CERP

Casting Emission Reduction Program

www.cerp-us.org

Operated by

Technikon

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Inorganic Binder Properties Study

1413-145 NA

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Inorganic Binder Properties Study

1413-145 NA

This report has been reviewed for completeness and accuracy and approved for release by the following:

Senior Process Engineer	*//Original Signed//* Thomas Fennell	Date
Vice President of Operations	*//Original Signed//* George Crandell	Date

The data contained in this report were developed to assess the relative performance profile of the process being evaluated. You may not obtain the same results in your facility.

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Table of Contents

List of Figures and Tables

Executive Summary

The objective of this testing was to compare process variables on select low emission binder systems. These variables included the tensile strength at various time intervals and humidity conditions and the ability of a core from each binder to be shaken out after being poured. Table 1 is a summary of each binder tested and the testing intervals.

Table 1 Test Plan Summary

Category	Description
Binders Used	Foseco Ecolotec® 750
	Hormel GMBond®
	HA International Cordis® 8266 with Anorgit® 8393
	HA International Cordis® 8323 with Anorgit® 8370
	Ashland GeoSet®
	HA International SigmaCure® (for shakeout tests and 2 hr tensile only)
	HA International Cordis® 4820BF (for shakeout tests only)
Test Intervals	5 min, 2 hours, 24 hours, 24 hours in a 100% relative humidity environment at 70°F

The dog bone (AFS standard, 1 in. thick tensile specimen) tensile test pieces were prepared by mixing the sand in an epicentric (KitchenAid®) sand mixer, blowing the dog bones on a Redford/Carver core machine, and storing them in a desiccator for the various time intervals. They were weighed on a MyWeigh i2600 scale, and tensile tests were performed using a Thwing-Albert QC-3A tensile tester.

The dog bones were all prepared with parameters based on AFS procedure 3315-00-S. Changes were made to some parameters to compensate for differences in the 3-on dog bone box. The specimens were tested per AFS procedure 3301-00-S. The results are shown in Table 2, and Figures 1 and 2.

Table 2 Average Tensile Strength of 30 Dog Bone Pieces for each Binder

Binder	Tensile Strength in psi at specific intervals			
	5 minute	2 hour	24 hour	24 hour humidity
Foseco Ecolotec® 750	70.3	88.9	88.3	85.7
Hormel GMBond®	230.5	235.6	325.7	29.2
HA International Cordis® 8266 with Anorgit® 8393	273.7	352.5	305.2	126.3
HA International Cordis® 8323 with Anorgit® 8370	197.4	259.2	270.7	31.6
Ashland GeoSet®	221.7	316.7	322.9	37.8
HA International SigmaCure®	NT	326.1	NT	NT

NT=Not Tested

Figure 1 Tensile Strength of Low Emission Binders over Time in a Dry Environment

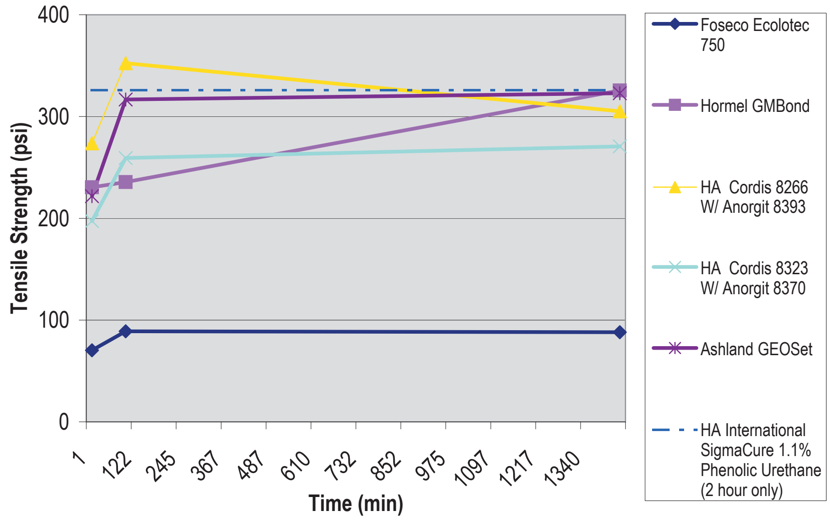
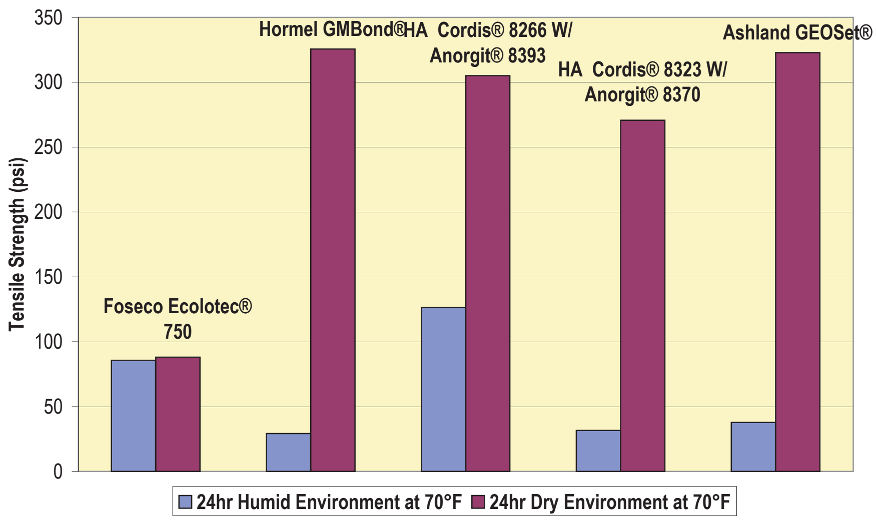


Figure 2 Tensile Strength of Select Inorganic Binders after a 24 Hour Period in a Desiccator in a 100% Relative Humidity Environment



The shakeout cores were prepared by mixing the sand in an epicentric (KitchenAid®) lab mixer and blowing the cores on a Redford Carver core machine. They were weighed on a MyWeigh i2600 electronic platform scale and poured in PepSet® bonded molds with A201 aluminum. The shakeout testing occurred using a Herschal HP 76 Model 'D' knockout machine and the amount of sand removed per second was measured by weighing in real time using a Mettler Toledo 12001 scale.

The shakeout results are reported in Table 3. The amount of sand that fell out was divided by the time it took for that sand to fall out, and that number was the average shakeout rate. The inorganic based binders shook out better than the organic based binders in this area.

Table 3 Shakeout Properties of Each Binder Used

	Foseco Ecolotec® 750	Hormel GMBond®	HA Cordis® 8266 W/ Anorgit® 8393	HA Cordis® 8323 W/ Anorgit® 8370	Ashland GEOSet®	HA 1.1% SigmaCure ® Phenolic Urethane	HA Cordis® 4820BF
Average Shakeout Rate*	3	7.1	73.1	57.5	48.2	3.8	37.5

*Rate in grams of sand per second

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1.0 INTRODUCTION

1.1. Background

Technikon LLC is a privately held contract research organization located in McClellan, California, a suburb of Sacramento. Technikon offers emissions research services to industrial and government clients specializing in the metal casting and point source emissions areas. Technikon operates the Casting Emission Reduction Program (CERP). CERP is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). The parties to the CERP Cooperative Research and Development Agreement (CRADA) include The Environmental Leadership Council of USCAR, a Michigan partnership of DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation; the U.S. Army Research, Development, and Engineering Command (RDECOM-ARDEC); the American Foundry Society (AFS); and the Casting Industry Suppliers Association (CISA). The US Environmental Protection Agency (US EPA) and the California Air Resources Board (CARB) also have been participants in the CERP program and rely on CERP published reports for regulatory compliance data. All published reports are available on the CERP web site at www.cerp-us.org.

1.2. CERP Objectives

The primary objective of CERP is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was designed to evaluate alternate materials and production processes designed to achieve significant air emission reductions. The facility's principal testing arena is designed to measure airborne emissions from individually poured molds. The testing is designed to facilitate the repeatable collection and evaluation of airborne emissions and associated process data.

Testing is conducted in order to evaluate the impact on air emissions process data from a proposed alternative material, equipment or process. The Technikon foundry is a simple, general-purpose mechanically assisted foundry, which was adapted and instrumented to allow the collection of detailed emission measurements, using methods based on US EPA air testing protocols. Measurements are taken during pouring, casting cooling, and shakeout processes performed on discrete mold and/or core packages under tightly controlled conditions not feasible in a commercial foundry.

Castings are randomly selected to evaluate the impact of the alternate material, equipment, or process on the quality of the casting.

The results of the testing conducted at the foundry are not suitable for use as general emission factors. The specific materials used (gray iron from an electric melt furnace, greensand with seacoal, and a cold box core with a relatively old resin binding system), the specific castings produced; the specific production processes employed, and the specific testing conditions (relatively low stack velocity, long sampling times, high capture rates) produce emission results unique to the materials, castings, casting processes and measurement conditions used. The data produced are intended to demonstrate the relative emission reductions from the use of alternative materials, equipment and processes, and not the absolute emission levels that would be experienced in commercial foundries. A number of process parameters, such as casting surface area, sand to metal ratio, pouring temperature, stack flow rate, LOI level, seacoal and resin content and the type of foundry (Cope & Drag versus Disa, for example) can have a significant impact on actual emission levels.

The foundry provides simultaneous detailed individual emission measurements using methods based on US EPA protocols for the melting, pouring, sand preparation, mold making, and core making processes. The core making area of the foundry contains three core blowers: a Georg Fischer Core Blower for the preparation of automotive block cores, a Redford Core Blower that is used for the production of step cores, and a second smaller Redford Core Blower to produce dogbone tensile test specimens used in this test.

1.3. Report Organization

This report has been designed to document the methodology and results of a specific test plan that was used to evaluate the impact of time and humidity on the tensile strength of select low-emission inorganic binders. Section 2.0 of this report includes a summary of the methodologies used for data collection and analysis, QA/QC procedures, and data management and reduction methods. Specific data collected during this test are summarized in Section 3.0 of this report with detailed data included in appendices of this report. Section

4.0 of this report contains a discussion of the results.

The raw data for this test series are included in a binder that is maintained at the Technikon facility.

1.4. Specific Test Plans and Objectives

This report contains the results of testing performed to assess the tensile strengths of each of select inorganic binders at various time intervals and humidity levels. Testing was also done to compare how well cores made of each binder would shake out. The objective of this testing was to gather data on process and production parameters of the next generation of low emission binder systems.

This report contains the results of experiments of binders formulated for use with aluminum. The results were compared to previously published results of a standard aluminum cold box phenolic urethane binder system, HA International SigmaCure®. SigmaCure® cores for the shakeout tests were made for comparison in this test.

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2.0 Test Methodology

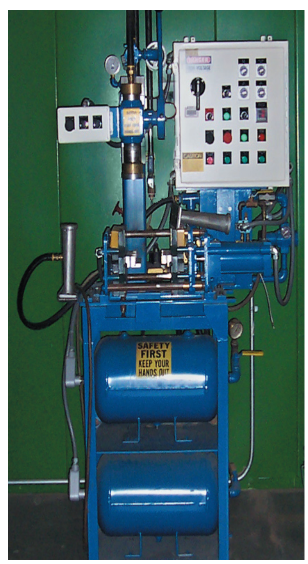
2.1. Description of Testing Program

2.1.1. Dog Bone Testing

The testing was conducted at the Technikon foundry core room and materials laboratory using methods based on the AFS Mold & Core Testing manual, 3rd addition. We added additional steps to ensure that the water activated dog bones and cores were fully cured. No air emission measurements were required for this test series. The sand was mixed using an epicentric sand mixer in a manner consistent across all the binder types (Figure 2-1). The dog bones were made in a Redford/Carver Dogbone Core Machine (Figure 2-2). The blowing was optimized for each binder in order to make good dog bones, but was held consistent within each binder type. The parameter changes in the dog bone manufacturing were either directed by the binder supplier, or were necessary when not using a CO_2 generator.

Figure 2-1 Epicentric Sand Mixer

Figure 2-2 Redford/Carver Dogbone Core Machine



The Redford-Carver machine is designed for cold box and hot box binders. The settings on the machine had to be adjusted to make the cores cured by dehydration, since the machine is normally set up to deliver triethylamine and purge air. To make the Ecolotec® cores, a CO_2

tank was used to gas the cores. The venting system on the dog bone core box is designed for cold box cores, but was modified to work with CO_2 gassed systems. The effect of these modifications on the performance of these cores is not known at this time. The dehydration set cores had a cycle time of about three minutes on the Redford-Carver machine, while SigmaCure® cold box cores have a cycle time of about 1 minute.

Figure 2-3 Three-on Dogbone Core Box

The Foseco Ecolotec® 750 binder was cured in a room temperature dog bone core box, and gassed with CO_2. The HA International Cordis® and Hormel GMBond® binders were all made with a pre-heated core box at 310°F and gassed with room temperature purge air. The Ashland GEOset® was made with a pre-heated core box at 450°F and gassed with room temperature purge air.

Figure 2-4 Thwing-Albert QC-3A Tensile Tester

Once the purge cycle stops, the core box three-on dog bone box used in making cores is opened (Figure 2-3). This was marked as the finish time, and the clock started on the interval time. Any sample that was hot was allowed to cool to room temperature then placed in a desiccator, except for the 5 minute interval dog bones. The samples were all stored on edge in a desiccator until it was time to test them. The humidity samples were stored with a pan of 200grams of water in the bottom instead of a pan of desiccant. Each sample was weighed on a Mettler Toledo SB12001 gravimetric scale prior to being tested, the sample weight was recorded, and placed in the Thwing-Albert QC-3A Tensile Tester (Figure 2-4), and pulled (Figure 2-5). The peak load of the test spectrum was recorded in strength in pounds per square inch. Once the strength was recorded the dog bone was discarded. A table that summarizes binder system test, binder content, and the core making method used for tensile testing appears in Section 3.0.

Figure 2-5 Close-up of Tested Dogbone with Core Fracture

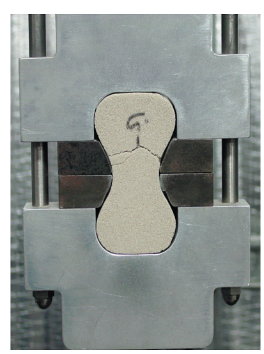


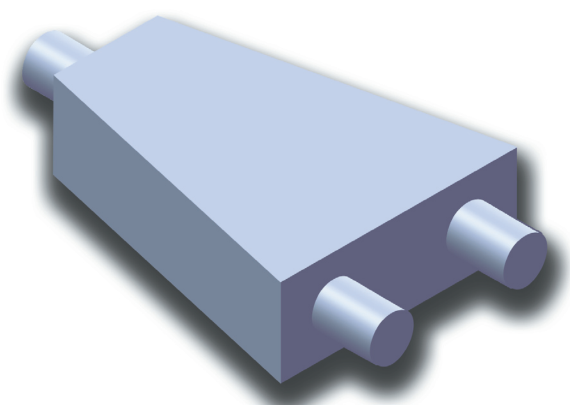
Figure 2-5 Close-up of Tested Dogbone with Core Fracture

2.1.2. Shakeout Testing

The shakeout cores were mixed and blown in the same way as the dog bones. The sand and binder was mixed in the larger Hobart mixer, and the cores were blown on the Redford Carver Core machine. The cores were blown in a core box that is not an AFS specified design, since the AFS does not have a specification for this test. The design for this core was approved by the AFS 4N Pollution Prevention Committee chair, and based on a core design used in similar tests in private industry.

The shakeout cores (illustrated in Figure 2-6) were all manufactured with similar parameters as the dog bones respective to each binder. In addition, HA International SigmaCure® and Cordis® 4820BF cores were manufactured for shakeout testing. The SigmaCure® cores were made at room temperature and gassed with TEA, and the Cordis cores were made at 310°F and purged with room temperature air.

Figure 2-6 Shakeout Core

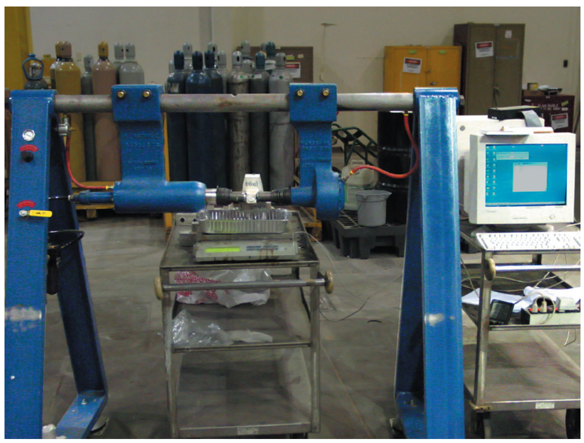


The cores were removed from the box after the purge cycle, labeled and weighed. Once the cores reached room temperature, they were bagged and saved until they were used in the molds. The molds for the shakeout castings were made using Wedron 530 sand and PepSet® at a binder level of 1.5% (BOS.) The cores were carefully tracked as each mold was assembled.

The castings were poured using A201 aluminum at a temperature of 1350 ±10°F. The molds were poured in the order that they were made, in order to help keep track of which cores were in which mold. Upon cooling the castings were broken out in a most delicate manner as to not shake the cores. The castings were labeled by their mold number. The casting were then stored on a cart until tested.

For testing each casting was weighed and placed in the clamps of the Herschal Hammer core knockout machine (Figure 2-7). A collection pan and scale were placed underneath, and a computer tracked the real time data weight change. Time was kept manually. After core sand stopped falling out, the knockout machine was stopped and the timer stopped. The sand that had fallen out was weighed, and any remaining sand was chipped out and weighed separately.

Figure 2-7 Herschal Hammer Shakeout Setup



2.1.3. Test Plan Review and Approval

The proposed test plan was reviewed by the Technikon personnel. Table 2-1 lists the process parameters that were monitored during each test. The analytical equipment and methods used are also listed. The test plan is included in this report in Appendix A.

Table 2-1 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Dogbone Core Weight	MyWeigh i2600 Electronic Platform Scale (gravimetric)
Shakeout Core Weight	Mettler SB12001 Electronic Platform Scale (gravimetric)
Sand and Binder Batching Weight	Mettler SB12001 Electronic Platform Scale (gravimetric)
Core Machine Pressure	Machine Mounted Pressure Gauge
Core Box Temperature	Machine Mounted J Type Thermocouple
Tensile Tester Ambient Temperature	Room Ambient Air Temperature Control System

2.1.4. Data Reduction, Tabulation and Preliminary Report Preparation

The analytical results of the tensile tests are included in Section 3.0 of this report.

2.1.5. Report Preparation and Review

The preliminary draft report was reviewed by Technikon to ensure its completeness, consistency with the test plan, and adherence to the prescribed QA/QC procedures. Appropriate observations, conclusions and recommendations are added to the report to produce a Draft Report. The Draft Report is reviewed by the Vice President-Measurement Technologies, the Vice President-Operations, the Manager-Process Engineering, the Technikon President, and the CERP Steering Committee. Comments are incorporated into a draft Final Report prior to final signature approval and distribution.

2.2. Quality Assurance and Quality Control (QA/QC) Procedures

In order to ensure the timely review of critical quality control parameters, the following procedures were followed:

- Immediately following the individual runs performed for each test, specific process parameters were reviewed by the Process Engineer to ensure that the parameters are maintained within the prescribed control ranges. Where data are not within the prescribed ranges, the Process Engineer and the Vice President-Operations determine whether the individual test samples should be invalidated or flagged for further analysis.

- All data taken were first processed by using a method that if more than 3 samples out of 30 were out of the upper and lower control limits, the entire test on that binder would be abandoned. The upper and lower control limits were defined by adding twice the standard deviation, and subtracting twice the standard deviation from the average.

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3.0 TEST RESULTS

The dogbones, other than Ecolotec®, were all comparable in two-hour strength to the cold box binders previously tested. The results of the testing are shown in Table 3-1. Figure 3-1 shows the change in strength over time for each binder. The Ecolotec® 750 was lower in strength, but it is not formulated for small lacy cores. After exposure in the high humidity environment Ecolotec® 750 did not lose any strength and was the second strongest after being in the humidity chamber. GMBond®, Cordis®, and GeoSet® are all water soluble binders that are set based on a dehydration process. This is the main reason that they are affected by the presence of humidity. SigmaCure® and Ecolotec® are both phenolic urethane binders; which are not sensitive to humidity.

The shakeout test revealed that the inorganic based cores GeoSet® and Cordis® shakeout very well. These cores completely shook out in an average of about 9 seconds. The organic based cores SigmaCure®, GMBond®, and Ecolotec® did not shake out at a rate as high as the inorganic based cores. SigmaCure® and Ecolotec® had about 10-15% of their core chipped out by hand after shaking out for over 2 minutes. GMBond® had to have approximately 3% of its core weight chipped out after about 1 minute of shake out.

Table 3-1 shows the average tensile strength of thirty (30) dogbone cores for each test.

Table 3-1 Summary of Average Tensile Strength

Binder	Tensile Strength in psi at Specific Intervals			
	5 minute	2 hour	24 hour	24 hour humidity
Foseco Ecolotec® 750	70.3	88.9	88.3	85.7
Hormel GMBond®	230.5	235.6	325.7	29.2
HA International Cordis® 8266 with Anorgit® 8393	273.7	352.5	305.2	126.3
HA International Cordis® 8323 with Anorgit® 8370	197.4	259.2	270.7	31.6
Ashland GeoSet®	221.7	316.7	322.9	37.8
HA International SigmaCure®	NT	326.1	NT	NT

Figure 3-1 displays the average tensile strength of 30 dogbone cores over time.

Figure 3-1 Average Tensile Strength Over Time

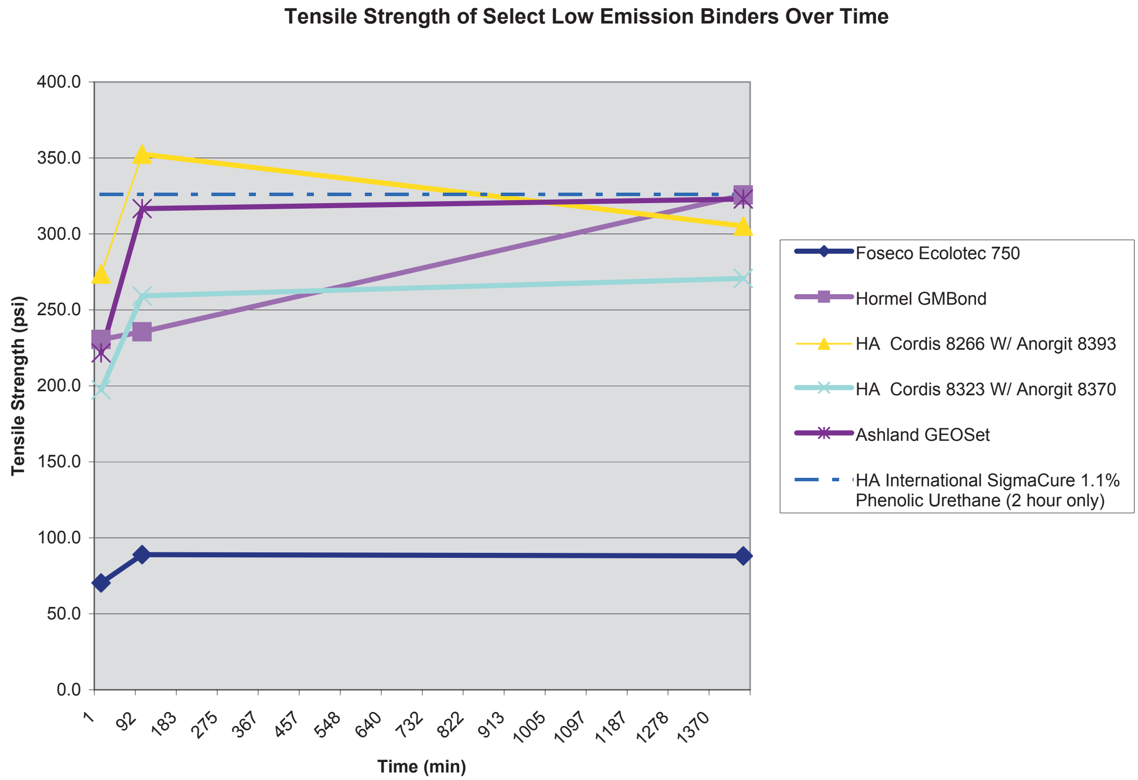

Table 3-2 shows the rate at which each core shook out.

Table 3-2 Shakeout Properties of Each Binder Used

	Foseco Ecolotec® 750	Hormel GMBond®	HA Cordis® 8266 W/ Anorgit® 8393	HA Cordis® 8323 W/ Anorgit® 8370	Ashland GEOSet®	HA 1.1% SigmaCure ® Phenolic Urethane	HA Cordis® 4820BF
Average Shakeout Rate*	3	7.1	73.1	57.5	48.2	3.8	37.5

*Rate in grams of sand per second

The details of these data are in Appendix B.

4.0 Discussion of Results

The results of this test showed promising results for this generation of low emission core binders for use in aluminum applications. The shakeout results were very promising as the inorganic based binders performed very well in the shakeout test. The inorganic based binders shook out at a rate more than 10 times greater than the shake out rate of the aluminum cold box binder. When the high humidity is not present, the tensile strength performance of these binders was also promising.

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Appendix A Approved Test Plan and Instructions for Test

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Technikon Test Plan

page 1 of 3

Fill-in and check all that apply

♦ **CONTRACT NUMBER:** 1413 **TASK NUMBER** 14 **DOUBLE ALPHA**

♦ **SITE:**	☒ On Site at Research Foundry ☐ Off Site at _____
♦ **DATE RANGE:**	From Dec. 1, 07 to Jan. 31, 07
♦ **TEST OBJECTIVE:**	☐ Emissions Testing ☒ Mechanical Properties ☐ Casting Quality ☐ Comparison to _____ ☐ Other _____
♦ **PROCESSES:**	☐ Pouring ☐ Cooling ☒ Shakeout ☐ Mixing ☐ Making ☐ Storage ☒ Other Tensile Testing
♦ **TEST TYPE:**	☐ Baseline ☒ Product ☐ Other _____
♦ **METAL:**	☐ Iron ☐ Aluminum ☐ Steel ☐ Other _____ Alloy _____ Pour Temp: _____°F
♦ **RUNS:**	Number for Conditioning _____ Duration _____ minutes Number for Testing Samples 30 Duration _____ minutes
♦ **PROPERTIES TO BE TESTED:**	☒ Mold Strength ☐ Moisture Content ☐ _____ °F LOI% ☐ _____ °F Volatiles ☐ Release Agent ☐ Binder ☐ Clay ☐ Sand ☐ Activator Other _____
♦ **RESULTS TO BE ANALYZED AND REPORTED:**	☐ Emissions: ☐ HAPs ☐ POMs ☐ Criteria Pollutants ☐ Greenhouse Gases ☐ Other _____ ☐ Casting Quality: ☐ Coated Cores ☐ One Cavity ☐ All Cavities ☐ Other _____ ☒ Mechanical Properties: ☒ Tensile Strength ☒ Weight Change ☐ Flowability ☐ Compressibility ☐ Other _____
♦ **BRIEF OVERVIEW:**	*This test will test the mechanical properties of Foseco Ecolotec 750, HA International SigmaCure 7227/7707, Hormel GMBond, HA International Cordis® 8323 with Anorgit® 8370, HA International Cordis® 8266 with Anorgit® 8393, HA International Cordis® 4820BF, Ashland GEOSET. The tests will be strength tests after 5 minutes, 2 hours, 24 hours, and 24 hours at 100% relative humidity at 70°F. All binders will be tested for weight loss during shakeout. .*
♦ **ADDITIONAL COMMENTS:**	*For some of these binders some of the tests have already taken place under previous charge codes, and duplication will not be done.*

Technikon Test Plan

page 2 of 3

Fill-in and check all that apply

♦ **CONTRACT NUMBER:** 1413 **TASK NUMBER** 14 **DOUBLE ALPHA**

	Cores	Molds	Other
♦ **PATTERN:**	☐ Step ☐ Other _____ Number _____ Number Cavities _____ Storage Temp: _____°F Storage Age: _____ Dimensions: ☐ Standard (24x24x10/10) ☐ Other _____	☐ Step ☐ Star ☐ Irregular Gear ☐ Other _____ Number _____ Number Cavities _____ Storage Temp: _____°F Storage Age: _____ Dimensions: ☐ Standard (24x24x10/10) ☐ Other _____	☒ Dogbone ☒ Shakeout ☐ Flowability ☐ Other _____ Number _____ Number Cavities _____ Storage Temp: _____°F Storage Age: _____ Dimensions: ☐ Standard (24x24x10/10) ☐ Other _____
♦ **BINDER :**	☐ Cold box ☐ Warm box ☐ Hot box ☐ No-bake ☐ Shell ☐ Oil ☐ Other _____ Concentration _____ (BOS) Ratio ($\frac{P1}{P2}$) _____ Product Name(s) _____	☐ Cold box ☐ Warm box ☐ Hot box ☐ No-bake ☐ Shell ☐ Oil ☐ Other _____ Concentration _____ (BOS) Ratio ($\frac{P1}{P2}$) _____ Product Name(s) _____	☒ Cold box ☐ Warm box ☐ Hot box ☐ No-bake ☐ Shell ☐ Oil ☒ Other Low emission Concentration _____ (BOS) Ratio ($\frac{P1}{P2}$) _____ Product Name(s) _____
♦ **CHEMISTRY:**	☐ Phenolic Urethane ☐ Furan ☐ Low Emission (inc. Sodium Silicate) ☐ Epoxy-Acrylic ☐ Alkaline Phenolic Ester ☐ Other _____	☐ Phenolic Urethane ☐ Furan ☐ Low Emission (inc. Sodium Silicate) ☐ Epoxy-Acrylic ☐ Alkaline Phenolic Ester ☐ Other _____	☒ Phenolic Urethane ☐ Furan ☒ Low Emission (inc. Sodium Silicate) ☐ Epoxy-Acrylic ☐ Alkaline Phenolic Ester ☐ Other _____
♦ **CATALYST:**	☐ CO_2 Cured ☐ SO_2 Cured ☐ Acid Cured ☐ TEA Cured ☐ Hot Air Cured ☐ Methyl Formate Cured Concentration _____ BOS Concentration_____ BOR ☐ Other _____	☐ CO_2 Cured ☐ SO_2 Cured ☐ Acid Cured ☐ TEA Cured ☐ Hot Air Cured ☐ Methyl Formate Cured Concentration _____ BOS Concentration_____ BOR ☐ Other _____	☒ CO_2 Cured ☐ SO_2 Cured ☐ Acid Cured ☒ TEA Cured ☒ Hot Air Cured ☐ Methyl Formate Cured Concentration _____ BOS Concentration_____ BOR ☐ Other _____

Technikon Test Plan

page 3 of 3

Fill-in and check all that apply

♦ **CONTRACT NUMBER:** 1413 **TASK NUMBER** 14 **DOUBLE ALPHA**

	Cores	Molds	Other
♦ **SAND:**	☐ Greensand ☐ No-Bake ☐ Other _____ Additives _____ to yield _____ %LOI Product Name(s) _____	☐ Greensand ☐ No-Bake ☐ Other _____ Additives _____ to yield _____ %LOI Product Name(s) _____	☐ Greensand ☐ No-Bake ☒ Other _____ Additives _____ to yield _____ %LOI Product Name(s) Wedron 530
♦ **RELEASE AGENT:**	Concentration _____ Application Method _____ Product Name(s) _____	Concentration _____ Application Method _____ Product Name(s) _____	Concentration _____ Application Method _____ Product Name(s) _____
♦ **COATING:**	☐ None ☐ All Runs ☐ Conditioning Runs Only ☐ Test Runs Only ☐ Baumé _____ ☐ Other _____ Application Method _____ Drying Method _____ Product Name(s) _____	☐ None ☐ All Runs ☐ Conditioning Runs Only ☐ Test Runs Only ☐ Baumé _____ ☐ Other _____ Application Method _____ Drying Method _____ Product Name(s) _____	

This test plan routed to or reviewed by:

- Senior Process Engineer
- Technical Director/Foundry Manager
- Director of Measurement Technologies
- Vice President of Operations
- Applicable Steering Committee Members

1413-1.4.5

Tensile and Shakeout Testing of Various Core Binders

Process Instructions

A. Experiment:

1. To test the tensile strengths of each of the low emission binders used in the 1412 contract: Foseco Ecolotec® 750, HA International Cordis® (3 kinds), Hormel GMBond, Ashland Isocure, and Ashland GEOSET. The binders will be tensile tested at intervals of 5 min after removal from the core box, 2 hours after removal from the core box, 24 hours after removal from the core box, and 24 hours after removal from the core box in a 100% relative humidity environment at 70°F.

B. Materials:

1. Dog bone sand:

a. Wedron 530 silica.

b. GMBond Pre-coated Sand

2. Binders and percent levels (BOS):

a. Foseco Ecolotec® 750 - 2.0%

b. Hormel GMBond® - 1.0%

c. HA International Cordis® 8323 – 2% with Anorgit® 8370 – 1%

d. HA International Cordis® 8266 – 2% with Anorgit® 8393 – 1%

e. HA International Cordis® 4820BF – 2.5%

f. HA International Sigma Cure 7227/7707 – 1.1%

g. Ashland GEOSET – 3.6%

Number of Samples per Binder/Time Combinations to be tested

	Foseco Ecolotec 750	**Cordis® 8323 with Anorgit® 8370**	**Cordis® 8266 with Anorgit® 8393**	**Cordis® 4820BF**	**Hormel GMBond®**	**Sigma Cure 7227/7707**	**Ashland GEOSET**
5 min	30	30	30		30		30
2 hr		30	30				30
24 hr	30	30	30		30	30	30
24 hr Humidity	30	30	30		30		30
Shakeout	4	4	4	4	4	4	4

C. Mixing:

1. For Ecolotec and HA International Cordis Cores

- **a.** Weigh out 3000.0 ± 1g Wedron 530
- **b.** Add the sand to the Hobart mixer
- **c.** Set the mixer to setting 2
- **d.** Weigh out the appropriate binder (± 1g) per the list below
  - **1)** Foseco Ecolotec® 750
  - **2)** HA International Cordis® 8323 with Anorgit® 8370
  - **3)** HA International Cordis® 8266 with Anorgit® 8393
  - **4)** HA International Cordis® 4820BF
  - **5)** HA International Sigma Cure 7227/7707
- **e.** Mix until sand is coated

2. For GMBond Cores
- **a.** Weigh out 3000.0 ± 1g pre-coated sand
- **b.** Add the sand to the Hobart mixer
- **c.** Set the mixer to setting 2
- **d.** Weigh out 60g of water (2% weight of sand)
- **e.** Mix until even distribution is obtained (~30 seconds). Allow binder to absorb moisture for 2 – 5 minutes. Remix briefly (~15 SECONDS).

3. For GEOSET
- **a.** Weigh out 3000.0 ± 1g Wedron 530
- **b.** Add the sand to the Hobart mixer
- **c.** Set the mixer to setting 2
- **d.** Weigh out the appropriate binder (± 1g) per the list below
  - **1)** Part I .... 7.5 g
  - **2)** Part II....................................... 75 g
  - **3)** Part III...................................... 25.5 g
- **e.** Add and Mix until coated

D. Dog Bone Blowing

1. Set up the dog Bone machine per the parameters below. (adjust parameters if necessary, note on make sheet)
- **a.** For all low emission binders
  - **1)** Blow Time.. 1 sec
  - **2)** Blow Pressure ....90 psi
- **b.** For Foseco Ecolotec® 750
  - **1)** CO_2 gas time .... 15 sec
  - **2)** CO_2 gas pressure ....40 psi
- **c.** For LaempeKuhs BeachBox® LK700-376, LK700-403 and HA International Cordis®
  - **1)** Box Temperature..300°F
  - **2)** Purge Time .... 6 sec

   3) Purge Pressure .... 90 psi
  d. For Ashland GEOSET®
   1) Box Temperature .... 450°F
   2) Purge Time .... 6 sec
   3) Purge Pressure .... 90 psi

2. Fill the blow head with the sand binder mixture
3. Press the "LH horizontal clamp start" and the "RH horizontal clamp start" buttons until the "horizontal clamp engaged" light comes on.
4. Place the blow head on the dog bone boxes and compress it down using the lever.
5. Press the "blow start" button.
6. Wait for a set amount of time as stated
   a. GMBond 80 Seconds
   b. All Cordis Derivatives 60 seconds
   c. Ecolotec 750 and SigmaCure 00 seconds
   d. GEOset 60 seconds
7. Remove the sand head and replace it with the gas head.
8. Gas the dog bones
   a. For Foseco Ecolotec® 750, manually open the valve on the CO_2 tank.
   b. For LaempeKuhs BeachBox® LK700-376, LK700-403 and HA International Cordis® press the "gas start" button.

9. Remove the gas head.
10. Remove the dog bones, mark them and record the time they were made.
11. Let the dog bones cool to ambient temperature.
12. Store them in a desiccator until they are to be tested.
13. Repeat until 30 dog bones for each test have been manufactured.

E. The humidity chamber
1. The humidity chamber will be a desiccator that is modified to have an environment at 70°F and 100% relative humidity (RH.)
2. The chamber will be set in a room controlled at 70F. A pan of 200g of water will be placed at bottom.

F. Test times
1. 5 min from dog bone box removal.
2. 2 hr from dog bone box removal.
3. 24hr from dog bone box removal.
4. 24h from dog bone box removal in a humid environment.

G. Dog Bone Testing
1. Turn on the tensile tester
2. Weigh the tensile specimen.

3. Place the tensile specimen in the grips.
4. Press the "test" button at the appropriate time.
5. Record weight, time, and peak load.

H. Shakeout Testing

1. Core Making
   a. The cores will be made on the small Redford Carver core blowing machine
   b. The cores should be completely cured, but not over-cured for this test.
   c. The cores should be made with settings as close too the settings to make dog bones as possible.
   d. The cores will be cooled to room temperature and then bagged until molding.
2. Mold Making
   a. The mold for the cores will be made with Wedron 530 sand and Pepset at 1.5% BOS.
   b. Add 50 lb of sand to the Klein mixer and .4 lb of part 1 of PepSet and .35 lb of part 2 Pepset.
   c. Mix until coated, be careful not to over mix to avoid preset.
   d. Pack the sand in the cope or drag molds and let cure.
   e. When cured strip mold.
   f. Repeat until molds are made for all cores tested.
   g. Assemble molds with cores in the order that the cores were made to keep track of them.
   h. Take detailed notes on which cores are in which molds.
   i. Close and label the mold so it can be identified after it is poured.
3. Pouring
   a. Arrange the molds in numerical order so that after being poured the castings can be kept in order.
   b. Pour A201 aluminum at 1350 ± 10 °F
   c. Record Pour times and temperatures for each mold.
4. Mold Shakeout
   a. It is important to gently remove the castings from their molds, in order to not remove any more core sand than necessary.
   b. Label each casting as it is being removed
5. Shakeout Testing
   a. It is important to test the castings in the order the cores were made in order to keep track of the cores.
   b. Set up the Herschel Hammer, with the pressure at 90psi.
   c. Set-up the Mettler Toledo 12001 scale and collection pan underneath the clamps on the Herschel Hammer
   d. Connect the scale to the computer
   e. Weigh the casting with the core.
   f. Clamp the casting in the Herschel Hammer
   g. Start the data collection program

h. Start the Herschel Hammer and the clock at the same time.
i. When sand stops falling out of the casting, stop the hammer, clock, and data collection.
j. Record the time and sand weight that has fallen out
k. Save the data file so it can be accessed later.
l. Clean the sand out of the collection pan, and then re-zero the scale
m. Chip out the remaining sand in the castings, record that amount.
n. Weigh the now empty casting and record that amount.
o. Repeat for all castings.

APPENDIX B PROCESS DATA DETAILS

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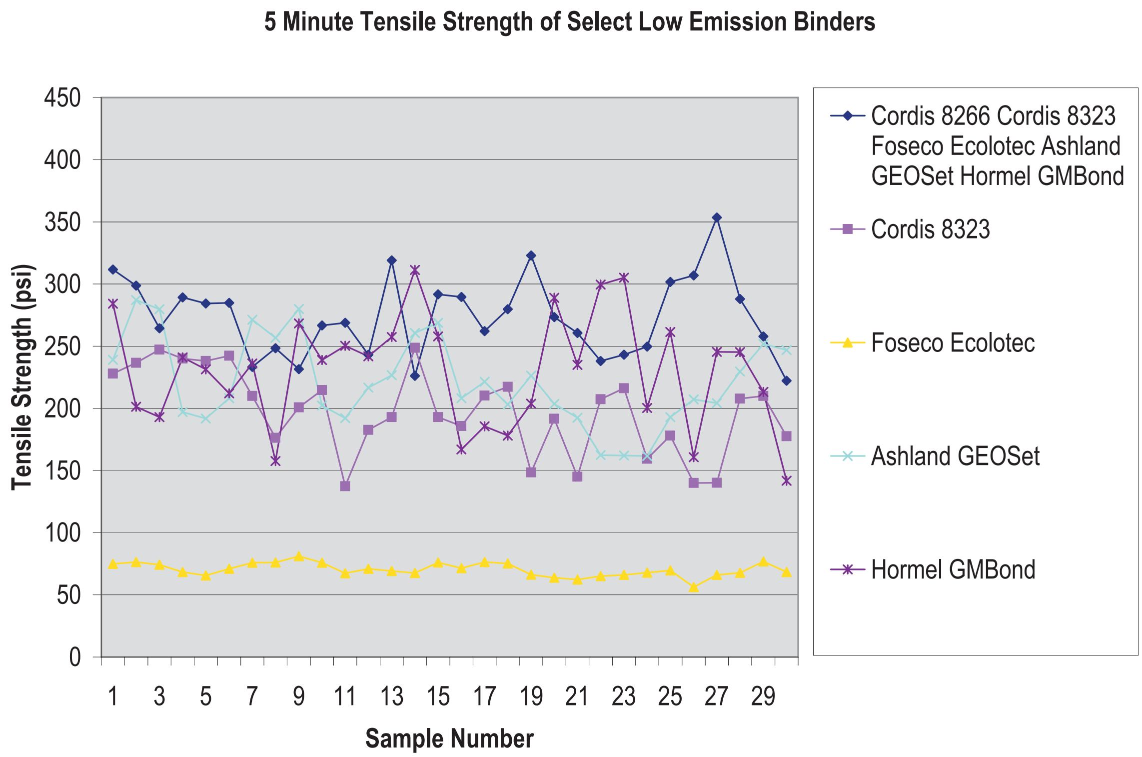
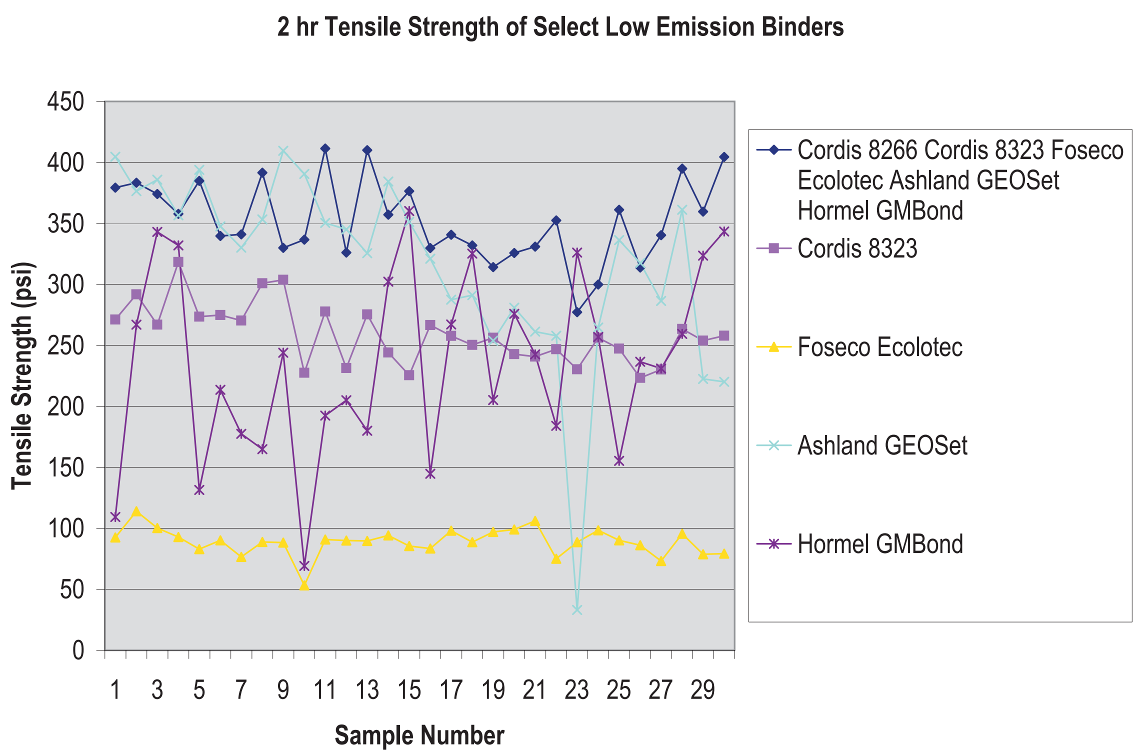
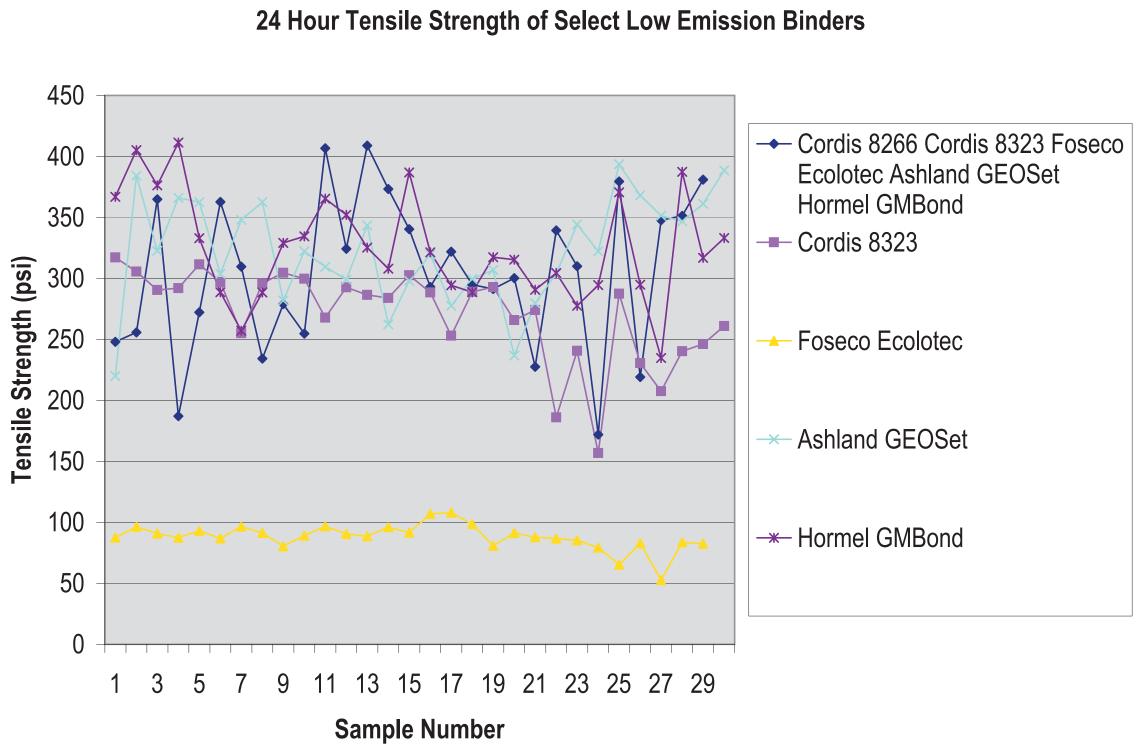
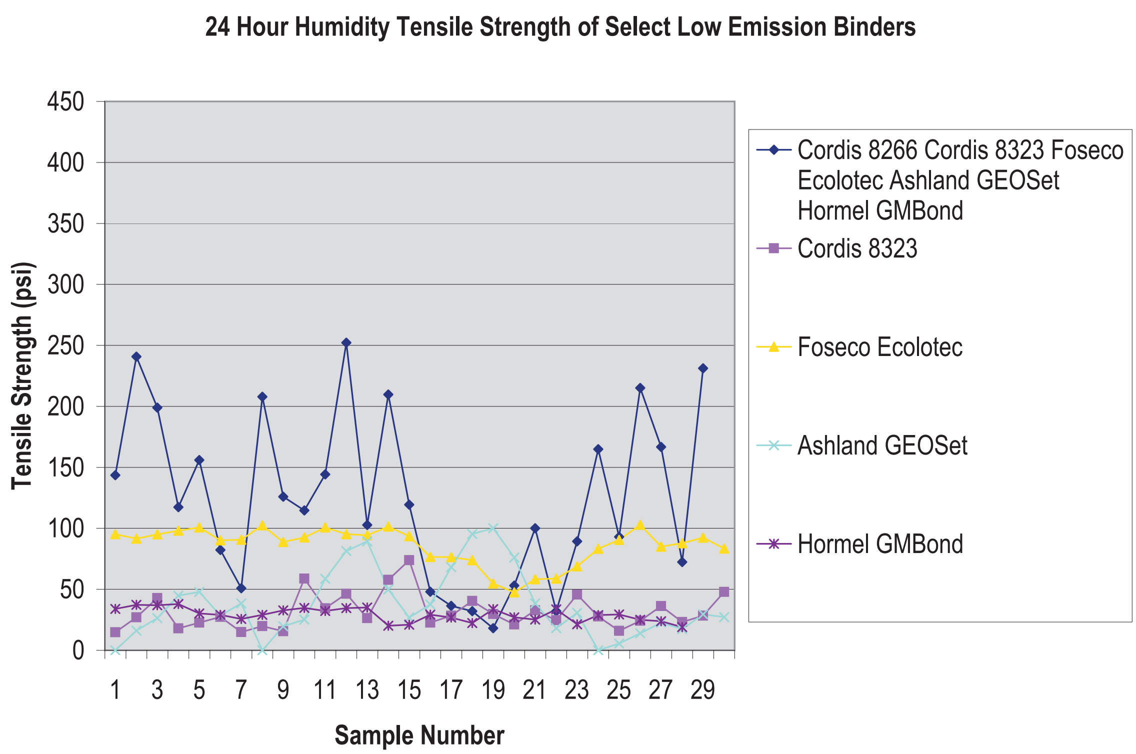

5 Minute Tensile Strength of Select Low Emission Binders
Tensile Strength (psi)
450
400
350
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Sample Number
Cordis 8266 Cordis 8323 Foseco Ecolotec Ashland GEOSet Hormel GMBond
Cordis 8323
Foseco Ecolotec
Ashland GEOSet
Hormel GMBond


2 hr Tensile Strength of Select Low Emission Binders
Tensile Strength (psi)
450
400
350
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Sample Number
Cordis 8266 Cordis 8323 Foseco Ecolotec Ashland GEOSet Hormel GMBond
Cordis 8323
Foseco Ecolotec
Ashland GEOSet
Hormel GMBond


24 Hour Tensile Strength of Select Low Emission Binders
450
400
350
300
250
200
150
100
50
0
Tensile Strength (psi)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Sample Number
Cordis 8266 Cordis 8323 Foseco Ecolotec Ashland GEOSet Hormel GMBond
Cordis 8323
Foseco Ecolotec
Ashland GEOSet
Hormel GMBond


24 Hour Humidity Tensile Strength of Select Low Emission Binders
450
400
350
300
250
200
150
100
50
0
Tensile Strength (psi)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Sample Number
Cordis 8266 Cordis 8323 Foseco Ecolotec Ashland GEOSet Hormel GMBond
Cordis 8323
Foseco Ecolotec
Ashland GEOSet
Hormel GMBond

APPENDIX C ACRONYMS AND ABBREVIATIONS

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Acronyms & Abbreviations

AFS	American Foundry Society
ARDEC	(US) Army Armament Research, Development and Engineering Center
BO	Based on ( ).
BOS	Based on Sand.
CARB	California Air Resources Board
CERP	Casting Emission Reduction Program
CISA	Casting Industry Suppliers Association
CRADA	Cooperative Research and Development Agreement
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
LOI	Loss on Ignition
NA	Not Applicable; Not Available
ND	Non-Detect; Not detected below the practical quantitation limit
NT	Not Tested - Lab testing was not done
QA/QC	Quality Assurance/Quality Control
US EPA	United States Environmental Protection Agency
WBS	Work Breakdown Structure