A NEW METHOD OF MEASURING GREEN AND FIRED PERMEABILITY OF INVESTMENT CASTING SHELLS

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Abstract

A new method of measuring permeability has been developed using a flat plate instead of the traditional Ping-Pong ball specimen. Details of the test are given. It is possible to measure both green and fired permeability on the same sample. Data are presented for fiber enhanced and traditional non-fiber slurries. Fiber containing slurries are more permeable in both green and fired states. Like the ping pong ball test, there is a large amount of sample to sample variation in all slurries tested.

Introduction

Foundries have long known the importance of having a shell that has sufficient permeability to allow air to penetrate the shell during the pouring of metal rather than remain trapped in the metal or at the metal/mold interface. More recently the issue of shell permeability in the green state is being considered as an important factor in the ability of a shell to dewax without cracking. The traditional method of producing a shell sample for measuring fired permeability is to insert and seal a hollow rod into a ping pong ball and then invest the ball and a few inches of the tube. After final dry the invested ball and rod are placed into a furnace and the ball is burned out. Permeability can then be measured after cooling.

The above method may be acceptable for relating to hot permeability at pour, but can not be used to investigate autoclave dewax issues because of the ball inside the shell. Buntrock Industries Technology Lab undertook the task of developing a green (prior to dewax) permeability test. Objectives were to make the test easy to do, inexpensive, and repeatable. The test is described below.

Permeability Test Description

Purpose: To determine the green and fired permeability of an investment casting shell specimen.

Wax Specimen: 2” wide x ¼” thick x 5” long. Do not clean or etch wax. Depending on polymer used in the first dip, additional release agent may be needed. The idea is for the first dip NOT to stick to the wax as the shell will be removed from the wax and not autoclaved or flash fired to remove wax. See Figure 1.

Dipping: Depends on purpose of test, but shell thickness is about ¼” – 1/3”. Scrape edges between backup dips to make shell grinding easier. See Figure 2.

Shell Prep: After final dry, grind edges and carefully remove shell from wax. Cut into 4 samples roughly 2” x 2” x ¼”. A ¾” plastic 90 degree elbow fitting is then sealed to the face coat side of the shell. Sticky wax is used to seal the fitting to the shell. The entire face coat and also the edges of the sample are sealed to ensure airflow is through the shell. See figure 3.

Apparatus: See Figure 4.

1. Air compressor with dryer. Any small air compressor will work.
2. Air pressure regulator capable of reducing pressure to about 10 psi.
3. U-tube Manometer 50” length.
4. Flow meter to measure air flow (20 – 800 ml/min.)
5. Flow control needle valve.

Calculations:
Permeability is defined by the following general equation:

$$K = (VFT/AP)$$

K = Permeability (Darcys)
V = Viscosity of gas used (cP) (centipoise)
F = Gas Flow Rate (ml/sec.)
T = Sample thickness (cm)
A = Area of sample (sq. cm)
P = pressure drop across sample (atmospheres)

For this test, the gas is air, the flow rate is in ml/min., and delta P is fixed at 44 inches of water. We use units of cD (centiDarcys) because the gas viscosity is so low,183 micropoise.

K (cD) = 100 x 0.0183 (centipoise) F/60 x T x 2.54 cm/in
*5.586 (cm*cm) x 44 (In of water) / 406.8 (In of water/Atm)

OR

K (cD) = 0.128 x F x T
F = flow rate (ml/min.) and T = sample thickness (Inches)

Experimental Procedure

Two different types of slurry systems were investigated. The first was an organic fiber enhanced slurry (BI2010) and the other was a non-fiber enhanced fused silica slurry with sand in the slurry. Prime dips were zircon/ fused silica flour, small particle binder with polymer and zircon stucco. Backup slurries did not contain polymer. Both types used 50x100 mesh for intermediate and 30x50 mesh for backup fused silica stucco. To investigate the variability in the test and samples, sixteen samples were made and measured for each of the two above slurry types. Samples were measured green, then heated to 650 C. for 2 hours to remove all organic substances. Since samples needed to be cooled back to room temperature for “fired” measurements, firing temperature was kept low to prevent cristobalite formation.

Other conditions on both slurry types were investigated. Samples with no prime and double primes as well as samples with no seal dip were made and measured.

Permeability Results:

Standard: 1 Prime + 1 Intermediate + 3 Backups + Seal

	BI 2010	Green	Permeability
	Thickness	Flow	K (cD)
A1	0.264	128	4.33
A2	0261	147	4.91
A3	0.252	147	4.74
A4	0.284	147	5.34
A5	0.253	136	4.40
A6	0.253	136	4.40
A7	0.273	185	6.46
A8	0.274	156	5.47
A9	0.286	166	6.08
A10	0.258	147	4.85
A11	0.274	185	6.49
A12			
A13	0.268	147	5.04
A14	0.273	204	7.13
A15	0.248	128	4.06
A16	0.260	175	5.82
Average	0.265		5.30
Std Dev			0.92
95% Confidence Interval			0.47

	BDS	Green	Permeability
	Thickness	Flow	K (cD)
A1	0.242	128	3.96
A2	0.224	136	3.90
A3	0.232	109	3.24
A4	0.237	128	3.88
A5	0.221	156	4.41
A6	0.221	118	3.34
A7	0.238	128	3.90
A8	0.250	166	5.31
A9	0.237	147	5.31f
A10	0.232	156	4.63
A11	0.219	91	2.55
A12	0.245	147	4.61
A13	0.220	166	4.67
A14	0.219	91	2.55
A15	0.234	91	2.73
A16	0.218	73	2.04
Average	0.231		3.79
Std Dev			0.90
95% Confidence Interval			0.44

	BI 2010	Fried @	650C
		Flow	K (cD)
A1		185	6.25
A2		224	7.48
A3		224	7.23
A4		224	8.14
A5		224	7.25
A6		204	6.61
A7		244	8.53
A8		224	7.86
A9		244	8.93
A10		196	6.47
A11		234	8.21
A12			
A13		204	7.00
A14		264	9.23
A15		196	6.22
A16		244	8.12
Average			**7.57**
Std Dev			**0.96**
95% Confidence Interval			**0.49**

	BDS	Fried @	650C
		Flow	K (cD)
A1		185	5.73
A2		185	5.30
A3		166	4.93
A4		185	5.61
A5		185	5.23
A6		175	4.95
A7		175	5.33
A8		215	6.74
A9		204	6.19
A10		204	6.06
A11		166	4.65
A12		215	6.74
A13		244	6.87
A14		175	4.91
A15		166	4.97
A16		109	3.04
Average			**7.57**
Std Dev			**0.96**
95% Confidence Interval			**0.49**

No Seal Dip

BI 2010	Green	Permeabil-ity	
	Thickness	Flow	K (cD)
B1	0.258	215	7.10
B2	0.234	166	4.97
B3	0.257	175	5.76
B4	0.253	128	4.15
Average		No Seal Dip	**5.46**
Std Dev			**2.00**
95% Confidence Interval			**1.96**

BI 2010	BDS	Green	Permeabil-ity
	Thickness	Flow	K (cD)
B1	0.204	303	7.91
B2	0.205	283	7.43
B3	0.167	315	6.73
B4	0.215	293	8.06
Average		No Seal Dip	**7.53**
Std Dev			**2.42**
95% Confidence Interval			**2.37**

No Prime Dip:

BI 2010	Green	Permeabil-ity	
	Thickness	Flow	K (cD)
C1	0.249	166	5.29
C2	0.262	283	9.49
C3	0.249	204	6.50
C4	0.251	347	11.15
Average		No Prime	**8.11**
Std Dev			**3.18**
95% Confidence Interval			**3.12**

BI 2010	BDS	Green	Permeability
	Thickness	Flow	K (cD)
C1	0.218	253	7.06
C2	0.223	315	8.99
C3	0.217	234	6.50
C4	0.213	293	7.99
Average		No Prime	**7.63**
Std Dev			**3.01**
95% Confidence Interval			**2.95**

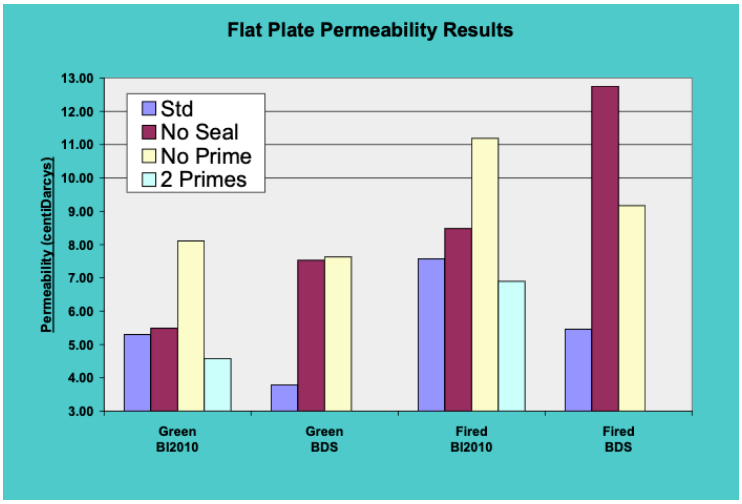
Two Prime Dips:

BI 2010	Green	Permeability	
	Thickness	Flow	K (cD)
D1	0.294	91	3.42
D2	0.297	166	6.31
D3	0.292	100	3.74
D4	0.295	128	4.83
Average		2 Primes	**4.58**
Std Dev			**2.82**
95% Confidence Interval			**2.77**

BI 2010	BDS	Green	Permeability
	Thickness	Flow	K (cD)
D1	0.268	0	0.00
D2	0.255	0	0.00
D3	0.269	0	0.00
D4	0.275	0	0.00
Average		No Prime	**0.00**
Std Dev			
95% Confidence Interval			

Discussion of Results:

First of all it is evident that there is a lot of variability in this test. This is also my experience with the Ping-Pong ball test. Clearly one or even 4 replications are not enough to discern differences that may be important.



Looking at the graph of the averages, the two types of slurries have different mechanisms occurring. The BI2010 fiber containing slurry shows little difference in permeability with or without a seal dip. In the BDS shell, the green and fired permeability is less and the seal dip has a major impact.

Putting on a second prime on the BI2010 shell decreased the permeability some, but with two primes on the BDS shell, no airflow was measurable. Note that zero is probably not correct, but the flow was not measurable on the flow meter.

This test does not measure any reduction in permeability due to sintering of the shell above 650 C.

CONCLUSIONS

1. A new test for measuring the permeability of shell samples in the green state has been developed. The variability from sample to sample is quite high and so high numbers of samples are needed.
2. The test was able to show that different shell systems have different amounts of permeability in both green and fired states.
3. Double primes reduce green and fired permeability.
4. Seal dip dramatically reduces permeability in the typical non-fiber slurry, but has little impact on the fiber containing slurry.
5. Additional work needs to be done to improve the test by using larger samples (more square inches of surface area).
6. Work with foundries needs to be done to relate the test to autoclave cracking and non-fill defects.

Figure 1. Wax sample prior to dipping.

Figure 2. Shell dipped on wax and edges ground for removal from wax.

Figure 3. Plastic fitting sealed onto face of shell sample.

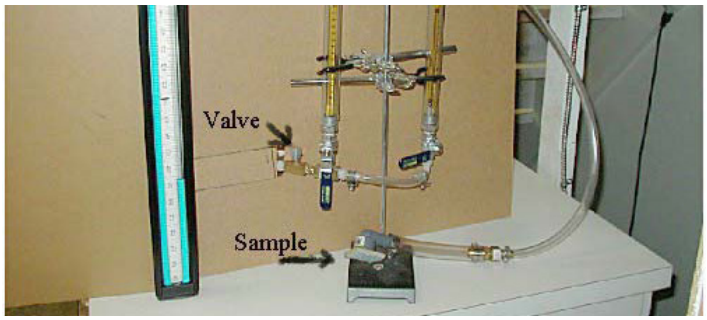


Figure 4. Permeability Apparatus: Manometer, Flow Meters, Flow Control Valve.