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CERAMIC MATERIALS IN DENTISTRY AND TECHNOLOGICAL PROCESSES USED IN THE FABRICATION OF CERAMIC DENTAL PROSTHESES

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МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ РЕСПУБЛИКИ БЕЛАРУСЬ
БЕЛОРУССКИЙ ГОСУДАРСТВЕННЫЙ МЕДИЦИНСКИЙ УНИВЕРСИТЕТ
КАФЕДРА ОБЩЕЙ СТОМАТОЛОГИИ

Н. М. Полонейчик, Д. В. Гарабурда, И. А. Шипитиевская

КЕРАМИЧЕСКИЕ МАТЕРИАЛЫ В СТОМАТОЛОГИИ И ТЕХНОЛОГИЧЕСКИЕ ПРОЦЕССЫ, ИСПОЛЬЗУЕМЫЕ ПРИ ИЗГОТОВЛЕНИИ КЕРАМИЧЕСКИХ ЗУБНЫХ ПРОТЕЗОВ

CERAMIC MATERIALS IN DENTISTRY AND TECHNOLOGICAL PROCESSES USED IN THE FABRICATION OF CERAMIC DENTAL PROSTHESES

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П52 Керамические материалы в стоматологии и технологические процессы, используемые при изготовлении керамических зубных протезов = Ceramic materials in dentistry and technological processes used in the fabrication of ceramic dental prostheses : учебно-методическое пособие / Н. М. Полонейчик Д. В. Гарабурда, И. А. Шипитиевская. – 2-е изд. – Минск : БГМУ, 2018. – 40 с.

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Содержит необходимые студенту сведения о керамических материалах в стоматологии, а также изложены основные данные о технологических процессах, используемых при изготовлении керамических зубных протезов. Первое издание вышло в 2017 году.

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INTRODUCTION

Ceramics (porcelains) are widely used as restorative materials in dentistry. The first use of ceramics in dentistry was for denture teeth; however, ceramic denture teeth are rarely used today because of their tendency to abrade natural teeth and damage edentulous ridges. But since about 1950, ceramics have been used in esthetic restorations for teeth.

According to numerous investigations dental porcelain (dental ceramics) is considered to be among the best materials used in denture manufacturing. Dental ceramics are strong, durable, wear resistant, and virtually indestructible in the oral environment; they are impervious to oral fluids and absolutely biocompatible.

Dental ceramics, have undergone numerous modifications in terms of chemistry since their introduction. Ceramics have been able to give heed to the ever changing needs in dentistry. To delve deep into the relevance of ceramic in dentistry, one should understand the physics of forces acting in the oral cavity. The masticatory (chewing) force is the strongest force present here. Other minor forces include that of the tongue and periodontal ligament, which do not relate to the use of ceramics in dentistry.

The masticatory force is generated outside the oral cavity by basically strong muscles, that move the jaw, open it or close it. Closure of jaw produces two kinds of forces. It is predominantly compressive in nature. Frequently impact kind of force is also experienced. Hence a ceramic has to undergo cycles of these forces indefinitely, without fracture, to result in a successful restoration of lost teeth structures.

In order to have a complete idea of what ceramic means to dentistry, we need to look at the complete range of ceramics used in this discipline.

HISTORY OF DENTAL CERAMICS

As we peep into the dental history, a French dentist De Chemant patented the first porcelain tooth material in 1789. In 1808 Fonzi, an Italian dentist invented a “terrometallic” porcelain tooth that was held in place by a platinum pin or frame. Ash developed an improved version of the platinum tooth in 1837. Dr. Charles Land patented the first Ceramic crowns in 1903.Vita Zahnfabrik introduced the first commercial porcelain in 1963.

Structurally, dental ceramics contain a crystal phase and a glass phase based on the silica structure, characterized by silica tetrahedra containing central Si^4+ ion with four O- ions. It is not closely packed having both covalent and ionic characteristics. The usual dental ceramic is glassy in nature, with short range crystallinity. The only true crystalline ceramic used at present in restorative dentistry is Alumina (Al_2O_3) which is one of the hardest and strongest oxides known. Ceramics composed of a single element are rare. Diamond is a major ceramic of this type, the hardest natural material used to cut tooth enamel.

To reduce the risk of internal microcracking during the cooling phase of fabrication the porcelain-fused-to-metal (PFM) crown was developed in the late 1950’s by Abraham Weinstein. The bond between the metal and porcelain prevented stress cracks. Lost-wax fabricated metal copings also addressed the problem of the marginal fit experienced with traditionally constructed porcelain jacket crowns. While PFM crowns have a decrease in porcelain failures, the addition of a metal block-out opaque layer diminished the esthetics of these restorations. A resurgence of an all-ceramic restoration came in 1965 with the addition of industrial aluminous porcelain (more than 50 %) to feldspathic porcelain manufacturing. W. McLean and T. H. Hughes developed this new version of the porcelain jacket crown that had an inner core of aluminous porcelain containing 40 % to 50 % alumina crystals. Although it had twice the strength of the traditional PJC, it still could be used in the anterior region only (due to its lower strength). Its higher opacity was also major drawback.

Another development in the 1950s by Corning Glass Works led to the creation of the castable Dicor® crown system. Glass was strengthened with various forms of mica. The process involved the use of the lost-wax casting technique, which produced a casted glass restoration. Then, this was heat-treated or “cerammed”. The ceramming process provided a controlled crystallization of the glass that resulted in the formation and even distribution of small crystals. The type of crystal formation depended on the feldspathic formulation used. Examples of different crystalline formations are leucite, fluoromica glass, lithium disilicate, and apatite glass ceramics. The crystal formation increased the strength and toughness of the glass ceramic. For the Dicor® material, time and temperature controlled the rate of growth, amount, and size of tetra silicic fluoromica crystals. The resultant monochromatic crown was shaded with an application of a superficial color layer. The processing difficulties and high incidence of fracture were factors that led to the abandonment of this system.

Leucite was first added to feldspathic porcelains to raise the coefficient of thermal expansion to match the metals to which they were fired. Crystalline leucite phases also helped feldspathic porcelain slow crack propagation. High leucite-containing ceramics Empress® 1 and optimal pressable glass (OPC) were introduced in the late 1980s and were the first pressable ceramic materials. Although the initial steps for fabrication of Empress and OPC were similar to Dicor and Cerestore in which the restoration was formed in wax, a heated leucite-reinforced ceramic ingot was pressed into the mold using a specially designed pressing furnace, whereas the Dicor crown was created using centrifugal casting.

This process of pressing ceramic ingots became very popular due to the esthetics and ease of use in the laboratory. Despite the increase in strength of leucite-reinforced pressed Empress material, fracture was still possible when used in the posterior region.

During this time, a glass-infused ceramic core system was developed. Vita used a slip-casting process in which the core achieved an 85 % sintered alumina by volume and introduced the In-Ceram® system. This glass-infused alumina core had a flexural strength of 352 MPa. To increase the translucency and esthetics, Vita replaced the sintered alumina with spinel ($MgAl_2O_4$). The change of infused oxides slightly reduced the flexural strength but produced a restoration more appropriate for the anterior region. Vita also added another variation of the infused core by mixing alumina with zirconium oxide crystals which increased the flexural strength to 700 MPa. It was intended for posterior crowns and bridges.

In the mid 1990s Nobel Biocare introduced the Procera® AllCeram core, which was the first computer-aided design/computer-aided manufactured (CAD/CAM) substructure. This core consisted of 99.9 % alumina on which feldspathic ceramic was layered.

The use of CAD/CAM technology spurred a whole new generation of ceramic substructures consisting of zirconium dioxide. Several manufacturers (Lava, 3M ESPE; Procera Forte, Nobel Biocare; and Cercon, DENTSLY) introduced crown-and-bridge frameworks milled from blocks of presintered yttrium-stabilized zirconium dioxide blocks. The oversized milled frameworks were then sintered for 11 hours at 1500 °C providing excellent fit with 900 MPa to 1300 MPa of flexural strength. Other manufacturers (Everest, KaVo, DC-Zirkon, Precident DCS) milled fully sintered zirconium dioxide blocks (because it removed the shrinkage factor and had a superior marginal fit). Both fabrication methods provide a framework with sufficient flexural strength, allowing them to be used for multi-unit posterior bridges.

In 1998 Ivoclar introduced IPS Empress II, a lithium disilicate ceramic material used as a single- and multiple-unit framework indicated for the anterior region. The framework was layered with a veneering ceramic specially designed for lithium disilicate. A 5-year study revealed a 70 % success rate when used as a fixed partial denture framework.

Authentic®, a second-generation, low-fusing, high-expansion, leucite glass-reinforced ceramic material was introduced into the European market in 1998 by

Ceramay GmbH & Co and later that year was introduced into the US market by Microstar. Laboratory technician Brian Lindke experimented with pressing Authentic to specific alloys. Alloys with matching coefficients of thermal expansion were developed and hence the Press-to-Metal™ technique was introduced. Soon this technique was adopted substituting the metal with zirconium dioxide frameworks. Ceramic pressable ingots with a compatible coefficient of thermal expansion were developed for this technique.

Lithium disilicate re-emerged in 2006 as a pressable ingot and partially crystalized milling block (Cerec® for chairside and inLab® milling units for laboratories). The flexural strength of the material was found to be more than 170 % higher than any of the currently used leucite-reinforced ceramics. The ceramic material can be milled or waxed, and then pressed to full contour and subsequently stained. Another option allows cutting the crown back, followed with layering with different specially designed apatite ceramic glass. The layering ceramic has the same basic components as natural tooth enamel. CAD/CAM milling of a framework (zirconium dioxide or metal), a full-contoured crown (lithium disilicate at chairside or in the laboratory), or an implant abutment has opened the market for digitized restorative dentistry.

Dental material manufacturers seem to be leaning away from metal alloy-containing restoratives and favoring all-ceramic restorative dentistry. Research and development appear to be heading in two directions — improving the strength and esthetics of bilayered zirconium dioxide restorations and achieving a milled monolithic posterior bridge material.

CERAMIC MATERIALS IN DENTISTRY

The word ceramic derived from the Greek word *keramos* which literally means “burnt stuff” but which has come to mean more specifically a material produced by burning or firing.

Ceramics — are inorganic non-metallic compounds produced by the sintering (firing) of the initial ingredients at high temperature.

Applications of ceramic materials in dentistry:

– fabrication of full-ceramic and porcelain fused to metal (PFM) dentures;

– ceramic denture teeth for removable dentures;

– fabrication of ceramic crucibles for metal melting, firing trays for ceramic sintering;

– as an abrasive material used for ceramic materials and polishing pastes manufacturing;

– as a binding material for grains in abrasive instruments;

– as a filler in different dental restorative materials.

CLASSIFICATION OF DENTAL CERAMIC MATERIALS

1. According to their fields of use (figure 1):

– *esthetic dental ceramic materials* — some kinds of silicate ceramics, which resemble natural enamel and dentine;

– *structured dental ceramic materials* — cast glass and polycrystalline ceramics — their relative opacity makes it difficult to mask the core with glass infiltration and may therefore limit the esthetic qualities of the final restoration.

a ***b***

Fig. 1. Esthetic and structured classes of dental ceramic materials:
a — esthetic dental ceramic; *b* — structured dental ceramic

2. According to its function within the restoration (by J. J. Manappalil):

Core ceramic: supports and reinforces the restoration.

Opaquer ceramic: masks or hides the metal.

Veneering ceramic:

a) *body or dentine:* simulates the dentine portion of natural teeth;

b) *incisal:* simulates the enamel portion of natural teeth;

c) *gingival:* simulates the darker gingival portion of teeth;

d) *translucent:* simulates translucent incisal enamel seen sometimes in natural teeth;

e) *stains:* used to color ceramics to improve esthetics;

f) *glaze:* imparts a smooth glossy surface to the restoration.

3. According to the fusion temperature:

– the high-fusing ceramic has a fusing range — from 1290 to 1350 °C;

– the medium-fusing ceramic — from 1095 to 1260 °C;

– the low-fusing ceramic — from 870 to 1065 °C;

– the ultra-low-fusing ceramic (below 850 °C).

4. According to the type (by Dr. R. W. Phillips):

– feldspathic porcelain;

– leucite-reinforced glass ceramics;

– lithium disilicate glass ceramics;

– alumina-reinforced ceramics;

– spinell-reinforced ceramics;

– zirconia-reinforced ceramics.

5. According to fabrication process:
- condensable ceramics;
- slip-cast glass-infiltrated ceramics;
- hot-pressed ceramics;
- castable ceramics;
- machinable ceramics;
- various combinations of the aboves.

BASIC CONSTITUENTS AND MANUFACTURE

Silicate ceramic consists of homogeneous glassy phase (80 %) with incorporated refractory crystals (crystalline phase) (figure 2).

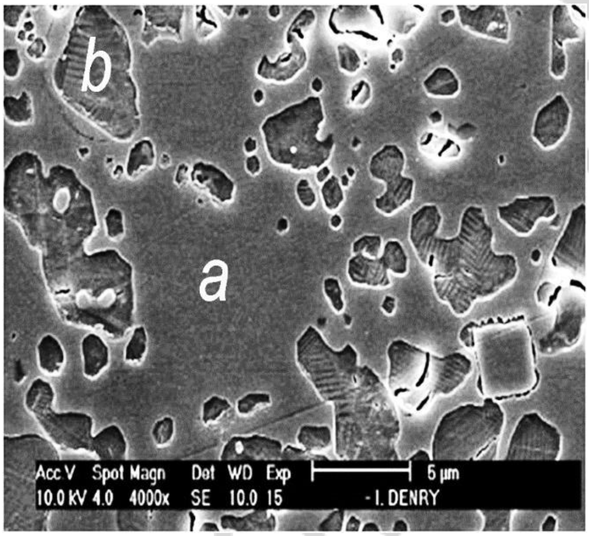


Fig. 2. Homogeneous glass matrix (*a*) and crystals of silicate ceramic (*b*)

The quality of any ceramic depends on the choice of ingredients, correct proportioning of each ingredient, and the control of the firing procedure. Only the purest ingredients are used in the manufacture of dental porcelains because of the stringent requirements of color, toughness without brittleness, insolubility, and translucency, as well as the desirable characteristics of strength and thermal expansion.

Feldspathic ceramic (dental porcelain) contains kaolin, quartz, feldspar and different colorants. Kaolin acts as a binder for filler particles (quartz), fastens and forms a solid base for ceramic.

Kaolin is a white or light-colored clay. The more content of kaolin in the mixture, the less transparence and the higher firing temperature of the ceramic mass. The major component of kaolin (99 %) is kaolinate consisting of 39.5 % Al_2O_3, 46.5 % SiO_2 and 14 % H_2O. Kaolin provides mechanical strength and thermal stability for the feldspathic ceramics.

Feldspar is a naturally occurring mineral that forms the base of feldspathic porcelain. The content of feldspar in the mixture is about 60–70 %. The more content of feldspar, the more transparence of the ceramic mass. Most of the components needed to make dental porcelain are found in feldspar. It contains potash (K_2O), soda (Na_2O), alumina (Al_2O_3) and silica (SiO_2). It is the basic glass former. When fused at high temperatures during manufacturing, it forms a feldspathic glass containing potash feldspar ($K_2O.Al_2O_3.6SiO_2$) or soda feldspar ($Na_2O.Al_2O_3.6SiO_2$). The melting temperature is about 1180–1200 °C. During heating feldspar as a more low-fusible component decreases the melting temperature of the mass, forms a glassy phase in which quartz and kaolin are dissolved. Feldspar provides plasticity for ceramic mass and forms shining and glazing surface after sintering.

Quartz (silica oxide, SiO_2). The content of quartz in the feldspathic ceramics is 25–30 %. Quartz is refractory, its melting temperature is 1710 °C. During sintering process quartz increases viscosity of the melting feldspar. In the temperature of 870–1470 °C quartz increases in its volume by 15.7 % and thus reduces the shrinkage of ceramic mass. Quartz decreases shrinkage and brittleness of ceramic, providing strength and chemical stability for ceramic product.

Metal oxides are usually usedas *colorants*. They color ceramic mass in different shades like natural teeth.

The composition of dental ceramics is also discussed in table 1.

Table 1

Basic composition of dental ceramics

Component	Functions
1. Feldspar	Basic glass former. It is the lowest fusing component, which melts first and flows during the firing, initiating these components into a solid mass
2. Silica (Quartz)	1. Strengthens the fired porcelain restoration. 2. Remains unchanged at the temperature normally used in firing porcelain and thus contribute stability to the mass during heating by providing framework for the other ingredients
3. Kaolin	1. Binder. 2. Increases moldability of the unfired porcelain. 3. Impacts opacity to the finished porcelain product
4. Glass modifiers, e.g. K, Na or Ca oxides	1. Added to provide porcelain at different firing temperatures. 2. Responsible for lowering the softening temperature of glass and increase fluidity.
5. Color pigments, e.g. Fe/Ni oxide (brown), Cu oxide (green), MgO (lavender), etc.	To obtain the delicate shade necessary to simulate the natural teeth.

MANUFACTURING OF PORCELAIN POWDER

Traditionally porcelain powders are manufactured by a process called *fritting* (figure 3). Various components are mixed together and fused. While it is still hot, it is quenched in water. This causes the mass to crack and fracture, making its powdering easier. The frit is ground to a fine powder and supplied to the consumer in bottles. Most of the chemical reaction takes place during the manufacture (pyrochemical reaction). During the subsequent firing in the dental laboratory, there is not much of chemical reaction. The porcelain powder simply fuses together to form the desired restoration.

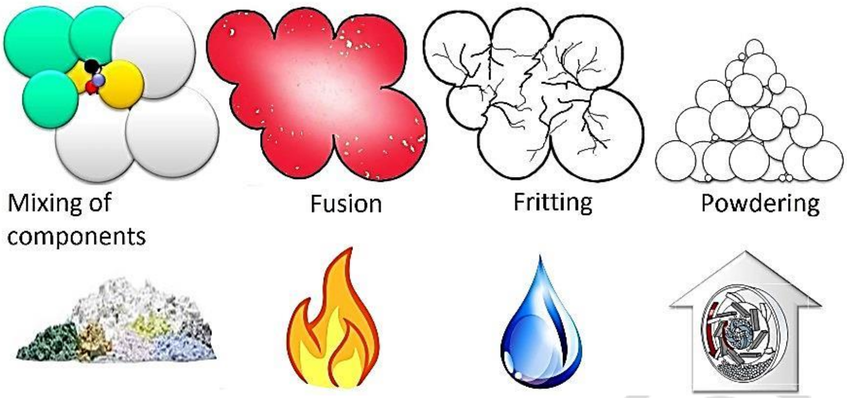


Fig. 3. Manufacturing of porcelain powder

Leucite reinforced porcelain

In reinforced ceramic materials special crystal additions are usually present (leucite, lithium silicate, etc.).

Feldspathic ceramic reinforced with leucite contains 35–40 % of leucite (figure 4). Leucite is grey or white mineral, potassium alumosilicate. The chemical name of leucite is $K[AlSi_2O_6]$ or $K_2O \cdot Al_2O_3 \cdot SiO_2$. Leucite composition is: K_2O — 20.59 %; Al_2O_3 — 23.22 %; SiO_2 — 56.1 %.

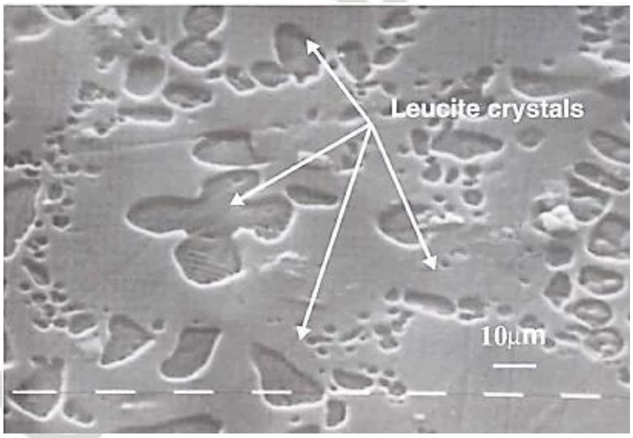


Fig. 4. SEM of the structure of a feldspathic ceramic reinforced with leucite

The optimum distribution of leucite crystals is achieved by thorough selection of material composition and precise technical process. By adding 17–20 % of leucite in ceramic mass its CTE (coefficient of thermal expansion) becomes close to CTE of metals.

Uses: inlays, onlays, veneers and low stress crowns.

Advantages:

1. They are more esthetic because the core is less opaque (more translucent) when compared to aluminous porcelain.

2. Higher strength.
3. No need of special laboratory equipment.

Disadvantages:
1. Fit is not as good as metal ceramic crowns.
2. Potential marginal inaccuracy.
3. Not strong enough for posterior use.

Lithium disilicate ceramics

To extend the application of all-ceramic restorations and the manufacturing of all-ceramic bridges a special material was developed (SiO_2-Li_2O system). Lithium disilicate ($Li_2Si_2O_5$) takes up 70 % of ceramic material mass.

Lithium disilicate is characterized by unusual microstructure which consists of multiple elongated and plane crystals dispersed in a glassy matrix (figure 5). The main advantage of lithium disilicate containing ceramics is their superior flexural strength and fracture toughness.

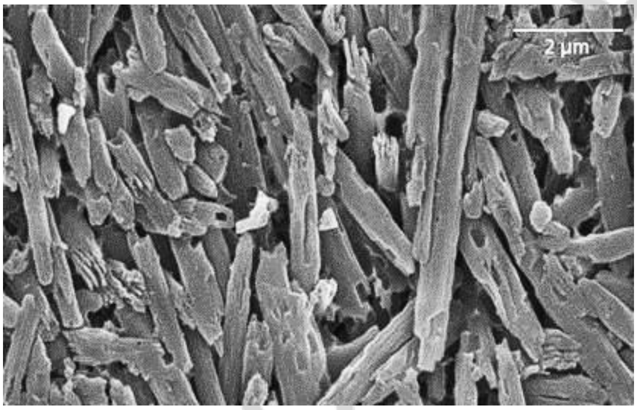


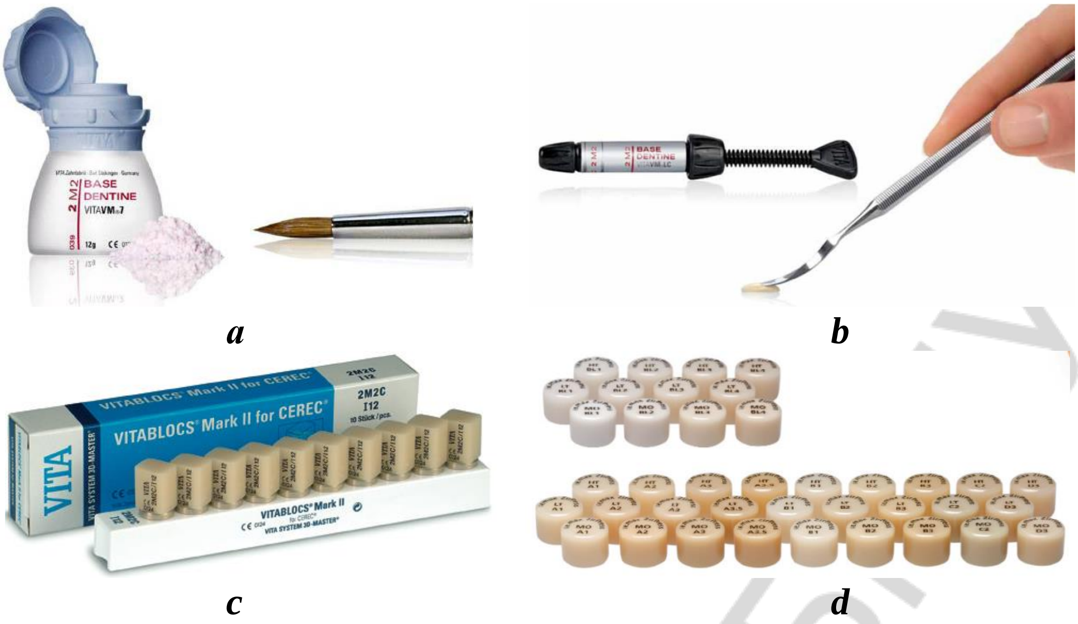
Fig. 5. SEM of the structure of lithium disilicate containing ceramics

In addition, in the structure of lithium disilicate containing ceramics one more crystalline phase is present — lithium orthophosphate (Li_3P0_4). The higher strength of ceramic reinforced with leucite provides manufacturing not only single crowns for anterior and posterior teeth but also the fabrication of all-ceramic bridges.

To veneer crystalline ceramic frames (based on lithium disilicate) special apatite ceramic is developed. During manipulation with this ceramic calcium hydroxyapatite ($[Ca_{10}(PO_4)_6{\bullet}2OH]$) is formed.

MANUFACTURING FORMS OF DENTAL CERAMICS MATERIALS, USED FOR DENTURE FABRICATION

Ceramic materials are supplied as **powders** (they need mixing with liquid, figure 6, *a*), **pastes** packed in special syringes (figure 6, *b*), ceramic blocks for CAD/CAM (figure 6, *c*), **ceramic ingots** for hot-pressing (injection molding) (figure 6, *d*), and **artificial ceramic teeth** (figure 7).



a *b* *c* *d*

Fig. 6. Forms of dental ceramic materials manufacturing, used for denture fabrication: *a* — powders; *b* — pastes in special syringes; *c* — ceramic blocks for milling; *d* — ceramic ingots for injection molding

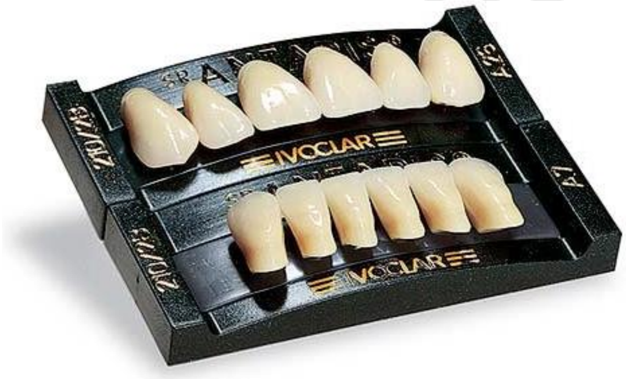


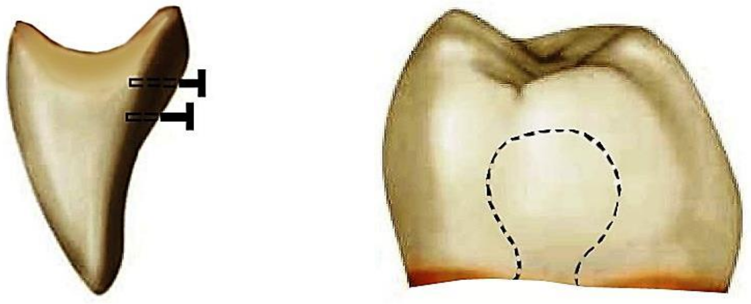
Fig. 7. Set of artificial ceramic teeth for upper and lower jaws

PORCELAIN DENTURE TEETH

Porcelain for artificial teeth fabrication has been used more than 100 years. Porcelain for artificial teeth manufacturing is made of kaolin composed of white clay (3–10 %), quartz (15–25 %) and feldspar (60–75 %). Kaolin acts as a binder, quartz provides strength for ceramic mass and feldspar melts and fills all the voids during heating.

Smooth shining surface which covers porcelain teeth contains about 90 % of feldspar. Porcelain stains are metal oxides: titanium, nickel, cobalt, gold and platinum. Such organic substances as starch, paste, etc. are usually added as gluing agents to ceramic mass (they burn out without excessive residue).

The *anterior teeth* have one or two gold-covered *pins* to provide retention in the denture base. The *posterior teeth* have *diatoric spaces* located centrally in the underside of the teeth for retention in the denture base (figure 8).



a *b*

Fig. 8. Porcelain tooth with pin (*a*) and diatoric space (*b*)

The main *advantages* of porcelain denture teeth are their superior esthetics, resistance to abrasion and excellent shade stability.

The disadvantages of porcelain denture teeth are:

1. They are brittle and make a clicking sound during contact.
2. They require a greater interridge distance as they cannot be ground as thin as acrylic teeth in the ridge-lap areas without destroying the diatoric channels or pins that provide their only means of retention.
3. The higher density increases their weight.
4. Difficulty of polishing the surface after occlusal adjustment resulting in significant wear of the opposing teeth.

A comparison of resin and porcelain teeth is presented in table 2.

Table 2

Comparison of resin and porcelain denture teeth

Resin	Porcelain
High fracture toughness	Brittle, may chip
Crazing is not cross-linked	Susceptible to crazing by thermal shock
Clinically significant wear	Insignificant wear
Easily ground and polished	Difficult grinding, danger of glaze removal
Silent on contact	Clicking sound on impact
Dimensional change with water	Dimensionally stable
Cold flow under stress	No permanent deformation
Loss of vertical dimension	Stable
Self-adjusting	Difficult to fit in the diminished interarch space
Chemical bond to denture	Mechanical retention
Minimal abrasion of opposing dentition	Abrades opposing dentition

GLASS-INFILTRATED CERAMICS

Glass-infiltrated ceramics are characterized by high concentration (up to 70–80 % by volume) of refractory particles in glassy (vitreous) phase.

Types. Currently there are three types depending on the core material used.

1. Glass-infiltrated alumina core (In-Ceram-Alumina).
2. Glass-infiltrated spinel core (In-Ceram-Spinel).
3. Glass-infiltrated zirconia core (In-Ceram-Zirconia).

In feldspathicglass no more than 50–60 % (by volume) of refractory particles can be added because of restrictions due to the fritting process. The alternative approach was the invention of a new system called In-Ceram (Vita). Materials used for ceramic frame fabrication contain about 85 % of aluminum oxide (In-Ceram-Alumina).

Aluminum oxide ceramic dentures are made by slip-cast method. In this system, a sintering (hard — particles agglomeration) takes place at the temperature of 1120 °C. These particles (their average size is nearly 3 μm) form junctions on the contact points (figure 9). The structure of such materials has a chalk-like consistence and can be easily processed. The strength of the porous frame is low, about 6–10 MPa.

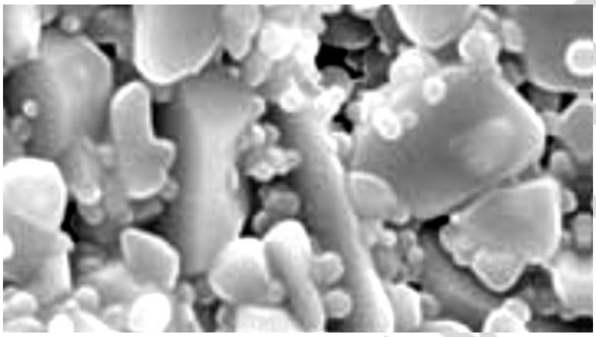


Fig. 9. Sintered particles of aluminum oxide

The porous structure is then infiltrated with glass. Only after this stage glass-infiltrated In-Ceram materials obtain their high strength and tooth-like shade. Lanthanum glass is used for glass-infiltration. This type of glass has excellent bond with corundum and at the infiltration temperature of 1100 °C the melted mass has a low viscosity. This melted mass can penetrate in pores and owing to this process a dense ceramic material is obtained (figure 10).

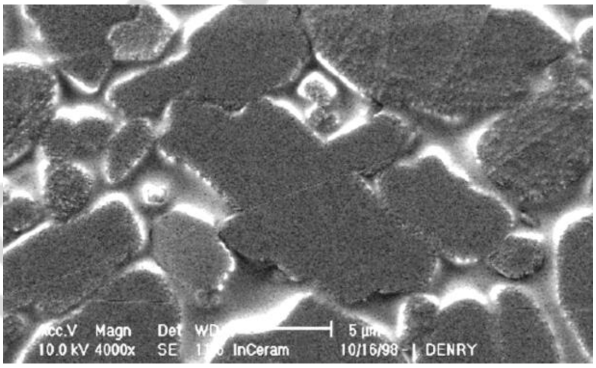


Fig. 10. The ceramic structure after glass-infiltration of aluminum oxide particles with lanthanum glass

The same approach was used for the fabrication of full-ceramic frames of magnesia spinell ($MgAl_20_4$) (In-Ceram-Spinell) and zirconia oxide (In-Ceram-Zirconia). In-Ceram-Zirconia is based on In-Ceram-Alumina ceramic adding 33 % of zirconia oxide (figure 11).

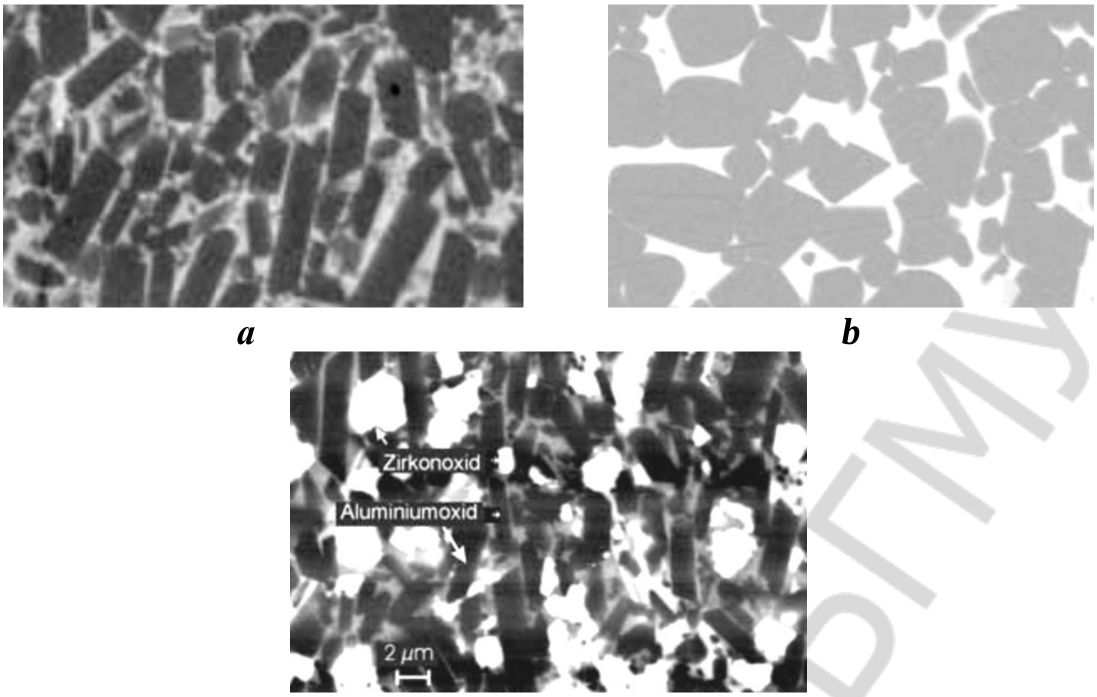


Fig. 11. Sections of glass-infiltrated materials VITA In-Ceram Alumina (*a*), VITA In-Ceram Spinel (*b*) and VITA In-Ceram Zirconia (*c*), SEM 5.000×

Polycrystalline (oxide) ceramic is characterized by the absence of amorphous glassy phase. In dentistry high-quality oxide ceramics of pure aluminum oxide or zirconia oxide are used. These materials have dense, non-porous micro mass with high strength and hardness.

The main raw for zirconia oxide manufacturing is a mineral zircon ($ZrSiO_4$). Zirconium oxide is produced of zircon by eliminating silica oxide.

Zirconium oxide is known in 3 phases: monoclinic (M), tetragonal (T), and cubic (C). During heating zirconium oxide changes its structure (phase). Monoclinic phase is stable in the room temperature and up to 1170 °C. At the higher temperature zirconium oxide transfers into a denser tetragonal phase. Tetragonal phase remains stable from 1170 °C to 2370 °C. At the temperature higher than 2370 °C zirconium oxide transfers into a cubic phase. This transition from monoclinic (M) to tetragonal (T) phase occurs during heating with 5 % volume decrease. A transfer from tetragonal (T) to monoclinic (M) phase occurs during cooling in the range of temperatures from 100 °C to 1070 °C with the following 3–4 % volume increase (figure 12).

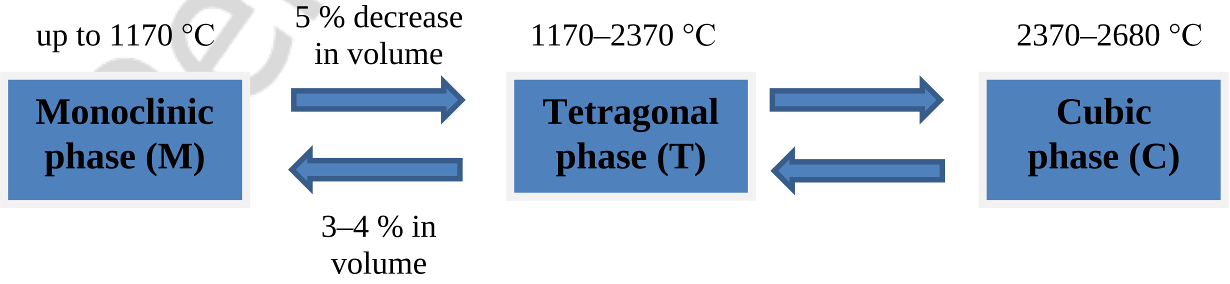
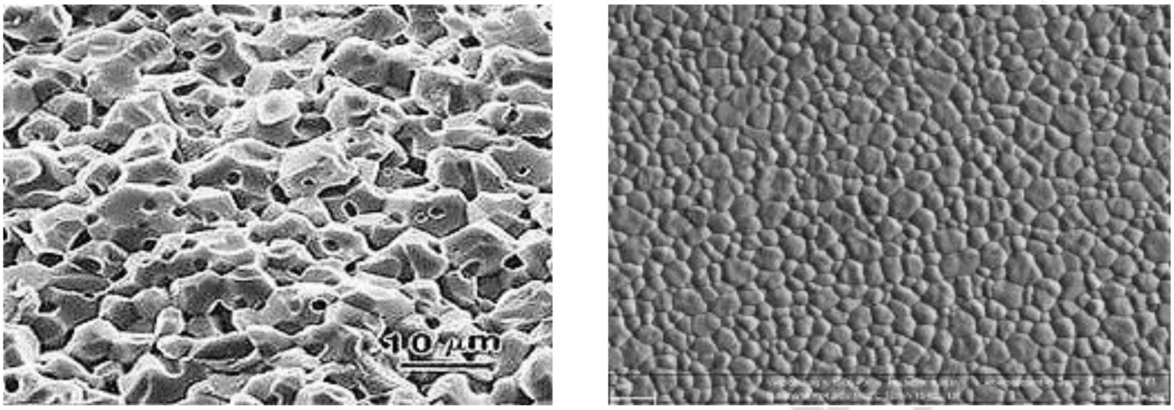


Fig. 12. Phase transfer of zirconium oxide

Adding of stabilizing oxides (like calcium oxide, CaO, magnesium oxide, MgO, cerium oxide, CeO_2, and yttrium oxide, Y_2O_3) may put down the phase transformation of the material. According to the amount of stabilizing agent partially stabilized zirconium oxide (PSZ, figure 13, *a*) and completely stabilized zirconium oxide (FSZ, figure 13, *b*) are known.



a ***b***

Fig. 13. The structure of partially stabilized zirconium oxide (*a*) and completely stabilized zirconium oxide (*b*)

Partially stabilized zircon consists of ZrO_2 (95 %) + Y_2O_3 (3–5 %) and can be produced of the granules with 50 µm diameter by dry isostatic pressing. After pressing the blocks are fired at 1100° during 30 minutes (figure 14).

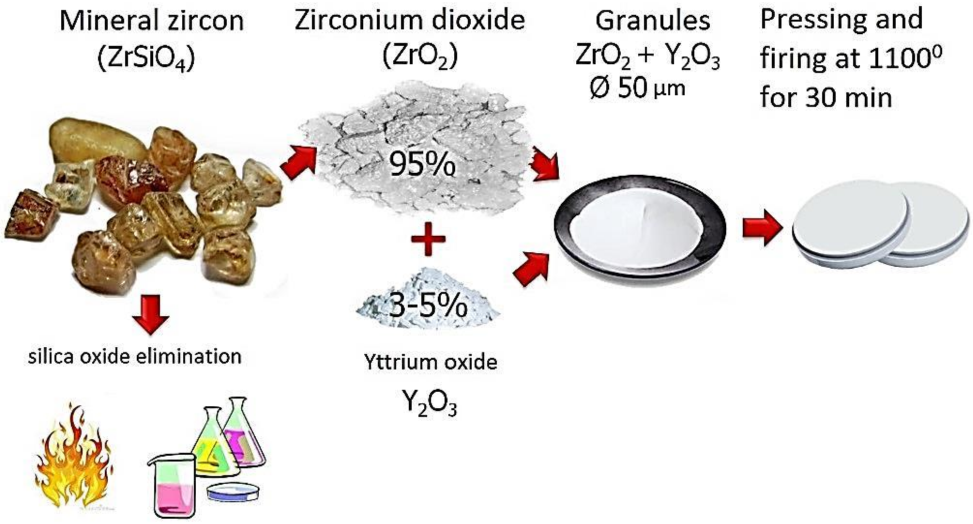


Fig. 14. Scheme of partially stabilized zirconium (PSZ) fabrication

Partially stabilized zirconium oxide (figure 15) has a high porosity (50 %), low flexural strength (50 MPa) and this provides milling in a more simple way (because the consistence of material is soft and chalk — like). And only after milling the sintering is made at 1500–2000 °C temperature. After sintering the material's strength becomes higher.

Fig. 15. Blocks made of partially stabilized zirconium oxide

Completely (fully) stabilized zirconium oxide (FSZ) is produced by adding CaO (7.9 % by weight), MgO (5.86 % by weight), Y_2O_3 (13.75 % by weight) to its composition (figure 16). Completely (fully) stabilized zirconium oxide (FSZ) has a cubic phase (C). The porosity of material is minimal and flexural strength is the highest among ceramic materials (up to 1200 MPa). On the other hand a high strength of this material leads to prolonged milling, quick wear of abrasive instruments.

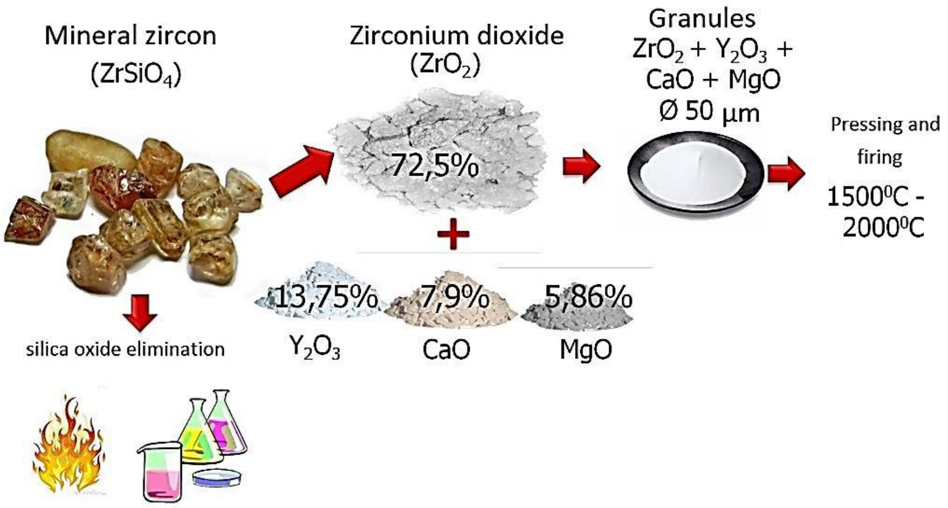
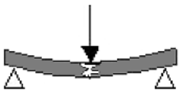


Fig. 16. Scheme of fully stabilized zirconium (FSZ) fabrication

COMPARISON OF CERAMIC PROPERTIES

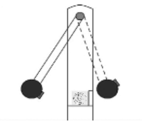


Bending strength (MPa) of different ceramic types is represented in table 3.

Table 3

Comparison of ceramic bending strength

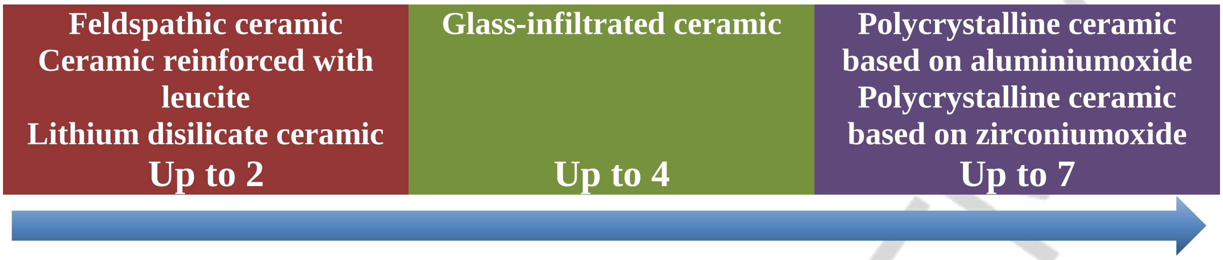
Feldspathic Ceramic	Ceramic Reinforced with leucite	Lithium disilicate ceramic	Glass-infiltrated ceramic	Polycrystalline ceramic based on aluminum oxide	Polycrystalline ceramic based on zirconium oxide
60-70	120	360	350–650	600–700	1120



Impact viscosity (MPa, $m^{0.5}$) of different ceramic types is represented in table 4.

Table 4

Comparison of ceramic impact viscosity



Feldspathic ceramic Ceramic reinforced with leucite Lithium disilicate ceramic	Glass-infiltrated ceramic	Polycrystalline ceramic based on aluminiumoxide Polycrystalline ceramic based on zirconiumoxide
Up to 2	Up to 4	Up to 7

Properties of three types of glass-infiltrated ceramics are compared in table 5.

Table 5

Comparison of glass-infiltrated ceramics

Property	In-ceram Alumina	In-ceram Spinell	In-ceram Zirconia
Composition	Al_2O_3 and lanthanum glass	$MgO – Al_2O_3$	$Al_2O_3 – ZrO_2$
Flexural strength (MPa)	500	350	700
Translucency	Translucent	Highly translucent	Opaque
Strength	Better	Good	Best
Indications	Anterior and posterior crowns, anterior 3-unite bridges	Anterior crowns, inlays and onlays	Posterior crowns and bridges

CAD/CAM RESTORATIONS

CAD/CAM (figure 17) — *computer aided design/computer aided manufacture*. This is a high-tech approach to providing patients with durable tooth-colored restorations. It involves recording an optical impression from which a restoration can be designed using a computer. The design elements are then used to construct the restoration using a milling machine which cuts the desired shape of a monolithic block of ceramic under the control of the computer.

The design of the restoration on the computer screen takes between 10 and 25 minutes depending on the complexity of the restoration and the extent of the patient's occlusal correction. The milling process takes 5–10 minutes.

Fig. 17. CAD/CAM dental equipment

A CAD/CAM equipment for manufacturing dental appliances and restorations at the chairside using computer-generated images and computer controlled milling equipment is shown on the figure 17. There are the control unit and the computer used for viewing the scanned images on the right of the figure and there is a milling machine in which the shapes are cut of a variety of materials on the left.

ADVANTAGES AND DISADVANTAGES OF CAD/CAM

Advantages:

1. Reduced chair time.
2. Stronger porcelain. Milled ceramic is stronger.
3. In some systems the scanning is done directly in the mouth so there is no need to make an impression.
4. One visit.
5. Lab equipment can be minimized as the equipment involved with metal casting and processing is not required.
6. The possibility to copy the original form of the tooth enables the dentist to duplicate a pre-prepared tooth.

Disadvantages:

1. Costly equipment.
2. The technique of scanning the preparation is sensitive (there may be many errors).
3. The lack of computer software to control the occlusal adjustment.

TECHNOLOGICAL PROCESSES, USED IN FABRICATION OF CERAMIC DENTURES

Technological processes used in the manufacturing of dentures with the use of dental ceramics, are shown in figure 18.

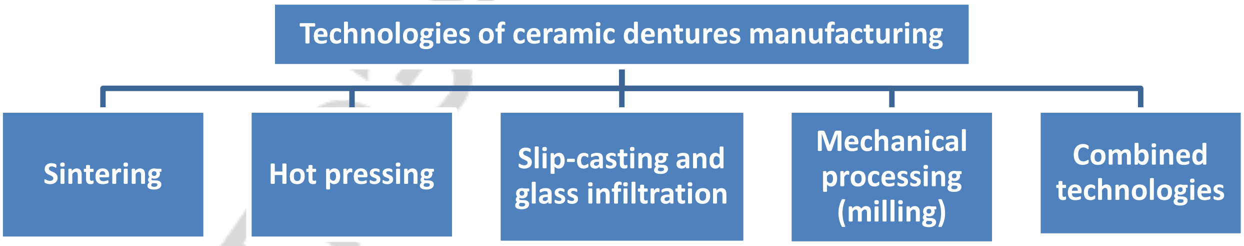


Fig. 18. Technological processes used in ceramic dentures manufacturing

CERAMIC SINTERING TECHNOLOGY

Ceramic dentures of feldspathic ceramics (veneers, inlays, specific cases of crowns on anterior teeth) are manufactured by sintering technology. Ceramic powder is baked (sintered) into fused components with the help of layer-by-layer application of powder-liquid schlicker onto a platinum foil or onto a refractory model. Schlicker (from German) — a dough like mass is a water slurry consisting of finely ground ceramic material and water.

During the sintering there is no chemical interaction between components, but on reaching glass transition temperature the glass starts to melt, particles are fused to each other due to the formation of liquid phase. Therefore, the only thing occurring during the sintering is the fusion of separate particles with the formation of monolithic solid material (figure 19).

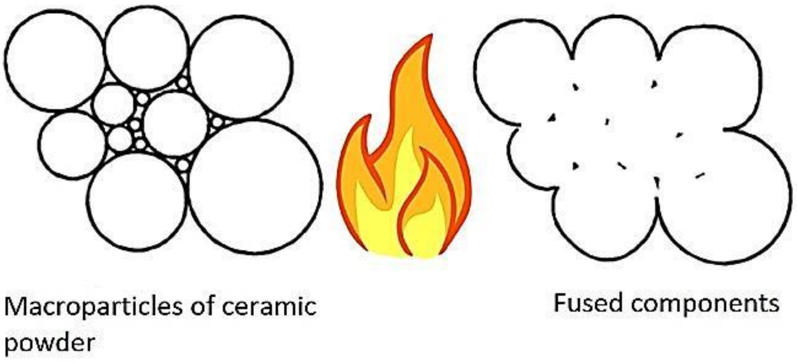


Fig. 19. Sintering of ceramic powder into fused components

The division of powder particles according to their sizes is the decisive factor which influences density of particles in raw product. The more dense is their packing, the less is the shrinkage of material during the sintering (R. Noort, 2002).

The average size of particles in the powder is around 25 µm, and the range of overall sizes is rather wide, that's why particles of smaller sizes fill free spaces between big particles (R. Noort, 2002).

In sintering technology ceramic mass is spread directly onto gypsum stamp, covered by platinum foil (foil thickness is 0.005–0.025 mm), or onto refractory stamp (figure 20).

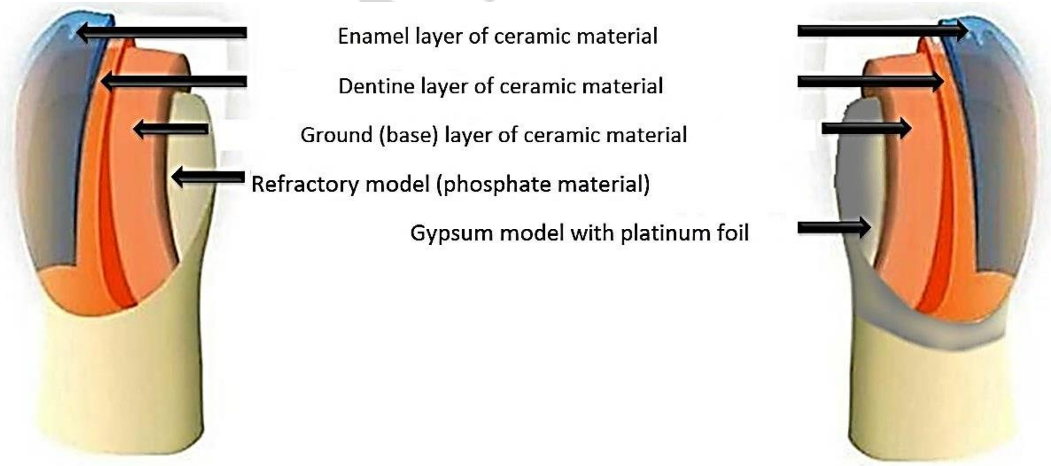


Fig. 20. Ceramic sintering technology

Ceramic mass is prepared by mixing the powder with a special liquid (distilled water possible) until mushy consistency is received (figure 21). Firstly the basic (core) layer is applied. The prepared mass is spread in small portions onto a platinum cap. Each portion is condensed, and water excess is removed with a paper napkin. It is repeated many times until full and equal spread of core ceramic on the platinum cap is achieved. The platinum cap with core porcelain mass prepared in the described way is taken off the stamp and installed onto ceramic firing tray (tragger), which is placed into the sintering furnace. The sintering of ground layer is carried out in special furnaces in vacuum (figure 22). The sintering of ceramic in vacuum decreases porosity in the ceramic mass.

Fig. 21. Preparation of powder-liquid schlicker of silicate ceramic materials for layer application and the sintering of ceramic

Fig. 22. Vacuum furnace for ceramic sintering

According to R. Philips (1991), silicate ceramic sintered in atmospheric conditions contains ×60 more pores than the one sintered in vacuum (figure 23). Then the application and sintering of dentine and enamel layers follows. The application of several layers of ceramic mass allows reproducing of all individual features of natural teeth of a patient.

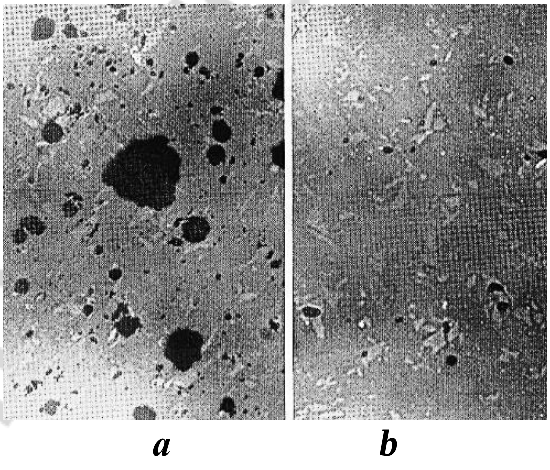


Fig. 23. Microsections of feldspathic ceramic sintered in atmospheric air (*a*) and in vacuum (*b*) (R. Philipps, 1991)

The last laboratory step of producing a porcelain crown is glazing. Glazing is carried out in atmospheric conditions. Due to the melting of fluxes all over the porcelain surface of the crown a gloss (glaze) is produced. After glazing the porcelain crown is cooled down at room temperature, checked carefully and after the removal of platinum foil is given to the clinic.

On figure 24 the steps of the sintering of ceramic mass on platinum foil are represented.

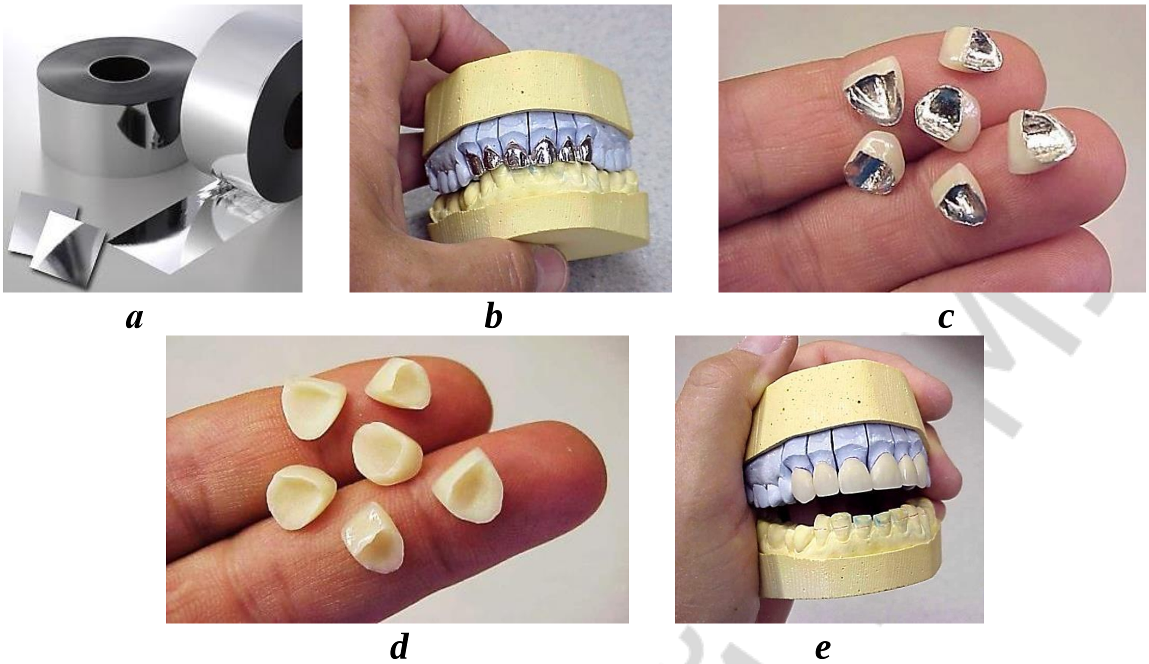


Fig. 24. Laboratory steps of the sintering of ceramic mass on platinum foil: *a* — platinum foil; *b* — split stamps of gypsum model covered with platinum foil; *c* — ceramic, sintered on platinum foil; *d* — ceramic dentures after removal of platinum foil; *e* — ceramic dentures set on gypsum model

The use of refractory materials consisting of phosphate compounds and withstanding high temperatures allow skipping the use of platinum foil which makes the process cheaper. To produce a denture on a refractory model, the refractory mass with CTE (coefficient of temperature expansion) similar to the CTE of the ceramic should be used. In most cases the manufacturing company of a ceramic mass supplies corresponding refractory mass as well.

The vacuum sintering of glass crystals on the platinum foil or refractory model allows dentists to produce very accurate constructions with relatively little time spent on it. Feldspathic ceramic gives a chance to apply individual shaded layers and transparent detailing, which reproduces transparency and light conductivity of the natural tooth tissues and provides highly esthetic result. But the bending strength of feldspathic porcelain is pretty low (60–70 MPa). Because of low mechanical strength and significant volume shrinkage during the sintering (till 30 %) the rate of complications connected with fractures of constructions is very high (D. S. Zaharov, 2009).

Feldspathic ceramic is widely used for esthetic veneering of crowns and bridges made of more strong ceramics.

HOT-PRESSING TECHNIQUE

Pressing technology which substituted casting technology of DICOR ceramic (Dentsply International & Corning ware New York) received a wide application in modern clinics. One of the most widespread systems of thermal pressing on dental market is the IPS Empress system by “Ivoclar” company.

IPS Empress Esthetic ingots (figure 25, *a*) are made of leucite glass-infiltrated ceramic, consisting of glass and crystal phases (leucite crystallization makes around 35 % of glass ceramic). During ingots manufacturing, semi-finished product in a powder form is pressed to achieve maximal homogeneity. Given the difference in the coefficients of thermal expansion (CTE) between the glass phase and the crystal phase (leucite), cooling after the sintering produces compressive stress in the glass phase. This mechanism results in an increase in strength and enables IPS Empress Esthetic to achieve a flexural strength of 160 MPa. Pressed restorations have high accuracy and homogenous surface. IPS Empress Esthetic ingots are manufactured in 12 shades. On the final step restorations can be painted by IPS Empress Universal stains and/or veneered individually by layering ceramics IPS Empress Esthetic Veneer.

IPS e.max Press ingots (figure 25, *b*) are lithium disilicate glass ceramic ingots for press technique containing about 60–70 % crystal lithium disilicate in glass matrix. Manufacturing technology allows producing homogenous ingots of different opacity degree, with bending strength of 400 MPa. Therefore, IPS e.max Press is the strongest pressed ceramic material.

IPS e.max ZirPress ingots (figure 25, *c*) are fluorapatite glass ceramic ingots for technology of pressing onto zirconium oxide. Fluorapatite crystals in the material have different size which ensures optimal ratio of transparency, opalescence and brightness of restorations. In its turn, this allows complete masking of zirconium oxide framework of the denture which is less transparent.

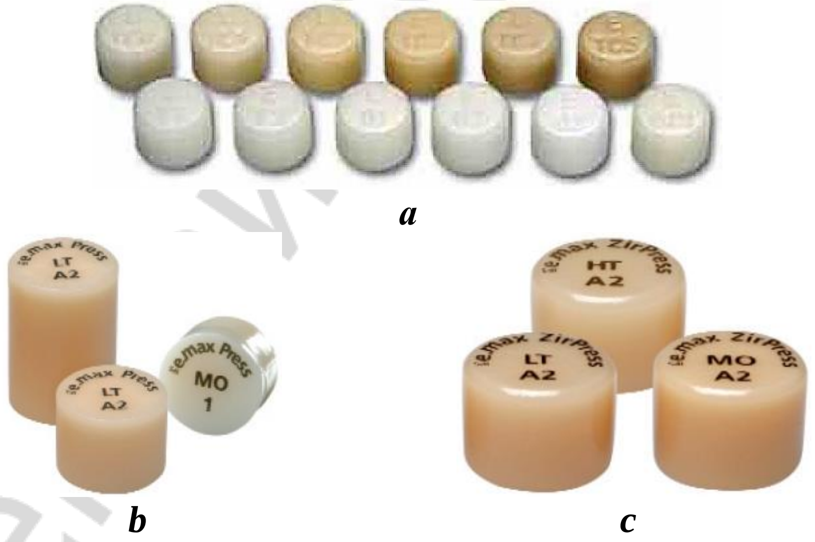


Fig. 25. Glass-ceramic ingots for pressing:
a — leucite glass ceramic IPS Empress Esthetic; *b* — lithium disilicate ceramic ingots IPS e.max Press; *c* — fluorapatite glass ceramic ingots IPS e.max ZirPress

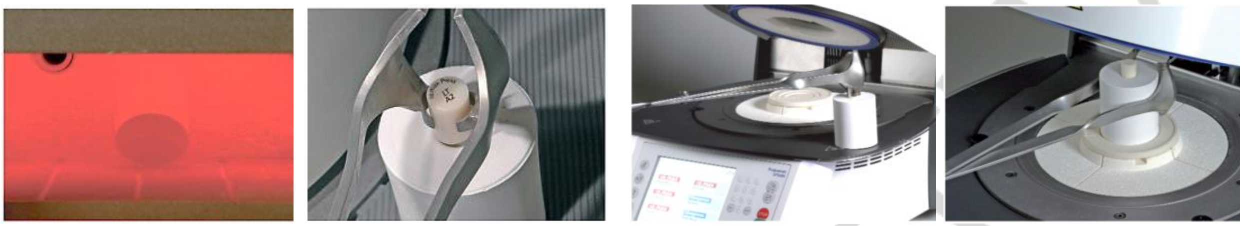
Figure 26 represents the steps of ceramic crown manufacturing by hot press technique with the following shade correction and glazing.

Making a split model and application of compensatory varnish

Modelling an artificial crown

Installing sprues onto sprue base of a crucible system

Installing a silicone ring and investing with refractory mass



Refractory mass recovered from the silicone ring is heated in the muffle furnace till 1200 °C

Ceramic ingot is placed into a heated casting box

Aluminum oxide plunger is placed above the ingot

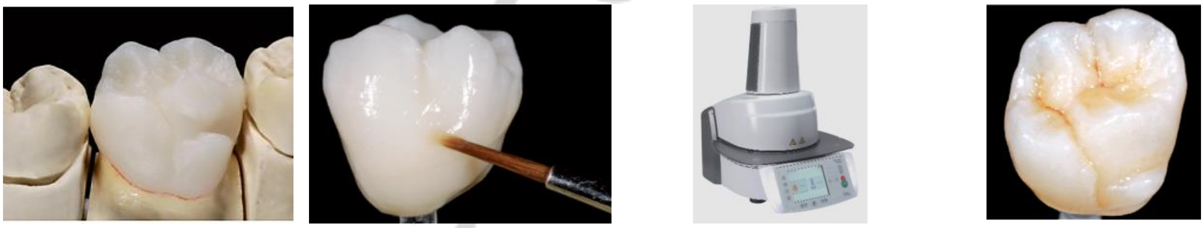
The heated mold is installed into a press furnace

Furnace with software control for the pressing and firing of ceramics

Divesting the cast

The cast after the divestment

Sprues are cut with a diamond disc



Fitting the crown on a work model

Characterization and staining of an artificial crown with special ceramic masses

The firing of stains following special (instructed) parameters

The restoration after stains firing

Glaze application

Glaze firing according to instructed parameters

A completed restoration

Fig. 26. Steps of ceramic crown manufacturing by hot press technique with following shade correction and glazing

Hot pressing method is partly based on casting technique.

Firstly a wax model of restoration is made, then this model is invested with refractory material. Wax is burned out and a space in the received mold is filled with glass ceramic. Then, in specially developed press furnace (figure 27), the space in the mold under 1.5 atm pressure is filled with glass ceramic, which was received as a result of ceramic ingot heating at 1180 °Cuntil the state of viscose melt (R. Noort, 2002).

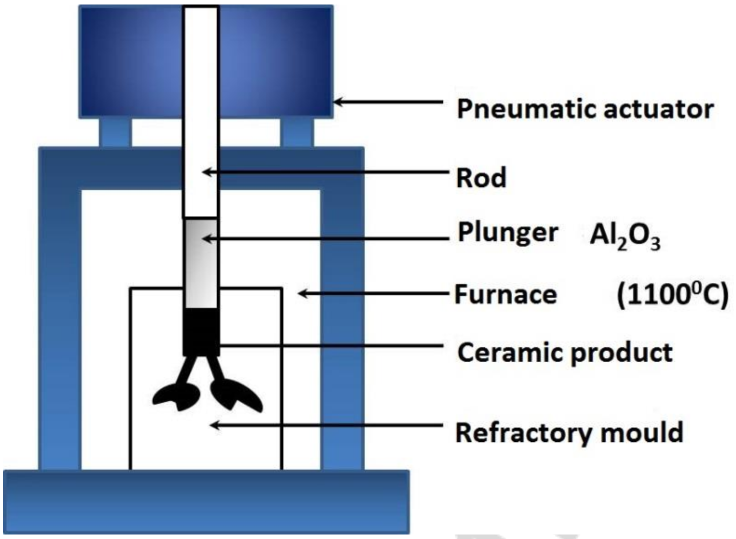


Fig. 27. A scheme of hot pressing process used for the manufacturing of glass ceramic restorations

Shade correction of dentures made by hot pressing method can be done with staining technique (figure 28, *a*), cut-back technique (figure 28, *b*) or layering technique (figure 28, *c*) with the use of nano-fluorapatite veneering ceramic IPS e.max Ceram which is used for layering onto any components of IPS e.max, glass ceramic and zirconium oxide as well.

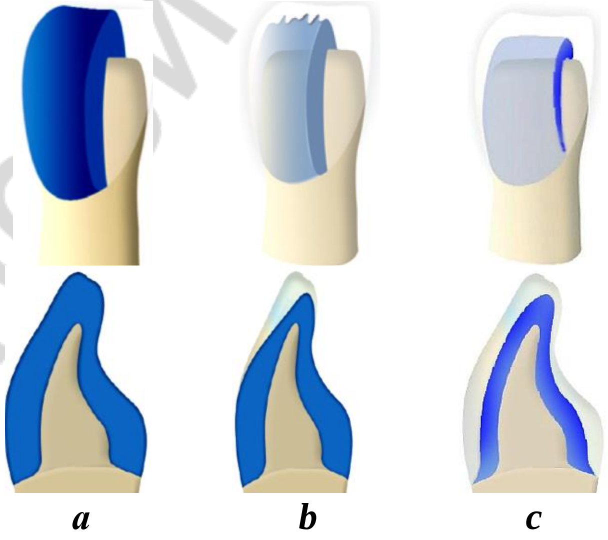


Fig. 28. Methods of shade correction of dentures produced by hot pressing of ceramic: *a* — staining technique; *b* — cut-back technique; *c* — layering technique

SLIP-CASTING TECHNIQUE WITH GLASS-INFILTRATION
(slip-casting, VITA In-Ceram System, WOL-CERAM-EPC-CAM)

In 1980s Dr. Michael Sadoun with the VITA company developed a slip-casting technique. Slip-casting supposes the manufacturing of ceramic dentures by the firing of metal oxides (sintering), impregnation of the framework with glass (glass infiltration) and their following veneering with conventional glass ceramic. Framework material can be aluminum oxide (VITA In-Ceram-Alumina), magnesial spinell ($MgAl_2O_4$) (VITA In-Ceram-Spinel) or aluminum oxide + 33 % additional zirconium oxide (VITA In-Ceram-Zirconia). This process is called slip-casting.

Laboratory steps of ceramic crowns fabrication by slip-casting technology are represented on figure 29 (VITA In-Ceram-Spinel).

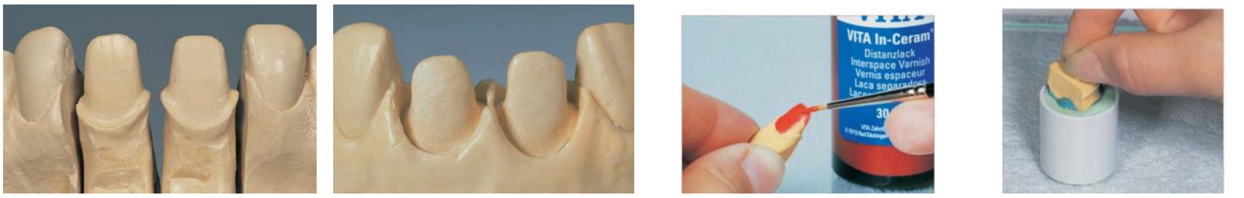
An impression is obtained in clinic. A split model (working model) and a simple model (control model) are made with this impression. To apply and fire the slip, the models (stamps) from the refractory material of the same system are used. Refractory stamps are done by duplication of gypsum models with the help of silicone materials.

To prepare the slip, powder which contains one of metal oxide crystal compositions, is mixed with deionized water. A dispersive agent is added to make the mixture of powder with water homogenous. To run the dispersion process, the mixture is processed in the ultrasonic apparate Vitasonic. Vacuum is used to remove voids.

The slip (solution of metal oxide) prepared according to manufacturer instructions is applied with a brush onto a refractory stamp. Water is removed by capillary action of the porous refractory material. The framework is afterwards placed into Inceramat furnace (Vita Corporation) and fired. The program of firing is selected according to instruction. At the temperature of 1120 °C the sintering occurs, it means particles of metal oxides form links on contact points by the superficial diffusive processes. Melting temperature of the oxides, which is necessary for full condensing of the powder due to liquid phase sintering, is very high, that's why only hard-phase sintering of material can occur. The ceramic framework produced in this way is made of metal oxide particles and has a porous structure. The strength of a porous framework is not high. The structure obtained in this way, has chalky consistency and is easily processed.

Only after the next processing step — glass-infiltration — the material acquires its high strength. Special lanthanum glass is used for glass infiltration, it has wonderful properties of adhesion with sintered framework and at the infiltration temperature of 1100 °C it has very insignificant viscosity with full filling of the free porous space between metal oxide particles. This melt can penetrate into pores, due to what a dense ceramic material is received.

The framework has to be processed with the removal of glass excesses with abrasive instruments and sand-blasting apparatus (processing with particles of Al_2O_3 with 50 μm diameter under 3 atm pressure).

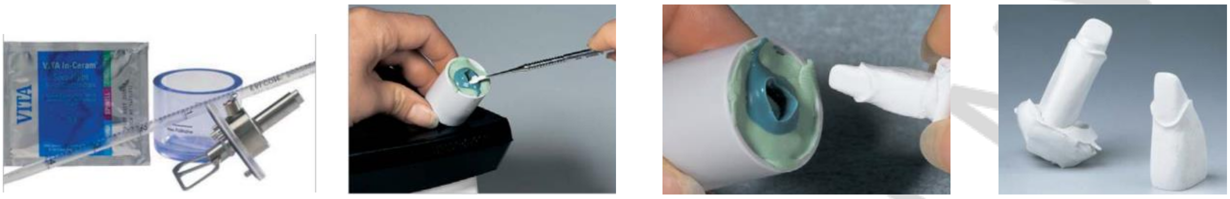


Making a split model of high strength class of stone

An additional simple model is made to check the fit of frameworks

Application of separating varnish onto gypsum stamps (the layer is around 45 μm thickness)

Duplication of gypsum stamp in silicone material



Preparing a refractory material

Investing a silicone mould with the refractory material

Recovering the model from the mold

Refractory models

Dozing of slip mass components

Mixing slip components in ultrasonic device VITASONIC

Pumping the air out of the slip with vacuum device

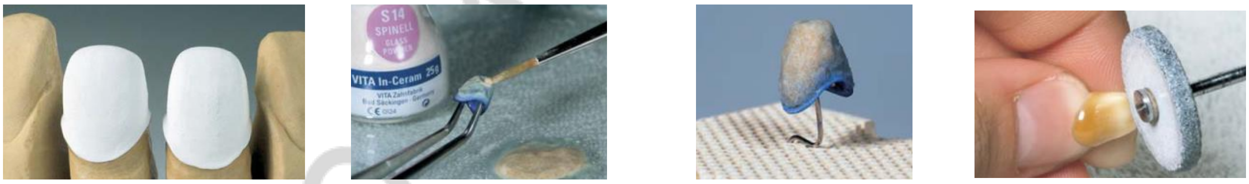
Slip application

VITA INCERAMAT furnace

The 1st sintering of the framework in VITA INCERAMAT furnace

Sintered framework on refractory model

The 2nd sintering of the framework in VITA INCERAMAT furnace

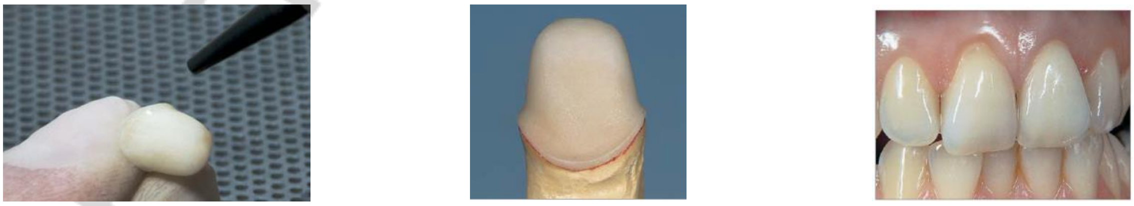


Denture frameworks are fit onto working model

Glass application

Glass infiltration firing in VITA INCERAMAT furnace

Processing of the framework with abrasive instruments



Sandblasting of the framework with Al_2O_3 particles (Ø 50 μm) under 3 atm pressure

A framework after the processing, fit onto gypsum model

Artificial ceramic crowns are fixed in the patient’s mouth

Fig. 29. Laboratory steps of ceramic dentures fabrication by slip-casting technique (VITA In-Ceram-Spinel)

To create functional and esthetic form of the crown the framework is veneered with conventional dental feldspathic ceramic. In WOL-CERAM-EPC-CAM system (Germany) aluminum oxide is applied onto the surface of a gypsum stamp by galvanoplastics. The gypsum stamp is coated with special composition for galvanization and placed into the ceramic slurry. After drying of the slip the ceramic framework is fired at 1140 °C for 60 minutes. At this time separate particles of alumina oxide ceramic undergo the so-called superficial diffusion. Then glass slip is applied onto the framework and at 1120 °C glass infiltration occurs. The infiltration is carried out on the platinum foil. Glass excess is removed with diamond rotative instruments and sandblasting (particles diameter is 110 μm and the pressure is 3.5 atm). The prepared framework is to be veneered with glass-ceramic veneering materials by firing the layers.

MACHINABLE CERAMIC MILLING (CAD/CAM)

Mechanical processing (milling) of ceramic is a gradual removal of the material with rotating multi-bladed instruments (cutters or diamond heads), their cutting edges are in the interrupting contact with the processed material.

CAD/CAM technologies became widespread among modern ways of manufacturing dentures (Computer Aided Design, Computer Aided Manufacturing). The idea of using computer (CAD/CAM) technologies in dentistry belongs to Duret (1970). 10 years later Mermann developed Cerec® system firstly represented on market by Siemens company (nowadays by Sirona) — the first system that permits the restoration fabrication exactly in the presence of a patient.

Recent years are characterized by a rapid development of automatized laboratory systems due to permanent perfection of computer technologies and software.

Most of CAD/CAM systems include a scanning module to receive an image, a software module for processing information and designing the denture (CAD-module), and a milling module with computer control to fabricate a denture (CAM-module). There is a general scheme of ceramic denture fabrication with the help of CAD/CAM technologies on figure 30.

Some systems provide the possibility of using special explorer (profilometer) for the scanning of gypsum models. In the scanning process the explorer contacting with gypsum model determines more than 50 thousand of digital values which characterize parameters of each unit of ceramic denture. Scanners transform the information about external look of the model into a computer file.

The next step of producing CAD/CAM restorations is a computer modeling of the denture construction. With the help of a special software (CAD-module) the denture is constructed on a virtual model. The computer software contains a catalogue of standard teeth shapes and saves individual work files. The virtual model of the denture can always be “taken off” from the model, viewed in any aspect and any cross-section.

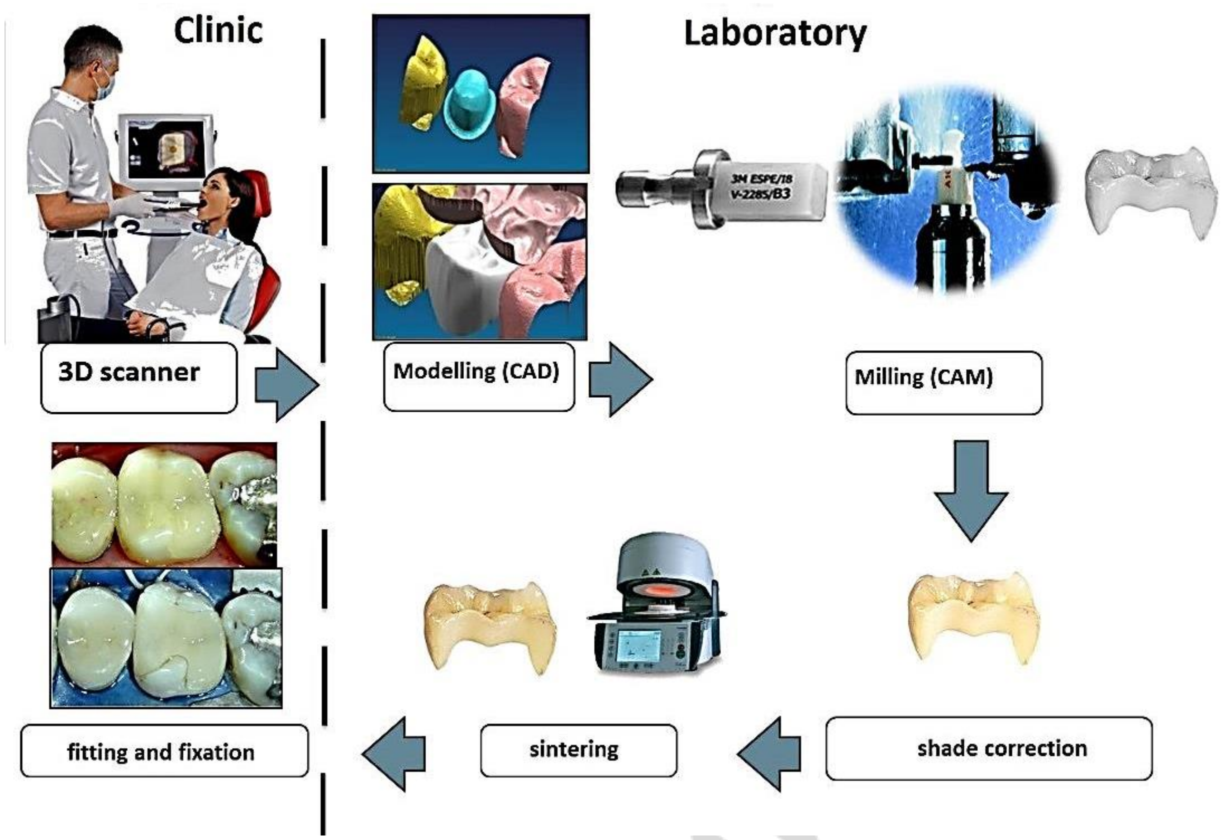


Fig. 30. General scheme of ceramic dentures fabrication with the help of CAD/CAM technologies

Information about ceramic dentures, saved in files, can be used afterwards to perform milling in special devices. Devices for milling can be located directly in the clinician's office (individual minisystems, for example Cerec®), in dental labs (individual macrosystems, for example Cerec in-Lab®, LAVA®, Everest® etc.) or in distant specialized centers to where information is passed by internet (centralized macrosystems, for example Procera®, Decim® etc.).

Machines with computer numerical control (CNC) are used for milling. An important feature of the machines used for CAM milling, is the number of freedom degrees during detail processing. Machines used in dentistry can have 3, 4 and 5 axes. The more freedom degrees, the more complicated detail can be manufactured.

As an example of using CAD/CAM technologies for the computer milling of ceramic dentures the steps of denture fabrication with the help of Cerec® system are shown on figure 31.

In the clinic an optic impression is receivedwith the help of intraoral cam (figure 31, *a*). It is digitized and passed to a computer for processing (figure 31, *b*). The next step of CAD/CAM restorations manufacturing is the computer modelling of the denture construction (figure 31, *c*). Computer software is used for this purpose. In the software of Cerec 4.0 a preview of the restoration can be performed (figure 31, *d*). Standard blocks are used for milling (figure 31, *e*), they are made of ceramic feldspar material (Vitablocs® Mark II, Vident). The block is secured in the CNC machine with a holder (figure 31, *f*). The processing of ceramic block is carried out under water cooling with diamond cutters in an automatized computer regime (figure 31, *g*). The ceramic denture produced by milling method is fit in oral cavity and fixated (figure 31, *h*).

a ***b*** ***c***

d ***e*** ***f***

g ***h***

Fig. 31. Steps of ceramic dentures fabrication with the help of Cerec®

The so-called “hard” machining allows milling the blocks made not only of ceramic feldspathic material Vitablocs® Mark II, Vident (figure 31, *e*), but blocks on the base of leucite such as IPS Empress® CAD, Ivoclar (figure 32, *a*) and lithium disilicate IPS e.max CAD, Ivoclar (figure 32, *b*).

a ***b***

Fig. 32. Blocks on the base of leucite (*a*) and on the base of lithium disilicate (*b*)

IPS e.max CAD is a lithium disilicate glass-ceramic block for the CAD/CAM technique. It is fabricated using an innovative process which ensures an impressive homogeneity of the material. The block can be processed very easily in a CAD/CAM unit at this crystalline intermediate stage. The typical and striking color of IPS e.max CAD ranges from whitish to blue and bluish-grey. This shade is a result of the composition and the microstructure of the glass-ceramic. The strength of the material in this processable intermediate phase is 130–150 MPa. After the IPS e.max CAD blocks are milled, the restoration is crystallized in an Ivoclar Vivadent ceramic furnace (e.g. Programat® P300, P500, P700). Unlike some other CAD/CAM ceramics, the approximately 20–31-minute, easy-to-conduct crystallization process neither causes any major shrinkage, nor any complicated infiltration processes are required.

The crystallization process at 840–850 °C (1544–1562 °F) results in a transformation of the microstructure during which lithium disilicate crystals grow in a controlled manner. The densification by 0.2 % is accounted for in the CAD software and taken into consideration upon milling.

The final physical properties such as the strength of 360 MPa and the corresponding optical properties are achieved through the transformation of the microstructure.

Ceramic ingots for the future dentures are produced industrially which compared to lab ceramic sintered layer by layer, allow to receive material with much more homogenous and thin crystalline structure.

The milling of framework of a “soft” ceramic block is an alternative to slip-casting technique with glass infiltration with the use aluminum-oxide, spinell or aluminum-oxide with 33 % zirconium oxide.

The blocks of metal oxides named above which are partly stabilized (previously sintered) are used for milling. Industrial production of ceramic blocks (figure 33) is held on under a strict technological control which promotes the homogeneity of microstructure, increases density, decreases porosity and residual stresses. The machining takes much less time if compared with the sintering technique.

Fig. 33. Porous, previously sintered blocks VITA In-Ceram

After the preparation of teeth, a clinician obtains impressions. A working model is made and therefore placed into a scanning laser device to create a digital model of the prepared tooth and to perform a computer modelling — CAD. On finishing CAD, the ceramic block of selected type and size is placed into a milling camera, where diamond cutters will cut out the framework of restoration from the ceramic. The framework is afterwards fit on the model and corrected. The framework is neither too brittle nor soft. Despite the porous structure of In-Ceram material, its strength is high enough — 50–60 MPa — nearly the same as the one of tightly-fired porcelain. After the milling of the framework, the step of glass infiltration with lanthanum glass is done like it's done for ceramic frameworks prepared with slip-casting. Pores in the framework are filled with lanthanum glass on the step of glass infiltration.

To create the final anatomical shape of the restoration, the framework is covered with silicate ceramic veneering of the corresponding shade and transparency degree.

In recent years dental CAD/CAM systems for "soft" milling of polycrystalline (oxide) ceramic on the base of zirconium dioxide became widespread. PSZ — Partially Stabilized Zirconia has high porosity and comparatively low value of flexural strength which simplifies the milling of frameworks. The milling of the shape of framework takes place in its soft, just presintered state (chalk-like state). And only after the milling the final firing of ceramic (agglomeration) is performed (at the temperature 1500–2000 °C) after which the material receives its phenomenal strength.

On figure 34 the steps of ceramic dentures fabrication with CAD/CAM system for "soft" milling of polycrystalline (oxide) ceramic on base of zirconium dioxide (LAVA®, 3M ESPE) are shown.

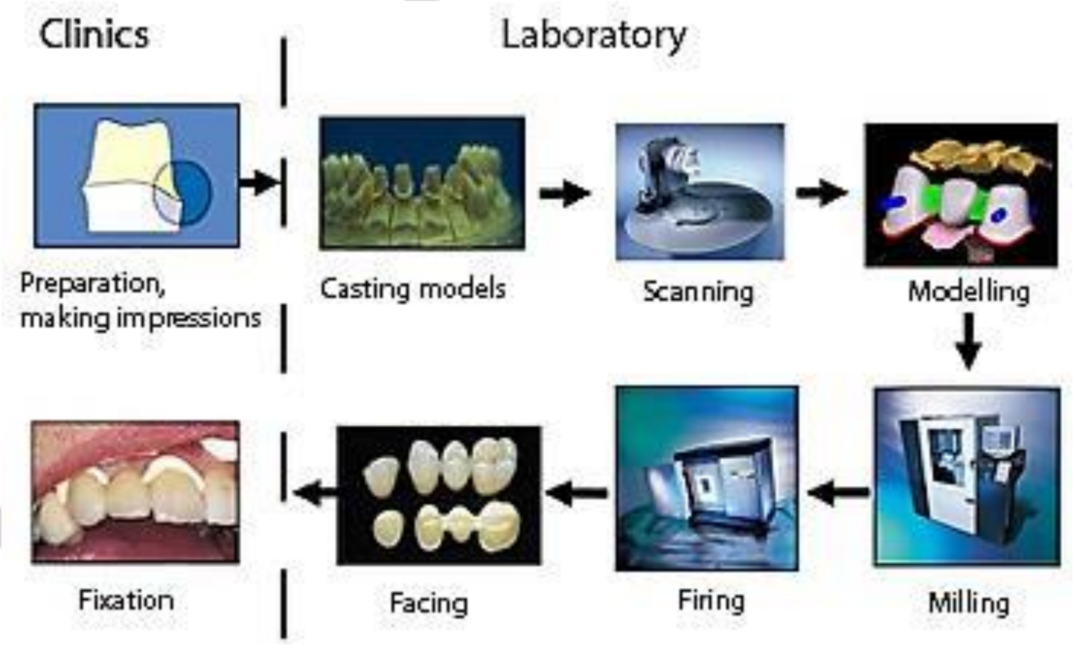


Fig. 34. Steps of ceramic dentures fabrication with the use of LAVA®, 3M ESPE

One of the features of ceramic dentures fabrication from PSZ is its shrinkage during final firing (20–23 %).

On the industrial ingots (figure 35) there is a numerical marking which describes accurate data about future shrinkage of the framework. A computer counts the size of the milled framework, considering these data. It makes possible to obtain details with the compensation of zirconium dioxide shrinkage (figure 36). After the modelling the file goes to a control module of the milling machine. The milling machine mills the framework of the ingot. The average time of single crown milling is 17 min, and 3-units bridge — about 40 min. As a result, the 3D model designed on the computer before is produced. After the milling the framework is stained and placed for firing into special agglomeration furnace where it obtains its final size, shade and strength at the temperature of 1500–1600 °C.

Fig. 35. Ceramic blocks for “soft” milling of ceramic on t base of zirconium dioxide before and after milling

Fig. 36. Volume shrinkage of the restoration after the sintering is compensated by an accurate increase of the milled detail volume

To create the final anatomical shape of the restoration, a special silicate ceramic coverage of appropriate shade andtranslucency is applied (figure 37).

Fig. 37. Veneering of ceramic framework by layered sintering of ceramic

Unlike classic CAD/CAM technologies, in system Cercon® (Dentsply/Degussa Dental) the wax-up model of the future restoration is scanned. After obtaining impressions and making models, a technician makes traditional wax modelling with the use of conventional modelling materials. After the modelling the wax-up construction is taken off the gypsum model and secured by wax profiles in special holder. A presintered zirconium dioxide ingot is installed into device. The scanning of wax model and milling firstly with coarse and then more fine cutter is performed automatically.

There are other “soft” milling technologies of ceramic materials by milling machines which are not software controlled but provide an accurate copy during the milling with a possible changing of the dimensions. In the base of device work there is a pantograph principle (*apparatus for redrawing the images in original or altered scale)* invented in 1603 by Cristoph Scheiner. The framework is milled manually from PSZ block, reproducing the relief of the polymer or wax-up model. The reproduction is placed on one side of the system (“scanning” side), and the ceramic ingot — on the milling side. The location of a probe (contact profilometer put into contact with the model is passed simultaneously onto the cutter located on the milling side and cuts off the material. Taking into consideration zirconium dioxide shrinkage during final the sintering the milling works can be carried out in enlarged scale. The methodcompletes internal and external surfaces of the framework performing gradual milling (figure 38).

Fig. 38. Milling machine (pantograph) for PSZ frameworks fabrication by copy-milling method

Some CAD/CAM systems (Everest®, KaVo etc.) provide the milling of zirconium dioxide in fully agglomerated (stabilized) state FSZ — Fully Stabilized Zirconia. But the so-called “hard” machining of FSZ is a long process (2 hours for the fabrication of 1 unit) demanding the use of powerful milling equipment to process super-strong material and followed by fast wearout of the working tools.

COMBINED TECHNOLOGIES OF CERAMIC DENTURES FABRICATION

All the technologies named above, except the sintering technology suppose the esthetic correction of the framework (core) ceramic.

On figure 39 the variants of using combined technologies of ceramic dentures fabrication are shown.

The framework of a ceramic denture, produced by CAM from zirconium dioxide can be esthetically veneered with pressing or sintering of dentine and enamel layers with the following individualization with stains. In combined technologies veneering ceramic mass should be selected with consideration of CTE (table 6).

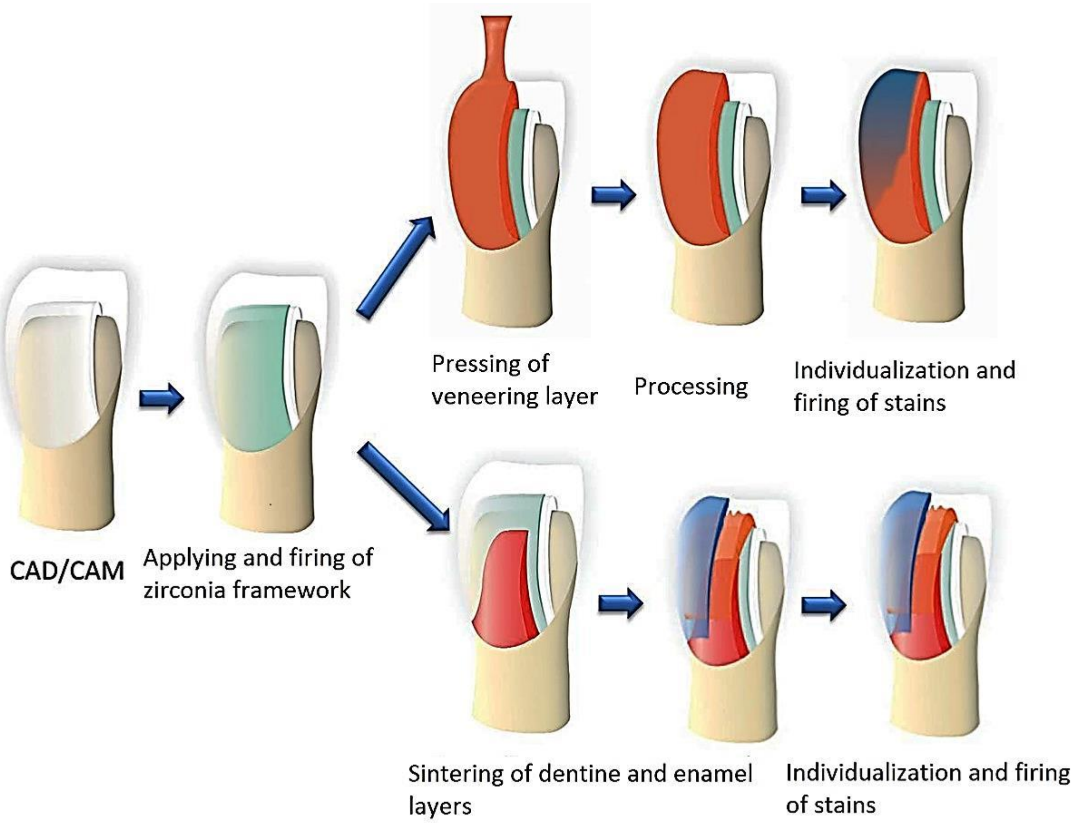


Fig. 39. Examples of combined technologies of ceramic dentures fabrication

Table 6

Coefficients of thermal expansion of framework ceramic

Framework ceramic material	Linear CTE(25 - 500ºC)
VITA In-Ceram® ALUMINA	$7.2–7.6 \times 10^{-6} \times K^{-1}$
VITA In–Ceram® SPINELL	$7.5–7.9 \times 10^{-6} \times K^{-1}$
VITA In–Ceram® ZIRCONIA	$7.6–7.8 \times 10^{-6} \times K^{-1}$
Zirconia dioxide	till $10.5 \times 10^{-6} \times K^{-1}$

CTE influence onto the spread of tensions is shown on figure 40. If framework material CTE is lower than veneering ceramic CTE, then tangential tensile stress increases and radial microcracks are formed (figure 40, *a*). If framework material CTE is significantly higher than veneering ceramic CTE, then tangential compressive stress increases and causes microcracks leading to the chippings of ceramic (figure 40, *b*). Perfect spreading of tangential tensile and compressive stress takes place when framework material CTE is optimally correlated with veneering ceramic CTE (figure 40, *c*).

a ***b*** ***c***

Fig. 40. CTE influence onto the spread of tensions in veneering layer of ceramic

On figure 41 ceramic materials used for ceramic dentures fabrication with the use of different technologies are shown.

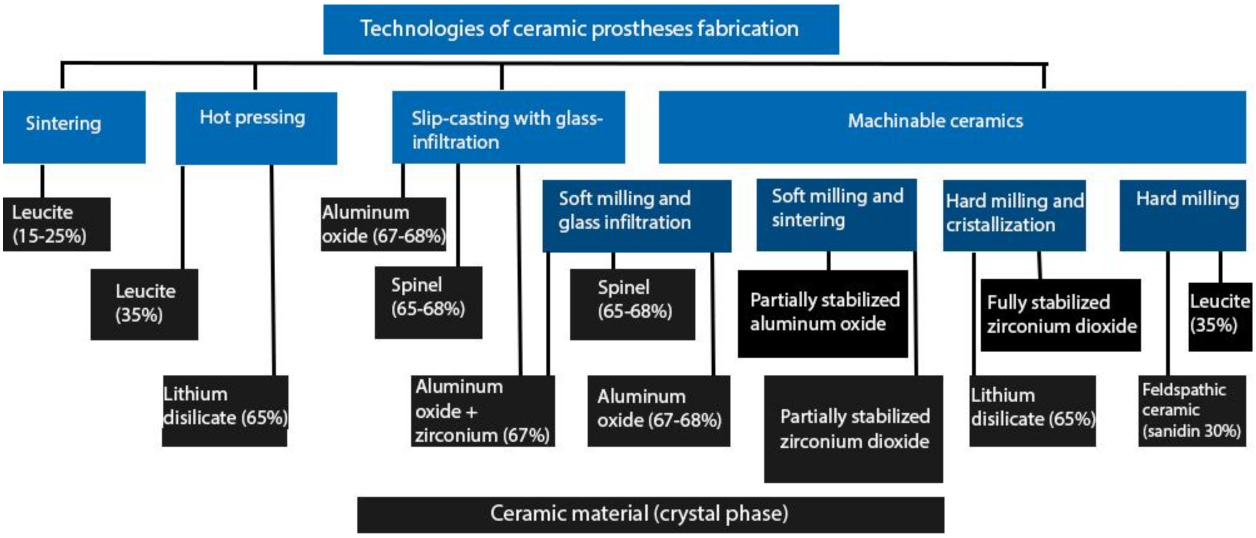


Fig. 41. Ceramic materials used for ceramic dentures fabrication with the use of different technologies

METAL-CERAMIC (Porcelain-fused-to-metal = PFM; ceramometal)

Metal-ceramic is a technological connection of two materials — a metal alloy or metal (titanium) and dental porcelain where the first one serves as a framework and dental ceramic as a facing (veneering).

Veneering is covering of a detail surface with natural or synthetic material with different practical (protective) and decorative properties.

In dentistry, ceramic veneering mimics the metal framework and resembles natural color of tooth hard tissues.

Metal-ceramic dentures consist of a metal framework onto which ceramic veneering is applied (figure 42).

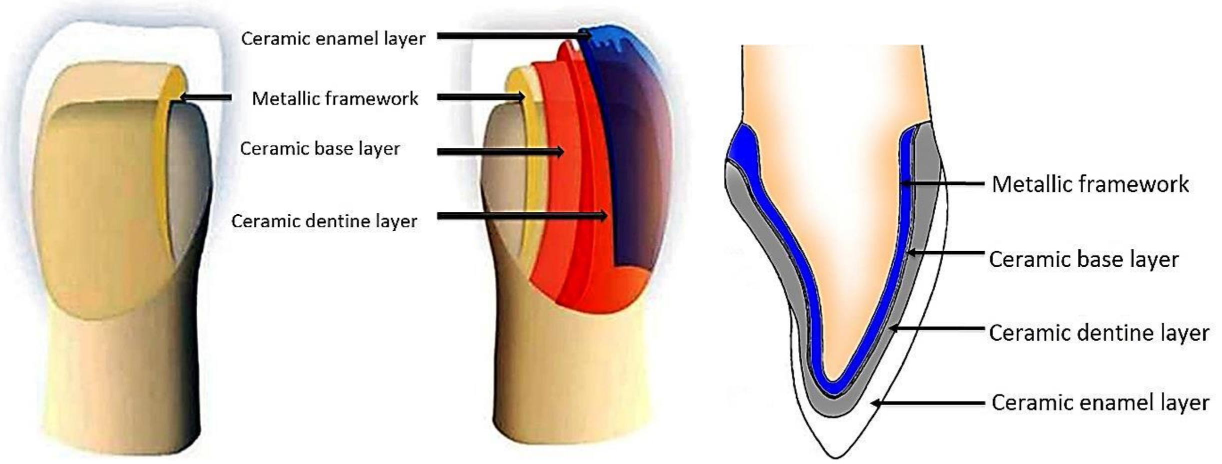


Fig. 42. Scheme of ceramic veneering of metal-ceramic dentures

For the metal framework manufacturing the following alloys are used:

– highly noble metal alloys (mass fraction of gold at least 75 %);

– noble metals alloys (gold or platinum group metals mass fraction is 25–75 %, on the base of gold, palladium and platinum, on the base of palladium and silver, palladium and copper or silver and palladium);

– base alloys of metals (on the base of cobalt and chrome, on the base of nickel and chrome or on the base of titanium).

For the metal framework manufacturing for metal-ceramic constructions the following methods are used:

– individual casting;

– CAD/CAM;

– galvanotechnics (galvanoplastics, only for single crowns);

– SLS — Selective Laser Sintering.

The greatest number of metal-ceramic frameworks in our country is manufactured by individual casting.

After the denture framework casting (thickness of crown framework should be at least 0.3 mm) a technician provides their preparation for the following veneering with ceramic.

There are 3 mechanisms which form bonding between the ceramic and metal framework (figure 43).

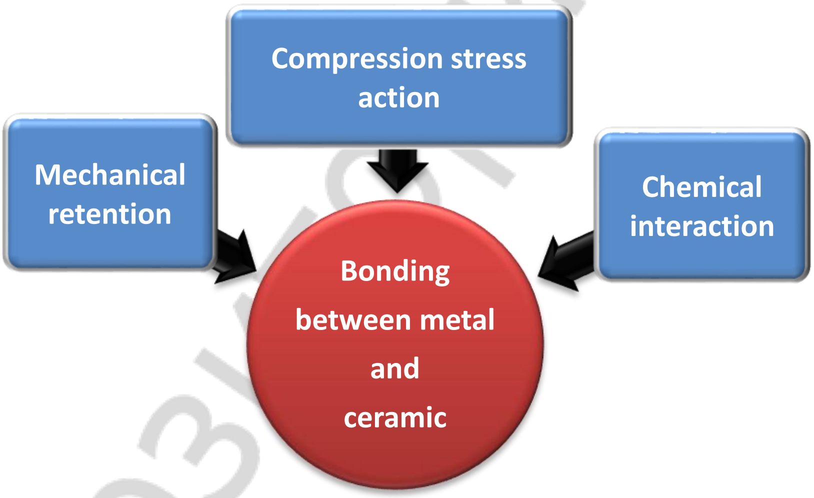


Fig. 43. Mechanisms of bonding formation between the ceramic and metal framework

On receiving cast frameworks a dental technician performs their grinding and sandblasting. The sandblasting creates roughness on the metal surface and microretentional points increasing the surface of future contact between the metal and ceramic (**mechanical retention**).

Afterwards the oxidation of the prepared framework is carried out: it is creation of superficial oxide layer which possesses certain chemical composition and structure and ensures its strong chemical bonding with ceramic (**chemical interaction**).

CTE of the majority of ceramic materials used for metal framework facing is slightly lower than that of the metals and their alloys. On cooling down metal shrinks faster than ceramic because its CTE is higher (R. Noort, 2002). It leads to remain of ceramic in compressed state (**compression stress action**).

After the metal framework manufacturing and preparation facing ceramic masses (silicate) are layer by layer applied and fired (sintered). The core, dentine and enamel layers reproduce the most accurate natural teeth features. Furthermore, with the individual aspects consideration artistic characterization and glazing of the crown is done.

If the metal framework of the crown is fabricated of pure gold (99.9 %) by galvanoplastics, veneering is done by the press-on technique of lithium-disilicate glass-ceramic ingots (see hot-press technique).

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Учебно-методическое пособие

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