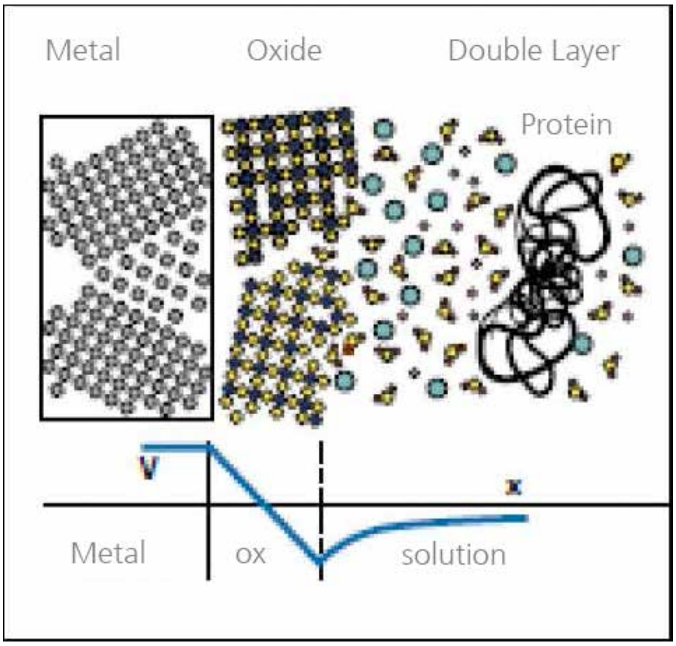

Fig. 1 Schematic of metal-oxide-solution interface with protein molecule and voltage variations (with kind permission of L. Gilbert)

1. Uniform or general corrosion refers to the inevitable corrosion to which all metals immersed in electrolytic solutions are condemned.[11] It is the uniform removal of material from surfaces, a phenomenon for all metals. Alloys used for implants have a high resistance against uniform corrosion, making it a very slow, visibly undetectable process.

2. Galvanic or two-metal corrosion is the dissolution of metals driven by macroscopic differences in electrochemical potentials, usually as a result of dissimilar metals in proximity.[12] This form of corrosion needs 3 conditions, of which all have to be met:

a. Two different metals (= different corrosion resistances)

b. Physical (conductive) contact (for electron transfer)

c. Aqueous (electrolytic) environment (for ion transfer)

3. Fretting corrosion (and erosion) is corrosion assisted by mechanical action: the passive layer of a metal or alloy is permanently damaged, leading to accelerated corrosion of the unprotected surface. It is defined as deterioration at the interface between contacting surfaces as the result of corrosion and a slight oscillatory slip between two surfaces.[4] Fretting currents consist of dissolution and repassivation reaction.[13]

4. Crevice corrosion is the localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from the full environment of close proximity between the metal and the surface of another material.[4] Crevices can appear as narrow cracks, e.g., after the overload of a metallic device, or as small gaps between interfaces of modular components. The conditions in the crevice are different from the environment, leading to a small galvanic element and local corrosion.

5. Pitting corrosion is a form of localized, symmetric corrosion in which pits form on the metal surface.It is initiated by mechanical stress, such as scratches or tribological loads.

6. Intergranular corrosion is a form of galvanic corrosion due to impurities and inclusions in an alloy. [11] It is a local attack, initiated by grain boundaries whose composition and structure differ strongly from the grains. Corrosive attacks can be intensified by galvanic effects between grains and grain boundaries. Intergranular corrosion is more likely for cast alloys than for wrought alloys.

7. Selective leaching is a form of corrosion that results from chemical differences not within grain boundaries but within the grains themselves[11] and is defined as the removal of specific components of an alloy from the device's surface, initiated by weakly bound or readily solvable elements and/or aggressive media. Leaching is more likely for multiphase alloys with grains of different composition and structure than for single-phase materials. Leaching can be a process accompanying the passivation of a surface. Solvable elements, such as Fe or V, leave the surface and lead to a higher concentration of corrosion resistant elements, such as Cr or Ti, thus protecting against further corrosive attacks.

8. Stress corrosion and corrosion enhanced fatigue are phenomenons in which a metal in a certain environment, especially those rich in chlorides, is subjected to stress and falls at a much lower level than usual as a result of corrosion.[14] General or uniform corrosion cannot be avoided. However, for modern implant materials, it is an extremely slow process (some ng per cm^2 and per day). Taking account only of general corrosion, the lifetime of an implant exceeds by far the life of the patient. All other forms of corrosion can be avoided or reduced by appropriate choice of materials, designs and handling. If corrosion cannot be avoided, care has to be taken to limit it as much as possible.

Corrosion is – like wear – a system property and multifactorial. It depends on the material: metal type – composition, structure, homogeneity, impurities, defects, electropotential, repassivation capacity etc.; the manufacturing process; the surface conditions, especially roughness; the design (dimensions and tolerances), especially for modular connections like a Morse taper; and the surrounding environment, especially load, motion and pH5 and the complex metallurgical, chemical, electrical, and tribological factors.[12,15,16]

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