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INVESTIGATION OF COATINGS WHICH PREVENT MOLTEN ALUMINUM/WATER EXPLOSIONS

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Abstract

The Aluminum Association contracted Alcoa in 1995 to identify and test new protective coatings for casting pits as a replacement for Porter International's 7001 (Tarset Standard). Three new coatings have been identified through a series of selection criteria including: 1) A standardized splash test used to evaluate personal protective clothing, 2) An industry-standard molten metal explosion test, 3) A multiple-exposure test to measure durability, and 4) An external shock impact test. The results of this program will be reviewed. This study only tested protective coatings at the "in-service cure time", as defined by the manufacturer. These curing times can be excessive for a production casting facility. The Aluminum Association has contracted Alcoa in a second program to investigate the effect of reduced cure times on adhesion and their effectiveness in preventing molten metal/water explosions. A status update of this new two year program is provided.

Introduction

The aluminum industry had used Porter International's 7001 (Tarset Standard) successfully as a protective coating in casting pits for over 20 years to prevent molten aluminum and water explosions. In 1994, the unavailability of certain raw materials, as well as environmental and industrial health concerns caused its withdrawal from the market. During the period of 1995 August through 1997 March, research contracted by the Aluminum Association, on behalf of a group of sponsoring companies, identified alternate coating materials which would be an acceptable replacement for 7001 [1].

Alcoa used its polymer chemistry background, familiarity with the coating industry and discussions with experts to screen the various options. Test panels for 38 different coatings from eleven vendors in seven different classifications were obtained for evaluation.

Research Program

The Alcoa program and methodology was reported previously by Richter et al. [2]. The series of selection criteria used to screen these coatings included: 1) A standardized splash test used to evaluate personal protective clothing, 2) An industry-standard molten metal explosion test, 3) A multiple-exposure test to measure durability, and 4) An external shock impact test. The latter three screening tests were performed using equipment in the Alcoa Explosion Bunker, located at the Alcoa Technical Center (ATC), east of Pittsburgh, PA.

Molten metal explosion testing was conducted using equipment similar to that used in previous studies at Alcoa [3,4]. The experimental set-up is shown in Figure 1. A minimum of five tests were performed with each coating. Uncoated (bare) steel pans were tested as controls. In addition, tests were performed on 7001 and ESP's WiseChem E-212-F coated pans. WiseChem E-212-F had been tested in previous explosibility studies, and is currently used by the industry as a protective coating.

The Durability Tests consisted of repeating the explosion test, as outlined above, on the same container, until an explosion occurred. The pans received no recoating or other pre-treatment between exposures.

Previous work [3] had noted that an aluminum/water explosion could be initiated by a shock external to the water container under normally protected conditions. An apparatus was constructed which provided an external shock-pulse trigger perpendicular to the falling molten metal (see Figure 2). The shock tests in this study were performed using a 150 lb. pendulum which provided a calculated impact of 220 ft-lb.

Results

Phase I - Coating Selection

After reviewing all 38 potential coatings against the selection criteria shown in Table I, a team composed of representatives from the Sponsor Companies chose seven coatings which would undergo explosion testing:

Coal Tar Epoxies:	Phenolics:
Bitumastic 300M	Cor-Chem 205
Intertuf 132 HS	
Epoxy Mastics:	100% Solid Epoxies:
Interzone 954 HS	Multi-Gard 955CP
Cor-Chem #283	WiseChem E-115

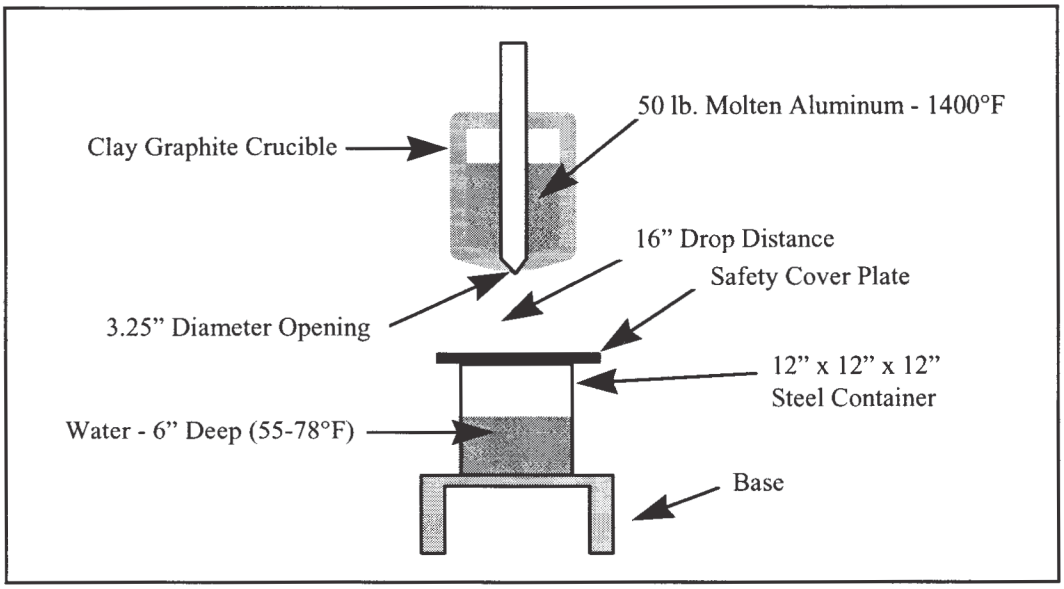

Figure 1: Standard Explosion Test Set-up

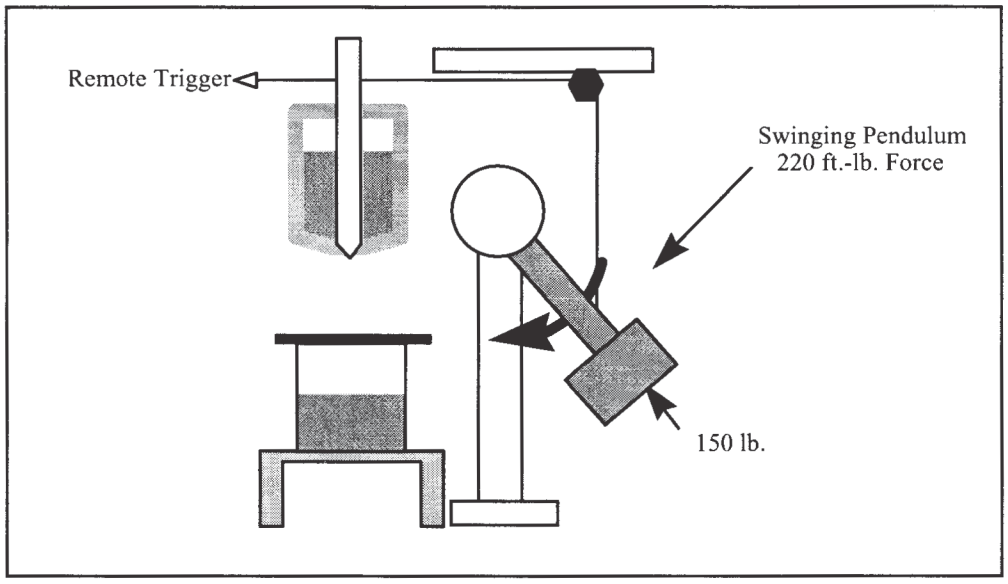

Figure 2: Shock Impact Test Set-up

Table I: Coating Selection Criteria

First order requirements

- Explosion avoidance
- Durability (after molten metal contact)
- Short drying/curing time
- Adhesion
- Environmental and industrial health friendliness in manufacturing and during application

Second order requirements

- Submergibility in water
- Ease of repair
- Resistance to erosion, impacts & abrasion
- Ease of application (on wet & dry surfaces)
- Cost

Attachment I contains property characteristics for the top seven coatings in addition to Tarset Standard and WiseChem E-212-F which were also tested as controls.

Phase II - Explosion Testing

Table II contains the results of the molten aluminum/water explosion tests. No explosions were observed in any of the tests using the top seven candidate coatings. However, as expected, all seven of the bare control pans produced molten metal explosions. Neither the WiseChem E-212-F or Tarset Standard coated pans exploded, as expected.

Table II: Explosion Test Results

Coating	Number of Tests	Number of Explosions
Coal Tar Epoxies		
Bitumastic 300M	8	0
Intertuf 132HS	6	0
Epoxy Mastics		
Interzone 954HS	8	0
Cor-Chem #283	6	0
Phenolic		
Cor-Chem #205	6	0
100% Solid Epoxies		
Multi-Gard 955 CP	6	0
WiseChem E-115	6	0
Control (uncoated/oxidized steel)	7	7
Others		
Tarset Standard	1	0
WiseChem E-212-F	2	0

Among the control tests, explosions ranged from Force 1 (simple expulsion of molten metal within 15 feet) to Force 3 (extensive equipment damage, with metal thrown a considerable distance) as defined by the Aluminum Association.

After finalizing the explosion tests, five of the coatings were selected for inclusion into the next phase. The main criteria used were:

- Visual assessment of amount of charring.
- Amount of peeling in non-molten metal contact areas.
- Quantity/Quality of bare spots.
- Ease of application when brushed, on a scale of 1 to 10 [1 = easiest, 10 = hardest] (Refer to Attachment I)

Phase III - Durability and Shock-Impact tests

Table III summarizes the results of the durability tests. In this phase, two different thicknesses of the WiseChem E-212-F were tested to cover the range of applications currently used in the industry.

Note that none of the five candidate coatings performed as well as Tarset Standard, and we found no detectable difference between the two coating thicknesses.

After a review of the test data and the coating properties, a final selection of the best three candidate coatings was made by the Alcoa Team, the Aluminum Association and the Sponsor Companies. These were:

1. Intertuf 132HS, a coal tar epoxy by Courtaulds.
2. Multi-Gard 955CP, a 100% solids epoxy by Carboline.
3. WiseChem E-115, a 100% solids epoxy by ESP.

Table III: Durability Test Results

Coating	Test number at which the explosion occurred
Coal Tar Epoxies	
Bitumastic 300M	4
Intertuf 132HS	3
Epoxy Mastics	
Cor-Chem #283	3
100% Solid Epoxies	
Multi-Gard 955 CP	4
WiseChem E-115	3
Others	
Tarset Standard	5
WiseChem E-212-F (8-10 mils)	4
WiseChem E-212-F (16-20 mils)	4

Table IV contains the results of the shock impact tests.

Table IV: Shock Impact Test Results

Coating		Explosion (Y/N)
Coal Tar Epoxies		
Bitumastic 300M	Test #1	Y
	Test #2	Y
Intertuf 132HS		N
Epoxy Mastics		
Cor-Chem #283	Test #1	Y[1]
	Test #2	N
100% Solid Epoxies		
Multi-Gard 955 CP		N
WiseChem E-115		N

[1]This test was invalidated due to impact timing issues.

Phase IV - Extended Tests

Statistical confidence in the explosion test results was strengthened by: 1) Following procedures established in previous studies which consistently achieve explosions when conditions are set accordingly, and 2) Conducting 15 additional tests on the final three candidates.

The risk associated with concluding that no explosion will occur can be calculated from "*N*", the number of tests performed and "*x*", the number of explosions observed. The *Power of the test* is defined as = 1-Type II error[2]. This quantity gives us the probability of detecting that a coating can yield an explosion.

None of the three coatings exploded during this phase, while all control tests did. Since the final three candidates were tested total of 21 times, statistics showed that, if the probability for an explosion is 1-in-10, then our chances of detecting an explosion was approximately 87.8%, however, for an explosion probability of 1-in-100, there was an 18.2% chance of observing an

[2]Type II error (β) - Saying it will not explode when in fact it will.

explosion. Budgetary constraints made it prohibitive to perform the required number of tests to increase the confidence level. Statistically it would require 250 tests to have a 91.9% confidence level.

New Research Program

During this investigation, a key issue arose: Given the long cure times recommended by the manufacturer for the best candidates, what is the effect of reduced cure or water immersion times on adhesion and their effectiveness in preventing molten metal/water explosions?

In September of 1988 Alcoa was contracted by the Aluminum Association to address the Cure Time issue. We formulated a multi-step approach using Alcoa and vendor expertise, and the Alcoa Technical Center Explosion Bunker along with equipment and expertise related to steam explosion prevention developed at Oak Ridge National Labs (ORNL) under a Cooperative Research And Development Agreement (CRADA) with the Aluminum Association. Figure 3 shows a flowchart of the new four-phase program.

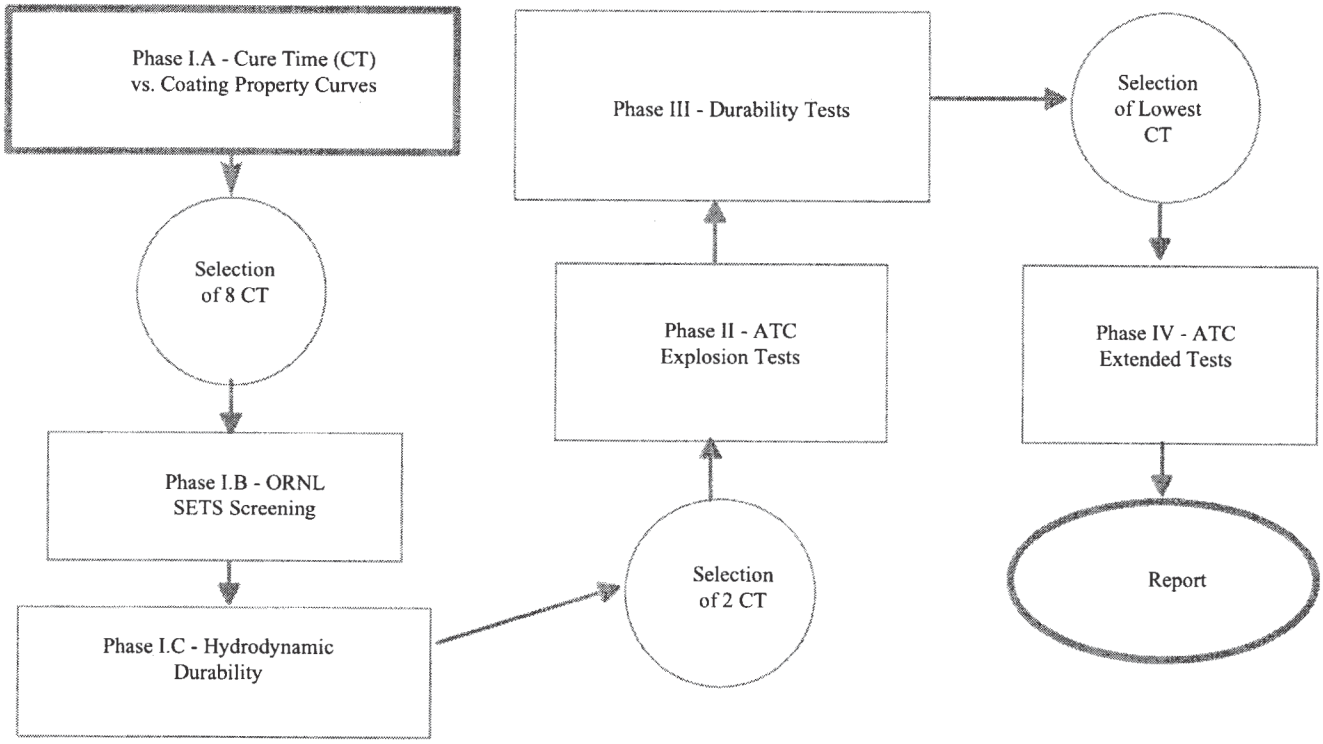

Figure 3: Effect of Coating Cure Time on Adhesion and Explosion Program Flow Chart

Alcoa is currently in Phase IA of this new program: Develop Coating Characteristic vs. Cure Time Curves. Various analytical techniques, typically used in the coatings industry, are being used to measure the changes occurring in the coatings over time. Four analysis are being performed:

- Differential Scanning Calorimetry (DSC) — A technique which measures energy changes in the coating as it is heated at various rates. This tool is used to predict chemical rates of reaction. It is also the primary tool that will be used to predict the coating's cure cycle.

- Thermo-Mechanical Analysis (TMA) — This equipment measures the coating integrity after the material cures for a given time span. Specifically, it determines the shift in the glass temperature of the coating. This technique can be applied to materials cured in air and under water.

- Thermo-Gravimetric Analysis (TGA) combined with Mass Spectrometry (MS) — This technique would qualitatively identify and quantitatively measure the evolution of volatiles as the coating cures at a given temperature.

- Modified Steam Attack Test — A procedure used for evaluating the adhesion of a coating. Steam under pressure is blown over the coating to simulate the hot environment within casting operations.

In this phase, Alcoa will develop a series of curves for each technique detailing the effect of time. These curves would then be used to select a reduced number of cure times for inclusion into Phase I.B: Screening of selected cure times at Oak Ridge National Labs.

Oak Ridge's Steam Explosion Triggering Studies (SETS) equipment provides a fast and relatively inexpensive method to select cure times which will be evaluated at the Explosion Bunker in Phases II and III during the summer of 1999. Alcoa expects to complete the Extended Tests (Phase IV), providing information on minimum cure times required for each coating, by the summer of 2000.

In Summary

1. Alcoa, under contract with the Aluminum Association, identified and screened 38 candidates for evaluation in a study to investigate coatings which could prevent molten aluminum/water explosions.

2. Seven coatings were selected and screened for explosibility using a molten aluminum discharge technique developed by Alcoa.

3. From the top seven candidates, the best five coatings were selected based upon the observations made during the screening tests.

4. The top five coatings were evaluated for durability via repeated molten metal exposures and for explosion avoidance when mechanically impacted.

5. The results of this study applies only to coatings tested after the "In-service time" as defined by the vendors. Explosion test results may be different at less than the "in-service time."

Conclusions

1. None of the top seven candidate coatings exploded during the screening tests. However, all the control (uncoated/oxidized steel) pans did produce an explosion.

2. None of the candidate coatings performed as well in the durability tests as 7001 (Tarset Standard).

3. Based on the overall screening results, three coatings were selected for extended testing by the Alcoa Team and the Sponsor Companies. No explosions were observed in the fifteen additional tests performed on each of these three coatings. However, all the uncoated controls did.

4. The final three coatings were:
   Intertuf 132HS,
   Multi-Gard 955CP and
   WiseChem E-115

5. Given the number of tests performed per coating, we obtained a confidence level of 87.8% for a 1-in-10 probability of an explosion, or, 18.2% for a 1-in-100 probability of an explosion. A prohibitively large number of tests would be required to gain confidence levels greater than 90%.

6. Given the long cure times involved for the best coating candidates, The Aluminum Association commissioned a new two-year program, which started in September of 1998, to investigating the effect of reduced cure or water immersion times on adhesion and their effectiveness in preventing molten metal/water explosions.

References

[1] León, D. D., Richter, R. T., Levendusky, T. L., *Investigation of coatings which prevent molten aluminum/water explosions - Final report to the Sponsor Companies*, Report No. 97-475-18-DDL, 1997 June.

[2] Richter, R. T., León, D. D., Levendusky, T. L., *Investigation of coatings which prevent molten aluminum/water explosions - Progress Report*, Light Metals 1997, 126th TMS Annual Meeting, Orlando, FL, 1997 February

[3] Hess, P. D., Miller, R. E., Wahnsiedler, W. E., and Cochran, C. N., *Molten Aluminum/Water Explosions - 1979*, Alcoa Research Laboratories Report, October 1979.

[4] Hess, P. D., Miller, R. E., Wahnsiedler, W. E., and Cochran, C. N., *Molten Aluminum/Water Explosions,* Light Metals 1980, 109th AIME Annual Meeting, Las Vegas, NV, 1980 February.

Attachment I - Coating Properties

Coating System	Coating Supplier	Cure Time	Pot Life	VOC (lb./gal)	No. of Coats @ Applied Thickness	Ease of Application	How to Apply
Coal Tar Epoxies							
Bitumastic 300M	Carboline	144 hr. @ 75 F	3 hr. @ 70-75 F	2.01	1 @ 16 mils DFT	1	Brush, Roll or Spray
Intertuf 132 HS	Courtaulds	168 hr. @ 75 F	4 hr. @ 75 F	1.73	2 @ 8 mils = 16 DFT	1	Brush, Roll or Spray
Porter Int. 7001 (Tarset Stnd)	Courtaulds	168 hr. @ 75 F	Not available	2.37	2 @ 8 mils = 16 DFT	1	Brush, Roll or Spray
Epoxy Mastics							
Interzone 954HS	Courtaulds	168 hr. @ 75 F	1 hr. @ 75 F	1.47	1 @ 20 mils DFT	10	Brush, Roll or Spray
Cor-Chem #283	Glidden	72 hr. @ 70 F	1 hr. @ 70 F	0.15	1 @ 20 mils DFT	7	Heated Airless, Brush or Roll
WiseChem E-212F	ESP	16 hr. @ 70 F	4 hr. @ 77 F	N/A	2 @ 5 mils = 10 DFT (Steel)	8	Brush, Roll or Spray
100% Solid Epoxies							
Multi-Gard 955 CP	Carboline	168 hr. @ 75 F	1.5 hr. @ 75 F	0.04	2 @ 8 mils = 16 DFT	2	Brush, Roll or Spray
WiseChem E-115	ESP	16 hr. @ 77 F	1 hr. @ 77 F	0.00	1 @ 8 mils = 8 DFT (Steel)	9	Brush, Roll or Airless Spray
Phenolics							
Cor-Chem #205	Glidden	120 hr. @ 70 F	1 hr. @ 70 F	0.03	1 @ 20 mils DFT	6	Heated Airless, Brush or Roll

Notes:
1) All coatings can be applied to steel or concrete surfaces
2) Cure times - Time required for coating to harden prior to placing in service, as defined by the vendors
3) Pot Life - Time period after mixing during which the coating remains usable
4) VOC - Volatile Organic Compounds
5) Ease of Application - Qualitative rating based on brushing on steel (1 is easiest)
6) All of the coatings tested had an "A" rating (Pass) in the Molten Metal Splash Test

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