

# Plasters and Gypsum Cements

## Plasters for the Ceramic Industry

Plaster molds are a vital to producing many types of ceramicware. Along with a few other materials, plaster is the basic modeling material for tooling in the ceramic industry. Consequently, a review of recommended procedures and the relationship between plaster tooling and hand and mechanized clay fabrication may prove helpful.

Following are definitions of common technical terms mentioned in this discussion.

**Block Mold.** Original mold made from a finished model. Used to make check casts before case molds are fabricated.

**Case Mold.** Made from the block mold, it becomes the die for fabricating working molds.

**Working Mold.** Sometimes called a production mold, it can be one of three types: casting mold, jigger mold, or press mold.

**Consistency.** The water-to-plaster ratio or number of parts of water, by weight, mixed with 100 parts of plaster, by weight.

**Alpha Hemihydrate.** Gypsum calcined under pressure, producing a lower-consistency material with different crystalline structure than ordinary plaster. It produces harder and stronger casts with limited absorptive power. Alpha hemihydrate can be obtained in different formulations to control expansion, consistency and strength. Also known as gypsum cement.

**Beta Hemihydrate** (also known as plaster of paris, kettle plaster, kettle stucco). Gypsum calcined in a kettle at atmospheric pressure. The individual particles are highly irregular in shape, which causes high water demand to make a workable slurry.

**Snap-Set of Plaster Slurry.** The condition when plaster sets before it is sufficiently soaked and completely mixed.

**Slow Set of Plaster.** Plaster unusually slow in setting.

### Absorption: Key to Slip Casting

The absorptive property of plaster molds makes slip casting possible. The mold can be likened to a rigid sponge, drawing water from the slip, retaining it and gradually passing it through the mold to the back, where it evaporates. Maintaining a desirable rate of casting depends upon establishing equilibrium between water absorption from the slip and drying out of the mold. The factors governing this relationship are:

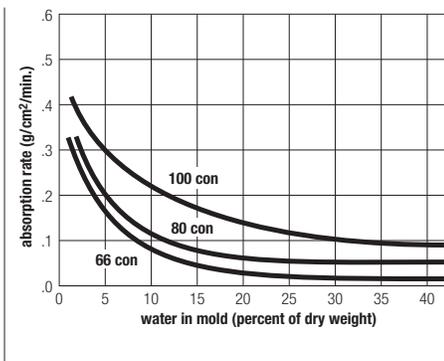
1. The water-to-plaster ratio (varying from 68 to 90 parts of water to 100 parts of plaster, by weight) governs the initial absorptive power of the mold. In large, multi-piece sanitaryware molds, some parts of the mold require a higher water-to-plaster ratio than others to give greater absorption to selected portions of the cast.
2. Homogeneity (freedom from pinholes and bubbles) governs to some extent the even capillary movement of water through the plaster mold. Uniformity is a function of mold-making technique and attention to detail in the mixing operation.
3. The rate of absorption over a broad range of water content in the mold governs the long-term casting quantities of the mold. At what minimum moisture content is the high absorptive rate too great? At what maximum moisture content is the low absorptive rate enough to do the job?

Best results generally are achieved when the driving power of a mold is "in balance" with the layer of slip that has built up on its working face. The ability of a mold to transport water from the ware surface should have some relation to the rate at which water reaches the interface between ware and mold.

If the mold absorbs water from the slip too quickly, the result is surface shrinkage of the body immediately next to the mold. This produces a reduced rate of casting, surface cracks, case hardening or premature release of the ware. If the mold removes water too slowly, the cast does not build up at a satisfactory rate, is likely to be soft or "mucky," and the ware tends to stick to the mold. Once a state of approximate equilibrium is reached, continuous capillary columns exist from the slip-mold interface entirely through the mold to its exterior.

The data in Fig. 1 indicates how fast water may be taken up by a casting mold in various shop conditions. The maximum rate of absorption varies from approximately 0.38 g/cm<sup>2</sup>/min. through a fairly typical value of 0.20 g/cm<sup>2</sup>/min. to a practical minimum of 0.08 g/cm<sup>2</sup>/min. It is important to note that a major determinant of absorption rate is the amount of free water present in the mold. Fig. 1 demonstrates the importance of optimum mold "conditions." With typical water-to-plaster ratios, the presence of 5% free water reduces the rate of absorption approximately 50%. It generally is good practice to have a minimum of 5% free water, and many shops have as much as 15%.

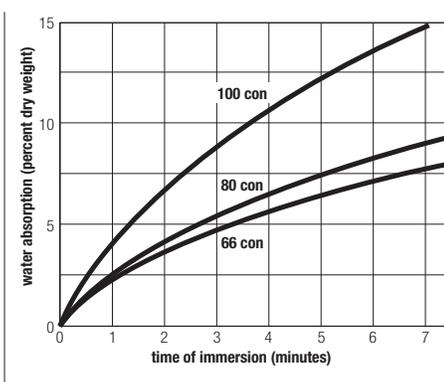
**Figure 1: Effect of consistency and free water in sample on the rate of water absorption during immersion.**



### Free Water and Absorptive Rate

The presence of free water markedly reduces the absorptive rate of a given mold, and best results are achieved only when proper allowances are made. The best method of conditioning a mold is to dry it to a constant weight at 110 °F, then dip it in water for a few seconds to a few minutes. Fig. 2 indicates the time required to condition a plaster mold to perform in the range of the flat part of the curve shown in Fig. 1.

**Figure 2: Accelerated absorption during initial immersion.**



If the character of the slip is reasonably uniform and shop conditions are optimum, it is possible to determine free water content by weighing well-performing molds, then using this figure as a guide for the entire shop. A more practical procedure is to ascertain the maximum safe rate at which water can be released by the slip, then adjust both the consistency of the mold and the free water contained in it to determine a compatible absorptive rate. Plaster casting bodies probably will not release water safely much faster than about 0.2 g/cm<sup>2</sup>/min. to 0.3 g/cm<sup>2</sup>/min.

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To hold down costs, use as dense a mold as shop conditions permit. Denser molds are stronger, more resistant to deterioration, and longer lived. Many shops could improve quality and productivity by using denser molds.

Summary: as free water in the mold is removed by drying and evaporation, pores of the mold seal to some degree. For optimum performance, they must be re-opened. This is accomplished by immersing the dried mold in water, then re-drying and re-immersing to condition; or by immersing to condition and discarding the first casting.

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### Absorptive Rates

In early service life, casting molds gain markedly in rate of absorption, improving until the mold reaches equilibrium with the drying environment. At this early stage, absorptive power of the mold is limited by either the rate at which water can be taken from the slip, or the rate at which water is removed from the mold by drying. In most shops, rate of drying is the limiting factor. Typical rates of absorption for conventionally made molds: partial immersion of a new dry mold—0.38 g/cm<sup>2</sup>/min.; partial immersion of a new mold after three wetting and drying cycles—0.60 g/cm<sup>2</sup>/min.; estimated safe rate of casting of plastic clay slip—0.30 g/cm<sup>2</sup>/min.; drying rate in typical clay shop environment—0.01 g/cm<sup>2</sup>/min.

In the average shop, ability of the mold to function consistently depends greatly upon how efficiently it is dried between cycles. If the rate of mold drying is adequate, molds may be denser since comparatively large reservoir action is not needed. (See U.S. Gypsum Bulletin IG-502 for drying information.) The chief advantages of a denser mold are longer life and greater economy.

Rates of absorption previously listed are considered maximum for plaster molds. In practice, shop conditions affect absorptive rates, probably lowering them. Actual values in the clay shop should be determined by successive weighings of molds when new, dry, in good condition, and periodically during service.

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### Some Tests for Absorption

Rate of absorption can be tested as follows:

If molds are not casting fast enough or are sticking, weigh them. Molds of the same design should weigh about the same at the same point in the casting cycle. If they are much different, reweigh the molds elsewhere in the casting cycle. If the molds do not lose the same percentage of weight during the drying cycle, drying is the problem. On the other hand, consistency and, therefore, total pore volume could be different. If identical dry molds differ significantly in weight, the problem is lack of uniformity from batch to batch.

Predictable water movement requires only with sound, homogeneous, properly made molds. Homogeneous molds in turn are maintained only by practicing proper mixing and casting methods. (For recommended mixing methods, see U.S. Gypsum Bulletin IG-503.)

Rate of absorption can be checked by claying small metal rings on the surface of a dried mold. By timing the absorption of a certain volume of water through the surface area within the ring, you can compare the rate of one mold versus another. Also, by running a check at various times in the life of a mold, relative rates can be retested.

When the clay shop bench-casts greenware, the design of the plaster tooling and working molds has considerable latitude. The mold's shape, wall thickness, etc., can be varied to create the best casting mold. However, when the clay shop is mechanized, considerable latitude is lost. Some of the basic operations in a mechanized clay shop are a continuing casting line, mechanical jiggering and the RAM® process.

In mechanized casting, a mold is usually delivered to a pouring spout and clay slip is poured into the mold. The filled mold is carried through controlled temperature and humidity in a set time interval, after which the partly dried ware is removed. The empty mold passes through controlled drying conditions for a specific time and the cycle is repeated. A modification of this procedure is to pressure-cast the slip while subjecting the mold exterior to a vacuum. (For hollow-cast ware, drying must be preceded by draining the excess slip.)

	<p>In mechanical jiggering, a clay bat of measured size is cut off a column of pugged clay so as to fall on the mold face. A stamping or rotary pressing operation pre-forms the clay shape and a jigger tool is applied. Mold and ware are carried automatically through a regulated drying atmosphere. After the partly dried ware is removed, the empty, dry mold is returned for another cycle.</p> <p>The press forming of electrical porcelain bodies is quite similar to automatic jiggering, except that a flame is constantly applied to the forming tool to facilitate fabrication. Here the clay piece is also dried on, or in, the mold.</p> <p>In the RAM process, the clay bat is shaped by mating male and female dies made of CERAMI-CAL® Gypsum Cement. The dies are sufficiently permeable for use with air pressure or vacuum, as desired, and the greenware is removed immediately after forming. Drying the dies is not a problem, since water is removed immediately by pressure-induced evaporation.</p>
<p><b>Characteristics of Mechanized Fabrication</b></p>	<p>In manual fabrication of clayware, a skilled craftsman is able to make adjustments, within limits, to compensate for variations in the absorption, dimensions, strength, and relative dryness of molds.</p> <p>Mechanization greatly changes this situation. Instead of relying on the craftsman to adjust for changed conditions, everything possible is standardized so desired results will be obtained uniformly and automatically.</p> <p>Once adequate control is established over the forming process, it is typical to mechanize subsequent operations, such as trimming and finishing.</p> <p>With mechanized forming, superior process control is required all along the line. This is especially true for molds, which must be uniform in size and shape, smoothness, amount and rate of water absorption, strength and toughness, and ability to produce acceptable ware.</p> <p>Ordinarily, mechanized production molds enter or are retired from service in sets rather than individually. This practice simplifies cost accounting, facilitates experimentation and analysis, reduces the work of mold makers and handlers, tends to produce more uniform clayware, and results in fewer damaged molds. Batching demands that all molds in a given set wear at about the same rate. Otherwise, downtime for partial mold replacement will minimize the advantages of mechanization.</p>
<p><b>Mechanization Shortens Time Cycle</b></p>	<p>An additional advantage of mechanization is faster production per mold. Careful mold-drying for automatic casting has allowed fabrication of three times as many pieces per mold per day. Automatic jigger cycles have been cut to a matter of minutes. These improvements make it possible to reduce mold inventory, conserve space, allow more time for mold-drying and generally improve integration production efficiency between mold shop and clay shop.</p>
<p><b>Obtaining Best Results with Plaster Molds</b></p>	<p>The three important factors to be considered in mechanization of clayware fabrication are:</p> <ol style="list-style-type: none"> <li>1. machine design and operation,</li> <li>2. model, block, and case mold tooling, and</li> <li>3. control of mold shop variables.</li> </ol>
<p><b>Machine Design and Operation</b></p>	<p>The natural properties of plaster molds must be recognized. Some of these fundamental characteristics are:</p> <ol style="list-style-type: none"> <li>1. Plaster molds calcine destructively when the time-temperature-humidity factors are not balanced properly.</li> <li>2. Plaster molds have a thermal expansion coefficient of approximately 0.000083 in./in./°F, and will crack when suddenly cooled from temperatures over about 100 °F. Plasters containing thermal shock ingredients better withstand temperature changes.</li> <li>3. The compressive strength of a dry, well-made conventional plaster mold is approximately 2,000 psi.</li> <li>4. The tensile strength of a dry, well-made conventional plaster mold is approximately 290 psi.</li> </ol>

5. The resistance of plaster molds to shearing stresses is very low, approximately 450 psi.
6. The compressive strength and abrasion resistance of a wet mold are approximately half that of a dry mold.
7. Gypsum has a moderate degree of solubility—0.2% in distilled water at room temperature—somewhat more in warmer water and in water containing sodium sulfate.

When these important points are overlooked, results have been as follows:

- Too rigorous drying with consequent calcination and thermal shock. (See U.S. Gypsum Bulletin IG-502 for drying information.)
- Punched centers or cracks from excessive forming pressure exerted over inadequately supported molds.
- Excessive localized wear resulting from repetitious stress such as undue solution and abrasion of gypsum caused by injecting slip in exactly the same spot cycle after cycle.
- Excessive wear on mold bottoms from long travel on abrasive belt conveyors.

In general, it is good practice to confine stresses in molds to those of a compressive nature, and to make sure the mold is well supported while forming the ware.

Mechanization affords an unparalleled opportunity to dry molds properly to prevent excessive loss from “sweatout” (too wet), calcination (too dry), and thermal shock (cooled too fast). (See U.S. Gypsum Bulletin IG-502 for drying information.)

Special pottery plasters designed for maximum resistance to calcination and thermal shock are available and should be used where these problems exist.

In general, molds ruined on automatic forming equipment is often the result of carelessness. For example, cold air from open windows may blow directly on hot molds and crack them. Or, clearance between jigger tools and mold faces may be poorly set, so molds are gouged or scraped. Also, clay may collect under the ring or between molds to prevent good fit and result in breakage.

**Model, Block and Case Mold Tooling**

For best results in mechanized forming, design the original model to cope with stresses likely to be encountered.

In general, it is good practice to:

- Provide for snug fit between model and ring or jig that will carry the working mold, to improve ware quality and minimize grinding and chipping of molds.
- Avoid thin mold edges that will be susceptible to calcination.
- Avoid significant variations in cross-sectional mold thickness to minimize differential thermal stresses during heating and cooling.
- Provide integral metal reinforcement where needed.
- Allow adequate volume of plaster; 1-1/2-in. minimum wall thickness for casting molds usually is appropriate.

High-speed mechanized forming requires more accurate molds than manual forming. For example, dimensional tolerance on the jigger mold for a plate is frequently specified as  $\pm 0.008$  in. The average model-maker with a “twirler” can turn only to  $\pm 0.03$  in. Mechanization requires suitable model-forming and measuring equipment.

Ordinarily, pottery plaster will expand approximately 0.17% in all directions upon setting, if free movement is permitted. If expansion is restricted in one direction, it will take place to a greater degree in another. The amount and direction of setting expansion should be determined by experience for the piece being made, and anticipated in the blocking and casing process.

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For blocking and casing, setting expansion is multiplied twice (once in block mold and once in case mold). Consequently, it is good practice to block and case with specially formulated gypsum cements with setting expansion of just 0.05%. These gypsum cements are dense and therefore not absorptive enough to serve as working molds, but are eminently suited to accurate blocking and casing.

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### **Handling Expansion Problems**

Many situations exist where flexible, rubber-faced or urethane elastomer case molds may be used to eliminate or reduce expansion difficulties. Sometimes all that is needed is a small metal, rubber or urethane insert at a particularly troublesome spot in an otherwise conventional case mold. Several sanitary potteries now use urethane elastomer case molds for the majority of their long-run pieces. However, for maximum precision, several precautions must be taken to prevent distortion of the elastomer. Either the rubber must be bonded to the backup or have sufficient thickness to hold the dimensions.

Case and block molds must be properly stored, since considerable time may elapse between uses. It is important to cover cases and blocks; place molds flat, or brace to prevent distortion caused by cold flow; maintain relative humidity of at least 30%, and maximum temperature of 100 °F to prevent calcination; occasionally dampen stored molds; use an indexing system to show names or code numbers on mold exteriors. This reduces breakage caused by excessive handling and saves time in locating case molds.

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### **Summary**

Well-made molds handled with reasonable care on well-designed machines last longer and produce higher ware quality than hand forming.

The causes of premature mold failure in mechanized and hand forming do not differ greatly. Generally, these are:

1. Abrasion, chipping and cracks caused by unduly weak molds, rough handling and mechanical wear.
2. Thermal shock and calcination from drying too fast or too long (jigger and hot press).
3. Weak or "rotten" molds from too little drying (casting molds).
4. Pinholes resulting from inadequate mixing.
5. Localized wear caused by repetitive machine stresses.

Best results are achieved only when mold shop variables are well controlled. Proper equipment should be provided to make good control possible, and periodic checks on procedures should be made. Mold performance on the machine should be followed regularly and adjustments made as needed. Painstaking attention to detail in production and use result in satisfactory, long-wearing molds.

