Dental Casting Alloys

Desirable Properties of Casting Alloys

Cast metals are used in dental laboratories to produce inlays, onlays, crowns, conventional all-metal bridges, metal-ceramic bridges, resin-bonded bridges, endodontic posts, and removable partial denture frameworks. The metals must exhibit biocompatibility, ease of melting, casting, soldering and polishing, little solidification shrinkage, minimal reactivity with the mold material, good wear resistance, high strength and sag resistance (metal-ceramic alloys), and excellent tarnish and corrosion resistance. Generally, conventional type 2 and 3 gold alloys represent the standards against which the performance of other casting is judged.

Biocompatibility

All the material used in the oral cavity must be biocompatible. Potential biologic hazards from the base metal alloys, particularly nickel and beryllium, are controversial. These potential hazards may affect not only the patient but also the dentist and the technician.

Classification of Dental Casting Alloys

Several hundred brands of crowns and bridge alloys are currently available on the world market. Since 1989, ADA-approved casting alloys can have any composition as long as they pass the tests for toxicity, tarnish, yield strength, and percentage of elongation. The tests yield strength, and percentage of elongation differs according to the stresses subjected to the restorations.
Alloy Classification of the American Dental Association:

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>Total Noble Metal Content</th>
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<tbody>
<tr>
<td>High noble metal</td>
<td>Contains ≥40 wt% Au and ≥60 wt% of the noble metal elements (Au + Ir + Os + Pt + Rh + Ru +Pt)</td>
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<tr>
<td>Noble metal</td>
<td>Contains ≥25 wt% of the noble metal elements</td>
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<tr>
<td>Predominantly base metal</td>
<td>Contains &lt;25 wt% of the noble metal elements</td>
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Identification of Alloys by Principal Elements

In fixed prosthodontics dental alloys are classified according to not only function, but also according to their composition (principal element or elements). When an alloy is identified according to the elements it contains, the components are listed in declining order of composition with the largest constituent first followed by the second largest constituent. An exception to this rule is the identification of certain alloys by elements that significantly affect physical properties or that represent potential biocompatibility concerns, or both. For example, nickel-chromium-molybdenum-beryllium alloys are often designated as nickel-chromium-beryllium alloys because of beryllium's contributions to the control of castability and surface oxidation at high temperatures, and because of its relative toxicity potential compared with other metals. Molybdenum or tungsten often exist in greater concentrations than beryllium to decrease the thermal coefficient of expansion. However, the concern for the biocompatibility of beryllium is a more important factor,
and some research reports list these alloys as Ni-Cr-Be rather than Ni-Cr-Mo or Ni-Cr-Mo-Be.

**Alloys for All-Metal and Resin Veneer Restorations**

**Gold Alloys**

In 1927, four types of gold alloys were recognized: Type I through IV according to dental function/ with hardness increasing from Type I to Type IV. The gold contents decreased from type I [83% by weight] to type IV. On 1989, the Specification No. 5 of the ADA classified the four alloy types by their properties and not by their compositions:

- **Type I** (soft)—small inlays, easily burnished and subject to very slight stress.

- **Type II** (medium)—inlays subject to moderate stress, including thick three-quarter crowns, abutments, pontics, and full crowns.

- **Type III** (hard)—inlays subject to high stress, including thin three-quarter crowns, thin cast backings, abutments, pontics, full crowns and denture bases, and short-span fixed partial dentures. Some Type III gold alloys usually can be age hardened, especially those containing at least 8 wt% of copper.

- **Type IV** (extra hard)—inlays subject to very high stresses, including denture base bars and clasps, partial denture frameworks, and long-span fixed partial dentures. (Full crowns are often made of this type.) The compositions of these alloys are usually based on a majority of either gold or silver; gold alloys can be age hardened by an appropriate heat treatment.
Dental Casting Alloys

Types I and II gold alloys are used for inlay and so can be referred to as inlay alloys. Traditional Types III and IV alloys are generally called crown and bridge alloys although Type IV alloys also are used occasionally for high-stress applications such as removable partial denture frameworks and full arch fixed restorations.

Gold alloys can be significantly hardened if the alloy contains a sufficient amount of copper. Types I and II alloys usually do not harden, or they harden to a lesser degree than do the Types III and IV alloys. The actual mechanism of hardening is probably the result of several different solid-state transformations. The criteria for successful hardening are time and temperature. Alloys that can be hardened can, also be softened. In metallurgic terminology the softening heat treatment is referred to as solution heat treatment. The hardening heat treatment is termed age hardening.

**Softening Heat Treatment**

The casting is placed in an electric furnace for 10 minutes at a temperature of 700° C (1292° F), and then it is quenched in water. During this period, all intermediate phases are presumably changed to a disordered solid solution, and the rapid quenching prevents ordering from occurring during cooling. The tensile strength, proportional limit, and hardness are reduced by such a treatment, but the ductility is increased. The softening heat treatment is indicated for structures that are to be ground, shaped or otherwise cold worked, either in or out of the mouth. The proper time and temperature are specified by the manufacturer.
Hardening Heat Treatment

Hardening heat treatment of dental alloys can be accomplished by "soaking" or aging the casting at a specific temperature for a definite time, usually 15 to 30 minutes, before it is water quenched. The aging temperature depends on the alloy composition but is generally between 200° C (400° F) and 450° C (840° F). The proper time and temperature are specified by the manufacturer. Ideally, before the alloy is given an age-hardening treatment, it should be subjected to a softening heat treatment to relieve all strain hardening, if it is present, and to start the hardening treatment with the alloy as a disordered solid solution. Hardening heat treatment increases the strength, proportional limit, and hardness and reduces ductility of alloys. Because the proportional limit is increased during age hardening, a considerable increase in the modulus of resilience can be expected. The hardening heat treatment is indicated for metallic partial dentures, saddles, bridges, and other similar structures.

Low-gold alloys

For economical reasons, a number of major alloy manufacturers introduced a series of gold-based compositions defined as “low-gold alloys“. Like conventional gold alloys, these new materials also were based on a combination of gold, copper and silver. However, instead of 70 to 75 percent gold, these new alloys contained gold in amount ranging from 40 to 60 percent. To compensate for the potential lack of corrosion resistance offered by the reduced gold content, the alloy's palladium and silver content was increased substantially. The amount of palladium in these alloys ranges from 2.7 to 9.1 percent. The lower the gold content, the higher the amount of palladium required for tarnish and corrosion.
Dental Casting Alloys

resistance. The clinical performance of these alloys is at the same level of excellence as the high-gold alloys.

These alloys all exhibited nearly the same physical and mechanical characteristics of conventional type III and IV gold alloys.

Silver-Palladium Alloys

These alloys are white and predominantly silver in composition but have substantial amounts of palladium (at least 25%) that provide nobility and promote the silver tarnish resistance. They may or may not contain copper and a small amount of gold. Casting temperatures are in the range of the yellow gold alloys. The copper-free Ag-Pd alloys may contain 70% to 72% silver and 25% palladium and may have physical properties of a Type III gold alloy. The investment of choice is the phosphate bonded investment. Ag-Pd-Cu alloys might contain roughly 60% silver, 25% palladium, and as much as 15% or more of copper and may have properties of Type IV gold alloy. The investment of choice is the gypsum bonded investment. The Ag-Pd alloys can produce acceptable castings. The major disadvantage of Ag-Pd alloys, in general, and the Ag-Pd-Cu, in particular, is their greater potential for tarnish and corrosion. They should not be confused with Pd-Ag alloys that are designed for metal-ceramic restorations.

Nickel-Chromium and Cobalt-Chromium Alloys

These alloys are described in more detail in the sections on metal-ceramic.

Titanium and Titanium Alloys

These alloys are described later.
Copper-Aluminum Alloys

It is developed in Brazil at 80s of the last century; it is composed primarily of copper and aluminum at a ratio of nearly 10:1.

Because of the increasing interest in aesthetics by dental patients, a decreased use of all-metal restorations has occurred during the past decade. The use of metal-ceramic restorations in posterior sites has increased relative to the use of all-metal crowns and onlays.

Alloys for Metal-Ceramic Restorations

Requirements for alloys used with ceramics

These alloys need to develop and maintain strength at high temperature involved in porcelain applications and to provide a firm bond to the applied porcelain. Bonding necessitates the use of small quantities of iron, indium and tin. Controlling oxidation of the castings produces an oxide coating on the alloy surface to which the porcelain adheres. The design of many ceramo-metallic restorations emphasizes the need to be able to cast thin sections and the need for high yield strength.

High Noble alloys

Ceramo-metallic alloys containing more than 40 wt% gold at least 60 wt% of noble metals (gold plus platinum and palladium and/or the other noble metals) are generally classified as high noble.
Dental Casting Alloys

**Gold-Platinum-Palladium Alloys**

These alloys have a gold content ranging up to 88% with varying amounts of palladium, platinum and small amounts of base metals. Some of these alloys are yellow in color. Alloys of this type are susceptible to sag deformation so fixed partial dentures should be restricted to three unit span, anterior cantilevers or crowns.

**Gold-Palladium-Silver Alloys**

These alloys contain between 39% and 77% gold. The silver increases the thermal contraction coefficient, but it also has a tendency to discolor some porcelains.

**Gold-Palladium Alloys**

These alloys contain gold between from 44% to 55%. The lack of silver results in a decreased thermal contraction coefficient and the freedom from silver discoloration of porcelain. Alloys of this type must be used with porcelains that have low coefficients of thermal contraction to avoid the development of axial and circumferential tensile stresses in porcelain during the cooling part of the porcelain firing cycle.

**Noble Alloys**

The noble alloys must contain at least 25 wt% of the noble metals but they do not necessarily contain any gold. The noble classification refers in most cases to all palladium-based alloys that contain between 54 and 88 wt% palladium, but it also describes the silver-palladium alloys for all-metal or resin-veneer restorations that contain only 25 wt% palladium. The density of palladium-based alloy is midway between that of base metal and of high noble alloys.
Palladium-Silver Alloys

Pd-Ag alloys were introduced widely in the late 1970s but now a days their popularity has declined somewhat in recent years because of their tendency to discolor porcelain during firing. One theory that has been proposed for this greenish-yellow discoloration “greening” is that the silver vapor escapes from the surface of these alloys during firing of the porcelain, diffuses as ionic silver into the porcelain and is reduced to form colloidal metallic silver in the surface layer of porcelain. Not all porcelains are susceptible to silver discoloration, because some apparently do not contain the necessary elements to reduce the ionic silver.

Other palladium alloys contain 75% to 90% palladium and there is no silver. They were developed to eliminate the greening problem. Some of the high-palladium alloys develop a layer of dark oxide on their surface during cooling from the degassing cycle and this oxide layer is difficult to mask by the opaque porcelain.

Other high-palladium alloys such as the Pd-Ga-Ag-Au type seem not to be plagued by this problem.

The compositions of Pd-Ag alloys fall within a narrow range: 53% to 61% palladium and 28% to 40% silver. Tin or indium or both are usually added to increase alloy hardness and to promote oxide formation for adequate bonding of porcelain. In some of these alloys, the formation of an internal oxide rather than an external oxide is possible which increases the mechanical rather than the chemical bonding.

The replacement of gold by palladium increases the melting range and lowers the coefficient of contraction. Increasing the silver content tends to lower the melting range and raises the coefficient of contraction.
Dental Casting Alloys

The problem of greening can be solved by gold metal conditioners or ceramic coating agents or the use of porcelains that are advertised as "nongreening”.

Some of the alloys in this class are with lower silver contents (approximately 28%) appear to be easily burnishable compared with other noble metal alloys. The alloy will be easy to grind and polish.

**Palladium-Copper Alloys**

This alloy type is comparable in cost to the Pd-Ag alloys. Because of their low melting range, these alloys are expected to be susceptible to creep deformation “sag “at elevated firing temperatures. So more precautions are needed in using these alloys for long-span fixed partial dentures with relatively small-connectors.

Some of these alloys like the Pd-Ag alloys contain 2% Au. This small amount of gold serves no useful purpose. Porcelain discoloration due to copper is possible but it is not a major problem.

Some of these alloys are sensitive in casting, presoldering and proper oxidation treatment. In some instances the molten alloy should have a thin oxide film appearing on its surface at the casting temperature. The heating must be maintained for an additional 7 seconds beyond the point at which a rolling motion of the alloy is seen.

**Palladium-Cobalt Alloys**

This alloy group is comparable in cost to the Pd-Ag and Pd-Cu alloys. The noble metal (based on palladium) ranges from 78% to 88%. The cobalt content ranges between 4 and 10 wt%.

These alloys have a fine grain size to minimize hot tearing during the solidification process. This Pd-Co group is the most sag resistant of
Dental Casting Alloys

all noble metal alloys. These alloys have good handling characteristics. Although these alloys are silver free, discoloration of porcelain can still result because of the presence of cobalt. This is not considered a significant problem.

No metal coating agents are required to mask the oxide color or to promote adherence to porcelain. Like the Pd-Ag and Pd-Cu alloys the Pd-Co alloys tend to have a relatively high thermal contraction coefficient and would be expected to be more compatible with higher-expansion porcelains.

**Palladium-Gallium-Silver & Palladium-Gallium-Silver-Gold Alloy**

This group of alloys was introduced because they tend to have a slightly lighter colored oxide than the Pd-Cu or Pd-Co alloys and they are thermally compatible with lower expansion porcelains. The oxide that is required for bonding to porcelain is relatively dark but it is somewhat lighter than those of the Pd-Cu and Pd-Co alloys. The silver content is relatively low (5 to 8wt %) and is usually inadequate to cause porcelain greening.

These Pd-Ga-Ag alloys tend to have a relatively low thermal contraction coefficient and would be expected to be more compatible with lower expansion porcelains.

**Predominantly Base Metal Alloys**

These alloys are based on 75 wt% or more of base metal elements or less than 25 wt% of noble metals. Base metals are invaluable
components of dental casting alloys because of their low cost and their influence on weight/strength, stiffness, and oxide formation (which is required for bonding to porcelain). Compared with noble metals, base metals are more reactive with their environment. Certain base metals can be used to protect an alloy from corrosion by passivation. Most of the base metal alloys are based on nickel and chromium, or cobalt-chromium but few iron based alloys are available.

Properties of Base Metal Alloys

The corrosion behavior of base metal alloys depends on its chemical properties; chromium, molybdenum and niobium are added to increase the corrosion resistance. A thin, invisible chromium oxide layer provides a complete and impervious film that passivates the surface of the alloys.

The base metal alloys have high hardness which makes any occlusal adjustment or polishing very difficult. They also have high yield strength, and high modulus of elasticity. Nickel-chromium alloys have the highest elastic moduli of all dental alloys. Elongation is about the same as for gold alloys. The high tensile strength and elastic moduli permits the use of thinner metal sections than would be possible if noble metal alloys were used, this is advantageous for ceramo-metallic alloys.

Nickel-chromium alloys, especially those containing beryllium, have castability properties that are superior to all other base metal alloys groups. This castability properties permits easier casting of thin sections and produces sharp margins on castings. The addition of beryllium to nickel chromium alloys results in lowering the melting range and also increase fluidity. Beryllium controls also the surface oxides and so higher porcelain metal bond results.
Base metal alloys have casting shrinkage 2.3%, this requires modification of the casting techniques and the use of phosphate bonded investment to allow for accurate casting.

Nickel-chromium alloys show sag resistance higher than all noble metal alloys. This characteristic, along with its high stiffness and high tensile strength allows for the use of these alloys in fixed partial dentures.

The base metal alloys have bad biocompatibility properties, since nickel and beryllium are reported to be potentially health hazard.

**Titanium and Titanium Alloys**

Titanium and titanium alloys are recently introduced in Fixed Prosthodontics. They have excellent biological properties, good corrosion resistance. They have low density compared to gold or palladium. Limitations to the use of titanium are due to its high melting point 2000°C, its rapid oxidation and its reaction with investment materials. Some new brands of investment were introduced that have little reaction with titanium. On the other hand, to overcome the difficulties in casting titanium, a system (Procera) has been developed to manufacture copings from blocks of pure titanium by machine duplication and spark erosion. Then an esthetics veneer is applied to the titanium coping to complete the restoration.