Effects of Wax Viscosity and Shell Permeability on Shell Cracking

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1.0 INTRODUCTION AND BACKGROUND

Perhaps the number one shell problem faced by investment casters is cracking. At times the shell is blamed and in other instances the wax is blamed. In truth of course, the entire system must be considered when evaluating shell cracking. The objective of this preliminary investigation is to measure the effect of three common variables upon shell cracking: non filled pattern wax viscosities, prime particle size distributions, and number of prime dips.

The questions we will attempt to address include the following: “to what degree is the wax responsible for shell cracking” and “how much is the prime permeability to blame?” Further, “what is the permeability loss when adding a second prime dip?” Hypothetically, if the prime coat permeability can be improved dramatically, new ranges of acceptable wax viscosities could be used while still avoiding shell cracks.

A common belief in investment casting is that one or both of the following conditions are required for successful dewaxing. Use of low viscosity wax at autoclave temperatures is required. This allows the wax to melt and exit before it expands putting the shell in tension. Secondly, the prime, and perhaps intermediate layer, should be permeable enough to allow wax to soak into the shell. In fact, past laboratory testing at Minco suggests the prime dip controls as much as 50% of the permeability of the entire shell (single prime dip on a six dip shell). Wax penetration through a shell as well as permeability was studied by J. Snow in significant detail in 2002 (ref.1).

In the experience of these authors, permeability and MOR data alone provides a poor representation of any shell’s ability to resist autoclave cracking. This fact was originally discussed in some length in a 2007 ICI paper by S. Bhattacharja and presented the same year by R. Rosmait (ref. 2). This paper demonstrated the ability of a hollow cylindrical tube, commonly recognized as one of the most challenging geometries to dewax, to clearly differentiate various shell systems, colloidals and latexes with respect to cracking.

The test has a proven sensitivity and, critical to the dip personnel, an ease of generating large quantities of shelled pipes for meaningful results. The same method of choice was chosen to achieve the objective in this study.

2.0 EXPERIMENTAL

2.1 Materials

Two pattern wax types were injected into the geometry: 1.25” OD, ID of 0.75”, length of 4.0”. The gate was sized as follows: 0.75”x 1.25**”** at the attachment point and reduced down to 0.375”x 1.25” at the cylinder (see Fig. 1). Wax 1 is a low viscosity non filled pattern wax, while wax 2 is a higher viscosity non filled pattern wax. The two pattern waxes chosen have significantly different viscosities to clearly show the effect viscosity can have upon shell cracking. It is important to note that both waxes are used successfully at a variety of PIC facilities. Only non filled waxes were chosen for this initial study.

Fig. 1. Hollow Wax Cylinder

The viscosities of the waxes were measured using a Brookfield viscometer in the range of 140°F to 200°F. Values below 140°F could not be measured in Wax 2. Therefore it was decided not to indicate the viscosity values of either wax below that temperature. The graphical representation of the waxes can be seen below (Fig. 2). It is important to note here that both pattern waxes had more than a 10°F higher ring and ball softening point (per ICI Test Procedures) than that of the red downsprue to which they were attached (Table 1).

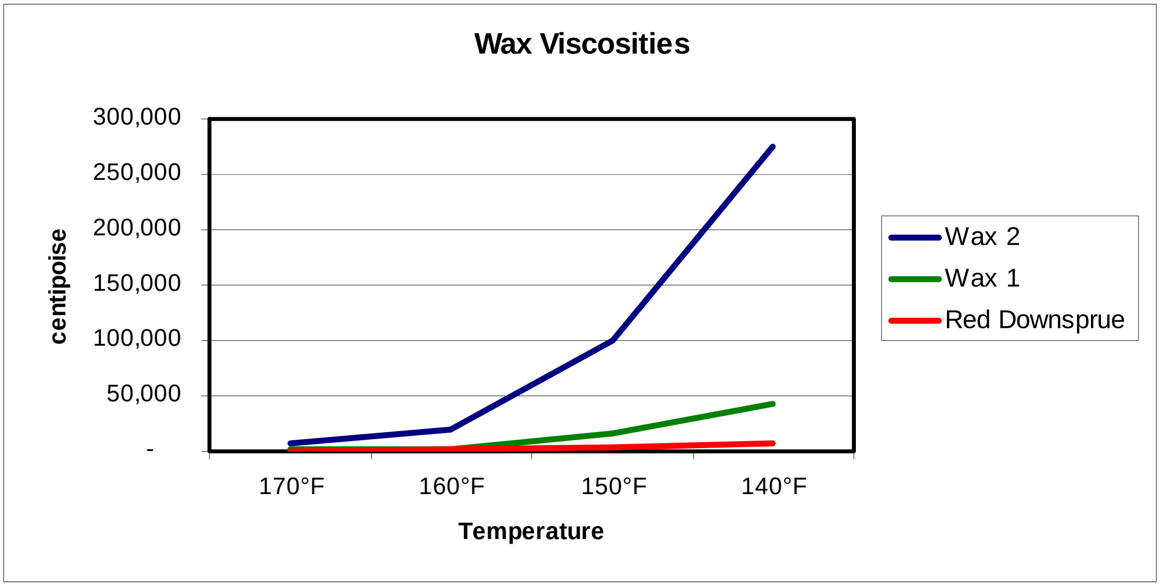


Fig. 2. Wax Viscosity Curves.

	Wax 1	Wax 2	Red Downsprue
Ring and Ball Softening Point	162°F	178°F	150°F

Table 1. Ring and Ball Softening Points.

Wax pipes were arranged six to a tree, three on each side of a 1”x 2” red wax extrusion used as a downsprue.

Three prime slurries were mixed and creamed-in overnight. The first was a blend of 25% 200 mesh zircon and-75% 120 mesh fused silica. The second slurry was a 50-50% blend of 200 mesh zircon and 200 mesh fused silica. The last slurry was experimental but also used both fused silica and zircon flours. All three slurry systems were run at 43 – 45 sec on a Zahn EZ #5 cup using Nalco 1030 colloidal and Minco HP latex.

The intermediate and backup slurry used was mixed using Minco WDS, Nalco 1130 and Minco HP. This was run at 18-20 sec on an ISO 6mm mini dip cup.

2.2 Shelling

Half of the trees (18) were shelled with one prime dip and zircon stucco. Six were dipped in slurry one, six in slurry two and six in slurry three. The other half of the trees were shelled with two prime dips, the first stucco being zircon and the second stucco being fused silica 50x100. All shells received three backups and a final seal dip. Table 2 and Fig. 3 below depict how both types of pipes were shelled and what waxes were used.

TEST MATRIX- Number of Pipes

Wax Visc	# Prime Dips	25-75 Zircon- Silica	50-50 Zircon Silica	New Prime
High	1	18	18	18
Low	1	18	18	18
High	2	18	18	18
Low	2	18	18	18

6 pipes per tree x 3 trees = 18 pipes

Table 2. Test Matrix for Permeability Study.

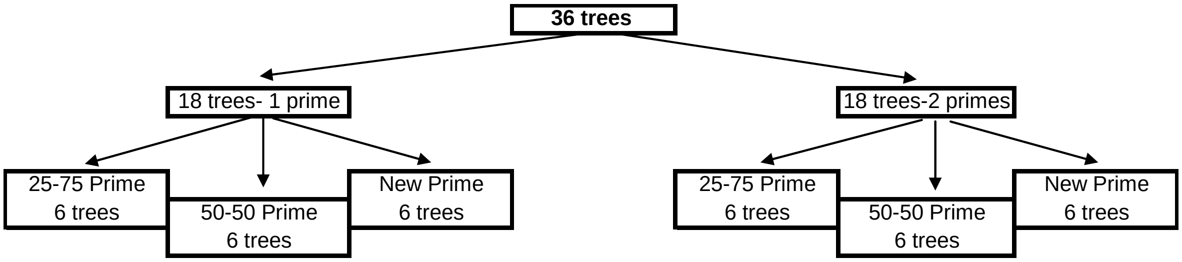


Fig. 3. Visual Depiction of Test Matrix.

Ten pipes per dip sequence were shelled at PSU using the new combination burst and shell permeability test developed by B. Snyder and J. Snow (ref. 3). These tests were completed at the Minco R&D lab

2.3 Autoclaving and Measurement

Dewaxing was performed at PSU's investment casting laboratory's steam autoclave. This has a 2 ft diameter and 3 ft in length chamber built by WSF Industries. The autoclave operating temperature is a consistent 338F (170C) at a pressure of 100 psi. The dewax cycle time is 25 minutes.

Six trees per cycle are dewaxed at a time. Steam from the accumulator enters the top of the autoclave in the center top of the chamber. Due to concerns with differences in steam exposure directly under the vent, shells were placed at both ends of the chamber and none in the center of the loading tray. This was accomplished with three trees in the front, no trees in the center and three trees at the rear of the loading cart (see Fig. 4) in the auto clave.

Fig. 3. Autoclave Tray Ready for Loading (courtesy R. Rosmait, PSU).

Once cooled to room temperature after removal from the autoclave, shells are visually inspected with use of a lighted magnifying glass. Cracks are counted and lengths of each are measured and recorded. The total crack lengths were then calculated for each subgroup for simplest comparison.

3.0 RESULTS AND DISCUSSION

3.1 Prime Particle Size Data

Perhaps a quick refresher is in order on particle size distribution (PSD) nomenclature. PSD's are typically described in terms of D10, D50 and D90. These denote the particle sizes at which 10% are smaller than the micron size noted as D10. Likewise, D50 and D90 represent the particle sizes where 50% and 90% of the particles are smaller than the value noted. A comparison of the three prime slurry PSD's using these descriptors is provided below in Fig. 5.

The figure shows that the proprietary prime's distribution is the widest and coarsest. The 50-50% 200F Zircon 200F Fused Silica is the finest and narrowest distribution, while the 25-75% 200 Zircon/ 120 Fused Silica is between both.

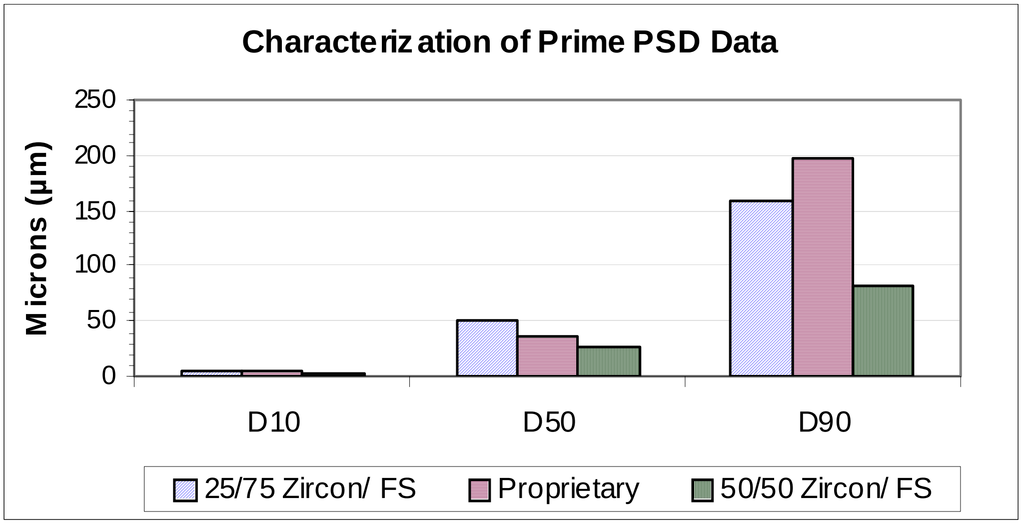


Fig. 5. Characterization of the three Prime Slurry PSD's.

Specific surface area of the refractory prime flours was measured and is shown in Fig. 6 below. The experimental prime clearly dominates with the greatest surface area, well ahead of the standard prime blends. The 25/75 blend of zircon/ fused silica has the lowest surface area which corresponds as expected when compared to the coarser particle size distribution summary above.

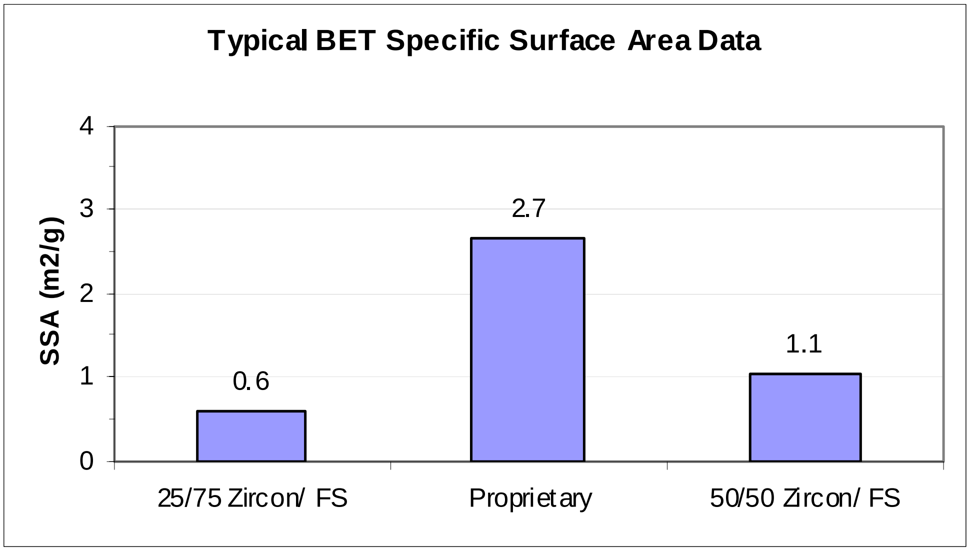


Fig. 6. BET Surface Area Data for the three Prime Slurries.

3.2 Shell Permeability

Shell permeability was measured at Minco (see Fig. 7 below) using the combined permeability and burst test mention above. Somewhat unexpectedly, no significant difference was seen in shells with one prime application except perhaps for the 50/50 fused silica/ zircon prime (shown below as prime type 3) which is somewhat lower in permeability. In all cases the permeability drops with a second prime application although the proprietary prime dropped in permeability much less than the other two primes. The proprietary slurry appears to be somewhat less sensitive to the additional prime layer.

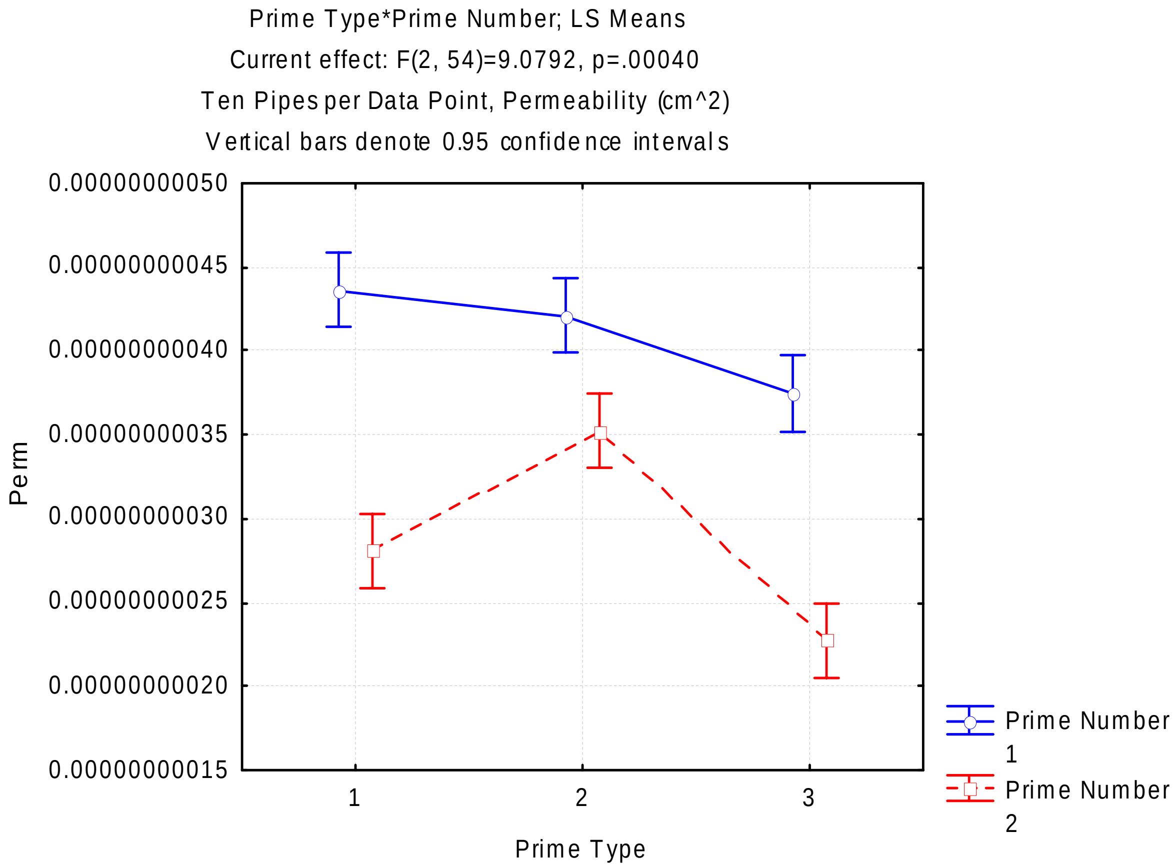


Fig. 7. Permeability of One and Two Primes

(1= 25/75 FS/ Zircon, 2= Proprietary, 3= 50/50 FS/ Zircon)

Fig. 8 below shows the overall effect of an additional prime dip to shell permeability. The additional prime dip dramatically reduces the permeability of a shell by 30%. Table 3 depicts the results of the ANOVA calculations.

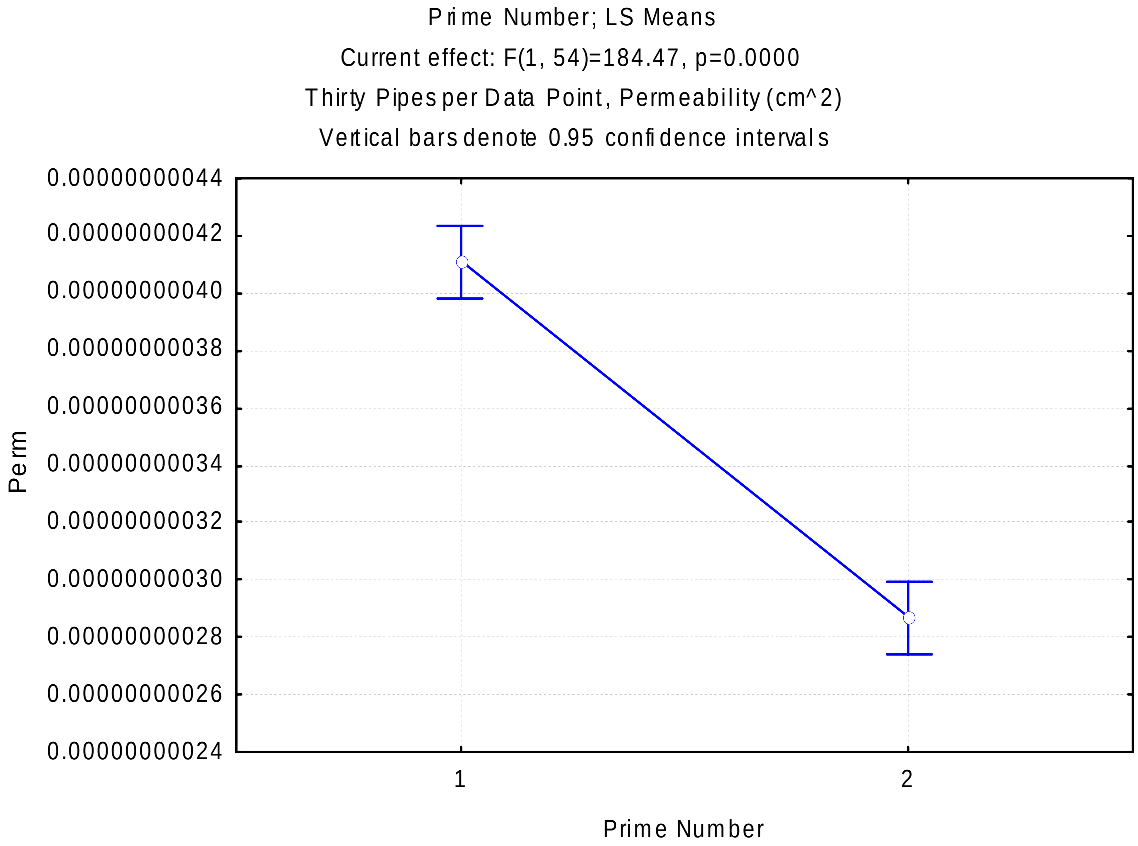


Fig. 8. Overall Effect of Prime Dips upon Permeability.

Effect upon Perm	**SS**	**Deg. Of Free.**	**MS**	**F**	**p**
Prime Type	0	2	0	30.4	.000*
Prime Number	0	1	0	184.5	0.000*
Prime Type*Prime Number	0	2	0	9.1	.000*

Table 3. ANOVA for Permeability

3.3 Maximum Tangential Stress Results (Burst Test)

Once the permeability of the shells was established, the maximum tangential stresses were determined in the hot/wet state by burst testing as referred to above. Fig. 9 depicts the maximum tangential stress experienced at failure. Clearly the prime type did not affect the overall shell burst strength when one prime dip was used. Only the 50/50 fused silica/ zircon slurry stands out as different with two prime applications. This prime is the finest and narrowest of the three prime distributions. It is possible that this distribution provides better prime strength and the second layer gave this prime an edge in burst testing.

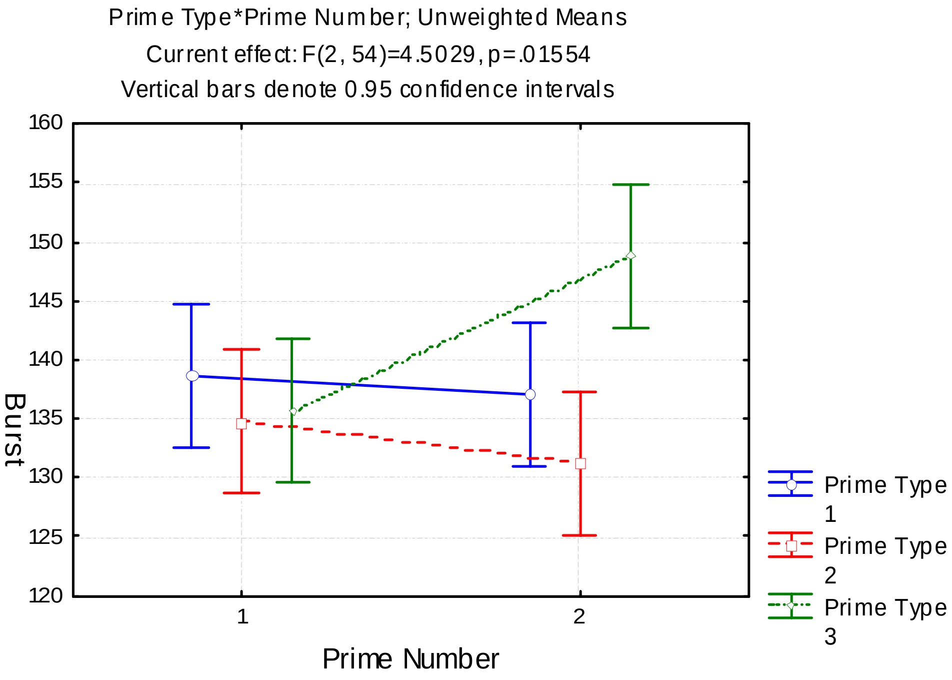


Fig. 9. Maximum Tangential Stress in Pipes (psi)

(1= 25/75 FS/ Zircon, 2= Proprietary, 3= 50/50 FS/ Zircon)

Table 4 below summarizes the ANOVA calculations for burst testing.

Effect upon Burst	**SS**	**Deg. Of Free.**	**MS**	**F**	**p**
Prime Type	841.2	2	420.6	4.574	.015*
Prime Number	107.6	1	107.6	1.17	0.284
Prime Type*Prime Number	828.1	2	414	4.503	.016*

Table 4. ANOVA Summary for Burst Testing.

3.4 Autoclave Shell Crack Results

3.4.1 Effect of Wax Type upon Cracking

Hollow pipes inspected after dewaxing at PSU were measured for crack length on each pipe. Crack lengths were then added for each subgroup for a ‘Total Crack Length’ value. This appears in the subsequent graphs.

In Fig. 10, Wax 2, with a higher autoclave temperature viscosity, clearly shows a greater propensity to generate cracks in a single prime dip shell.

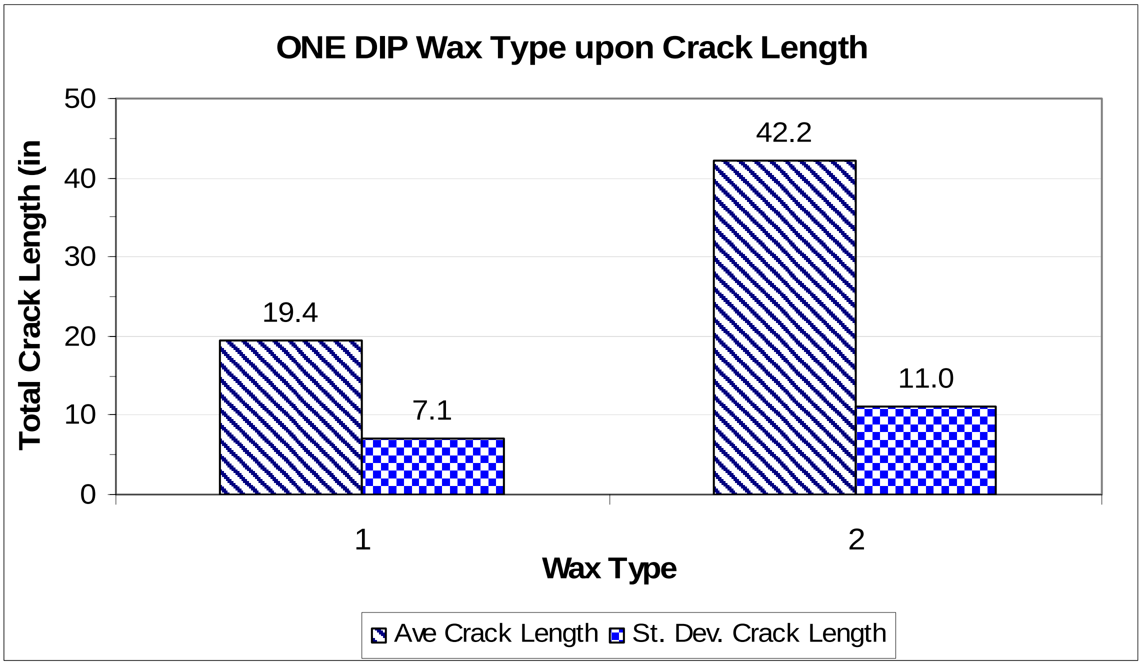


Fig. 10. Single Dip Prime and Affect of Wax Type upon Cracking

Fig. 10 below shows a quite similar result with little difference noted between one and two prime dips. The wax difference is clearly a large factor.

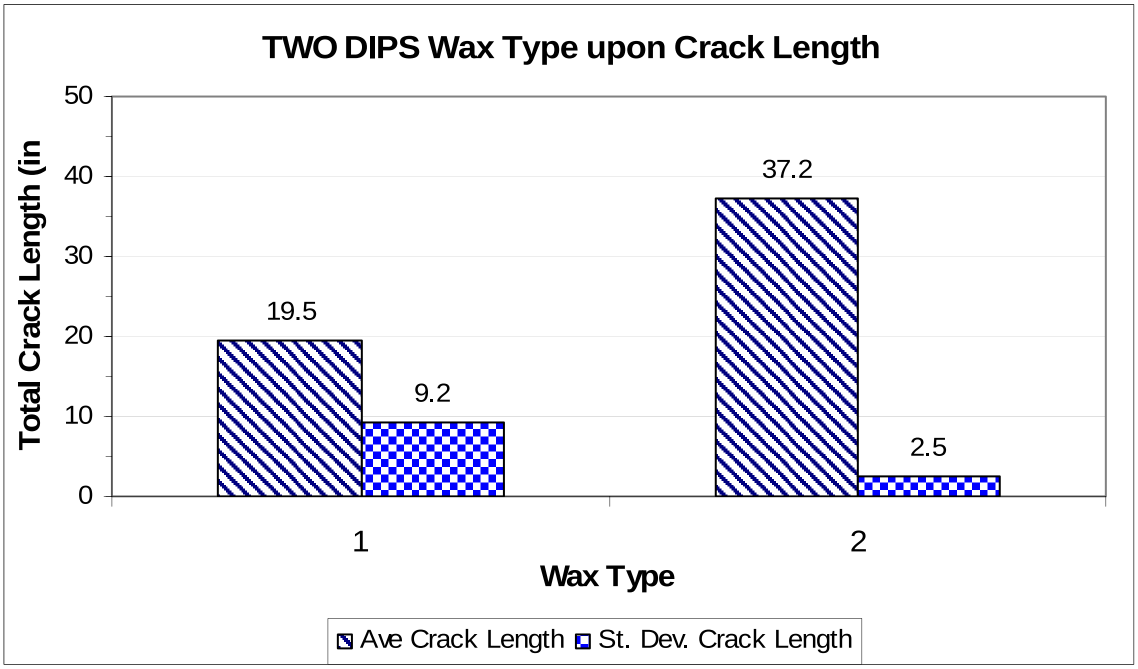


Fig. 11. Two Prime Dips and the Affect of Wax Type upon Cracking

3.4.2 Effect of Primes upon Cracking

Unexpectedly, the effect of the number of prime dips upon shell cracking did not seem to make any difference overall (Fig. 12). However, upon comparing each individual prime system, the 50/50 zircon/ fused silica prime did demonstrate less total cracking (Fig. 13).

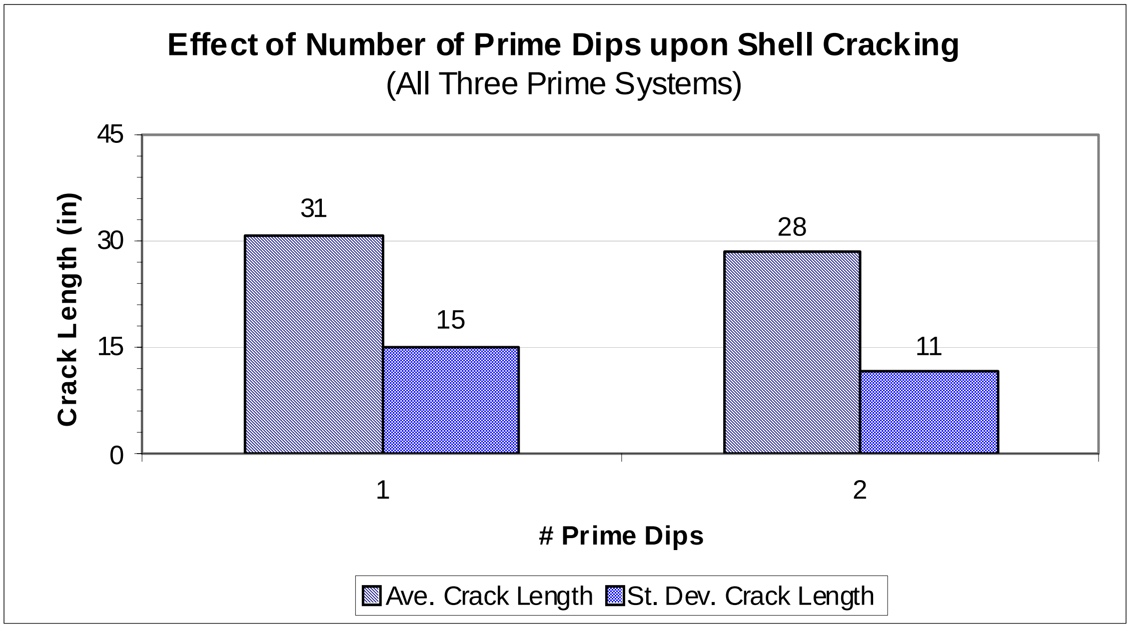


Fig. 12. Effect of Number of Prime Dips upon Crack Generation.

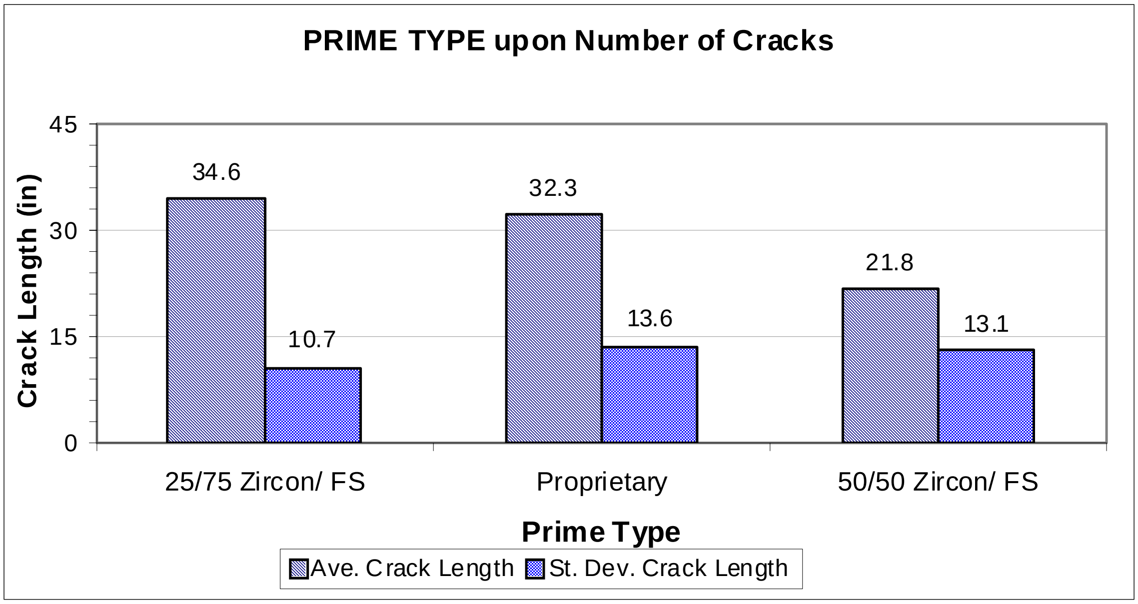
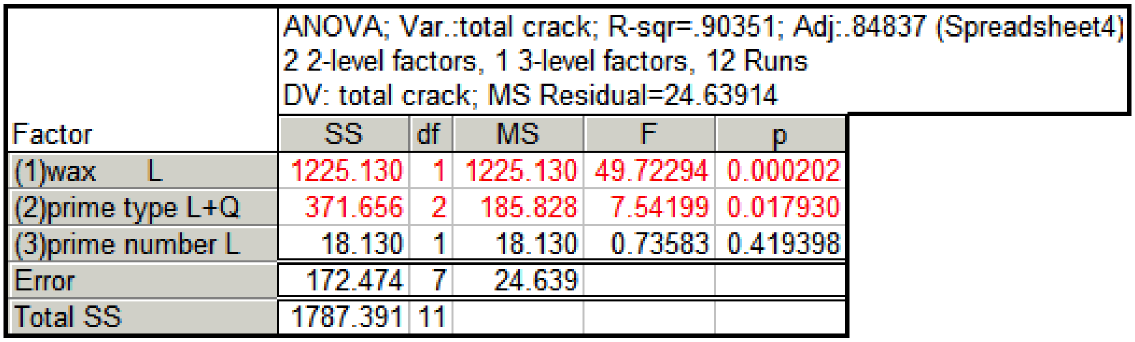


Fig. 13. Effect of Prime Type upon Crack Length (one and two prime dip shells).

An analysis of variance calculation is given below. An ANOVA (Table 5) indicates that a retest would perform the same with respect to wax viscosity on cracking with a 99.8% confidence. The data suggests the prime types would behave similarly with respect to shell cracking if the test was repeated (p=0.018). With a high p-value of 0.42 however, there is considerable risk that the relationship between number of prime dips and occurrence of shell cracking that appears in Fig. 12 is not accurate. This suggests that in fact additional prime dips could affect shell cracking.



ANOVA; Var.:total crack; R-sqr=.90351; Adj:.84837 (Spreadsheet4)
2 2-level factors, 1 3-level factors, 12 Runs
DV: total crack; MS Residual=24.63914

Factor	SS	df	MS	F	p
(1)wax L	1225.130	1	1225.130	49.72294	0.000202
(2)prime type L+Q	371.656	2	185.828	7.54199	0.017930
(3)prime number L	18.130	1	18.130	0.73583	0.419398
Error	172.474	7	24.639		
Total SS	1787.391	11			

Table 5. ANOVA Results on Shell Cracking

4.0 CONCLUSIONS:

1. In this study the greatest effect upon shell cracking was shown to be wax viscosity. The higher wax viscosity resulted in significantly more cracked shells.
2. Shell permeability was lowered by adding a second prime dip. Permeability was decreased the most by a second typical prime slurry dip, while a second proprietary prime dip decreased the least.
3. Shell burst strengths were unaffected by prime type and number of dips. One exception is the 50/50 zircon/ fused silica prime which had slightly higher burst strength after a second prime dip.
4. Unexpectedly, an additional prime dip made essentially no difference in shell cracking in this study. This result is contrary to the common experiences with multiple prime applications.

6.0 REFERENCES

1. J. Snow, et.al. “Permeable Prime Coats: Effect on Dewax Shell Cracking”, 50th Annual Technical Meeting of the Investment Casting Institute, 2002, pp 17:1-36.
2. S. Bhattacharja, et.al., “Effect of Refractory Particle Size and Polymer Selection on Autoclave Performance”, 55th Annual Technical Meeting of the Investment Castings Institute, 2007, pp 18:1-14.
3. B. Snyder, et.al. “A New Combination Shell Strength and Permeability Test”, 51st Annual Technical Meeting of the Investment Castings Institute, 2003, pp 11:1-26.

7.0 ACKNOWLEDGEMENTS

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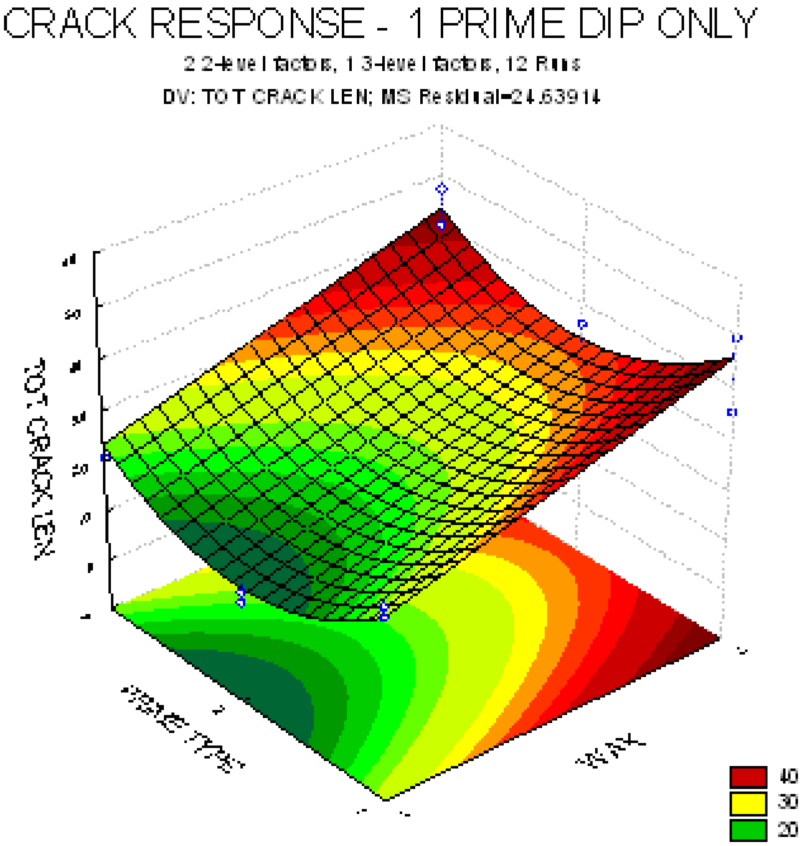
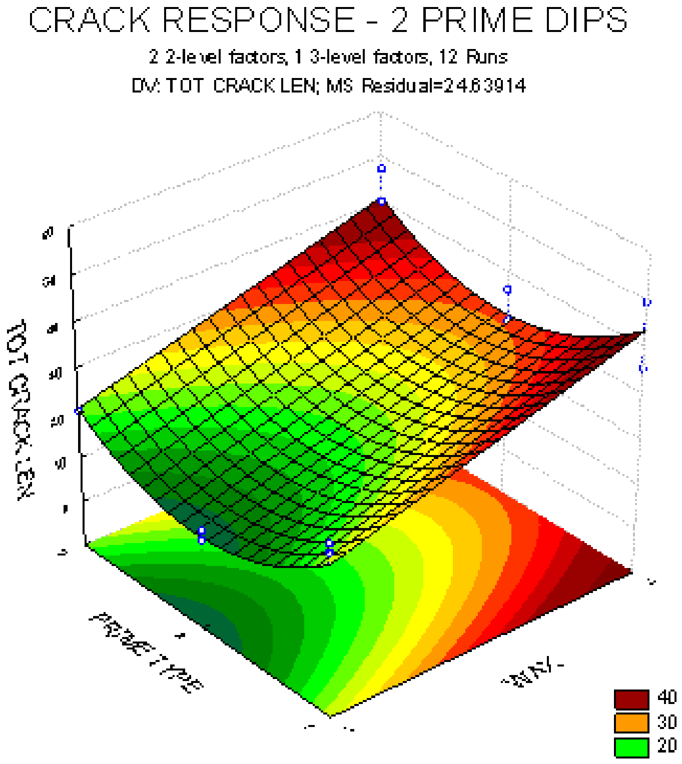
8.0 ADDENDUM


CRACK RESPONSE - 1 PRIME DIP ONLY
2 2-level factors, 1 3-level factors, 12 Runs
DV: TOT CRACK LEN; MS Residual=24.63914
TOT CRACK LEN
PRIME TYPE
WAX
40
30
20


CRACK RESPONSE - 2 PRIME DIPS
2 2-level factors, 1 3-level factors, 12 Runs
DV: TOT CRACK LEN; MS Residual=24.63914
TOT CRACK LEN
PRIME TYPE
WAX
40
30
20