

REVIEW ARTICLE

**STUDIES ON THE IMPORTANCE OF
METAL-CERAMIC BOND IN MERGING CERAMIC MASS ON
METAL COMPONENT**

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ABSTRACT

Metal-ceramic restorations are widely used in dental prosthetics. After initiation of the competition, starting with the '80s between the two techniques: metal-composite and metal-ceramic, the metal-ceramic technology has seen an unprecedented use. These restorations combine the natural effect of a brittle material (dental porcelain) with mechanical strength and marginal adaptation of the metal cast. The metal component provides porcelain a strong non deformable support which enhance the porcelain properties (mechanical strength, chemical fusion, color stability). Metal-ceramic prosthesis success essentially depends on the compatibility of the two components (metal / ceramic) and the correct indication of such restorations. Regardless of the obtaining technique, the metal-ceramic bridges must meet universal principles: bio-functional, biomechanical and prophylaxis. This paper aims to present the advantages and limitations of using metal-ceramic bridges in morpho-functional restoration of partially edentulous patient and the clinical methodology and technique for obtaining these dentures.

KEYWORDS: *metal/ceramic, fusion/merging, biofunctional, Metal-Ceramic bond.*

The long-term clinical success of fixed metal-ceramic crowns and bridges depends on the firmness of the bond/ link between metal and ceramic mass. To be able to appreciate the nature of this relationship it is necessary to consider all stages of application and sintering of the porcelain on the alloy. John W.Mc. Lean, although describing them a simplified manner, clarifies to some extent the phenomena taking place in the interface zone in each stage:

Stage I – the surface metal coat or the bridge infrastructure is conditioned by sandblasting and spray vapor under pressure. The surface roughness

produced by sandblasting increases, facilitates wetting of the contact surface and participates in mechanical microretention of the porcelain.

Stage II - The alloy is degassed by heating at 1000 ° C under vacuum for about 10 minutes and then cooled slowly in the presence of air, under atmospheric pressure. This technique will degas the cast and cause age-hardening of the alloy (figure 1). At the same time, the base metal atoms will diffuse onto the cast surface to form an oxide film (indium ions, zinc, tin) [1].

Stage III - the opaque porcelain is applied to

the cast surface as thin layer. The overlying opaque porcelain and alloy are then slightly heated, dried, causing a contraction of the opaque porcelain on the metal surface.

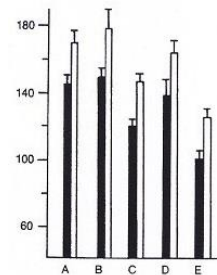
Stage IV-This system consists of opaque porcelain plated metal component is introduced into the oven chamber and by raising the temperature inside a primary sintering of the ceramic particles will take place. In this stage, the ceramic mass will begin to wet the metal surface and, depending on the efficiency of irrigation, the effects of superficial pressure will be shown. The term of "van der Waals" bonds or wetting connections is used to describe these adhesive forces. However, regardless of the nature of this watering action, the main guiding force is the surface tension. It is known that the surface tension of a liquid is associated with a tendency to wet the surface it is in contact with. The angle between the vectors of the two substances, solid and liquid, determines the degree of wetting and as the angle is smaller, the more melting porcelain will wet the alloy which is in solid form. If watering is effective, porcelain will penetrate all small irregularities on the surface of the alloy and mechanical microretention may occur. Along with this phenomenon, the basic atoms of the alloy will continue to diffuse into the surface and will form an oxide film which will further form a chemical bond with the substrate coated ceramic mass.

Stage V – The opaque porcelain is heat treated to maturation temperature (930-960 ° C). At this stage porcelain will continue to contract by sintering and by eliminating pores. During the porcelain combustion - sintering cycle, it does not become molten or fluid, except for a coating film (25µm) which occurs when reaching the coating temperature. Consequently, porcelain exercise restrictive forces in the opposite direction of the alloy expansion (Vickery and Badinelli, 1968). During cooling, the alloy tends to return to its original shape due to the fact that the

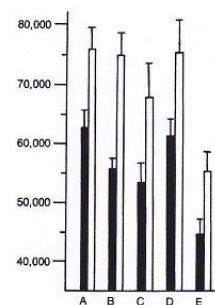
expansion is higher than that of the porcelain, and its contraction will be faster. Thus, the alloy due to its tendency to shrink faster than the porcelain will be subject to tension forces, while the coating ceramic mass is subjected to compressive forces.

Stage VI - In this stage the ceramic mass for enamel and the one for dentin is applied and sintered under conditions of maximum density. The process will be similar to the opacifying ceramic sintering, developing the same compressive forces during contraction and cooling of the ceramic enamel. A gradual thermal expansion of the coating mass to the opacifier coating will harden the entire ceramic body.

Durity



Maximum resistance to elongation



Proportional limit

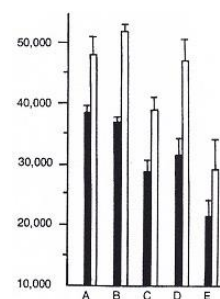


Figure1. The mechanical properties of high fusible gold alloys used in metal-ceramic technology (Lienfelder et. al J.McLean)[2]

Studies on the nature of metal-ceramic bond

A study of all phases of ceramic sintering on the metal infrastructure indicate a complex system of adhesion. The nature of this metal-ceramic bond covers several components (figure 2), as follows:

- *Mechanical*: the surface tension facilitates intimate contact between irregularities of the metal surface and porcelain (stages IV and V);
- *Chemical*: Atomic diffusion of the basic alloy elements will produce an oxide film on its surface that will provide a link with crystallized elements of the ceramic (stages IV and V);
- *Compression*: sintering shrinkage and thermal contraction of the plating ceramic develops compressive forces by means of which porcelain is strongly bonded to the metal infrastructure (stages V and VI).

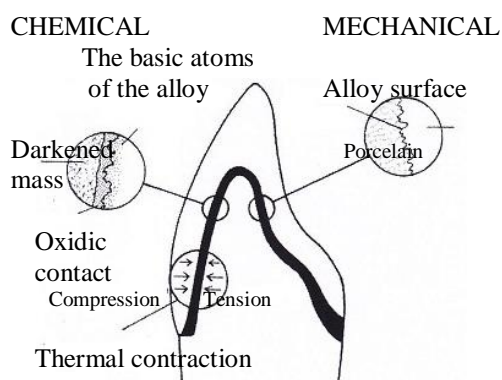


Figure 2. *Components of metal-ceramic bond*
(John W. McLean)

In the literature most authors, agree that adherence of porcelain on the metal component is the result of three factors: mechanical retentions, Van der Waals forces and chemical bonds.

To facilitate fusion, *McLean* recommends baking a layer initially opaque at a temperature of 20 ° C higher than the temperature indicated by the manufacturer for burning such porcelains. Mechanical retention of metal ceramic increase the value of the metal ceramic fusion (*Phillips, McLean*).

Other authors describe the depth to which there are adherent oxides to the metal surface arguing that

the mechanical retention may affect ceramic adhesion to metal. Rough metal surfaces create gaps in the ceramic mass at the interface area which may affect fusion of ceramic on metal and implicitly the value of the metal-ceramic bond. Contact angle measurements, ceramic-metal indicate the role of Van der Waals forces on the porcelain to metal bonding. *O'Brien and Ryge* have shown that, theoretically, Van der Waals forces provide sufficient strength to the bond and the fusion resistance is increased by the presence of the oxide layer. Regarding the chemical bond one can emphasize that when burning the ceramic at the interface dissolves partially and is saturated with metal oxides. The surface layer of ceramic saturated with metal oxides is in a thermodynamic equilibrium with the metal oxides on the metal surface. By the ion-exchange a continuous structure from metal to porcelain resulting in a strong chemical (ionic, covalent and metallic) bond.

The interface between non noble alloys and ceramic mass

Satisfactory adhesion of ceramic masses to noble gold alloys has been confirmed both experimentally and clinically.

However, in recent years, due to the high cost of noble alloys and the need for increased resistance of ceramic plating support increased the research interest in non noble alloys used in this technology. *Poggioli et al.* studied the metal-ceramic bond for the following alloys: austenitic Fe-Cr alloy, austenitic Fe-Cr alloy (Ta-Nb) Ni-Cr-Mo alloy, stellytes Co-Cr-(Ni). They also found that Ni-Cr alloys are the most effective in the ceramic chemical bonding to form a mechanically strong bond with the opacifying ceramic while stellytes form a low resistance bond which facilitates the fracture of the interface area.

They concluded that in denture practice, the design plays a fundamental part in preventing early

disjunctions agreeing with Vickery and Badinelli, who state that the strength of the bond is largely due to compressive force generated by the slight mismatch between the thermal expansion coefficients of the two components (alloy and ceramic mass).

Evaluation of tensile strength of the bond measured by Moffa et al. has shown that there is significant difference between the two non noble alloys and both values are much higher than those reported with noble gold alloys.

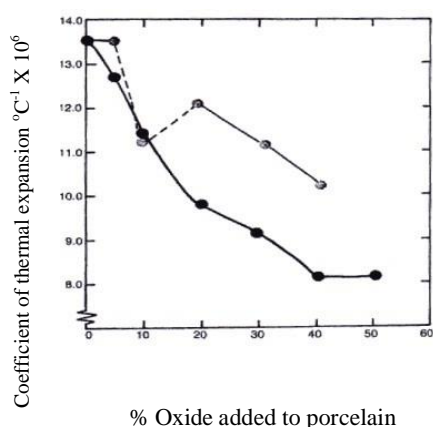


Figure 3. The effect of Ni and Cr oxides on the coefficient of thermal expansion of the ceramic VITA V.M.K. 68 (J.W.McLean, I.R.Scud)

Another study by Lubovich and Goodkat confirmed increased bond strength of the metal-ceramic bond of the three non noble alloys as compared to that of noble alloys. The experiments of McLean and Scud have shown that the strength of the bond that is established between plating porcelain and non noble alloys is negatively affected by the formation of oxides of chromium and nickel. According to the authors, when these oxides are formed at the interface, they reduce the thermal expansion coefficient of the ceramic (Figure 3), favoring the residual forces that occur at this level.

It is noted that when the oxidation of the non noble alloys is reduced by controlling the oxygen in the sintering furnace chamber, there is no chemical reduction reaction of the constituents of the porcelain structure by the chromium ions, reducing the

formation of chrome oxides as well. When using a sintering atmosphere rich in hydrogen, K_2O reduction may occur at $1000\text{ }^\circ\text{C}$, while chromium ions will be reacted by reduction of K_2O , Na_2O și SnO_2 . The reduction reaction occurs in current practice because, until maturation of porcelain, the interface area is in contact with the atmosphere of the sintering furnace chamber. Thus any reduction reaction is dependent on the oxidative potential of the atmosphere inside the chamber.

This phenomenon probably explains, the "transparency" of the non noble alloy by the plating ceramic mass, in reality the alloy being not visible but the reduction reaction products which have a gray color (figure 4).



Figure 4. Section through the ceramic mass which was removed after sintering from the cylindrical cone casted from the non-noble (I.R.Scud și J.W.McLean)

Bond strength of non noble alloys and ceramic mass

Due to the high degree of residual strength, the ceramic bond strength determined as Co-Cr alloys, as well as of the Ni-Cr appears to be higher than that obtained from noble gold alloy when sintering is carried out in an oxidizing atmosphere, the average force required for porcelain separation being increased than tensions in the ceramic sintered on noble gold alloys (McLean and Scud).

However, these results may be erroneous as to take into account the high degree of residual forces occurring in the interface due to the action of the chromium oxide of reducing the coefficient of thermal expansion. If the action of the residual stress

has an opposite direction of the test force application then it should be removed before the results are recorded (they shall be increased).

Although the strength of the bond between the non noble alloy and the ceramic can achieve 36N/mm^2 it is especially important the type of fracture that occurs (through porcelain or at the interface). Non nobles alloys suffer fractures, usually at the interface (figure 5), while the noble gold alloys suffer usually cohesive fracture through the ceramic mass.

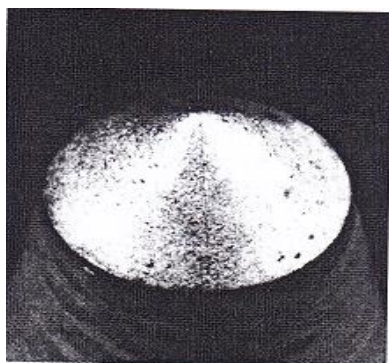


Figure 5. The fracture surface of an alloy Ni-Cr/ceramic mass (I.R.Scud și J.W.McLean)[1]

Types of fractures of the ceramic-metal system

Classification of metal-ceramic system disjunctions was made by O'Brien (figure 6) as follows [3]:

- alloy-porcelain disjunction – the fracture occurs at the interface, leaving a smooth surface of the alloy. This type of fracture is produced when the surface of the alloy is not oxidized prior to the sintering of the ceramic oxides or when oxides that form are not enough. It may be also due to the contamination or a porous metal surface;
- metal oxide-porcelain disjunction – the ceramic mass is fractured near the interface, leaving metal oxides on the metal surface.

- This type of fracture is the most common for non noble alloy;
- alloy-metal oxides disjunction - is a fracture in the interface where oxides are detached from the alloy

- surface and remain attached to the plated/coated ceramic. This disjunction occurs with non noble alloys when forming Ni și Cr oxides in excessive;
- metal oxides- metal oxides disjunction - this type of fracture occurs at the interface also being generated by the "sandwich effect" that may have an overproduction of metal oxides;
- cohesive fractures in alloys – are not a fracture characteristic of metal-ceramic system, it may occur at the points of the body-bridge solidarity elements;
- cohesive fractures in porcelain - is the best type of fracture that occurs in ceramic mass. In this case the strength of the bond is higher than that of the porcelain. It is an ideal situation in which the oxide film has a thickness of several microns to form a solid solution with the ceramic mass. This type of fracture occurs most frequently in noble gold alloys, confirming their constant clinical success.

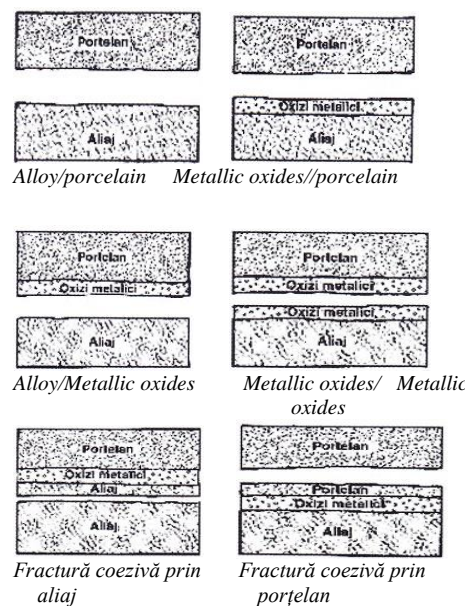


Figure 6. Classification of the types of fracture of the metal-ceramic system (O'Brien)[3]

Prolonged or repeated sintering of metal-ceramic crown may cause excessive solubilization of the oxide layer overlying the ceramic mass. In this case, the system fracture can occur in the porcelain and cannot indicate the residual stress in the interface generated by the difference between the thermal

expansion coefficients of the two components. This type of fractures may occur in non noble alloys.

In terms of formation of metal oxides on the interface with the porcelain, it is obvious that any alloy which is designed for the metal-ceramic technology should contain non noble alloy micro percentages able to produce these oxides in the following conditions:

- oxides should form only a very thin layer but allowing the alloy to come into contact with the plated atomic mass ;
- the oxide layer should have a satisfactory adhesion to the surface of the alloy;
- the oxide layer should react with the porcelain layer without altering the required characteristics for the clinical success of the final denture, such as thermal expansion, strength, color and degree of the translucence.

Tin and indium oxides formed in the case of noble alloys are subject to the above requirements. The chromium oxide which is the major product of the oxidation of a high-Cr alloys limit the indications of these alloys in the metal-ceramic technology. However, micropercentages of chrome in the modern non noble alloy composition give them a high degree of corrosion resistance.

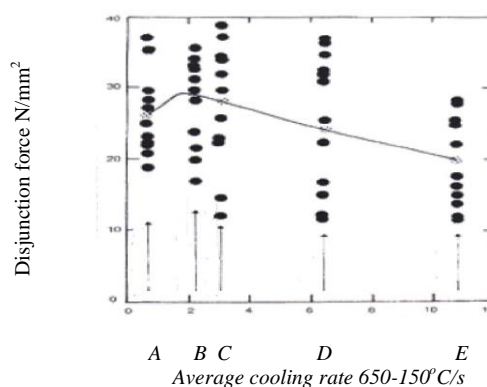
The effect of degree of oxidation and the cooling rate on the metal-ceramic bond strength

There is no well defined correlation between the degree of pre-oxidation and strength of the bond between non noble alloys and sintered overlying ceramic masses. However, it seems that pre-oxidation favors stronger bonds [1,4] Against this higher resistance the interface fracture leaves quite frequently significant amounts of oxide with greenish alloy surface (figure 8)

The cooling rate affects the extent of metal-ceramic bond strength. It was observed that at a higher cooling rate there is a significant drop in resistance (figure 7).

This could be a consequence of the release, by fracturing, of residual forces during or immediately after cooling. The higher the cooling rate (He) the bigger the ceramic mass and fractures propagated. These results are against the theory of increased resistance by artificial induction of the residual forces in the system. At a cooling rate of 2,1°C/s it is reported a percentage of 85% of the frequency of occurrence of fracture compared to a slow gradual cooling. An ideal cooling rate of the system is considered to be the one where the metal – ceramic system is allowed to cool slowly in the mouth of a sintering furnace and its early removal is contraindicated (figure 7).

From the clinical point of view it is more important to examine the type of fracture in a metal-ceramic system, for example at the interface or ceramic in the absence of tensile rupture in the ceramic/porcelain, the clinical safety of metal-ceramic system should be suspected as the max ultimate strength not was obtained, and varies depending on the specific conditions for the preparation of restoration.



- A – Cooling in furnace NPL
- B – Cooling in furnace VITA
- C – Cooling in the entrance of the furnace
- D – Rapid cooling with air
- E – Rapid cooling with helium

Figure 7. The effect of cooling rate on the strength of the bond between a Co-Cr alloy and ceramic mass VITA VMK (J.W.McLean, I.R.Scad)[1,4]

Metal-ceramic system compatibility depends

on properties combination of alloy and porcelain. Clinical and technological success of metal-ceramic prostheses have as a prerequisite the chemical, thermomechanical and aesthetics compatibility of the alloy and porcelain. Resistance to thermal shock can measure resistance to transient thermal stresses and identifies relatively incompatible systems [5-7]. Thermal compatibility between components is complex, there are authors who argue that basic ceramic masses have different coefficients of expansion (α). *Bertolotti and Shelby* have shown that the transition temperature of the primer differs from that of the base layer (body porcelain) for certain ceramic masses. Metal-ceramic prostheses present residual thermal stresses due to thermal expansion coefficient mismatch since the moment of ceramic masses burning. The residual thermal stress add to the stresses occurring after application in the oral cavity [5-9]. There are no thermal coefficient to perfectly match the whole thermal cycle or for all dental metal-ceramic systems. There is a degree of compatibility which is attributable to the expansion coefficients of the two components, the ignition temperature of porcelain, metal resistance to high temperatures, releasing internal stresses from metal and ceramic, the proportion between the metal and the ceramic thickness and strength of the bond between metal and dental porcelain [10].

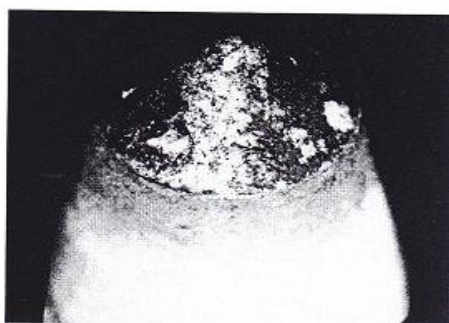


Figure 8. *Fracture surface of a Co-Cr/porcelain alloy specimen which was preoxidated a higher amount of time (I.R.Scud , B.E.Hopkins , J.W.McLean)[1,4]*

Using mixed metal-ceramic bridges requires

the focus and maximum exigencies in the technical clinical stages of obtaining this prosthesis. For integration into the biofunctionality of the maxillary dental system, the metal-ceramic bridges must meet the following requirements, derived from observations made on casuistry taken for treatment purpose [11-24]:

- prior to treatment with prosthetic metal-ceramic bridges, the prosthetic field will be prepared carefully to ensure dental periodontal tissues health ;
- dental preparation will be done with proper tools of shapes, sizes compatible with metal-ceramic technology;
- metal-ceramic bridges require perfect marginal adaptation to avoid unsightly appearance and the appearance of local inflammatory phenomena;
- the best results - confirmed by clinical cases - on marginal adaptation were obtained through the use of unidental fingerprints (ring and thermoplastic or silicone material);
- the work pattern of choice was the model made of gypsum superdur movable abutments. The model in composite resins was also used;
- sample for the metal component of metal-ceramic crowns and bridges was made of prefabricated models of controlled thickness;
- use was made of the method with medium and semiadaptable articulator. These simulators have allowed an accurate individualization of occlusal areas and guiding routes ;
- metal parts were made of the entire range of alloys for metal-ceramic technology (noble, non noble and titanium);
- the best results (aesthetic, functional) were obtained with a bridge whose metal component was cast of the noble Au-Pt alloys and titanium alloys;
- metal-ceramic bond – as noted in clinical cases - requires careful preparation of metal components (blasting, degreasing, bonding application) and use of ceramic masses as specified by the manufacturer;

Modern technology of metal-ceramic bridges is a leading prosthetic solution with wide applicability in modern dentistry.

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