Refractory Molds for Glass Sintering
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FINAL REPORT

Prepared for

Recycling Technology Assistance Partnership (ReTAP)

A program of the Clean Washington Center (CWC),
a division of the Pacific Northwest Economic Region

2200 Alaskan Way, Suite 460
Seattle, Washington 98121

December, 1995

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Report No. GL-95-1
1.0 INTRODUCTION

Recovered glass can be formed into useful articles by filling a refractory mold with powdered glass and heating the glass and mold to a high temperature so that the glass sinters or flows to take the shape of the mold. The process requires precise engineering of both mold materials and mold design to match the glass type, the product application, and scale of the operation.

There are several physical constraints which must be considered for successful glass sintering. The design of the mold must be such that there are no undercuts or reverse entries that would prevent removal of the solidified glass article after heat treatment. Differences in the thermal contraction characteristics of the glass and the refractory mold must be considered and the design of the mold must be such that the glass article does not lock in or become stressed during cooling.

Some glass casting processes use a mixture of plaster of paris and silica sand as a one-time mold material. The plaster of paris degrades during high temperature exposure and the mold can be broken away from the cast piece. However, it is of interest, for economic and practical reasons, to have a mold material which can be used several times to produce multiple pieces. Industrial materials called castable refractory concrete are widely used for furnace linings and multiple-use mold materials in metallurgical and ceramic industries. These materials consist of a refractory hydraulic setting cement phase, typically compounds of calcium oxide and aluminum oxide called calcium aluminates, and an aggregate material. The concretes are generally classified according to their aggregate as silica- or alumina-based materials. The type of aggregate largely determines the temperature capabilities and thermal expansion characteristics of the refractory.

Attempts to use castable refractories for glass molding sometimes encounter problems when the glass sticks to the mold so that either the glass article or the mold breaks while separating the two. The purpose of this assessment was to investigate different mold materials, surface release agents, and different heating schedules to improve release characteristics and produce molds suitable for multiple use cycles without sticking or breaking.
2.0 PROCEDURES

In the following sections, castable refractory shapes are referred to as molds and the original shapes used to define the molds are referred to as models.

2.1 THERMAL GRADIENT FURNACE

A thermal gradient furnace was used to investigate the flow and sintering characteristics of various glasses as a function of temperature. It consists of a SiC element furnace with a muffle tube 2.5 inches in diameter and 26 inches long (6.4 cm by 66 cm). The elements and furnace design establish a natural gradient from the center of the furnace to cooler sections at either end. A hearth in the lower half of the muffle tube contains thermocouples placed at intervals so that the temperature can be measured as a function of position. A typical run with a 5 hour heating cycle heating the center of the furnace to 1000 °C resulted in the following temperature profile:

<table>
<thead>
<tr>
<th>Position from Center (inches)</th>
<th>Temperature (Degrees C)</th>
<th>Temperature (Degrees F)</th>
</tr>
</thead>
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Long, slender castable refractory molds with a cavity approximately 1 by 1 by 12 inches (2.5 cm by 2.5 cm by 30.5 cm) were fabricated and tested in the thermal gradient furnace to determine the glass/mold interactions as a function of temperature. Results are described in Section 3.0.

2.2 UNIFORM TEMPERATURE FURNACE
A SiC element box furnace with a heating chamber approximately 12 by 12 by 12 inches was used for the uniform temperature treatments. Molds made for the gradient trials and new molds with a 6 inch square cavity 3/4 inch deep (15.2 by 15.2 by 1.9 cm) were used. Two heating cycles were employed: a fast cycle, 5°C/min. (9°F/min) with 15 minutes at peak temperature and a slow cycle, 2.5°C/min. (4.5°F/min) with 30 minutes at peak temperature. All specimens were cooled in the furnace and required several hours to reach room temperature. Results are described in Section 3.0.

2.3 GLASS MATERIALS

Clear recovered container glass ground to 6 mesh (3.36 mm opening) and 20 mesh and smaller (0.84 mm opening) was used. Some red glass from a local producer of stained glass was also provided for a preliminary trial.

2.4 MOLD MATERIALS

Two general types of castable materials were used in this investigation. The first type contained fused silica as the aggregate¹ and the second type contained calcined kaolin or fireclay grog as the aggregate². Manufacturer’s data for castable refractories are given in Appendix A. The major difference between the two materials was the thermal expansion coefficient. The silica based material had a very low coefficient of approximately 0.5 x 10⁻⁶ /°C, while the fireclay material had a thermal expansion coefficient of 8.5 x 10⁻⁶ /°C. This becomes important when considering the relative contraction on cooling from the processing temperature. The thermal expansion coefficient of typical container glass is approximately 9.6 x 10⁻⁶ /°C. With regard to sticking and release, both refractories gave similar results. The fireclay based material cost less than the silica based material.

2.5 MODEL MATERIALS

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¹ Easy Cast, National Refractories and Minerals Corp., Livermore, CA 94550 (510-449-5010)
² Lo Cast 50, North American Refractories Co., Cleveland, OH 44115 (216-621-5200) See Appendix A
The refractory concrete can be cast against any model provided the model surface is well sealed and care is taken to ensure there are no undercuts to prevent release from the model. As will be shown later, a smooth, nonporous surface on the refractory is essential for glass release. As the castable will faithfully reproduce the model surface, care must be taken during this stage of the process.

Flexible polyurethane’s smooth surface and durable construction make it a good model material, particularly for production of a large number of molds. The urethane model must first be formed by casting against an original positive model of the final mold shape. Manufacturer’s data for polyurethane is given in Appendix B.

When a small number of molds is required, the refractory can also be cast directly against wood provided the model surface is smooth and well sealed. For example, the wood model can be sealed with a spray polyurethane paint and further sealed with several coats of paste wax.

2.6 CASTING REFRACTORY CONCRETE

The suppliers of castable refractories provide instructions for mixing and casting. It is important to follow the specifications for water content to avoid a mix that is too stiff or too wet. For example, the Lo-Cast product specifies 6.75 to 8% water by weight (dry cement basis). The mixing can be done by hand in various batch sizes provided adequate containers and tools are used to ensure thorough mixing. Mixing should continue for approximately 15 minutes as the flow characteristics of the castable change dramatically with mixing time. A thin sprayed coating of ordinary cooking oil on the model before casting will facilitate removal of the cast ceramic mold from the model. The casting must be vibrated by bumping, shaking, or with a mechanical vibrator to ensure a smooth surface against the model. After casting, the ceramic mold is covered with plastic to prevent premature drying while the hydraulic set occurs. After 24 hours the mold can be removed from the model, air-dried for 24 hours, and then in a dryer for an additional 24 hours at moderate temperatures (less than 100°C; 212°F). The mold is then

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3 PMC - 744, Smooth-On, 1000 Valley Road, Gillette, NJ 07933 (908-647-5800) See Appendix B

4 PAM spray-on release agent
fired to 900°C (1650°F) to remove water and stabilize the ceramic. Small molds can be fired at ramps of 300°C/hr (572°F/hr) while large molds with thick sections should be heated more slowly and allowed to equilibrate at the peak temperature.

To prevent flow and mechanical sticking of the glass, it is important to repair any defects such as pores or bubbles appearing on mold surfaces that contact the glass. An air setting refractory mortar of the type used to make thin joints in refractory furnace walls is suitable for this purpose. This mortar is a thick, flowable particle suspension which is applied to the mold with a small spatula and smoothed in place before it sets hard at room temperature.

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5 SairSet Kiln Mortar, Seattle Pottery Supply, Seattle, WA 98134 (206-587-0570)
3.0 RESULTS

3.1 THERMAL GRADIENT TRIALS

The temperature gradient tests showed that clear glass was fully sintered and did not stick to the surface of the concrete in the temperature range of 870 - 920°C (1598-1688°F). Although the glass first shows signs of shrinkage and sintering at 600°C, it did not flow and was porous and easily broken. At lower temperatures the glass did not sinter and was weak and friable. At the coolest end of the test mold, it was essentially unchanged. At temperatures above 920°C the glass became fluid, wetting the mold and becoming firmly attached to the mold surface. In these conditions, because the mold material had thermal contraction less than that of the glass, major cracking and crazing of the glass occurred because of its greater shrinkage during cooling.

The red glass was either unsintered or very fluid and stuck to the mold, indicating a very short working range and a very rapid change in viscosity with temperature. The glass began to flow at 760 to 780°C (1400 to 1436°F) and immediately stuck to the walls of the mold.

3.2 UNIFORM TEMPERATURE TRIALS

Using the temperature range specified in Section 3.1, uniform temperature trials were run on both 1 x 1 x 12 inch and 6 x 6 x 3/4 inch molds using minus 6 and minus 20 mesh glass materials.

3.2.1 1 x 1 x 12 inch Molds

Both the fast cycle (3.33 hr. to 920°C, 15 min. at peak temperature) and the slow cycle (6.66 hr. to 870°C, 30 min. at peak temperature) resulted in strong sintered glass that released easily from the mold without sticking or wetting. The slow cycle (870°C) corresponded to a 011 standard cone* . The initial charge of powdered glass was one inch deep, and the final part thickness was 0.6 inches for a shrink factor of 0.6 times the initial depth. Lateral shrinkage was negligible. The two different size glass

* Cones are used to measure the actual amount of heat work during a firing.
powders behaved similarly, except that the large particle size material was more translucent and had a more visible grain structure.

3.2.2 6 x 6 x 3/4 inch Molds

This larger mold was used to simulate tile and flat patterned relief products that can be produced through sintering. The slower heating cycle was used for the larger tile. To ensure proper heating through the entire charge, which contained about twice the glass content as the bars, a one hour dwell time at peak temperature was used. Strong, dense tiles that released easily from the cement mold were obtained. The final thickness from the 3/4 inch deep charge was about 1/2 inch resulting in a shrink factor of 0.6 to 0.62 times the initial depth. The dimensional change in the lateral direction was small with the final dimension of 5.95 x 5.95 inches.

Up to 15 successful trials were made on the 1 x 1 x 12 inch molds and the mold surface was generally in excellent condition. However, small air bubbles and defects in the cement surface progressively enlarged with each casting. For repeated use of one mold, an air setting cement mortar was used to fill the holes and defects in the molds, as described in the “Procedure” section. This patching technique increased the mold life and did not adversely effect the finish of the glass.

No trials were made on articles having detailed surface features. However, on one of the 6 x 6 tiles the glass was fluid enough to flow into and fill a tiny pore less than one millimeter in diameter. Even under these flow conditions, the glass did not wet and stick to the smooth refractory surface, indicating that casts with fine detail can be produced.

3.3 GLASS PARTICLE SIZE

Ground glass was separated into two size fractions: large grains (6 mesh) and small grains (20 mesh and smaller). Sintered samples from the small grain material were milky-white in color and had a very smooth surface finish, whereas samples made from the large grain materials were semi-transparent glass with a rougher, granular looking surface finish. The large granules did not melt together as quickly or
smoothly because of the decreased surface area contact between the glass particles. It would be necessary to increase the peak temperature and dwell time at peak temperature for better flow of the large granules.

3.4 THERMAL EXPANSION

Figure 1 shows thermal expansion versus temperature curves for sintered glass and Lo Cast 50 refractory mold material. The change of slope of the glass expansion at 550°C indicates the glass transition temperature for this container glass. This is the temperature at which the glass changes from a solid (low temperature) to a liquid-like material (high temperature). The turnover in the curve at 575°C, indicating shrinkage of the fine particle material, is typical for glass and is caused by deformation or flow under the small pressure exerted by the measuring instrument. The curve for the material made from coarse particles is unusual. The flattening of the curve at 575°C indicates flow, but also indicates some resistance to shrinkage deformation persists up to 870°C.

The thermal expansion of the refractory is less than that of the glass. This relationship may be interpreted as follows for the sintering process: At the maximum temperature for sintering, e.g. 870°C, the glass flows into the mold and the two are in contact and are the same size. On cooling, the glass can deform and accommodate temperature changes until the glass transition temperature in the range 570 to 550°C. From this point down the glass behaves as a solid, and the thermal expansion curve, now considered in the contraction mode, tells us that the solid glass shrinks more than the refractory. If the glass does not stick to the refractory, it will pull away from the walls and release from the mold. However, if the glass sticks to the refractory, then its attempts to shrink away from the mold walls will cause cracking of the glass. Differential contraction during cooling must also be considered when patterns exist in the mold surface. Two points in the glass must not lock into the mold pattern and the glass must be free to contract if cracking is to be avoided. The differential contraction from 550°C to room temperature is 0.2% or 0.020 inches in a 10 inch span.
4.0 CONCLUSIONS

1. Molds made from castable refractory cement can be used to sinter dense glass articles from powdered recovered container glass provided the mold surfaces are smooth and pore free, and the time temperature cycle is closely controlled.

2. Industrial grade castable refractory with a fireclay or calcined kaolin aggregate is suitable for mold fabrication. High temperature refractories with high purity alumina aggregate or special low expansion refractories with fused silica aggregate are not required. However, it is essential that the castable refractory is able to produce a smooth, pore free surface against a model.

3. The refractory molds can be used for repeated casts without wear or damage provided the mold surface is smooth and minor defects are repaired between runs.

4. The glass charge becomes dense and pore free at 870 to 920°C (1598 °F to 1688°F). Finely ground clear container glass (20 mesh and finer) flows and sinters at 870°C into a dense, pore free, milky white material. Larger size glass particles (6 mesh) require approximately 920°C for sintering and produce a translucent material with a visible residual grain structure.

5. The one-inch thick glass charges saw a reduction in thickness by a factor of about 0.6 and very little reduction in lateral dimensions. The difference in shrinkage between the glass and the refractory on cooling is approximately 0.2% with the glass shrinking more than the refractory. Differential contraction during cooling should be considered when patterns exist in the mold structure.
5.0 ACKNOWLEDGMENTS

The assistance of Mr. Steven Sofie in carrying out the many casting and heating trials in this work is gratefully acknowledged.

ReTAP is a joint venture of the Clean Washington Center (CWC), an organization with a strong involvement in the market development of recycled materials through the development of new technologies, and the National Recycling Coalition, a 3,500 member nonprofit organization committed to maximizing the benefits of recycling. ReTAP is an affiliate of the national Manufacturing Extension Partnership (MEP), a program of the U.S. Commerce Department’s National Institute of Standards and Technology. The MEP is a growing nationwide network of extension services to help smaller U.S. Manufacturers improve their performance and become more competitive. ReTAP is also sponsored by the U.S. Environmental Protection Agency and the American Plastics Council.
APPENDIX A

Manufacturer Literature for Refractory Castable
North American Refractories Company

LO-CAST 50 HS

FEATURES

High Hot Strength. Exceptional strength up to 2000°F makes LO-CAST 50 HS resistant to abrasion, mechanical abuse and erosion by molten metals or hot gases.

Low Hot Load Deformation. Longer service due to LO-CAST 50 HS's ability to retain its structural stability even when heavily loaded.

Excellent Thermal Shock Resistance. Much less susceptible to damage caused by thermal cycling.

Low Porosity- High Density. Results in low permeability which stops penetration by liquid metals, sags and corrosive gases.

High Strength. Excellent resistance to mechanical abuse and no loss in strength between 1000°F and 2000°F as seen with conventional castables.

Volume Stable. Installed with less water than conventional castables so there is less chance of any shrinkage cracking in service or during (17-out).

APPLICATIONS

Minerals Processing. Feed ends, chain sections, cooler walls, cooler discharge slopes, multiple hearth roasters and tunnel kiln car tops.

Ferrous Metals. Reheat furnace walls and roofs, bull ladles, heat treat furnace car tops and forge furnaces.

Non-Ferrous Metals. Aluminum furnace sub-hearths, doors, jambs, lintels, sills, and roofs; flue caps and precast headwalls in carbon baking furnaces.

Chemical Processing and Refining. Boiler ash hoppers; sections of coke calcining and alumina kilns; shop casting of FCCU cyclones and transfer lines,

Steel Mills. Coke oven roofs, doors and standpipes; soaking pit walls; skid rail tiles; car tops in heat treat furnaces and tundish back-up linings.
North American Refractories Company

Brand L0-CAST 5O HS
Class Low-Moisture Castable
Plant Curwensville, Pennsylvania

Typical Test Data

Maximum Recommended Temperature, °F. °C 3000-1649
Pyrometric Cone Equivalent, cone 34
Material Required, lb/ft³ - kg/m³ 135 - 2160
Water Required to Temper, % by Wt. 8.0
Abrasion Test, 1500 degrees F (816°C) - cm³ 13

Thermal Shock, % Strength Loss
Fired @ 22000F (1204°C) - Cycling 2200 degree F (1204°C) 27
Fired @ 2500°F (1371°C) - Cycling 2200°F (1204°C) 30
Fired @ 2900 degree F (1593°C) - Cycling 2200 degree F (1204°C) 92

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<th>Bulk Density (lb/ft³)</th>
<th>Total Linear Change (%)</th>
<th>Modulus of Rupture @ Temp (lb/in²)</th>
<th>Hot MOR Crushing Strength (lb/in²)</th>
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Chemical Analysis, As Received, Wt., %

- SiO₂: 47
- Al₂O₃: 48
- Fe₂O₃: 0.9
- TiO₂: 1.5
- CaO: 2.1
- MgO: 0.1
- Na₂O.K₂O: 0.4
- L.O.I: 0.5
- LOI: 0.5

Material Safety Data Sheet available Upon Request.

The data given above are based on averages of test results on samples selected from routine plant production by standard A.S.T.M. test procedures where applicable. Variation from the above data may occur in individual tests. These results cannot be taken as minima or maxima for specification purposes.
Installation Procedures
LO-CAST-Type Castables

Job Site Conditions:

Temperature: 60-80°F of dry castable arid mixing water.

Water Quality: Clean potable water

Mixing Equipment:

High-intensity Eirich-type or heavy-duty paddle mixer

3-8 minutes dependent upon mixer intensity. Do not over or under mix.

Vibration Equipment:

High intensity pneumatic form vibrators or high intensity immersion vibrators

Environment:

Do not attempt to install frozen material. Also, installed material must be protected from freezing until dried out

Installation:

Temper castable starting with the minimum quantity of water recommended or required for placement with the vibration equipment available. Allow at least 4 to 5 minutes of mixing time before any additional water is added. Water can then be added in 0.1 to 0.2 percent increments to obtain the flow required for proper densifications. Mixing time for these water additions should be about two minutes. Flow can be checked by removing a small quantity of material from the mixer and placing it in contact with vibration. For materials containing steel fiber additions, the water requirements may increase by 0.3 to 0.5 percent. Adjust subsequent batches slightly wetter or drier dependent upon flow required during vibration placement.

Densify castable installation with adequate vibration. Unless castable is tempered too wet, separation caused by excessive vibration is unlikely.

Install castable NON-STOP until job is complete.
Curing: Curing should be at 70-90°F for 18 to 24 hours. Moisture loss should be prevented by covering the cast material with an impervious material.

Dry Out:
- Slow fire 50°F per hour to 250°F
  Hold at 250°F for 1 hour per inch of thickness
  Raise 75-100°F per hour to 1200°F
  Hold at 1200°F for 1 hour per inch of thickness
  Raise at 100-150°F per hour to operating temperature

If high pressure steam, massive quantities of steam, or material spalling are observed at any time during heat-up, the temperature should be held or reduced until steaming stops. Then the schedule can be resumed.

NARCO will provide alternate dry out schedules for specific applications upon request.

Safe Heat-up Rate: After material has been properly dried and has been allowed to cool to ambient temperature, it can be reheated at a maximum rate of 300°F per hour to operating temperature.
BRAND: LO-CAST 50 HS

APPLICATION: VIBRATABLE CASTABLE

DESCRIPTION: Low iron 3000°F abrasion resistant high strength vibratable castable mix.

SERVICE DATA: (ASTM C113, C133, C20)
(After firing to stated temperature)

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Grain Size: -4 mesh
Abrasion Loss (ASTM C-704) 7-10 cm³

APPLICATION DATA:
Maximum Service Temperature (MST) (°F) 3000
Amount Required for Installation (pcf.) 142-145
Bulk Density - After Drying at 220°F (pcf.) 144
- After Firing to 2500°F (pcf.) 142
Water required for 100 lbs. dry (Approx.) (wt.%) Vib-Cast 6.0 - 6.75
Pencil Vibrate - 6.75 - 8.00

CHEMICAL DATA:
Alumina (Al₂O₃) 47.4 % Lime (CaO) 2.2 %
Silica (SiO₂) 46.2 % Magnesia (MgO) .1 %
Titania (TiO₂) 1.8 % Alkalies (Na₂O, K₂O) 1.2 %
Ferric Oxide (Fe₂O₃) .4 % L.O.I. .4 %

All data are based on results of control tests and describe typical average values that are subject to reasonable variation. Values are not intended, nor should they be used, for specification purposes.
**EZ CAST 2200-FS**

**SELF FLOW/PUMPABLE FUSED SILICA LOW CEMENT CASTABLE**

Recommended Service Temperature Limit ........................................ 2200°F
Water Required For Mixing: Self Flow ........................................ 7.0 - 8.0%
: Vibrated, External or Internal Vibration .................................. 4.5 - 5.5%
Material Required Per Ft³: Self Flow ...................................... 118-122 lb
: Vibration ........................................................................ 122-126 lb
Packaging ............................................................................. 55 lb bag

**SELF FLOW/PUMPABLE CONSISTENCY**

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<td>118-122</td>
<td>-0.4 to 0.0</td>
<td>1000-1600</td>
<td>4000-7000</td>
<td>12-14</td>
</tr>
<tr>
<td>2000</td>
<td>115-119</td>
<td>-0.6 to -0.2</td>
<td>1200-1600</td>
<td>5000-8000</td>
<td>13-15</td>
</tr>
</tbody>
</table>

**CAST-VIBRATED CONSISTENCY**

<table>
<thead>
<tr>
<th>TEMPERATURE (°F)</th>
<th>BULK DENSITY (lb/ft³)</th>
<th>LINEAR CHANGE (%)</th>
<th>MODULUS OF RUPTURE (lb/in²)</th>
<th>COLD CRUSHING STRENGTH (lb/in²)</th>
<th>APPARENT POROSITY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>123-127</td>
<td>-0.2 to 0.0</td>
<td>1200-1600</td>
<td>5000-8000</td>
<td>8-10</td>
</tr>
<tr>
<td>1500</td>
<td>122-126</td>
<td>-0.4 to 0.0</td>
<td>1200-1600</td>
<td>7000-10000</td>
<td>9-11</td>
</tr>
<tr>
<td>2000</td>
<td>123-127</td>
<td>-0.5 to 0.0</td>
<td>1200-1600</td>
<td>8500-11500</td>
<td>9-11</td>
</tr>
</tbody>
</table>

**CHEMICAL ANALYSIS:**

- Al₂O₃ ............. 11.0%
- SiO₂ ............... 87.8
- Fe₂O₃ .............. Tr
- TiO₂ .............. Tr
- CaO ............... 1.1
- MgO ............... Tr
- Alkalies ........... 0.1
- Mean Temperature (°F)  
  - Pour Cast  
  - Vibration Cast
- K-Factor (BTU-in/h-ft²-°F)
  - Pour Cast  
  - Vibration Cast
- HOT MODULUS OF RUPTURE (lb/in²)
  - At 1500°F .......... 2000-2500
- ABRASION LOSS (cm³)
  - Pour cast at 7.5% water
  - Vibration Cast at 4.0-5.0% water

These data represent average properties obtained on self-flow and vibration-cast specimens from test production lots by ASTM Standards tests, except where noted; other forming methods and/or test procedures may yield different data.

This data sheet was published December 11, 1991. Check with your National Refractories sales office to make sure you have current data sheet.
EZ CAST

MIXING INSTRUCTIONS

Mixer: Refractory Paddle Mixer or Vertical Shaft Turbine Mixer

Water: Potable water only

<table>
<thead>
<tr>
<th>Consistency Desired</th>
<th>EZ CAST 2200-FS or 2200-FS AL</th>
<th>EZ CAST 2800</th>
<th>EZ CAST 3000 or 3000-AL</th>
<th>EZ CAST 3200 or 3200-AL</th>
<th>EZ CAST 3400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self/Flow Pumpable</td>
<td>7.0-8.0%</td>
<td>7.0-7.5%</td>
<td>5.5-6.5%</td>
<td>5.5-6.0%</td>
<td>5.0-5.5%</td>
</tr>
<tr>
<td>Vibrated</td>
<td>4.5-5.5%</td>
<td>4.5-5.5%</td>
<td>4.0-5.0%</td>
<td>4.0-5.0%</td>
<td>4.5-5.0%</td>
</tr>
</tbody>
</table>

Sequence:
1. Add 4.0-5.0% water
2. Mix two-three minutes
3. Add additional remaining water
4. Mix five minutes minimum after initial water is added
5. Recommended wet mix temperature is 60-100°F

Additions:
1. Slowly add metal or XR fibers before water is added
2. Dry mix two-three minutes
3. Follow standard mixing sequence above
4. Metal fibers can also be added slowly during wet mixing

Working Time: Minimum of one hour after mixing

Pumps:
No Additions - Swing tube (S valve) type preferred or ball valve pump
With Additions - Metal fibers restrict usage to swing tube (S valve) type

NOTE: EZ CAST 3400 not recommended for pumping

Vibration: External vibrators are preferred

Flow Test: A special flow test is available to determine proper consistency. National Refractories representatives should be contacted for additional information.

Shelf Life: Six to nine months. Mixes should be stored in a cool, dry area under cover.

Classification: EZ CAST 2200-FS, 2200-FS AL, 3000,3000-AL, 3200, 3200-AL AND 3400 Series mixes are low-cement castables per ASTM C 401. EZ CAST 2800 is classified as a regular castable.
Drying Schedule

The following are general guidelines for drying and initial heat-up of EZ CAST self flow castables.

1. Allow to cure at ambient temperature for 24 hours after the castable is in place. Ambient temperature should be 60°F to 100°F. For installation temperatures outside this range, consult a National Refractories representative.

2. Keep the castable moist during the ambient curing period by using a membrane curing compound, plastic sheet or a water mist spray.

3. Drying schedule:
   a. Increase from ambient to 300°F at a rate of 50°F per hour
   b. Hold at 300°F for one hour per inch of lining thickness (minimum of 6 hours)
   c. Raise to 450°F at 50°F per hour
   d. Hold at 450°F for one hour per inch of lining thickness (minimum of 6 hours)
   e. Raise to 600°F at 25°F per hour
   f. Hold at 600°F for one hour per inch of lining thickness (minimum of 6 hours)
   g. Raise to 1000°F at 50°F per hour
   h. Hold at 1000°F for one hour per inch of lining thickness (minimum of 6 hours)

4. The structure can then either be cooled or raised to normal operating temperature at 100°F per hour.

NOTES:
A. The use of 55F fibers in the castable does not guarantee a rapid heat-up rate. But, it does significantly reduce the possibility of internal damage during heat-up.
B. Temperatures should be monitored at the refractory surface at several locations in the unit.
C. The schedule should be controlled initially by the hottest area monitored. If this results in exceeding the recommended rate in the coolest area of the unit, then the coolest area should become the control and the schedule picked up again at that point.
D. If steaming is observed at any time during the schedule, the temperature should be held constant until the steaming subsides. The schedule can be resumed when steaming ends.

NOTICE:
This schedule is not a guarantee, nor is it intended to cover every installation of National Refractories products. However, it is to be used as a general guideline and is not necessarily applicable to all installation conditions. National Refractories representatives should be consulted for assistance with specific circumstances.

Schedule 100 08-27-81

NATIONAL REFRACTORIES & MINERALS
COLD WEATHER INSTALLATION

EZ CAST mixes have set times of 8-10 hours when wet mixed between 60-100°F using freshly made material. Even after a dry storage time of six months, the mix should still set up overnight when used within this temperature range. With winter coming on, lower temperatures will further extend these working times. This temperature-related phenomenon also occurs with KRICON~ products, but it affects EZ CAST even more. This is because EZ CAST products are designed to have longer set times to facilitate the pumping and self-flow characteristics. Early form removal when using EZ CAST mixes can be dangerous! The result can be material flowing in all directions.

To combat this problem, the following procedures should be used during cold weather conditions:

1. Ensure that the dry material is stored above 60°F prior to use.
2. Use warm water to keep the wet mix temperatures above 60°F.
3. Ensure that temperatures during the curing time remain well above freezing.
4. Preheat the mold area prior to installation of EZ CAST.

It may not always be possible to meet all of the above requirements. Therefore, we have two EZ CAST formulations specifically for cold weather. These two will be the EZ CAST 2800-W and EZ CAST 3200-W. They must be ordered with the W designation to ensure that the proper formulation is shipped. At this time we believe there is need for only these two EZ CAST winter versions. Remember, only order the special mixes when cold weather conditions cannot be overcome. Recently produced EZ CAST winter versions may set in thirty minutes or less when used in a warm environment.

FORM CONSTRUCTION

When preparing to use EZ CAST mixes, ensure that the forms are of sturdy construction. This is required in order to withstand the high hydrostatic pressures created by the flow characteristics of these mixes. Some of the initial installations were aborted due to the use of flimsy forms. Internal forming should be properly secured to prevent the form from lifting or shifting during the casting of the fluid EZ CAST mixes.
Free Flowing Castables

A new line of self-leveling castables is now available from National Refractories for use in casting large or intricate refractory shapes, forms with extensive anchoring, and hard to reach service areas -- all without the need for vibration or other settling techniques.

The new Ez CAST™ products have been designed specifically to provide refractory users and contractors with a series of clay/alumina castables that can simply be poured into place from the mixer or pumped/poured using regular concrete pumps.

This ease of placement creates an extensive listing of applications, including rotary hearth furnaces, preformed shapes, furnace roofs, cyclones, ladles, tundishes, delta sections, cooler walls, etc.

Eight mixes are currently being offered: Ez CAST 2800, Ez CAST 3000 or 3000-AL, Ez CAST 3200 or 3200-AL, Ez CAST 3490, and Ez CAST 2200-FS or 2200-FS AL. The product name corresponds to the product’s recommended maximum service temperature, with the AL signifying a non-wetting version for aluminum contact and the FS identifying fused silica products.

Unlike most other refractory castables that require heavy external vibration to assure a quality casting, this new line of mixes will flow effectively without vibration at a very low water content (below 6% in many cases). Further improvement in properties can be obtained using internal or external vibration in the 4-5% water range.

The products require a minimum of five minutes mixing time using standard paddle or high-intensity mixers. Additional mixing can further increase fluidity. Placement can be achieved through ordinary swing-valve or ball valve concrete pumps using 2’ or larger hose or pipe.

Although the Ez CAST mixes appear very wet when properly mixed, they develop most of their strength overnight and forms can be stripped within 24 hours. They are designed to be installed at an ambient temperature between 60°F and 100°F. For installation temperatures outside this range, consult a National Refractories representative.
APPENDIX B

Manufacturer Literature for Flexible Polyurethane Mold Material
PMC-744 was developed specifically for the Hobby/Ceramics field and the making of ceramic molds. Years were spent in research and testing. The result is a compound that is excellent for making molds that are strong, durable and dimensionally stable. Low viscosity ensures fine detail reproduction. PMC-744 will last longer in production than plaster and will not shrink like latex, saving you time and money.

PMC-744 is also ideal for making plaster block molds, reproducing ornamental plaster, pre-cast concrete molds, casting a variety of resins (including Smooth-On urethane resins) and making a variety of mechanical rubber parts.

### Technical Overview

**Key Values:**
- **Mix Ratio:** Two parts A to One part B by weight.
- **Color:** Clear Amber
- **Pot Life:** 15 minutes.
- **Shore A Hardness:** 45
- **Demold Time:** 16 hours.

**Description:** PMC-744 consists of two components, Part A (Yellow Label) and Part B (Blue Label). When combined in a mix ratio of two parts A to one part B, PMC-744 cures to an elastomer suitable for a variety of applications.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Color</th>
<th>Viscosity</th>
<th>S.G. g/cm³</th>
<th>Specific Volume</th>
<th>Mix Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>PART A</td>
<td>Clear Yellow</td>
<td>4,500 cps</td>
<td>1.020</td>
<td>27.1 cm³/in²/lb</td>
<td>2 Parts by Weight</td>
</tr>
<tr>
<td>PART B</td>
<td>Amber</td>
<td>3,400 cps</td>
<td>1.000</td>
<td>27.7 cm³/in²/lb</td>
<td>1 Part by Weight</td>
</tr>
<tr>
<td>Mixed</td>
<td>Clear Amber</td>
<td>3,400 cps</td>
<td>1.010</td>
<td>27.5 cm³/in²/lb</td>
<td></td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>300 psi</td>
<td></td>
<td></td>
<td>100% Modulus</td>
<td>100 psi</td>
</tr>
<tr>
<td>Elongation At Break</td>
<td>400%</td>
<td></td>
<td></td>
<td>Tear Strength (80%)</td>
<td>90 psi</td>
</tr>
<tr>
<td>Compression Set</td>
<td>15%</td>
<td></td>
<td></td>
<td>Shrinkage</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

### Start by Preparing Your Model

**Porous Models Require A Sealer...** Moisture may interfere with the proper cure of polyurethanes. Reasonably dry surfaces are necessary. Models made of porous materials (gypsum plasters, wood, stone, brick, masonry) must be sealed to eliminate porosity before a release agent is applied. Paste wax (wipe on, then buff) is excellent for smooth surfaces. Spray shellac is suitable for rougher contours. U-10 Soap Solution (available from Smooth-On) is the recommended sealer for gypsum plaster surfaces because of its minimal effect on surface texture.

This soap solution should also be used without the ensuing coating of release agent whenever permanent staining of the mold surface (stone, masonry) must be minimized.

**Non-Porous Models...** made of metal, glass, acrylic, pvc, other hard plastics and sulfur-free clays require only a release agent which should be allowed to dry before applying the rubber.

**Apply a Release Agent...** Polyurethanes are adhesive. A release agent is required to facilitate demolding.

You can purchase a suitable release agent from Smooth-On or from your local Smooth-On distributor. A liberal coat of mold release should be applied onto all surfaces that will contact the rubber, including the table and surrounding forms.

**IMPORTANT:** To ensure thorough coverage, lightly brush the release agent with a soft brush over all surfaces of the mold (especially areas of intricate detail). Let the release agent dry for 30 minutes before applying rubber.

**Special Cases...** Certain lacquers and thermoplastics (polystyrene) must be protected from the dissolving action of plasticizers in urethane compounds. A thorough coating of PVA (polyvinyl alcohol) is mandatory. After the PVA has dried, apply a mold release over the PVA. Modeling Clay that contains sulfur, which may inhibit the cure of polyurethanes, must also be coated. Shellac or PVA serve the purpose. If shellac is used, a thorough coat of a mold release must be applied due to the potential bond of shellac and polyurethanes.

**If there is any question** about the effectiveness of any sealer or sealer/release combination, a small scale test should be made on an identical surface for trial purposes.
MIXING AND POURING PMC-744

Proper mixing of this product is critical to achieving best results.

Unclassified, in general, are moisture sensitive and will absorb atmospheric moisture. Mixing tools and containers should be clean and made of metal, glass or plastic. Do not use wooden utensils or paper containers. IMPORTANT: Immediately replacing the lids on both containers after dispensing product will prolong the shelf life of the unused product. ~ SHELF LIFE OF PRODUCT IS DRASTICALLY REDUCED AFTER OPENING. REMAINING PRODUCT SHOULD BE USED AS SOON AS POSSIBLE.

Again, the mix ratio of this product is 2 Parts A to 1 Part B by weight. Mixing should be done in a well ventilated area.

Minimize skin contact by wearing latex gloves and long sleeve garments. Pour desired amount of Part A as measured by weight into a container. Add the proper amount of Part B by weight and mix thoroughly, making sure that you scrape the bottom and sides of the container several times. On average, 3 minutes mixing time at room temperature (77 F) is sufficient. Your mixture should now be a clear amber. Do not delay between mixing and pouring the rubber. Elevated temperature and humidity levels will reduce the pot life of PMC-744 significantly. Pouring a continuous steady stream in one corner of the mold cavity until the...

GETTING THE MOST OUT OF YOUR MOLD

Curing ... Allow the mold to cure overnight (at least 16 hours) at room temperature (77 F/25 C) before demolding. Molds will reach ultimate properties in about 7 days. The mold will cure faster at higher temperatures and will cure slower at lower temperatures. Do not cure the mold where the temperature is less than 65 F/18 C.

Using the mold ... No release agent is necessary when casting wax or gypsum in PMC-744. Spreading the mold with soap solution prior to casting reduces air bubbles in the plaster and aids separation. Thermosetting materials such as epoxies and polyurethanes can be cast into PMC-744 with the use of a proper release agent. The mold should be sprayed with the release agent, brushed over all surface areas, and allowed to dry prior to pouring the thermosetting material into the mold. The number of castings that can be cast from PMC-744 depends on many factors including detail of the mold, type of material being cast, choice of release agent, etc. If casting Polystyrene, we recommend a thorough continuous coating of Polyvinyl Alcohol (PVA) to protect your mold from chemical degradation prior to applying release agents.

Mold Performance and Storage ... Fully cured molds made of PMC-744 are tough, durable and will perform well if properly used and stored. The physical life of your mold depends on how you use it (materials cast, frequency, etc.). Casting abrasive materials such as concrete will eventually erode detail from the mold's working surface. You will enjoy longer mold life if casting non-abrasive materials such as wax. Before storing, the mold should be cleaned with a soap solution and wiped fully dry. Two-part (or more) molds should be assembled. Molds should be stored on a clean and level surface, indoors in a cool and dry area. Do not expose the mold to moisture or sunlight (ultraviolet light sources). Do not stack molds on top of each other as warpage could result.

SAFETY FIRST!

The Material Safety Data Sheet for this or any Smooth-On product should be read before using and is available upon request. All Smooth-On products are safe to use with proper handling and precautions. Read and follow directions carefully.

Be careful. PMC-744 Part A is a TDI prepolymer. Vapors, which can be significant if prepolymer is heated or sprayed, cause lung damage and sensitization. Use only with adequate ventilation. For both Parts A and B: Contact with skin and eyes may cause severe irritation. Flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with soap and water. Prepolymers contain trace amounts of TDI which, if ingested, must be considered a potential carcinogen. Refer to the MIDS for this product. Avoid skin contact by wearing long sleeve garments and latex gloves. If skin contact is made, remove immediately with soap and water. If eye contact is made, flush eyes with water for 15 minutes and seek immediate medical attention.

Important: The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe a patent. User shall determine the suitability of the product for its intended application and assumes all risk and liability whatsoever in connection therewith.

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Our FAX Number (24 Hours A Day) .......... (908) 604-2224

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SMOOTH-ON rigid urethanes are two part liquid plastics (Part A and Part B) that mix and pour easily. Low viscosity ensures flawlessness pick up of even the finest detail. They cure at room temperature to form tough, solid plastics. Good for a variety of applications including:

- Prototype Parts
- Production Parts
- Durable Models
- High Impact Tooling
- Ultra thin-wall castings
- Die Fittings
- Vacuum Forming Molds
- Foundry Patterns
- Artistic Creations
- Durable Miniatures
- Architectural Models

Smooth-On ... Your Mold Making Partner.