Accelerated Curing and Drying of China Products

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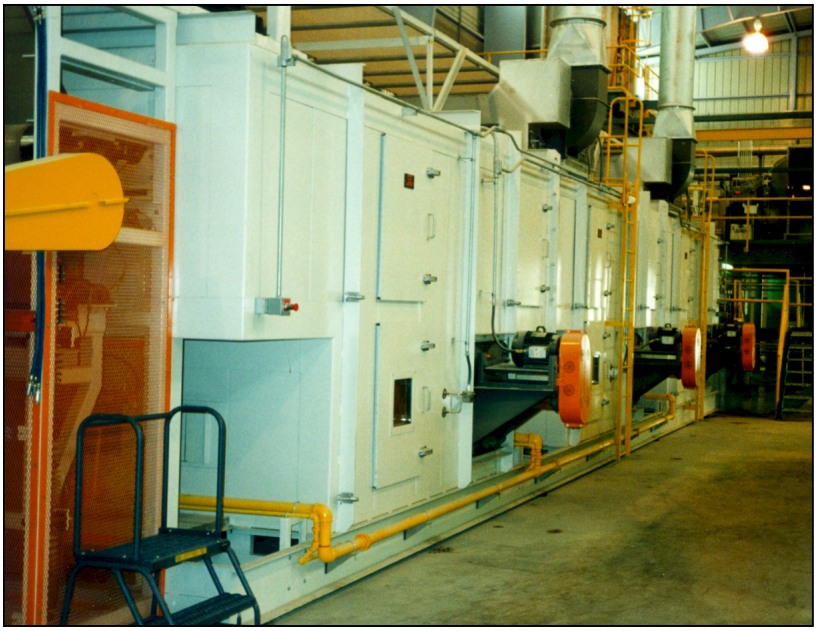
Performed by:
The Lanly Company
June 18, 1998

OBJECTIVE:
To determine the optimum parameters for drying complex ceramic products in order to significantly reduce production time. The products included single and multiple piece cast shapes. Products composed of multiple molded components, referred to as stick-ups, were assembled wet, prior to drying. Additionally, we were requested to investigate the minimum drying time limits of the material used for these products.

OVERVIEW:
Tests were performed over a three-day period in The Lanly Company's Heat Process Technology Laboratory. The laboratory programmable air impingement dryer was used to demonstrate the capability of Lanly forced air equipment to dry the sample products. In accordance with our preferred development test procedures, representatives from the company were present to observe, and participate in, the testing.



Example of a Ceramic Dryer

The testing involved the actual casting and drying of all products under varying temperature and moisture environments. The products were inspected during and after each test to evaluate the drying process and determine the best process parameters for each piece. Pieces were examined both visually and by instrumentation.

EQUIPMENT:

- Lanly Dryer
  Batch style, direct fired gas dryer with variable speed circulation fan. The system is designed to supply forced air to both the top and bottom of the product under test. Temperature and humidity are programmable.
- Balance
  A & D model EK-12KA (with .05 oz. resolution)
- LumenX Audit X-Ray Inspection System - including
  Thompson dual mode image intensifier
  Sony XC-75 CCD camera

PROCEDURE:

The test procedure followed these steps:

1. The china company representatives cast various pieces and assembled the stick-ups using the following process:
   - Check slip to confirm density of 1680 grams/liter
   - Pour slip into molds to slightly overflowing
   - Let set for specified time
   - Invert molds and let drain for recommended time
   - Remove pieces from molds
   - Stick the pieces together where required
2. The items were weighed
3. The items were placed in the dryer (wait times prior to dryer insertion are noted when applicable)
4. The items were remove from the dryer and weighed periodically. The time periods were determined by prior test results
5. The items were returned to the dryer for continued drying
6. Steps 4 and 5 were repeated until the weight between two subsequent readings was unchanged. The dry time was then recorded as the first of these two times; the beginning of the period where the weight did not change.

TESTING:
Ivory and bone slip, provided by the company, were cast. One of the company's representatives observed and directed the testing.

The shapes tested included:

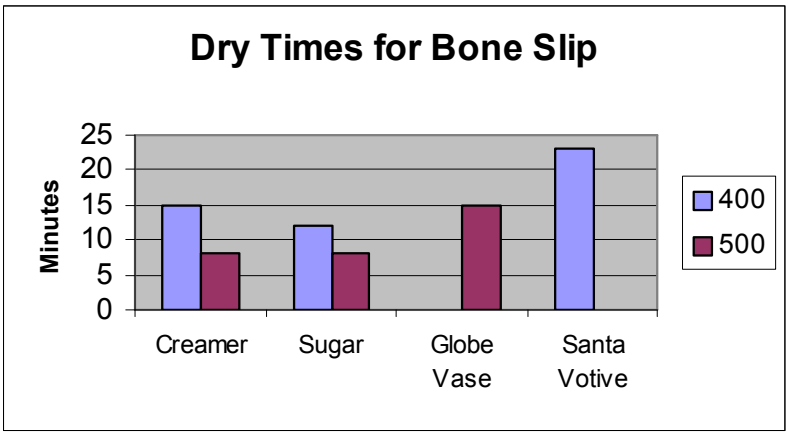
- Holiday Santa Figure Votive, 3-piece stick-up
- Santa's Toyshop (Nutcracker Santa), 2-piece stick-up
- Classic Creamer, 2-piece stick-up
- Debut Sugar Vessel
- Mothers Day Vase 1999
- Globe Vase

The Creamer and Sugar bowl were cast in bone only. All of the other shapes were cast in both bone and ivory.

TEST RESULTS:
Table I is a summary of the tests and the findings. As can be seen from the table, humidity was only induced for the first six pieces, three each of the Holiday Santa Figure Votive and Nutcracker Santa. The humidity reading of 32% was within the range of humidity readings (25% to 32%) obtained in a previous series of tests.

In previous production testing, humidity was used to obtain better results on the Holiday Santa Figure Votive. It was found, however, that if the parts were carefully cast and the assembly was out of the molds for at least one hour prior to entering the dryer, we were able to dry this difficult piece without any induced humidity.

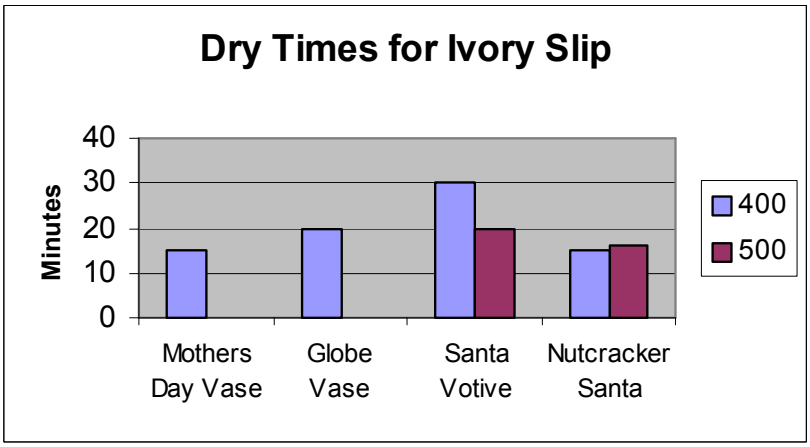
Chart A



With induced humidity, both the Holiday Santa Figure Votive and the Nutcracker Santa, cast in ivory, were dried in 75 minutes. Following the new procedures, the ivory Votive dried in 30 minutes, after being out of the mold and under plastic for 4 hours prior to drying at 400°F.

Using the same parameters, the Nutcracker was dry in 15 minutes. When the stick-ups were under plastic for 5 hours before being subjected to 500°F, the Votive was dry in 20 minutes and the Nutcracker in 16. The comparison of these dry times, along with others, is shown on Charts A and B.

Chart B



All of the pieces were dried successfully without induced humidity at both 400°F and 500°F. The results can been seen both in Table I and on Charts A and B. The dry times listed in Table I, based on our test procedure, are the times at which we reached a weight that was not decreased with further time in the dryer. Some pieces, however, lost only .05 oz in the final 3 to 5 minutes prior to being totally dry. This is noted in the status column by listing the weight and time of those readings. Depending upon the level of dryness required, these pieces could be considered dry at those times. This would shorten the cycle time even further.

Table I

6/15 - 6/17 Test Data Item	Test Parameters	Weight (oz) Initial	 Dry	Dry Time (minutes)	Status
Holiday Santa Figure Votive Ivory 3 piece stickup	180 deg F w/32% RH for 45 min 280 deg F w/ambient humidity	17.20 16.80 17.40	13.65 13.25 13.80	75 75 75	OK OK Small crack on bottom at end of body/sack joint
Nutcracker Santa Ivory 2 piece stickup	180 deg F w/32% RH for 45 min 280 deg F w/ambient humidity	17.35 17.20 17.50	13.75 13.65 13.80	75 75 75	OK OK OK
Mothers Day Vase Ivory	400 deg F w/ambient humidity	15.90 16.10 15.85	12.55 12.75 12.55	15 15 15	OK OK OK
Debut sugar Bone	400 deg F w/ambient humidity	10.30 10.10 10.35	8.30 8.15 8.25	15 15 15	OK OK OK
Debut sugar Bone	400 deg F w/ambient humidity	12.20 12.35 12.05	9.80 9.90 9.70	12 12 12	OK OK OK
Globe Vase Ivory	400 deg F w/ambient humidity	55.30	43.05	20	OK
Nutcracker Santa Ivory 2 piece stickup	400 deg F w/ambient humidity	18.55	15.00	20	OK
Holiday Santa Figure Votive Ivory 3 piece stickup	400 deg F w/ambient humidity	16.10	13.00	20	Cracked - inside sack
Creamer Bone 2 piece stickup	400 deg F w/ambient humidity	11.00 11.30 11.25	8.85 9.10 9.10	15 15 15	OK OK OK
Holiday Santa Figure Votive Ivory 3 piece stickup	400 deg F w/ambient humidity after 4 hrs under plastic	15.30	12.40	30	OK
Nutcracker Santa Ivory 2 piece stickup	400 deg F w/ambient humidity after 4 hrs under plastic	18.60	15.15	15	OK
Globe Vase Bone	500 deg F w/ambient humidity	53.00	42.60	15	OK, 42.65 at 10 minutes
Creamer Bone 2 piece stickup	500 deg F w/ambient humidity	11.40	9.20	10	OK

Table I
(continued)

6/15 - 6/17 Test Data Item	Test Parameters	Weight (oz) Initial	 Dry	Dry Time (minutes)	Status
Sugar Bone	500 deg F w/ambient humidity	12.65	10.20	10	OK
Creamer Bone 2 piece stickup	500 deg F w/ambient humidity	11.35 11.30	9.25 9.20	8 8	OK OK
Debut Sugar Bone	500 deg F w/ambient humidity	12.45 12.35	10.10 10.00	8 8	OK OK
Holiday Santa Figure Votive Ivory 3 piece stickup	500 deg F w/ambient humidity after 5 hrs under plastic	15.40	12.60	20	OK
Nutcracker Santa Ivory 2 piece stickup	500 deg F w/ambient humidity after 5 hrs under plastic	19.30	15.80	16	OK
Holiday Santa Figure Votive Ivory 3 piece stickup	400 deg F w/ambient humidity out of mold for 1 hour prior to dryer	14.50	NA		2:15 Big crack in sack by left hand. 7:30 Front of teddy blows off, air hole closed. 8:20 Crack in rear of sack.
Holiday Santa Figure Votive Bone 3 piece stickup	400 deg F w/ambient humidity out of mold for 1 hr prior to dryer	13.55 13.80	10.95 11.15	23 23	11.00 at 18 minutes 11.20 at 18 minutes
Nutcracker Santa Ivory 2 piece stickup	400 deg F w/ambient humidity out of mold for 1 hr prior to dryer	17.75	14.30	18	14.35 at 15 minutes
Debut Sugar Bone	800 deg F w/ambient humidity	12.60 12.50 12.25	NA NA 9.75	 ?	Handles exploded off Handles exploded off
Mother's Day Vase Bone	800 deg F w/ambient humidity	18.05	NA		Exploded to granulate
Mother's Day Vase Ivory	800 deg F w/ambient humidity	19.10 18.85	NA NA		Exploded to granulate Exploded to granulate
Nutcracker Santa Ivory 2 piece stickup	800 deg F w/ambient humidity	17.15	NA		Arm w/ nutcracker exploded
Nutcracker Santa Bone 2 piece stickup	800 deg F w/ambient humidity	17.20	NA		Right toe exploded

X-rays were taken of the Holiday Santa Votive to examine it in greater detail. The equipment used included a high frequency source for fine resolution. Samples were inspected for internal stress cracks and material voids. The samples were imaged at 40 kV @ 6mA, magnified and then captured on the Sony CCD camera. The results were printed on a photographic image printer. For the most part, the pictures supported our visual findings; however, there were substantially more voids than anticipated. It was agreed that the voids were directly related to the pouring and setting of the molds and were a significant contributor to internal stress fractures.

SUMMARY:
With properly cast parts it is clear that the company's ware, both individual pieces and stick-ups, can be successfully dried in a relatively short time using Lanly impingement air equipment. It was demonstrated that even stickups could be dried at both 400°F and 500°F. Table II summarizes the results of the three-day testing period. Although each of the products requires a different drying profile, the average reduction in drying time for all products was greater than 600%.

Table II
Successful Drying Times (minutes)

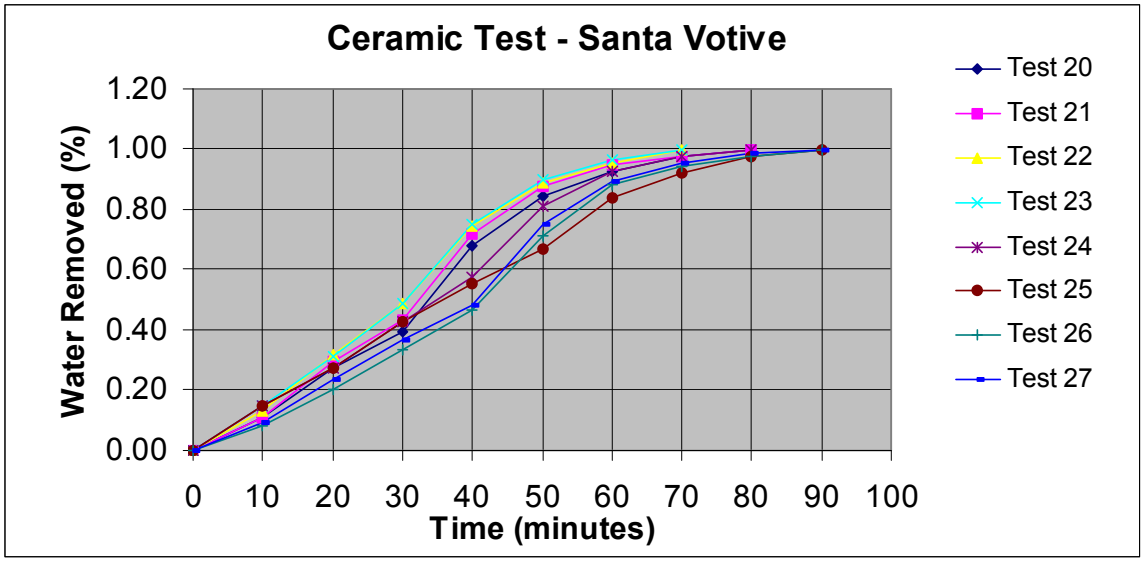
Product	400°F	500°F
Mothers Day Vase – Ivory	15	
Globe Vase – Ivory	20	
Holiday Santa Votive – Ivory Stickup	30[1]	20[3]
Nutcracker Santa – Ivory Stickup	20 / 18[2] / 15[1]	16[3]
Debut Sugar – Bone	12	8
Creamer – Bone Stickup	15	8
Globe Vase – Bone		15
Holiday Santa Votive – Bone Stickup	23[2]	

[1] 4 hours out of mold under plastic prior to drying
[2] 1 hour out of mold prior to drying
[3] 5 hours out of mold under plastic prior to drying

The Holiday Santa Votive is a very complex and difficult piece to dry. The company stated that they have even experienced problems when air drying this product. By following the established tables we were able to dry all of the products, including the Holiday Santa Votive, without any cracks or other defects. Chart C details a few of the tests on this product illustrating the weight at various times during the dry cycle.

As a follow up to the above process analysis, it was requested that we test these products at very high temperature. The objective was to see if the material could withstand the stress of drying significantly faster under high temperature. A series of tests was performed at 800°F. At this temperature, 7 of the 8 pieces failed. From these results, it was obvious that 800°F is beyond the limits of the materials under consideration.

Chart C



In conclusion, induced humidity does not appear to be a necessity. It was shown, however, that induced humidity would add flexibility to a dryer and broaden the scope of drying profiles available. This would allow a single system to accommodate a wider range of sensitive pieces, such as the Holiday Santa Votive in this study.