

INVESTMENT MATERIALS: A REVIEW

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ABSTRACT

Investment casting process is known to its capability of producing clear net shape, high-dimensional accuracy and intricate design. Consistent research effort has been made by various researchers with an objective to explore the world of investment casting. The investment material should be of suitable consistency for adaptation to the wax metal and have a reasonable setting time. To withstand the temperatures required for the casting process there should be no distortion, no decomposition, the investment should not fragment or disintegrate under the impact of molten metal; material should be porous to allow the escape of air and gases and the investment should be easily removed from the casting after cooling. Success in dental casting restorations for fixed partial(FPDs) on the casting procedure. The goal of a prosthodontist is to provide the patient with restorations that fit precisely. Regardless of the alloy used for casting, the casting technique should yield a casted alloy, which should possess sufficient mass, surface hardness and minimal porosity after casting. So, this review article aims to discuss different investment materials available with recent modifications.

KEYWORDS: Gypsum bonded, phosphate bonded, casting.

INTRODUCTION

Esthetics is important in today's society. Dentists and researchers share this concern, and they have even more demands. They insist on good mechanical and physical properties of materials as well as on reasonable longevity of the restoration. They also require that the technique of preparing such a restoration be relatively easy and that the cost not exceed that of existing materials designed for the same purpose.^[1]

An investment can be described as a ceramic material that is suitable for forming a mold into which a metal or alloy is cast. The operation of forming the mold is described as investing.^[2] The investment material should be of suitable consistency for adaptation to the wax metal and have a reasonable setting time. In 1906 Dr. William Taggart of Chicago is given major credit for its introduction. Casting metals by the lost wax process have been recognized in the industry and the arts for many years. No record exists when and where this type of the casting procedure was first developed. In dentistry, lost wax process of casting metals became common practice after it was introduced by Taggart. Castings made by

Taggart were generally too small and did not fit the cavities properly.^[2]

Types of Investment Materials

Conventional investment material^[3]: Gypsum-bonded Investment, Phosphate-bonded Investment and Ethyl silicate-bonded investment.

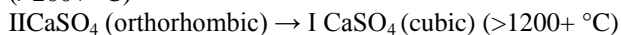
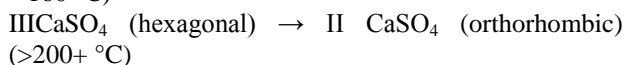
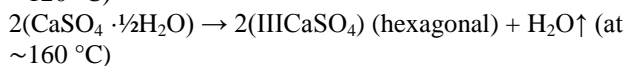
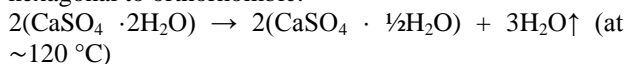
New investment material^[4]: Magnesia and alumina-based phosphate-bonded investment materials Alumina-based gypsum-bonded investment materials, Magnesia-based silica-bonded investment materials, Magnesia-based aluminous cement-bonded investment materials, Alumina–magnesia-based spinel-bonded investment materials and Calcia-based lost resin-bonded investment materials.

Gypsum Bonded Investment

The chemistry of this material was investigated several decades ago. It sets by crystallisation
$$2(\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}) + \text{H}_2\text{O} \rightarrow 2(\text{CaSO}_4 \cdot 2\text{H}_2\text{O})$$

When heated, evaporation of the excess water required for mixing takes place between 60 and 100 °C, followed

by the loss of water of crystallisation. With further heating, the structure of the anhydrite changes from hexagonal to orthorhombic.

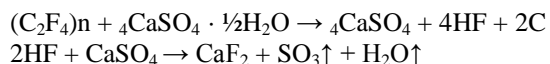


Higher setting and thermal expansions are recorded when stone replaces plaster. Stone produces a workable mix at a lower water–powder ratio, hence a denser set structure. Although the mould is heated in air, a localised wet environment is created in the initial stage of burn-out, more so if the mould still contains a significant part of the excess water required for effective mixing. A dense set structure and wet environment favours the formation of stone when the mould is heated. After the remaining water of crystallization has been lost, the transformation of the anhydrite from III CaSO₄ to II CaSO₄ takes place more rapidly and at a lower temperature when stone has formed during heating (of the mould). The matrix contracts less as a result of the denser structure and rapid transformation.^[5]

Empiric development led to small additions of boric acid and sodium chloride to reduce shrinkage resulting from the loss of water of crystallization during heating. The denser structure resulting from stone formation and rapid transformation lead to less contraction in the matrix during heating. Unfortunately, most of the gain appears transient. Sintering decreases the difference between modified and unmodified materials. The action of boric acid is different. Upon heating, it decomposes to B₂O₃ which inhibits evaporation of the last water of crystallization to prevent the prompt initiation of the III CaSO₄ to II CaSO₄ transition and suppress densification of the porous structure.^[6]

As an additive, boron has other uses. The cast surface on some precious alloys is discoloured. Although the reaction product, CuO, can be removed by pickling, preventing its formation would be preferable. An addition of a powdered reactive element, such as boron, to the investment powder can achieve this. It would be misleading to suggest this is totally effective since black CuO is replaced by the less conspicuous red Cu₂O. Strength is increased, attributed to B₂O₃ acting as a sintering agent. While higher strength is a bonus, it may not be significant.^[7,8]

An addition of up to 1% fine polytetrafluoroethylene (PTFE) particles will prevent the undesirable loss of fine investment particles during production of the investment.^[9] On burn-out, PTFE decomposes to form HF as an intermediate compound which reacts immediately with the calcium sulphate.



The calcium fluoride is believed to coat the anhydrite to produce a more refractory matrix, thereby eliminating gas evolution from anhydrite decomposition at the surface in contact with the molten alloy.^[9]

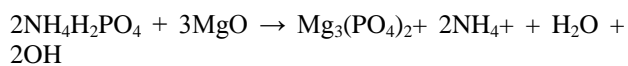
Phosphate Bonded Investment

All commercial dental products utilise the reaction of a blend of NH₄H₂PO₄ and MgO powders mixed with water. A positively identified struvite (crystalline MgNH₄PO₄ · 6H₂O) in the set investment and proposed a simple reaction to account for its formation.^[10]



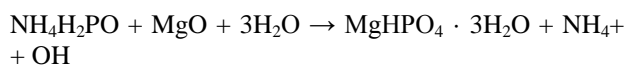
Its presence was confirmed and was provided with the mechanism. The acid phosphate dissolves rapidly and saturates the solution, thereby lowering the pH which leads to dissociation of the magnesia. As a consequence of that dissociation the pH rises and colloidal struvite particles form to produce setting by gel formation.^[11] Recently, an alternative mechanism in which nucleation of struvite takes place on the surface of the magnesia particles (not in the body of the liquid), and grows outward using hydrated magnesium ions from solution. When the magnesia surface is fully covered with a monolayer of hydrated magnesium ions [Mg(H₂O)₆], magnesium ions can no longer be released, a point that corresponds with setting.^[12] This model allows acid phosphate, magnesia and struvite to co-exist in the set material.

In addition to recording the presence of struvite, 31P solid-state Magic Angle Spinning Nuclear Magnetic Resonance (MAS-NMR) spectroscopy has revealed the existence of amorphous Mg₃(PO₄)₂.^[13] A lack of crystallinity does not prevent positive identification of a structure by solid-state MAS-NMR spectroscopy, as it does when using x-ray spectroscopy.^[4]



The existence of a fine amorphous Mg₃(PO₄)₂ structure and the absence of Mg₃(PO₄)₂ peaks in x-ray powder diffraction spectra are consistent with the proposition that a gel forms first during setting. Across a product range, amorphous Mg₃(PO₄)₂ and struvite are present in variable amounts and either can dominate.

In some products, amorphous MgHPO₄ and newberyite (MgHPO₄ · 3H₂O) have been detected by 31P solid-state MASNMR spectroscopy.



Crystalline newberyite had not been reported previously. As it is present in a minor amount, it might not have registered above the ragged saw-tooth background in the multi-peaked x-ray diffraction spectrum. However, it is known to be the binding compound formed when an alternative to $\text{NH}_4\text{H}_2\text{PO}_4$ is used in dental casting investment.^[14]

In theory, it is possible to employ acid phosphate compounds other than $\text{NH}_4\text{H}_2\text{PO}_4$ as a reactant in dental phosphate-bonded investments. Health and safety concerns about the release of hot ammonia gas during burn-out has prompted research on an ammonium-free replacement.^[13,14] Therefore, $\text{Mg}(\text{H}_2\text{PO}_4)_2$, preferably predissolved in water, produces an investment with potential.

In general, the results of x-ray powder diffraction spectroscopy and differential thermal analysis have been interpreted to identify structures and temperatures at which they exist. With the progressive loss of water of crystallisation and ammonia, an amorphous ionic glass forms. Its existence was hypothesised from the x-ray powder diffraction spectra obtained at temperatures either side of the range within which the glass occurs.^[11] This range varies from study to study, but there is general agreement on 300–620 °C.^[11,16]

Ethyl Silicate-Bonded Investment

For some silica-based phosphate-bonded products, the setting expansion is particularly sensitive to the mixing method.^[17] Change in the growth and morphology of the struvite crystals formed during setting is an obvious explanation.

The absence of constraint at the end of the mould leads to a vertical expansion that is similar to free expansion.^[18,19] Horizontal expansion is constrained, thus less. In all cases, the effective expansion has to be considered in both horizontal and vertical directions. They may differ significantly.

Internal constraint arises from the rigidity of the pattern material when the pattern surrounds part of the investment, as in the core of the mould for a crown. Since a wax pattern constrains only part of the mould. As much as 80% of setting expansion will be lost in an investment core that is surrounded by a wax pattern.^[20] Consequently, there could be negligible setting expansion over much of the fitting surface of an acrylic pattern.

Invariably, the strength of set material is quoted. With some justification, this can be described as inadequate. The material is brittle and susceptible to tensile failure. Room temperature is not the temperature at which in-service failure takes place and the composition of the binder changes during burn-out. Knowledge of the strength before burn-out has a value, but this is limited to events experienced by the mould at that stage alone.

There is a belief that room temperature strength can be used as a guide to high temperature strength. As for any belief, evidence – no matter how slim – is cited to justify this. The simple truth is that room temperature compressive strength is not a reliable guide to fracture strength at burn-out temperature. The rank order of products is not the same at each temperature.^[21] This underlines the inappropriateness of room temperature measurements.^[20]

In general, as the burn-out temperature increases (above the 400 °C lower limit for the test), the tensile (disc rupture) strength falls due to progressive decomposition of the binder and the quartz $\alpha \rightarrow \beta$ transformation.^[4]

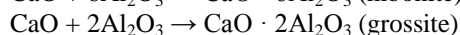
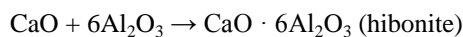
It is important to distinguish between the temperature to which the mould is heated (burn-out or casting temperature) and the actual temperature experienced by the investment. The molten alloy might be 100 °C higher than the investment. Consequently, the inflowing liquid will raise the temperature significantly. The part of the mould in contact with the metal is at an elevated temperature for a time sufficient to allow the investment to deform plastically before solidification.^[22]

Magnesia and Alumina Based Phosphate-Bonded Investment Materials

In general, the chemistry of the binder is the same as that for silica-based investment. At least four refractory oxides have been used to replace some or all of the silica. The reaction with a magnesia-/alumina-/silica-based investment (Rematitin Plus®) releases aluminium into the molten titanium. An α -case forms to a depth of ~20 μm , confining the aluminium (an α -stabiliser). Silicon segregates ahead of this, concentrating in a zone extending to 70 μm . The hardened layer is limited to the depth to which oxygen can penetrate. A third zone of oxygen-containing acicular α -titanium grains takes the hardened layer to a total of 200 μm .^[23] The microstructure produced by silica-/alumina-based investment (T-invest CB®) is similar. Silicon, aluminium, phosphorus and oxygen are found in the first 50 μm with acicular grains extending to a depth of 150 μm .^[24]

Alumina-Based Gypsum-Bonded Investment Materials

Ultimately, silica-based gypsum-bonded investment is limited by the reaction between anhydrite and silica. The temperature for this breakdown is usually taken to be around 1250 °C. If alumina replaces silica the resulting investment material has a low, but usable set strength and the same setting expansion (~0.5%) as that of silica-based material.



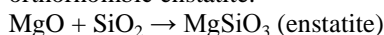
These reactions produce an expansion of 3%, which can be adjusted by altering the alumina–gypsum ratio; 4: 1

appears to be the optimum. Most of this reaction expansion is retained when the mould is cooled. However, the strength of the cooled burnt-out material is very low.^[25] Such improvement is expected, given the presence of highly stable Al_2O_3 , CaO and MgO .^[26] Sulphur dioxide will be released when the alumina-based investment is heated (as it is from overheated silica-based investment). No information is available on whether it is a problem.

Magnesia-Based Silica-Bonded Investment Materials

Magnesia and magnesia–alumina–zirconia- (1: 1:trace) based experimental investments have been developed to cast titanium.^[27,28] It is surprising that silica was chosen as a binder considering that oxides more stable than silica replaced it as the refractory phase. Setting is accompanied by contraction. the investment expands up to 1% at the burn-out temperature of 900 °C. To minimise surface reaction the mould is cooled to 70 °C and cast at that temperature.

At 830 °C, there is a strongly exothermic reaction between these oxides, which results in the formation of orthorhombic enstatite.



Thus, reactivity of the investment could be reduced and if enstatite formation is accompanied by expansion, this will be retained on cooling with the potential for accurate castings.^[4]

Magnesia-Based Aluminous Cement-Bonded Investment Materials

An investment with this chemistry is available commercially, Selevest D®. Since the investment contains about one-third aluminous cement binder, negligible change on setting should be anticipated. Selevest D® contracts during setting. When heated, the cement dehydrates which offsets thermal expansion and, at the 900 °C burn-out temperature, the result is a small net expansion. If the mould is cooled to room temperature for cold casting, changes in the binder during the burn-out leave a net contraction, 0.32%.^[29]

A binary experimental investment (85 MgO: 15 aluminous cement) has a net 0% change at burn-out (700 °C) then contracts 0.9% on cooling to room temperature (for casting).^[30] Contraction is inherent to the system. To overcome this deficiency, 2.7% zirconium powder has been added. (Product names Selevest DM® and Selevest CB® appear in the literature. The difference, if any, is not given.) The setting contraction remains unchanged, 0.04%. However, between 550 and 700 °C, the investment expands rapidly, to 1.1% for Selevest CB® and to 1.4% for Selevest DM® due to oxidation. Nearly all of this expansion is retained when the mould is cooled to room temperature for casting. Mixing appropriate proportions of zirconium-free and zirconium-containing variants has been proposed to adjust the expansion.^[31]

Alumina–Magnesia-Based Spinel-Bonded Investment Materials

Titavest CB®, intended for casting titanium, is a blend of 70% MgO , 25% Al_2O_3 and 5% ZrO_2 which is mixed with a 30% magnesium acetate solution containing 5% ethanol. An undisclosed but small addition of ZrN is present to aid thermal expansion. The mould expands 1.2% as it sets. Upon heating, decomposition of the binding compound causes a contraction until the spinel (MgAl_2O_4) forms at 880 °C whereupon the investment expands rapidly to 1.3%. Cooling to the 600 °C casting temperature reduces the expansion to 1.0%.^[4]

Calcia-Based Lost Resin-Bonded Investment Materials

Dispersing the refractory powder in a monomer to produce an investment that sets by polymerisation is a radically different approach. Organic binder and wax pattern burn off together, after which sintering provides cohesion. This pre-existing technology (for the production of crucibles) has been adapted to give a calcia-based experimental investment containing 78% CaO , 2% CaF_2 and 20% methylmethacrylate monomer. The autopolymerised acrylic binder gives a composite with adequate set compressive strength (~22 MPa) and burns off completely by 400 °C. Unfortunately, polymerisation produces a setting shrinkage which sintering worsens. Calcium fluoride is required as a sintering agent. If absent, the strength after burn-out is inadequate. Closure of pores by sintering increases strength at the expense of greater shrinkage; a compromise is necessary. Sintering at 900 °C avoids excessive contraction and produces low but acceptable strength.^[32,33]

CONCLUSION

Far from being a stable technology, dental casting investment material is still undergoing a sea change in formulation. The casting of metallic restorations and implant components in substantial numbers continue to make this material a key element in dental technology. CAD/CAM offers an alternative method for fabrication, but does not have the flexibility with cost effectiveness of lost wax casting. The requirements set many years ago hold true to this day. While the two types most widely used today (silica-based gypsum-bonded and silica-based phosphate-bonded) perform well, it is clear that improvements are still possible. All products, without regard to chemistry, are now within the scope of an ISO standard for casting investment material. There is no bar to products with new chemistries seeking to comply with the ISO standard, to give the consumer an assurance that the product is fit for purpose. Thus, the centenary of Taggart's publication has been marked by a very significant development.^[4]

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