Biomaterials

First Course

Third Stage

By

Prof. Dr. Qahtan Adnan Hamad

Lecture No. (8)

Shape Memory Alloys & Bio-metallic Failure

Titanium and Titanium Alloys

Commercially pure titanium (CP Ti) and its alloys (Ti-6Al-4V) are the two most common use as base implant biomaterials. These materials are classified as biologically inert biomaterials. Titanium based alloys are finding for ever increasing applications in biomaterials due to their excellent mechanical, physical and biological performance. Titanium and its alloys are getting great attention in both medical and dental fields because of:

(a) Excellent biocompatibility.

(b) Light weight.

(c) Excellent balance of mechanical properties.

(d) Excellent corrosion resistance.

Titanium and titanium alloys are commonly used for implant devices replacing failed hard tissue, for example, (1) artificial hip joints, (2) artificial knee joint, (3) bone plate, (4) dental implants, (5) dental products, such as crowns, bridges, and (6) used to fix soft tissue, such as blood vessels.

Titanium and titanium alloys are common use in cardiovascular implants, because of their unique properties. Early applications examples were prosthetic heart valves, protective cases in pacemakers, artificial hearts and circulatory devices.

The advantages of titanium in cardiovascular applications are that it is strong, inert, and non-magnetic while the disadvantage is that it is not sufficiently radio-opaque in finer structures.

One titanium alloy (Ti-6Al-4V) is widely used to manufacture implants biomaterials. The main alloying elements of the alloy are aluminum (5.5-6.5%) and vanadium (3.5-4.5%). The addition of alloying elements to titanium enables it to have a wide range of properties. **Titanium alloy (Ti-6Al-4V) versus Pure titanium (Ti) metal are:**

- Titanium alloy is stronger than titanium metal.
- Both have relatively low elastic modulus.
- Both have low wear resistant than SS or Co-Cr-Mo alloys.

- Both have the best corrosion resistance.
- Both have excellent bone bonding.

While the other type of titanium alloy is titanium—nickel (Ti Ni) alloys show unusual properties, that is, after it is deformed the material can snap back to its previous shape by heating of the material. This phenomenon is called **shape memory effect (SME)**.

The (Ni Ti) alloy exhibits an exceptional SME near room temperature: if it is plastically deformed below the transformation temperature (room temperature) it reverts back to its original shape as the temperature is raised to room temperature. Figure (3) as can be seen, the stress does not increase with increased strain after the initial elastic stress region and upon release of the stress the metal springs back to its original shape in contrast to other metals such as stainless steel.

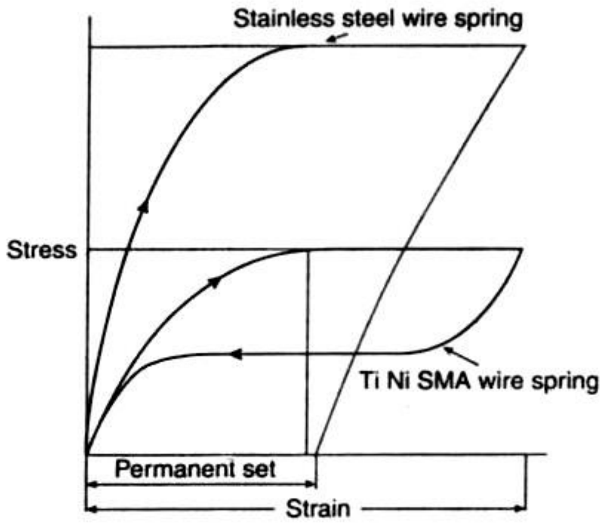


Figure (3): Schematic illustration of the stainless steel wire and TiNi SMA wire springs for orthodontic arch wire behavior Shape memory effect (SME).

Some possible applications of shape memory effects alloys are:

- Orthodontic dental arch wires.
- Skull clip.
- Contractible muscles for artificial heart.
- Vascular stent.

- Catheter wire guide.

Advantages of (Ni Ti) Alloy

1- Easily formed.

2- Highly biocompatible.

3- Outstanding corrosion resistance.

4- Better than stainless steel and cobalt-chromium alloys.

5- Forms protective oxide (TiO_2) layer.

6- Low elastic modulus.

Disadvantages of (Ni Ti) Alloy

1- Poor wear resistance.

2- Should not be used in articulated surfaces such as hip or knee joints unless surface-treated through ion implantation which improves wear resistance.

3- High sensitivity.

4- Existence of a scratch reduces fatigue life.

<u>Dental Metals</u>

Metals are used in dentistry for direct fillings in teeth (dental amalgams), fabricating crowns and bridges (noble metal and base metal alloys), partial denture frameworks (base metal alloys), orthodontic wires and brackets (stainless steel, Ti alloys and Ni-Ti alloys) and dental implants (CP Ti and Ti6Al4V).

Dental amalgam is an alloy made of liquid mercury and other solid metal particulate alloys made of silver, tin, copper, etc. The solid alloy is mixed with (liquid) mercury in a mechanical vibrating mixer and the resulting material is packed into the prepared cavity. The final composition of dental amalgams typically contains 45% to 55% mercury, 35% to 45% silver, and about 15% tin after fully set in about one day.

Gold and gold alloys are useful metals in dentistry as a result of their durability, stability and corrosion resistance. Gold filling are introduced by two methods: casting and malleting.

Gold alloys are used for dental restorations, since they have mechanical properties superior to those of pure gold.

Failure of Metals for Biomedical Devices

1- Corrosion

Metal implant is expose to corrosion during its services due to corrosive medium of implantation site. Types of corrosion that frequently found in implant applications are fretting, pitting and fatigue. Fretting corrosion most frequently happens in hip joint prostheses due to small movement in corrosive aqueous medium. And in most cases subjected to cyclic loading.

The factors, which can affect the corrosion of metals and alloys, are stress and surface roughness. When the stress in metal components of appliances produces, for example, by excessive or continued bending can accelerate the rate of corrosion and may lead to failure by **stress corrosion cracking**.

In pitting corrosion, the pits form in rough surfaces can lead to the setting up of small corrosion cells in which the material at the bottom of the pit acts as the anode and that at the surface acts as the cathode. The mechanism of this type of corrosion sometimes referred to as ***concentration cell corrosion***, is complicated mechanism. In order to reduce corrosion by this new mechanism, the metals and alloys used in the mouth should be polished to remove surface irregularities.

Ideally, a material placed into a patient's mouth should be non-toxic, non- irritant, have no carcinogenic or allergic potential and if used as a filling material, should be harmless to the patient's.

Passivation: Production of corrosion resistance by a surface layer of reaction products (normally oxide layer which is impervious to gas and water)

Passivity: Resistance to corrosion by a surface layer of reaction products.

Pitting: A form of localized corrosion, in which, pits form on the metal surface.

2- Fatigue Failure

During its service most of metallic implants are subjected to cyclic loading inside the human body which leads to the possibility for fatigue fracture. Factors determine the fatigue behavior of implant materials include microstructure of the implant materials. It was reported that Ti6Al4V has better fatigue strength properties.

3- Wear

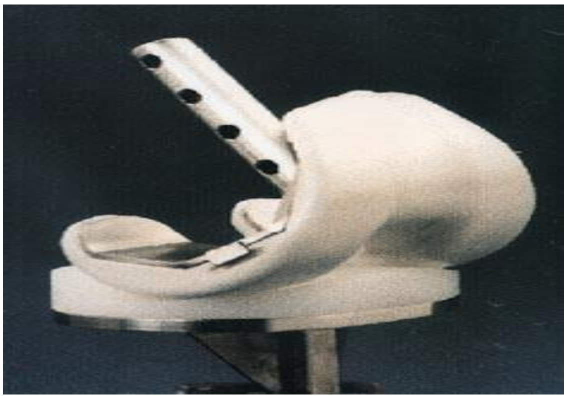
Together with corrosion process, wear is among the surface degradation that limits the use of metallic implant such as Ti alloy. Removal of dense oxide film which naturally formed on the surface of this metallic implant that caused wear process. In fact, the major factor that causing early failure of hip prostheses is wear process with multiple variables, thus increase the resultant wear rates.

<u>Specialty Metals for Biomedical Devices</u>

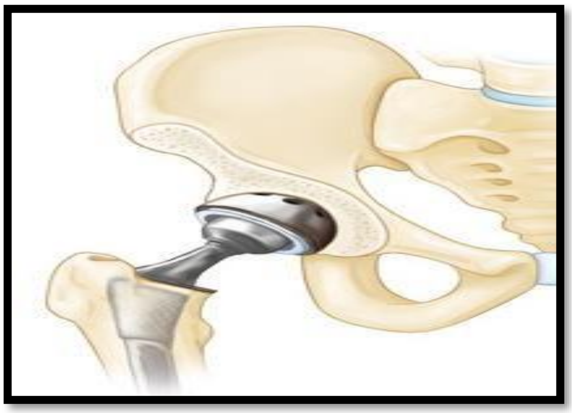
Along with the advances in biomedical technology and tissue engineering, biomaterials are desired to exhibit low elastic modulus, shape memory effect or super elasticity, wear resistance, and workability. In addition, they are required to eliminate all possibility of toxic effects from wear and corrosion. One of the concerns is avoiding the use of Ni in fabricating metal alloys, this demand leads to development new generation metallic biomaterials. Besides, the development in alloy’s composition and microstructure, also improve the new processing technology.

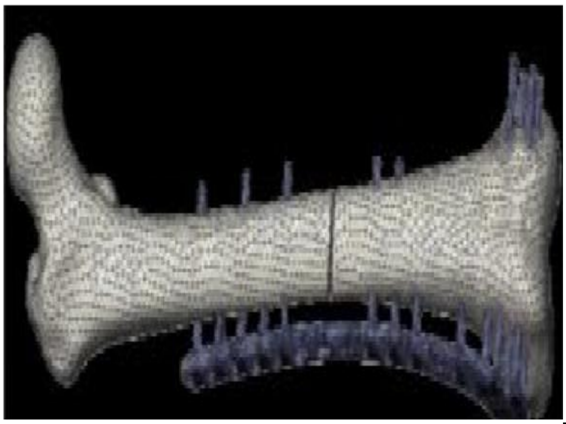
In Co Cr alloys, use C content to its upper limit and addition of Zr and N permit formation of fine and good distributed carbides which improves the wear resistance and mechanical strength from optimal precipitation hardening of CoCr alloy.

Ti alloy exhibits good mechanical properties than other alloy and pure Ti which makes it considered to be the first candidate for low elastic modulus metallic biomaterials. In Ti-Nb systems such as Ti29Nb13Ta4.6Zr and Ti35Nb4Sn, the elastic modulus can be reduced to (50-60 GPa.) which are closer to that of cortical bone (10-30 GPa.) Porous structure that is obtained through powder sintering, further reduces elastic modulus to get closer to that of cortical bone.




zilver
reliant
introducer





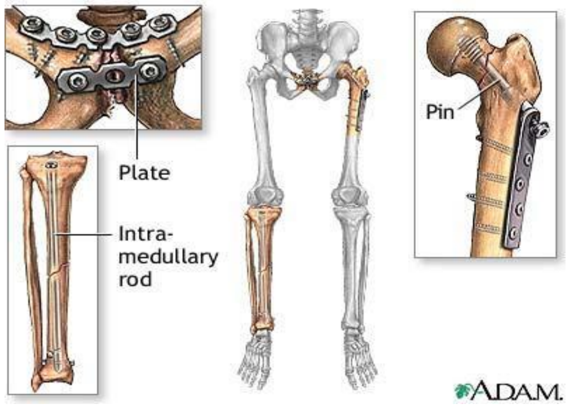


Plate
Intra-
medullary
rod
Pin
ADAM.