Universal Phosphate-Bonded Investments

Economic and Qualitative Decision Criteria

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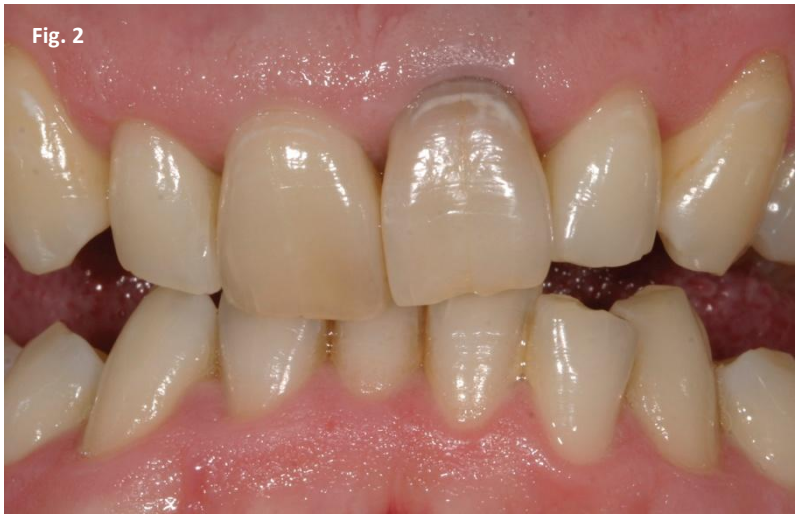
Indices:
Investing
Investment
Lithium disilicate
Pressable ceramics

Despite great advances in CAD/CAM technology, traditional pressing and casting still provides excellent results. Considering that cost management in dental laboratories is becoming more and more rigorous, well-proven techniques continue to ensure a reliable cost-benefit ratio for all involved. Bernhard Egger ponders economic and qualitative decision criteria with regard to the choice of universal phosphate-bonded investments.

Due to their high cost pressure and the resulting restrictions in their financial leeway, dental laboratories have to pay more attention to qualitative criteria when purchasing their materials and fabricating their products. Besides, time is a factor that indirectly, through the labour cost associated, influences the cost of production. This is why laboratories need technologies which guarantee reliable, predictable, top-quality results.

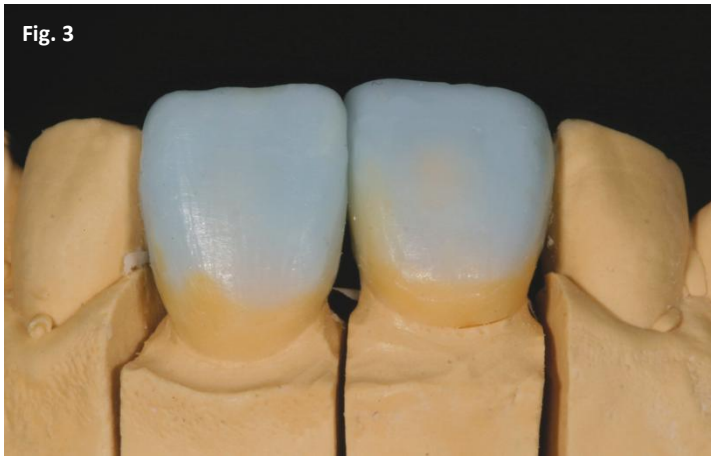
Pressable Ceramics

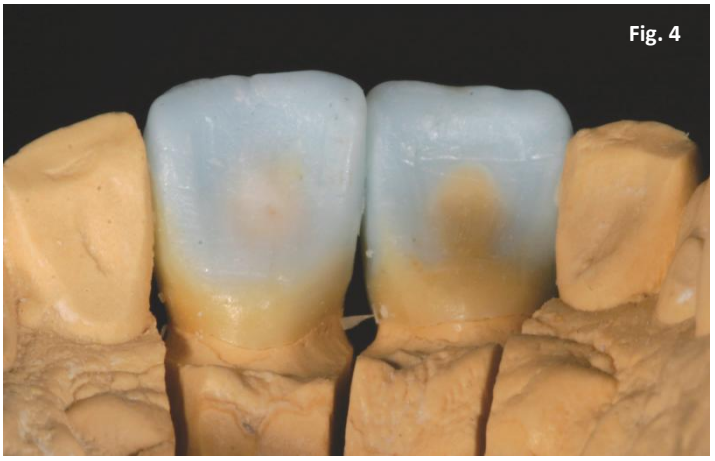
Pressable ceramics have become firmly established in the portfolios of most dental laboratories and proved to be a reliable technology (Fig. 2 to 6). Especially the launch of a pressable lithium disilicate ceramic (e.max) by Ivoclar has had a lasting effect on this development. The quality of restorations made of this material greatly depends on the furnaces and investments used.



◀ Fig. 2
Initial situation: The discolouration of non-vital teeth 11 and 21 made all-ceramic restorations an aesthetically challenging task.

▼Fig. 3 and 4
Labial and lingual wax: Dimensionally accurate wax patterns are indispensable to efficient production.





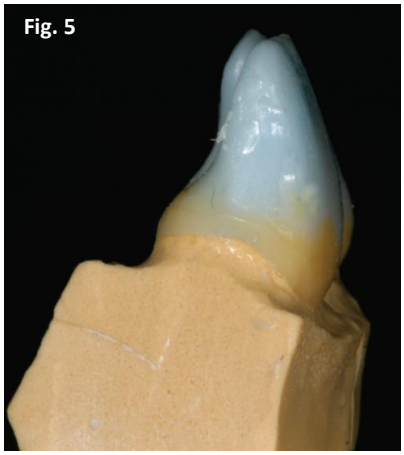
Speed Investments

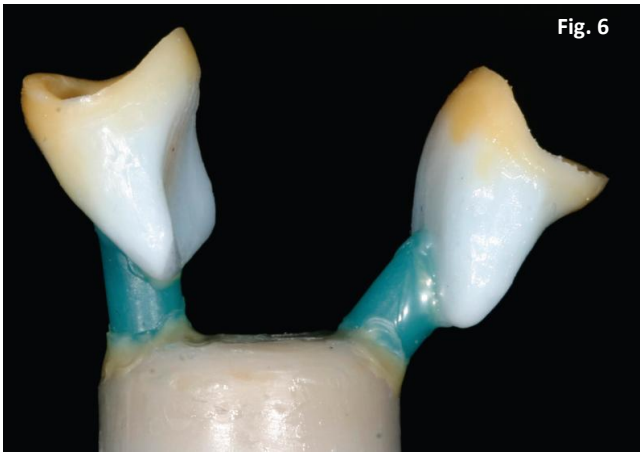
The development of what is known as “speed investments” has markedly changed the traditional time-consuming workflow. Conventional investments needed a preheating time of three to four hours, from investing to pressing or casting, while modern speed investments need only about 90 minutes. In addition, the preheating process for conventional investments should ideally start at room temperature, so that, in practice, casting or pressing could often be performed only once daily, particularly in small laboratories. This considerably limited daily production and frequently required strategic planning; besides, production times were significantly longer and timely reaction to failures was difficult.

Composition

This article focuses on the material characteristics of speed investments, which will be looked at in depth. Speed investments consist of a binder, i.e. magnesium oxide and ammonium dihydrogen phosphate, and a filler, i.e. the silicon dioxide (SiO_2) modifications quartz and cristobalite. They are mixed with a special liquid, consisting mainly of aqueous colloidal silica (Wikipedia: Colloidal silicas are suspensions of fine amorphous, nonporous, and typically spherical silica particles in a liquid phase). After mixing, the crystallisation of ammonium magnesium phosphate at room temperature causes the investment to harden. During subsequent preheating in the furnace, water and ammonia are separated and magnesium pyrophosphate is formed. This is a critical step in the process, which will be discussed in detail in the chapter “Problems with the Handling of Investments”.

▶Fig. 5
Margin wax: The user wishes to achieve pressed and cast objects that accurately fit without any subsequent adjustment.





▶Fig. 6
Spruing: The position of the pressed object is critical to the thickness of the reaction layer formed on lithium disilicate ceramics.

▶Fig. 7
Shofu Ceravety Press & Cast sets new standards in investment technology. It can be used as a speed investment for pressing/press-over and casting procedures, and also for conventional overnight heating. Thanks to its excellent expansion control, this investment ideally compensates for the shrinkage of pressed and cast objects. In this way, it creates very smooth surfaces with an outstandingly constant fit.

Fig. 7

Dimensional Behaviour
Investments undergo two types of expansion, setting expansion and thermal expansion. The rule is:

Total expansion = setting expansion + thermal expansion

Both setting expansion and thermal expansion are controllable by varying the concentration of the mixing liquid. The smaller the quantity of distilled water used for dilution, i.e. the higher the concentration of the mixing liquid, the higher the setting expansion and the smaller the pressed or cast object, generally speaking. When the investment is preheated, a contraction process occurs between the filler grains that are in contact with each other, so that, microscopically, a porous investment body is formed. These porosities are needed at a later time; they allow the gases produced inside the muffle during casting or pressing to escape. Expansion is largely determined by the filler used. Besides, a high colloidal silica content increases thermal expansion.

Surface Smoothness
As described above, the surface structure of investments is characterised by porosities, whose extent depends on the colloidal silica content of the mixing liquid.
The amorphous silicate particles formed by this colloidal silica partially seal the pores. To put it simply: The higher the colloidal silica content of the mixing liquid, the smoother the surface of the object fabricated.

Characteristics of Investments

Important characteristics of “ideal” investments include:

- Wide spectrum of indications
- Easy mixing and filling, short setting time
- Long working time
- Expansibility: good control of dimensional behaviour
- Smooth surfaces, high detail reproduction, e.g. at object margins
- Low surface roughness and porosity
- High mechanical strength at low and high temperatures
- No or little surface reaction with alloys
- Easy separation from cast or pressed objects.

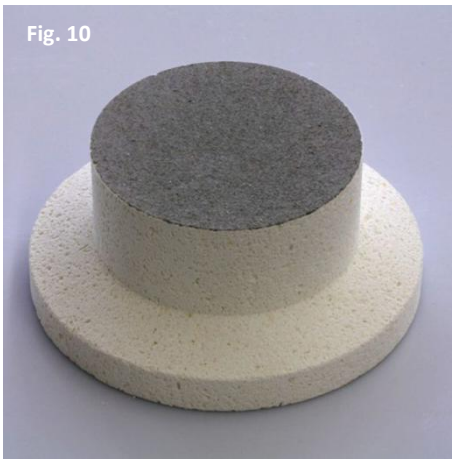
These characteristics depend on the ratios at which the components of investments are mixed, the raw materials used, and the reproducibility of the manufacturer’s production processes. In practice, these factors lead to considerable qualitative differences between the various investments available.
Even individual batches of one product may often differ greatly, which makes reliable work difficult. Due to these problems, it is almost impossible for many users to understand and correct their own procedural errors. All this can be remedied only by using controllable, reproducible work steps in the laboratory, on the one hand, and understanding the factors influencing the behaviour of investments, on the other hand. The aim to be achieved is the use of a reliable, suitable and qualitatively stable product (Fig. 7).

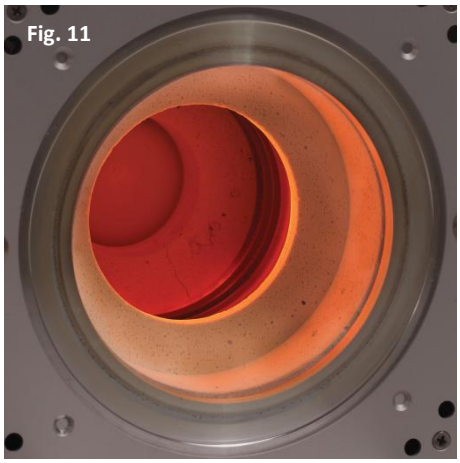
Fig. 8

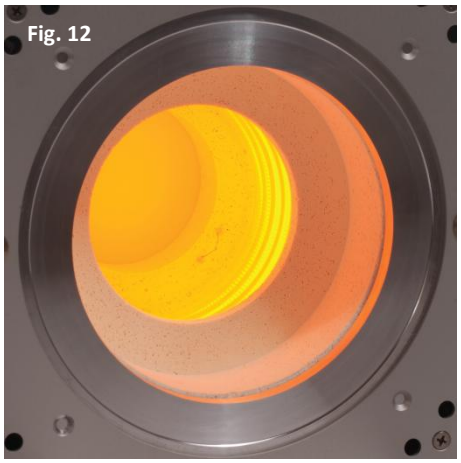
▲Fig. 8
press-i-dent: The Dekema Austromat 654 press-i-dent is equipped with a new, revolutionary automatic press time function from Software Version 03.00 onward. It is designed to minimise ceramic press times, reducing reaction layers while still ensuring perfect pressings. This makes the furnace even more reliable when used with the trixpress muffle system. The Austromat 354 press-i-dent can also be fitted with this new automatic press time function. A Hardware Update Kit is required for the use of Software V 03.00.

Fig. 9

◀Fig. 9
Pressing table: The optimised pressing table of this furnace has been designed on the basis of the latest insights into temperature distribution in firing chambers of ceramic furnaces; its special punctual contact surface allows radiant heat to circulate in the firing chamber. This leads to a more even temperature distribution in the muffle and helps to improve the quality of pressed objects.







▲Fig. 10
Firing table: A conventional firing table does not allow radiant heat to circulate at the bottom of the muffle. This leads to an unfavourable temperature distribution inside the muffle and may have a negative effect on the quality of pressed objects.

▲Fig. 11
Old heating element: High-quality results cannot be achieved when using a time-worn heating element. Accurate temperature control is not ensured, irrespective of the type and manufacturer of the furnace used.

▲Fig. 12
New heating element: An intact heating element is an integral part of the production chain leading to high-quality firing/pressing results.

Fig. 13

▲Fig. 13
Dekema trixpress muffles: Especially when fabricating implant superstructures in the press-over technique, larger muffle sizes are often necessary. This is where traditional 200 g muffles reach their limits. The trixpress system includes 100 g, 200 g and 380 g muffles, which have been specially adapted to the functionality of the Austromat 3001 press-i-dent and the Austromat 354 press-i-dent, but can also be used in other furnaces.

Problems with the Handling of Investments

Investment Structure – Intermediate Spaces, Grain Sizes

The granular structure of the powder leads to the inclusion of water during mixing. The grains contained in the powder are connected by the binder. Depending on the grain size of the powder and the specific admixtures, the size of the intermediate spaces may vary.

Generation of Pressure

The inclusion of water results in dimensional instabilities during preheating. This can be explained as follows:
Liquid water turns into a gas at 100°C, which leads to a 1700-fold increase in volume. This gas expansion generates pressure when the water included in the intermediate spaces of the investment structure evaporates, and the vapour is then pressed out through the intermediate spaces. If the investment is heated too quickly, high pressure will cause fine cracks to form (see Table).

Stress Cracking

Whenever tensile or compressive forces act on a material, and its dimensional stability prevents it from being deformed, stress will develop. The vapour pressure described above and the various expansion processes cause mechanical stress to build up inside a muffle. As a result, especially pressable ceramics with low strength may crack after the cooling process. In the case of alloys, stress may develop inside a cast object.

Fig. 14

▲Fig. 14
The trixpress range: Three sizes cover all pressing and press-over techniques, from individual crowns to 14-unit bridges. The disposable spacers, which can be arranged as desired, allow the user to handle up to 30 g of ceramic and/or five different colours during a single pressing process. The utilisation of the press pellets can be optimised by distributing the ceramic to several plungers.

Lithium Disilicate Ceramics

Lithium disilicate ceramics are characterised by high strength and suitable for pressing. Depending on the furnace and investment used, quality may vary greatly, which can be attributed to the sensitivity of lithium disilicate to temperatures above 900°C, the holding time, and the contact with phosphate-bonded investments (Fig. 8). The temperature reached in the core of the muffle may differ considerably from the temperature in the firing chamber of the furnace. Due to the thermal resistance of the investment, even extended holding times will never result in an even temperature distribution in the muffle. So, a loss of energy between the surface and the centre of the muffle can be observed, which means that if the firing chamber temperature remains constant, there will never be a homogeneous temperature distribution inside the muffle.
To still allow users to completely press their objects, many furnace manufacturers have tried to solve this problem by raising the final temperature. However, this method also has the disadvantage of an increase in temperature in the pressing muffle from the inside outward; this means that the ceramic is inevitably pressed from the colder core to the warmer surface. And as a result, the ceramic is deliberately overheated to ensure the necessary viscosity for pressing.
This has a negative effect on quality, especially when using sensitive materials like lithium disilicate, because high temperatures and long holding times increase the thickness of the reaction layer formed on the surface.
Thicker reaction layers, in turn, mean not only a poorer fit, but also a change in the volume of the pressed object in the subsequent work steps, which may lead to intolerable results. Therefore, in addition to the choice of a suitable furnace, the investment used is also critically important to the thickness of the reaction layer (Fig. 9 to 12).

Calculating the Volume of an Ideal Gas
The equation used is:

$p*V = n*R*T$

where
p is the pressure in Pa ($1\ Pa = 1\ N/m^2$)
V is the volume in m^3
n is the amount of substance in mol
R is the universal gas constant = 8.314 J/(K*mol)
T is the temperature in K

In order to calculate the volume based on mass, amount of substance n is replaced by mass m divided by molar mass M: n = m/M, so that:

$p*V = m/M*R*T$

When using 1,000 l of water at 4°C and vapour at 100°C and 1013 mbar in this ideal gas equation, the (theoretical) vapour volume will be 1,700 m^3.

Thermal Conductivity

Phosphate-bonded investments consist of two components, a powder mixture and a mixing liquid. The mixing liquid consists of water and colloidal silica, normally mixed at a ratio of 70:30. Further admixtures may include alkalis (Na_2O), which help to prevent the growth of algae (when storing the liquid for a long time). The only function of the mixing liquid is to control expansion; it cannot be used to directly improve the quality of phosphate-bonded investments by means of any special

admixtures. The material properties of the investment are therefore determined by the components of the powder:
The critical parameters are the grain size and mixing ratio of the powder formulation. As described above, the thermal conductivity of the investment is particularly important in this context.

Definition
Thermal conductivity (λ, l, k or κ) is the property of a solid, liquid or gas to conduct thermal energy ("heat"). It is a temperature-dependent material constant measured in watts per metre kelvin.
(Based on Wikipedia)

In practice, this means that the investment acts like an insulation material:
Most users seem to think that a muffle has been evenly heated after a holding time of about one hour at the final temperature in the preheating furnace. Afterwards, there is no temperature difference between the surface and the core of the muffle. However, this assumption is not correct; there is a significant difference in temperature. The hotter surface does reach the desired final temperature, whereas the core is up to 80°C colder, depending on the thermal conductivity of the investment used (Fig. 15). Importantly, this means that the thickness of the reaction layer formed when pressing lithium disilicate ceramics may vary, depending on the position of the pressed object in the muffle (Fig. 16). The use of suitable firing programs, optimised firing chamber designs, and investments with optimised thermal conductivity can help to solve this problem in such a way that almost no reaction layer is formed (Fig. 17 and 20). It is hard to understand why manufacturers do not include this important fact in their directions for use. Or why numerous manufacturers are not even aware of its importance, as the research done for this article revealed.

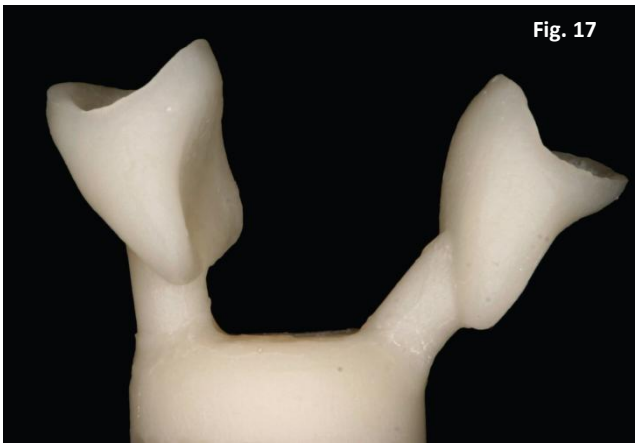
▲Fig. 15
The use of a silicone muffle former increases the surface area of a muffle. In theory, it is assumed that the muffle is then more effectively heated by the radiant heat from the heating spiral. In practice, this factor has not proved particularly important; the thermal conductivity of the investment is more significant to the final result.

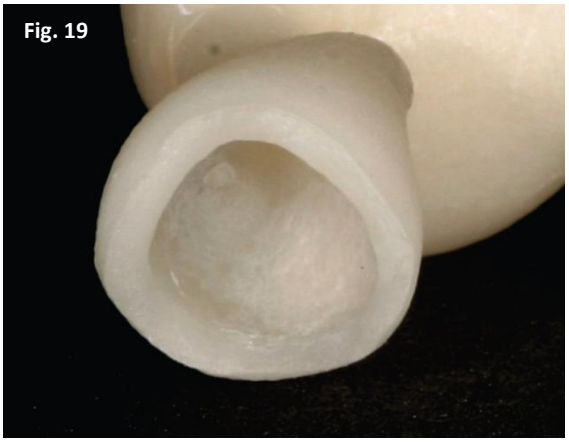
▲Fig. 16
Cross-sectional view of a muffle: To put it simply, the hotter the investment, the thicker the reaction layer. Since the core of a muffle is always colder than the surface, reaction layers formed in the core are thinner.

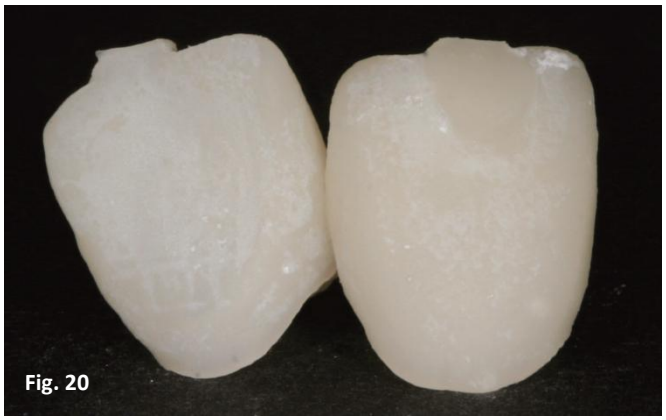
Differences

Product	Working time (at 23°C room temperature)	Mixing time in vacuum	Setting time in speed technique	Suitable for pressing & casting
Shofu Ceravety	6 min	60 s	20 min	Yes
Ivoclar PressVest Speed	4.5 min	180 s	40 min	No
GC MultiPressVest	6 min	60 s	20 min	No
Bego BellaCer	6 min	150 s	40 min	No

Data indicated by manufacturers for a 200 g muffle.





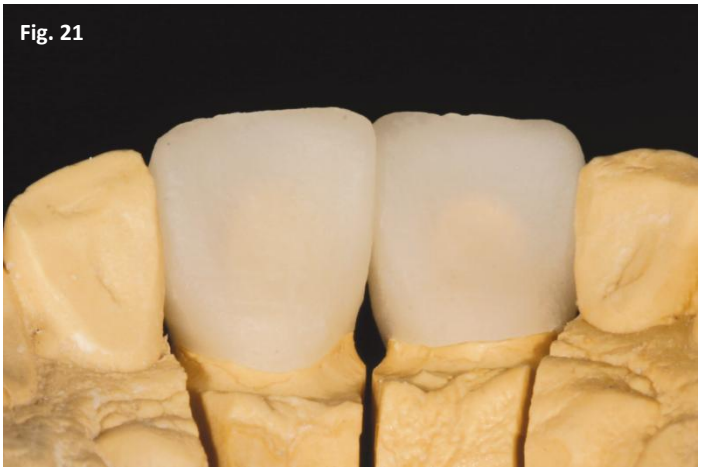


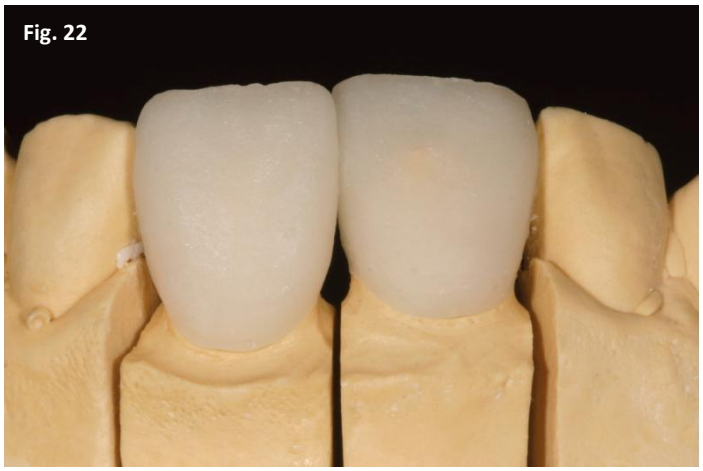
▲Fig. 17
The result of the pressing process after sandblasting

▲Fig. 18
Comparison of two different investments used under identical conditions. The result achieved with Ceravety (on the left): under optimal conditions, no reaction layer will be found on lithium disilicate ceramics after divestment. In contrast to the investment recommended by the manufacturer of the lithium disilicate ceramic (on the right), the object pressed using Ceravety is characterised by higher surface quality and excellent detail reproduction at the margin.

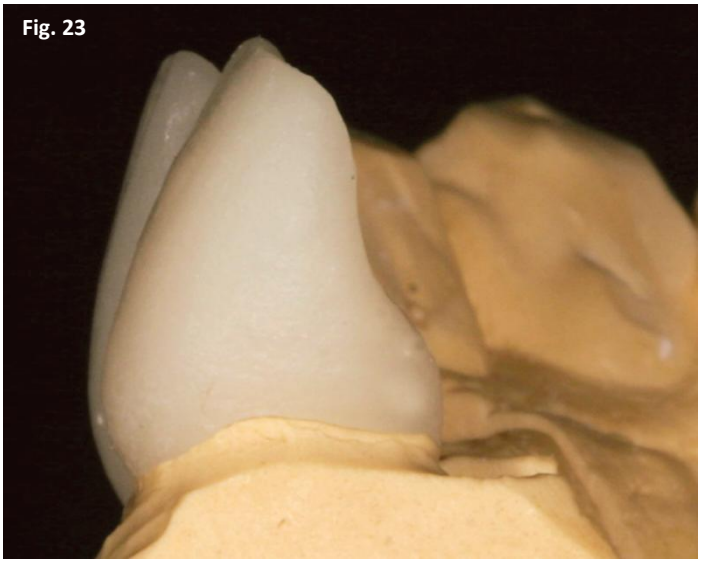
▲Fig. 19
Marginal precision: Thanks to excellent expansion control, the investment ensures accurate margin reproduction.

▲Fig. 20
Comparison of reaction layers: The crown on the left shows the lingual surface that was closest to the surface of the muffle. The reaction layer is thicker, as compared to the crown placed in the centre.





▲Fig. 21 and 22
Lingual and labial surfaces: This is the accuracy of fit achieved with Ceravety, directly after divestment, without any adjustments using rotary instruments.

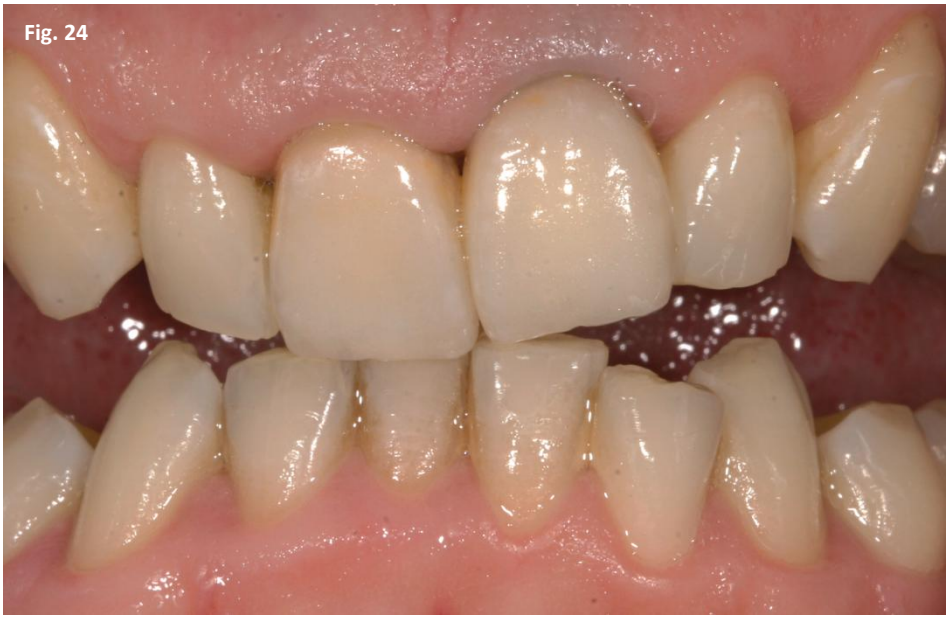


▶Fig. 23
Marginal fit: This accuracy makes work highly efficient, because pressed objects require almost no corrections, depending on the preparation design used.

This comparison of material properties shows considerable differences in handling and indications. The shortest setting times, only 20 minutes from start of mix, are offered by Shofu (Ceravety) and GC (MultiPressVest). The setting times indicated by Ivoclar (PressVest Speed) and Bego (BellaCer) for a 200 g muffle reach the upper limit of the working timeframe (30-40 min) and are twice as long as the times of the Shofu and GC products. When adding the times required by the firing programs of the various pressing furnaces, the resulting overall time differences may be up to 40 minutes.
The shortest time needed to reach the end of the pressing cycle is 120 minutes; the longest time is 160 minutes. The spectrum of indications is also an essential quality criterion. Ceravety is the only speed investment tested which can be used for multiple indications, i.e. for both pressing/press-over and traditional casting techniques.

Divestment
In addition to indication spectrum and handling properties, divestment is an important aspect. The hardness of the investment after pressing/casting and the thickness of the reaction layer formed on the pressed/cast object have a critical effect on the time required for divestment. Depending on the investment used, this step may take up to 15 minutes for lithium disilicate in a 200 g muffle.

The Ceravety investment also shows the best results in this respect. Only low blasting pressure is needed, which helps to minimise the stress acting on pressed objects with thin walls. In the press-over technique, metal or ceramic objects may also be invested (Fig. 21 to 23).



◀Fig. 24
Final result: When optimally combining and coordinating the various components of the production chain, reproducible and aesthetic results can be achieved. The Ceravety investment sets new standards in reliability, efficiency and accuracy.

In summary, it can be stated that the examined combination of Shofu Ceravety investment and Dekema furnace offers excellent results with lithium disilicate ceramics (Fig. 24):

- Thinnest reaction layer of all products tested
- Very short setting time
- Outstanding detail reproduction
- Quick divestment at low blasting pressure
- Optimal thermal conductivity for lithium disilicate ceramics.

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