Richard Austin (1936-1990) was a metalsmith and author, with several hundred articles to his credit. After his death I was given custody of an extensive collection of manuscript material-mostly on the technical issues of metalworking.

This text represents the first effort to organize the material-an attempt merely to group the files by topic. None of this is finished, and the text makes reference to illustrations that were never done-illustrations which were stored separately in any case, making it extremely difficult to bring the parts together.

It is unlikely that I will ever be able to spend the time to sort this all out. But it seemed a shame to let these articles languish unread by those who might benefit from them in some small way. So I have decided to release them in their roughly sorted form in the hopes that someone may find them useful.

This information is provided without warranty of any kind. No liability for its use will be assumed by the publisher. It is provided purely as an historic document.
There is some difference of opinion concerning the need for some degree of vibration during the vacuum investing process in vacuum units with an integral pump. The pump vibrating may have this effect. Various vibrators have been attached to the vacuum tables or the technician may vibrate the table by hand.
**Investment Materials** - Kerr Manufacturing provides a wide range of casting investments. The properties of these investments have been adjusted to provide outstanding results in commercial or one of a kind production. Specific formulations are available for almost every application.

**Satin Cast Regular** - This material has been in production for a number of years. It remains popular with casters all over the world. It is suitable for use with gold alloys, silver, brass, bronze and other metals melting at temperatures below 2000°F/1093°C.

**Satin Cast 20** - This updated version of the Satin Cast line is formulated for the demands of contemporary technology. It is also suited for materials melting at temperatures of 2000°F/1093°C or less.

**Satin Cast 20 With Fiber** - This version of the Satin Cast line is especially formulated for applications requiring extra strength. Applications would include vacuum assist casting with vent rods and the casting of large heavy pieces.

**Supervest 20** - Supervest 20 is intended for commercial application. It yields a thicker slurry which minimizes water separation and water marking on patterns.

**Platinate** - This investment is specially formulated for casting at high temperatures. Applications include platinum and ferrous alloys including stainless steel.
**Spectra Cast** - This is a high temperature phosphate based investment specially formulated for casting steel, nickel or cobalt-based superalloys.

**G-3005 Series** - A new fiber has been used in this industrial investment to provide excellent physical properties for casting sculpture and precision industrial components.

**G-400 Series** - Provides controlled expansion which works well with a wide range of metals. However it is especially well suited for casting aluminum and pewter.

**G-700** - Has a finer size particle distribution which yield excellent surface properties. Especially useful for small intricate parts or in any application where "surface" quality is a prime consideration.

**Luster Cast** - Contains deoxidizing agents which minimize metal oxide formation on non-ferrous alloys. Can be used for bimetal casting applications.

**Cristobalite Inlay** - An old favorite in the dental trade. It can also be used for non-ferrous jewelry and small industrial parts.
INVESTMENT                                by:  Richard D. Austin

The results achieved in the investment casting process relate
to a wide range of material, process and design variables.
Because of its versatility, the investment casting process
has achieved widespread application in jewelry manufacturing
and industrial applications. Investment casting is a
versatile process which can be applied in the one-man
artist/craftsman shop or in major industrial operations.
Since the unique characteristics of the investment material
provide this degree of versality, the study of these materials
is key to all successful applications.

In the last thirty to forty years, there has been a continuous
evolution in investment materials, as well as a constantly
expanding knowledge base about their application. This has
resulted in improved quality and consistency in the investment
casting process. Unfortunately, it is also rendered much of
the published information and accumulated wisdom obsolete.
INVESTMENT

Topping Off - Generally speaking the investment rise on the second vacuuming will be less than the first cycle, however some room will be required. Some literature suggest "topping off" the flasks. With this method the flask is filled just enough to cover the model. After vacuuming additional investment is added to fill the flask. This technique has several disadvantages. First, if may come late in the solidification processes. Second, the fill may not come to the top of the flask. This means that the "skin" can't be removed and the gas permeability of the mold is decreased. Third, if you add enough investment the flask tends to run over.

The use of a collar on the flask avoids these problems. The collar may be a rubber sleeve designed for this purpose. Alternately, a collar of masking tape may be used.
CALIBRATION OF INVESTMENT MIXING PROCEDURES

By: Richard D. Austin

Most casters know how to deal with gross investment defects such as bubbles. However, the subtle problems of low strength, poor surface quality and breakout may be more difficult to correct. Proper investment mixing procedures can yield a significant quality improvement in the casting process. Because details of shop practice and conditions vary, no universal procedure is completely satisfactory. This article will provide the information needed to develop a proper mixing cycle for your shop situation.

The material presented here is appropriate for calcium sulphate based jewelry casting investments. Most of these investments are based on combinations of calcium sulphate, silica, cristobalite and various additives. The calcium sulphate provides the reactive base which combines with water to harden the investment. The working time of a calcium sulphate based investment is a critical element in determining the proper investing cycle.

In order to achieve consistent results, all elements in the investing process must be kept in tight control. These include:

. Investment Storage
. Proportion Of Ingredients
Temperature
Mixing Time
Mixing Cycle

I am assuming that the first four elements are in good control. All of this discussion will focus on the development of the Mixing Cycle.

Superficially, the application of the investment appears to be very straightforward. Mix some investment in water to form a slurry and about ten minutes later it becomes hard. Unfortunately, the situation is not that simple. The moment the materials are combined the water and the calcium sulphate begin to react. This reaction continues for an hour or more after the material appears to be hard. The properties of the slurry and the solid change constantly during this period. Most of the changes occur gradually and are difficult to measure. However, there is a key point which can be measured. This is called the "gloss off". The best way to understand gloss off is to observe it for yourself. Prepare a small batch of investment (perhaps a 1/3 of a cup) and process it through your existing mixing procedure. Note the time at the moment you combine the ingredients.

After about nine minutes, place the bowl under a bright light where you can see the surface clearly. You will note that the mix is glossy and wet looking. Somewhere around the tenth to
twelfth minute the appearance will suddenly change. Beginning at the edge, or perhaps around some small bubbles on the surface, the material will suddenly lose its gloss and begin to appear dry. Note the elapsed time. This is the gloss of time. The final vacuum step must be completed about 1½ minutes before gloss off. The time from initial mix to gloss off, less one and a half minutes is known as the work time.

Different investments, ambient conditions and mixing cycles will change the gloss off (and working times) significantly. Temperature and the proportions of water are two of the more significant variables. Increased amounts of water extend gloss off time and higher temperatures decrease the time.

For Kerr Satin Cast and Satin Cast 20 gloss off time will be around 10 or 11 minutes if you follow the manufacturers procedure. Variations are not critical as long as the procedure is consistent and you calibrate the process to take into account the actual time required for gloss off. Some industrial casters operate at an elevated temperature to shorten the investment cycle and save time. I wouldn't recommend this for most artist craftsman. It is vitally important that you control this system for absolute consistency.

It is obvious that a physical change in the investment takes place at gloss off. Gloss off time is used to calibrate the investment process.
Before considering specific details let's begin by reviewing the mixing cycle:

**Measurement** - Careful measurement is vital. Typically, the investment is measured by weight and the water by weight or volume. No matter how much experience you have, measurement "by eye" will not produce consistent results.

**Mixing** - Manufacturer's tests and experience indicate that the best investment properties are developed if the investment is mixed for a minimum of 2½ minutes. Times over three minutes do not continue to improve the properties but longer mixing doesn't cause any problems. Since the first 30 seconds of mixing are required to blend the ingredients I usually mix for 3 minutes from the time the water and investment are combined.

**Vacuum** - In my experience the vacuum cycle requires approximately 60 seconds. Yours may vary depending on the size of your equipment, the quality of your vacuum pump etc.

**Open** - At this point, mixing and vacuum treatment are complete but, as we shall see later it is too soon to begin pouring. In my experience there are usually 2 or 3 minutes where the investment can sit. This time can be used to paint or dip the models with investment. Mixing time may also be extended to use up this interval. Note that the investment will tend to settle during this period and a brief mixing is
required to bring up the solids before pouring.

**Pouring** - Pouring a group of flasks usually requires about 60 seconds.

**Second Vacuum** - The second vacuuming requires an additional 60 seconds.

**Setting** - At this point in time, the viscosity begins to increase very rapidly. Although the investment is still a liquid it's properties change rapidly during this period.

**Gloss Off** - The gloss off time occurs during the period when the viscosity of the investment mix reaches a very high level. At the end of the gloss off period the material is essentially a solid.

Viscosity is the key system property which changes at gloss off. Think of two fluids such as water and honey. The honey is more viscous. This means it flows more slowly. If fine solid material is mixed with honey and with water it will settle much more slowly in the honey. The formulation of an investment involves a compromise with regard to viscosity. The mix must be thin enough so that it will flow into the detail of the model and allow air bubbles to move out of the mix. On the other hand, it must be thick enough to hold the solid fillers in suspension. Settling of the fillers after the flask is poured is one of the key causes of poor casting quality. In extreme cases this shows up as a river like patterns of raised ridges (see attached photograph). This defect
is called channeling. A key objective of the mixing cycle is to minimize the time which the full flasks stand before setting.

The viscosity of an investment mix changes during the time between mixing and setting. This change is continuous, not instantaneous. The relationship between time and viscosity can help you to understand many properties of the investment. The top half of the attached graph illustrates the time/viscosity relationship for three investment mixes. One is a mix with standard amount of water, the second has about 2% less water and the third has about 2% extra water. Note that less water causes a higher viscosity and a shorter work time. More water decreases viscosity and extends working time. Also note that the ±2% water causes the gloss off time to vary for at least one minute.

The lower half of the graph illustrates a mixing cycle based on the standard mix. The work time is complete just before the rapid rise in viscosity. The short time period between pouring the flasks and the rapid viscosity rise minimizes channeling and associated defects. Obviously, there must be some margin in the system. Vacuuming after the effective work time will produce cavities in the mold and gross modular defects on the surface of the casting. At the other extremum, vacuuming at too low a viscosity will tend to produce small surface bubbles.
The investment process must balance all of these elements to achieve the optimum result. Working with these principles, Three basic steps will allow you to develop a specific mixing cycle for your own shop.

1. Select an investment and establish a mixing procedure based on the manufacturer's directions. Pick an operating temperature, method of mixing etc.

2. Measure the gloss off time for the system you have selected.

3. Subtract 1½ minutes from the gloss off time to establish the work time. Balance the total cycle to include mix, vacuum, pour and second vacuum time.

Don't shortcut. The extra effort is well worth it.

I would like to express my appreciation to the Kerr Division of Sybron Corporation for their assistance in the preparation of this article.
CASTING INVESTMENT

MATERIALS AND APPLICATIONS

BY: Richard D. Austin

The investment casting process enjoys wide popularity in the production of commercial and one-of-a-kind art metal objects. However, production practice varies widely. At one extreme, design renderings are turned over to a production shop. In other cases, individuals choose to carry out the complete production process in their own studios. In either case, a clear understanding of the materials and processes will help insure optimum results. There are a wide range of technical considerations involved in the investment casting process. This paper will focus on various aspects of investment application. It will begin with a discussion of investment materials. This will be followed by specific application techniques and some troubleshooting suggestions.

The two most common classes of casting investment are based on different chemical systems.

- Calcium Sulphate
- Ammonium Phosphate/Magnesium Oxide

The majority of commercial jewelry castings are made with calcium sulphate based systems. They provide a good balance of economy, workability, and physical properties. This discussion will be limited to calcium sulphate based systems. The information presented should not be applied to other investment systems.
The ingredients used in an investment formulation establish its basic properties. The calcium sulphate jewelry investments are composed primarily of:

**Gypsum** - Provides a structural base for the investment by the formation of a solid during the reaction between water and the gypsum powder.

**Quartz** - Powdered quartz (silica) provides reinforcement for the investment material.

**Cristobalite** - A form of silica added to adjust the thermal expansion properties of the investment.

In addition, other materials may be added in small amounts:

**Wetting Agents** - Improve flow and insure intimate contact between the investment and the model.

**Defoaming Agents** - Minimize the development of bubbles in the mix.

**Reducing Agents** - Added to reduce surface oxidation on the castings.

**Fibers** - Improve structural properties.

Each of these materials will be considered in more detail. When heated to about 190° C, hydrated calcium sulphate \(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}\) dehydrates to form the hemihydrate \(2\text{CaSO}_4 \cdot \text{H}_2\text{O}\). The hemihydrate is referred to as plaster of paris or gypsum. This is a reversible reaction. When mixed with water, the hemihydrate reverts back to its original composition. During this reaction a mass of interlocking crystals is formed. On a
chemical basis, about 18% water (by weight) would be needed to complete the reaction. However, excess water is added to prevent cracking and to insure that the reaction proceeds to completion. The excess water is evaporated during the burnout. Two factors strongly influence the rate of the reaction between the water and gypsum:

- Proportions Of Water
- Temperature

Manufacturers generally recommend that variation in the amount of water be limited to ± 5%. Less water will shorten the setting time and more water will extend it. The ± 5% change in water content will typically change the setting time by ± 30 - 45 seconds. Increasing the water content will also cause a thinner mix.

Increasing temperature can significantly shorten investment setting time. Hold the shop and water temperature constant. If you experience seasonal temperature variations in your studio, it may be necessary to adjust your investment cycle.

Other variables also influence the rate of reaction. A key factor is the amount of moisture which is absorbed by the investment during storage (partial rehydration). An obvious source is the moisture in the air. If the investment is stored in an open container it will react with water in the air and deteriorate. This can cause several problems. In the worst case the investment
will harden and form lumps. However, a number of more subtle changes occur before the investment solidifies. The primary concern is the change in working time of the investment. Moisture absorption will increase investment work time and decrease final strength.

Two forms of silica are used in many contemporary investments. A number of minerals exist which have a common chemical structure but exist in two or more physical forms. This characteristic is known as polymorphism. For example, carbon can exist as graphite or diamond. There are several polymorphous forms of silica. Two of these may be used in investment materials. The first is ordinary quartz and the second is cristobalite. Both have the same chemical form, SiO₂, but they have dramatically different physical properties. The specific property of interest is thermal expansion. By using a proper proportion of the two forms of silica, it is possible to tailor the thermal expansion properties of the investment.

Figure 1 illustrates the thermal expansion properties of two investments. One is based entirely on quartz (80%) and calcium sulphate (20%). The other is a mixture of quartz, calcium sulphate and cristobalite. The chart indicates that the cristobalite based investment will expand about 1.2% as it is heated from room temperature to 300° C. In the same range, the quartz investment will expand approximately 0.05%. You will notice that the expansion curve of the cristobalite
investment has a very sharp break. This corresponds to the silica inversion point at 232° C (450° F). At about 300° C, the investment stops expanding to any significant degree. This sudden change in expansion properties causes cracking if the investment is cooled below the inversion point.

Typical alloys of gold, copper, and silver all contract roughly the same amount as the investment when cooling from solidification to room temperature. This means that the investment expands enough to compensate for the contraction of the metal during cooling. Older literature often suggests the use of compensation for contraction. In many cases, the descriptions deal with materials which did not incorporate cristobalite. Modern cristobalite investments need very little or no compensation for expansion. Figures 2 and 3 will help put this in perspective. The ring model and the test bars were fabricated from acrylic plastic. This allowed precise measurement. Both parts were invested, cast and remeasured. The photographs and subsequent measurement show that very little contraction occurred. The test bars contracted 0.71% and 0.86%. After sanding (400 grit) and polishing, the ring was essentially the same size as the model.

Many apparent cases of shrinkage are actually caused by poor measurement. Most waxes are flexible. A ring model may stretch as much as a size during measurement and it's easy to build a wax bezel with a snap fit. The cast metal is not
flexible and what appears to be a case of shrinkage is simply poor measurement. Note that masters for wax injection do require compensation due to wax shrinkage during the injection process.

The physical strength of the investment is obviously important. During solidification an interlocking matrix of crystals forms around the filler material. The final physical strength of the investment is affected by the proportion of ingredients, storage conditions and the method of mixing the investment. The physical strength of the investment may be significantly decreased by improper handling. The importance of physical strength may not be obvious. There is a relatively wide margin for safety in the process. Cases of catastrophic failure are rare. However, more subtle factors may be at work. Diminished strength of the investment may cause decreased quality of the surface as the material spalls or is eroded during the metal fill. Any loose material ends up somewhere in the casting. Poor strength can also generate fins or webs on the casting. The fact that the investment survives the casting process does not mean that it developed its full strength or was properly applied.

A study of the investment application process immediately discloses two basic problems. First, the literature seems to be inconsistent. Second, actual shop practice varies widely. Many casting operations produce excellent results with procedures
at variance with the manufacturer's directions. The principle problem with the literature is straightforward. It accumulated over a period of years and materials have changed. Almost invariably, no reference is made to specific investment material. Is it calcium sulphate based or phosphate based? Does it contain cristobalite? Even the brand is seldom mentioned. This means that the literature is filled with references to different materials with different working properties. It should come as no surprise that any specific recommendations are difficult to apply.

Variations in contemporary practice can be understood in terms of specific applications. The investment process is flexible. Within certain parameters you can modify the process to fit your own shop situation. The following information will allow you to tailor your shop procedures to insure consistent results in your own studio.

Two basic system properties must be considered.

- Viscosity
- Work Time

The viscosity of the system is the physical property which changes most dramatically during the investment process. Viscosity relates to the flow properties of a slurry or solution. Honey is more viscous than water. This property of the system is important when suspended solids are present.
Particulate matter will settle quickly in a low viscosity system and more slowly from a high viscosity system. The formulation of the investment itself is influenced by these characteristics. The investment must be thin enough to flow into every detail of the master model. On the other hand, it must be thick enough to suspend the particulate fillers in the system. Settling of the suspended solids is one of the key causes of casting defects.

The viscosity of the investment mix changes almost constantly during the time between mixing and setting. If you measure this viscosity change, the requirements of the investment process become clearer. The top portion of Figure 4 illustrates the viscosity properties of an investment mix. The system starts out with a low viscosity which increases dramatically at the setting time. The rapid rise in viscosity is a very significant characteristic. It establishes the amount of time available to complete the investment process. This is known as the work time.

The moment that the investment and the water are combined, a chemical reaction begins. This reaction continues for an hour or more after the solidification of the investment. Many of the changes (such as viscosity) can only be measured under laboratory conditions. However, there is one characteristic of the investment mix which is easy to observe. This is referred to as the "gloss off". In essence, the gloss off is the transition from a slurry to a semi-solid.
I would recommend that you observe this phenomenon in your own studio. Following the manufacturer's instructions, prepare a small batch of investment and pour it into an open container. Place the container under a bright light. Time the mix from the moment the water and investment are combined (the investment is added to the water). When the materials are mixed, they have a wet, glossy appearance. After 9 - 13 minutes you will see a change. In less than a minute the appearance will change from wet and glossy to flat and dull. The investment has lost its gloss. Note the time when you can first observe this change. This is referred to as the gloss off time. This time period is very important in developing an investing cycle. If you refer to Figure 4 you will note that gloss off corresponds to the sudden viscosity increase. Obviously the investing process must be completed at some point in time before gloss off begins. All handling of the investment must be completed about 1½ minutes before gloss off. The period of 1½ minutes before gloss off is referred to as the setting time. The beginning of the setting time is called the work time. Work time is the amount of time available for processing.

With this information, a specific investing cycle can be established. Several elements must be considered. First, the chemical reaction between the water and calcium sulphate is influenced by mixing. The optimum properties of the investment are developed when mixing is continued for at least 3 minutes. The second element relates to the nature of the slurry. It is
a combination of water and solids. If the investment is poured too soon the solids will settle out. When this occurs serious surface defects will be encountered. The optimum properties will be achieved when the material is thoroughly mixed and the pouring of the investment is done as close to the gloss off time as practical.

It should be noted that the gloss off time in investments with other chemical bases (such as phosphate investment) are more difficult to measure. In these cases you must rely on the manufacturer's directions. Other investment systems may also be more sensitive to ambient conditions and/or exposure to moisture in the air. Calcium sulphate investment is more forgiving than most of the other materials available.

There are four key operations which must be accomplished during the investment process. These must be integrated into an appropriate time schedule.

. Mixing
. Initial Vacuum
. Pouring
. Second Vacuum

**Mixing** - A minimum mixing time of 3 minutes is required to develop the optimum physical properties of the investment. Shorter times may cause decreases in physical strength and attendant surface defects, break-out, or webbing. Mixing may be performed with a spatulator, commercial mixer or by hand.
An ordinary kitchen whisk works well for hand mixing.

**Initial Vacuum** - Although spatulation and vibration may be used to replace the vacuum, the vacuum cycle is preferred. Depending on the size and capacity of your equipment, the vacuum cycle requires about 60 seconds. Roughly 45 - 50 seconds are required to fully evacuate the chamber. At this point the investment will rise significantly. About 4 - 5 seconds after the rise, the investment will collapse and the character of the bubbling will change. About 10 additional seconds of vacuuming should be applied. Over vacuuming may cause very small spherical nodules to form on the casting. No additional benefit is achieved by continuing to vacuum more than 10 seconds after the collapse.

**Pouring** - Pouring a group of flasks usually required about 60 seconds. Some shops pour in two steps. First a partial fill and second, a top off after vacuuming. This allows the investment to rise in the flask without overflowing. In my experience, topping off is probably not the best procedure. It extends the cycle and sometimes comes too late. The head space at the end of the flask may not be sufficient for investment rise, even when the investment barely covers the model. The use of a rubber or masking tape collar is preferred.

**Second Vacuum** - The second vacuuming step requires an additional 60 seconds. You will note that the rise of the investment on the second vacuum cycle will be much less than the rise during the
first vacuuming.

If you add up the times involved, you will find that some excess time is available.

- Mixing: 3 Minutes
- Initial Vacuum: 1 Minute
- Pouring: 1 Minute
- Second Vacuum: 6 Minutes

Since a typical work time is in the range of 9 minutes there are several alternate uses for this extra time. You may set the investment aside during this period. If you allow the investment to stand it will be necessary to mix it briefly before pouring since the ingredients will tend to separate. Alternately you may continue to mix the investment until you have consumed the available time. In the case of power mixing in industrial processes, this is the common procedure. Extended mixing times (within the work time) do not materially affect investment characteristics. In rare cases, it may still be useful to paint the investment onto the surface of the model. This should only be considered when there are very deep, sharp recesses in the surface texture or when no vacuum is available. Some literature suggests that the model should be painted with investment (sometimes thinned investment) and then sprinkled with dry investment powder before the procedure continues. There is little reason to use this technique with contemporary materials and processes.
The open time available allows for other adjustments to the cycle. For example, the investment can be mixed with heated water to shorten the work time in high volume production. Other modifications can also be made if they are applied consistently and if they do not interfere with the basic working properties of the materials. By applying the glost off time to your own requirements an individualized investment cycle can be developed.

The investment process cannot be treated as an independent operation. The design of the model, spruing, pre-treatment of the model surface, post-treatment after setting and burnout may have a dramatic influence on the result. Some other specifics are important. Surfactants or wetting agents improve the contact between the investment and the waxy surface. Commercial materials are available in two basic types. Those which are formulated for use with vacuum systems and those for use with non-vacuum systems. There is another factor which is beginning to influence surfactant application. Many casters attempt to improve their results by adding additional wetting agents to the investment. A combination of too many wetting agents will actually be less effective. As time goes on it is likely that there will be more wetting agents incorporated in the investment material and less emphasis on treating the model. If you wish to add surfactants to the investment, experiment carefully. Another factor may cause problems. Waxes cast in silicone rubber molds are very hydrophobic and are more subject to defects caused by poor wetting.
The reaction between the gypsum and water continues for an extended period of time after setting. During this period the investment continues to cure and gain strength. Introduction of the flask into the furnace stops the reaction. If heating is started too soon it will result in a significantly weaker mold. Small flasks should cure for at least 2 hours and a cure time of 4 - 6 hours should be used for larger flasks. After the reaction is complete, any excess moisture will evaporate. There is no inherent problem with room temperature storage of the flask for an extended period of time. However, the flask should be remoistened before burnout. The sprue former should be removed prior to rewetting so that the water will flush away any particles of investment which break loose when the sprue former is removed.

The basic objective of the burnout cycle is to remove the model from the cavity and then eliminate any carbon residue from the pores of the investment. The second objective is to bring the flask to temperature without undue stress. This means a slow temperature rise. Since the investment is an insulating material the rate of rise must be controlled. One problem with the fiber insulated furnaces is the fact that they have a very high rate of temperature rise. They must be monitored carefully to avoid cracking the investment. The calcium sulphate begins to break down at about 730°C or 1350°F. This breakdown may degrade the surface of the mold cavity and/or release decomposition products. These products contain sulfur which reacts with the alloys present.
If a brief pickling does not remove the discoloration, acid treatment or abrasion may be required. Since the torch flame may play into the sprue opening, this effect is sometimes localized in the sprues or sections of the work directly adjacent to the sprues.

Most metal workers recognize the inherent dangers of molten metal and a spinning casting arm. However, there are some less obvious dangers in the process. A 10 inch bell jar has a surface area of approximately 1,000 square inches. This means that when it is evacuated there is a total pressure of over 14,000 pounds on its surface. An implosion caused by a defective or damaged bell jar can be very dangerous. The typical investment materials contain as much as 80% silica. Long term inhalation of the dust can lead to a lung disease known as silicosis. Good hygiene is very important. Keep your work area clean. If you are working in a casting shop or involved with handling of bulk investment you should wear a suitable dust mask.

In my opinion, asbestos is the most serious health threat in the casting operation. Most of the references to asbestos for flask or crucible liners were written before this hazard was fully understood. I would strongly recommend that you not use any asbestos in your shop. The use of asbestos as a flask liner was often associated with early dental investments which had a high setting expansion. No liner is necessary for most contemporary jewelry investment. If you feel that a liner
is necessary, Kerr Manufacturing and others offer asbestos substitutes. The use of asbestos crucible liners was recommended to promote metal purity and preserve the crucible. Proper fluxing of the crucible is sufficient. However, you may experience flux buildup to the point where flux is carried into the mold cavity. This generally causes small, bright crystalline porosity on the casting surface. Proper sprue arrangement will generally minimize or eliminate this problem.

Before presenting specific troubleshooting suggestions there are some fundamental rules which you should always follow.

. When in doubt, read and follow directions. If you have no better information, follow the manufacturer's instructions faithfully.

. Weigh and measure the ingredients carefully.

. Develop an investing cycle which takes advantage of the full working time of the investment.

. No matter what cycle or process you select, be consistent.

Many casting defects may be caused by more than one problem. The preparation of the model, the use and application of the investment, burnout, metal alloy and melting, can all have an impact on quality. However, to the extent that the investment relates to the visible defects in the casting the following should be considered.

Channeling - The channeling (watermarks) defect which is illustrated in the photograph can be caused by too much water
in the investment, pouring too early in the investment cycle, or excess vibration during handling. Pattern size, shape and orientation in the flask may also contribute.

**Fins** - Finning or webbing can be caused by several factors. Improper investment proportions, rapid temperature rise in the burnout oven and/or cycling the mold below the cristobalite inversion point all tend to cause webbing. Placing the flask in the oven too soon or abusive handling may also cause fins.

**Gross Nodules** - Large, irregularly shaped nodules on the casting usually means you have waited too long in the investment cycle to pour the material. The investment viscosity is so high that significant amounts of air are trapped, forming large cavities.

**Spherical Nodules** - The majority of spherical nodules are caused by incomplete air removal from the investment. The solution is proper vacuuming and/or spatulation and vibration during the investment process. Very small nodules may occur if the material is vacuumed for too long. Failure to use an appropriate wetting agent may also be the problem. If your equipment lacks a reliable vacuum gauge, you may check the vacuum level by placing a tumbler of room temperature water in the chamber. It should come to a boil about 1 to 1½ minutes after the vacuum pump is started.

**Poor Surface Texture** - Poor surface texture can be caused by a wide range of factors. The excess use of wetting agents (they should be allowed to dry) improper burnout cycle, excessive
water in the investment or reactions between the model material and the investment may degrade the surface. This last problem usually occurs with certain kinds of plastics. Natural organic materials cause poor surface texture if they absorb water. Improper model design, spruing, short cure time and rapid temperature rise may all cause surface defects.

**Surface Discoloration** - Overheating the investment will free sulfur compounds which react with the metal surface and may be very difficult to remove. Overheating also contributes to poor texture.

The quality of an investment casting is influenced by every step, from the original design sketch to final buffing. In the case of production items cast from injected waxes, a modest level of reject castings are not a serious problem. However, failures are extremely frustrating if you produce one of a kind objects. In this case, all of the labor invested in model construction is lost if a casting fails. A clear understanding of investment properties and application can significantly decrease the risk of casting failure. Extra care will produce results which more than justify the extra effort.

I would like to thank the Kerr Manufacturing Company for the help and advice provided in the preparation of this article.
DEBUBBLIZER

Fundamentally the debubblizer is a wetting agent which allows the investment to make intimate contact with the Model. If you spill water on a freshly waxed tile floor it tends to form small beads. If the tile is freshly washed with strong detergent the water will form a smooth uniform film. The detergent allows the water to come into complete contact with the tile. The various wetting agents act on the same way. There are at least a dozen commercial debubblizers for investment casting. These are available in bulk as well as aerosol and mechanical spray cans. You can also make your own with a 50 - 50 mixture of tincture of green soap and hydrogen peroxide. The commercial products are so inexpensive that I never bother to make my own. However, I don't use any of the sprays as these seem to be a waste. The are more expensive per ounce of product and 95% of what you use doesn't get on the work. You will find that different brands work differently on difficult kinds of wax or plastic. For this reason I keep several different types around and I always check carefully to be sure that whatever I use forms a good film.

Although some people prefer to dip the model in the debubblizer I usually paint it on with a soft artists brush. It's less messy and you don't end up with a dirty beaker. I usually apply the compound liberally and let it stand while I put a liner in the flask and get organized. Before the model is invested all excess investment must be removed. This can be accomplished by blowing the excess material off. Failure to remove the extra dububblizer can result in poor surface texture in the final casting. If I have a piece of work where the surface texture is particularly important I apply the debubblizer, allow it to stand, rinse the work in water of approximately 70 F and allow it to dry before investing.
CASTING INVESTMENT

Although it might seem at first glance that the characteristics of casting investment should range through a very narrow band, there are sufficient differences among various formulations to provide for considerable latitude and also a good deal of personal preference. The fact that a particular caster swears by a given grade and brand of investment may simply mean that accidently or intentionally is well suited for his purpose. More likely, experience has made him familiar with the unique characteristics of the material, and give him the knowledge of how to apply it in the best way. One of the key areas of difference between various investment formulations is in the viscosity of the investment. From a practical viewpoint, two properties are probably being balanced. A very high viscosity would be desirable from the viewpoint that it would tend to eliminate or minimize channeling. That is, it would minimize the water separation during the investment process. On the other hand, a very low viscosity in that it would tend to minimize the presence of air bubbles in the system. It should at least in theory be far easier to remove air bubbles from the lowest possible viscosity mix. Obviously, any investment must be a compromise with regard to its properties. The precise point where that compromise is struck becomes in the final analysis a matter of personal judgement and familiarity.
VIBRATORY VERSUS VACUUM INVESTING

The essential requirement of the mixing process is to provide a smooth bubble-free mix which is in perfect surface contact with the surface of the model. This can be best accomplished with some mechanical assistance. Although it is possible to achieve high quality results entirely by hand, the use of vibratory or vacuum systems for investment insure the highest possible yield of quality castings. The use of these mechanical aids deskill the process and insure good results, even with little experience. For the commercial jeweler, the use of mechanical assistance in investing saves significant amounts of labor. In commercial casting considerable automation has occurred. However, this discussion will be limited to mechanical and simple vacuum systems as they are applied in individual shops and limited production situations.
VIBRATORY VS. VACUUM INVESTING

The process of mixing the investment and pouring it around the model is one which generates considerable divergence of opinion and far more mystery than is necessary. Given a clear understanding of the investment materials and access to modern equipment, there is no reason that any part of the investing process should be mysterious.

Historically, the lost-wax casting process predates the use of any kind of special mechanical equipment by thousands of years. It is obviously possible to achieve very high quality results with a minimum of equipment or machinery. However, the modern craftsman has at his disposal tools, equipment and materials which not only make the process fast, but insure a very high probability of success. The actual technical problem is fairly straightforward. The objective of the investment process is to achieve a strong mold which is faithful to the pattern being invested. Strength of the mold is faithful to the pattern being invested. Strength of the mold is largely a matter of the investment material; the proportions of water, and to a lesser degree, the way it is mixed.

The culprit in many cases is the presence of air bubbles. The bubbles become attached to the surface of the model and the holds or voids which they create show up as nodules on
the surface of the casting. There are three tools or techniques which can be used to minimize this problem:

1. Mechanical Spatulators
2. Vibrators
3. Vacuum Systems

**Mechanical Spatulators** - I have always been very surprised that the use of mechanical spatulators for investment preparation is not much more widespread among both professional and amateur craftsmen who produce small volumes of investment castings. The use of a hand spatulator provides one of the biggest increments of quality improvement for the price of any technique that can be used in investment casting. Combined with a vibratory system, spatulation can produce small castings of very high surface quality. Figure 3 shows a photograph of a Kerr spatulator. Basically, the system is a small rubber bowl, with a special lid containing a gear system crank and paddle.

I generally take the approach that spatulation and vibration need to be combined to achieve any consistent success. From this point forward in our discussions, when I talk of vibratory, I am assuming that the investment has been spatulated in a commercial spatulating machine.

The small size of most mechanical spatulators available to the jewelry hobbyist or individual craftsman, places a
limitation on the use of this technique. The spatulators available were developed in the dental field, where small castings are the norm rather than the exception. This means that any flask where the volume of much more than half a cup will present real problems of spatulation because the material will have to be spatulated in more than one lot.
VACUUM INVESTING

When a high quality, mechanical vacuum apparatus is used a high degree of vacuum is achieved. If an air aspirating system is used, a somewhat lower degree of vacuum is achieved. This difference can have an impact on the nature of the way the vacuum investing process operates and how it should be managed. First, let's consider the high vacuum approach.

After a preliminary mixing of two and one half minutes or more, the investment is placed in the vacuum chamber and the air evacuation begins. From the moment the pressure starts to fall, the air bubbles within the investment grow larger and larger. As they increase in size, they find their way to the surface of the investment and burst. Obviously, there will still be very small bubbles which may remain even at this lower pressure. However, when the vacuum is released and pressure returns, they collapse. At very low pressures a second phenomenon takes over. A decrease in pressure lowers the boiling point of water. At some degree of vacuum, the water will boil at room temperature. This amount of vacuum is relatively each to achieve with most commercial investing machines.

It is rather hard to tell the difference between these two phenomenon, but if you observe closely during a vacuuming
process, you can see the change. When the investment is first introduced into the chamber, it looks rather like the rising of bread dough. This is the description almost always used in the literature and it seems appropriate. After the material rises to a certain point, it will suddenly collapse. Bubbles continue to rise to the surface but their characteristics change. Rather than rising and increasing the volume of the material, large, rather flatulent bubbles will burst on the surface. The closest analogy would be a mud flat in a volcanic region where the high viscosity mud boils slowly. This is precisely what is happening in the investment. At this point, the investment begins to splatter and spray onto the inside of the belljar. Boiling the investment will not achieve further improvement in the castings. As a practical matter, if boiling continues too long, you will actually remove necessary water from the system. The water will boil away, leaving the investment behind and changing the proportions of water in the system.

There are various rules of thumb about how to proceed. Generally speaking, the material needs to be vacuumed for only a very short period of time after the initial collapse of the bubbles. A common procedure is to increase the vacuum, allow the investment to rise and collapse, and then continue vacuuming for approximately ten more seconds. At this point, the vacuum can be released and you will achieve
all that is practical.

The water aspirating systems, which are occasionally used in the laboratory and craft type vacuum investing apparatus, operate on a completely different principle than the oil diffusion pumps in commercial equipment. The ejector in the aspirator works by the flow of water. In this case, it can achieve a vacuum no higher than the vapor pressure (boiling point) of the water used to operate the aspirator itself. In essence, that means that the aspirator will only create a vacuum down to that pressure where water would boil at the temperature it comes through the system. In the case of tap water, this may be in the range of 50 or 60°F. This is appreciably cooler than the water used in the investment (72°F.). It is at least theoretically possible, for a vacuum aspirating system to boil the water in a batch of investment. This will only happen in an extremely efficient, well-designed system. As a practical matter, the air aspirating systems take considerably longer to evacuate the vacuum chamber. For this reason, the chamber should be as small as practical for the application. However, these systems are usable where water is available and sufficient time (labor) can be provided.
INVESTMENT

The directions for measuring casting investment usually specify that the investment powder and water be measured by weight or that the investment be weighed and the water measured in a graduated cylinder. The water really presents no problem. If your jewelry supply shop doesn't carry a graduated cylinder almost any photo shop will. The ones sold to the photo hobbieits are plastic and more or less unbreakable. For most jewelry work the 50 millimeter size is just right. Measuring the investment is an altogether different problem. A suitably precise scale of the right capacity is not cheap. Worse yet, handling the dry investment is an awful mess. I gave up on the weight method years ago. All that's really needed is a consistent, reproducible method of measurement. In my shop I use a kitchen type 1/3 cup measuring cup. I fill the cup heaping full and tap the outside a half dozen raps with a spatula. Then I smooth it perfectly even with a straight edge. When I try a new brand of investment I weigh three 1/3 cups and average the weight. Next I calculate the proper amount of water.

The shelf life of investment can be a problem. Since it hardens by reacting with water it will react with any water it comes in contact with. That includes moisture in the air. This can be a particular problem anywhere there is high humidity. A midwestern basement in the summer can be a particular problem. Always store your investment in a vapor proof container and keep it well sealed.
FLASKS

The flask is needed to contain the investment slurry and to provide a higher degree of structural strength to the mold. This simply means that with any given size model, the mold can be smaller since it is contained within the steel ring. This containing force prevents the model from bursting out or cracking the investment. If the investment is massive enough it is not necessary to have any flask. I have made small centrifugal castings that were invested in a paper cup so that at the end of burn out there was no flask at all. I wouldn't recommend this but it proves the point. If the model is small relative to the volume of the investment, there is no particular reason other than structural reinforcement to have a flask. As a practical matter, some commercial casting is done with a cylinder of wire mesh, rather than a solid flask. In certain circumstances this can be solid steel flask. It is particularly attractive from an inventory cost viewpoint.

A discussion of the structural strength supplied by the flask leads to the general problem of structural strength and the position of the model within the flask. There are some rules of thumb which suggest that the model should never be closer than about a quarter of an inch from the surface of the investment or the flask wall. However, on a practical
basis the closeness of the model to the surface of the investment depends very strongly on the configuration and location of the model. Figure 26 illustrates the same shape located two different ways in the flask. Obviously, shape A, with a large flat surface near the surface would put much more strain on the investment than shape B where the only pressure near the pressure is located at a small point. The configuration of the investment material has a dramatic effect on its structure strength and, therefore, a significant effect on how close the model can be placed on the surface of the investment. The same general principles can be applied to how closely the model can approach the walls of the flask. If a large area is in close proximity to the wall of the flask, it is very possible for the material to break down and fall away from the wall. However, if only a tiny point projects very close to the wall I've seen successful castings where the model was within 1/16 of an inch of the flask. If the model approaches too closely to the surface, there is one other potential difficulty and that is the change in temperature or difference in temperature through different parts of the mold. If the mold is buried deep in the investment, all areas will remain at nearly the same temperature when it is removed from the furnace. However, since the mold loses heat from the surface, if the model is very close in one area, this portion of the model may tend
to cool more quickly and therefore chill prematurely. Again, if it is a small point, this usually doesn't present a significant problem.

One reason I'm dwelling on the issue of the configuration of the mold within the flask is that there are a number of practical reasons to use the smallest practical flask. This benefits the caster in several ways. First of all it simply is less expensive since less investment is used. The model is closer to the surface of the mold and air can travel more easily. Also heat transfer is faster resulting in a shorter burnout. A larger piece of work can be done with any particular sized machine. This is a benefit since machines generally increase in cost as their capacity goes up. The most pervasive reason is the fact that it is usually simpler to get a high quality, bubble free investment mix (particularly without a vacuum) in a smaller batch of investment. This means that for the amateur the quality of the surface of the casting is almost always inversely proportional to the size of the flask used. Large flasks may lead to lower quality.
INVESTMENT

There are two principle elements of control which the investment manufacturer can apply to the dimensional control problem.

. Setting Expansion
. Thermal Expansion

The addition of colloidal silica to phosphate based investments can be used to modify the setting expansion of these materials. Since the colloidal silica tends to solidify with time, there is a move toward eliminating this material from the system.
VACUUM INVESTING

When an industrial quality vacuum apparatus is used to treat casting investment, a relatively high degree of vacuum is achieved. If an air aspirating system is used a somewhat lower degree of vacuum is achieved. This difference can have an impact on the nature of the way the vacuum investing process operates, and how it should be managed. First, let's consider the high vacuum approach.

The investment is placed in the vacuum chamber, and the air evacuation begins. From the moment the pressure starts to fall, the air bubbles within the investment grow larger and larger. As they increase in size, they find their way to the surface of the investment and burst. Obviously, there will still be very small bubbles, which may remain even at this lower pressure. However, when the vacuum is released, these collapse when the pressure returns. At very low pressures a second phenomenon takes over. A decrease in pressure lowers the boiling point of water. At some degree of vacuum, the water will boil at room temperature. This amount of vacuum is relatively easy to achieve with most commercial investing machines.

It's rather hard to tell the difference between these two phenomenon, but if you observe closely during a vacuuming process, you can see the change. When the investment is
first introduced into the chamber it oeks rather like the rising of bread dough. This is the description almost always used in the literature, and it seems appropriate. After the material rises to a certain point, it will suddenly collapse. Bubbles continue to rise to the surface, but their characteristics change. Rather than rising and increasing the volume of the material, large, rather flatulant bubbles will burst on the surface. The closest analogy would be a mud flat in a volcanic region where the high viscosity mud boils slowly. This is precisely what's happening in the investment. At this point the investment begins to splatter and spray onto the inside of the belljar. Boiling the investment will not achieve further improvement in the castings. As a practical matter, if boiling continues too long, you will actually remove necessary water from the system. The water will boil away, leaving the investment behind, and changing the proportions of water in the system.

There are various rules of thumb about how to proceed. Generally speaking, the material needs to be vacuumed for only a very short period of time after the initial collapse of the bubbles. A common procedure is to increase the vacuum, allow the investment to rise and collapse, and then continue vacuuming for approximately 10 more seconds. At this point, the vacuum can be released, and you will achieve all that's practical.
The water aspirating systems which are occasionally used in the laboratory and craft type vacuum investing apparatus operate on a completely different principle than the oil diffusion pumps in commercial equipment. The ejector in the aspirator works by the flow of water. In this case, it can achieve a vacuum no higher than the vapor pressure (boiling point) of the water used to operate the aspirator itself. In essence, that means that the aspirator will only create a vacuum down to that pressure, where water would boil at the temperature it comes through the system. In the case of tap water, this may be in the range of 50 or 60° F. This is appreciably cooler than the water used in the investment (72° F). It is at least theoretically possible for a vacuum aspirating system to boil the water in a batch of investment. This will only happen in an extremely efficient, well-designed system. As a practical matter, the air aspirating systems take considerably longer to evacuate the vacuum chamber. For this reason, the chamber should be as small as practical for the application. However, these systems are usable where water is available and sufficient time (labor) can be provided.
CASTING INVESTMENT MATERIAL

Commercial casting investments can be based on a number of different chemical reactions. The most common investments used in the jewelry manufacturing process are based on plaster or Gypsum. The reaction of water with the Gypsum creates a solid mass with reasonable structural integrity. In some cases, plain plaster can be used as a mold making material. However, truly adequate investment systems are somewhat more complex. The best way to understand the investment is in terms of its ingredients. The three basic ingredients in most common jewelry investment are:

Gypsum - the Gypsum or plaster provides the structural base of the investment.

Quartz - Powdered quartz (silica) serves as a cushion and a structural reinforcement in the investment material.

Cristobalite - This is another form of silica which is added to the investment to adjust its thermal expansion properties to closely match the shrinkage characteristics of the jewelry metals.

A number of additives are also blended with the investment to adjust its properties. These would include wedding agents, defoaming agents, and chemicals which adjust or control the setting time.
Reducing agents may also be added to minimize surface oxidation on the casting. A more detailed understanding of the ingredients and the way they function in the investment material, will help you understand how to use the material and how to take the maximum advantage of its properties.

**Gypsum** - Gypsum is a hydrated calcium sulphate. Gypsum dehydrates when it is heated to about 1,900°C. When it dehydrates it forms the hemihydrate. This hemihydrate is called Calcined Gypsum or Plaster of Paris.

When the Plaster of Paris is mixed with water the hemihydrate converts back to the original hydrated sulphate. This reaction causes it to harden into a solid mass of interlocking crystals. In theory, only about 18% water (by weight) would be required to cause this reaction. However, in practice considerable excess water is used to ensure that the reaction goes to completion and that the physical properties of the material are fully developed. Any excess water evaporates during storage or burnout.

The speed at which the reaction occurs is influenced by the amount of water present, the temperature of the mix, and the degree of agitation which occurs before the material sets up.

Another key influence on the reaction is the actual degree of hydration which exists in the calcine material. When the
material is dehydrated it immediately begins to try to rehydrate. One way this can occur is by reacting with moisture in the air. Thus, if the material is stored in an open container or comes in contact with water in any way it will begin to react immediately. This may not result in enough reaction to fully setup but it can significantly change the properties of the material. It is extremely important to store the investment in a moisture proof container and to use it up as quickly as possible. If the investment develops hard lumps during storage, do not attempt to break these up and use the material. Discard it and work with fresh material.

Quartz/Cristobalite - Many minerals occur which have a single chemical structure that exists in more than one physical structure or form. This characteristic is called polymorphism. Carbon can exist as both graphite and diamond. There are also several polymorphist forms of silica. Two of these are used in the investment process. The first is ordinary quartz and the second is cristobalite. They both have the same chemical structure. However, their physical properties are significantly different. The key difference in this application is there thermal expansion. By using the proper balance of the two forms of silica it is possible to adjust the thermal expansion property of the investment mixture.
The physical characteristics of the investment are directly related to the three principle ingredients and are also significantly influenced by the amount of water added, the actual handling of the investment during the cure process and the presence of additives.

The three principle characteristics of the final investment which are important to the goldsmith are:

- Coefficient of Thermal Expansion
- Physical Strength
- Permeability

Each of these characteristics warrants further discussion. Probably the thermal expansion properties of investment materials are the least well understood of these properties.

**Thermal Expansion Properties** - Jewelry textbooks usually provide some rule of thumb about making a jewelry casting model somewhat larger than the final ring is to be. Some books suggest that it be made as much as a full size larger than the final ring. In practice this is somewhat misleading. A proper understanding of the physical characteristics of the investments and the craftmetals will put this problem in better perspective.

As I have mentioned elsewhere the dental casting literature
has some of the best technical information on precious metal casting. There has been considerable research which has attempted to reconcile the physical properties of the investment and flask system to the final dimensions of the cast part. However, a general discussion of the expansion characteristics of the precious metal should serve to help you understand what occurs during the casting process.

Figure 26, illustrates the thermal expansion properties of two different investment casting materials (data courtesy of Kerr Manufacturing). One of the investments is made from a simple mixture of 20% plaster and 80% quartz powder. The other investment is based on a mixture of cristobalite. The differences between these two curves illustrate how effective this additive can be in changing the expansion properties of the investment. Fundamentally, the addition of cristobalite adjusts the thermal expansion properties of the investment to compensate for the shrinkage which occurs in the metal during the cooling process. Properly done this provides for very precise dimensional control of the casting. Since it's useful to have an understanding of the physical properties of the cast metals, a brief discussion of the expansion characteristics of these metals should help you relate this to the investment properties.
The expansion or contraction of solid materials is described or expressed as the COEFFICIENT OF Thermal Expansion. In scientific terms, this characteristic is measured in units per unit, per degree centigrade. The actual units supplied can be any measuring system since the coefficient represents a proportion and not an absolute change. If you look at the expansion characteristics of the investment you will see that it may be different at different temperatures. The same situation may prevail with metals. The coefficient of expansion at room temperature might be very different than it is at 1,000°F. However, for practical purpose the rate of expansion does not vary too much over the temperature range under consideration.

The three most common jewelry alloy constituents have the following coefficients of thermal expansion.

- Gold       13.2 x 10  
- Copper     14.09 x 10    
- Silver     17.04 x 10
The investment casting process can be used to cast large objects, such as sculpture. However, the cost of materials may inhibit experimentation with larger objects. Budget limitations may also limit application in a school situation. In less sensitive applications you can prepare your own investment. At the most basic level investment can be prepared by combining plaster and silica.

If you would like to make your own investment, simply blend 20%-25% of molding plaster with 75%-80% (by weight) of 200 mesh silica. The silica should be available through a ceramics supply house. The thermal expansion properties of your blend will probably be similar to the lower line of Figure 69. This means that there will be less control over metal dimensions. The investment calibration procedure can be used to determine the working properties of the blend. Gloss off time may vary significantly. Careful use of wetting agents on the model can compensate for the lack of surfactant in the investment.
INVESTMENT POSITIONING

By: Richard D. Austin

Fine jewelry design is often characterized by a very high degree of symmetry. Maintaining this symmetry can be a challenge during the fabrication complex soldered assemblies. In limited production it is not economical to prepare tooling or fixtures to hold or locate the parts during the joining process. An alternate method is to use investment to hold the parts in place during the soldering operation.

Let's begin by considering the materials available. Several suppliers sell special soldering investments. They seem to be characterized by shorter setting times and a coarser grade of fillers. All of the soldering investments I have tried work satisfactorily. There is some debate about whether regular casting investment is suitable. I've successfully used both materials. If you do a volume large enough to warrant the extra inventory I would suggest that you do use one of the special formulations. The project illustrated in this article assembled using commercial soldering investment.

For purposes of illustration I have chosen a very simple example. This is the assembly of a head and shank. They are quite large so you should be able to see the process in the photographs. See Figure I. Obviously, this method is even more useful with complex assemblies of small commercial components.
The basic concept of the process is very simple. The parts are assembled with wax. The assembly is embedded in investment, leaving the areas to be soldered exposed. There are an infinite variety of situations so you must approach each piece as an individual project. However, some generic comments are in order. If you are assembling very tight combinations of heads, you may need to block or control solder flow. Conventional shop practice would suggest an ochre paste to block the solder. However, the ochre tends to flow during the investment process and it invariably ends up on a joint. There is a better alternative. Solvent based typewriter correction fluids work very well. They are easy to control during application, they stay in place during investment and they provide excellent flow control. They should be used in any situation where there is the slightest possibility of solder flowing into the wrong location. Water based correction fluids work less well so stick with solvent systems. You should also remember that you can do the soldering in several steps. The investment is excellent for protecting solder joints which have already been completed.

**Instructions**

The following steps detail the investment soldering process for the assembly of a head and shank. Additional comments also suggest how the process can be applied to other situations.

1. **Assembly** - The basic objective is to assemble the components in their final arrangement using wax where the
solder joints will be located. Remember that wax must not completely cover the parts to be embedded. The metal must be able to "lock" into the investment. I find that Kerr Utility Wax works well for assembly. Figure II illustrates the joining of the two components.

2. **Embedment** - The work must be fixed into a container which will hold the liquid investment. I usually use the bottom portion of a plastic cup. Cut the cup off at an appropriate height and locate the work. It may be necessary to block up the work with bits of binding wire to allow enough thickness to develop a sturdy investment block. Figure III shows the ring in place in the cup. A small amount of investment is mixed and poured into the cup. A slight tapping will help level the investment. I must confess that I don't weigh the ingredients. This application seems to be less demanding and I haven't had any trouble to date. Figure IV shows the work with the investment in place.

3. **Preparation** - About an hour after the investment has set, I strip off the plastic cup and set the assembly aside for about 24 hours. This allows most of the excess water to evaporate from the investment. This wait is not necessary if you are going to pre-heat the assembly. The next step is to remove the wax. I generally warm the work and absorb as much wax as
possible with a cotton swab. If necessary you can com-
plete the clean up with wax solvent. Figure V illustrates
the work with the cup and the wax removed. At this point
there is some divergence of opinion about how to proceed.
Some craftsmen go directly to the soldering stage and
some pre-heat the investment before proceeding. I believe
that both views are correct. The choice depends on the
situation. Without pre-heating, the investment will still
contain considerable moisture. This moisture will exert
a strong cooling effect during the soldering process.
In some layouts this cooling may cause soldering problems.
This seems to be particularly true when soldering parts
of significantly different mass. In any event, a pre-
heating can't cause any problem and I like to be on the
safe side. I use an old toaster-oven to warm the work.
I usually place the investment in the oven for 15-20
minutes at about 250°F.

4. Soldering - Soldering is done while the assembly is hot.
When the joint is complete, break away the investment
and clean the work carefully before proceeding to the
second joint. If you want to be very cautious, you could
invest the work a second time. I simply completed the
second joint with a lower melting grade of solder.

If you are careful in how you use the wax to block out the
work, you can assemble very complex pieces with this technique.
Wax sheet can be used to support the assembly. One last
warning, because the wax is opaque, you can't see the actual contact points. The wax can bridge a gap of almost any size and you can end up with an open space. Keep the assembly tight and you will achieve a much better finish.
INVESTMENT FORMULATION

If your shop specializes in limited production or a wide variety of sizes of shapes and castings, you'll find yourself investing flasks of all sizes and proportions. Sometimes this makes the job of investment measuring a little more complicated. However, if you have enough discipline and organization all of this can be made a lot simpler and in the long run you can save quite a bit of time. One of the key things you can do is set up a system to allow you to measure or prepare the proper amount of investment for a mixed lot of casting flasks. The way to do this is to determine how much volume your casting investment will fill.

The easiest way to illustrate this is with an example of how I arrange the system in my own shop. This can easily be modified to fit whatever circumstances you use. A number of years ago I decided to go pretty much completely metric in all of the measurements which we use. However you can use pounds an ounces in the same general system.

The fist step was to determine what volume of investment could be filled by any given weight

Having determined that 1g. of investment would fill about 0.42 cubic centimeters of flask space, the next step was to
figure out a convenient system for working with the flasks. What I ended up doing was measuring all of my flasks and stamping them with a machine-a-stamp to indicate their capacity or volume. For example, a flask 3cm high and 8cm in diameter would have volume of \(1.5 \times 1.5 \times \pi \times 8\) \(\approx 56.5488\)cm. This flask would be stamped with the number 59. In the future, when I was lining up a roll of flasks I'd simply record all the volumes and multiply this times the amount of investment I need. Since the and the models themselves take up some of the volume you should end up with sufficient investment. However, I usually round this up if I found that I needed 475g. of investment; I would probably mix 500 knowing I'd rather throw a little away than come up short on a flask.
WETTING AGENTS

Investment casting directions usually call for the use of a debubblizer or wetting agent. The function of these materials is clearer if you consider the basic character of the surfaces of the material (wax or plastic). Generally speaking, materials can be divided into two major groups. Those that are hydrophilic and hydrophobic. The hydrophilic materials are materials that have an attraction or affinity for water and hydrophobic materials are those that tend to reject water.

The simplest way to think of this is to consider a newly waxed car. The painted, waxed metal is highly hydrophobic. That is, it rejects the water placed on it. The result of this is the beading which is associated with a good wax job. The water tends to break up into individual droplets which are relatively large in comparison to their diameter. Over a period of time the deterioration of the wax and the accumulation of various oxides and materials from the atmosphere tend to make the surface of the car more and more hydrophilic. Eventually, water places on the car will form a smooth film. Generally speaking, soapy compounds convert the surface from hydrophobic to hydrophilic. For example, a ceramic plate with a greasy film is highly hydrophobic. However, a strong detergent solution will remove the grease and make the surface hydrophilic. This is exactly the kind
of function that debubblers or wetting agents perform on
the wax model.

Almost all waxes are hydrophobic in nature. Although the
degree of hydrophobia varies widely, you may notice that
some waxes are much more difficult to wet out, even when you
use a wetting agent. If you use several different waxes on
a single model, you may notice that on some areas even the
wetting agent will tend to bead up while other parts coat
uniformly almost instantly.

Silicone rubber is extremely hydrophobic. When wax is cast in
silicone rubber molds, minute traces of the silicone are
transferred. These tend to make the wax even more hydrophobic
than usual.
THE INVESTMENT PROCESS

In the previous article, we discussed the physical behavior of the investment in terms of thermal expansion. Two other properties are important:

1. Physical Strength
2. Permeability

Although the precise measurement of these properties are not important to the caster, they can have a major impact on casting success.

Physical Strength - The physical strength of a casting investment is a function of the formation of an interlocking matrix of crystals. These crystals encase the silica granules in a manner exactly analogous to the aggregate in ordinary concrete. The final properties of the investment relate to the proportion of the ingredients, their quality, and the treatment they receive during mixing and the subsequent reaction. All of these factors will be discussed in more detail under the specific directions for the investing process. It is important to realize that the physical strength of the investment will be decreased by improper handling. It might appear that maintaining the strength is of relatively minor importance. If the investment is never stressed to its limit, a 50% strength improvement seems meaningless.
However, most casting failure does not occur by catastrophic destruction of the investment. Occasionally the back of a flask will blow out, but most casting failures are far more subtle. Decreased tensile and compressive strength of the investment can cause these failures. For example, if temperature cycling or model expansion stresses the surface of the mold, there may be surface damage to the investment, even though the stresses may not be great enough to cause total failure. Stress may also cause cracking, which shows up as fins or webs in the final casting. The investment mass may survive the casting process, and yet produce castings of poor quality. For these reasons, it is vitally important to achieve the optimum physical properties of the investment, even though they may not be required for the gross physical strength of the system.

Permeability - Permeability is the property of the material which allows air to escape from the mold cavity through the investment material. Permeability is a very fine scale porosity. Air can travel through pores much too fine for the metal. This is like holding mercury in a piece of cloth. Although the cloth is quite open, the surface tension in the mercury will keep it from flowing through. This is exactly analogous to what happens in the investment process. The porosity has to be fine enough to mold a smooth surface, and yet coarse enough to allow for easy and rapid flow of the air out of the mold. Permeability can be
influenced by a number of factors, but the prime influence is the burnout cycle. Having considered the material properties let's go on to the details of the casting process.

**General Directions - Some Rules**

I have always been frustrated by the directions for investing. They often seem ambiguous and talking to casters doesn't seem to shed much light on the process. People told me I should modify or adjust the process all kinds of ways. I should use warm water, cold water, mix it hard, mix it hardly at all, and so on. Even among those who obtained a very high quality of work, there was considerable variation in practice. I've since discovered that this is not inconsistent with the basic technology involved. There are four fundamental rules which should be applied to the investment process:

1. Follow The Manufacturer's Directions
2. Mix The Ingredients In Proper Proportions
3. Use The Full Working Time Of The Investment
4. Be Consistent

**Follow The Manufacturer's Directions** - There is a classic piece of advice which will serve you well. "When in doubt, read and follow the directions." This is all that would need to be said if the manufacturer's were to provide clear, unambiguous instructions with their products. However, many
products reach the user with no direction. This is a special problem when rock shops repackage investment.

In fairness to the manufacturer's, it is difficult to describe all of the system variables. Also, the bulk of these materials are sold into manufacturing operations where the technology is understood. Another source of information is the dealer who sells the product. However, in my experience, many dealers are misinformed and a lot of the products are sold by mail. I have found that most of the larger suppliers are quite helpful if you write and ask for specific directions for one of their products. Finally, I hope that this article will shed some light on the issue.

Mix The Ingredients In Proper Proportions — The investment mixing process is a chemical reaction just as surely as the chemical reactions we all remember from high school chemistry laboratory. Investment and water should be measured very carefully. Mixing investment by feel or eye is absolutely inappropriate and will usually lead to periodic if not consistent problems.

Use The Full Working Time Of The Investment — It is possible to change the investment working time. However, the investment process must use up the working time. Investing too soon is one of the principle mistakes which leads to poor detail or surface quality. In the extreme cases, it
leads to channeling (water marks), which can dramatically increase the clean up work on a casting, or make it completely useless.

Be Consistent – Whatever practices you develop, and however you choose to modify the investment process to suit your own requirements, consistency is the ultimate requirement. Without consistency, there will be no way to correct your faults or to even understand any difficulties which you encounter.

Investing Steps
The process of investing a model requires a number of steps.
These include:

1. Material Preparation
2. Measurement of Ingredients
3. Mixing and Debubblizing
4. Flask Fill
5. Debubblizing the Flask
6. Cure
7. Storage
8. Burnout

Each step contributes to the success of the casting process. Unfortunately, "Popular Wisdom" and literature references will suggest different "Best Ways" to perform each step. The best way to deal with these individual issues is to treat them in the context of the reaction which occurs when the water and investment are mixed together. The parameters of this reaction are expressed in terms of "Work Time".
Work Time - It always seems a little difficult to describe the work time of investment. Changes in the investment begin to occur immediately after the water is added to the powder. Although the reaction proceeds quickly, the appearance changes are subtle.

The setting time is established by working backward from what is called the frost or gloss-off time. If you observe a batch of investment carefully, after about ten to fifteen minutes there will be a sudden change in the surface appearance of the mix. The gloss-off time is the time when water begins to disappear from the investment surface. Gloss-off occurs one to two minutes after the "setting" time of the investment.

If the investment glosses off at eleven minutes, the setting time is about nine minutes. At the setting time the viscosity of the mix will increase rapidly. This means that the model must be imbedded and debubblized within nine minutes after the initial mixing period. The work time and setting time establish the boundaries or limits of the casting process. The work time of a typical jewelry investment is illustrated in Figure 2. The actual work time may vary widely.

Although the investment appears to set quite suddenly, the reaction process begins the moment the investment and water
combine, and it continues for some hours after setting. This is the reason it is difficult to "eyeball" the measurement of ingredients. The viscosity at the start of the mix will be different than at the time the investment is poured. With this basic concept in mind, let's examine the steps of the investment process.

1. Material Preparation - The first step is to treat the properly sprued model with the correct wetting agent. Wetting agents, or surfactants (surface active agents) may be introduced to the investment or applied to the wax.

There are two different types of wetting agents which are applied to the wax depending on whether the system is to be vacuumed or treated by vibratory methods. Usually, the wetting agent is applied to the wax and allowed to dry for fifteen to twenty minutes or more. It is important to follow the manufacturer's directions.

In modern investments various wetting agents are sometimes added to the investment material by the manufacturer. Many professional casters also add wetting agents to their investment mixes. This increasing use of surfactants creates a potential problem. Many surfactants function better in combination. For example, two different surfactants combined, may be more portent than either one individually. A third material may further improve the properties.
However, as more and more materials are combined, the system may begin to be less effective. If you're encountering difficulties in surface quality or texture, a good place to begin is to remove all the surfactants from your system. Next, experiment by returning them one at a time. Since many modern investments contain wetting agents, it is possible to get perfectly adequate castings with no wetting agents applied to the wax.

It should also be noted that surfactants are often tailored or specialized to particular applications. The fact that a particular additive works for a kind of wax or a particular manufacturing situation does not mean that it represents the universal solution to casting problems.

The water used to mix the investment also needs some preparation. You may have noticed that if you run cold water from the tap, small bubbles will form on the inside of the glass. The change in pressure releases the air trapped in the water. Also, the cold tap water is considerably below room temperature. Investment should be mixed with water which has been allowed to sit at room temperature for a few hours.

2. Measurement of Ingredients - My preference is to measure the investment by weight and the water by volume. However, since some individual craftsmen and small shops are
reluctant to invest in a scale, I will describe a system for measuring investment by volume. If you are going to measure investment by volume, the key is to be absolutely consistent. The following method will allow you to achieve a reasonable level of reproducibility.

A set of ordinary kitchen measuring cups are a good size for this application. In order to calibrate the system you will need access to an accurate scale. A range of 0-400 grams would be about right if one cup is the largest size you will be measuring.

When you receive a barrel of investment, it will have been handled and vibrated until it is very hard and compact. The first step is to loosen up the investment. Use a spatula or scoop to turn over the top portion of the investment until it will pour freely.

Calibration begins by weighing each measure while it is clean and empty. This weight (the tare weight) should be recorded. Next, each cup is weighed full of investment powder. Begin by filling the cup to overflowing, then settle it uniformly. A good way to do this is to tap the cup three or four times. Finally, using a straight edge, slice off the investment absolutely level. Weight the cup and the investment and subtract the weight of the cup to determine the weight of the contents. Repeat this procedure
four to six times for each container.

You will note that there are small variations in the weight of investment measured. Average all the weights for each cup and use this for your standard investment weight. When you return to your own shop, you follow the identical procedure and assume that the weight is that which you've calibrated. You will find that a one-third to one-half cup measure of investment is an excellent unit of measure for the small Kerr spatulator.

It is important to remember that if you change brands or types of investment, the system must be calibrated for each new material. It is a good idea to recheck your system from time to time just to make sure you are consistent. Although this is not the best way to proceed, it is certainly more accurate than any "eyeball" system for measuring the investment.

The problems of a limited production shop or the individual artist/craftsman may be somewhat specialized. For example, a commercial shop may cast a very large number of flasks of a given size but they may use a limited number of sizes. I've visited commercial shops that do the vast majority of their casting in only two or three sizes of flasks. At last count I had about 50 different flask sizes in my studio. This creates a good deal of confusion in measuring up the
investment, balancing the casting equipment and so on. A few simple measures can help organize the situation.

I always work with investment on a cubic centimeter basis. I have established that one cubic centimeter of mixed investment requires about 1.4 grams of dry investment power (Kerr Satin Cast 20). You can check this yourself by taking a known quantity of the investment which you use (by weight), adding the appropriate amount of water, mixing it, and pouring it in a graduated cylinder. Measure the volume and then rinse it out before it sets up. Once you have this measurement, you can calculate how much investment to weigh out by calculating the volume of the flask.

If you are a little rusty on your high school math, remember that the volume of a cylinder is its area times its height. To calculate the volume of a flask begin by measuring the inside diameter and height of the flask (I always work in centimeters). Then

\[
\text{Volume} = 3.1416 \times \frac{\text{diameter}}{2} \times \frac{\text{diameter}}{2} \times \text{height}
\]

If you work in centimeters your answer will come out in cubic centimeters. For example, if your flask were 5 centimeters in diameter and 40 centimeters high

\[
\text{Volume} = 3.1416 \times 2.5 \times 2.5 \times 40 = 785\text{cc}
\]
To mix investment for this flask I would begin with at least 785 x 1.4 = 1099 grams of investment. In order to avoid recalculating, I have stamped the appropriate volume on the flasks in my shop. I usually round the numbers upward. In our example case, I would probably mark the flask as 790cc.

3. Mixing and Debubblizing - Although the investment process can be accomplished entirely by manual means, there are three pieces of equipment which are commonly used to improve productivity or quality.

   1. Spatulators
   2. Vibrators
   3. Vacuum Systems

Before discussing their application, let me describe them individually.

**Spatulators** - A spatulator is a mixing device which uses a wiping motion to blend the investment. This action minimizes air entrapment and removes bubbles introduced during initial mixing. Large commercial spatulators are available for production work. For the individual craftsman, the most practical spatulators are the small, hand-cranked devices developed for the dental industry. In the jewelry trade, the only one which is widely available is sold by Kerr Manufacturing Company. This is illustrated in
Figure 3. This product currently has a suggested list price of about $64. I would consider it a good investment in quality casting for any shop which does not have vacuum equipment. It should be recognized that this product was developed for small batches of investment, and it has inherent limitations.

This spatulator has a bowl which will hold about 160 cubic centimeters of investment. It becomes much less efficient (at bubble removal) as it is filled to the top. From a practical viewpoint, you can only spatulate about 100 cubic centimeters of investment at a time. In spite of its small size, this spatulator, combined with a vibrator can provide excellent results on small investment batches. I have successfully cast several thousand pieces of jewelry using the vibrator/spatulator system. However, the small hand spatulator is not suitable for large flasks or production casting.

Vibrators - A vibrator can be used to debubblize the mix, or help to flow the investment around the wax model. There are a number of vibrators available commercially. One of these is illustrated in Figure 4. It is useful if the vibrator has several intensity settings. However, for a small shop this is not an absolute requirement. A number of makeshift systems can also be used to vibrate the investment.
Vacuum Systems - For larger individual flasks, or production work, there is no substitute for a vacuum system. Vacuum debubbling will help ensure high quality and productivity. There are a number of commercial vacuum systems available. The Kerr machine which I use is illustrated in Figure 5. The smaller vacuum systems are relatively simple, consisting of a bell jar mounted on some kind of a table, which is connected to a vacuum pump. Various kinds of valving and metering are included to operate the system.

In any system, you need a way to determine if you have sufficient vacuum. The quickest way to tell is to put a small dish of room temperature water under the bell jar. Decrease the pressure, and see if the vacuum will boil the water at room temperature. If the vacuum system will boil water, you have sufficient vacuum for investment purposes. A good quality commercial vacuum pump should bring room temperature water to a boil in about 30-40 seconds.

If you want to build your own system, laboratory supply houses sell vacuum pumps. Using one of these pumps, it is possible to put together your own vacuum system. However, you won't save much unless you can pick up a used pump.

Although it is safe to experiment with building your own vacuum systems, you should never use a makeshift bell jar or
vacuum chamber. The bell jar and baseplate must be of top quality and structurally able to support the air pressure present on the outside when the chamber is brought to a full vacuum. Do not use makeshift or homemade vacuum chambers. Purchase good quality parts from a reputable laboratory supplier. The specifics of the vacuum process will be discussed as a part of the investment sequence.

Mixing - When the proper amounts of investment and water have been measured, and the model has been sprued and treated with a wetting agent, the next step is mixing. The measured water should be placed in the mixing bowl and the investment added slowly with constant stirring. If you are going to use a vacuum system to debubble the investment, the bowl used should have a volume of about two and one-half times that of the investment mix to allow for the "rise" of the mix.

When the ingredients are combined, the clock begins to run. You have about nine minutes to complete the process.

If you are going to use a spatulator for mixing, the material should be vibrated for 15-20 seconds before mixing. If you are going to use the vacuum, simply proceed with the mix. Mixing should continue for two and one-half minutes more. If you mix by hand, use a steady, smooth motion which does not whip air into the investment mix. An ordinary
cooking wisk, such as the one illustrated in Figure 6, will help provide a smooth, consistent mix. Continue mixing for at least two and one-half minutes. This mixing time is necessary to ensure the maximum structural strength of the investment. Proper mixing can significantly increase the structural strength of the investment. This helps minimize casting defects or blowouts during the casting process. Whatever mixing procedure you choose to use, apply it consistently for the same length of time to every investment batch.

The speed of the vacuuming process relates to the nature of the equipment, the size and number of castings and so on. However, the process usually proceeds quickly. Once the bell jar is in place, and the vacuum is turned on, it takes approximately 30 seconds for the investment to rise. This rising has been described as being rather like the rising of dough. It is characterized by the presence of a very large number of small bubbles. This rising process lasts for perhaps 10-15 seconds, then the investment will collapse back down. Vacuuming should proceed for approximately 10 more seconds after the collapse. This means that in my system, the vacuuming is completed in roughly 50 seconds. On the time diagram illustrated, I have provided 60 seconds for vacuuming. Generally speaking, the reaction is much more vigorous during the first vacuuming. This is because the bubbles introduced during the mixing process have not
been cleared. It is important to be sure that your mixing bowl is not too full. If there is considerable air present in the mix, it may expand as much as two and one-half times its original volume before it collapses. This means that 100 cubic centimeters of bowl at the height of investment would require 250 cubic centimeters of bowl at the height of the reaction. During the second vacuuming cycle the rise will be much less.

If you observe the system carefully, you will note that the action of the investment changes after the collapse. When the investment is rising and initially breaking down, there is a pattern of a very large number of small bubbles. These are caused by the expansion of air bubbles within the system. After the collapse they become much less numerous, and much larger. The investment tends to splatter and the reaction becomes very vigorous. At this point, you are simply boiling the water out of the investment and no further benefit is achieved by continuing the process. The 10 seconds after collapse is sufficient for bubble removal.

When the investmented flask is placed in the vacuum chamber it will expand as much as 25% when the air pressure is removed. Obviously, if the flask is full it will overflow during this time. A common practice is to partly fill the flask. After vacuuming the flask is "topped off" by adding enough additional investment to fill the flask. I've never
been a particular fan of this approach. I think the less handling at this point, the better. For this reason I either use a rubber sleeve to extend the flask or simply use a masking tape collar. This collar is put in place before the investment is added so that the material can be brought to the top of the flask and the expansion will be contained within the collar during vacuuming.

4. Flask Fill – As in so many other parts of the investment process, both the literature and individual shop practice vary widely. There are suggestions that you begin by dipping the model in investment before it is put in the flask, that you fill the flask with investment and then place the model, and so on. However, the majority of practices fall into one of two basic methods. For most volume production, the flask is filled by pouring the investment down the side so that it runs down the wall and fills the space from the bottom upward. This tends to push all of the air out of any small cracks or crevices ahead of the rising investment. This may or may not be done while the flask is being vibrated. In any event, the flask can be filled quickly by this method.

The alternate is to use some method to introduce the investment to the fine detail of the model before the bulk of the material is poured around it. In cases where there is a very high degree of surface detail which can trap small
air bubbles, painting the model with investment may improve casting quality. When I have a finely detailed model, I usually take a small artist's brush and very carefully paint the model, trying very carefully to force the investment to the bottom of all of the surface texture. The investment can be painted on and blown or shaken with a vibrator until you feel that you have perfectly covered the surface. I will even examine the surface with a binocular magnifier to be sure that it is fully wetted before proceeding. After this treatment, the actual investment process can proceed by pouring investment down the side of the flask until it is full.

If I feel that there is excess wetting agent, or I've been experiencing any kind of surface texture problems which I feel the wetting agent may be causing, there is another technique that seems to help. The model is placed in the flask, but before the investment is added to fill the cavity, a teaspoon or two of investment is poured over the model while the flask is being vibrated. This is allowed to run completely off the surface of the model. All that should remain is a very light, thin film of watery investment. This seems to help wash off any excess wetting agents, and coat the surface with investment. After this step, I proceed by quickly filling the flask by the method described above.
5. Debubblizing the Flask - The debubblizing of the invested flask proceeds exactly as the debubblizing of the bowl of investment. However, you will notice a couple of significant differences. First of all, if you have successfully removed most of the bubbles from the investment mix, there will be far less rise at this stage. The investment may only rise a quarter of an inch or so before it collapses and begins to boil. As we stated previously, there is no advantage from continuing to boil the investment under vacuum. After the investment has risen and collapsed, ten seconds of additional vacuuming should be adequate.

There is one practice which I would like to point out here. Because the rise isn't too high, many casters simply fill the flask with investment about to the top of the model. This leaves a little head space for the investment to expand. After investing, they "top off" the flask. Generally speaking, this seems to me to be a rather marginal procedure. I think it is better (because you are working close to the end of the investment working time) to accomplish everything in one step. For this reason, I always use either rubber collars or masking tape to build up the flask to accommodate the expansion. This means that the investment simply rises into the flask or collar, collapses down, and no topping off is required.

6. Cure - Although the investment "sets" quite suddenly
after about 12 minutes, its properties are not fully developed. The strength during this early period when the investment is solid but not fully reacted is usually referred to as "green strength". The green strength of the investment can be very important to the caster. The green strength of the material grows over a number of hours or even days. If the investment is suddenly heated, it dries out and the moment the water is removed, the reaction stops as does the growth of the green strength. That fundamentally means that you can arrest the investment at some condition where it has not developed its full physical properties by heating it too soon. This can easily decrease strength by as much as 50%. Again, this can lead to a number of casting defects or problems. One common problem associated with insufficient curing time is webbing or finning from stress on the investment.

Most instructions indicate that the investment is quite fragile during the early period of its cure (say less than one hour). Although the investment is fragile, this may be somewhat overrated. One reads directions indicating that the investment should not even be moved during the first hour. In my own experience, it is perfectly safe to move the invested flasks after 5-10 minutes. Generally speaking, after 40 minutes no damage is encountered from removing the sprue former.
It is critical that the model develop a high strength level before burnout begins. Since there is some variation, depending on flask size, no hard rules can be given. However, even the smallest flask should cure for an hour and larger sizes should stand for 3-4 hours before burnout.

7. Storage - The treatment of cured, invested models is probably an area where practice varies more widely than any other technical consideration in casting. Generally speaking, the manufacturers of investment recommend that invested models be stored damp. If the molds are allowed to dry out, they are to be remoistened before they are put into the burnout oven. However, many commercial shops simply invest the models and allow them to dry for varying degrees of time from a few hours to days or weeks.

When you talk to a commercial caster, you learn that the reason they turn the models over quickly is they don't want to have a large inventory of flasks tied up. Once the model is put in the flask, they like to get it cast, and get the flask back into circulation as quickly as possible. This cost of the inventory of flasks has led to use screen wire reinforcing of the investment to avoid the flask inventory. This way, finished models can be carried through the investment process, and inventoried for long periods of time. They can be cast the moment an order is received, and the supplier can get very rapid turn-around time.
From a technical viewpoint, I never know quite how to respond to these various approaches. When people tell me that the investment may break down in storage, I'm reminded of the fact that I've seen houses with plastered walls well over a hundred years old. On the other hand, I've seen plastered walls that were a few weeks old that displayed various kinds of crystallization and faults. Obviously, when properly reacted and stored, the plaster need not undergo any significant deterioration over an extended period of time. On the other hand, why take a chance. One of the problems which I faced is that, the details of shop practice seem to influence this. I've done only limited experiments, but I've never been able to demonstrate a probably bad surface by investing the models, storing them for a week or two, and putting them in the oven dry.

Another reason suggested for not pre-wetting the models is that it takes more energy to dry the water out, which comes out as time and oven cost. If the models are completely dried out at room temperature, they can rise more quickly to heat. It is intriguing to note that this may be the reason for some of the alleged defects associated with dry loading. The lack of water means that thermal shock is put on the model as it is heated rapidly from room temperature. Certainly the presence of the water would generally insure that the model comes to a temperature of 212°F. all the way through its thickness before the outside could rise.
appreciably in temperature.

It is worth noting that most of the common sprue waxes and the non-polyethylene or non-synthetic waxes will be softened or actually melted at the boiling point of water. However, acrylic plastics in some of the polyethylene may only slightly soften at these temperatures and will remain in the mold cavity. In any event, the temperature hold which occurs within the flask during the water elimination phase should effectively remove most of the wax present.

8. Burnout – The burnout of the invested model is the last step before the actual casting process. The parameters of the burnout cycle are limited by the physical nature of the investment and the requirement to remove all traces of the carbon residue from the pores of the invested mold.

The investment process is time/temperature dependent. That is, the burnout of the carbon occurs more rapidly at a higher temperature. This means that a high temperature burnout accomplishes the same result in less time. The fundamental limitation of the process is the calcium sulphate. At a temperature of about 1350°F, the investment binder begins to break down. This can cause poor surface texture and the sulfur compounds which it liberates can react with the metal being cast.
The elimination of the wax or model takes places in two stages. As the investment temperature rises, the wax melts and a portion of it runs out of the sprue opening. However, a major portion of the melted wax is absorbed directly into the investment material. As the temperature continues to rise, the wax residue is carbonized within the investment pores. Although the mold cavity is actually empty very early in the cycle, the flask is not ready for casting.

There is a possibility that residues in the cavity may react with the molten metal but the major problem is the fact that the carbon in the pores will prevent the air from leaving the mold cavity and interfere with the mold filling process.

The high temperature portion of the burnout eliminates the carbon residue. At the higher temperatures, the carbon reacts directly with oxygen in the air to form carbon monoxide and/or carbon dioxide. These are both gasses that find their way out of the mold. For this reaction to proceed, there must be some air available for the reaction. When a very large number of models are being burned out at one time, it is useful to leave the oven door ajar, or an open vent in the oven during the early portion of burnout to provide some oxygen to burn up the carbon.

Although the investment is a very sturdy material, sudden changes in temperature can cause shock or cracking.
Generally speaking, the flask should be introduced to the oven at a temperature of 300°F or less. The temperature rise from the initial starting temperature to 1000° should proceed over a minimum time of one hour.

As a practical matter, the burnout of most materials, including the majority of plastics, can be accomplished at 1000°F if sufficient time is allowed. For this reason, unless you have a very large load, about all that is really required is to cycle small flasks to about 1200 or 1300°F and immediately let them drift back down to the casting temperature. Larger flasks require a longer time to come to temperature. For this reason, on small flasks, it may be just as well to allow them to burnout at 1000°F, so that only slight or no temperature adjustment is required at the end of the cycle. In any event, you should not cast into flasks which are operating at maximum burnout temperature.

There is another key area which causes some difficulty. These are the problems associated with cooling the mold to too low a temperature for whatever reason. For example, if you wish to cast investment castings of pewter, you need to bring the mold back down to nearly room temperature. Alternately, if you should have an electrical failure during burnout, the molds may cool before they are cast. In any event, if the molds are cooled below about 400°, the sudden changes in dimension are very likely to crack the molds.
and/or create a bad surface texture. Although I occasionally do pewter castings by cooling investment molds to room temperature (I've even discussed this in various articles), it is not a particularly good technique and I wouldn't recommend it as a general practice.

**Defects**

One of the supreme frustrations of the casting process is the fact that it is not always possible to assign a cause to the defect you are encountering. I sat down one day and listed at least ten causes for casting porosity. Many of these, such as gas entrapment, turbulence, improper spruing, and flux impurities have little to do with the investment process. However, some investing defects can appear in this same general class of porosity. For example, an improper mix may weaken the investment and small pieces of material will come loose under the pressure of the casting metal. These bits of investment can be embedded almost anywhere in the casting and are rather difficult to tell from other kinds of porosity.

However, most of the specific defects which you can associate with the investment process are ones which I would
call "surface imperfections". There are three classes of
defects which are common in the casting process. These are:

1. Surface Nodules
2. Channeling
3. Poor Surface Texture

Each of these may present a different appearance in
different situations but they're all so common as to seem
the universal plagues of the caster.

1. Surface Nodules - There are two common types of nodules.
The most common are small, spherical nodules which are
attached to the surface of a casting. These are most likely
to appear in corners or in recesses in the texture. Their
cause and cure is fairly simple. These are air bubbles
which attach themselves to the surface of the model. The
source of these air bubbles is improper debubbling of the
mix, or careless filling of the flask. If you use a vacuum
system and bring the material to a full vacuum, this
particular kind of defect should be very rare. In
spatulator/vibratory investment systems, it is far more
common. In the latter case, the spruing arrangement and
the angle of the model in the flask may also contribute
significantly to the problem. It is vitally important for
the model to be set up so that rising bubbles don't get
trapped anywhere in the system. With the manual systems,
the use of investment painting will tend to minimize this
problem. This is particularly true with deeply textured surfaces. Texture traps the bubbles. They can be broken down before the flask is filled.

I rarely see gross nodules but occasionally, someone will wait a little too long to fill the flask, and the investment is too thick to flow into the surface detail of the model. Usually you can tell when this is happening and stop the investment process before the flask is filled. It is a lot easier to junk a batch of investment than it is a batch of castings.

2. Channeling - I probably see more channeling than any other problem of surface texture. It is particularly apparent in large, flat objects such as belt buckles and medallions. Channeling is caused by the flow pattern of the settling investment and rising water which can occur if the investment is mixed with too much water, is over-vibrated, or poured too soon. I recently conducted an experiment to see if I could create some channeling. Figure 9 is the back of a medallion which was invested with an investment mix using about 10 percent too much water, poured after about five minutes, and vibrated extensively. If you want to know what channeling looks like, this is it. The riverbed type pattern which grows more severe toward the top (away from the sprue) is a classic example of the channeling effect. Channeling may be so mild that you have to examine the work
with a loop to see it. It is corrected by using the proper proportion of water to investment, by using the full work time, and by minimizing vibration.

3. Poor Surface Texture - Surface defects can be as much of a puzzle as casting porosity. Like porosity, they can occur from a broad range of causes. Some of these are not necessarily related to the investment process itself. For example, overheating during burnout and reactions between model making material and the mold may deteriorate the surface. Cooling of the flask below the 400° break point in the expansion curve can deteriorate texture since it tends to spall off the surface of the cavity. Investment related causes may be the storage and rewetting of the model before burnout, the rate of burnout, the proportions of the investment materials, and excess wetting agents. If you find yourself producing castings with consistently bad texture, your best hope is to be extremely consistent and modify one or more variable of the system, one at a time, until you learn what is wrong.

There is one additional type of surface defect that should be considered. Various kinds of surface discoloration may appear on the casting.
Metal Discoloration - A certain amount of surface discoloration is normal with sterling silver and the karat golds used in jewelry. However, if the discoloration persists after a normal pickle you may have one of several problems. Residue in the mold may be the culprit. This residue can be carbon from the wax which would be the result of incomplete burnout or it could be caused by imcombustable material in the pattern. For example, some plastics have fillers or pigments which won't burn away. A second possible cause is overheating of the mold. The calcium sulfate in the investment begins to break down at around 1350°F. and the decomposition products will tend to discolor the metal.

You will sometimes experience discoloration of the casting just opposite the sprue. This is most common when the sprue is short and large. This seems to be the result of the contact of the hot gases from the torch flame being directed into the sprue opening. This is minimized by melting the metal before placing the flask in the cradle.

If there is no detail in the discolored area the color can usually be ground out and polishing can proceed. Some references recommend boiling in nitric acid pickle or repeated heating in air followed by cooling in air and sulfuric acid pickle. Frankly, I would not recommend nitric acid or sulfuric acid pickle for the average shop. If you
WETTING AGENTS

Investment casting directions usually call for the use of a debubblizer or wetting agent. The function of these materials is clearer if you consider the basic character of the surfaces of the material (wax or plastic). Generally speaking, materials can be divided into two major groups. Those that are hydrophilic and hydrophobic. The hydrophilic materials are materials that have an attraction or affinity for water and hydrophobic materials are those that tend to reject water.

The simplest way to think of this is to consider a newly waxed car. The painted, waxed metal is highly hydrophobic. That is, it rejects the water placed on it. The result of this is the beading which is associated with a good wax job. The water tends to break up into individual droplets which are relatively high in comparison to their diameter. Over a period of time the deterioration of the wax and the accumulation of various oxides and materials from the atmosphere tend to make the surface of the car more and more hydrophilic. Eventually, water places on the car will form a smooth film. Generally speaking, soapy compounds convert the surface from hydrophobic to hydrophilic. For example, a ceramic plate with a greasy film is highly hydrophobic. However, a strong detergent solution will remove the grease and make the surface hydrophilic. This is exactly the kind
of function that debubblizers or wetting agents perform on
the wax model.

Almost all waxes are hydrophobic in nature. Although the
degree of hydrophobia varies widely, you may notice that
some waxes are much more difficult to wet out, even when you
use a wetting agent. If you use several different waxes on
a single model, you may notice that on some areas even the
wetting agent will tend to bead up while other parts coat
uniformly almost instantly.

Silicone rubber is extremely hydrophic. When wax is cast in
silicone rubber molds, minute traces of the silicone are
transferred. These tend to make the wax even more hydrophic
than usual.
INVESTING LARGE OBJECTS

If you stay with the craft metal work long enough you are going to want to try a large project. In addition to the problems of your basic equipment capacity and flask measurement there can be some real difficulty just in mixing a large batch of investment. If you are using the spatulation and vibration technique described earlier you may feel particularly limited. However, you will find that the setting process of the investment is slow enough to allow the investment to be mixed and poured in a series of pours. All that is really required is a little organization.

Begin by calculating the volume of your flask. Measure the inside diameter and height of the flask. Although I find it easier to use metric measurements inches will also work. The formula for the volume is $3.14 \times \text{radius}^2 \times \text{height} = \text{volume}$. 

For Example:

For a 20mm diameter
the radius = $\frac{20}{2} = 10$

\[ \begin{array}{c}
\text{20mm} \\
\hline
\text{35mm}
\end{array} \]

This means that the volume equals 3.14 times 10 times 10 times 35 or the volume equals 3.14 times 100 times 35 or 3.14 times 3500 or 10,990 cubic millimeters.

If a single batch of investment makes 6,000 cubic millimeters then you would need two batches to fill the flask. I've made a number of castings that required 8 - 12 batches of investment. Begin by calculating the number of batches of investment that you are going to need. Then spread out the same number of sheets of tablet or newspaper and measure a batch of investment powder on each sheet.
You can also measure out the same number of small paper cups of water. When you are ready mix and pour the first batch. Without bothering to clean the tools you can just keep mixing subsequent batches as quickly as you can. If your mixing gear get really messy you can stop and wash after every fourth or fifth batch. Just keep going -\* until the flask is full.
FLASKS

The flask has a relatively simple role in the investment casting process. During investing, it simply provides a container for the liquid investment until it can solidify. In the actual burnout and casting process, it provides structural strength to reinforce or support the relatively fragile mold. In theory, you could dispense with the flask completely. Occasionally, I have someone invest a project in a paper cup. During burnout, the paper cup is destroyed and you have a block of investment to work with. I've successfully cast a number of these, although if you want to try this, you should use a considerably larger flask so there is a good mass of investment on all sides of the model. In any event, the flask is simply a device to reinforce or support the mold. In industrial practice the flask may be replaced by wire mesh.

We've discussed the thermal expansion properties of the investment materials extensively. Various materials have different expansion properties and this is certainly true of the stainless steel used in investment flasks. Since the stainless steel will expand or contract at a different rate than the investment undergoing temperature changes, this will tend to create certain stresses in the flask/mold system. Historically, the use of asbestos paper lining in the flasks was included to provide a certain cushioning
against the stresses which might be created. This tended to allow the investment to expand more freely and gave better dimensional control in all directions. Also, in theory the asbestos provided a more open channel for airflow toward the ends of the flask as the cavity fill.

In recent years, the health hazards associated with asbestos have essentially eliminated it from this process. There are certain synthetic materials provided by manufacturers such as Kerr which can be used to replace the asbestos flask liner. In my own practice, I simply invest the material directly onto the stainless flask. If you follow good dimensioning and process control processes, I've found that this gives you no difficulty with regard to dimensional tolerances, or airflow in the flask system. As an actual matter of practice, I simply stopped using asbestos in my shop one day and quite frankly, could detect no measurable difficulty as a result.

From time to time, I need special sizes or shapes of flasks which I don't have in my stock. In my experience, there are a number of perfectly adequate alternatives. For single use in large sizes, I've had moderately good success using tin cans as flasks. I've also used ordinary electrical conduit cut to various lengths. The tin cans only make it through burnout cycle, but I've used the ordinary steel flasks for as many as 100 burnouts. Perhaps the only caution when
using conduit is the fact that they are plated with various materials which may tend to burn off or vaporize. The first few burnouts should be made with very good ventilation, so you're not breathing any of the fumes from the plated metal. One of my students had access to a lot of copper tubing and tried using this for the flasks. Although the copper is very rust-proof at room temperature, it oxidizes very rapidly at high temperature. The copper flasks only survived a few burnout cycles. Plain, mild steel seems to survive much better. Also, if you have any access to any industrial grade steel tubing, this seems to work quite well. A trip to a refrigerator repair/maintenance shop may produce a number of odds and ends of metal tubing large enough for flasks.
INVESTMENT PROCEDURES

The overall objective is to complete the investment process at some point just before the gloss off time. The investment procedure should be completed and the flask set aside approximately 1½ minutes before gloss off. When you're able to establish a gloss off time for the system you can examine the other steps and define the total process. The following steps define the complete procedure:

. **Start** - Preliminary mixing the investment takes about 30 seconds to combine the two materials and smooth them out. I do not consider this part of my mixing time.

. **Mixing** - I've standardized on a 3 minute mixing cycle for all investment.

. **Vacuum** - At the completion of mixing the investment should be vacuumed if possible. This cycle normally takes 60 seconds.

. **Open** - Working backwards you'll find that you should have anywhere from 2 to 3 minutes of open time. You can continue to mix during this period or you can paint or dip you model.

. **Pour** - In my experience it takes another 60 seconds to pour a typical batch of flasks.
. **Vacuum** - The second vacuum cycle it performed after the flasks are poured.

. **Setting Time** - This is the initial period when the viscosity of the investment rises rapidly prior to gloss off.

. **Work Time** - The total time until the beginning of setting is the total work time available for preparing investment mix. In our example this is about 9½ minutes.

. **Gloss Off** - At the completion of the gloss off period the investment is a semi-solid.

The attached illustration indicates the general relationship between the viscosity of the investment mix and the various steps in the investment cycle. Notice that the second vacuum cycle is completed 30 to 60 seconds before the initial rapid rise in viscosity.

A few percent difference in the amount of water added to the mix can vary the cycle by as much as a minute. Changes in temperature, the age of the investment and other properties can further move the cycle forward or backward in times. This is the reason that it's important to be consistent and to measure the properties of each new batch of investment. If you use up your investment in a few weeks and store it properly, it's sufficient to calibrate each batch. However,
if you store your investment for some months it's a good idea to repeat the calibration process and be certain that nothing has changed.

There are several alternatives for this procedure. First the mixing can be extended for 2 to 3 minutes and it can replace the open time. In my own case, I usually use this open time to paint dip or specially prepare any of the models which have an extra amount of detail or texture. If you're using a vacuum process this is not necessary for simplier form smooth surfaces.
INVESTMENT VIBRATION

A commercial vibrator is a very useful tool. One purchased from a namebrand company should give many years of service. However, if you only do an occasional casting or you want to build your own equipment, there are several other ways to vibrate the work. On a couple of occasions when I didn't have a vibrator available, I have used a mechanical hammer on a flexible shaft machine to vibrate the flask. Be reasonably gentle. Use some care. The hammer can deliver a very hard blow. You can get a very mild vibration by touching the flask against the housing of an electric motor on a lapidary system. If the equipment is running true and the wheels are well dressed, there won't be too much vibration.

You can make a simple vibrator by buying an inexpensive, used electric motor of about one-quarter horsepower. A small concentric weight can be mounted on the shaft. A little experimentation is required but the weight need not be too large and it should be firmly mounted since it will tend to vibrate loose. The motor is mounted to the bottom of a piece of plywood suspended on a spring system. When the motor is turned on, the off center weight will vibrate the plywood and you will have an excellent vibratory platform. If any of you have vibratory tumblers or metal finishing units you can simply touch the flask against the housing of one of these
to provide the vibration. A vibrating lap system also works quite well. Remember that over vibration can lead to casting defects.
CALIBRATION OF INVESTMENT MIXING PROCEDURES

By: Richard D. Austin

Most casters know how to deal with gross investment defects such as bubbles. However, the subtle problems of low strength, poor surface quality and breakout may be more difficult to correct. Proper investment mixing procedures can yield a significant quality improvement in the casting process. Because details of shop practice and conditions vary, no universal procedure is completely satisfactory. This article will provide the information needed to develop a proper mixing cycle for your shop situation.

The material presented here is appropriate for calcium sulphate based jewelry casting investments. Most of these investments are based on combinations of calcium sulphate, silica, cristobalite and various additives. The calcium sulphate provides the reactive base which combines with water to harden the investment. The working time of a calcium sulphate based investment is a critical element in determining the proper investing cycle.

In order to achieve consistent results, all elements in the investing process must be kept in tight control. These include:

- Investment Storage
- Proportion Of Ingredients
. Temperature
. Mixing Time
. Mixing Cycle

I am assuming that the first four elements are in good control. All of this discussion will focus on the development of the Mixing Cycle.

Superficially, the application of the investment appears to be very straight forward. Mix some investment in water to form a slurry and about ten minutes later it becomes hard. Unfortunately, the situation is not that simple. The moment the materials are combined the water and the calcium sulphate begin to react. This reaction continues for an hour or more after the material appears to be hard. The properties of the slurry and the solid change constantly during this period. Most of the changes occur gradually and are difficult to measure. However, there is a key point which can be measured. This is called the "gloss off". The best way to understand gloss off is to observe it for yourself. Prepare a small batch of investment (perhaps a 1/3 of a cup) and process it through your existing mixing procedure. Note the time at the moment you combine the ingredients.

After about nine minutes, place the bowl under a bright light where you can see the surface clearly. You will note that the mix is glossy and wet looking. Somewhere around the tenth to
twelfth minute the appearance will suddenly change. Beginning at the edge, or perhaps around some small bubbles on the surface, the material will suddenly lose its gloss and begin to appear dry. Note the elapsed time. This is the gloss of time. The final vacuum step must be completed about 1½ minutes before gloss off. The time from initial mix to gloss off, less one and a half minutes is known as the work time.

Different investments, ambient conditions and mixing cycles will change the gloss off (and working times) significantly. Temperature and the proportions of water are two of the more significant variables. Increased amounts of water extend gloss off time and higher temperatures decrease the time.

For Kerr Satin Cast and Satin Cast 20 gloss off time will be around 10 or 11 minutes if you follow the manufacturers procedure. Variations are not critical as long as the procedure is consistent and you calibrate the process to take into account the actual time required for gloss off. Some industrial casters operate at an elevated temperature to shorten the investment cycle and save time. I wouldn't recommend this for most artist craftsman. It is vitally important that you control this system for absolute consistency.

It is obvious that a physical change in the investment takes place at gloss off. Gloss off time is used to calibrate the investment process.
Before considering specific details let's begin by reviewing the mixing cycle:

**Measurement** - Careful measurement is vital. Typically, the investment is measured by weight and the water by weight or volume. No matter how much experience you have, measurement "by eye" will not produce consistent results.

**Mixing** - Manufacturer's tests and experience indicate that the best investment properties are developed if the investment is mixed for a minimum of 2½ minutes. Times over three minutes do not continue to improve the properties but longer mixing doesn't cause any problems. Since the first 30 seconds of mixing are required to blend the ingredients I usually mix for 3 minutes from the time the water and investment are combined.

**Vacuum** - In my experience the vacuum cycle requires approximately 60 seconds. Yours may vary depending on the size of your equipment, the quality of your vacuum pump etc.

**Open** - At this point, mixing and vacuum treatment are complete but, as we shall see later it is too soon to begin pouring. In my experience there are usually 2 or 3 minutes where the investment can sit. This time can be used to paint or dip the models with investment. Mixing time may also be extended to use up this interval. Note that the investment will tend to settle during this period and a brief mixing is
required to bring up the solids before pouring.  

**Pouring** - Pouring a group of flasks usually requires about 60 seconds.

**Second Vacuum** - The second vacuuming requires an additional 60 seconds.

**Setting** - At this point in time, the viscosity begins to increase very rapidly. Although the investment is still a liquid it’s properties change rapidly during this period.

**Gloss Off** - The gloss off time occurs during the period when the viscosity of the investment mix reaches a very high level. At the end of the gloss off period the material is essentially a solid.

Viscosity is the key system property which changes at gloss off. Think of two fluids such as water and honey. The honey is more viscous. This means it flows more slowly. If fine solid material is mixed with honey and with water it will settle much more slowly in the honey. The formulation of an investment involves a compromise with regard to viscosity. The mix must be thin enough so that it will flow into the detail of the model and allow air bubbles to move out of the mix. On the other hand, it must be thick enough to hold the solid fillers in suspension. Settling of the fillers after the flask is poured is one of the key causes of poor casting quality. In extreme cases this shows up as a river like patterns of raised ridges (see attached photograph). This defect
is called channeling. A key objective of the mixing cycle is to minimize the time which the full flasks stand before setting.

The viscosity of an investment mix changes during the time between mixing and setting. This change is continuous, not instantaneous. The relationship between time and viscosity can help you to understand many properties of the investment. The top half of the attached graph illustrates the time/viscosity relationship for three investment mixes. One is a mix with standard amount of water, the second has about 2% less water and the third has about 2% extra water. Note that less water causes a higher viscosity and a shorter work time. More water decreases viscosity and extends working time. Also note that the ±2% water causes the gloss off time to vary for at least one minute.

The lower half of the graph illustrates a mixing cycle based on the standard mix. The work time is complete just before the rapid rise in viscosity. The short time period between pouring the flasks and the rapid viscosity rise minimizes channeling and associated defects. Obviously, there must be some margin in the system. Vacuuming after the effective work time will produce cavities in the mold and gross modular defects on the surface of the casting. At the other extreme, vacuuming at too low a viscosity will tend to produce small surface bubbles.
The investment process must balance all of these elements to achieve the optimum result. Working with these principles. Three basic steps will allow you to develop a specific mixing cycle for your own shop.

. Select an investment and establish a mixing procedure based on the manufacturer's directions. Pick an operating temperature, method of mixing etc.
. Measure the gloss off time for the system you have selected.
. Subtract 1½ minutes from the gloss off time to establish the work time. Balance the total cycle to include mix, vacuum, pour and second vacuum time.

Don't shortcut. The extra effort is well worth it.

I would like to express my appreciation to the Kerr Division of Sybron Corporation for their assistance in the preparation of this article.
FIBERS - Some investments have been reinforced with various kinds of temperature resistant fibrous material. Historically, the material may have been asbestos, however, contemporary reinforced investments have fillers which are safer. Generally speaking, the fiber reinforced investments would be associated with more massive castings or industrial applications.

Reducing Agents - Reducing Agents or anti-oxidents tend to produce a brighter finish on the castings. However, for most shop practices, the use of proper alloys, melting procedures, and pickling make the anti-oxidents unnecessary. However, they are useful in the preparation of castings of multi-metal composition. The reducing atmosphere tends to improve the bond between the various metals.

The investment manufacturer is confronted with adjusting the properties of the investment for a specific application. However, in practice, the manufacturer has no control over how the material is actually used. In practice, if the investment exceeds the minimum required structural strength and survives the burn-out cycle, one of the key considerations is the viscosity of the investment mix. Generally speaking, I think it's fair to say that commercial investments have a higher mix viscosity than investments intended for limited production operations. Although the materials are effectively interchangable the higher viscosity investments perform best when appropriate manufacturing techniques are used, particularly control time cycles, and vacuuming. Basically, the viscosity is a trade-off between providing a good flow and de-aeration which would come with low viscosity and the anti-settling properties of a higher viscosity. Within a narrow range you can adjust the viscosity of
your own investment by changing the amount of water present. However, it's important to understand that this also changes the setting time. If you wish to refine your system to a high degree, then you may use a lower amount of water on simple, larger castings, and use a greater amount of water in the mix for fine, detailed models.
INVESTMENT

Investment techniques tend to diverge depending on whether or not a vacuum investing approach is used. If you can possibly afford an investment system, use this approach. It will produce better results and perhaps even more important, it will produce consistent results. Millions of successful castings have been made without benefit of a vacuum and excellent quality of results can be achieved.
INVESTMENT

MIXING CALIBRATION

Dealing with gross investment defects such as modules is usually straightforward. However, the subtle problems of low strength, poor surface quality, and breakout may be more difficult to correct. Proper investment mixing procedures can yield a significant quality improvement in the casting process. Because details of shop practice, conditions and material vary, no universal procedure is completely satisfactory. The procedure described will allow you to develop a suitable mixing cycle for your shop. The procedure described is intended for calcium sulfate based, jewelry casting investments.

Supervicially, the procedure appears to be very straightforward. Mix some investment in water to form a slurry about 10 minutes later it becomes hard. Unfortunately, the situation is not that simple. The moment the materials are combined, the water and calcium sulphate begin to react. This reaction continues for an hour or more after the material appears to be hard. The properties of the slurry and the solid change constantly during this period. Most of the changes occur gradually and are difficult to measure.

In order to achieve consistent results, all elements in the investing process must be kept under close control. These include:

- Investment Storage
- Proportion of Ingredients
- Temperature
. Mixing Time
. Mixing Cycle
The following discussion will focus on the development of the Mixing Cycle.

The working time of the investment is a critical element in determining the proper investing cycle. How much time is available between the start of mixing and the completion of the investment cycle.

The key element in determining a proper investment cycle is the measurement of "gloss off" time. Stand gloss off is to observe it for yourself. Prepare a small batch of investment (perhaps 1/3 of a cup) and process it through your existing mixing procedure. Note the time at the moment you combine the ingredients.

After about nine minutes, place the bowl under a bright light where you can see the surface clearly. You will note that the mix is glossy and wet looking. Somewhere around the tenth to twelfth minute, the appearance will suddenly change. Beginning at the edge, or perhaps around some small bubbles on the surface, the material will suddenly lose its gloss and begin to appear dry. The work time of the investment is about 1 1/2 minutes less than the gloss off time. The investment process must be complete before the work time has elapsed.

Different investments, ambient conditions, and mixing cycles will change the gloss off (and working times) significantly. Temperature and the proportions of water are two of the
most important variables. Increased amounts of water extend the
gloss off time and higher temperatures decrease the time.

For Kerr Satin Cast and Satin Cast 20, gloss off time will be
around 10 or 11 minutes if you follow the manufacturer's
procedure. (pick up article test here).
Gloss off measurement is an excellent technique for monitoring your investment operation. If you live in an area where there are relatively wide swings in temperature in your studio you should consider measuring gloss off during the high and low points of the year. If you find changes (which can be in the range of 30 to 60 seconds in some situations) then you can make an appropriate adjustment in your procedure. It is also a good safety check to measure the gloss off of each new large batch of investments or when you place an older batch of investment into the system. In any case, when the investment has been stored for more than a couple of months, I would consider testing it before committing to any volume production.

There are a number of other things going on in the investment which may or may not have any significant impact on your application. Most investments exhibit some degree of expansion during solidification. In some cases, such as the phosphate investments used in the dental trade, colloidal silica is added in various proportions to adjust the expansion characteristics. To some extent the flask may act as a restraint to inhibit expansion during this period. This is the general justification for the use of flask liners. Generally speaking, most the investments used in the jewelry trade do not require this degree of cushioning. However, if you have a reason to use a very high expansion investment this may be appropriate.

Although it should have relatively little impact on the investment process, all investments exhibit some degree of temperature rise (exotherm) during solidification. You will probably notice a much
greater temperature rise in the phosphate based investments than you will in calcium sulphate based systems.

In many cases hollowing out the inside of a wax pattern presents more problems and may even consume more time than developing the outward form. In certain cases, this operation can be significantly shortened by the use of plastic inserts to rebuild the form after the hollowing is complete. In essence, the concept is to fully develop the outside form of the ring and then remove the material from both the outside and inside leaving only the basic skeleton of the form. The next step is to replace any opened, single compound curves with sheet plastic. This can be put in place quite crudely and built up with blue inlay wax. The inside of the curve should be radiused and wax solvent can be used to clean up at the end of the work. If you find that very crisp forms are important, it may be useful to make the model slightly undersized. The use of wax solvents may tend to radius some of the edges and soften the form. If the size is made undersized it can be reamed with an ordinary scraper to provide a nice crisp edge. This is done after of the polishing is complete.

Removing the last traces of the sprue connection and cleaning up any other defects, requires cutting away the material. Obviously if it's in an open flat area filing works very well. However, on the insides of rings and in less accessible areas, power mechanical means are the fastest. There are really two types of material which you can use. These are abrasive tools and cutting tools. As a matter of personal preference, I vastly prefer the cutting tools since they don't generate as much heat. If you're working
quickly and holding a ring blank in your hand while you grind from the inside, the temperature rise associated with grinding is quite uncomfortable and you may actually have to pause in the work. A sharp tungsten carbide burr will seldom generate enough heat to make this operation uncomfortable.