Casting Alloys for Prosthodontic Restorations- A Review

Dr. Vidya Shenoy K*, Dr. Shobha Rodrigues, Dr Sharon Saldanha[+], Dr. Madhu Keshava Bangera[++]**

Introduction

There is a dramatic increase in the number and types of alloys for application in prosthodontic restorations over the past few years. For the longevity of a restoration proper selection and manipulation of the alloys is imperative. The most important factors in alloy selection are the cost, strength and biocompatibility. Since dental casting alloys are widely used in applications that place them in contact with oral tissues for many years, biocompatibility of casting alloys is paramount. Certain base metal alloys like nickel, cobalt have high potential to cause allergy, other elements like chromium are known mutagens and still others like beryllium and cadmium are known carcinogens in different chemical forms.[1-4] Although documented allergies have also been reported for, gold, platinum, palladium and other high noble alloys the incidence has been very rare.[5] Despite all these facts, there is little evidence that support concerns of casting alloys causing systemic toxicity, mutagenic or carcinogenic effects and most researchers in this area would agree that the benefits far outweigh the risks for many alloys currently used in dentistry.[4]

This article is a review on casting alloys for prosthodontic restorations and important physical properties in clinical practice.

Clinically and biologically relevant properties of dental alloys

All casting alloys must first be biocompatible and exhibit physical and mechanical properties to ensure adequate function and structural durability over long periods of time. It is paramount to understand the following clinically relevant properties for patient safety and to minimize the risk of medico legal situations.

Grain Size

An alloy is a metallic material formed by combination of two or more metals or one or more metals with a non-metal.[6]When a molten alloy cools to the solid state, crystal form around tiny nuclei. As the temperature drops, these crystals grow until crystal boundaries meet each other in the solid state. Each crystal is called a grain and boundaries between the crystals are grain boundaries [7]

Small grains have been found to improve the elongation and tensile strength of the cast gold alloys.[8] For base metal alloys small, dispersed secondary phases are critical to the strength of the alloys. In other base metal alloys, the grains are large and may approach 1mm in diameter. [9] A grain size 30microns or less has been reported to be desirable in dental alloys.[10] Grain sizes vary from 10-1000 microns and determined by cooling rate of the solidifying alloy, the presence of special grain-refining elements in the alloy composition such as iridium or ruthenium, heat treatment after casting, and the composition of the alloy.[11]

Phase structure

The components of the alloy will have varying degrees of solubility in each other. Alloys can be either single phase or multiple phase depending on the solubility of the alloy elements.[12] Alloys will be single phase when all the elements are completely soluble in each other (e.g. gold, palladium and copper) and has homogenous composition throughout. If one or more elements are not soluble in each other, the alloys are multiple phase. (e.g. gold & platinum) Multiple phase alloys are prone to higher corrosion rates because of galvanic effects between the microscopic areas of different composition .[13,14] However, the presence of multiple phase allows alloys to be etched for bonding and makes them stronger than single phase alloys. The effect of phase structure on strengthening depends on the nature of the phase II, its composition and dispersion throughout the other phases. [15] Single phase alloys are easier to manipulate in the laboratory, have more consistent properties and are less technique sensitive. Phase structure of an alloy is not discernible by the naked eye and one must rely on manufacturer's instructions to know the alloy's phase structure.

Strength, hardness and elastic modulus:

The mechanical properties important for good clinical performance include yield strength, hardness and modulus of elasticity. Alloys with tensile yield strengths above 300 MPa are strong enough to resist permanent intra oral deformation in most clinical situations.[16] The most common site for the permanent deformation is between pontics in a long span FPD. Yield strength is defined as the stress required to permanently deform a small standardized amount of an alloy expressed as a percentage of length of the specimen being tested.

The hardness of the alloy must be enough to resist wear from opposing teeth or restoration and not so hard as to wear enamel or porcelain. Alloys with a Vickers hardness of less than 125 kg/mm^2 are susceptible to wear and alloys that are harder than hardness of enamel i.e. 340 kg/mm^2 can cause wearing of opposing teeth. [15, 16]

The modulus of elasticity is a measure of the stiffness or rigidity of an alloy. The higher the elastic modulus better is the flexural strength. This is important with metal ceramic restorations where any flexure will cause fracture of the porcelain. In long span metal-ceramic restoration or RPD, Ni or cobalt based alloys, which have moduli of 180-230 G pa may be more appropriate. [17]

Color:

In the past yellow colored alloys were associated with high gold content, high cost and high social value. The color of the alloy is often described as being yellow or white. Color should never be the sole basis to judge the clinical performance. Alloys that contain more than 10 wt. % palladium will be white, regardless of the gold content [18] and alloys with no gold present may have a yellow color (Pd-In-Ag). Though the color may be of esthetic consideration to the patient clinical performance of alloys is related to its physical property[19] except the color and cost can be influenced by the cost of palladium, platinum and silver.

Corrosion:

Corrosion of alloys occurs when elements in the alloy ionize.[20] Corrosion may compromise the strength of the restoration, leading to catastrophic failure [21] or the release of oxidized components may discolor natural teeth, ceramic restorations or soft tissues in severe cases [4]. Corrosion is measured visually by observing the alloy surface, electrochemical tests that measure elemental release indirectly through the flow of released electrons[22] or by tests that measure the release of the elements directly by spectroscopic methods.[23]

The presence of multiple phases in a solder and high percentage of non-noble elements may enhance corrosion or the presence of pits or crevices in a single alloy may enhance corrosion .[24-27] Corrosion is related to biocompatibility because the release of elements from the alloy is always necessary for adverse biologic effects and response to released elements depends on which element is released, the quantity, duration of exposure and other factors.

Corrosion resistance of a material is derived from components being too noble to react in the oral environment (gold or palladium) or by forming passivating surface film by components which inhibit surface reaction. (e.g. chromium).

Porcelain bonding properties:

The properties of the alloy to be considered are color and thickness of alloy, expansion between the metal and ceramic, melting range of the alloy.

For reliable bonding of the porcelain to the alloy an adequate oxide layer is required and if these oxides are not completely masked, they will impart a lower value to the porcelain shade. The properties of the oxide layer such as oxide color, thickness, and strength vary among the alloy types and are critical to the esthetics and strength of the restoration.[28]

High gold alloys have a relatively light-colored oxide because of their noble character and require additions of trace elements like tin, gallium, indium etc. to promote oxide formation and even after additions oxide layer are thinner.[29] This oxide layer is easier to mask with opaque porcelain. Base metal alloys have darker, gray oxides because these alloys contain elements that form oxides easily during the initial oxidation step. This oxide layer requires thicker layers of opaque porcelain to mask. Generally, there is an increased risk of metal ceramic bonding failure with thicker oxides as oxides are brittle and weaker than either porcelain or the alloy. In addition, stress may be induced in the oxide layer due to occlusal load.[30]

Casting alloys containing high amounts of silver and copper may cause porcelain discoloration due to release of elemental vapor during the application of porcelain and is termed greening.[31]

Coefficient of Thermal expansion

Both alloys and porcelain expand when healed and contract when cooled. If porcelain contracts less than the alloy, then the porcelain will have residual compressive stresses at room temperature and if porcelain contracts more than the alloy, then the porcelain will have residual tensile stress at room temperature. Porcelain will not tolerate tensile stress well as it is brittle and subject to failure by crack propagation. Therefore, it is critical to select porcelain for a given alloy which has coefficient of thermal expansion less than that of the alloy. However, it cannot be too small as the failure may occur as a result of compressive stresses. Generally, a 0-$5\times10^{-6}/^{0}C$ difference in coefficients is desirable.[32]

Melting Temperature

Each alloy has lower solidus temperature at which melting begins and a higher liquidus temperature at which the entire alloy is melted. The firing temperature of the porcelain should be below the solidus temperature of the alloy by at least $50^{0}C$[33] to prevent distortion of the alloy substructure at high temperature. This distortion is referred to as sagging and is exacerbated by thin metal substructures or long spans. During soldering operations after porcelain application, the solder must have a liquidus temperature at least $50^{0}C$ below that of the porcelain sintering temperature and the solidus temperature of the alloy.

Alloy solidus and fit

When a molten alloy solidifies from the liquid state to solid state a large amount of shrinkage occurs. Because of this the final casting will be smaller in dimension and the risk of ill-fitting restoration is much greater. Therefore, the shrinkage must be compensated by die expansion, application of the die spacer, use of special expanding investment mechanisms, or increasing the burn out temperature of the investment. The amount of shrinkage is proportional to the solidus temperature of the alloy. For the high gold alloys with solidi of about $950^{0}C$, shrinkage values range from 0.3%-0.5% and nickel-based alloys with solidi of about $1300^{0}C$ -$1400^{0}C$ the shrinkage value is 2.5%.[34]

Biocompatibility and Allergic Components

Biocompatibility is related to how an alloy interacts with or affects biologic system. It is attributed to release of elements from the alloy into the oral cavity.[4, 19]Therefore it is important to select the proper alloy and manipulate it properly in the laboratory as many of procedures can alter the corrosion properties of casting alloys. Beryllium has been considered as potentially toxic under uncontrolled conditions. In certain nondental industrial applications and environmental conditions, nickel and its compounds have been implicated as potential carcinogens and as sensitizing agents. Therefore, proper precautions must be used when these alloys are used.[35]

Currently available alloys:

Current classification of alloys is based on American Dental association compositional classification system. The ADA system divides casting alloys three groups based on wt.% composition and into four groups based on physical properties of yield strength and elongation.

Table I

Current ADA definitions for alloy classification by composition[36]

Class	Composition
High noble	**Au content ≥40 wt%** **Noble metal content≥60 wt%**
Noble	**Noble metal content >25 wt%**
Predominantly Base metal	**Noble metal content <25wt %**

Table II

Current ADA definitions for alloy types by physical properties[37]

ADA Type	Hardness	Clinical use	Yield strength (MPa)	Elongation (%)
I	Soft	Low stress, no occlusion, inlays	<140	18
II	Medium	Moderate stress, light occlusion, onlays and inlays	140-200	18
III	Hard	High stress, full occlusal load, crowns, short span FPD's	201-340	12
IV	Extra-hard	Very high stress, thin veneer crowns Long span FPD, RPD	> 340	10

High noble alloys:

These include gold platinum (Au-Pt), gold palladium (Au-Pd), gold copper silver (Au-Cu-Ag). Gold platinum alloys are used for full cast or metal ceramic applications. They are multiple phase alloys containing zinc or silver as hardeners. Gold palladium is also used for metal ceramic applications and contains tin, indium or gallium as oxide forming elements to promote porcelain adherence When palladium or platinum contents are above 10% weight the solidus temperatures of the alloys are higher and the alloys are white in color.[16] Gold copper silver alloys are used exclusively for full cast restorations because of the low melting range and high silver and copper content. They are yellow in color and have moderately high yield strengths and hardness but only moderate elastic moduli. They are single phase alloys which makes them easy to cast and solder.

Noble alloys:

They have no stipulated gold content but must contain at least 25% noble metal. This includes gold-copper-silver, palladium copper gallium, palladium silver, silver palladium. Gold –copper-silver are single phase alloys and are used for full cast restorations and porcelain applications. The color varies from yellow to reddish yellow to silver depending on how the reduced gold is compensated for. Palladium-copper-gallium alloys are used for full cast or metal ceramic applications. They have high melting ranges and must be cast using induction-casting and special high temperature investments.[21] The gallium lowers the liquidus temperature, can provide porcelain adherence and contributes to strength.[38,39] They are multiple phase alloys[40] and have the highest elastic modulus among the gold and palladium based systems. Palladium silver or silver palladium are multiple phase. The Pd-Ag alloys are far more common in dentistry and are far superior in strength, corrosion resistance, modulus and hardness. The high silver content of the Ag-Pd alloys makes them usable only for full cast restorations.

Base metal alloys:

The base metal alloys can be grouped into Ni-Cr-Be, Ni-Cr, Ni-high –Cr, and Co-Cr. They contain less than 25% wt. noble metal according to ADA classification, but in practice most contain no noble metal. Nickel-chromium is used for full cast and metal ceramic restorations and RPD frameworks. They contain > 60% nickel and are multiple phases. They may contain >20% wt. chromium, <20%chromium with no beryllium or with 1-2%wt beryllium. Beryllium is added to reduce the liquidus temperature so that the investing and casting are easier[34], but it increases the corrosion.[41] They may or may not contain approximately 0.1% wt. carbon which hardens the alloy via the formation of carbides. Cobalt chromium alloys contain 60% wt. cobalt and 30 wt.% of chromium. Carbon is added to strengthen the alloy. They are multiple phase. Cobalt chromium alloys have the highest melting ranges and laboratory manipulation of these alloys is difficult. Base metal alloys are used for full cast, metal ceramic or R.P.D. Base metal alloys have the highest modulus of elasticity. They are difficult to solder because of their propensity for formation of surface oxides and form thick oxide layer which is difficult to mask during porcelain application. Base metal alloys have superior mechanical properties and reduced cost as compared to the gold alloys. However, its potential nickel allergy may be a cause of concern.

Titanium alloys have been proposed for full cast, metal ceramic and RPD frameworks. Their use is limited because of need for special casting machines and investment and expertise required for the casting process. Base metal alloys have elastic moduli twice as high as those of other systems and superior mechanical properties. They can be etched for resin bonding. Drawbacks of these alloys include higher corrosion, difficulty in polishing, dark thick oxides, risk of allergy and difficulty soldering. Their liquidus temperature is the highest among all prosthodontic alloys making it harder to cast and ensure proper marginal fit.

Summary

In conclusion, important physical and biologic properties of dental casting alloys have been reviewed. Corrosion is one property that is most relevant to biocompatibility because the release of elements from the alloy is always necessary for adverse biologic effects and response to released elements depends on which element is released, the quantity, duration of exposure and other such factors. Although carcinogenic effects of dental casting alloys have not been demonstrated, the clinician must avoid alloys containing known carcinogens. Although selection of an alloy must be made on an individual basis using relevant corrosion and biologic data from manufacturers, the goal may be achieved by using high noble or noble alloys with single phase microstructure. The evolution of titanium as an alloy with the least potential for eliciting adverse reaction in individual hypersensitive patients therefore a non-toxic biocompatible replacement for existing alloys for fixed and removable prosthesis may renew interest in this metal.

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* Professor and Head,
Department of Prosthodontics
AJ Institute of Dental Sciences,
Mangalore

** Professor and Head
Department of Prosthodontics
Manipal College of Dental
Sciences, Manipal Academy of Higher
Education
Mangalore, India

+ Associate Professor,
Department of Prosthodontics,
Manipal College of Dental Sciences,
Manipal Academy of Higher Education
Mangalore, India

++ PhD Research Scholar
Department of Dental Materials
Manipal College of Dental Sciences,
Manipal Academy of Higher Education
Mangalore, India

Author for Correspondence:

Shobha J Rodrigues,

Professor and Head,
Department of Prosthodontics

Manipal College of Dental Sciences,
Light House Hill Road
Mangalore – 575001
Karnataka, India
Ph: +918242428716, Extension: 5661 – (O)
E Mail: Shobha.J@Manipal.Edu