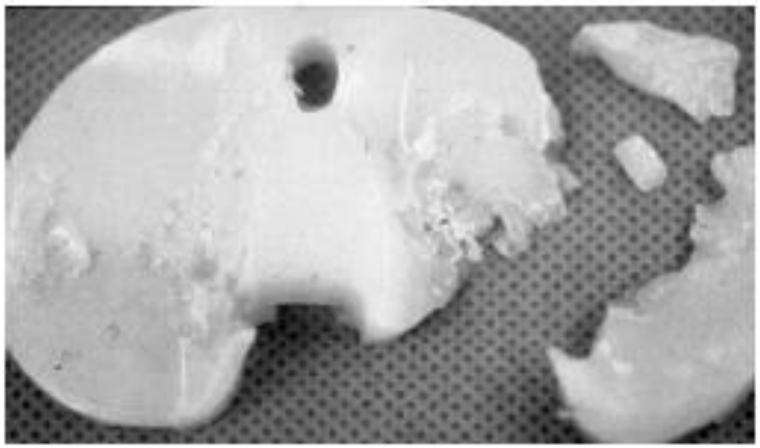
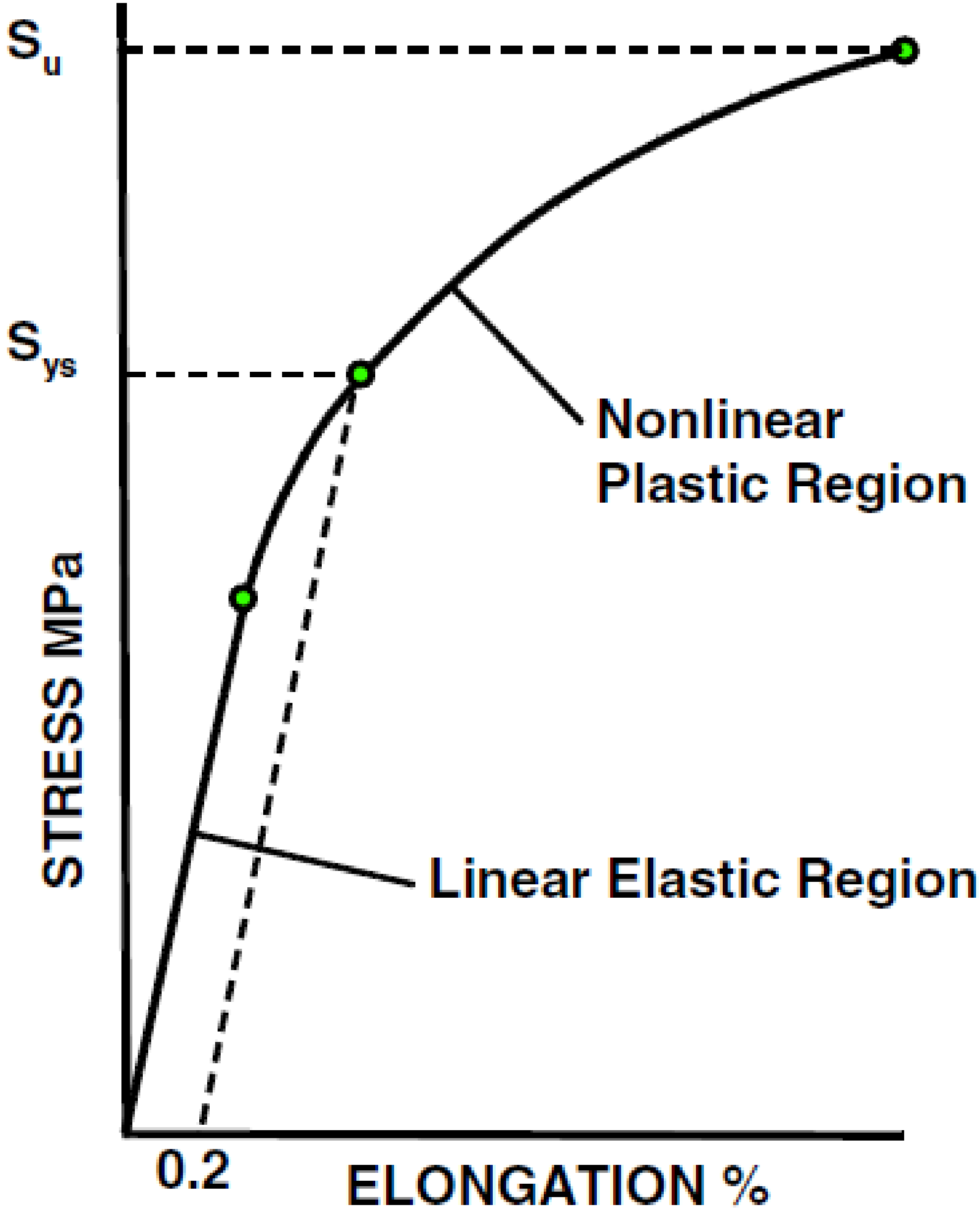
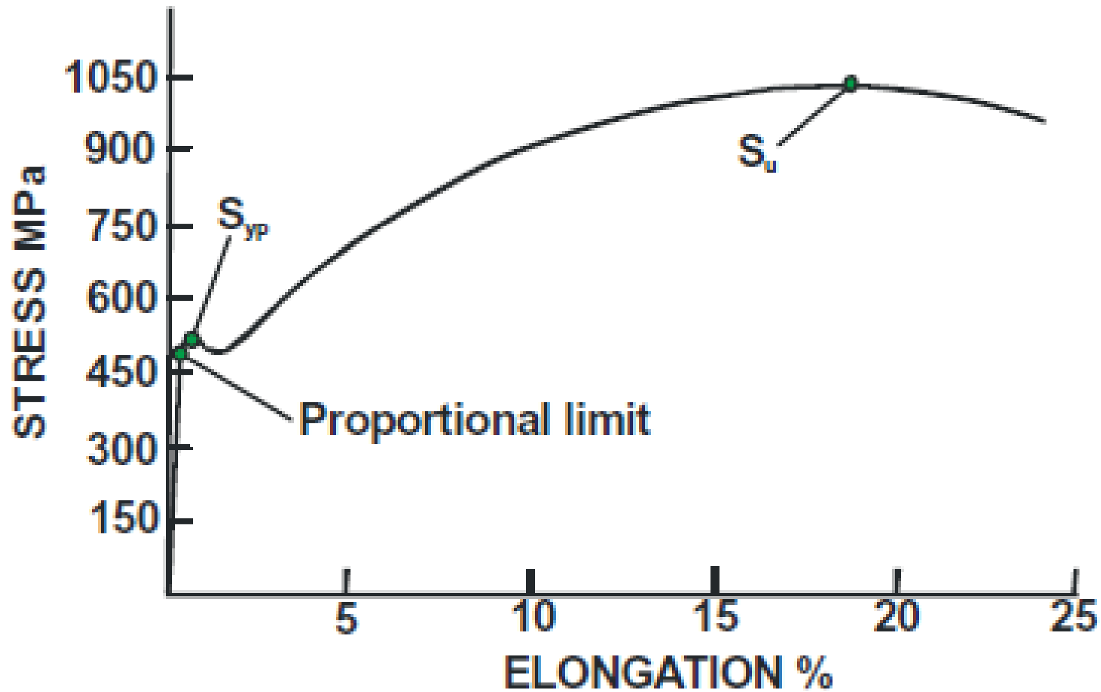
Failure modes





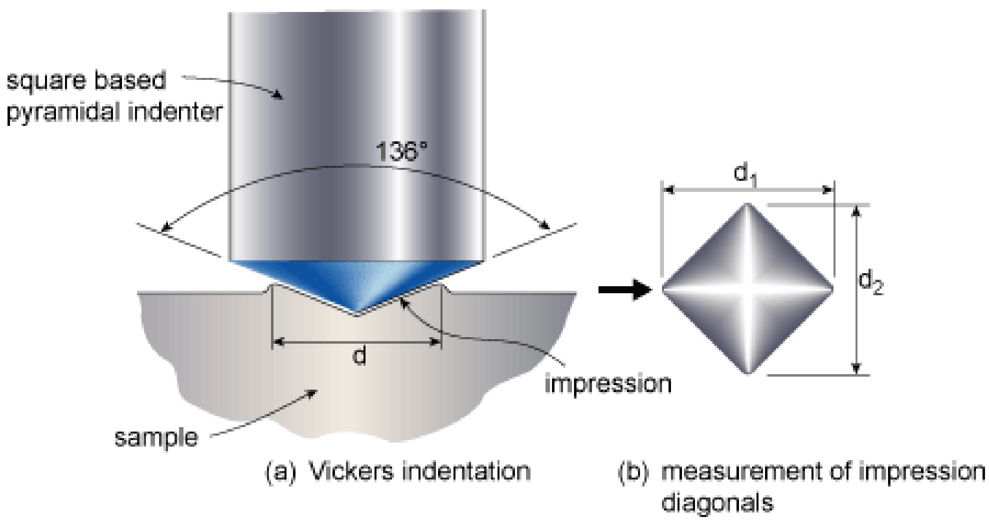
Typical Tensile Stress – Strain Diagram for Many Metals

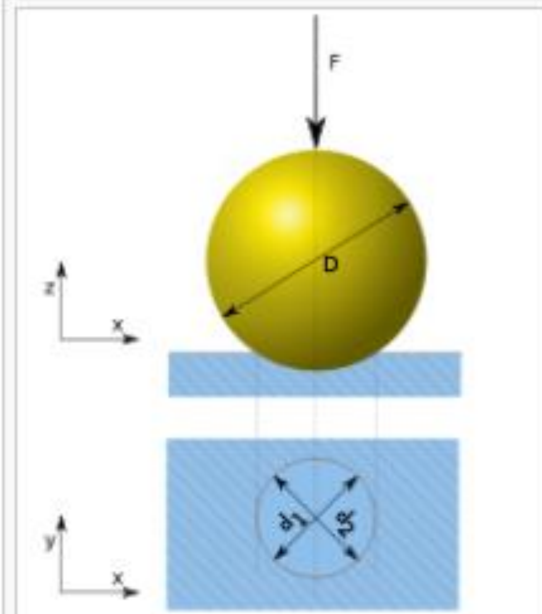
Typical Stress – Strain Diagram for Steels



Hardness

Hardness is measured as the resistance to penetration by a specifically defined penetrator. A machine applies a specified load with a specified penetrator. For example the Rockwell hardness value scales ranging from A through G are used primarily for metals. The Vickers machine is used to test hardness of extremely hard metals and ceramics. The scales are such that the greater the hardness number the harder the material.





Force diagram

Brinell scale, or Rockwell

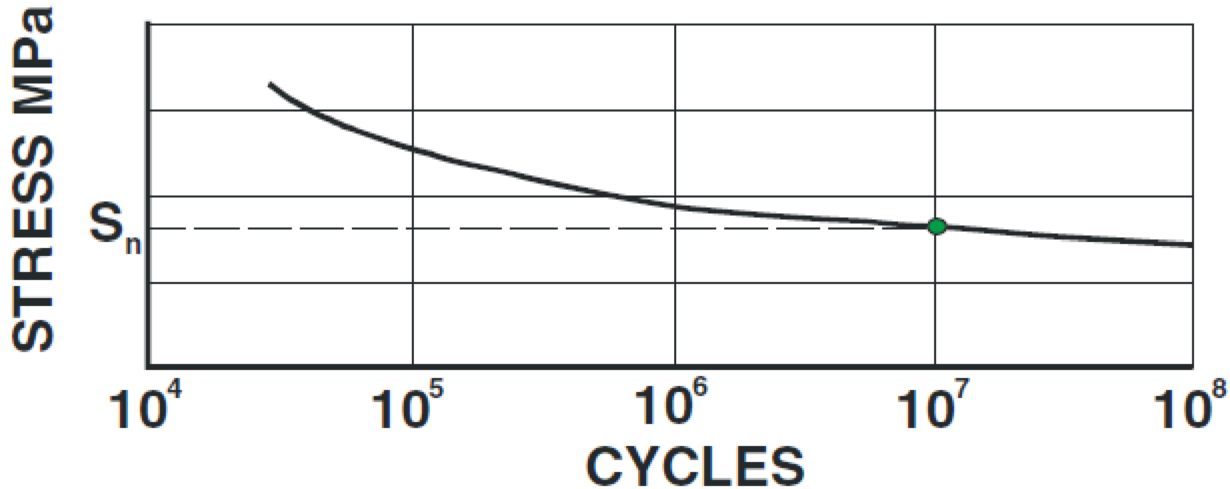
Fatigue Resistance

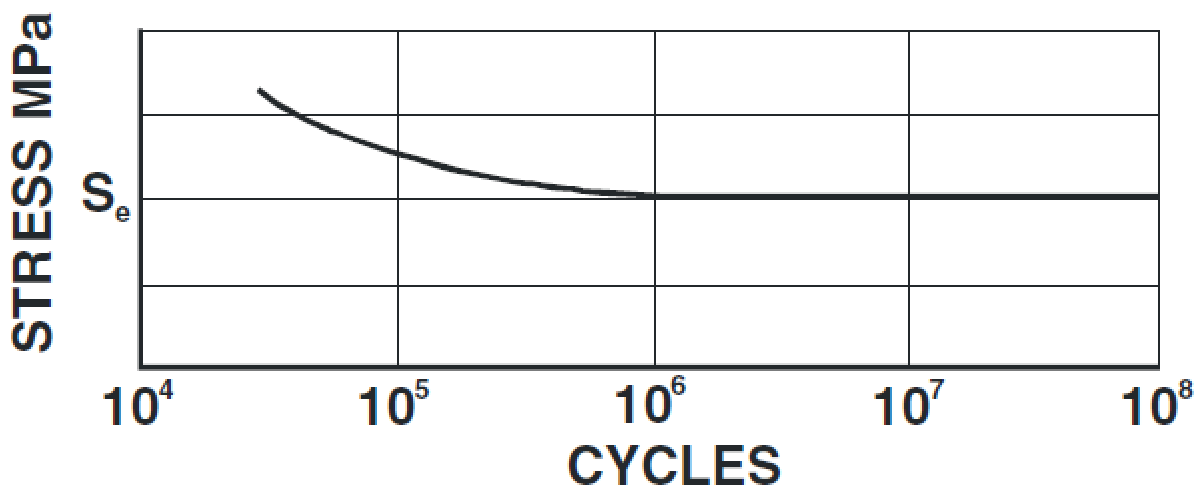
The values obtained from a tensile test may be used for the stress analysis of a part under static loading. Under fluctuating loads, however, additional fatigue properties are needed to provide information on how designs may behave under such loading.

Fatigue Resistance

The SN Diagram

Fatigue strength S_n





Steels:
Endurance Limit, S_e

Stress Analysis

Stress

$$\sigma = \Delta P \div \Delta A$$

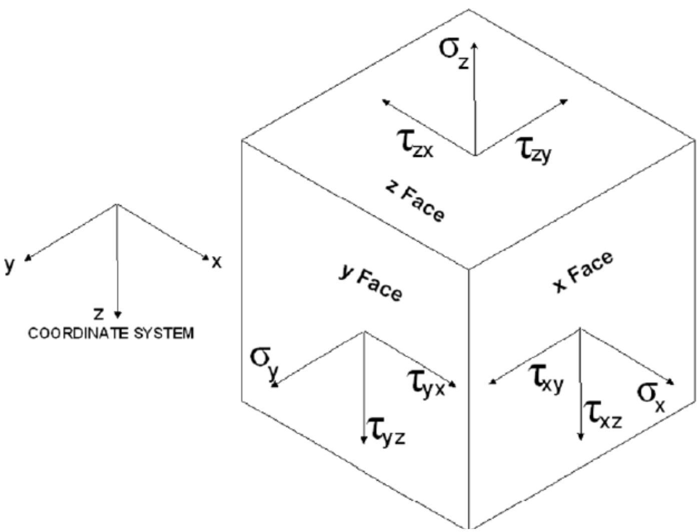
$$limit\ \Delta A \rightarrow 0$$

ΔA is the area loaded

ΔP is the force on this area

and σ is the stress.

Combined 3D Stress



Distortion Energy Theory

$$\sigma_{eq}{}^{2} = \sigma_1{}^{2} + \sigma_1{}^{2} + \sigma_1{}^{2} - \sigma_1 \sigma_2 - \sigma_1 \sigma_3 - \sigma_2 \sigma_3$$

where σ_{eq} is the equivalent stress, often called the "Von Mises" stress

Soderberg Failure Criterion – Fatigue Failure

$\sigma_f = \sigma_m + \sigma_r S_y/S_n$,

where

$\sigma_m = (\sigma_{max} + \sigma_{min})/2$

$\sigma_r = (\sigma_{max} - \sigma_{min})/2$

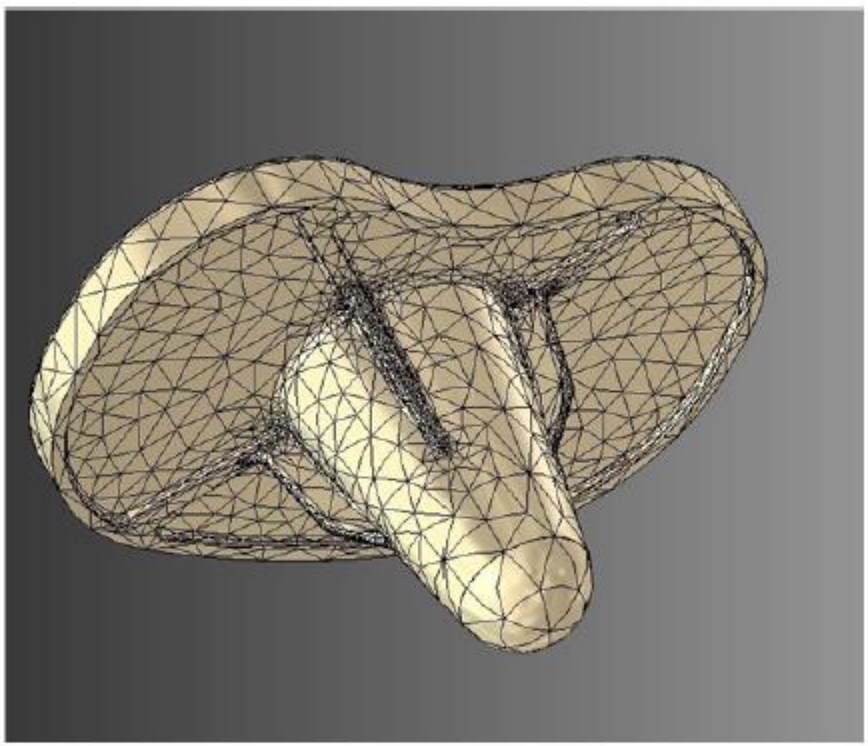
and σ_f is the failure stress, σ_{max} is the maximum stress at a point during the fluctuation and σ_{min} is the minimum stress, S_n, fatigue strength, S_y, yield strength.

For a typical implant or instrument, a part is assumed safe against fatigue, if:

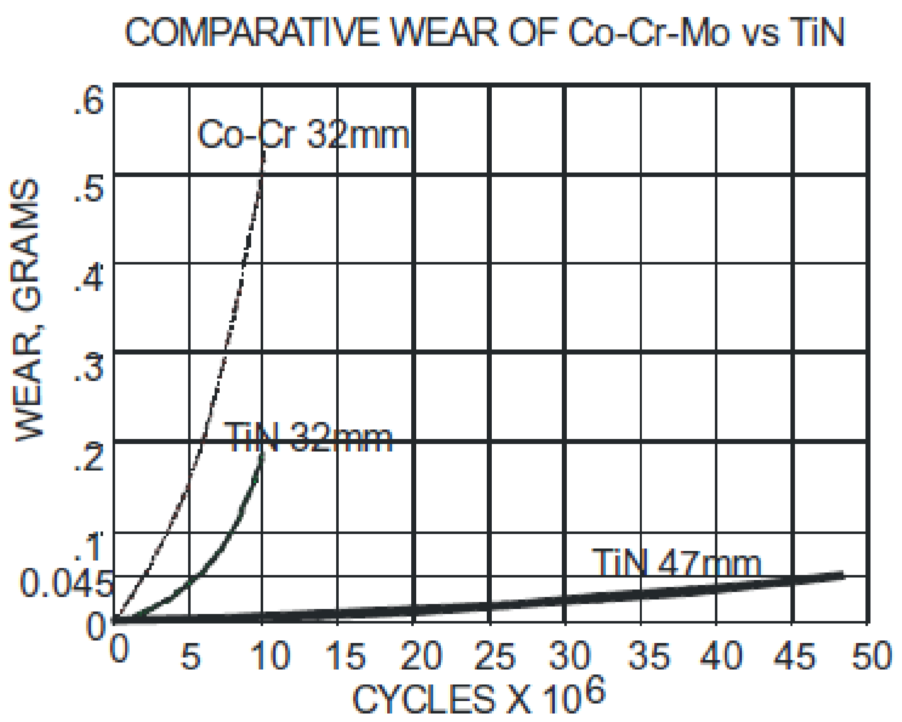
$S_n/N < \sigma_m + \sigma_r S_y/S_n$, where N is the factor of safety.

Stress Computation

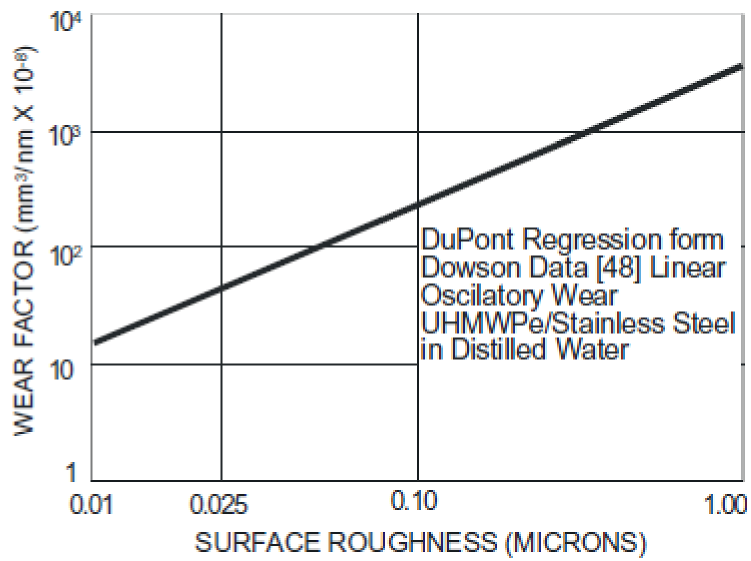
Finite Element Analysis (FEA)



Mechanical Testing



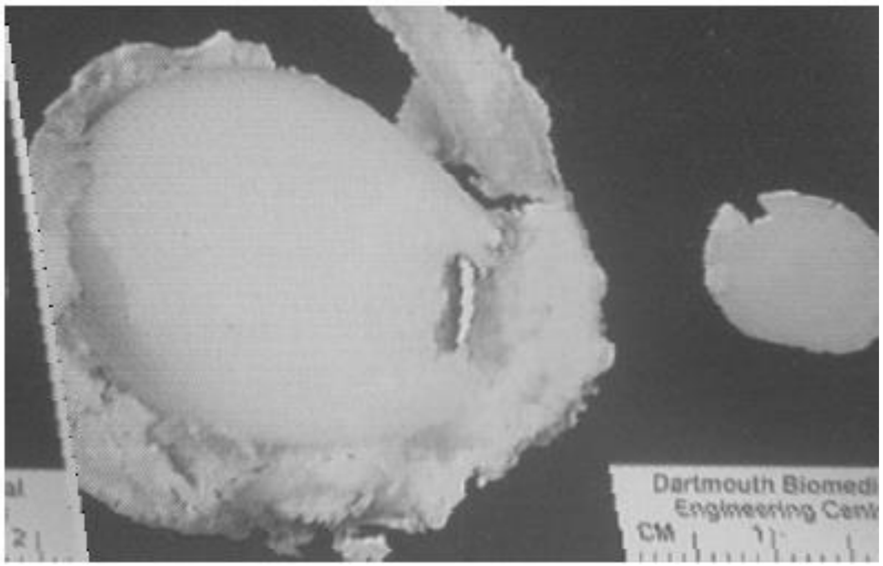
Wear in a Hip Simulator Comparing TiN and Co-Cr vs. UHMWPe



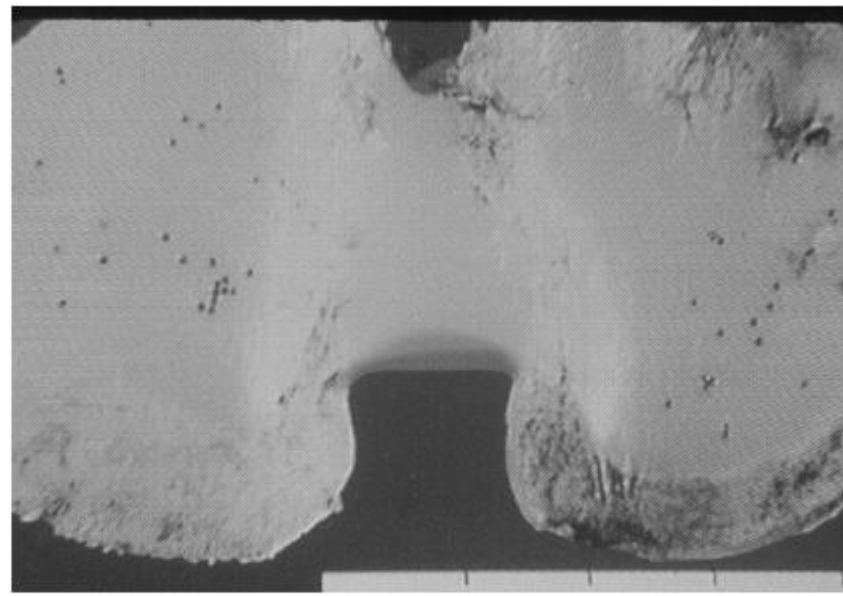
Wear vs. Surface Roughness

Wear

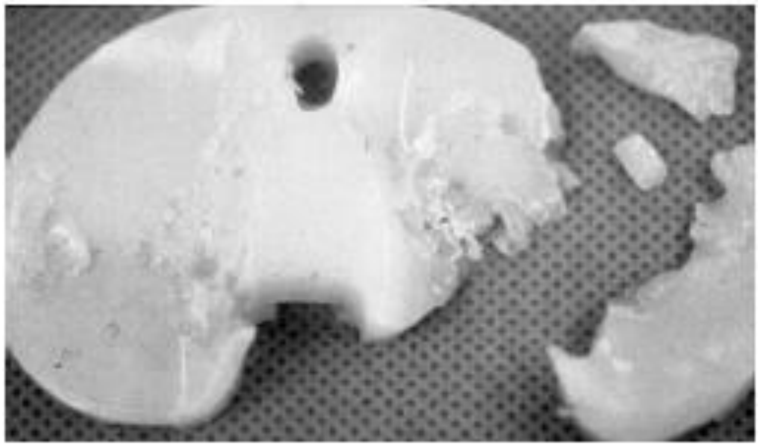
The most serious mechanical complication is wear rather than fracture or deformation of the metallic elements of a device



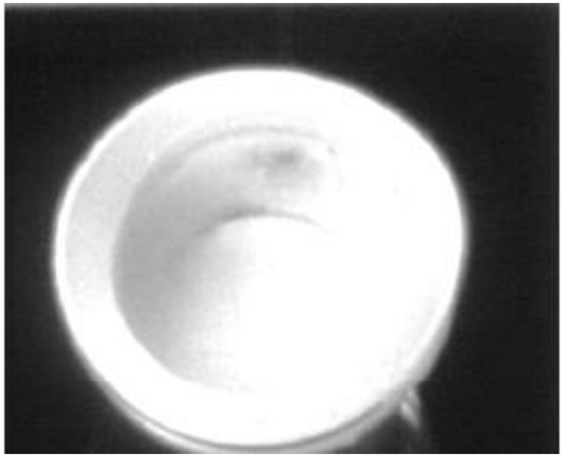
Failed Metal-Backed Button Type Patellar Component



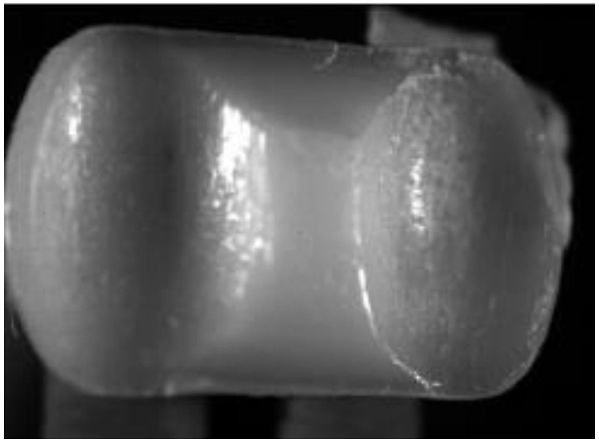
Typical Failed PCA Bearing



Fractured UHMWPe Tibial Knee Bearing



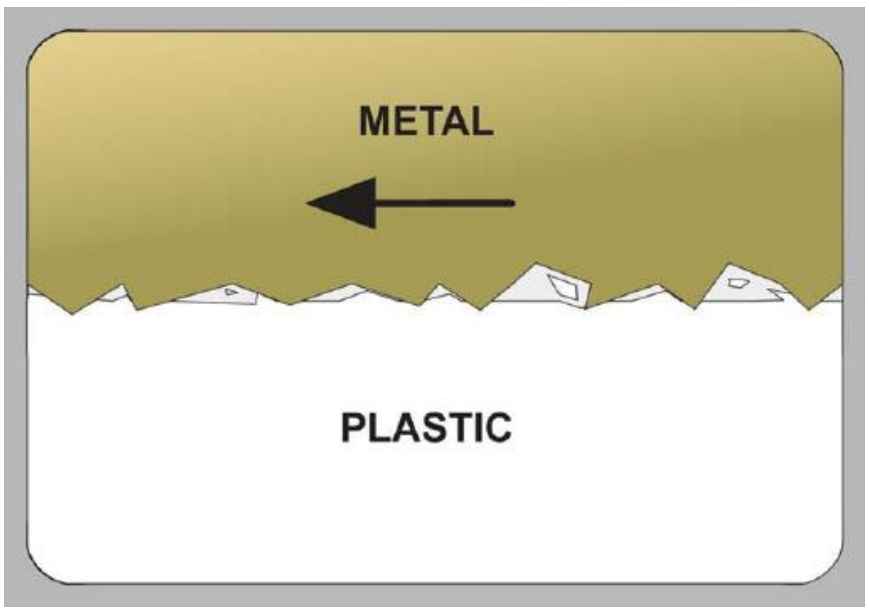
Worn Through Acetabular Cup, 17 Year Retrieval

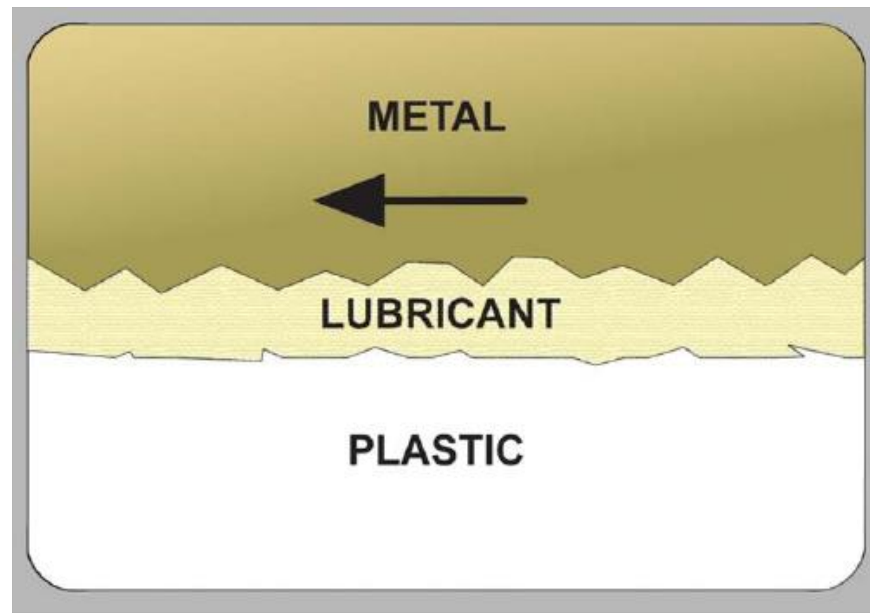


Total Condylar Tibial Component Showing Fatigue Pits

Abrasive Wear

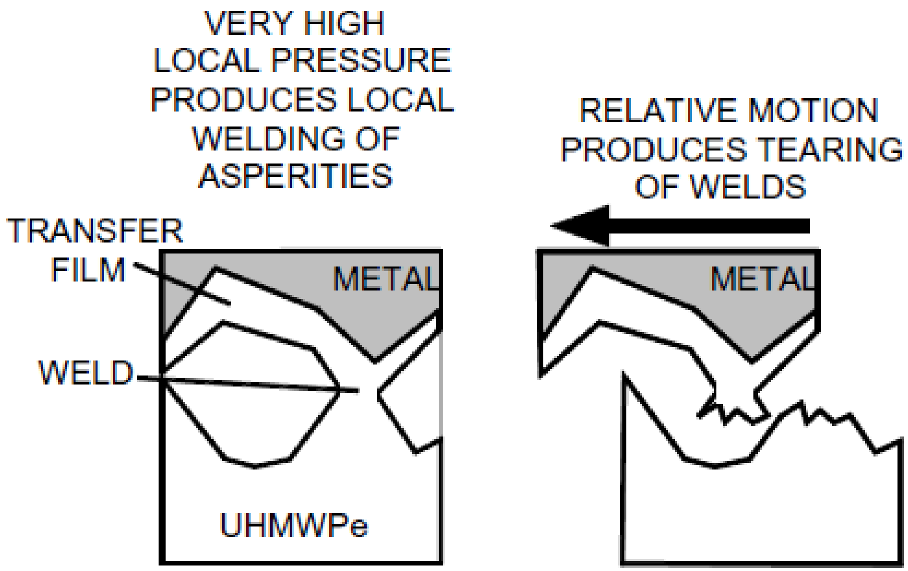
Abrasive wear results from direct contact between the metal and plastic components





Adhesive Wear

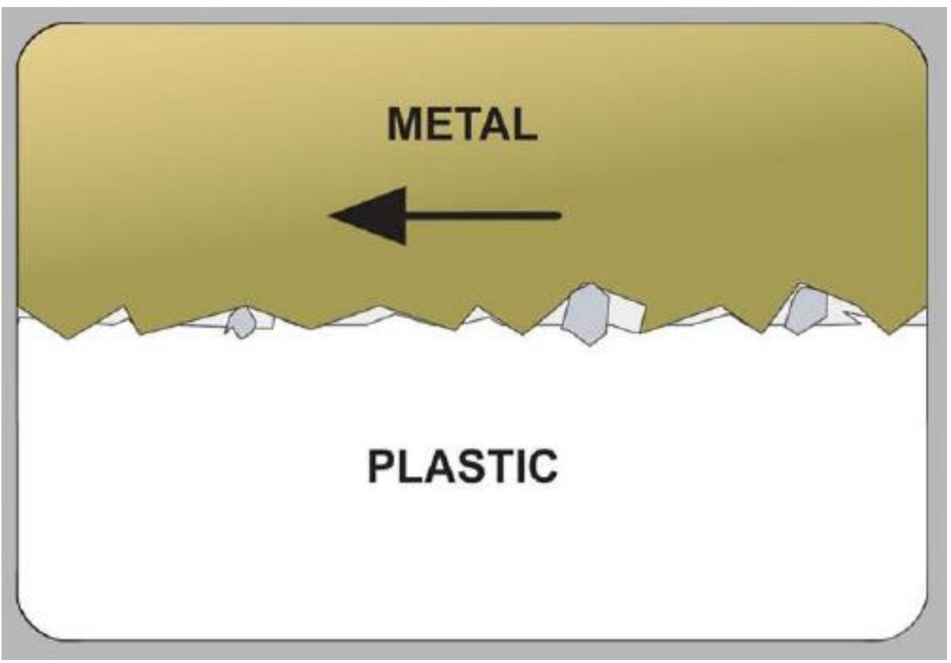
This type of wear results from localized welding and tearing, rather than gouging, of the contacting surfaces

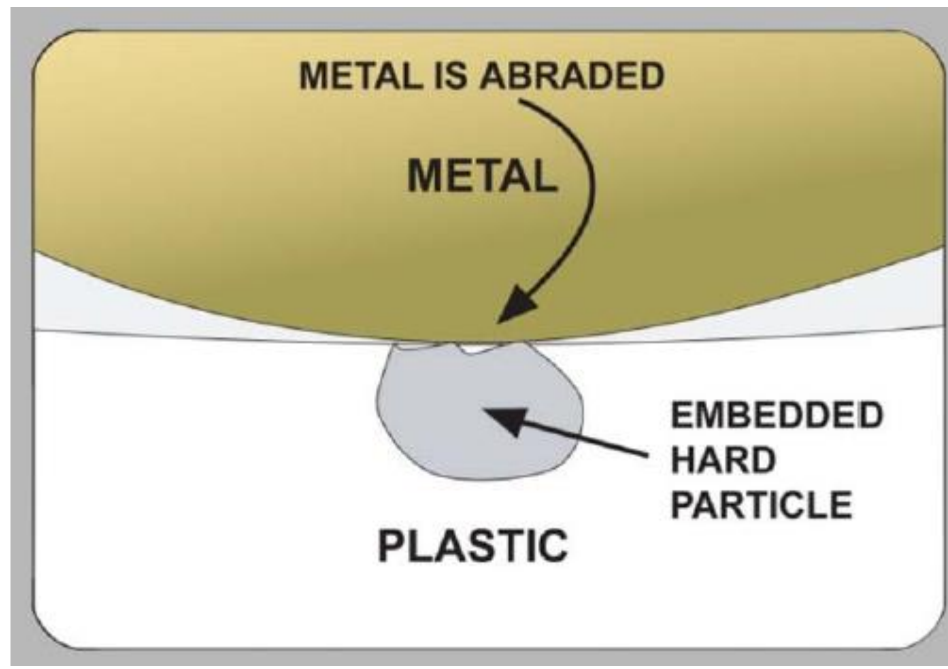


Such wear can apparently be minimized with ceramic - UHMWPe articulations

Third-Body Wear

The presence of contaminants such as cement, bone debris, and loose metallic beads, as well as the wear debris of the articulating couple, also contribute to wear. This contribution is called "three-body wear"

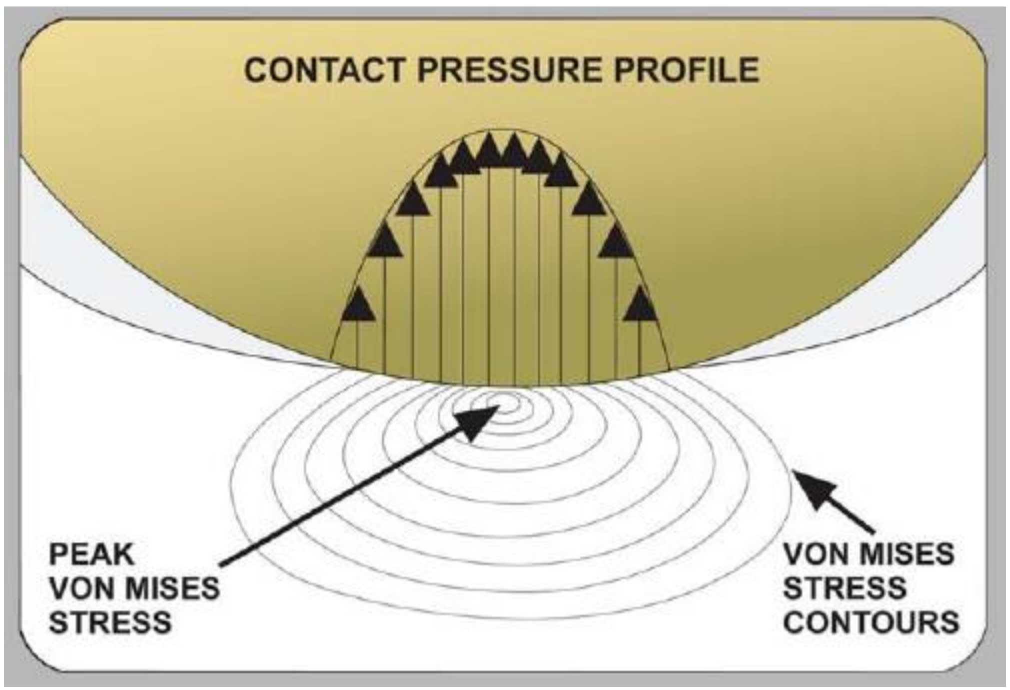


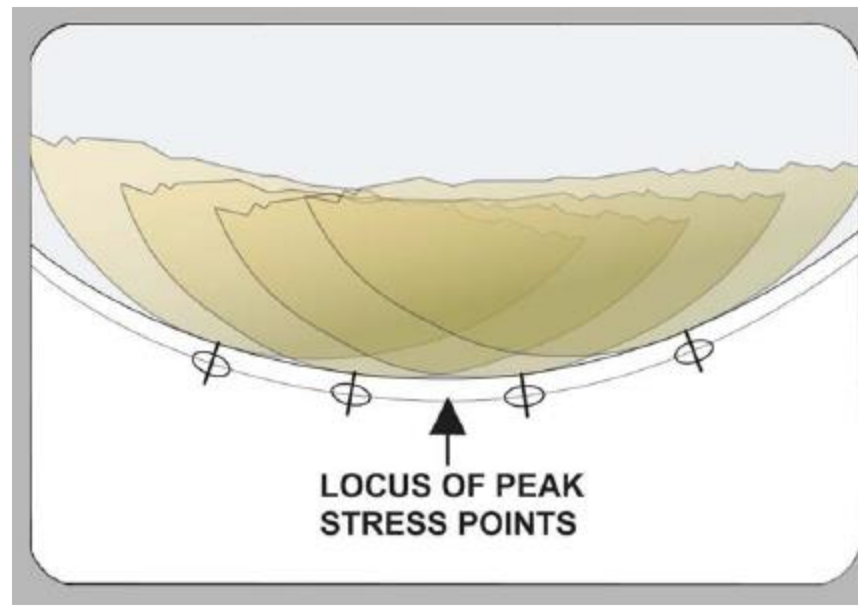


The much harder ceramic surfaces are more resistant to the effects of such contaminants

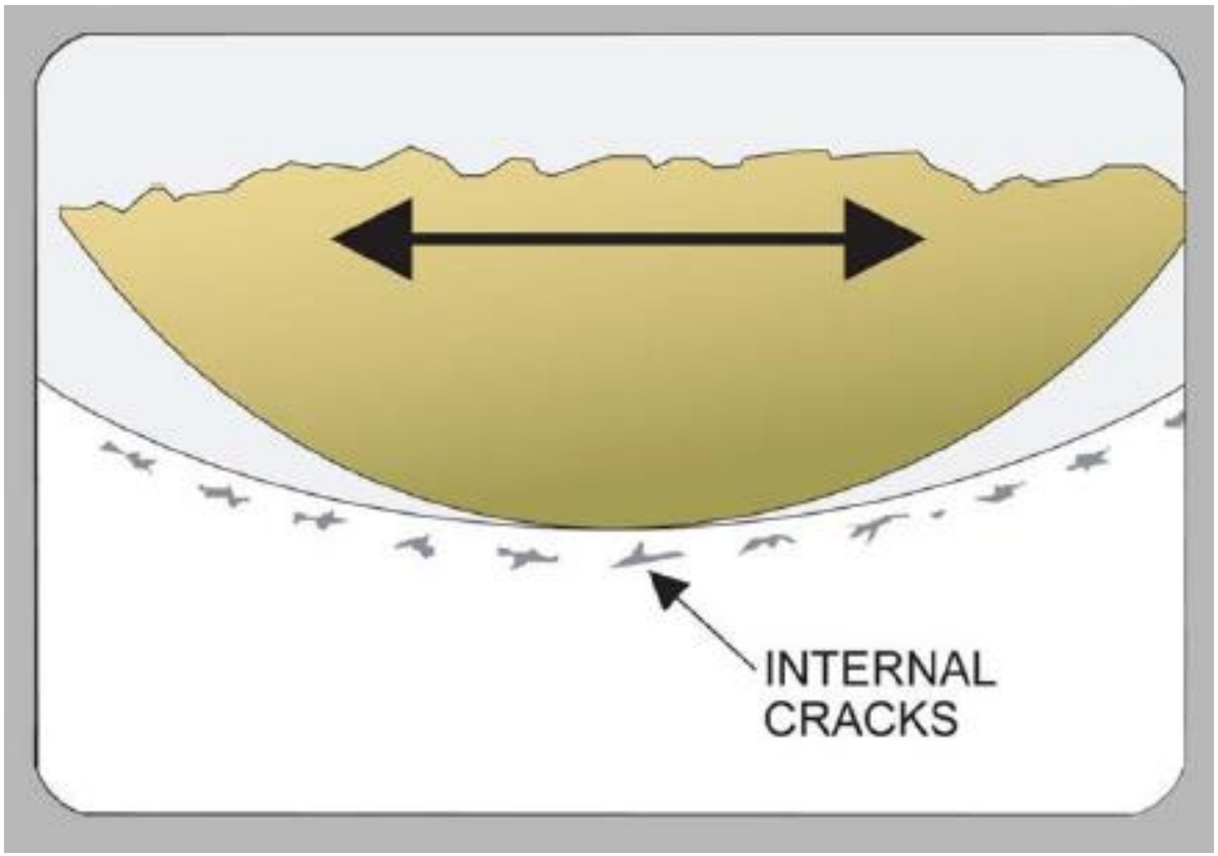
Surface Fatigue

As the metal component slides and rolls over the surface of the weaker plastic surface the point of peak stress will move under the surfaces of the plastic

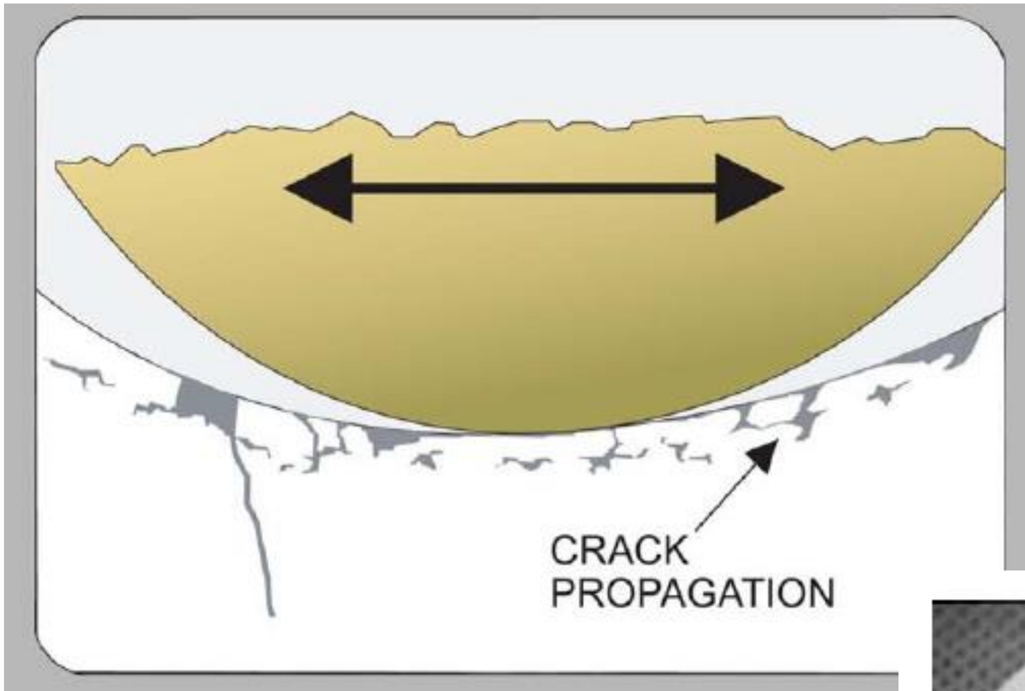


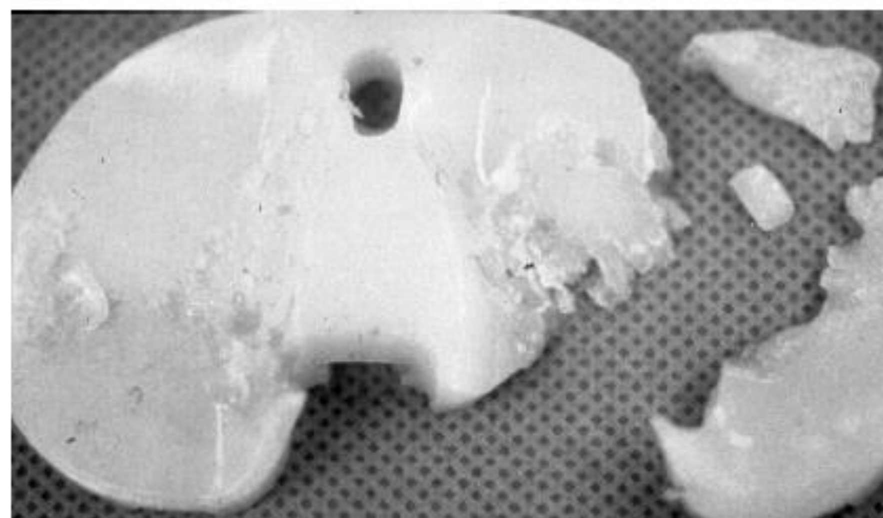


If the stress is high enough cracks will initiate below the surface



The cracks may then coalesce to produce pitting, delamination, and by propagation through the part, catastrophic failure





Biological Failure

Infection

Septic joint replacements occur in 1-2% of cases overall. The gram positive organisms of staph aureus and staph epidermides are most common and generally thought to occur at the time of initial surgery or shortly afterwards if the skin incision fails to heal in a timely fashion.

Osteolysis

Small (submicron) polyethylene or metallic wear particles incite an inflammatory process, whereby macrophages and giant cells, phagocytose the particles and attempt to digest them with lyzozymes and proteolytic enzymes. The wear particles persist in the cytoplasm of these cells and continue to stimulate digestive enzyme production, which spills over into the surrounding bone and begins to digest this host bone. Once enough bone is lost in this osteolytic process, a cystic cavity filled with these macrophages and giant cells replaces the normal bone and begins to expand.

Progressive Osteoporosis

Disuse atrophy of the bone, also known as progressive osteoporosis occurs when the patient fails to load the bone sufficiently to maintain its strength and integrity

Avascular Necrosis

Vascular compromise (lack of blood flow) to supporting bone causes bone cell death, known as avascular necrosis or osteonecrosis, response to tissue injury caused by pressure , friction , repeated load or overload and external trauma.

Peri-prosthetic Fracture

Although there is a mechanical component to fractures surrounding joint replacement implants, it is a failure of the bone that creates instability and can even be life-threatening if sufficient fat emboli compromise cardio-vascular function.

Tumor Formation

Pseudotumors or malignant tumors can compromise a well-functioning joint arthroplasty. Pseudotumors generally form from wear debris particles that accumulate.