Porcelain-Fused-to-Metal
BONDING

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PFM bonding (porcelain-to-metal bonding, also called ceramo-metal bonding, and porcelain-metal bonding) is critical to the success of PFM restorations. [CLICK] The porcelain is rigidified by the high modulus casting substructure and requires that the interface is a strong one.
In any bonding situation, there is always an opportunity for physical, chemical, and/or mechanical bonding to occur. Physical bonding is generally very weak and in this situation contributes very little to PFM bonding. Mechanical bonding is produced by sandblasting the casting alloy prior to porcelain addition. Chemical bonding occurs because of mixing of the oxide on the alloy surface and the oxide of the porcelain. This will be discussed more in detail shortly.

[CLICK] To get intimate adaptation and encourage mechanical bonding, it is important that the porcelain wet the surface of the alloy. [CLICK] The SEM figure on the left shows the metal substructure at the bottom with a rough surface to which the opaque porcelain layer has adapted well. Above the opaque porcelain layer is the first body porcelain layer. [CLICK] The interface is magnified and shown to the right. Mechanical interlocking is crucial to the interfacial bonding.
### Chemical Bonding: Extensive

1. Occurs by oxide mixing:
   a. Thin metal oxide alloys with porcelain oxide.
   b. Transition zone of oxides from metal to porcelain.

2. Oxidation of metal alloys (or surface pre-treatments):
   a. Sn, In, Fe, or Zn may be added to alloy.
   b. Pre-oxidizing treatments may be painted on surface.
   c. Metalizing bonding agents may be painted on.

3. Precautions for bonding:
   a. Overheated alloy prematurely oxidizes the bonding elements.
   b. Thick oxide layers should be sandblasted to minimize oxide thickness before adding porcelain.

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Chemical bonding occurs because of “oxide mixing.” The metal substructure attains an oxide during the castings process. This initial oxide is partially eliminated by sandblasting to roughen the surface. However, it quickly reforms during the initial temperature rise in the porcelain furnace at the start of the vitrification procedure for the first layer of porcelain. The metal oxide encourages good wetting of the porcelain (oxide). At high temperatures, the two oxides diffuse into one another and create a mixed oxide zone. This oxide creates true chemical bonding between the metal and porcelain materials.

To encourage metallic substructure alloys to oxide at their surfaces, certain metallic elements have been included into the alloys. In gold alloys for PFM restorations, either Fe impurities in gold or intentionally added iron produces an iron oxide film that facilitates bonding. In all other alloys, Sn, In, or Zn is added to create a bonded surface oxide. Indium (In) is probably the most widely used alloy addition.

There are several conditions that may defeat effective formation of a mixed oxide zone. If the alloy is overheated, the elements that promote metal oxidation may be locally depleted during the casting procedure. They would then not be available to reform the oxide during the porcelain firing stage. Overly thick metal oxides will actually weaken the mixed oxide layer.

If there is a question as to the ability of the metallic substructure to form an oxide, surface treatments can be applied that add metallic ions that preferentially oxide, but that is not the preferred method of oxidation.

The original oxide mixing zone remains during subsequent porcelain firing stages. At the end of the process, the metal alloy surface is slightly depleted in oxidized elements such as Indium or Zinc. A metal oxide is partially mixed with porcelain forming a mixed oxide zone. Beyond this zone is regular opaque porcelain. Above the opaque porcelain is 2-3 layers of body porcelain. All of the porcelains are composed primarily of SiO2-Al2O3-K2O. The rest of the porcelain is oxides that contribute to the special properties of opacity, translucency, and/or color. Generally, there is more residual porosity in the outermost layer of porcelain that has only been fired one time, as opposed to the opaque
MECHANICAL FAILURES

A. Porcelain-to-Metal Fracture:
   (Most common site for “short-term” failures to occur.)
   (More common for base metals.)

1. **Fractures originating at the metal surface:**
   a. Surface metal contamination
   b. Incomplete degassing
   c. Under-fired opaque porcelain
   d. Improper metal thickness
   e. Incorrect metal conditioner
   f. Reused metal alloy

2. **Fracture at the opaque and entering the bulk porcelain:**
   a. Porosity at the opaque layer
   b. Cracks at the opaque layer
   c. Incomplete opaque bonding from firing at too low a temperature.

Probably the most simplistic classification of PFM failure is as “short-term” [CLICK] or “long-term” events. Short-term failures may arise in days or weeks. Long-term failures often are years (e.g., 5+ years). We will look at each category separately. [CLICK] Consider the schematic image from the slide before once more. [CLICK] Short-term failures in PFM restorations tend to arise either for 2 reasons. Examining the actual restoration is extremely helpful. It is usually apparent where the fracture started, giving a strong clue as to the real problem.

[CLICK] Fractures originating at the metal surface are all related to fabrication conditions that leave the mixed oxide layer in a less than ideal condition. [CLICK] Fractures occur along the mixed oxide interface.

[CLICK] Fractures that occur in the opaque layer are due to inadequate firing, residual porosity, and/or cracks that form during cooling. [CLICK] Fractures tend to propagate toward the bulk porcelain.
MECHANICAL FAILURES

B. **Porcelain Fractures:**  
(Most common site for “long-term” failures to occur.)  
(Design or fatigue problems.)

1. **Design or procedural errors:**
   a. Too little bulk of metal
   b. Sharp angles in porcelain
   c. Improper margin design

2. **Malocclusion or impact stresses:**

3. **Thermal contraction incompatibility:**
   a. Built-in stresses generate cracks at pores
   b. Thermal fatigue propagates cracks

REPAIR SYSTEMS

A. Silane + Acrylic (e.g., FUSION, George Taub Products, Inc.)
B. Silane + Composite (e.g., PULPDENT Porcelain Repair Kit)
C. Silane + Composite (e.g., MIRAGE PFM Repair)

Porcelain fractures [CLICK] are related to cracks from surface defects or residual internal pores. [CLICK] Cracks in both regions occur more quickly if there are design errors such as inadequate porcelain thickness, sharp angles, or improper margin shapes.

Porcelain that is glazed and/or well-polished should be immune from surface cracks. [CLICK] However, malocclusion or impact stresses can generate surface cracks as well. [CLICK] These must be removed. It is critical to remember that occlusal adjustments result in rough porcelain surfaces and these must be followed by polishing down to sub-micron finish using diamond polishing pastes.

[CLICK] Internal cracks arise at pores for a number of reasons. Porcelain cooling that is too rapid generates thermal stresses. [CLICK] Since the porcelain is an insulator, it takes considerable time to exchange heat from the inside to outside and allow the entire object to cool uniformly. If cooling is too quick, then residual stresses arise that are relieved by forming cracks at residual porosity. There are always some pores in the porcelain. Internal pores, over the long term, generate cracks due to fatigue from mechanical loading or cyclic thermal changes.

[CLICK] PFM fractures usually include the loss of about one-third of the facial porcelain on a restoration. [CLICK] Generally, this is due to the effects of flexure or inadequate porcelain thickness. Because of the great expense and time involved in replacing the PFM restoration, it is usually repaired intraorally with composite. [CLICK] Repairs typically last 4-5 years and may be redone if necessary. The exposed surface may either be metal or the opaque layer of porcelain. After proper isolation, the surface to be repaired is (1) roughened with a micro-blaster, (2) carefully acid etched with hydrofluoric acid, (3) treated with silane and (4) composite is layered into place and light cured to replace the missing porcelain. A couple of recent products are hyperlinked to this page as examples to examine.
Thank you.