# Investment Powders and Investment Casting

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## Investment powders

The basic composition of investment powders has remained relatively unchanged for the last 50 years and is the starting point from which all investment powders have been developed.

The binder, which is used to hold together the investment powder, is plaster, which has been produced from gypsum rock. Gypsum is a sedimentary rock of considerable geological age, which crystallises in a prismatic form with a layered structure held together with water molecules. Before the gypsum can be used as a binder it has to be converted to the hemi-hydrate state by autoclaving. This is an unstable form, which requires water to restore it to its original and more stable di-hydrate gypsum form. When investment powder is added to water in the investing process, it is the bonding mechanism as the intermeshing crystals of gypsum are gradually restored, which holds the investment mould together. As the setting process advances, the strength and properties of the investment powder are influenced by trace additions of crystal modifiers, which affect the length, and shape of the crystal needles from the original nuclei.

**Figure 1**

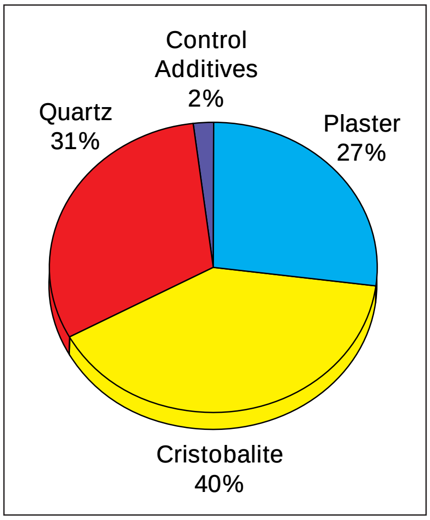


**Figure 2 -** Typical investment powder composition

The investment powder manufacturer will control the rate of growth of the crystal nuclei with the addition of retarders which poison the crystal growth, or accelerators which will increase the rate at which the hemi-hydrate goes into solution or increase the rate of di-hydrate formation. The end user of the investment powder will influence the speed and extent of the set by changing the powder:water ratio, the temperature of the slurry, the mixing technique and by using contaminated water or equipment.

When the set investment mould is heated, the gypsum binder would naturally shrink badly above the point at which its water of crystallisation is driven off. This would be particularly severe at 300°C–450°C as the di-hydrate converts to anhydrite. If gypsum alone were used to produce investment for lost wax casting, the moulds would crack very badly in service and would also produce a casting that was a great deal smaller than the original pattern. Silica is used to compensate for this gypsum shrinkage and to regulate the thermal expansion of the mould.

Silica exists in several crystalline forms, which are used in the production of investment powders. Quartz is the most readily available form and its conversion from α to β form is accompanied by an increase in volume at around 570°C. Cristobalite is the other major constituent of investment powder and this form of silica also has a significant increase in volume as it inverts from its α to β crystal structure at around 270°C. These two allotropic forms of silica are therefore used to override the shrinkage effect of the plaster binder. A typical thermal expansion of a jewellery investment powder would show how the cristobalite provides the expansion up to 300°C then there is a temperature band up to 570°C where the plaster shrinkage dominates. Then the quartz inversion again takes over the thermal profile of the investment powder.

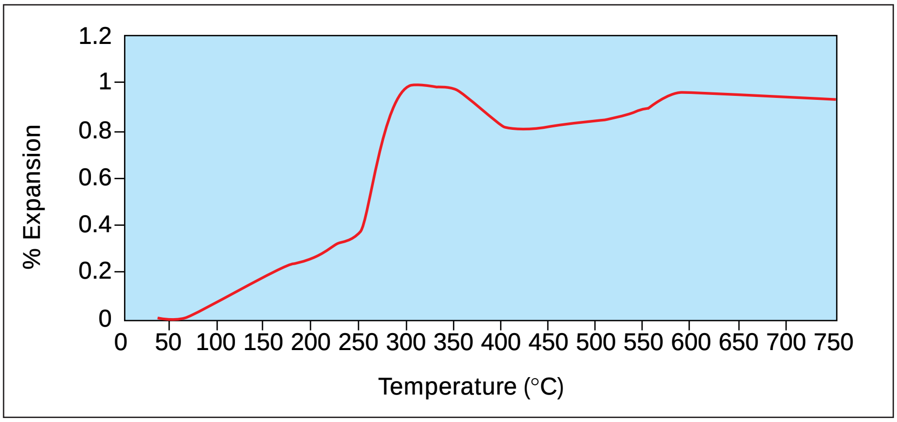


**Figure 3 -** Thermal expansion of a Gold Star Investment

It is important to remember that when the investment mould cools, it will pass through the silica inversions which, being reversible, will contract an equal amount to the original silica expansion, plus the permanent contraction of the plaster. This cooling curve is what can be used to understand the final casting size. After casting and on cooling, the gypsum plaster becomes very weak and coupled with the disruption caused by the cooling contraction of the silica inversions, enables the cast investment to be readily removed during quenching.

Investment manufacturers strive to make the seemingly simple composition suit more and more casters' requirements by subtle variations to raw material purity, proportions, particle size and control additions, which has led to the large selection of investment powders available today. In very general terms the types of investment powder and the differences in their properties can be summarised as follows:

Some investments are quite specific to a particular type of casting whereas other products are not easily categorised. Investments for glass casting have to be capable of withstanding much higher temperatures than conventional jewellery investments for long periods of time. As a result they are made from special refractories which will not crack in this application. Investments for casting gemstones in place are subjected to lower temperatures than normal but must protect the stones and therefore contain special additives for this purpose. Industrial investments are used in the manufacture of large aluminium or brass castings and are very strong; being specifically developed to withstand cooling to very low casting temperatures without cracking.

**Figure 4 -** Industrial Investment

**Table 1.**

| Investment application | Material Purity | Particle size | Strength | Permeability |
|---|---|---|---|---|
| High temperature Alloys | V. High | Fine | Medium | High |
| High quality gold castings | High | Fine | Medium | High |
| High volume gold & silver | Medium | Medium | Med./Low | High |
| High volume brass | Medium | Med./Coarse | Medium | Medium |
| Statue casting | Medium | Med./Coarse | High | Medium |
| Stone casting | High | Medium | High | Medium |
| Industrial casting | Medium | Coarse | V. High | Medium |
| Glas casting | Medium | Medium | Medium | Low |

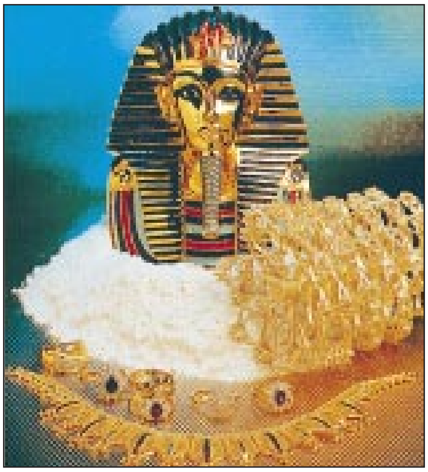

**Figure 4 -** Jewellery Investment

Traditional methods of testing raw materials and finished products are still used by manufacturers. However, increasing demands for quality and consistency have led to the introduction of new techniques. The leading manufacturers of investment powders are using very high technology equipment to look at the minute changes in raw materials using techniques like x-ray analysis. If a customer has any concern over a particular batch of investment it is now possible to look at a small sample and determine the exact chemical and crystallographic composition down to trace elements. This kind of attention to detail builds a confidence from customers in the quality of investment powders they are receiving.

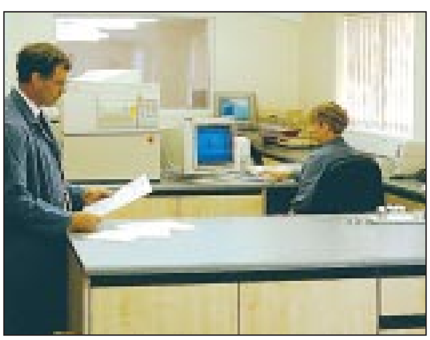

**Figure 6 -** Hoben X-ray Analysis Department

To control the manufacture process itself, ISO 9000 techniques are considered necessary and some companies are working with QS 9000 (automotive standard) techniques such as Advanced Quality Planning and PFMA (Potential Failure Mode & Effects Analysis) in which potential problems are continuously identified and corrected before they occur.

At the end of the day, the greatest influence on the quality of the castings that can be achieved comes from how the investing and casting process is carried out. Understandably casters do not always adjust their working practice to suit a particular investment powder. Therefore the best investment powders are designed to be flexible enough to tolerate misuse of all kinds. It is, however, impossible to defy the laws of nature and there is a limit on how much tolerance can be built into a powder. To achieve the optimal results, it is useful to review what is considered best practice. The following techniques and recommendations are applicable to all the leading investment powders.

## Investment Casting

### Investing

There are basic rules which should be followed for all techniques and types of investment used.

- The investment must be stored in clean, moisture free conditions to prevent deterioration and ideally at 20-22°C.
- All equipment used and the investing area must be kept clean. Contamination with set investment from the mixing equipment, dirty cans, etc. will result in the work time of the investment becoming shorter than normal. This can lead to problems with the investment trying to set while still in the vacuum chamber, for example.
- The water used must also be clean. As a guide, if it is safe to drink, it is safe to invest with. Contaminated water usually extends the work time and, in extreme cases, prevents setting altogether.
- Weighing equipment must be well maintained and calibrated at regular intervals to ensure the correct powder water ratio is maintained.
- Part used bags or drums of investment must be kept closed at all times to prevent moisture pick up from the atmosphere. Investment powder will deteriorate with time so it is important to rotate the stock of investment powder. Each bag or drum will have a unique date or batch number which should be used to ensure all old investment is used up prior to moving on to a new delivery.

The most common methods of investing are hand mixing, machine mixing or machine mixing under vacuum. The most important rules to remember are:

- The powder water ratio must be correct.
- The slurry temperature must be correct.
- The work cycle must be timed to use up the work time of the investment.
- Do not breathe investment powder dust.

**WARNING:** It is very important to know that investment powder contains a large percentage of crystalline silica and, because of the fine particle size used, this contains a respirable fraction. Silica is known to represent a health hazard and should always be handled under extraction or with suitable dust masks.

**Figure 7 -** Hand Mixing in Air

**Figure 8 -** Machine Mixing in Air

## Hand & Machine Mixing in Air

The following procedure is recommended for plaster bonded investment powders, which are either hand or machined mixed in air.

1. Weigh out the required amount of powder and measure its temperature
2. Measure the required volume of water and adjust its temperature to give a slurry of 20 – 22°C. As a guide, subtract the powder temperature from 40°C. This will give the required water temperature. e.g. powder temp = 25°C therefore recommended water temp = 15°C
3. Put the water in the bowl.
4. Slowly add the powder to the water and allow to soak for 30 seconds.
5. Mix by hand for 30 seconds to ensure all the lumps are dispersed.
6. Continue to hand mix or machine mix for a further 3 minutes.
7. Vacuum the slurry in the mixing bowl for a maximum of 2 minutes. Vibration may be applied at this stage to ensure entrapped air is released.
8. Gently fill the flasks pouring the investment down the inside of the flasks and not directly onto the wax tree to avoid breakages.
9. Vacuum the flasks for a further 2 minutes maximum. Vibration should not be used at this stage.
10. Allow the flasks to stand undisturbed for at least 1 hour.

Assuming that it takes around 1 minute to fill the flasks, the total cycle of work time is around $8^1/_2$ minutes. For the investment to have its optimum results, the di-hydrate crystals of gypsum would start to grow at exactly the time the filled flask is left undisturbed. The investment will then thicken and in around a further 3 minutes, it will have reached “gloss-off”. This is the moment when the surface of the investment goes from a shiny (gloss) appearance to a dull (“matt”) appearance as the water is drawn into the growing di-hydrate gypsum crystals. Over the next hour, the investment gains most of its maximum strength as the crystal structure develops. The flask is then strong enough to be handled.

If due to temperature, water quality or other reason the “gloss-off” occurs to soon or too late, it is preferable to extend or reduce the mixing time accordingly.

## Machine Mixing under Vacuum

The availability of vacuum mixing and pouring machines gives the ability to produce castings, which are virtually free of bubbles, but this calls for a totally different investing technique. Most investment manufacturers recommend a lower powder:water ratio for investments to be mixed under vacuum. These recommended ratios should be followed. With the lower powder:water ratio and using a vacuum mixer the work time of the investment powder will probably be reduced. It is therefore recommended that a trial be carried out into a bowl noting the gloss-off time. This should then be reduced by 3 minutes to give the total available work time. This can be used to work out how long the investment should be vacuum mixed. For example if it takes $11^1/_2$ minutes to gloss off, this gives an available work time of $8^1/_2$ minutes. If it takes $2^1/_2$ minutes to pour, then mix under vacuum for 6 minutes. The procedure for mixing under vacuum would then be:

1. Weigh out the required amount of powder and measure its temperature.
2. Weigh or measure the water and adjust its temperature to give a slurry of 20°C to 22°C.
3. Add the water to mixing chamber.
4. Add the powder to the mixing chamber and allow to soak for 30 seconds.
5. Start the mixer and vacuum and mix for 6 minutes.
6. Slowly fill the flasks. DO NOT VIBRATE.
7. Once the flask is full release the vacuum.
8. Allow the flasks to stand on a vibration free surface for a minimum of 1 hour to strengthen before stripping the base.

**Figure 9 -** Machine Mixing under Vacuum

Vibrations on vacuum mixing machines can cause problems if they are used when the flask has been filled. In general, they are considered unnecessary and unhelpful by investment powder manufacturers.

## De-wax & Burnout

Invested flasks should be left undisturbed for a minimum of 1 hour, preferably 2 hours, and then they can be placed in a furnace to remove the wax. The flasks should not be allowed to dry out completely before firing. This may result in the mould cracking, causing finning faults on the casting. If the invested flasks stand for more than one day, they should be immersed in water for one minute before firing.

In addition to removing the wax, heating in a furnace burns out any carbon residues from the wax, and brings the flask up to the correct temperature for casting. The strength and expansion characteristics of the mould will depend on the quality of raw materials and recipe of the investment powder.

Injection waxes used by the jewellery industry generally have melting points in the temperature range of 60–70°C. The wax is, therefore, removed quite quickly. Furnaces designed for de-wax & burn out should have the facility to remove the wax residue through the bottom of the furnace. The better furnaces will have heated stainless steel floor pans, which slope to allow the wax out.

**Figure 11 -** Positioning of flasks in furnace

In some cases, the caster may choose to remove the wax using steam. Steam de-waxing is often preferred when casting with stones already set in the wax models. Conventional jewellery investments are not designed to withstand steam under high pressures generated in autoclaves, as used by industrial shell casters. The de-waxed flask should be transferred directly to the furnace from the steam de-waxer for the remainder of the burn out cycle.

It is important to use furnaces which give even, controlled heating throughout the heating chamber and whatever furnace type is used, it should never be overloaded. The flasks should be positioned so that the wax can easily flow out from them, and so that air can enter the mould to assist the carbon burn out. The furnace should be powerful enough in its supply of energy, gas or electricity, and have an adequate control unit to regulate the temperature of the furnace throughout the de-wax and burn out cycle.

The burn out cycle of a typical flask is usually 12 to 14 hours, but some investment powders will allow a short cycle of 6 hours to be used. These investments are designed to aid steam release and to have a high thermal shock resistance. It is very important to remember that the gypsum binder used to bind jewellery investments will break down rapidly if the flask is heated above 740°C. In the presence of carbon, the calcium sulphate will break down to the calcium oxide & sulphur dioxide or sulphur trioxide. This condition will notably affect the strength of the mould but also will react with the molten metal giving rough discoloured castings, which are brittle when worked. When casting with stones already set in the wax pattern, it is necessary to modify the burn out cycle so that the maximum temperature attained is 630°C. Some gemstones, such as topaz, amethyst, emeralds, opals etc, are unsuitable for this technique.

**Figure 10 -** Hoben 40T/55 Furnace

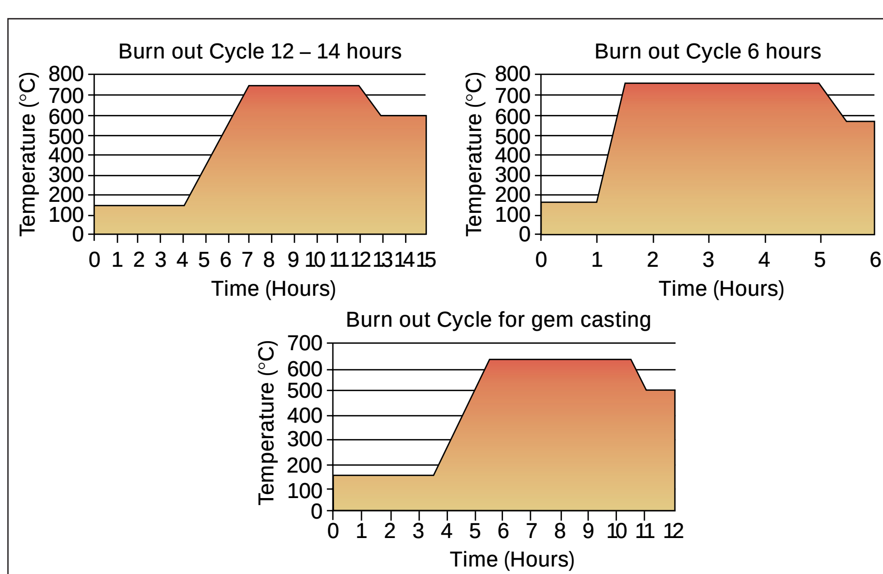


**Figure 12 -** Typical burn out cycles

### Casting

When the flask has been successfully burnt out, it can be reduced to the temperature required for casting metal into it. The flasks should be held at this temperature for some time, depending on the flask size, for the temperature to reach equilibrium throughout. On removal of the flask from the furnace, a visual examination of the button end should show it to be pure white with no evidence of black, which would indicate full burn out has not been achieved, with surface carbon deposits remaining.

There is a wide range of equipment available for casting and these machines can be divided into the centrifugal or static types with torch, electrical resistance or induction melting. Vacuum and inert gas are also used as a control over the quality of the melting and casting conditions. Complete and perfect form filling is the first requirement of a jewellery casting. It is therefore important to consider carefully the flow of molten metal into the mould.

Care in the design and method of spruing is vital for a successful casting. The molten metal should flow into the mould as smoothly as possible. The sprue should be as large as is economically possible and fixed into the heaviest section of the casting. Care in waxing up will also prevent fine feathers of investment powder projecting into the metal stream. These can easily become detached and form inclusions in the casting. Before casting, it is important that the metal temperature is correct; too low and it will not fill the mould, too high and it will cause porosity and shrinkage defects in the casting. It is therefore important to monitor the metal temperature accurately using either optical or contact pyrometers. Experienced casters are capable of judging the casting temperature by eye and are able to achieve very high quality castings. The selection and suitability of equipment will vary depending on the type and volume of castings required.

After casting, the flasks are quenched in water and any remaining investment removed from the tree of castings. The flasks should not be quenched immediately or left to go completely cold. Quenching too soon will result in brittle castings and too late will make the investment hard to remove. The metal button should have lost all of its red heat and typically a minimum of 10 minutes is required. Flasks containing gemstones cast in place should not be quenched. Quenching will cause the stones to crack. These flasks should be allowed to cool to room temperature and then cleaned with water blasting equipment. After cleaning, the individual pieces are cut from the tree using hand held or pneumatic sprue cutters. The castings can then be finished giving superb reproduction of detail and castings of the highest quality can be obtained.

For further information and technical advice including casting problems, please refer to the web site: http://www.hoben.co.uk/consultancy.htm


**Figure 13 -** Casting into the mould in static machine

**Figure 14 -** Cleaned Castings