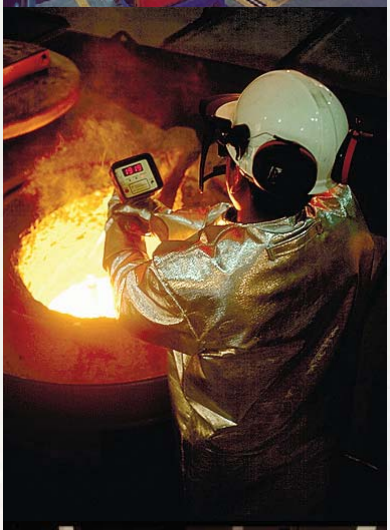
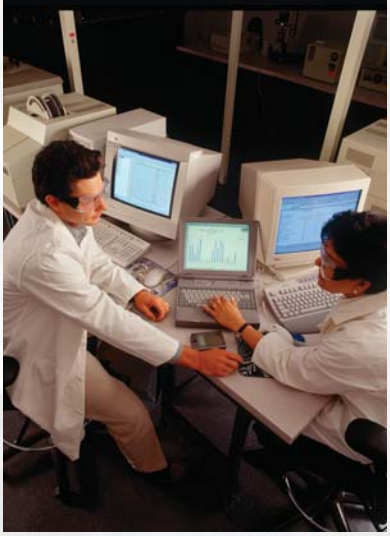
Casting Emission Reduction Program

www.cerp-us.org





Operated by

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US Army Contract W15QKN-05-D-0030
FY2005 Tasks
WBS # 1.1.7

Inorganic Binder Tensile Strength Testing

1412-117 HH

September 2006
(Revised for public distribution - October 2006)

CASTING INDUSTRY SUPPLIERS ASSOCIATION

AMERICAN FOUNDRY SOCIETY

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USCAR UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

DAIMLERCHRYSLER Ford GM General Motors

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Inorganic Binder Tensile Strength Testing

1412-117 HH

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

Process Engineer	*//Original Signed//* Thomas Fennell	_____ Date
V.P. Operations	*//Original Signed//* George Crandell	_____ Date

The data contained in this report were developed to assess the relative emissions profile of the product or process being evaluated. You may not obtain the same results in your facility. Data were not collected to assess cost or producability.

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EXECUTIVE SUMMARY

The objective of this testing was to determine the tensile strength at various time intervals of low emission binders (see Table 1) used in the CERP contract for FY2006 Tasks.

Table 1 Test Plan Summary

Category	Description
Binders Used	Foseco Solosil® 131 H&G S Corosil® GL HA International Cordis® LaempeKuhs BeachBox® LK 700-376 LaempeKuhs BeachBox® LK 700-403
Test Intervals	5 min, 2 hours, 24 hours, 24 hours in a 100% relative humidity environment

The dog bone (AFS 1 in. thick tensile specimen) tensile test pieces were prepared by mixing the sand in a Hobart type (Kitchenaid) lab 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 then 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 also tested per AFS procedure 3301-00-S. The results are shown in Table 2, and Figures 1-1 and 1-2 .

Table 2 Average Tensile Strength of 30 Dogbone Pieces for Each Binder

Binder	Binder Amount (BOS)	Core Making Method	Dog Bone Making Method	Test number
Foseco Solosil® 131	3.5%	Hand rammed, gassed with CO_2	Blown, gassed with CO_2	1412-123-HB
H&G S Corosil® GL	5.0%	Hand rammed, gassed with CO_2	Blown, gassed with CO_2	1412-122-GZ
HA International Cordis®	2.0%	Blown into 275°F box, purged with 300°F air	Blown into 300°F box, purged with 70°F air	1412-115-HF
LaempeKuhs BeachBox® LK 700-376	2.5%	Blown into 275°F box, purged with 300°F air	Blown into 300°F box, purged with 70°F air	1412-114-HC
LaempeKuhs BeachBox® LK 700-403	2.5%	Blown into 275°F box, purged with 300°F air	Blown into 300°F box, purged with 70°F air	1412-116-HD

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

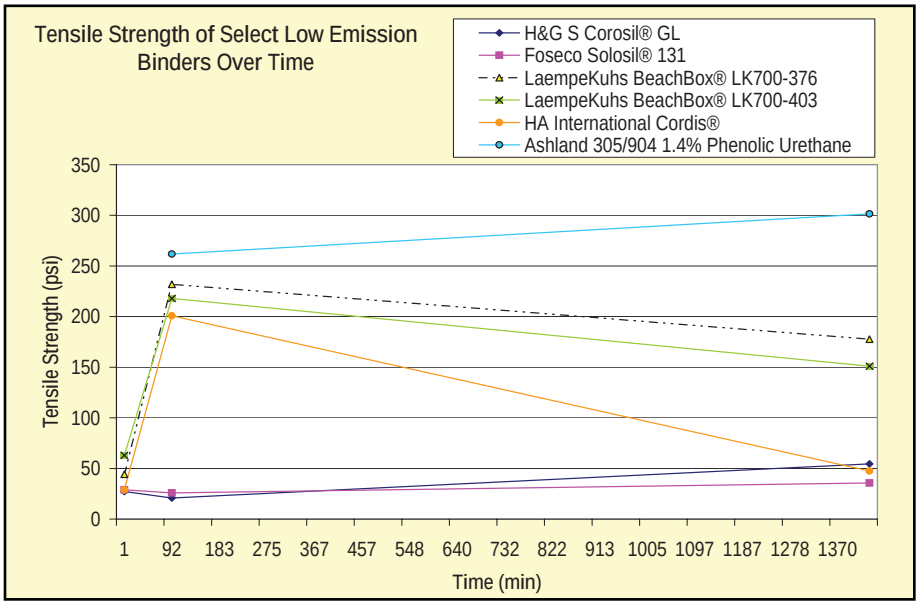
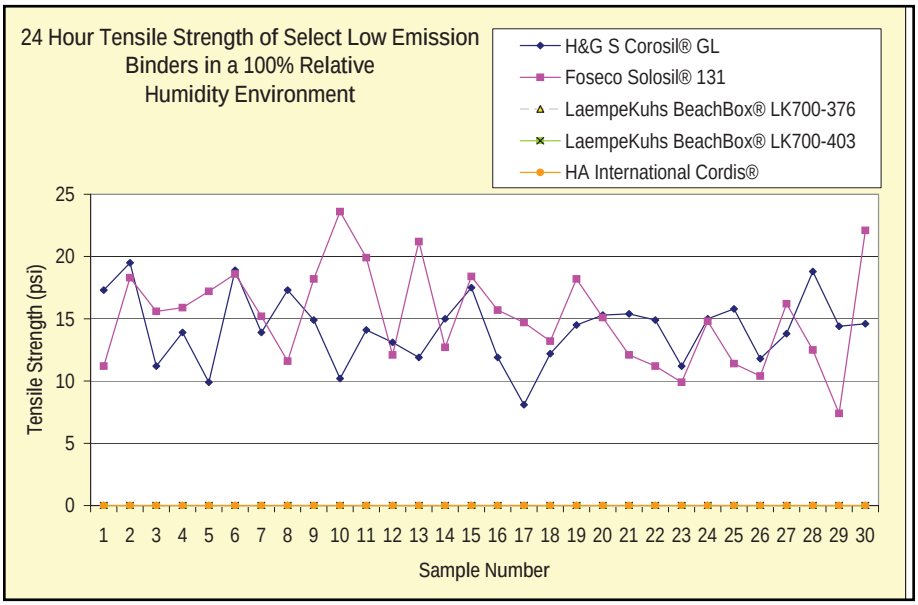


Figure 1-2 Tensile Strength of Select Inorganic Binders after a 24 Hour Period in 100% Relative Humidity Environment



Note: The LK700-376, LK700-403, and HA International Cordis® data points are overlapping on the zero axis.

The results of these tests indicated that this group of inorganic binders were lower in tensile strength than CERP's baseline phenolic urethane binders.

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. This testing arena facilitates the repeatable collection and evaluation of airborne emissions and associated process data.

Testing is conducted in order to evaluate the impact on air emissions 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 process-

es 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 data 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 five inorganic binders (see Table 1-1) at various time intervals and humidity levels. The objective of this testing was to gather the first phase of data on process and production parameters of the next generation of low emission (inorganic) binder systems.

Table 1-1 Average Tensile Strength for Each Binder over Time

	5 min	2 hr	24 hr	24 hr @ 100% Humidity
	Tensile Strength, psi			
Foseco Solosil® 131	29.0	25.8	35.7	105.2
H&G S Corosil® GL	27.3	20.9	54.6	103.1
HA International Cordis®	29.0	200.8	47.4	0.0
LaempeKuhs BeachBox® LK 700-376	44.3	231.9	177.8	0.0
LaempeKuhs BeachBox® LK 700-403	63.0	218.0	151.0	0.0
Ashland 305/904 Phenolic Urethane 1.4%	ND	261.7	301.4	ND

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2.0 TEST METHODOLOGY

2.1. DESCRIPTION OF TESTING PROGRAM

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. No air emission measurements were required for this test series. The sand was mixed using a Hobart 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.

The Foseco Solosil® 131 and H&G S Corosil® GL binders were cured in a room temperature dog bone core box, and gassed with CO_2. The HA International Cordis®, LaempeKuhs BeachBox® LK700-376andLaempeKuhsBeachBox® LK700-403 binders were all made with a pre-heated core box at 300°F and gassed with room temperature purge air.

Once the purge cycle stops, the core box

Figure 2-1 Hobart Type Epicentric Sand Mixer

Figure 2-2 Redford/Carver Dogbone Core Machine

three gang doge 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. 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 200g water in the bottom instead of a pan of desiccant. Each sample was weighed on a Mettler Toledo SB12001 gravimetric scale (Figure 2-4) prior to being tested, the sample weight was recorded, and placed in the Thwing-Albert QC-3A Tensile Tester (Figure 2-5), and pulled (Figure 2-6). 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. The average for each test is included in Table 2-1, which summarizes binder system test, binder content, and the core making method used for tensile testing.

Table 2-1 Process Equipment and Methods

Binder	Binder Amount (BOS)	Core Making Method	Dog Bone Making Method	Test number
Foseco Solosil® 131	3.5%	Hand rammed, gassed with CO_2	Blown, gassed with CO_2	1412-123-HB
H&G S Corosil® GL	5.0%	Hand rammed, gassed with CO_2	Blown, gassed with CO_2	1412-122-GZ
HA International Cordis®	2.0%	Blown into 275°F box, purged with 300°F air	Blown into 300°F box, purged with 70°F air	1412-115-HF
LaempeKuhs BeachBox® LK 700-376	2.5%	Blown into 275°F box, purged with 300°F air	Blown into 300°F box, purged with 70°F air	1412-114-HC
LaempeKuhs BeachBox® LK 700-403	2.5%	Blown into 275°F box, purged with 300°F air	Blown into 300°F box, purged with 70°F air	1412-116-HD

Figure 2-3 Three-on Dogbone Core Box

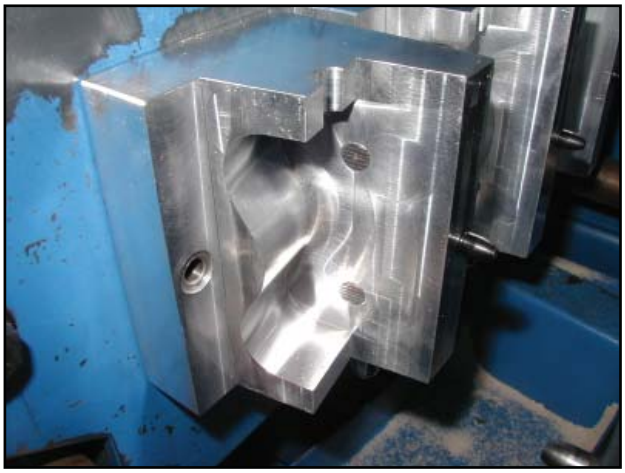


Figure 2-4 Weighing of Dogbones to 0.1 gram Resolution

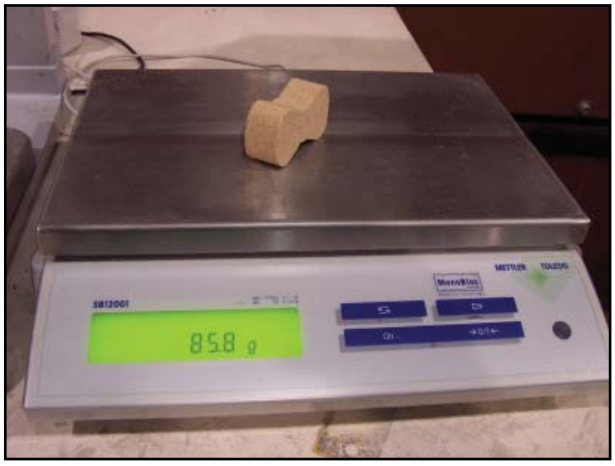
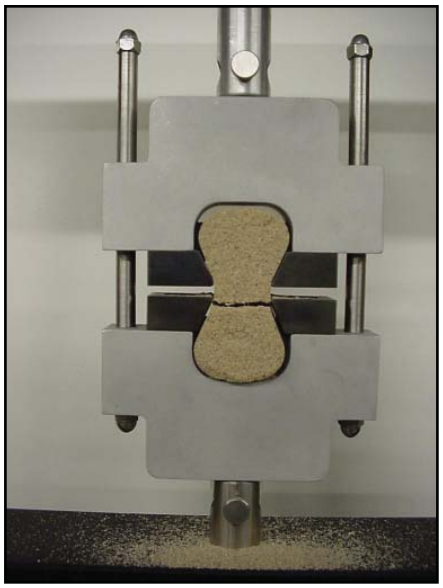


Figure 2-5 Thwing-Albert QC-3A Tensile Tester

Figure 2-6 Close-up of Tested Dogbone with Typical Fracture of Core



The 24 hour humidity test samples for HA International Cordis®, LaempeKuhs BeachBox® LK700-376 and LaempeKuhs BeachBox® LK700-403 did not hold up under their own weight overnight, and were not tested because they could not be accurately weighed, nor put in the tensile test machine.

2.1.1. Test Plan Review and Approval

The proposed test plan was reviewed by the Technikon personnel. Table 2-2 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 2-2 Emission Sampling and Analytical Methods

Parameter	Analytical Equipment and Methods
Dogbone Core Weight	MyWeigh i2600 Electronic Platform Scale (gravimetric)
Sand Temperature	Dial Thermometer
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

2.1.2. Data Reduction, Tabulation and Preliminary Report Preparation

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

2.1.3. 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.

2.3 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC) PROCEDURES

In order to ensure the timely review of critical quality control parameters, the following procedures are 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.

3.0 TEST RESULTS

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

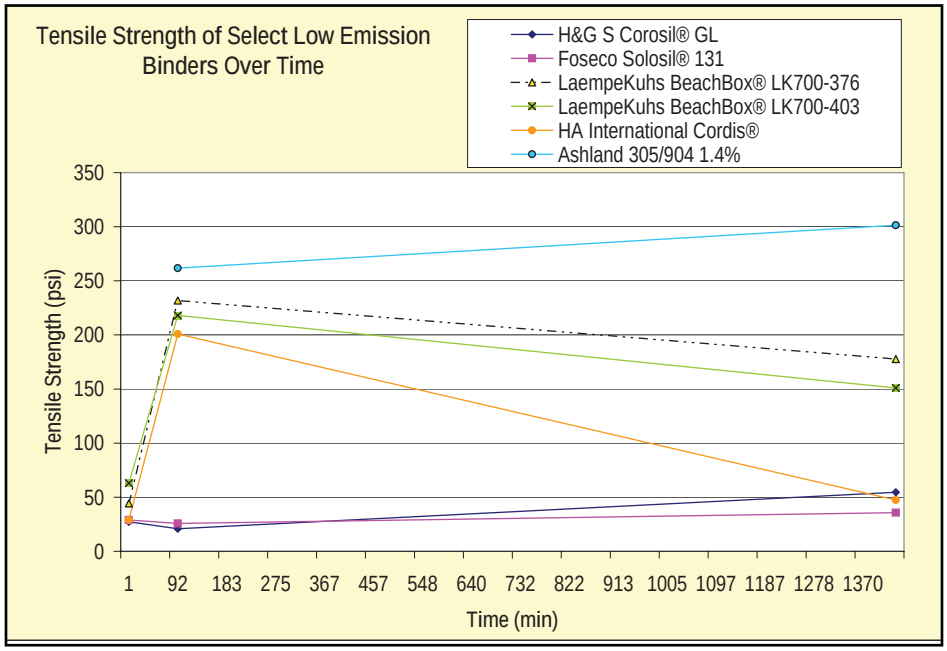
Table 3-1 Average Tensile Strength of 30 Dogbones for Each Binder

	5 min	2 hr	24 hr	24 hr @ 100% Humidity
	Tensile Strength, psi			
Foseco Solosil® 131	29.0	25.8	35.7	105.2
H&G S Corosil® GL	27.3	20.9	54.6	103.1
HA International Cordis®	29.0	200.8	47.4	0.0
LaempeKuhs BeachBox® LK 700-376	44.3	231.9	177.8	0.0
LaempeKuhs BeachBox® LK 700-403	63.0	218.0	151.0	0.0

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

The detail of these data is in Appendix B.

Figure 3-1 Average Tensile Strength of 30 Dogbones over Time



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4.0 DISCUSSION OF RESULTS

The average tensile strengths of all of the binders were in a relatively close range (27.3-63.0 psi) 5 minutes after curing. The binders supplied by HA International and LaempeKuhs increased significantly after 2 hours to above 200 psi, while the H&G and Foseco binders' strength decreased slightly. After 24 hours the strength of LaempeKuhs BeachBox® LK700-376 and LaempeKuhs BeachBox® LK700-403 dropped to below 200 psi, while the HA International Cordis® dropped to below 50 psi. The H&G S Corosil® GL and Foseco Solosil® 131 each rose slightly in 24 hour strength.

After 24 hrs in a 100% relative humidity environment, both H&G S Corosil® GL and Foseco Solosil® 131 achieved their highest strengths for this test. The HA International Cordis®, LaempeKuhs BeachBox® LK700-376 and LaempeKuhs BeachBox® LK700-403 binders all failed to sustain their shape while in the high humidity environment, and had zero strength (Figure 4-1).

Figure 4-1 Dogbone Test Specimens from HA International Cordis®

Testing results synopsis:

- All binder tensile strengths were lower than typical cold box cores.
- 100% humidity makes the salt based binders have zero strength.
- Both BeachBox® binders came closest to being competitive as a replacement binder system in tensile strength testing. HA International Cordis® might be acceptable if bench life was minimized.
- Sodium silicate cores were very low in tensile strength, but are used in the industry for larger cores that aren't limited by tensile strength.
- Emission testing results for all binders has been completed and are printed in separate reports.

APPENDIX A TEST PLAN AND PROCESS INSTRUCTIONS

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TECHNIKON TEST PLAN

- **CONTRACT NUMBER:** 1412 **TASK NUMBER** 117 **SERIES** HH
- **SITE:** Core Department
- **TEST TYPE:** Mixing, making, curing, and tensile testing of Dog Bones made from low emission binders used in the 1412 contract
- **METAL TYPE:** N/A
- **MOLD TYPE:** N/A
- **NUMBER OF MOLDS:** N/A
- **CORE TYPE:** Foseco Solosil® 131, H&G S Corosil® GL, HA International Cordis®, LaempeKuhs BeachBox® LK700-376, LaempeKuhs BeachBox® LK700-403
- **CORE COATING:** N/A
- **SAMPLE EVENTS:** 600
- **TEST DATE(S):** **START:** 5/1/06
  FINISH: 5/9/06

TEST OBJECTIVES:

To test the tensile strengths of each of the above mentioned binders at intervals of 5min 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 humid environment.

VARIABLES:

Each of the tensile specimens will be made with the binder percentage (Based on Sand) that was used to make the cores for CERP tests GZ, HB, HF, HC, and HD.

BRIEF OVERVIEW:

The tensile test specimens (dog bones) will be made and tested at Technikon. All specimens will be made using the Hobart (KitchenAid) mixer and Redford-Carver core machine. All specimens will be stored in a dessicator prior to testing. The specimens for the 24 hour humidity test will be stored in a dessicator, in substitution for dessicant, 200g of water will be put in the tray. All specimens will be weighed, and then tested on Thwing-Albert QC-3A tensile tester. 30 tensile specimens of each binder type, for each test scenario, will be made and tested.

SPECIAL CONDITIONS:

The tensile specimens that are made from Foseco Solosil® 131, and H&G S Corosil® GL will be made using the same parameters in respect to each other. The dogbones made from HA International Cordis, LaempeKuhs BeachBox® LK700-376, and LaempeKuhs BeachBox® LK700-403 will also be made the same in respect to each other. The two groups of binders will be made differently. The H&G and Foseco products will be made at room temperature and gassed with CO_2 with no purge. The HA International and LaempeKuhs specimens will be made with the box heated to 300°F, no gassing, and an air purge. Both sets of binders will have the dogbones made with the same blow pressure and time. Data from the test will be analyzed for mean, standard deviation, and upper and lower control limits. If more than 3 data points are outside of the upper and lower control limits the data will be scrapped, and the test re-run.

1412-1.1.7-HH

Mixing, Making, Curing, and Tensile Testing of Dog Bones made from Low Emission Binders used in the 1412 Contract

Process Instructions

A. Experiment:

1. To test the tensile strengths of each of the low emission binders used in the 1412 contract: Foseco Solosil® 131, H&G S Corosil® GL, HA International Cordis®, LaempeKuhs BeachBox® LK700-376, and LaempeKuhs BeachBox® LK700-403. 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.

B. Materials:

1. Dog bone sand:

a. Wedron 530 silica.

2. Binders:

a. Foseco Solosil® 131
b. H&G S Corosil® GL
c. HA International Cordis®
d. LaempeKuhs BeachBox® LK700-376
e. LaempeKuhs BeachBox® LK700-403

C. Mixing:

1. Weigh out 3000.0 ± 1g Wedron 530
2. Add the sand to the Hobart mixer
3. Set the mixer to setting 2
4. Weigh out the appropriate binder (± 1g) per the list below

a. Foseco Solosil® 131 .....105g
b. H&G S Corosil® GL 150g
c. HA International Cordis® 60g
d. LaempeKuhs BeachBox® LK700-376.....75g
e. LaempeKuhs BeachBox® LK700-403.....75g

5. Mix until sand is coated

D. Dog Bone Blowing

1. Set up the dog Bone machine per the parameters below.

a. For all binders
  1) Blow Time..... 1 sec
  2) Blow Pressure .....90 psi

b. For Foseco Solosil® 131 and H&G S Corosil® GL
  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

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. Remove the sand head and replace it with the gas head.
7. Gas the dog bones
  a. For Foseco Solosil® 131 and HA International Corosil® 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.

8. Remove the gas head.
9. Remove the dog bones, mark them and record the time they were made.
10. Store them in a desiccator until they are to be tested.
11. For the humidity tests instead of desiccant add a pan containing 200g water.
12. Repeat until 30 dog bones for each test have been manufactured.

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

F. 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.

Thomas Fennell
Process Engineer

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APPENDIX B PROCESS DATA CHARTS

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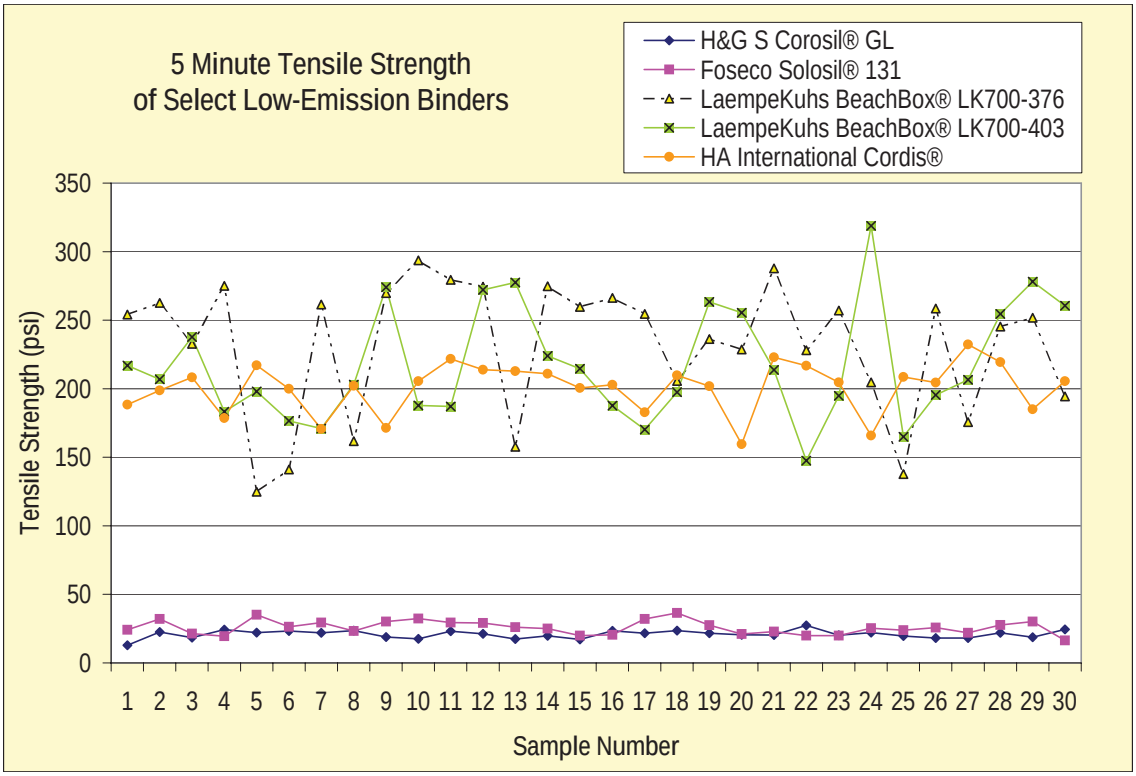
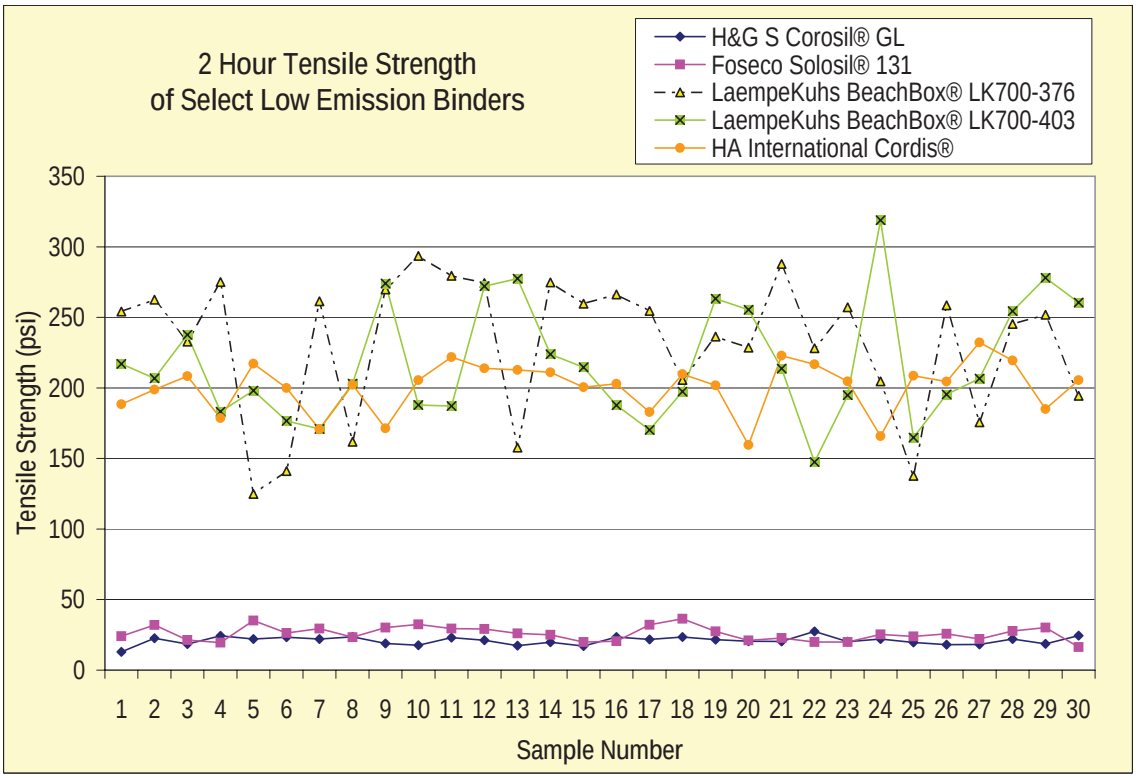
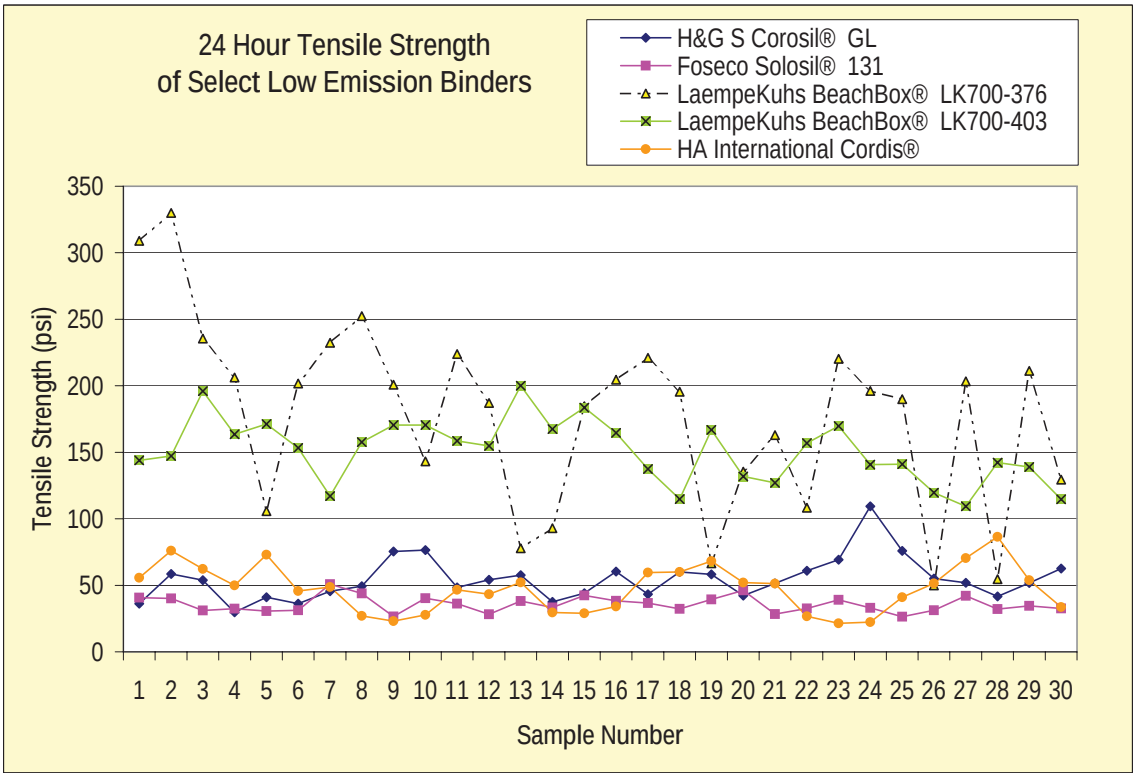
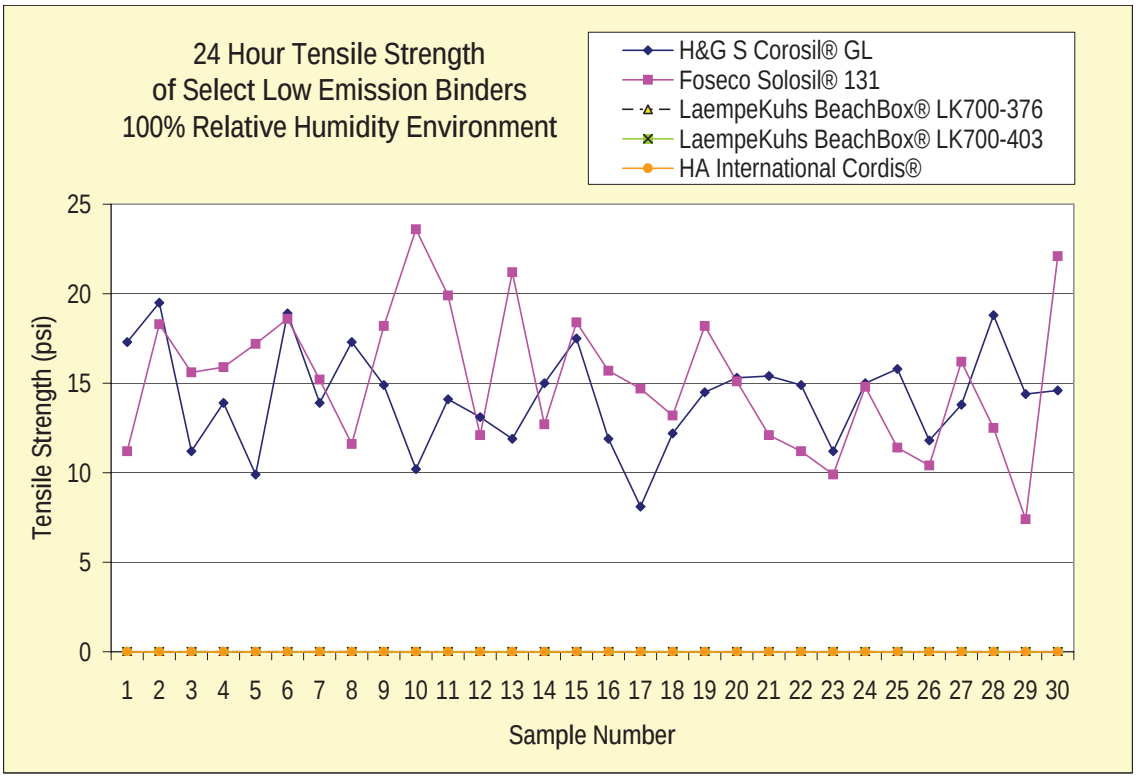

5 Minute Tensile Strength
of Select Low-Emission Binders
H&G S Corosil® GL
Foseco Solosil® 131
LaempeKuhs BeachBox® LK700-376
LaempeKuhs BeachBox® LK700-403
HA International Cordis®
Tensile Strength (psi)
0
50
100
150
200
250
300
350
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Sample Number


2 Hour Tensile Strength
of Select Low Emission Binders
H&G S Corosil® GL
Foseco Solosil® 131
LaempeKuhs BeachBox® LK700-376
LaempeKuhs BeachBox® LK700-403
HA International Cordis®
Tensile Strength (psi)
0
50
100
150
200
250
300
350
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Sample Number


24 Hour Tensile Strength
of Select Low Emission Binders
H&G S Corosil® GL
Foseco Solosil® 131
LaempeKuhs BeachBox® LK700-376
LaempeKuhs BeachBox® LK700-403
HA International Cordis®
Tensile Strength (psi)
0
50
100
150
200
250
300
350
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Sample Number


24 Hour Tensile Strength
of Select Low Emission Binders
100% Relative Humidity Environment
H&G S Corosil® GL
Foseco Solosil® 131
LaempeKuhs BeachBox® LK700-376
LaempeKuhs BeachBox® LK700-403
HA International Cordis®
Tensile Strength (psi)
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Sample Number

APPENDIX C ACRONYMS AND ABBREVIATIONS

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AFS	American Foundry Society
ARDEC	(US) Army Armament Research, Development and Engineering Center
ASAM	Association for the Standardization of Automation and Measurement Systems
BO	Based on ( ).
BOS	Based on Sand.
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CEMS	Continuous Emissions Monitoring Systems
CERP	Casting Emission Reduction Program
CFR	Code of Federal Regulations
CISA	Casting Industry Suppliers Association
COR	Contracting Officer's Representative
CRADA	Cooperative Research and Development Agreement
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
ERC	Environmental Research Consortium
GS	Greensand
IVI	Interchangeable Virtual Instruments
kW	Kilowatt - A unit of power equal to 1,000 watts
MSDS	Material Safety Data Sheets
NA	Not Applicable; Not Available
ND	Non-Detect; Not detected below the practical quantitation limit
NIST	National Institute of Standards and Technology
NT	Not Tested - Lab testing was not done
PCS	Pouring, Cooling, Shakeout
PM	Particulate Matter
PPE	Personal Protective Equipment
PUCB	Phenolic Urethane Cold Box
QA/QC	Quality Assurance/Quality Control
TEA	Triethylamine

TGOC	Total Gaseous Organic Concentration
US EPA	United States Environmental Protection Agency
USCAR	United States Council for Automotive Research
WBS	Work Breakdown Structure