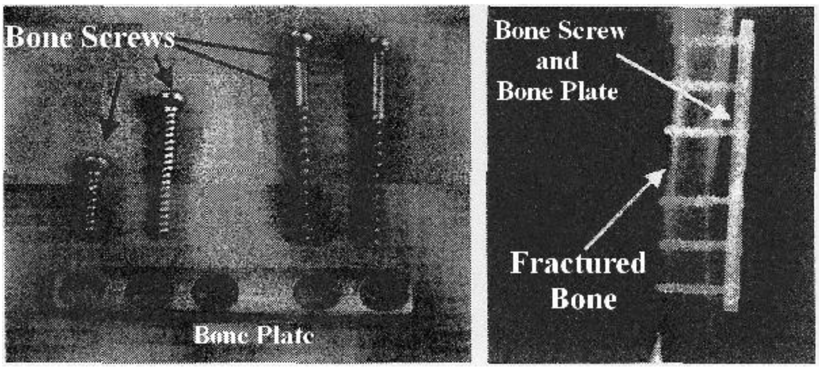
Chapter four

Metals and Alloys



Chapter Four Metals and Alloys

Metals and Alloys

Metals are used as biomaterial due to their excellent electrical and thermal conductivity and mechanical properties. Since some electrons are independent in metals, they can quickly transfer an electric charge and thermal energy. The mobile free electrons as the binding force to hold the positive metal ions together. This attraction is strong, as evidenced by the closely-packed atomic arrangement resulting in high specific gravity and high melting points of most metals. Since the metallic bond id essentially non-directional, the position of the metal ions can be altered without destroying the crystal structure, resulting in a plastically deformable solid.

Some metals are used as passive substitutes for hard tissue replacement

such as:

1- Total hip;

2- Knee joints;

3- For fracture healing aids as bone plates and screws;

4- Spinal fixation devices;

5- Dental implants, because of their excellent mechanical properties, and

corrosion resistance;

6- Vascular stents;

7- Catheter guide wires.

Stainless Steels

Stainless steel was first used successfully as an important material in the surgical field.

I- Type 302 stainless steel was introduced, which is stronger and more resistant to corrosion than the vanadium steel;

II- Type 316 stainless steel was introduced, which contains a small percentage of molybdenum (18-8sMo) to improve the corrosion resistance in chloride solution (salt water);

III- Type 316L stainless steel. The carbon content was reduced from 0.08 to a maximum amount of 0.03% for better corrosion resistance to chloride solution.

The inclusion of molybdenum enhances resistance to pitting corrosion in salt water. Even the 316L stainless steels may corrode in the body under certain circumstances in highly stressed and oxygen depleted region, such as the contacts under the screws of the bone fracture plate. Thus, these stainless steels are suitable to use only in temporary implant devices, such as fracture plates, screws, and hip nails.

CoCr Alloys

There are basically two types of cobalt-chromium alloys:

1- The CoCrMo alloy [Cr (27-30%), Mo (5-7%), Ni (2.5%)] has been used for many decades in dentistry, and in making artificial joints;

2- The CoNiCrMo alloy [Cr (19-21%), Ni (33-37%), and Mo (9-11%)] has been used for making the stems of prostheses for heavily loaded joints, such as knee and hip.

The ASTM lists four types of CoCr alloys, which are recommended for surgical implant applications:

1) CoCrMo alloy [Cr (29-30%), Mo (5-7%), Ni (2.5%)];

2) CoCrWNi alloy [Cr (19-21%), W (14-16%), Ni (9-11%)];

3) CoNiCrMo alloy [Ni (33-37%), Cr (19-21%), Mo (9-11%)];

4) CoNiCrMoWFe alloy [Ni (15-25%), Cr (18-22%), Mo (3-4%), W (3-4%), Fe (4-6%)].

The two basic elements of the CoCr alloys form a solid solution of up to 65% Co. The molybdenum is added to produce finer grains, which results in higher strengths after casting. The chromium enhances corrosion resistance, as well as solid solution strengthening of the alloy.

The CoNiCrMo alloy contains approximately 35% Co and Ni each. The alloy is highly corrosion resistant to seawater (containing chloride ions) under stress.

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Titanium and its Alloys

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.

They 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 dentures, and (6) used to fix soft tissue, such as blood vessels.

In the elemental form, titanium has a high melting point (1668oC) and possesses a hexagonal closely packed structure (hcp) a up to a temperature of 882.5oC. Titanium transforms into a body centered cubic structure (bcc) b above this temperature.

One titanium alloy (Ti6Al4V) is widely used to manufacture implants. 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:

1- Aluminum tends to stabilize the a-phase; it increases the

transformation temperature from a- to b-phase.

2- Vanadium stabilizes the b-phase by lowering the temperature

of transformation from a to b.

He titanium-nickel alloys show unusual properties, that is, after it is deformed the material can snap back to its previous shape following heating of the material. This phenomenon is called (shape memory effect) SME.

The equiatomic TiNi or NiTi alloy (Nitinol) exhibits an exceptional SME near room temperature: if it is plastically deformed below the transformation temperature it reverts back to its original shape as the temperature is raised.

Another unusual property is super-elasticity, which is shown schematically below in Figure.1. As can be seen the stress does not increase with increased strain after the initial elastic stress or strain, the metal springs back to its original shape in contrast to other metals, such as stainless steel.

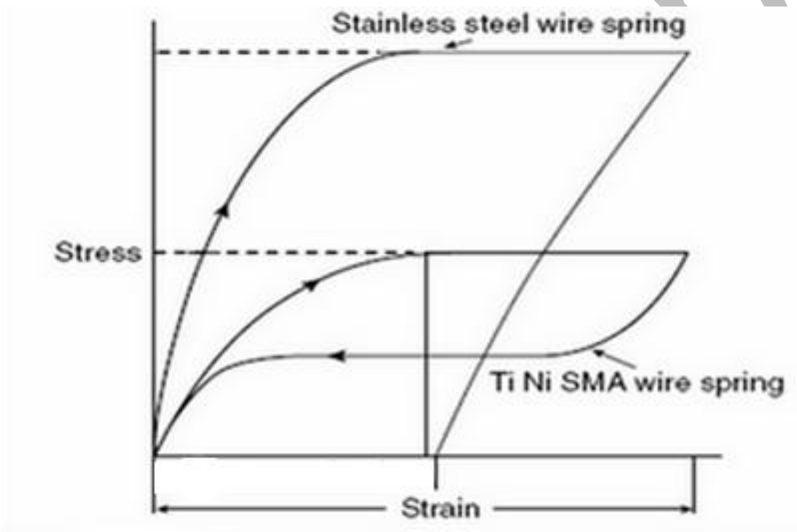

Fig.1 Schematic illustration of the stainless steel wire and TiNi SMR wire springs for orthodontics arch-wire behavior

Biomedical Applications

The applications of titanium and its alloys can be classified according to their biomedical functionalities:

1- Hard Tissue Replacement

Hard tissues are often damaged due to accidents, aging, and other causes.Titanium and titanium alloys are widely used as hard tissue replacements in artificial bones, joints, and dental implants. As a hard tissue replacement, the low elastic modulus of titanium and its alloys is generally viewed as a biomechanical advantage because the smaller elastic modulus can result in smaller stress shielding.

One of the most common applications of titanium and its alloys is artificial hip joint that consists of an articulating bearing (femoral head and cup) and stem as in Fig.2.

Titanium and titanium alloys are also often used in knee joint replacement, which consists of a femoral component, tibial component, and patella.

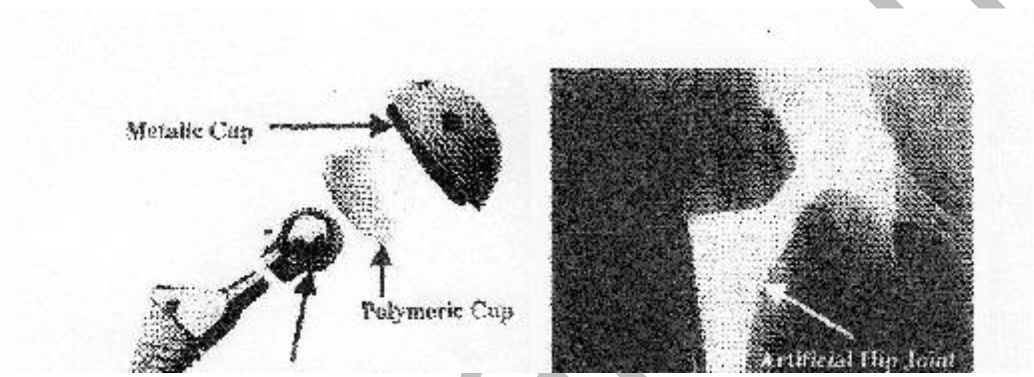

Fig.2. Schematic diagram of artificial hip joint

Titanium and titanium alloys are common in dental implants, the most commonly used implants are root-forming analogs. Fig.3 displays some of the popular designs, such as screw-shaped devices and cylinders.

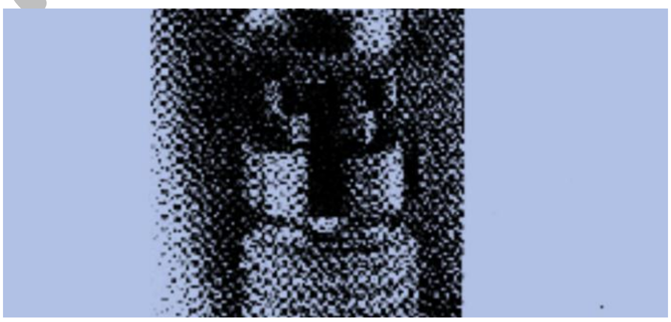

Fig.3. Schematic diagram of the screw-shaped artificial tooth

2- Cardiac and Cardiovascular Applications

Titanium and titanium alloys are common in cardiovascular implants, because of their unique properties. Early applications examples were prosthetic heart valves, protective cases in pacemakers, artificial hearts and circulatory devices. Recently, the use of shape memory Nickel-Titanium alloy (Ni-Ti) in intravascular devices, such as stents and occlusion coils has received considerable attention. The advantages of titanium in cardiovascular applications are that it isstrong, inert and anon-magnetic.

A disadvantage is that it is not sufficientlyradio-opaque in finer structures.

Many types of prosthetic heart valves have been used clinically.are commonly used in the treatment of cardiovascular disease. They dilate and keep narrowed blood vessels open. Stents are usually mounted on balloon catheters or folded inside special delivery catheters. Nickel-Titanium alloy is one of the most common materials used in vascular stents due to its special shape memory effects.

3- Other Applications

Titanium and titanium alloys are attractive materials in osteo-synthesis implant in view of its special properties that fulfill the requirements of osteosynthesis applications. Typical implants for osteo-synthesis include bone screws, bone plates (Fig.4), maxillofacial implants, etc.

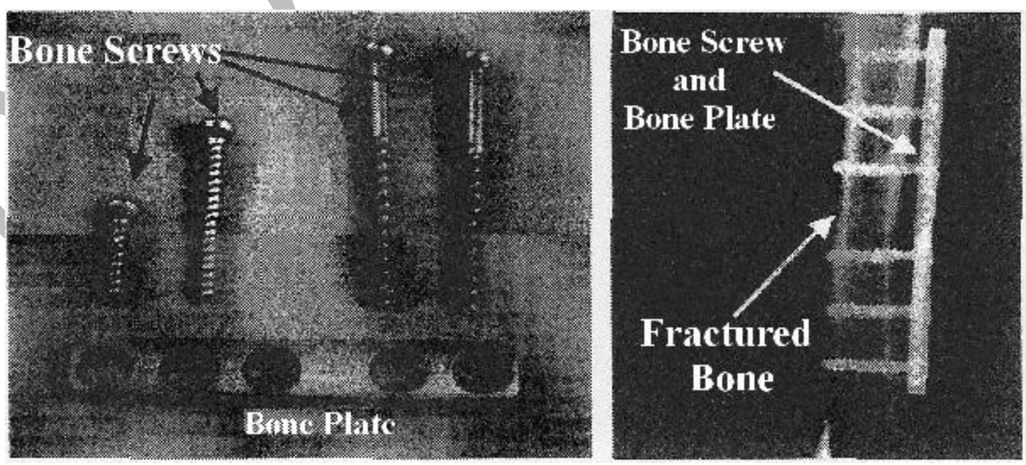

Fig.4: Bone screws and bone plate.

Surface Structure and Properties

There has been a considerable amount of scientific and technical knowledge published on the structure, composition, and preparation of titanium and titanium alloys, and many of the favorable properties arising from the presence of the surface oxide. It is well-known that a native oxide film grows spontaneously on the surface upon exposure to air. The excellent chemical inertness, corrosion resistance, repassivation ability, and even biocompatibility of titanium and most other titanium alloys are thought to result from the chemical stability and structure of titanium oxide film that is typically only few nanometers thick.

The characteristics of films grown at room temperature on pure titanium are summarized as follows in Fig.5.

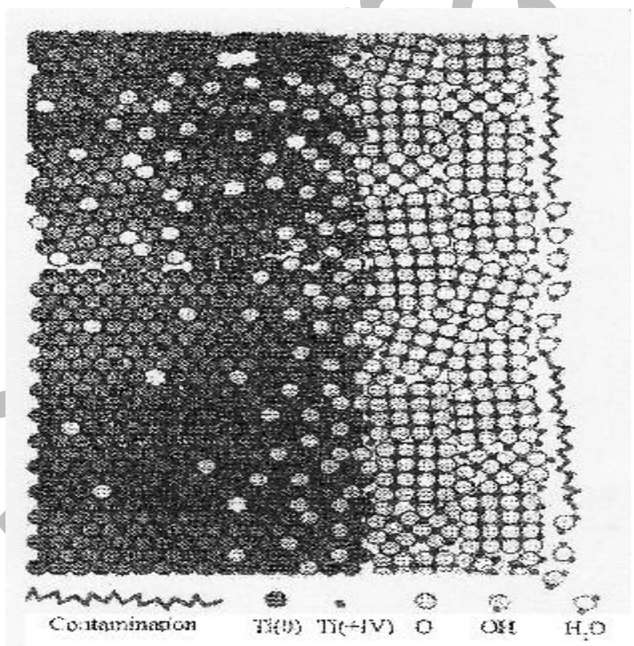

Fig.5 Schematic View of the oxide film on pure titanium

1- The amorphous or nano-crystalline oxide film is typically 3-7nm thick and mainly composed of the stable oxide TiO_2;

2- The TiO_2/Ti interface has an O to Ti concentration ratio that varies gradually from 2 to 1 from the TiO_2 film to a much lower ratio in the bulk;

3- Hydroxide and chemisorbed water bond with Ti cations leads to weakly

bound physisorbed water on the surface. In addition, some organic species like hydrocarbons adsorb and metal-organic species, such as alkoxides or carboxylates of titanium also exist on the outmost surface layer whose concentrations depend on not only the surface conditions, such as cleanliness bur also the exposure time to air as well as the quality of the atmosphere during storage.

Mechanical Properties

Titanium is very promising in orthopedics due to its high specific strength and low elastic modulus. However, titanium has low wear and abrasion resistance because of its hardness.

Biological Properties

Biocompatibility is the ability of the materials to perform in the presence of an appropriate host for a specific application. Titanium and titanium alloys are generally regarded to have good biocompatibility. They are relatively inert and have good corrosion resistance because of the thin surface oxide. They typically do not suffer from significant corrosion in a biological environment. Titanium readily absorbs proteins from biological fluids. Titanium and bones are generally separated by a thin non-mineral layer and true adhesion of titanium to bones has not been observed. Instead, the bond associated with osteo-integration is attributed to mechanical interlocking of titanium surface asperities and pores in the bones. In order to make titanium biologically bond to bones, surface modification methods have been proposed to improve the bone conductivity or bioactivity of titanium.

Table 4.1 Biomaterials fir Total Joint Replacements

Materials	Properties	Application
Co-Cr alloy	**Stem, head (ball)**	**Heavy, hard, stiff**
(casted or wrought)	**Cup, porous coating**	**High wear resistance**
	Metal backing	
Ti alloy	**Stem porous coating**	**Low stiffness**
	Metal backing	**Low wear resistance**
Pure titanium	**Porous coating**	**Excellent osseousintegration**
Tantulum	**Porous structure**	**Excellent osseousintegration**
	Good mechanical strength	
Alumina	**Ball, cup**	**Hard, brittle**
		High wear resistance
Zirconia	**Ball**	**Heavy and high toughness**
		High wear resistance
UHMWPE	**Cup**	**Low friction, wear debris**
		Low creep resistance
PMMA	**Bone cement fixation**	**Brittle, weak in tension**
		Low fatigue strength

Table 4.2 Types of Total Joint Replacements

Joint	Types
Hip	**Bull and Socket**
Knee	**Hinged, semi-constrained, surface replacement**
	Uni-compartment or bio-compartment
Shoulder	**Bull and Socket**
Ankle	**Surface replacement**
Elbow	**Hinged, unconstrained, surface replacement**
Wrist	**Ball and socket, space filter**
Finger	**Hinged, space filter**

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Dental Materials

Dental amalgam is an alloy made of liquid mercury and other solid materials 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. One of the solid alloys is composed of at least 65% silver, and not more than 29% tin, 6% copper, 2% zinc, and 3% mercury. 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 alloys are introduced by two methods: casting and malleting. Gold alloys are used for cast restorations, since they have mechanical properties which are superior to those of pure gold. The pure gold is relatively soft, so this type of restoration is limited to areas not subjected to much stress.

Other Metals

Tantalum has been subjected to animal implant studies and has been shown very biocompatible. Due to its poor mechanical properties and its high density (16.6 gm/cm3) it is restricted to few applications such as wire sutures for plastic surgeons and neurosurgeons, and a radioisotope for bladder tumors. Surface modifications of metal alloys such as coatings by plasma spray, physical or chemical vapor deposition, ion implantation, and fluidized bed deposition have been used in industry. Coating implants with tissue compatible material such as hydroxyapatite, oxide ceramics, bio-glass, and pyrolytic carbon are typical applications in implants. Such efforts have been largely ineffective if the implants are subjected to a large loading. The main problem is in the delaminating of the coating or eventual wear of the coating. The added cost of

coating or ion implanting hinders the use of such techniques unless the technique shows unequivocal superiority compared to the non-treated implants.

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Defining Terms

In vitro: In glass, as in a test tube. An in vitro test is one done in the laboratory, usually involving isolated tissues, organs, or cells.

In vivo: A test performed in a living body or organism.

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