Explaining Shrinkage in Molds and Cores

A series of tests show how each variable in chemically bonded molds affects shrinkage. KATHLEEN LOWE AND RALPH SHOWNAN, ASK CHEMICALS, DUBLIN, OHIO

While it is common knowledge chemically bonded molds and cores will either expand or contract a small amount following the initial cure, most of this evidence is anecdotal and lacks the support of published data.

Earlier work has shown that phenolic urethane coldbox (PUCB) cores shrink around 0.1% during the two days following coremaking.

To expand on this study, researchers recently used a controlled environment and PUCB binders as the standard to further characterize how different sands, binders and process conditions affect dimensional changes of cores and molds.

While dimensional changes may be smaller following the initial cure and during storage and handling may be small, they can be significant for applications with tight dimensional tolerances. The data can be used during casting design to account for these small but potentially important changes and may indicate the need for process-specific testing for critical applications.

Binder Type Matters
The most significant factor affecting shrinkage is the solvent used in the binder, specifically the evaporation of the solvent.

Vapor pressure of solvents affects
the rate of shrinkage with volatile solvents, causing faster shrinkage. While higher binder levels may initially slow the shrinkage, over time it is more likely to produce more total shrinkage.

Several theories exist to explain mold and core binder shrinkage.

The first involves the hardening and curing of the binder. Organic mold and core binders are thermosetting resins that harden and cure by cross-linking of polymer chains. As they react, an increase in density and a corresponding decrease in volume occurs. For the liquid resin only, the shrinkage can reach 10%. According to the theory, as the resin bridges contract, the sand grains are pulled closer together and the mold or core shrinks.

With most binder systems, the resin cures rapidly over a short time period. With coldbox cores, the reaction is caused by the introduction of catalyst gas into the corebox, and curing is nearly instantaneous. The curing and cross-linking and resulting shrinkage causes the core to decrease in size before ejection. One theory suggests if continued cross-linking and reaction occurs after the core is made, shrinkage will continue until the core is complete. The continuing strength development of the core over time suggests the curing process continues after the initial cure.

Another theory suggests core shrinkage is related to the solvents in the binder. Solvents may be used up to around 30% in a binder to reduce the viscosity of the resin, improve wetting of the sand grain surface, etc. When the binder cures, these solvents may be trapped in the resin. The solvents are relatively volatile and evaporate over time. As the solvents evaporate from the resin bridges, a volume reduction of the resin bridge occurs, resulting in shrinkage. The more solvent in the binder, the more shrinkage occurs, and the more volatile the solvent, the faster the shrinkage occurs.

It has been suggested that higher binder levels produce more shrinkage. With more binder, the thickness of the binder layer on the surface of the sand and the distance separating the sand grains would increase. A thick resin bridge would produce more shrinkage because it would be a higher percentage of the core volume.

The binder variables tested were binder levels, solvents, benchlife and binder chemistry. A binder made with no solvent had almost no shrinkage (Fig. 1). This explains the minimal shrinkage from the acrylic epoxy binder that contains lower solvent levels than PUCB binders. The furan nobake binder showed
high, rapid shrinkage. The curing mechanism of furan nobake binders involves a chemical reaction known as condensation, and more specifically dehydration, during which water is formed as a reaction byproduct. The cured binder has greater density than the uncured binder. Reduced shrinkage of PUCB with extended benchlife also can be explained by the solvents evaporating from the mixed sand prior to the core being blown.

The standard PUCB binder tested used a moderate to low volatility solvent, which may have slowed the shrinkage under the different conditions. The 24-hour result may not reflect the maximum shrinkage that would occur over extended times.

The heat-cured inorganic binder showed rapid out-of-box shrinkage, but this was likely caused by the thermal contraction of the sand rather than changes in the binder. Other systems that saw elevated temperatures as part of the process also were stable after heating. For organic binders, this was likely due to the rapid loss of solvents at higher temperatures.

Unexpectedly, shrinkage decreased with higher PUCB binder levels. The extended time study showed the higher binder level eventually reached the same shrinkage level. With more time, it may have surpassed the shrinkage of the cores with the lower binder levels. A possible explanation of the slower shrinkage rate may relate to resin bridges. With more binder, resin bridges would be larger in diameter and have a lower surface area-to-volume ratio. This lower ratio may delay the loss of solvents and the resulting shrinkage rate.

Sand Plays a Part in Shrinkage

The sand used to make a mold or core will have an impact on its shrinkage. Initially, it was thought these effects were related to core density differences caused by the sand. However, little correlation exists between density and shrinkage. Testing showed sand size, shape and distribution do affect shrinkage, while core sand density does not affect shrinkage.

When chemically bonded molds and cores are produced, the sand is first mixed with the binder to coat the surfaces of the sand grains. Ideally, all the sand grains have a thin, uniform layer of coating. When the coated sand is blown into a corebox or compacted in a flask, the sand grains come into close proximity and the surface films of the binder connect each other to create a resin bridge. The resin bridges separate the sand grains with a layer of liquid. When the resin cures, the sand is bonded together. If the resin layer shrinks or contracts, the sand grain will be pulled closer together and the entire mold or core will shrink (Fig. 2).

Chemically bonded molds and cores are 95-99% sand. During the next test to further examine the core shrinkage phenomenon, all test cores were made using standardized conditions and methods, except for the

![Image of sand cores being blown into a corebox]
specific variable under examination. The sand variables tested for their effect on dimensional change included grain fineness, shape, screen distribution, reclaimed sand and sand additives.

The test results showed finer sand developed smaller bridges with greater surface area-to-volume ratios, allowing for more rapid evaporation of solvents (Fig. 3). Variations in sand grain shapes and particle distributions also affected the number and size of the resin bridges. The silica sand cores examined shrank more in the testing period than the land sand due to silica sand’s rounded geometry. Cores made with sand with additives shrank more than those made with sand with no additives. New sand and mechanically reclaimed sand had similar shrinkage levels. The variation in shrinkage caused by using different sands is around 50% of the total average shrinkage.

DIAL INDICATOR TEST ACCURATELY MEASURES DIMENSIONAL CHANGES

The dial indicator’s measurement method, which can be used in any metalcasting facility, has been in use for many years to test dimensional change in cores.

The method measures the linear shrinkage of a 1 x 1 x 8 in. (25 x 25 x 200 mm) core using a dial indicator. A core is produced and immediately placed into a fixture with a spring-loaded dial indicator. The indicator is zeroed, and as the core shrinks, negative values are recorded over time.

Researchers have tested this method and been able to produce repeatable results. A recent study confirmed the test method is capable of detecting core dimensional changes over time with coremaking process and measurement method errors only contributing a small portion of the total changes. 

The dial indicator measurement method is a valid testing process that can produce accurate shrinkage recordings in any metalcasting facility.
Tests have shown that the type of binder used is the most significant factor causing shrinkage in cores after they are blown.

**Process Variables Have Little Effect**

Blow pressure and humidity had only a small effect on shrinkage. In theory, the higher the core density, the closer the sand grains must be together and the shorter the resin bridges. A poorly blown core or one blown with low blow pressure has more space between the sand grain and longer bridges.

Humidity also has been shown to affect core shrinkage, as it is known that moisture absorption by the organic binders will cause them to swell. Any volume increase in the resin bridge causes the cores to expand rather than shrink.

In the newest test, the blow pressure and resulting small differences in core density didn’t have as much effect on shrinkage as expected; however, the difference in the density was low. Greater density differences could increase the difference in shrinkage.

Similarly, in this study, humidity had a smaller than expected effect on shrinkage; however, this variable may change if a binder system other than PUCB is used.