106-74 CROSS REFERENCE EXAMINER

March 15, 1960 C. H. WATTS 2,928,749

INVESTMENT MATERIAL FOR PRECISION CASTING

Filed Dec. 12, 1956 5 Sheets-Sheet 1

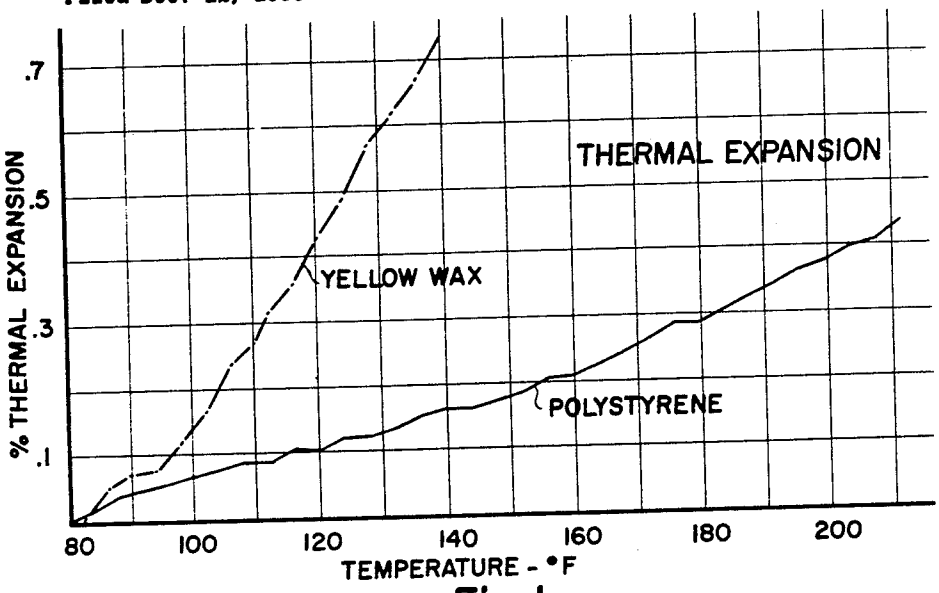


Fig. 1

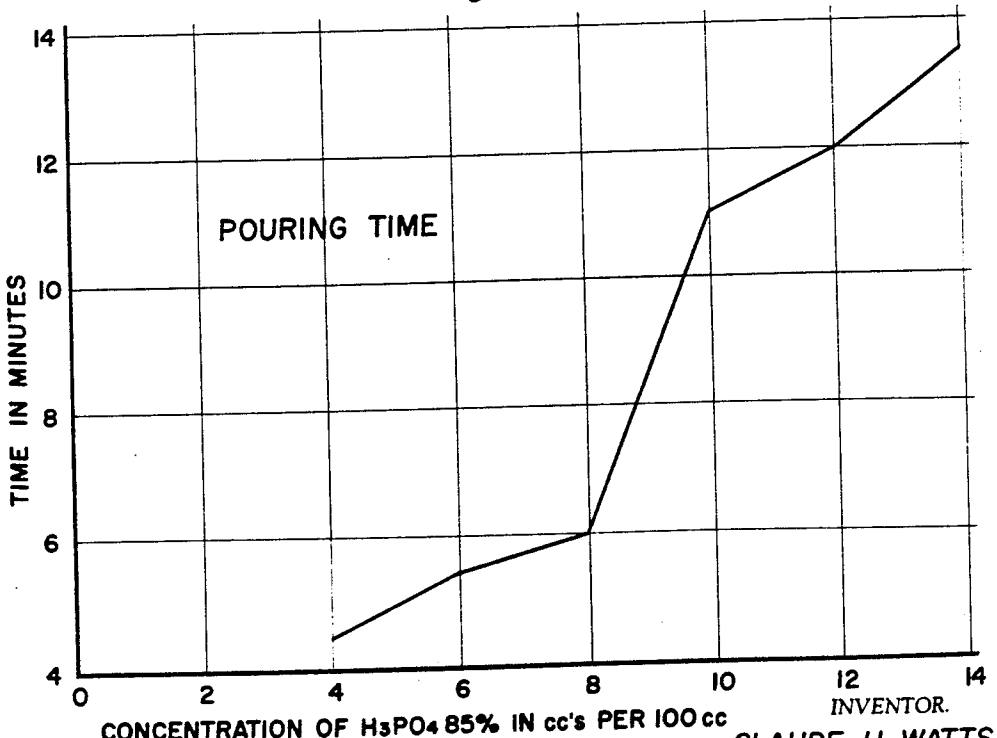


Fig. 2

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INVESTMENT MATERIAL FOR PRECISION CASTING

Filed Dec. 12, 1956 5 Sheets-Sheet 2

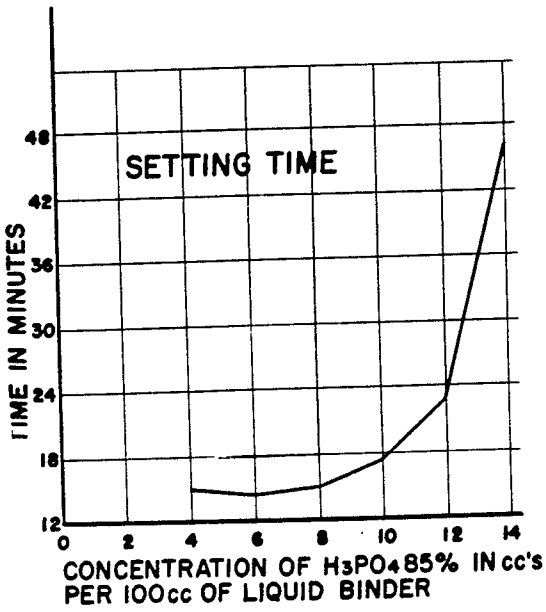


Fig. 3

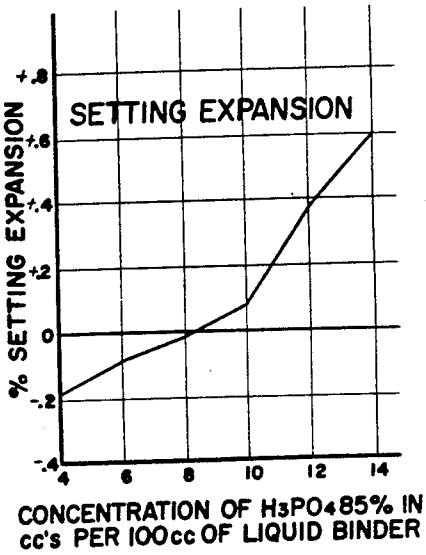


Fig. 4

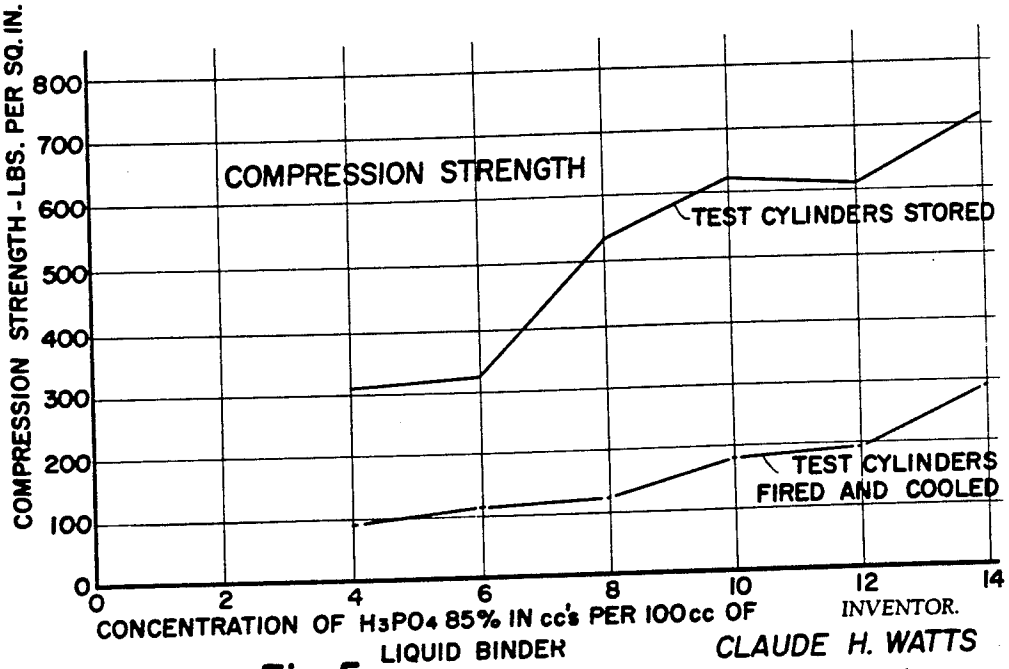


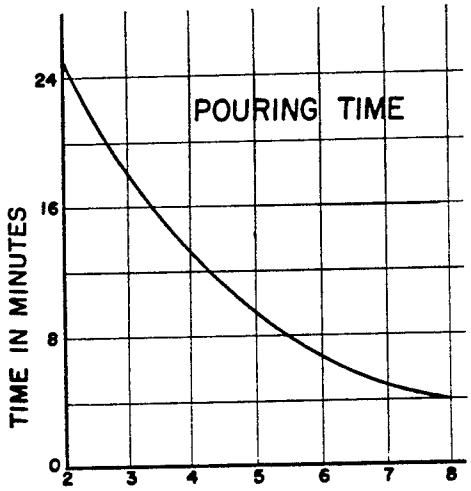
Fig. 5

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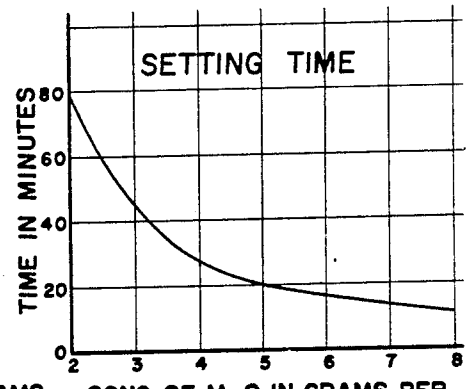
INVESTMENT MATERIAL FOR PRECISION CASTING

Filed Dec. 12, 1956 5 Sheets-Sheet 3



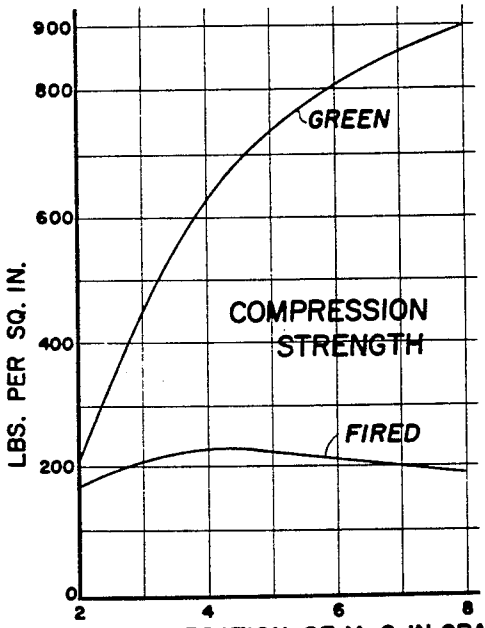
CONCENTRATION OF MAG. OXIDE IN GRAMS PER 100 G. OF INVESTMENT MATERIAL

Fig. 6



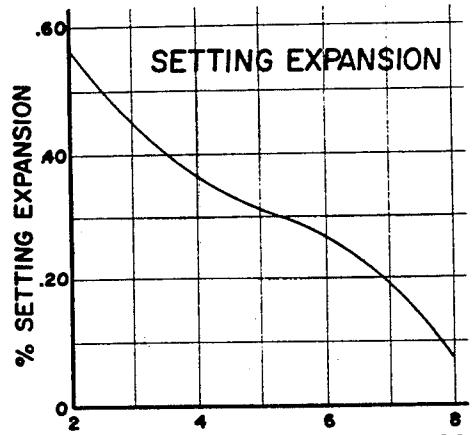
CONC. OF MgO IN GRAMS PER 100 G. OF INVESTMENT POWDER

Fig. 7



CONCENTRATION OF MgO IN GRAMS PER 100 G. OF INVESTMENT POWDER

Fig. 9



CONC. OF MgO IN GRAMS PER 100 G. OF INVESTMENT POWDER

Fig. 8

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INVESTMENT MATERIAL FOR PRECISION CASTING

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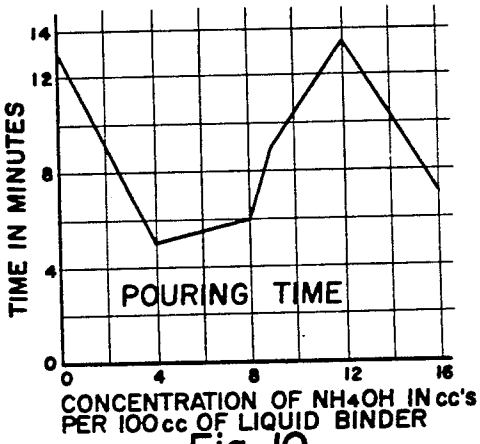


Fig. 10

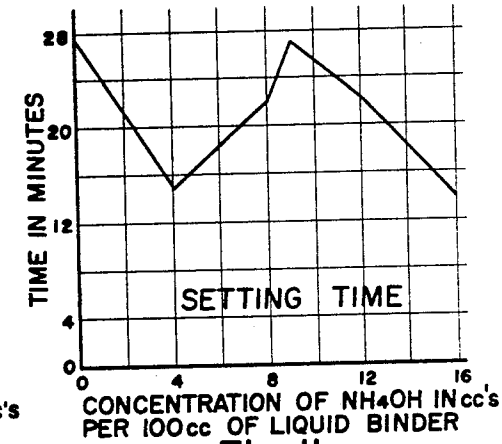


Fig. 11

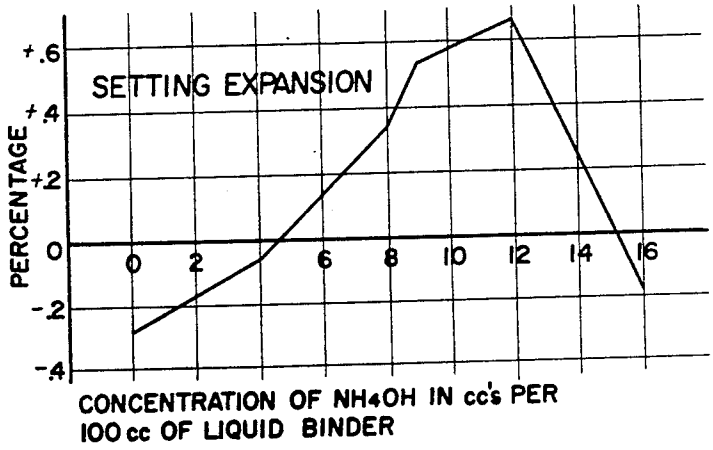


Fig. 12

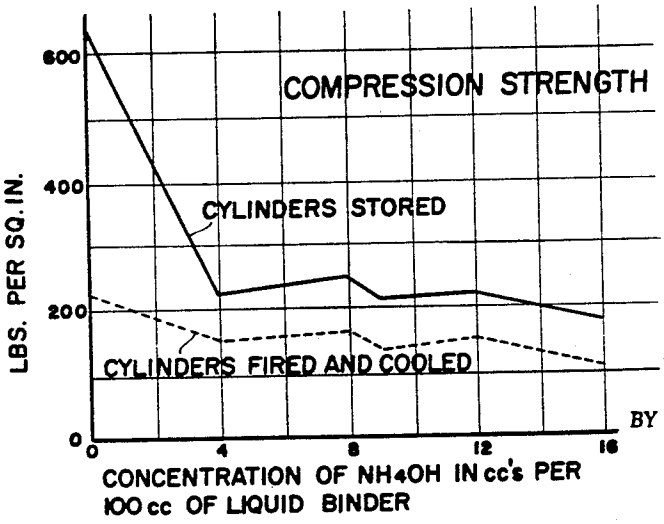


Fig. 13

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INVESTMENT MATERIAL FOR PRECISION CASTING

Filed Dec. 12, 1956 5 Sheets-Sheet 5

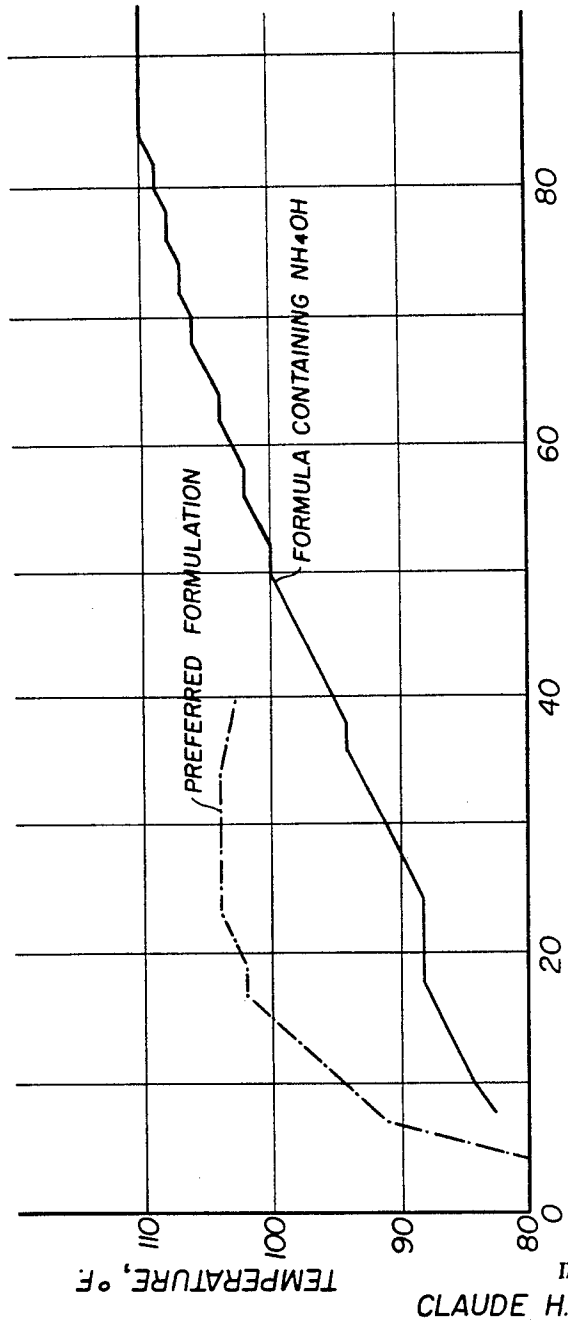


Fig. 14

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United States Patent Office 2,928,749
Patented Mar. 15, 1960

2,928,749

INVESTMENT MATERIAL FOR PRECISION CASTING

Claude H. Watts, Euclid, Ohio, assignor to Pre-Vest, Inc., Euclid, Ohio, a corporation of Ohio

Application December 12, 1956, Serial No. 627,825

9 Claims. (Cl. 106—38.3)

This invention relates to an improved bonded refractory investment material. Its use is primarily intended for the lost wax or lost pattern method of precision investment casting.

This invention also relates to the entire refractory investment mold, the materials of composition, the process and methods used in preparing the mold.

In the manufacture of metal castings by the lost pattern method, the following summary of steps which are well established in the practice of the art according to its present state of development will help to set the environment to understand the present invention.

An expendable pattern is made by one of a number of methods. Usually a metal mold is constructed so as to provide a cavity into which molten wax or plastic can be injected under pressure. The pattern material is allowed to solidify. The mold is constructed so that it can be held together by suitable clamps or bolts, and also so that after introduction of the pattern material, it can be disassembled and the pattern easily removed from the mold. The metal mold is designed so as to provide a pattern that is sized to compensate for thermal factors involved in the process. For example, the thermal changes will include: (1) wax shrinkage; (2) pattern expansion forces; (3) mold material shrinkage or expansion on setting in air; (4) pattern expansion during heat of reaction resulting from the chemical reaction of bond forming materials of the refractory investment powder; (5) thermal expansion of the investment mold; (6) metal shrinkage due to the change of the cast metal from the liquidus to the solidus; (7) metal shrinkage due to cooling down from the solidification temperature to room temperature; (8) additional shrinkage variables attributable to the size and configuration of the part being cast.

After the pattern or patterns have been made and inspected, they are "set-up" by attaching one or more patterns to a suitable assembly of wax gates and risers. These are generally referred to as the tree or finished set ups, and usually attached to a base member.

For casting the ferrous type of metals and other high fusing alloys melting about 2,000° F. or over, it is the usual practice to precoat the pattern assembly prior to the investing operation. The purpose of the precoat is to provide a more smooth surface to the mold for receiving the molten metal during the casting operation. This is a well established procedure that is thoroughly understood by those familiar with the art.

The precoat generally consists of a specially prepared liquid binder and a refractory powder. Liquid binders that have been used are sodium silicate, hydrolized ethyl silicate, and colloidal silica sol. Silica flour is generally used as the refractory powder with possible additions of china clay, aluminum oxide, and zirconium silicate for some applications. The development of a satisfactory precoat formulation has been the object of a considerable amount of research work. There are a number of formulas disclosed in the literature for precoating materials.

The thickness of the precoat may vary from a thin shell of from 1/64 to 1/32 inch thick to a shell approximately 1/4 inch thick. Precoat layers of varying thickness are obtained by dipping the pattern several times if required. Thicker precoat layers are desired in some instances to obtain satisfactory results as will be more fully described later.

The precoat can be applied to the wax pattern assembly by dipping or spraying. In most instances the pattern assemblies are simply dipped into the precoat solution. The patterns are then withdrawn and held in an inverted position so as to drain off excess coat. They are usually held at various angles and rotated slightly by hand during draining in order to insure complete coverage of the wax pattern as well as a uniform layer. After the patterns have been drained, placement sand having sharp grains and a particle size of from .15 to .60 millimeter in diameter is sifted onto the precoated patterns. This treatment serves to arrest further draining of the precoat. The sharp sand grains become partially embedded in the precoat. As the precoat dries and hardens, these grains of sharp placement sand help to prevent the precoat from cracking. A back-up investment material is placed around the precoated pattern, as will be well understood, but more fully described hereinafter. The placement sand will also form small anchoring points to help bond the precoat to the main body of the back-up investment mold. The anchoring action will be more fully described in the following section.

After the precoat has dried it may be desirable to apply a waterproofer, depending upon the type of precoat used and the kind of back-up investment used. Generally speaking, sodium silicate bonded precoats and colloidal silica sol precoats are referred to as water-base coats. These coats harden on drying as the water evaporates. They also are softened again when wetted with H_2O or H_2O solution. When a water-base back-up investment is used, such precoats require waterproofing to prevent the precoat from softening. Softening causes precoat failure, thereby producing rough surfaces, pits, and cracks to the casting. One waterproofer that has been used for this purpose is 5% Orange Shellac in ethyl alcohol. Another is an acid resisting paint having the trade name Tygon. (Composition unknown.) In actual practice, neither of these waterproofers are completely satisfactory for all applications.

One of the ways that this problem has been overcome is to use an ethyl silicate bonded precoat with an organic vehicle. Such precoats will not be softened by water after they have hardened. Therefore they can be invested directly with a water-base back-up investment, eliminating the waterproofing step.

The term "investment" should be well understood by those experienced in the art, and it pertains to encasing the pattern material in a slurry of plaster-like material which will harden around the pattern and form a solid mold capable of later holding molten metal to form a cast object.

Similarly a water-base precoat can be invested directly with a hydrolyzed ethyl silicate bonded back-up investment since the liquid bond comprises primarily ethyl silicate and organic vehicles. The small percentage of water that may be present is not sufficient to have any deleterious effect on the water-base precoat.

After the waterproofer has dried, if such is required, the precoated patterns are ready for investing.

A stainless steel flask open at either end is placed around the patterns and sealed to the base with wax.

The investment materials that may be used for casting metals that melt over 2,000° F. are generally classified according to their bonding ingredients as follows:

(1) Acid phosphate-magnesium oxide type bond.

(2) Hydrolyzed ethyl silicate type bond.

(3) Acidified sodium silicate type bond.

The refractory filler for all three types of bonding materials is usually a blended silica composition of carefully selected grain size distribution. For some applications small amounts of grog, fire clay, sillimanite, and zirconium silicate may be desirable. A number of formulations for refractory filler and bonding ingredients are well known in the art and are readily available in the literature.

The investing operation varies depending upon the type of investment material used. The acid phosphate-magnesium oxide type of investment material is usually vacuum invested in order to remove all air pockets, and insure a tight back-up of the investment against the precoat. After the vacuum investing operation the flasks are set aside for the investment material to harden.

The hydrolyzed ethyl silicate and acidified sodium silicate type of bonds shrink on setting in air at room temperature. In order to reduce the tendency for the molds to split or crack it is necessary to pour the refractory slurry into the flasks and then compact the solids closely together by a prolonged jarring or vibrating operation. In this way also the back-up investment is packed around the coated patterns, the air bubbles being eliminated by the vibrating operation, and the molds are less susceptible to cracking.

After the molds have dried and hardened they are heated to melt out the pattern material and then fired usually to about 1,600° to 1,800° F. in order to remove all traces of wax or plastic carbonaceous residue. Then molten metal is poured or cast into the mold cavity and allowed to solidify. Thereafter the mold is broken open to recover the castings. Cut-off wheels are used to separate the gates and risers from the metal parts and the pieces are then ready for the final operations of cleaning, sand blasting, gate grinding, deburring for removal of bubbles, flash, and other roughness or surface imperfections. The parts are then inspected as required for dimensions as well as for soundness and cracks by X-ray, Zyglo, hardness, magna flux, or others.

In order to better understand the objects of this invention, it is well to understand what shortcomings of prior practice must be overcome. The above outlined materials, procedures, and methods are not satisfactory for several reasons, including the following:

(1) The ethyl silicate and acidified sodium silicate require tamping to compact the mold and reduce the tendency for the mold to crack. The tamping procedure is objectionable because the wax or plastic set-ups are fragile, and considerable breakage occurs especially on fragile pieces. Tamping causes a settling away from underneath surfaces resulting in faulty back-up of the precoat with investment material thereby giving rough surfaces on the castings. Further, many patterns with blind holes and deep undercuts are impossible to fill by tamping since air is trapped and cannot escape.

The coarse and fine particles in the investment mold tend to segregate during tamping, resulting in a non-uniform aggregate of refractory particles with varying thermal expansion, permeability and strength characteristics within the same mold.

(2) The ethyl silicate and acidified sodium silicate materials both shrink on setting in air at room temperatures. Tamping will compact the aggregate and minimize the amount of shrinkable material. Thus, tamping will minimize shrinking—but will only partially overcome the tendency for the mold to split or crack.

(3) The ethyl silicate together with its ethyl alcohol vehicle requires careful handling to guard against the danger of explosions and fire.

(4) Both the hydrolyzed ethyl silicate and the acidified sodium silicate materials depend upon a gelling reaction for their green strength. Many variables effect the gelling time and it is therefore difficult to control.

(5) The acid phosphate-magnesium oxide type of back-up investment has a high heat of reaction that is generated immediately during and after the powder is added to the liquid for the mixing operation. The maximum temperature is usually reached after the mixture has taken an initial set. Pattern material is heat expandable. Therefore, expansion forces take place at the exact time when they are least tolerable. The heat generated varies to some extent depending upon the size of the flask being invested. For example a flask eight inches in diameter and ten inches high requires approximately 30 pounds of investment mix to fill the flask. The initial temperature as measured by placing a thermometer in the center of the flask with the bulb about five inches from the base was 73° F. Seventy minutes from the time that the powder was added to the water, and after the investment had set, the temperature had risen to a maximum of 133° F. for an increase of 60°.

For a flask six inches in diameter by eight inches high 16 pounds of investment mix are required to fill the flask. The initial temperature was 68° F. and after 50 minutes the temperature had risen to a maximum of 130° F., an increase of 62°.

For a flask five inches in diameter by six inches high 9 pounds 8 ounces of investment mix are required to fill the flask. The initial temperature was 67° F. and after 76 minutes the temperature had risen to a maximum temperature of 108° F., an increase of 41°.

The wax and plastic pattern materials have a high thermal expansion of about .010% to .020% per degree F. of temperature change in waxes, but usually less in polystyrene. See Figure 1. However, expansion is not alone a criteria of effect upon the precoat and the investment back-up mold. Wax softens with heat, and therefore is softer as it expands and exerts less force on the mold. Polystyrene, although having less expansion, exerts force over a longer temperature range. Wax may soften around 115° F. whereas polystyrene will remain firm and produce expansive force as high as 210° F. Therefore, the effective expansion forces tending to rupture the mold are greater in the polystyrene.

The high heat of reaction of the investment material causes the pattern material to begin to expand at a time when the mold back-up investment is just starting to set. At this time the investment material has for all practical purposes no strength and is not able to restrain the movement of the wax pattern. As a result the precoat is cracked. Cracks allow the cast metal to enter therein and create a flash on the finished casting. Also the mold cavity formed by the wax pattern is distorted due to the expansion forces of the wax pattern. Such expansion forces are subject to variables and are unpredictable and therefore undesirable.

(6) Acid phosphate-magnesium oxide investment slurries tend to settle after the flasks are invested resulting in a watery layer between the precoat and the back-up investment. This makes for a sloughing off of the precoat during the firing cycles resulting in rough surfaces, dirt, and inclusions in the final casting.

Having thus described the shortcomings of prior practice, it is the object of this invention to provide improved investment formulations, materials, and methods to overcome the above mentioned difficulties and to greatly improve the quality and uniformity of the castings produced.

One of the specific objects is to provide a material that can be vacuum invested and does not require subsequent tamping to compact the mold for the purpose of preventing mold splitting, but will tolerate such tamping if desired for other purposes.

Another object of this invention is to provide a material that has substantially no setting contraction and in fact may have a slight setting expansion on hardening at room temperature, thus reducing the tendency for the mold to split.

Another object of this invention is to provide a mate-

rial that is sufficiently strong after setting to restrain the expansion forces of the pattern material during the initial heating stages used to melt away the pattern and thus minimize mold distortion and possible fracture.

And another principal object is to provide a material that has a low heat generation so that the pattern expansion is minimized and therefore the tendency for cracking of the coat during the setting reaction will be reduced.

Another object is to provide a material that does not tend to settle away from the precoated patterns, thus assuring a homogeneous mold and a better bond between the precoat and the back-up investment.

Another object is to provide a material that will produce a smoother surface mold which will impart a like smooth surface on the finished casting free from flash, pits, and other surface irregularities.

Still another object of this invention is to provide an investment material free of fire and explosion hazard.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

Figure 1 is a chart indicating the expansion characteristics of two commonly used pattern materials;

Figures 2–5 are labeled graphs indicating change in characteristics with change in concentration of phosphoric acid;

Figures 6–9 are labeled graphs indicating change in characteristics with change in concentration of magnesium oxide;

Figures 10–13 are labeled graphs indicating change in characteristics with change in concentration of ammonium hydroxide; and

Figure 14 is a graph indicating temperature rise on setting of two embodiments of the invention.

Basically what has been discovered is that a certain combination of materials, all of which have been used before in this particular art, when combined in certain proportions, produce the quite surprising combined properties of:

(1) Setting expansion at zero, or slightly positive.

(2) Low setting and curing temperature rise.

(3) Tendency for separation of the back-up investment and the precoat substantially eliminated.

(4) Good green and fired strength.

(5) No special handling or loss of conventional desired characteristics.

The generic concept may be considered as an acid phosphate-sodium silicate-magnesium oxide type bond.

Phosphoric acid is the preferred acid phosphate, but for certain particular conditions may be partially neutralized by ammonium hydroxide to produce a mixed phase acid phosphate. Therefore, in order to illustrate the invention in its preferred form, the bulk of the following description will be given over the preferred embodiment.

A very satisfactory and preferred embodiment of this invention has a formulation which gives about 10 to 14 minutes of pouring time and 25 to 40 minutes of setting time with .2% to .4% percentage of setting expansion and having a green strength of about 500 pounds per square inch with a fired strength of about 200 pounds per square inch and is satisfactory for most investment casting procedures. This formulation is prepared in two separate phases. One phase consists of a liquid binder with a water vehicle as follows:

13.2 parts by weight of sodium silicate S–35.
20 parts by weight ortho phosphoric acid 85% with a specific gravity of 1.71.
78 parts by weight of water.

NOTE.—S–35 is a product name or trademark. It is listed in this manner only for convenience and is not to be interpreted as a limitation upon selection. Commercial sodium silicate solutions are made in such a manner that they may have various ratios of alkali to silica. This particular S–35 brand has a ratio of one part sodium oxide to 3.75 parts silica. This ratio is found to be very satisfactory and is recommended.

The second phase is a mechanical mixture of a refractory investment powder composition comprising:

96 parts by weight of graded silica refractory.
4 parts by weight of magnesium oxide powder.

The embodiment of this invention comprises in part a specially blended refractory investment powder along with the specially prepared liquid binder.

The preferred refractory investment powder may comprise, for example, the following blend:

4% fused magnesium oxide powder
30% 30 mesh silica
16% 50 mesh silica
50% 200 mesh silica

In this example, the reference to 30, 50 and 200 mesh silica is in the terminology used by suppliers of silica raw materials to refer to a particular brand or grade of product and is only roughly indicative of the particle size.

The particle size of the fused magnesium oxide powder is of considerable importance. I prefer to use a fused magnesium oxide known as Magnorite 100 F in the trade. A typical sieve analysis of Magnorite 100 F is as follows:

On 30	0.0
On 50	0.3
On 80	Trace
On 100	1.3
On 200	36.7
On 325	37.0
Pan	24.8
	100.1

The liquid ingredients are mixed preferably by adding the diluted silicate to the diluted acid with rapid vigorous stirring. This mixture should be made fresh at the time of intended use. The liquid binder and the refractory investment powder is then mixed in the proportions of about 23½ parts by weight of the liquid binder to 100 parts by weight of the refractory powder.

The resulting mixture will be a slurry which does not differ particularly in appearance to any other conventional investment material. Furthermore, common investment practices will be followed without any particular change, except for the fact that vacuum investment is entirely satisfactory. Vibration to compact the mold after investing is usually not necessary.

It is not always desirable to use a specific formula and accordingly the charts set forth in the drawings have been provided to permit the full understanding of the characteristics of the invention in order that anyone skilled in the art may adjust the details of the embodiments within the spirit and scope of the invention.

Figures 2 through 5 indicate the change of characteristics with change in concentration of phosphoric acid. In the charts of Figures 2 through 5, for the sake of convenience of illustration, the concentration of ortho phosphoric acid in 100 cc. of liquid binder is plotted as abscissas and the corresponding values for the physical property measured as ordinates. The materials may be mixed as follows, as an example:

(1) 10 cc. sodium silicate S–35—specific gravity 1.32 (6.75% Na_2O:25.3% SiO_2) water 40 cc.
(2) 12 cc. ortho phosphoric acid 85% in 38 cc. water

(The specific gravity and concentration is given for illustrative purpose and is not a precise requirement.)

Note that in the variation of the ortho phosphoric acid that the total volume for number 2 solution was always 50 cc. When the amount of the acid is varied, the volume of water was varied to compensate.

A liquid binder to powder ratio of from 21 to 22 parts

by volume to 100 parts to powder by weight was used, which is the 23+½ to 100 p.p.w. referred to before.

By observing the Figures 2 through 5, it will be seen that as the concentration of the phosphoric acid increased from 4 to 14 cc. per 100 cc. of liquid binder, the pouring time was varied roughly between 4 and 14 minutes. The setting is varied between 13 and 45 minutes. The setting expansion increased from a negative .2% to a positive .6%. The green compression strength increased from 300 pounds per square inch to better than 700 pounds per square inch, and the fired strength increased from about 100 to almost 300 pounds per square inch.

Having thus seen the variation possible within the basic concept of the invention by variation of the acid concentration, it is now of interest to illustrate the variation of characteristics available by varying the concentration of the magnesium oxide. This portion should be studied with the fact in mind that the magnesium oxide employed is the preferred sieve analysis obtainable in Magnorite 100 F.

The Figures 6 through 9 are graphs indicating the variation in physical properties obtained on the investment liquid and powder formulation for variations in the concentration of fused magnesium oxide in the investment powder.

In the graphs the varition in concentration of fused magnesium oxide is expressed as grams per 100 grams of investment powder and is plotted as abscissas. The corresponding values for the physical property measured are expressed as ordinates. The same starting liquid as before set forth, namely 10 cc. sodium silicate S–35 to 40 cc. water as solution number 1 with 12 cc. ortho phosphoric acid 85% and 38 cc. of water as solution number 2.

The liquid formula remains constant in this illustration. A liquid binder to powder ratio of 22 cc. of liquid to 100 grams of powder was used. The basic formula for the powder mixture embraces the same range and proportion of silicates with the same 4% fused magnesium oxide powder as a starting formula.

In this illustration for investment powder formulations are compounded having a fused magnesium oxide content of 2%; 4%; 6%; and 8% respectively. The concentration of 50 mesh silica was varied to allow for increases in magnesium oxide.

The temperature rise of the preferred embodiment is summarized in Figure 14. The total temperature rise indicated is typical. It is about half the temperature rise of some prior art investment materials.

An alternate type of composition which is useful for some cases, particularly where the pH value must be higher, is accomplished by partially modifying the phosphoric acid by means of ammonia. Although in theory mono ammonium phosphate could be employed, it has been found to be far more satisfactory to actually neutralize a portion of the phosphoric acid with liquid ammonia hydroxide. It is to be understood that the following description has limited usefulness in view of the fact that the preferred embodiment eliminates the need to handle ammonia and will provide proper characteristics for virtually all casting problems.

The specifications for the primary liquid binder materials for the alternate are as follows:

(1) Sodium silicate: specific gravity 1.32, 6.75% Na_2O; 25.3% SiO_2; 67.95% H_2O. Ratio of Na_2O to SiO_2 about 1–3.75
(2) Phosphoric acid: 85%—sp. gr. 1.71
(3) Aqua ammonia: 28% NH_3—sp. gr. 0.90

The following formula for liquid binder will serve as an example of this invention:

15 cc. H_3PO_4 85% equivalent to 25.6 g. H_3PO_4 85% or $25.6 \times .85 = 21.8$ g. H_3PO_4 per 100 cc.
9 cc. NH_4OH equivalent to 8.1 g. or $8.1 \text{ g.} \times .28 = 2.27$ g. NH_3 per 100 cc.
15 cc. sodium silicate equivalent to 19.8 g. Sodium Silicate or
$19.8 \times .0675 = 1.33$ g. Na_2O per 100 cc.
$19.8 \times .253 = 5.0$ g. SiO_2 per 100 cc.
6 cc. H_2O

This formula for liquid binder is used with the blended refractory powder previously given in the ratio of about 23.5 parts liquid to 100 parts powder by weight.

This combination of chemical ingredients results in the most amazing strength characteristics for such low concentrations of binding ingredients in combination with the other desirable physical and chemical properties outlined above.

Table of physical properties

(1) Pouring time	3 minutes.
(2) Setting time	33 minutes Vicat needle.
(3) Setting expansion	+0.54%.
(4) Thermal expansion	Max. @ 1800° F.+0.90%.
(5) Compression strength:	
Green strength aged overnight at 80° F.	208 lbs. per sq. inch.
Fired strength	134 lbs. per sq. inch.
(6) Heat of reaction—100 lbs. investment slurry—total increase in temperature	28° F.

The refractory investment mold does not decompose or give off corrosive gases at elevated temperatures or when molten metal is poured into the mold. Small amounts of ammonia gas are given off during the early firing stages but these are soon completely eliminated.

This particular liquid bond has an unusual characteristic of holding the refractory investment particles in suspension and in aiding the bonding of the back-up investment with the precoat. This makes for a substantial improvement in results obtained as evidenced by less precoat failure resulting in smoother castings.

The Figures 10 through 13 are graphs indicating the variation in physical properties obtained on the investment liquid and powder formulation for variations in the concentration of ammonium hydroxide in the investment liquid.

The addition of small amounts of ammonia seems to aid in lengthening the time during which the investment slurry can be poured. It may also lengthen the setting time excepting, however, that too much ammonia with relation to the phosphoric acid content may hasten the pouring and setting time.

Control of the pouring and setting times is absolutely necessary; however, care must be taken not to add too much since additions of ammonia reduce the green strength.

Another example for liquid binder is as follows:

5 cc. H_3PO_4 85%
3 cc. NH_4OH
5 cc. sodium silicate
87 cc. H_2O

This formula for liquid binder is used with the blended refractory powder previously given in the ratio of about 22 parts liquid to 100 parts powder by weight.

Table of physical properties

(1) Pouring time	5 minutes.
(2) Setting time	29 minutes.
(3) Setting expansion	−0.11% (over night).
(4) Thermal expansion	+1.15% (Max. at 1600° F.)
(5) Compression strength:	
Green strength aged over night at 80° F.	101 lbs. per sq. inch.
Fired strength	74 lbs. per sq. inch.
(6) Heat of reaction—10 lbs. investment slurry—total increase in temperature	16° F.

Another example for liquid binder is as follows:

20 cc. H_3PO_4 85%
12 cc. NH_4OH
20 cc. sodium silicate
48 cc. H_2O

This formula for liquid binder is used with the blended refractory powder previously given in the ratio of about 24 parts liquid to 100 parts powder by weight.

Table of physical properties

(1) Pouring time ---------- 13 minutes.
(2) Setting time ---------- 25 minutes.
(3) Setting expansion ---------- 0.64% (over night).
(4) Thermal expansion ---------- +0.900% (max. at 1600° F.).
(5) Compression strength:
Green strength aged over night at 80° F. ---------- 356 lbs. per sq. inch.
Fired strength ---------- 195 lbs. per sq. inch.
(6) Heat of reaction—10 lbs. investment slurry—total increase in temperature ---------- 30° F.

The temperature rise of this alternate embodiment is summarized in Figure 14. The total temperature increase indicated is typical. It is about half the temperature rise of some prior art investment materials.

In both of the embodiments thus described there have been references made to various characteristics of the products. In view of the fact the working materials of this invention are old and well known in the art, and that the invention resides in the proper combination and use of these materials, it is important to understand what kind of tests are employed to determine the characteristics in order that the prior art may be compared with the present invention on the same basis. It would serve no useful purpose to show particular characteristics of this invention if the means for determining those characteristics were vague and ill defined.

1. *Mixing and pouring time.*—The investment slurry must have sufficient mixing and pouring time to permit ease in handling and manipulating during the mixing of the liquid binder and the refractory powder, and the vacuum investing operations. It is common practice at the present time to mix powder and liquid batches totaling as much as 100 to 150 pounds and to fill one or more flasks each flask containing a portion or all of the entire mix. Thus flasks may range in size from 3 inches in diameter and 6 inches high for a small flask and from 14 inches in diameter and 16 inches high for a large flask. A small flask when filled with investment weighs approximately 2½ pounds, while a large flask would weigh about 150 pounds. Pouring time is defined as the time as measured from the moment that powder is added to the liquid that the material will flow under the force of gravity from one container to another after mechanical mixing for one to three minutes to thoroughly blend the powder and liquid.

A pouring time range of from nine to fifteen minutes has proven satisfactory under present day operating conditions.

2. *Thickening and setting time.*—The material must have a thickening and setting time that will permit handling the invested flasks under high production conditions. The invested flasks must harden sufficiently so that they can be moved without damage to a storage area or collecting area. This makes possible a more or less continuous flow of invested flasks through the investing operation to a storage area. Present day production schedules in some instances involve the processing of from 1,000 to 2,000 flasks per shift.

The setting time is determined using a Vicat needle and is defined as the time as measured from the point of adding the powder to the liquid that the needle will no longer penetrate to the bottom of a test patty about two inches in diameter and one inch high.

A setting time range of from twenty to forty minutes has been satisfactory with an optimum setting time of about thirty minutes.

3. *Consistency or viscosity.*—The material must have a suitable consistency or viscosity that will permit mechanical blending of the powder and liquid; investing flasks by pouring the mixed investment from the mixing container into the flasks; and vacuum investing the flasks in accordance with established procedures well known in the art.

The consistency is determined as follows:

A clean brass ring two inches high and one and three-eighths inches inside diameter is placed on a smooth glass plate about six inches square. The mold is filled with the mixed investment slurry and struck off flush with a spatula. At exactly six minutes from the time that the powder was added to the water the mold is lifted and the mixture allowed to slump or spread over the plate. The smallest and largest diameter of the slump mixture are taken and the average gives the slump. A consistency mix in terms of inches of slump may vary from three to five inches with an optimum figure of about four inches. The setting characteristics of the investment and the ratio of liquid to powder are variables that influence the consistency of the mix.

4. *Setting expansion.*—The investment mold material should have substantially no setting contraction. Setting expansion or contraction is defined as the increase or decrease in length of a standard test specimen as the setting reaction proceeds in air at room temperature.

The setting expansion is determined with a micrometer microscope comparator or equipment of comparable accuracy. The test specimen is poured up and reference readings taken at the time of initial set. The maximum change in dimension is recorded as the setting expansion or contraction of the investment material. Readings are taken up to twenty-four hours from the time of initial set.

A setting contraction of more than —0.20% is usually undesirable. The usual working range for setting expansion as provided by this invention is from 0.00% to +0.35%. For some applications a setting expansion up to +0.60% or more might be desirable.

5. *Thermal expansion.*—The thermal expansion is measured by the "fused quartz expansion apparatus." A test specimen approximately 1.2 centimeters in diameter by 20 centimeters long is prepared. This cylinder is placed in the testing apparatus and the temperature gradually raised from room temperature to 1800° F. in about two hours. The increase in length is recorded as percent thermal expansion. The thermal expansion usually falls within the range of .5% to 1.2% and the optimum is about 0.9%.

6. *Compression strength.*—One of the most commonly used tests to determine strength characteristics of investment materials is compression strength. Test cylinders are prepared by pouring the investment slurry into suitable molds so as to give a test specimen 1.3 inches in diameter by 2 inches high.

Green strength is defined as the strength obtained after aging the test specimens in air at room temperature (80° F.) for one day or longer.

Fired strength is defined as the strength obtained after firing to 1600° F. in two hours, holding at 1600° F. for one hour, and cooling slowly in the furnace to room temperature.

Compression strength is recorded as an average of five tests in pounds per square inch. Any cylinder having a compression strength value which varies more than 15% from the computed average is discarded and the average of the remaining tests re-figured. A minimum of three cylinders must fall within the acceptable range.

A green strength of from 250 pounds per square inch to 1,000 pounds per square inch and a fired strength of

from 100 pounds per square inch to 350 pounds per square inch is desirable.

7. *Heat of reaction.*—Heat of reaction is defined as the increase in temperature of the investment mold caused by the heat of reaction of the chemical binders as the setting reaction takes places. A lubricated chemical thermometer is suspended in the center of the test flask and held in place while the flask is filled with investment. Temperature readings are taken until no further increase in temperature is noted. The difference between the maximum temperature recorded and the initial temperature of the mixed slurry is taken as the increase in temperature due to heat of reaction.

The lowest possible increase in temperature due to heat of reaction is most desirable. An increase in temperature of 17° F. for a small flask containing two pounds of investment to an increase in temperature of 28° F. for a flask containing 100 pounds of investment are within the limits of acceptability.

8. *Permeability.*—Permeability is defined as a measure of the freedom with which the investment mold permits gases to pass through it. Hot permeability refers to data obtained on samples heated to elevated temperatures.

Permeability is determined using the American Foundrymen's Society Air Flow apparatus.

Permeability is expressed as the volume of air in cubic centimeters that will pass per minute under a pressure of one gram per square centimeter through a specimen one square centimeter in cross sectional area and one centimeter high, or

$$P=\frac{V.h}{p.a.t}$$

where

P=permeability number
V=volume of air at testing temperature passing through the specimen in cc.
h=height of specimen in cm.
p=pressure of the air in grams per square cm.
a=cross sectional area of specimen in square cm.
t=time in minutes.

For good results the permeability should be in the range of .3 to .6.

Investments for high temperature casting having a permeability number as low as .2 usually are not permeable enough for most precision casting work and imperfect castings with entrapped air pockets and possible misruns result. (Foundry Sand Handbook, 6th edition, page 67.)

9. *Stability.*—The refractory investment mold must not decompose or give off corrosive gases on firing to elevated temperatures or when the molten metal is poured into the mold.

10. *Suspension.*—The refractory investment slurry must adapt itself and attach itself to the outer or "sanded" face of the precoat so as to form a satisfactory mold that will withstand the firing cycle without separation of the precoat layer from the back-up investment. This requires that the investment liquid exhibit the property of holding the refractory particles in suspension.

Investment materials that tend to settle away from underneath surfaces or that tend to form a watery layer between the precoat and the back-up investment (not necessarily underneath surfaces) are prone to produce defective castings with rough surfaces, containing small particles of precoat inclusions.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. A refractory investment consisting essentially of the reaction products of 21 parts by volume of a binder consisting of the following 100 parts liquid:

10 parts by volume sodium silicate, specific gravity 1.32 (6.75% sodium oxide to 25.3% silicon dioxide)
12 parts by volume ortho phosphoric acid 85%, specific gravity 1.71
78 parts by volume water

and four grams of fused magnesium oxide for each 21 cc. of binder, the binder mixed with graded refractory substantially inert to rapid reaction with the balance of the ingredients and their reaction products.

2. A refractory investment consisting essentially of the reaction products of 21 parts by volume of a binder consisting of the following 100 parts liquid:

10 parts by volume sodium silicate, specific gravity 1.32 (6.75% sodium oxide to 25.3% silicon dioxide)
12 parts by volume ortho phosphoric acid 85%, specific gravity 1.71
78 parts by volume water

and 100 grams of the following mixture of fused magnesium oxide and graded refractory for each 21 cc. of the liquid:

96 parts by weight of graded refractory substantially inert to rapid reaction with the balance of the ingredients and their reaction products
4 parts by weight of fused magnesium oxide.

3. The method of making a refractory investment comprising the steps of providing 21 parts by volume of the following 100 parts liquid:

10 parts by volume sodium silicate, specific gravity 1.32 (6.75% sodium oxide to 25.3% silicon dioxide)
12 parts by volume ortho phosphoric acid 85%, specific gravity 1.71
78 parts by volume water

and 100 grams of the following mixture of fused magnesium oxide and graded refractory for each 21 cc. of the liquid:

96 parts by weight of graded refractory substantially inert to rapid reaction with the balance of the ingredients and their reaction products
4 parts by weight of fused magnesium oxide

said fused magnesium oxide having a graded particle distribution before reaction to produce a prolonged reaction time, and finally mixing the liquid and said mixture.

4. The method of making a refractory investment, comprising the step of: providing a powder of silica with graded fused magnesium oxide dispersed therein, said fused magnesium oxide having a typical sieve analysis showing a particle distribution:

On 30	0.0
On 50	0.3
On 80	Trace
On 100	1.3
On 200	36.7
On 325	37.0
Pan	24.7
	100.0

and providing a liquid mixture of about one part by volume sodium silicate of approximately 1.32 specific gravity with one part by volume ortho phosphoric acid 885% of approximately 1.71 specific gravity in about five parts by volume water, and finally mixing said liquid with said powder until a slurry is formed having:

Pouring time	minutes	9 to 15
Setting time	do	20 to 40
Setting expansion	percent	0.0 to .6
Green strength	p.s.i.	300 to 1,000
Fired strength	p.s.i.	100 to 350

5. A refractory investment, consisting essentially of a powdered mixture of graded refractory substantially inert to rapid reaction with the balance of the ingredients and their reaction products, and fused magnesium oxide:

	Parts by weight
Graded refractory	96
Graded fused magnesium oxide	4

and a liquid phase of a phosphate acidified sodium silicate in a water solution:

	Parts by weight
Sodium silicate (6.75% sodium oxide to 25.3% silicon dioxide)	13.2
Ortho phosphoric acid	20.5
Water	78

said liquid phase and powdered mixture being combined in about the proportions of 23 parts by weight of liquid to 100 parts by weight of powder.

6. A refractory investment, consisting essentially of a powder of graded refractory substantially inert to rapid reaction with the balance of the ingredients and their reaction products, and fused magnesium oxide:

	Parts by weight
Graded refractory	92–98
Graded fused magnesium oxide	2–8

and a liquid phase of a phosphate acidified sodium silicate in a water solution:

Sodium silicate	10 cc. at 1.32 specific gravity.
Ortho phosphoric acid	4–14 cc. 85% grade at 1.71 specific gravity.

Water to make 100 cc.

7. A binder composition for bonding a graded refractory substantially inert to rapid reaction with the balance of the ingredients and their reaction products, consisting essentially of about one part by volume sodium silicate of approximately 1.32 specific gravity with one part by volume ortho phosphoric acid 85% of approximately 1.71 specific gravity in about five parts by volume water, the resultant solution mixed with fused magnesium oxide dispersed in said graded refractory, said fused magnesium oxide being in a range of from 2 to 8 percent by weight to each 21 cc. of said resultant solution to result in a slurry which will have:

Pouring time	minutes	9 to 15
Setting time	do	20 to 40
Setting expansion	percent	0.0 to .6
Green strength	p.s.i.	300 to 1,000
Fired strength	p.s.i.	100 to 350

8. A refractory investment consisting essentially of a liquid phase as follows:

	Cc.
Sodium silicate—specific gravity 1.32 (6.75% sodium oxide to 25.3% silicon dioxide)	10 to 20
Water to make 50 cc.	
Ortho phosphoric acid, 85% specific gravity 1.71	10 to 20
Water to make 30 cc.	
Ammonium hydroxide, specific gravity 0.90	6 to 12
Water to dilute to 20 cc.	

the total being 100 cc.; a powder phase having 92–98 parts by weight of graded silica and 2–8 parts by weight of fused magnesium oxide, wherein about 22 parts of the liquid phase is mixed with the 100 parts of powder to make an investment slurry.

9. A refractory investment consisting essentially of a liquid phase, as follows:

	Cc.
Sodium silicate—specific gravity 1.32 (6.75% sodium oxide to 25.3% silicon dioxide)	5 to 20
Water to make 50 cc.	
Ortho phosphoric acid, 85% specific gravity 1.71	5 to 20
Water to make 30 cc.	
Ammonium hydroxide, specific gravity 0.90	3 to 12
Water to dilute to 20 cc.	

the total being 100 cc.; a powder phase having 92–98 parts by weight of graded silica and 2–8 parts by weight of fused magnesium oxide, wherein a ratio of about 22 parts of the liquid phase is mixed with 100 parts of the powder to make an investment slurry.

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