LUODOX® SK Colloidal Silica
Unique Enhanced Water-Based Binders
for Rapid Processing of Investment Castings

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What are Ludox® SK Binders?

LUDOX® SK binders are patented, ultra-stable binders designed for use in investment casting. Originally formulated as a face coat binder, the unusual stability, constant rheology, minimal slurry maintenance, and rapid processing capabilities make LUDOX® SK binders an excellent choice for use in backup slurries.

Ludox® SK Grades for Face and Backup Coats

Four grades of LUDOX® SK colloidal silica are now available. All grades of SK contain specially modified and deionized colloidal silica, water-soluble polymer, antifoam, and biocide. In addition, SK and SK-F contain surfactant to allow them to be used in face coats.

LUDOX® SK and SK-B colloidal silica are identical, except that SK contains surfactant and is typically used in face coats. SK-B is used as a backup coat and does not contain surfactant.

LUDOX® SK-F and SK-R colloidal silica are based on a modified selection of water-soluble polymer, which gives higher strength and improved rapid processing capabilities.

Face (Primary) Coats

LUDOX® SK colloidal silica: SK-B plus surfactant
LUDOX® SK-F colloidal silica: SK-R plus surfactant; higher strength than SK

Backup (Secondary) Coats

LUDOX® SK-B colloidal silica: no surfactant
LUDOX® SK-R colloidal silica: no surfactant; higher strength than SK

LUDOX® SK Colloidal Silica – Key Advantages

Contains a Soluble Polymer (not a Latex Dispersion)

- Rapid processing
- One-package system
- High shear mixing can be used
- Product and slurry stability

Silica Particles Surface Modified with Aluminum

- Insensitivity to pH variations
- Outstanding slurry stability
- Minimal slurry maintenance/monitoring

Very Low Sodium Content

- Improved high temperature behavior
- Stability of flow and plate weight

Replaces Ethyl Silicate

LUDOX® SK colloidal silica can be used to replace ethyl silicate binders in investment casting slurries. Providing sufficient airflow is used to promote maximum water removal rates, LUDOX® SK colloidal silica:

- Gives similar shell building times
- Gives the same dimensions as ethyl silicate
- Does not require achieving low humidities — minimizing investment

Compared with Colloidal Silica-Latex Combinations

LUDOX® SK colloidal silica provides similar processing times while giving:

- Better slurry life
- Less slurry maintenance
- Lower sodium level imparts better behavior at high temperatures; less shell creep; better dimensional stability

Superior Refractory Suspension

Refractories settle slower in LUDOX® SK colloidal silica, making it easier to maintain uniformity throughout the slurry tank.

Benefits of LUDOX® SK Colloidal Silica

Conventional “Enhanced” Binders

“Enhanced” binders is a term that has evolved to describe water-based binders to which a polymer is added to "enhance" the strength or other properties of the binder.

In most cases, the water-based colloidal binders are the same standard alkali-stabilized binders that have been in use in the industry for many years. The polymeric systems chosen to enhance their performance are latex additives.

These latex materials are colloidal dispersions themselves and are stabilized by added surfactants. They have a characteristic “milky” appearance because the latex particles are quite large. Most are somewhat unstable to continuous stirring, making them difficult to maintain in a ceramic slurry without aggregation.

Because of this sensitivity to mechanical shear, high-shear mixers are never recommended for slurry makeup with the latex present.

In many cases, the latex materials will not stay in suspension in the presence of colloidal silica without continuous agitation, requiring that they be supplied as a separate component to be added at the time of slurry production.
**LUDOX® SK Binders are different**

**Surface Treatment**

Other water-based binders need to be kept at a high pH in order to remain stable. The high pH puts a charge on the particles, which makes them repel each other. However, if the pH falls, so does the charge on the particles, and they become unstable. *Figure 1* shows this effect. *Figure 2* illustrates how each LUDOX® SK particle is surface-treated with aluminum to have a permanent charge that does not depend on the pH. This allows us to remove the alkali from the system and still maintain a stable product. In fact, LUDOX® SK binders are much more stable in most cases than regular binders.

**Soluble Polymer**

LUDOX® SK binders contain water-soluble polymers, rather than latex emulsions. They have good wax wetting character, are tough film formers, and give good wax adhesion. However, unlike other water-based binders in use in the investment casting industry, they do not require pH adjustment to remain stable.

**Low Sodium**

The elimination of sodium from LUDOX® SK colloidal silica results in its having less tendency to soften and flow at high temperatures; this has been shown to result in less high-temperature shell deformation. The low sodium content also decreases the rate of conversion to crystalline silica. Rheology-related characteristics such as flow and plate weight remain surprisingly constant with age in LUDOX® SK slurries.


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**Rapid Shell Processing with LUDOX® SK Binders**

Grace makes no claim that LUDOX® SK colloidal silica dries faster than other water-based binders. However, we have found that the shell strength increases to the maximum possible long before the shell is completely dry, allowing the shell to be re-dipped at one- or two-hour intervals with a final drying time to allow complete drying of the finished shell before de-wax. Because of this, processing times comparable to those used with ethyl silicate binders are possible.

We compared the effect of the re-dipping interval on test bars bonded with standard colloidal silicas and with LUDOX® SK-R colloidal silica. Strength data shown is a compilation of several experiments that included a number of refractory powders and standard alkali-stabilized binders, including those made by Grace and competitors. The dipping procedures we used are summarized in *Table 1*. Several studies using a variety of refractories and binders were run over several months. In all cases, strength development data on LUDOX® SK-R slurries was collected in the same test for comparison.

### Table 1: Dipping Procedures

<table>
<thead>
<tr>
<th>(\text{Slurry viscosity} )</th>
<th>(15 \text{ sec} #4 \text{ Zahn} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Immersion time} )</td>
<td>(10 \text{ sec} )</td>
</tr>
<tr>
<td>(\text{Drain time} )</td>
<td>(30 \text{ sec} )</td>
</tr>
<tr>
<td>(\text{Relative humidity} )</td>
<td>(50 – 60% )</td>
</tr>
<tr>
<td>(\text{Airflow} )</td>
<td>(150 \text{ ft/min (0.76 m/sec)} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(\text{Drying time between dips (hr)} )</th>
<th>(\text{Coat No.} )</th>
<th>(\text{Set 1} )</th>
<th>(\text{Set 2} )</th>
<th>(\text{Control} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>24 – 48</td>
<td>24 – 48</td>
<td>24 – 48</td>
</tr>
</tbody>
</table>

Relative humidity in the laboratory over the course of these several experiments was somewhat variable, between 50 and 65%, but the LUDOX® SK-R slurries were always run side-by-side with the standard colloids. Drying was done in a laboratory hood that was calibrated for airflow. The airflow was quite constant over the entire area of the hood and averaged about 150 ft/min (0.76 m/sec). This airflow is quite low compared to the 1200 ft/min (6 m/sec) that Leyland and Jones* found gave the maximum benefit to the drying rate.

Results are shown in *Figure 3* for the standard binders alone. Keep in mind that the results are given as a percentage of the results obtained when each layer was completely dried before the specimen was re-dipped.
Hence, the control specimens always read 100%, even though the actual strength values may have varied. All the specimens were completely dried before being tested. The residual water left in the shell was estimated from parallel experiments and is shown along the X-axis of Figure 3. The results indicate that the maximum strength is only attained if each shell layer is virtually dry when the next layer is applied. Re-dipping before the previous layers are completely dry results in a loss of strength in these systems. A disruption or weakening of the shell may take place during the re-dipping, or the disruption may take place during the final drying.

**Customer Testing of LUDOX® SK-R**

Experiments run at the customer* using LUDOX® SK-R colloidal silica/zircon slurries indicate similar results in water loss experiments. These data were collected on eight coat shells dipped every hour. Airflow was about 1200 ft/min (6 m/sec) (about 8× the airflow used in our laboratory studies).

Except for those shells made at 40% RH, the residual moisture left in the shell at the time of re-dipping was significant. Figure 5 summarizes the finding.

We do not have strength data comparisons for these drying conditions, but they may be inferred from the fact that shells are being produced and auto-claved in good yield at relative humidity up to 65% in production trials.

This means that ethyl silicate and LUDOX® SK-R colloidal silica lines could be run side by side, because LUDOX® SK-R colloidal silica does not require very low relative humidity levels where ethyl silicate systems will not function.

**NEL Studies of LUDOX® SK-R Slurries**

The National Engineering Laboratory (NEL) in Glasgow, Scotland, was commissioned to compare LUDOX® SK-R colloidal silica and ethyl silicate bonded Molochite shells. NEL has a standard protocol series of tests:

- Green modulus of rupture (MOR)
- Fired (hot) MOR
- Hot permeability
- Hot load bearing (resistance to deformation at temperature)

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"S. Jones, S. Leyland, “The Effect of Drying Conditions Upon the Wax/Ceramic Interface Temperature,” Precast 95"
Shells were produced with eight coats, as is the norm for ethyl silicate shells. We asked NEL to produce three sets of LUDOX® SK-R colloidal silica bonded specimens, using
- One hour between dips
- Two hours between dips
- Complete drying between dips

Airflow was moderate during the experiment and was estimated at about 400–500 ft/min (2–2.5 m/sec). Figure 6 summarizes the findings of this work.

The results are displayed as a ratio of the LUDOX® SK-R colloidal silica results to the typical ethyl silicate results, and, hence, the ethyl silicate value for each property is always 1. One of the common problems ethyl silicate users usually comment on about colloidal binders is that the green strength is too poor and the fired strength is too high. LUDOX® SK-R colloidal silica gives higher green strength, but fired strength is very comparable to ethyl silicate.

LUDOX® SK-R colloidal silica bonded shells are much more resistant to hot deformation according to these results. Hot permeability is similar to the ethyl silicate performance: actually somewhat better at one hour dry times and somewhat poorer at extended dry times between dips. Because the intention would be to minimize dry times between dips, this would not appear to be a problem.

How does LUDOX® SK Colloidal Silica react to different Refractories?

Zircon Slurries
Because LUDOX® SK binders are stable at virtually any pH, the rapid pH drop, often observed in zircon slurries, has no effect on slurry stability.

Figure 7 illustrates the long-term stability of LUDOX® SK slurries with zircon. This long slurry life with LUDOX® SK colloidal silica is not unique to zircon slurries, but is typically seen with most refractories.

Fused Silica and Alumino-Silicate Slurries
Excellent stability is observed with fused silica and alumino-silicate slurries. Fused silica slurries in LUDOX® SK colloidal silica tend to be smoother and give more uniform coverage than they do in alkaline binders.

Molochite gives very stable slurries in LUDOX® SK colloidal silica. Figure 8 is illustrative of the good stability and high strength of these slurries.

Alumina Slurries
Fused aluminas work very well in LUDOX® SK binders. Tabular aluminas vary in their interaction with LUDOX® SK colloidal silica.
Results to date have been variable, depending on the source of the alumina flour used. Some aluminas show a marked tendency to produce highly thixotropic slurries, while others give extremely stable slurries. Our data indicate that these results are related at least in part to the amount of leachable borates in the alumina. Borate can coagulate the water soluble polymer in LUDOX® SK colloidal silica, resulting in high thixotropy or actual gelling. Alumina flours with very low levels of borates should be selected.

**Zirconia Slurries**
Calcium-stabilized zirconia destabilizes LUDOX® SK colloidal silica over a period of time, due to leaching of the calcium from the lattice in the acidic environment. Non-stabilized zirconia appears to work well in LUDOX® SK colloidal silica.

**Refractories Milled with Iron Media**
Because of the acidic pH of the LUDOX® SK binder, iron residues will slowly come into solution and destabilize the slurry. Calcining the material after milling appears to help some, if the calcining temperature is sufficiently high (900 – 1100 °C [1652 – 2012 °F]), but eventually the presence of the iron will be detrimental.

**Note:** Calcining before grinding does no good. The iron will be present as active material.

You should check with your supplier to make sure ceramic media is used to grind your refractory. For the same reasons, iron or mild steel tanks or agitators should never be used in contact with LUDOX® SK slurries.

**Soluble Polymer versus Latex Dispersions**
The polymeric film formers in LUDOX® SK colloidal silica are more efficient than lattices as co-binders, because their molecular size more closely matches colloidal silica dimensions than the much larger latex particles. Figure 9 illustrates the relative size of the components. Water-soluble polymers are not prone to mechanical destabilization as are lattices. High shear mixers may be used to prepare LUDOX® SK slurries.

However, where high shear mixers are used to prepare face coats, we recommend that LUDOX® SK-B or SK-R colloidal silica be used and the surfactant added later as needed, in order to minimize the time required to allow for air to escape from the slurry.

Because LUDOX® SK-B and SK-R colloidal silica do not contain a surfactant, they will release air faster and foam much less readily than LUDOX® SK and SK-F colloidal silica. Not all surfactants are suitable. Consult your Grace representative.

**Building Slurries with LUDOX® SK**
We suggest that you use LUDOX® SK binders as received, without dilution and without pH adjustment. The products contain the necessary additives, and additional amounts should not be necessary, but if either foam or wetting should become a problem, small additional amounts of antifoam or wetting agent may be added. You should call your Grace representative for the proper additives.

- The weight of refractory and binder used should be approximately the same as are currently being used.
- Add the LUDOX® SK colloidal silica to the mix tank.
- Slowly add the refractory with agitation. The slurry will initially be thick but will thin with time as air is eliminated. High shear mixing equipment may be used to prepare LUDOX® SK slurries.
- Allow the slurry to equilibrate under normal agitation for about 24 hours.
- Add additional binder or refractory to make any final viscosity adjustment needed.

Backup slurry viscosity should be maintained at 10 – 15 sec (Zahn cup #4). This will give plate weights about 0.100 – 0.14 g/in² (0.016 – 0.022 g/cm²). These are typically higher than normally used in ethyl silicate slurries.
Slurry Maintenance

- Routinely add water (preferably distilled) to compensate for evaporation.
- At least once a week, check the silica content by separating the binder phase from the refractory by settling or centrifuging. Determine the specific gravity of the LUDOX® SK binder, and use Figure 10 or Table 2 to determine the silica content.
- LUDOX® SK slurries are often so stable they settle very slowly and are difficult to centrifuge down. Appendix A is a modified procedure to deal with this problem.
- Maintaining the SiO₂ content of the binder in the range of 24–26% is preferred.
- Do not make pH adjustments.
- Additions of extra wetting agents or antifoams should be made using only those recommended by Grace for use with LUDOX® SK colloidal silica.

Table 2: Silica Content vs. Specific Gravity

<table>
<thead>
<tr>
<th>% Binder Silica</th>
<th>% Binder Silica</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>LUDOX® SK</td>
</tr>
<tr>
<td>1.100</td>
<td>16.40</td>
</tr>
<tr>
<td>1.105</td>
<td>17.15</td>
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<tr>
<td>1.110</td>
<td>17.85</td>
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<td>1.115</td>
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<td>1.130</td>
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<td>1.140</td>
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</tr>
<tr>
<td>1.145</td>
<td>22.65</td>
</tr>
<tr>
<td>1.150</td>
<td>23.35</td>
</tr>
</tbody>
</table>

Fig. 10: LUDOX® SK-Silica Content vs. Specific Gravity

If you are currently using a water-based binder, we recommend that you measure the plate weight of your existing slurry, and use that as a starting point for your LUDOX® SK slurry trials.

If you are currently using an ethyl silicate slurry, we suggest you use a higher plate weight of LUDOX® SK slurry. The higher solid levels will give better strength, and the slower drying rate of the water-based LUDOX® SK slurry will allow for good stucco pickup, even though longer drain times may be used.

In Figures 11–17 (Appendix B), we have established the relationship between the plate weight, the flow time, and the filler loading of LUDOX® SK-zircon and LUDOX® SK-R-Molochite 200 slurries.
Personal Safety and First Aid

All persons handling LUDOX® colloidal silica should be thoroughly familiar with the Grace Material Safety Data Sheet.

Health Hazards
Contact with LUDOX® colloidal silica may cause transient irritation of the skin and eyes. Dust from spills or deposits may be considered to be amorphous silica, although the particles are normally larger than respirable size. However, when aerosols are intentionally produced, such as in spray applications, respirable droplets or dust may form that may cause irritation of the respiratory system and cause coughing. Studies have shown that when applied within the recommended limits, these materials are unlikely to produce health hazards, such as pulmonary fibrosis, as observed with crystalline materials. Users should review the Material Safety Data Sheet provided with each shipment for the various exposure limits.

Safety Precautions
Avoid contact with skin or eyes. Avoid circumstances that cause a mist or spray of the liquid or a dust of dried particles. Application methods using rollers or sponges are preferred to sprays that generate fine droplets. Installations for applying LUDOX® colloidal silica should include provisions for sufficient ventilation to control airborne particles and to keep exposures below recommended limits.

First Aid
In case of skin or eye contact, flush with plenty of water for at least 15 min. Call a physician. If large amounts are inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call a physician.

Storage and Handling
LUDOX® colloidal silica should be stored above 2°C (35°F) and below 43°C (110°F) to avoid irreversible gel formation or silica precipitation. Bulk storage tanks or drum storage areas should be located in heated buildings. Lines to and from storage tanks must also be protected from freezing. Outdoor storage facilities can be used, if suitably insulated, heated, and protected from the weather.

Storage tanks of cross-linked polyethylene or fiberglass-reinforced plastic (FRP) have proven suitable. Metal tanks of 304 stainless steel or mild steel lined with resin should also be satisfactory.

Piping and fittings of 304 stainless, polyvinyl chloride (PVC) Type 1, Grade 1 or Derakane® FRP should be used. Avoid brass or copper pipe or fittings.

Self-priming centrifugal pumps constructed of stainless steel or nylon are recommended for service with LUDOX® colloidal silica. Durco® II 316 stainless steel pumps have proven satisfactory. Mechanical seals are recommended, but if experienced mechanics are not available, packing should be used. A Viking® HL 724 pump run at low speeds would minimize packing problems.

Diaphragm-type pumps made of stainless steel and equipped with PTFE fluoropolymer resin parts (e.g. pumps of the Wilden Pump and Engineering Company) have given good service.

Valves should be of the same material as the piping. System design should minimize the number of valves, although each line should be valved at both ends. This permits flow control at point of use, prevents massive spills in case of a ruptured line, and also permits work on a line even when the storage tank is full.

The piping system should be flushed thoroughly to remove any silica that may form dried deposits between pumpings. Spills should be flushed with plenty of water. Watch for slipping conditions in the spill area.

Packaging
LUDOX® colloidal silica is available in 55-gal polyethylene nonreturnable drums and 275-gal bulk drums. In North America, also available in tank cars and tank trucks. LUDOX® colloidal silica products are not regulated as hazardous materials by ADR, IATA, DOT or IMO.
Appendix A

Slurry Testing of Difficult-to-Separate Slurries

This procedure will facilitate testing of slurries that are difficult to separate. LUDOX® SK slurries tend to be more difficult to separate than standard alkaline slurries.

Summary of the Method

Weighed portions of the slurry are diluted with known amounts of water to provide additional liquid for separation from the refractory. The diluted binder is separated and the silica content determined.

One portion of the slurry is dried to determine the original water content.

Using these data, the binder silica content of the original, undiluted slurry can be calculated.

The method described below uses two dilutions, and the results of the two experiments are compared for accuracy and averaged.

It is also suggested that the specific gravity of the slurry be determined as a control parameter.

Method

After making sure that the slurry is well mixed and uniform:

1. Weigh out about 100 grams of slurry into a small pan. Record the weight as Slurry Wet Weight (SWW).
2. Dry in an oven at 60 °C (140 °F) – preferably overnight. Record the weight of the dried slurry as Slurry Dry Weight (SDW).
3. Calculate the fraction water:  \( W = 1 - \frac{SDW}{SWW} \)
4. Weigh out two 500 gram aliquots of the slurry into jars with tight fitting lids and add 50 grams of water to one, 100 grams of water to the other. Label A and B, respectively.
5. Shake the water-slurry mixtures until thoroughly blended and then allow to settle.
6. After the slurries have settled somewhat, remove about 15 mL of liquid from the top of A and B, and centrifuge to further separate the binder from the refractory. The goal is to get at least 10 mL of binder phase to work with.
7. Measure out about 10 mL of each binder phase from A and B, and weigh each. Record the weight and volume from each as BWA, BVA, BWB, and BVB (Binder Weight A, Binder Volume A, etc.).
8. Calculate the Specific Gravity of each as:

\[
\text{Sp. G. (A)} = \frac{\text{BWA}}{\text{BVA}} \\
\text{Sp. G. (B)} = \frac{\text{BWB}}{\text{BVB}}
\]

9. Calculate the fraction of colloidal SiO\(_2\) in each as:

\[
\text{fSiO}_2 = \text{Sp. G.} \cdot 1.25 - 1.2125
\]

10. If \( X \) = the grams of Binder Silica in the original 500 g sample of slurry and \( fA \) and \( fB \) = the fractions of Binder Silica in samples A and B, respectively, then:

\[
fA = \frac{X}{50 + 500 \cdot W + X}
\]
and

\[
x = \frac{fA \cdot (50 + 500 \cdot W)}{1 - fA}
\]

\[
fB = \frac{X}{100 + 500 \cdot W + X}
\]
and

\[
x = \frac{fB \cdot (100 + 500 \cdot W)}{1 - fB}
\]

Note: The 50 and 100 are the amount of water added to dilute the original sample in each case.

11. The original % Binder Silica in the undiluted slurry, \( %\text{SiO}_2 \), can be solved for:

\[
%\text{SiO}_2 = \frac{100 \cdot X}{500 \cdot W + X}
\]

Appendix B

Plate Weight and Viscosity Data

Fig. 11: Correlation of Flow Times
Appendix B

Plate Weight and Viscosity Data (continued)

Fig. 12: LUDOX® SK-R-Molochite Slurries (Viscosity vs. Refractory: Binder Ratio)

Fig. 13: LUDOX® SK-R-Molochite Slurries (Plate Weight vs. Refractory: Binder Ratio)

Fig. 14: LUDOX® SK-R-Molochite Slurries (Plate Weight vs. Viscosity)

Fig. 15: LUDOX® SK-Zircon Slurries (Viscosity vs. Refractory: Binder Ratio)

Fig. 16: LUDOX® SK-Zircon Slurries (Plate Weight vs. Refractory: Binder Ratio)

Fig. 17: LUDOX® SK-Zircon Slurries (Plate Weight vs. Viscosity)
## Troubleshooting Guide

<table>
<thead>
<tr>
<th>Problem</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
</table>
| **Shell Delamination and Spalling** | - Spalling of prime coat on dewaxing (“flash firing”).  
- Delamination of outer layer on autoclave dewaxing | - Rapid vaporization of steam condensed in shell wall.  
- More complete drying of shell.  
- Depressurize autoclave slowly. |
| **Shell Cracking**               | - Cracks form during the drying period.  
- Cracks form at end of drying period, but prior to dewaxing.  
- Cracks form on dewaxing in:  
  - Steam autoclave.  
  - Gas furnace.  
- Cracks form on cooling after firing. | - Weight of wet coating deforms cantilever assembled pattern parts.  
- Uneven drying causes gel shrinkage stress development in shell.  
- Rotate pattern assembly while drying or dry in turbulent air.  
- Wax expansion because of an increase in temperature.  
- Wax warms and expands prior to liquefying.  
- Shell too weak to withstand dewaxing pressure.  
- Wax warms and expands prior to liquefying.  
- Shell too weak.  
- Shell too dense.  
- Use of crystalline silica as refractory powder.  
- Devitrification of amorphous to crystalline silica.  
- Impurities in stuccoes or refractory powders. | - Redesign pattern assembly to avoid cantilevered extremities.  
- Begin drying immediately after final coat.  
- Reduce $\Delta T$ ($\Delta T$ is the dry bulb temperature minus the wet bulb temperature).  
- Load, close, and pressurize autoclave more rapidly.  
- Increase thickness; more coats or larger stucco.  
- Increase modulus of rupture.  
- Use higher autoclave pressure.  
- Use lower melting point wax for gates, spruces, etc.  
- Increase furnace temperature.  
- Increase thickness; use more coats or larger stucco.  
- Increase modulus of rupture.  
- Increase shell permeability.  
- Use amorphous silica; i.e., fused silica.  
- Reduce firing time and temperature |
| **Abnormal Slurry Viscosity**    | - Viscosity too high or low as prepared. | - Grain not fully wetted.  
- Improper composition.  
- Entrained air (high viscosity, low density). | - Let mix overnight.  
- Measure density and adjust composition accordingly.  
- Stir slowly to allow air to escape; add antifoam agent only if necessary. |
## Troubleshooting Guide (continued)

<table>
<thead>
<tr>
<th>Problem</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity increases slowly with use:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density high.</td>
<td>Evaporation loss.</td>
<td>Add water.</td>
</tr>
<tr>
<td>Density normal.</td>
<td>Binder gelling due to instability with refractory.</td>
<td>Use only recommended refractory powder.</td>
</tr>
<tr>
<td>Density normal.</td>
<td>High slurry temperature.</td>
<td>Reduce stirring speed; cool slurry.</td>
</tr>
</tbody>
</table>

### Casting Defects

<table>
<thead>
<tr>
<th>Problem</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive defects or “plus metal.”</td>
<td>Prime dip viscosity too low.</td>
<td>Increase prime slurry viscosity to give better casting surface.</td>
</tr>
<tr>
<td>Mold buckle.</td>
<td>Weak shells because of:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Insufficient grain.</td>
<td>Check viscosity and density of slurry.</td>
</tr>
<tr>
<td></td>
<td>– Too thin shell or coats.</td>
<td>Check for slurry gelation (high viscosity, low density).</td>
</tr>
<tr>
<td>“Scabs” or irregular cavities.</td>
<td>Second coat penetrates cracks in prime coat, caused by too fast drying.</td>
<td>Check humidity in drying room to be sure it is near 40–60% (never below 30%). Also, temperature fluctuations and air draft causing irregular drying.</td>
</tr>
<tr>
<td>Metal flash or “fins” (&quot;plus metal&quot;).</td>
<td>Shell cracking because of:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Wax expansion.</td>
<td>Control dip room temperature and humidity. Dry and store at dip room temperature.</td>
</tr>
<tr>
<td></td>
<td>– Low burnout temperature or slow autoclave pressurization.</td>
<td>Increase temperature. Higher steam pressure or larger steam manifold.</td>
</tr>
<tr>
<td>Metal breakthrough (bubbles of &quot;plus metal&quot;).</td>
<td>Insufficient wetting of wax pattern.</td>
<td>Use adequate wetting agent in prime dip slurry. Use prewet solution of binder plus wetting agent.</td>
</tr>
<tr>
<td></td>
<td>Incomplete removal of silicone mold release agent.</td>
<td>Improve pattern cleaning with better solvents and/or detergents and/or procedure.</td>
</tr>
<tr>
<td></td>
<td>Bubbles in the prime coat.</td>
<td>Use light air blast (or blowing) to remove bubbles before stuccoing.</td>
</tr>
<tr>
<td>Generally rough surface.</td>
<td>Prime dip viscosity too low.</td>
<td>Increase viscosity to the extent possible while still filling mold cavities adequately.</td>
</tr>
<tr>
<td>Inclusions (nonmetallic).</td>
<td>Poor mold handling practices: stucco in mold.</td>
<td>Do not stucco final dip. Get full coverage with seal coat.</td>
</tr>
</tbody>
</table>
Additional Information

Other information available from Grace or your distributor to assist with use of LUDOX® colloidal silica for investment casting:


2. “Determination of Ingredients in a Three Component LUDOX® Slurry,”


10. “Rheology Effects on Shell Composition and Strength” W. O. Roberts, Investment Casting World Conference, Fall 1996.