Characterization of the Shell Sand Mold Bonding Process

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The shell mold bonding process is an advantageous casting method that allows for the casting of specialized parts in large batch sizes with a high quality surface finish. In order to optimize Hiler Industries' process, they seek to improve both the physical bonding process as well as properties of the resin to reduce mold failure rates. Molds and resin samples were analyzed to determine root causes of failure in order to provide optimization recommendations to Hiler Industries.

This work is sponsored by Hiler Industries, LaPorte, IN

Project Background

Shell sand mold casting involves the bonding of two mold halves at the parting line with glue drops composed of phenolic resin and vegetable oil.

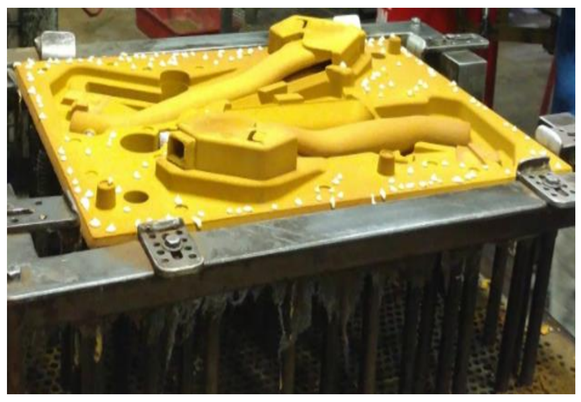

Figure 1: Pin machine used to bond two mold halves. Glue dabs are dropped on flat surface of parting line.

After applying glue dabs to the bottom half (Fig. 1), the top half is added and the pins press the halves together. When pouring molten metal into the finished mold, the metal exerts a pressure on the mold and without sufficient clamping force, flashing or mold failure can occur. Potential problems occur when there are small gaps present between the mold halves; this can be caused either by inadequate pressure or premature curing of the glue. In order to diagnose the issues with mold failure and long cycle times, a series of experiments were designed to determine the resin cure kinetics and resulting bond structure. In addition, alternative methods of squeezing the mold halves together in bonding were explored to reduce the long change-over time of the pin frame.

Mold Characterization

Mold Visual Analysis

The mean glue dab size and standard deviation for the distribution shown in Fig. 3 were 11.2 mm and 1.02 mm respectively. After breaking the mold apart, 83% of the glue dabs adhered to the bottom mold half, indicating that the dabs preferentially cure first on the half that they are applied to before the second mold half is applied.

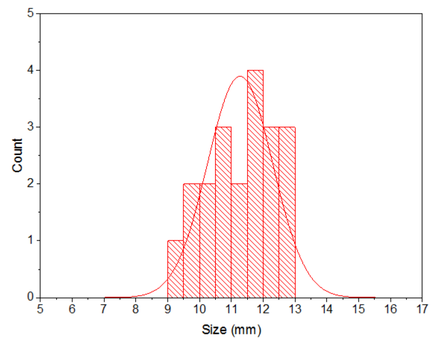

Figure 3: Measured glue dab size (diameter) distribution.

Operating Simulation

The bonding response for varying temperatures and time waited before application of the 5 kg load is shown in Fig. 4 with samples that formed gaps shown in red. The highlighted region indicates the transition zone between gap forming and well sealed molds. Fig. 5 shows the relationship between the gap width and the product of temperature and time waited. Gap width is weakly correlated with increasing wait time and temperature.

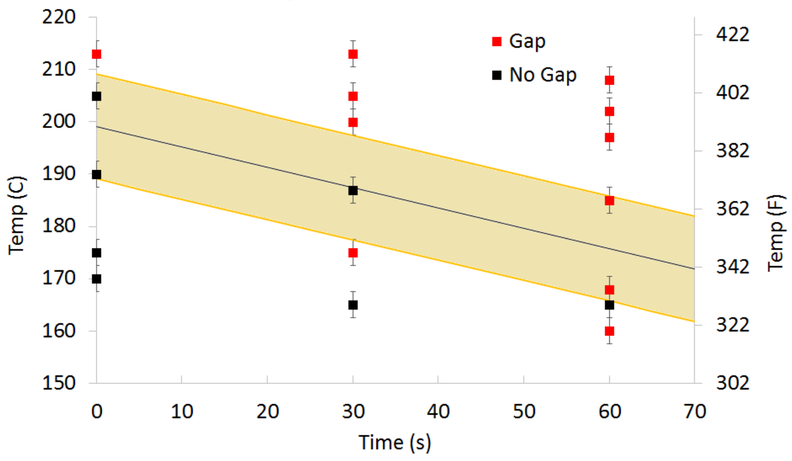

Figure 4: Map of gap and no gap regions as a function of temperature and time waited before applying a 5kg load. The yellow region is a transition region between gap formation and no gap regions.

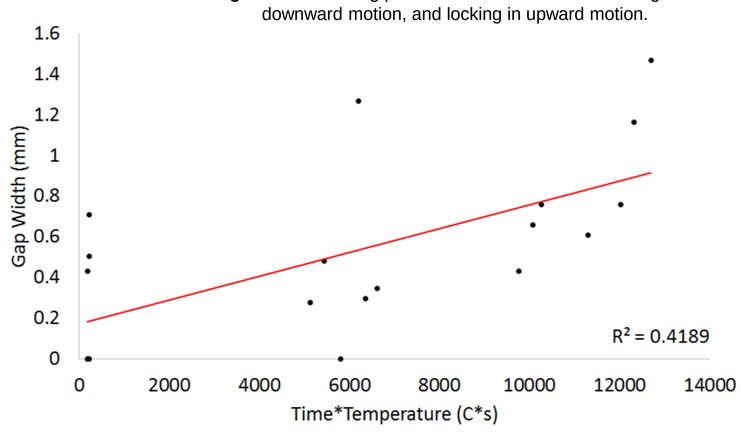

Figure 5: Thickness of furnace sample gaps compared to control factor of (Time * Temperature) which shows an increase as the factor increases.

Alternative Methods

A roughing pump was used to draw a vacuum on a mold covered with a garbage bag to account for porosity. A more robust bladder could be used to draw high enough vacuum to bond the mold without a pin system. Additionally, a system of ratcheting pins placed in an array that can conform to the surface and lock into place was considered as an alternative to the current pin system. Fig. 6 shows a schematic of the mechanism.

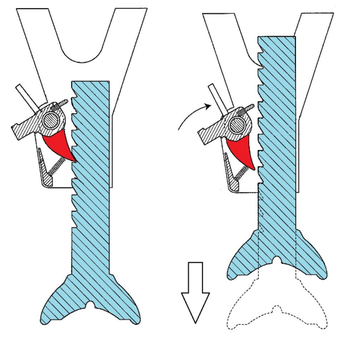

Figure 6: Ratcheting pin mechanism schematic showing free downward motion, and locking in upward motion.

Experimental Procedure

A bonded mold was sectioned and prepared for observation and statistical analysis. Pyrolization was evident from charred glue drops at the parting line, as seen in Fig. 2.

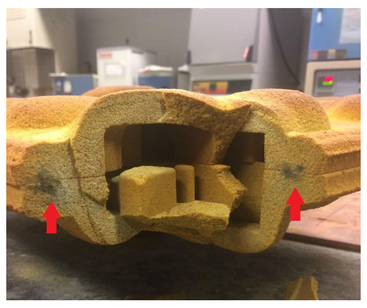

Figure 2: Sectioned mold corner with evidence of pyrolization at the parting line from the resin

Glue dabs on the mold sides were measured for relative sizes.

The metallostatic pressure and consequent force separating the mold halves were calculated to determine the force on the seam. For a 16''x20'' mold, the buoyant force exerted by the liquid metal is 84.3 lbs. For an estimated mold half weight of 20 lbs, the glue between the two mold halves must hold roughly 65 lbs.

Using simulated operating conditions of temperature and wait time for application of a weight, gap sizes between sectioned mold pieces were observed and measured.

Thermal characterization of the resin cure kinetics entailed observing the response at 400 ^{O}F. Glue samples were subjected to various relative humidity (RH) environments and mass change was recorded. Thermogravimetric analysis (TGA) was completed on the powdered resin (no oil).

An alternative bonding method was evaluated by evacuating a mold cavity using a vacuum pump. A second alternative bonding method involved using a ratchet jack system to replace the pin set-up to account for the variability in mold structures/cavities and reduce cycle time.

Resin Characterization

Thermal Analysis

As shown in Fig. 7a-b, rapid resin curing and oil separation occurred within 5 seconds of the application of glue dabs to a hot substrate (400 °F). The resin completely cured at 15 seconds (Fig. 7c), resulting in a hardened resin center within a puddle of oil. The rapid curing of the resin explains the gap formation at high temperatures shown previously in Fig. 4.

Thermogravimetric Analysis (TGA)

The powdered resin exhibits some water retention, as shown by the two peaks in the derivative of mass loss in Fig. 8. The peak at ~100 °F corresponds to nonbonded water evaporation, and the peak at ~200 °F may correspond to bonded water (possibly hydrogen bonding), indicating two different types of water retention in the resin.

Humidity Treatment

Glue samples were placed in 10%, 51% and 99% RH and the resulting change in mass was recorded, as seen in Fig. 9. A statistically significant change was noted between 51% (control group) and 99% RH groups, indicating that some mechanism exists that causes the resin to take on water mass, even while suspended in oil.

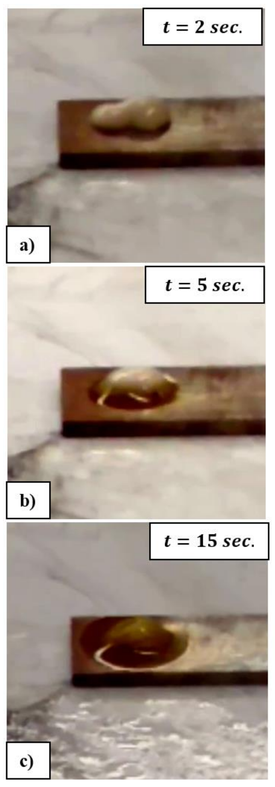

Figure 7: Still frames of resin curing on heated substrate.

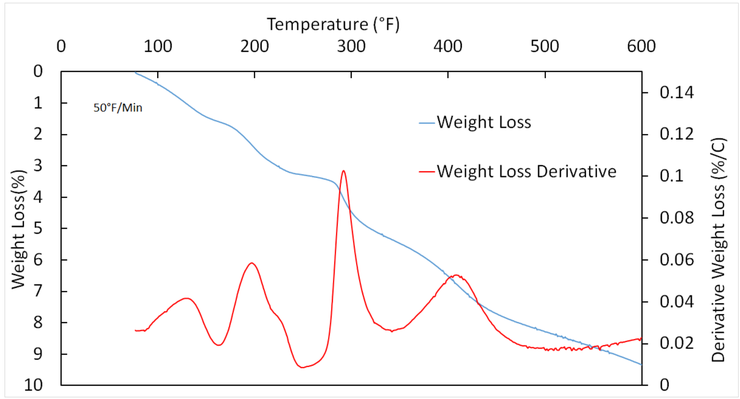

Figure 8. TGA plot of pure powdered resin. Peaks in the derivative of mass loss correspond to evaporation of nonbonded and bonded water in the resin.

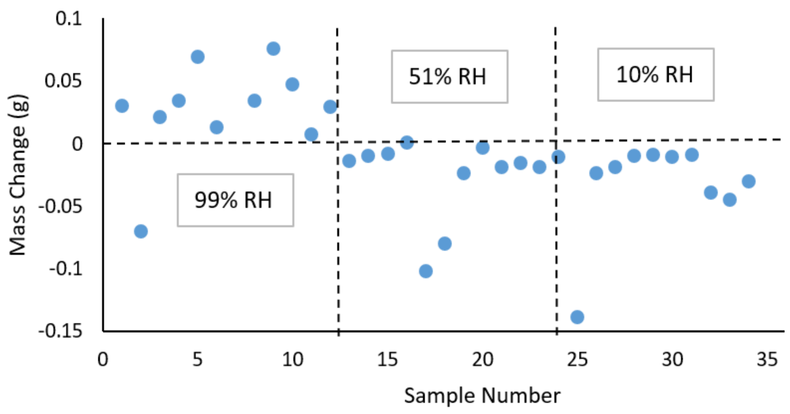

Figure 9: Plot of mass change for each sample at various relative humidities.

Recommendations

Our team recommends that Hiler Industries continues operating within their set temperature conditions of 350 - 400^{O}F but bond the mold halves at a faster rates to ensure proper sealing of the molds. The resin must also be well mixed more than once a day to ensure proper resin particle distribution.

Future Work

Further testing and implementation of the ratcheting jack system should be explored to reduce change-over time. The effects of humidity on resin cure kinetics and resulting bond structure should also be identified.