Casting Emission Reduction Program


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# Draft of Process Improvement: Klein Sand Mixer & Thwing-Albert Tensile Tester

**Technikon #1410-610 FX**

**July 2004**

*(revised for public distribution)*

United States Environmental Protection Agency

CISA

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# Draft of Process Improvement: Klein Sand Mixer & Thwing-Albert Tensile Tester

## Technikon # 1410-610 FX

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

| | | |
|---|---|---|
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| President: | *// Original Signed //*<br>William Walden | Date |

The data contained in this report were developed to assess the capability of the test apparatus relative to apparatus accepted as standard and used in the industry. You may not obtain the same results in your facility.

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## Executive Summary

The objective of this testing was to determine 1) the capability of the Klein eccentric oscillating production sand mixer to produce uniformly coated resin bonded core sand and 2) the relative capability of the Thwing-Albert QC-3A and the Dietert 405 Universal tensile testers to provide representative tensile data from test core "dogbone" test specimens.

The outcome of both sand mixing and tensile testing are subject to multi variable influences. The mixing process in addition to the geometry and speed of the mixer is influenced by the amount of binder to be incorporated, the temperature dependent viscosity of the binder, the adhesion of the binder to the sand, the weight of the sand load being mixed, the volume of the sand load relative to the mixer bowl and implements as well as the particle sizing and specific gravity of the sand itself. Tensile testing in addition to design considerations of the tester responds to the equipment & sand temperature, electronic stability of the readouts, uniformity of the binder throughout the sand mass, the dogbone manufacturing techniques, and again the sand sizing distribution.

In order to isolate the features of the tensile tester that affect the tensile values, the sand dogbone itself had to be made in a very uniform reproducible manner and the mixing of the sand going into the dogbones had to be thorough and consistent.

The degree of mixing thoroughness or "mixedness" is a measure of uniformity of the distribution of the binder throughout the sand but it requires a means of measurement. LOI is a valid measure of binder content. Variability in LOI measurements made on multiple samples sourced from various selected locations in each sand batch and from multiple batches was chosen as the criterion for measuring "mixedness". When using the LOI as an adjudicating test, samples from each variable were burned together in the oven on each cycle and several replicating runs were done with each variable's sample occupying a different location in the oven on each run.

In order to minimize the interference from the sand itself on the LOI's measurement of weight loss, four (4) sands where characterized for minimal indigenous LOI value and variability. Wedron 530 silica sand was chosen as the test sand on this basis.

The Hobart Epicentric lab mixer was chosen as a reference mixer because it is a well known mixer with a history of being thorough. Measurement of the LOI variability of sand mixed in the model K45SSWH Hobart mixer in a series of LOI tests based on batch size clearly pointed to a 4000 gram batch as producing sand batches with minimal variation in mixedness. The mixing protocol as developed at Ashland Chemical Co. called for a 4 minute total mixer cycle time in this type of mixer for doing core binder tests.

The Klein E101D099 eccentric oscillating production mixer, by contrast, was run at the factory set batch size of about 50 pounds and cycle of 45 seconds.

A series of 10 mixes in each mixer was LOI tested. Based on the LOI measurement and standard deviation of the series of replicating tests from 12 locations in each mixer the two mixers were indistinguishable. The Hobart K45SSWH mixer was chosen from an historical perspective as the standard and the Klein E101D099 mixer the comparative to produce mixed sand for dogbone tensile test specimen manufacture for the tensile test machine comparison.

The tensile measurement is a force divided by cross sectional area measurement. In order to control the cross section at the fracture zone a fully enclosed dogbone core box was chosen over an open faced multi-cavity core die. This decision mandated a blown core rather than a hand packed one which carried the benefit of removing the operator behavior from the list of variables contributing to inconsistency of the tensile test piece, the dogbone. A new three (3) cavity end–blown no-draft, no-slide-surface core box was manufactured to replace the two (2) cavity side-blown core box previously used.

A set of 60 TEA gassed dogbones was made in the new 3-cavity core box from Hobart mixed sand aged 15 minutes to 45 minutes to determine if a cavity positional bias on the tensile strength existed in the core box. The center cavity exhibited a 1-2 % superiority over the outboard cavities however the superiority was only 0.5 standard deviation of the tensile strength and therefore the cavities would have to be considered indistinguishable.

Finally 60 TEA gassed sets of three (3) cores were made with Wedron 530 sand having 1.4 % Ashland ISOCURE ® 305LF/904GR binder mixed in 5 batches in the Hobart mixer for 4 minutes at 72-77 $^{o}$F. The Cores were all batch, blow cycle and core cavity identified, aged 24 hours and randomized (within cavity) to the two tensile machines and broken. The same procedure was repeated using two sand batches from the Klein mixer a total of 360 dogbones.

The Thwing –Albert tensile tester measured the tensile strength of randomized dogbones of the same composition, same sand mixer, and same core making method 64 psi higher than the Dietert 405 tensile tester. This same difference in tensile strength occurred with dogbones whose sand was mixed in either mixer.

Both Tensile testers measured the tensile strength of randomized dogbones of the same composition, and same core making method 24 psi higher for sand mixed in the Hobart mixer vs. sand mixed in the Klein mixer.

Dogbones whose sands were mixed in either mixer gave tensile strength measurements that had less variability using the Dietert 405 tensile tester vs. the Thwing-Albert machine.

The most consistent tensile values came from sand mixed in the Klein mixer tested on the Dietert 405 tensile tester. The least consistent was from sand mixed in the Hobart mixer tested on the Thwing-Albert tensile tester.

Table 1 summarizes the numeric results of this evaluation:

**Table 1 Sand Selection, Mixer Batch Size, Mixer Selection, Core Box Cavity Bias, and Tensile Test Comparisons.**

| Process Event | Mixer | Variable | Criterion | Average | Standard Deviation |
|---|---|---|---|---|---|
| Sand Selection | Hobart | Wexford W450 Lakesand | LOI, % | 0.037 | 0.038 |
| | | Amador A-70 Silica | | 0.125 | 0.018 |
| | | US Silica OK-90 Silica | | 0.114 | 0.015 |
| | | Technisand Wedron 530 Silica | | **0.077** | **0.015** |
| | | | | | |
| Mixer Batch Size | Hobart | 2000 gram batch | LOI % | 1.383 | 0.032 |
| | | 3000 gram batch | | 1.340 | 0.028 |
| | | 4000 gram batch | | 1.346 | **0.015** |
| | | | | | |
| Mixing Homogeneity | | Hobart Epicentric mixer | LOI, % | 1.187 | 0.116 |
| | | Klein Eccentric mixer | | 1.195 | **0.093** |
| | | | | | |
| Core Box Cavity Bias | Hobart | North cavity | Thwing-Albert Tensile Strength, psi: Cavity difference from cavity average | 1.3 | 3.7 |
| | | Center Cavity | | -3.1 | 6.7 |
| | | South Cavity | | 1.8 | 7.1 |
| | | | | | |
| Tensile Strength Capability | Hobart | Thwing-Albert QC-3A | Tensile strength, psi | 301.5 | 21.62 |
| | | Deitert 405 | | 237.7 | **16.20** |
| | Klein | Thwing-Albert QC-3A | Tensile strength, psi | 277.7 | 16.44 |
| | | Deitert 405 | | 213.7 | **9.03** |

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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 mobile 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). Its purpose is to evaluate alternative casting materials and processes that are designed to reduce air emissions and/or produce more efficient casting processes. Other technical partners directly supporting the project include: the American Foundry Society (AFS); the Casting Industry Suppliers Association (CISA); the US Environmental Protection Agency (US EPA); and the California Air Resources Board (CARB).

## 1.2 CERP OBJECTIVES

The primary objective of CERP is to evaluate the impact of new materials, equipment, and processes on airborne emissions from the production of metal castings. To accomplish this objective, the Technikon facility has been created to evaluate alternate materials and production processes designed to achieve significant airborne emission reductions, especially for organic Hazardous Air Pollutants (HAPs). HAP emissions reduction from the alternative materials, equipment and production processes is expressed as a comparison to similar emissions from a baseline or reference test. These alternate materials, equipment, and processes may need to be further adapted and defined so that they will integrate into current commercial green sand casting facilities smoothly and with minimal capital expenditure.

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 USEPA air testing protocols. Measurements are taken during pouring, casting cooling, and shakeout processes performed on <u>discrete</u> 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 <u>relative</u> 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 ratios, pouring temperatures, stack flow rates, LOI levels, seacoal and resin contents, 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 for the preparation of automotive block cores, a Redford that is used for the production of step cores, and a second smaller Redford to produce dogbone tensile test specimens as 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 variability of mixing and tensile testing. Section 2 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 of this report with detailed data included in appendices of this report.

Section 4 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 impact of mixing sand for tensile test specimens, dogbones, using the Hobart Epicentric and the Klein eccentric oscillating core sand mixer. Secondly, the report contains the results of testing to compare tensile testing measurements made on the Thwing-Albert QC-3A tensile tester to those made on the Deitert 405 tensile tester. All tensile test dogbones were prepared in a manner to be statistically indistinguishable

A summary of the test plan for the individual test series is shown in Table 1-1.

### Table 1-1 Test Plan Summary

| Parameter Varied | Reference equipment | Comparative equipment | | |
|---|---|---|---|---|
| **Sand mixers** | Hobart K45SSWH | Klein E101D099 | | |
| **Tensile testers** | Deitert 405 Universal | Thwing-Albert QC-3A | | |
| **Test sands** | Wexford W450 Lakesand | Wedron 530 Silica | Amador A-70 Silica | US Silica Oklahoma 90 |
| **Test type** | **Binder** | **Binder content** | **Adjudication basis** | **Repetitions** |
| **Selection of test sand** | None | NA | LOI content & LOI variability | 12 each sand |
| **Reference mixer batch size selection** | Ashland Chemical ISOCURE® LF305/904GR | 1.4 % | LOI variability | 12 locations each of three (3) batch sizes |
| **Selection of mixer for dogbone sand** | Ashland Chemical ISOCURE® LF305/904GR | 1.4 % | "Mixedness"<br>LOI variability | 12 locations in each of 10 batches from each mixer<br>240 total |
| **Core box qualification** | Ashland Chemical ISOCURE® LF305/904GR | 1.4 % | Tensile test<br>Thwing-Albert | 30 qualified dogbones from each cavity |
| **Compare Tensile testers** | Ashland Chemical ISOCURE® LF305/904GR | 1.4 % | Tensile test | 30 qualified dogbones from each mixer from each core cavity for each tensile tester<br>360 total |

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# 2.0 Test Methodology

## 2.1 DESCRIPTION OF TESTING PROGRAM AND EQUIPMENT

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 first objective of the testing was to evaluate the mixing characteristics of the Klein sand mixer relative the reference Hobart laboratory sand mixer in order to choose the mixer that would contribute to the most uniform dogbone tensile test piece. The second objective was to evaluate by comparison the tensile testing capability of the Thwing-Albert QC-3A tensile tester relative to the reference Dietert 405 tensile tester.

The outcome of both sand mixing and tensile testing are subject to multi variable influences. The mixing process in addition to the geometry and speed of the mixer is influenced by the amount of binder to be incorporated, the temperature dependent viscosity of the binder, the adhesion of the binder to the sand, the weight of the sand load being mixed, the volume of the sand load relative to the mixer bowl and implement volume as well as the particle sizing of the sand itself. Tensile testing in addition to geometric design considerations of the tester responds to the equipment and sand temperature, stability and resolution of the readouts, uniformity of the binder throughout the sand mass, the dogbone manufacturing techniques, and again the sand sizing distribution as it affects the packing density of the sand.

In order to isolate the features of the tensile tester that effect the tensile values, the sand dogbone itself had to be made in a very uniform reproducible manner and the mixing of the sand going into the dogbones had to be thorough and consistent.

**Figure 2-1 Tree Panning Tool for Sand Sampling**

**Figure 2-2 Sand Splitter for Sample Homogenization**

**Figure 2-3 Programmable LOI Oven**

The degree of mixing thoroughness or "mixedness" is a measure of uniformity of the distribution of the binder throughout the sand. It requires a means of measurement. LOI is a valid measure proportional to binder content. Variability in LOI measurements made on multiple samples sourced from various selected locations in each sand batch and from multiple batches was chosen as the criterion for measuring "mixedness". LOI measurements are made by measuring the weight loss from having burned a sample in air in an oven for 2 hours at 1800°F. When using the LOI as an adjudicating test biases in the burning of the samples are mitigated by placing the samples from each process variable together in the oven on each burn cycle and replicating the burns with each variable's sample occupying a different location in the oven.

**Figure 2-4 Hobart Epicentric Sand Mixer**

**Figure 2-5 Klein Eccentric Oscillating Sand Mixer**

**Figure 2-6 Klein Eccentric Sand Mixer Bowl**

Raw sand carries an indigenous LOI value resulting from breakdown of limestone and clay minerals present. In order to minimize the interference from the sand itself on the LOIs measurement of weight loss, four (4) sands where characterized for minimal indigenous LOI value and variability. Wedron 530 silica sand was chosen as the test sand on this basis. See table 3-1

The Hobart Epicentric lab mixer was chosen as a reference mixer because it is a well known mixer with a history of being thorough. Measurement of the LOI variability of sand mixed in the Hobart K45SSWH mixer in a series of LOI tests based on batch size clearly pointed to a 4000 gram batch as producing sand batches of Wedron 530 with minimal variation. The protocol, as developed at Ashland Chemical Co., called for a 4 minute total mixer cycle time in this type of mixer for doing core binder tests. See Table 3-2

The Klein eccentric oscillating sand mixer, by contrast, was run at the factory set batch size, about 50 pounds, and a total cycle time of 45 seconds.

A series of 10 mixes in each mixer was LOI tested. Based on the LOI measurement and standard deviation of the series of replicating tests from 12 locations in each mixer, the two mixers were indistinguishable. The Hobart K45SSWH mixer was chosen from an historical perspective as the standard and the Klein mixer the comparative to produce mixed sand for dogbone tensile test specimen manufacture for the tensile test machine comparison. The Klein mixer produced a slightly smaller variability. See Tables 3-3a and 3-3b.

**Figure 2-7 Redford/Carver Dogbone Core Machine**

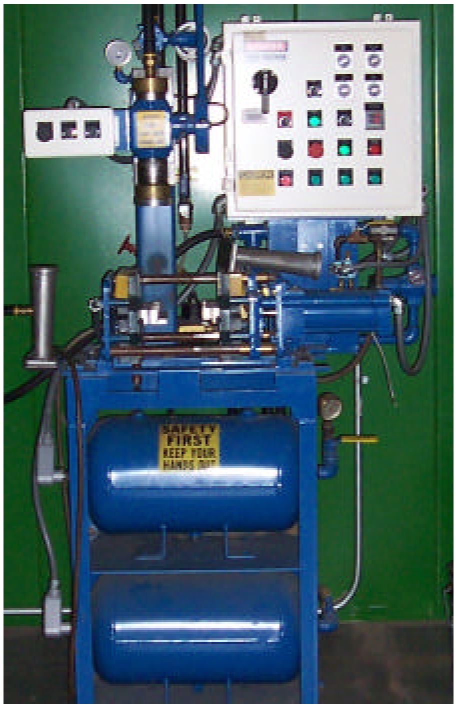


**Figure 2-8 Three-On Dogbone Core Box**

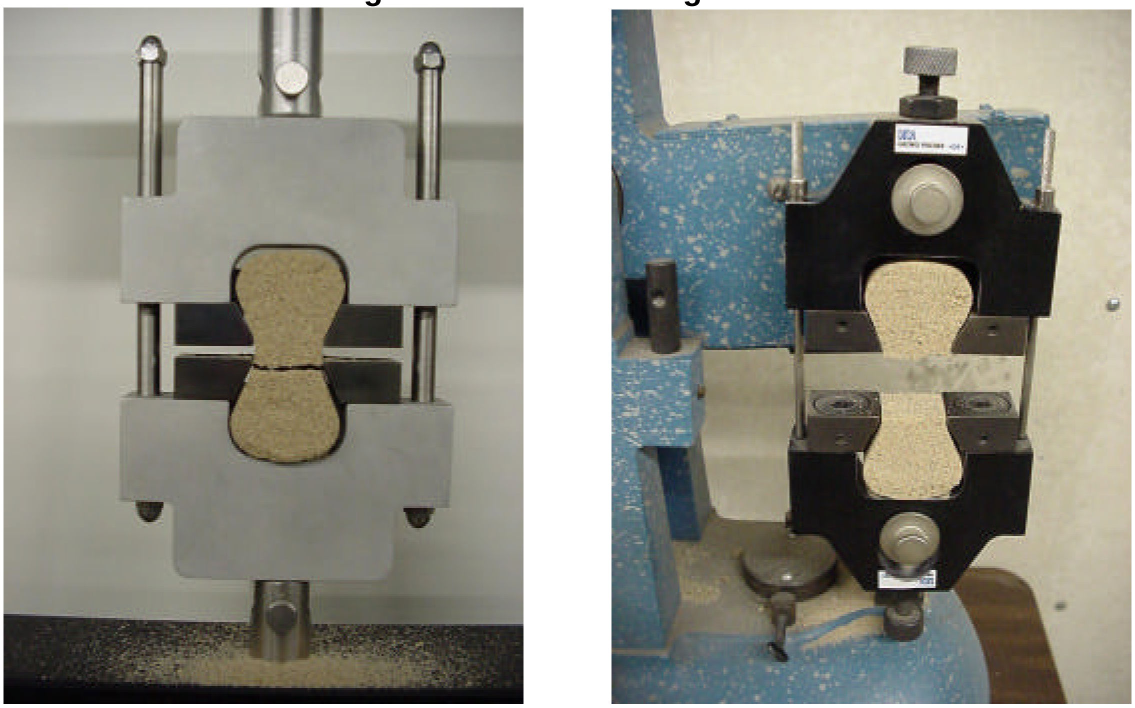
The tensile measurement is a force divided by cross sectional area measurement. In order to control the cross section at the fracture zone a fully enclosed dogbone core box was chosen over an open multi-cavity core die. This decision mandated a blown core rather than a hand packed one which carried the benefit of removing the operator behavior from the list of variables contributing to inconsistency of the tensile test piece, the dogbone. A new three (3) cavity end–blown no-draft, no-slide-surface core box was manufactured to replace the two (2) cavity side-blown core box previously used. Re-orientation of the blow direction may be the single factor having the greatest influence on the change in the average core tensile values compared to historical values using the same binder system and sand. A set 60 dogbones made from mixed sand aged 15 minutes to 45 minutes was made on the new 3-cavity box to determine if a cavity positional bias existed in the box. See Table 3-4

Finally 60 TEA gassed sets of three (3) cores were made with Wedron 530 sand having 1.4% Ashland ISOCURE® 305LF/904GR binder mixed in 5 batches in the Hobart mixer for 4 minutes at 72-77$^{o}$F. The Cores were all batch, blow cycle and cavity identified, aged 24 hours, randomized (within cavity) to the two tensile machines and broken.

**Figure 2-9 Weighing Dogbones to 0.1 Gram Resolution**

**Figure 2-10 Thwing-Albert QC-3A and Dietert 405 Tensile Testers in Temperature Controlled Room**

**Figure 2-11 Tested Dogbones**



The same procedure was repeated using a single sand batch from the Klein mixer. See Table 3-5.

**Test Plan Review and Approval**

The proposed test plan was reviewed by the Technikon personnel and approved. Table 2-1 lists the process parameters that were monitored during each test. The analytical equipment and methods used are also listed.

**Table 2-1 Process Parameters Measured**

| Parameter | Analytical Equipment and Methods |
|---|---|
| Core weight | Mettler SB12001 electronic platform scale (gravimetric) |
| Sand Temperature | Fluke 52 thermocouple |
| LOI | Denver analytic (AFS procedure 5100-00-S) |
| Sand batching weight | Mettler SB12001 electronic platform scale (gravimetric) |
| Core machine pressure | Machine mounted pressure gauge |
| Tea gas & purge air temperature | Chromo lox temperature controller |
| Tensile tester ambient temperature | Room ambient air temperature control system |

**Data Reduction, Tabulation and Preliminary Report Preparation:**

The analytical results of the LOI and tensile tests are included in Section 3 of this report. Calibrations and other QA/QC measurements are kept on file at Technikon.

**Report Preparation and Review:**

This Preliminary Draft Report was reviewed by the Process Team 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 USCAR Representative.

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

Detailed QA/QC and data validation procedures for the process parameters, are included in the "Technikon Testing, Quality Control and Quality Assurance, and Data Validation Procedures Manual" 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 Manager-Process Engineering to ensure that the parameters are maintained within the prescribed control ranges. Where data are not within the prescribed ranges, the Manager-Process Engineering and the Vice President-Operations determine whether the individual test samples should be invalidated or flagged for further analysis.

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## 3.0 Test Results

Table 3-1. Average and standard deviation of LOI for 4 sands evaluated as a sand to make tensile test dogbone test pieces.

Figure 3-1a Values of LOI from 4 sands evaluated for use as a sand to make dogbone tensile test pieces.

Figure 3-1b Aggregate Standard Deviation from sequence of LOI measurements from sands evaluated for use as a sand to make dogbone tensile test pieces.

Table 3-2 Average and Standard deviation of LOI measurements made on 2000, 3000, & 4000 gram sand batches of Wedron 530 mixed in the Hobart sand mixer.

Table 3-3a Hobart mixer mixedness. Summary of Standard deviation of LOI for Wedron 530 sand mixed in Hobart mixer, sampled 12 locations.

Table 3-3b Klein mixer mixedness index. Summary of Standard deviation of LOI for Wedron 530 sand mixed in Klein mixer, sampled 12 locations.

Figure 3-2. Data from Tables 3-3a and 3-3b.

Table 3-4 Standard deviation of tensile strength for 3 cavity core box by core box cavity for Wedron sand mixed in Hobart mixer.

Table 3-5. Average and Standard deviation of tensile strength for dogbones containing 1.4 % binder, made from Wedron 530 sand mixed in the Hobart mixer for 4 minutes or mixed in the Klein mixer for 45 seconds and made within 15-45 minutes after mixing in the new three-on core box, aged 24 hours and tested on the Thwing-Albert or Dietert 405 tensile tester
The details of this data are in appendix B.

**Table 3-1 Indigenous LOI of Raw Sands Considered for Making Tensile Test Specimens.**

| | A-70 | OK 90 | Wedron 530 | Wexford W450 |
|---|---|---|---|---|
| Average % LOI | 0.125 | 0.114 | 0.077 | 0.366 |
| LOI St Dev | 0.018 | 0.015 | 0.015 | 0.038 |

**Figure 3-1a Accumulative LOI Average Values of a Sequence of Determinations on Four (4) Sands Evaluated for Use as a Sand to Make Dogbone Tensile Test Pieces.**

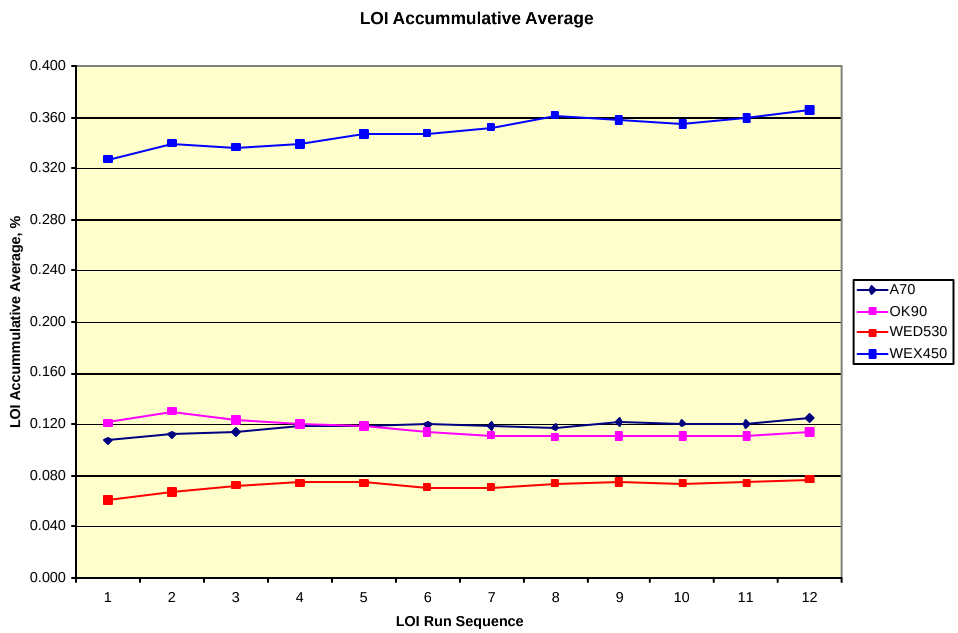



**Figure 3-1b Accumulative LOI Standard Deviation of Sequence of LOI Measurements on Sands Evaluated for Use as a Sand to Make Dogbone Tensile Test Pieces.**

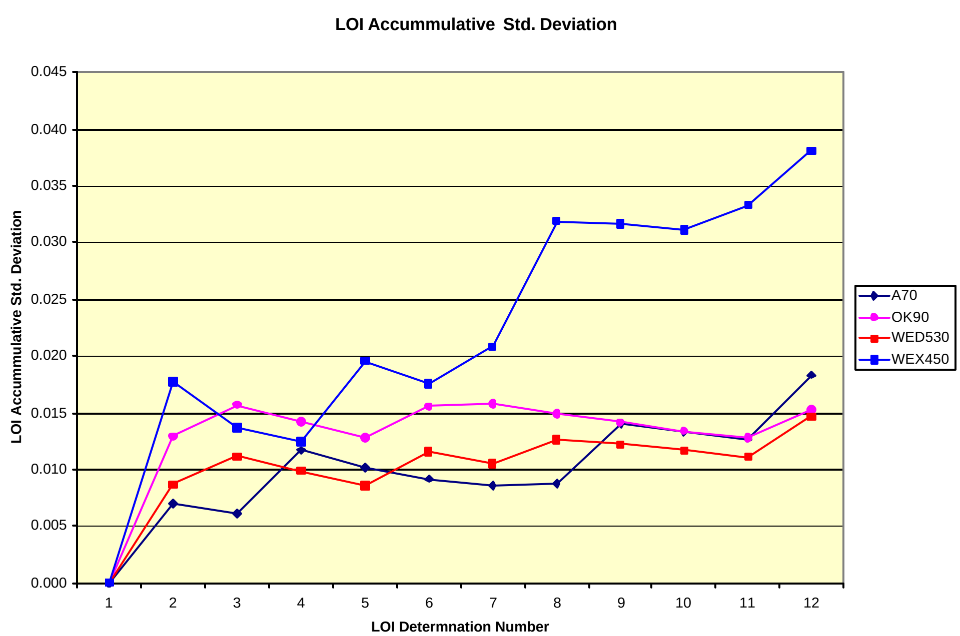


**Table 3-2 Average and Standard Deviation of LOI Measurements Made on 2000, 3000, & 4000 Gram Batches of Wedron 530 Sand Mixed in the Hobart Mixer.**

| LOI Sequence No. | Location ID | 2000 gram batch LOI | Location ID | 3000 gram batch LOI | Location ID | 4000 gram batch LOI |
|---|---|---|---|---|---|---|
| 1 | 2000-12-1 | 1.3764 | 3000-12-1 | 1.3192 | 4000-12-1 | 1.3343 |
| 2 | 2000-6-1 | 1.4226 | 3000-6-1 | 1.3299 | 4000-6-1 | 1.3452 |
| 3 | 2000-3-1 | 1.3828 | 3000-3-1 | 1.3190 | 4000-3-1 | 1.3397 |
| 4 | 2000-9-1 | 1.4327 | 3000-9-1 | 1.3090 | 4000-9-1 | 1.3417 |
| 5 | 2000-12-2 | 1.3821 | 3000-12-2 | 1.3492 | 4000-12-2 | 1.3312 |
| 6 | 2000-6-2 | 1.3429 | 3000-6-2 | 1.3107 | 4000-6-2 | 1.3270 |
| 7 | 2000-3-2 | 1.3891 | 3000-3-2 | 1.3155 | 4000-3-2 | 1.3314 |
| 8 | 2000-9-2 | 1.3468 | 3000-9-2 | 1.3763 | 4000-9-2 | 1.3389 |
| 9 | 2000-12-3 | 1.3585 | 3000-12-3 | 1.3710 | 4000-12-3 | 1.3581 |
| 10 | 2000-6-3 | 1.3641 | 3000- 6-3 | 1.3278 | 4000-6-3 | 1.3633 |
| 11 | 2000-3-3 | 1.3673 | 3000-3-3 | 1.3884 | 4000-3-3 | 1.3601 |
| 12 | 2000-9-3 | 1.4355 | 3000-9-3 | 1.3701 | 4000-9-3 | 1.3775 |
| **Average** | | **1.3834** | | **1.3405** | | **1.3457** |
| **St. Dev.** | | **0.0315** | | **0.0281** | | **0.0152** |

**Table 3-3a Hobart Mixer Mixedness. Summary of Standard Deviation of LOI for Wedron 530 Sand Mixed in Hobart Mixer, Sampled 12 Locations.**

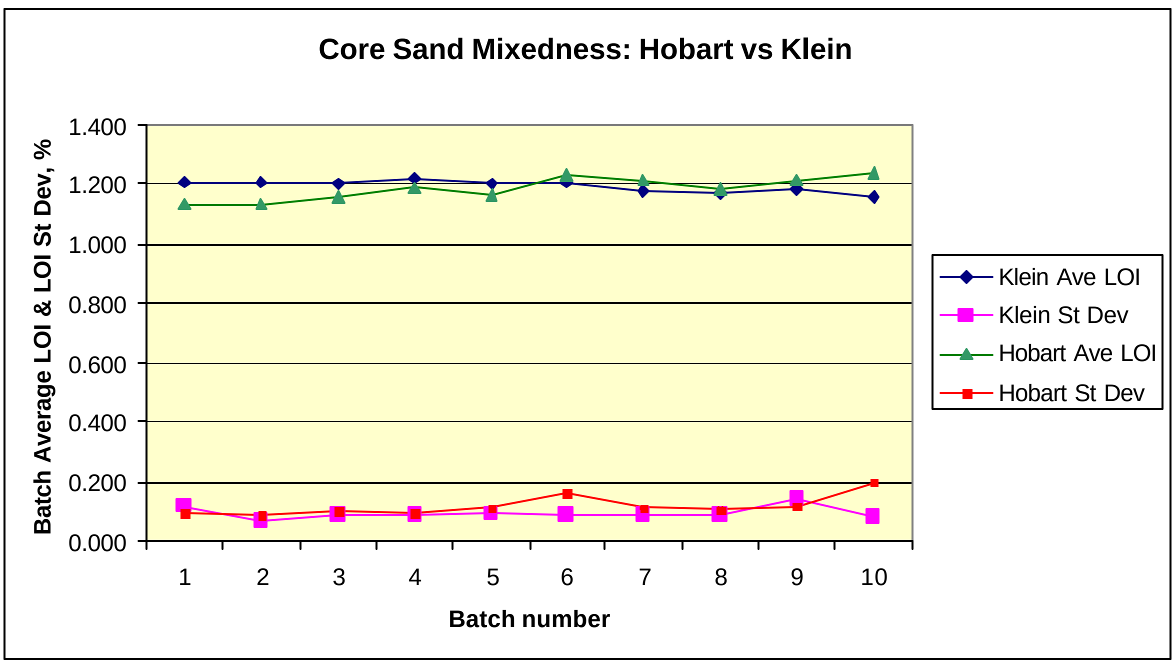
| Position in bowl | Batch number 1 see note | Batch number 2 | Batch number 3 | Batch number 4 | Batch number 5 | Batch number 6 see note | Batch number 7 | Batch number 8 | Batch number 9 | Batch number 10 | Position averages see note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H 3-1 | 1.196 | 1.198 | 1.260 | 1.286 | 1.294 | 1.305 | 1.450 | 1.422 | 1.451 | 1.432 | 1.349 |
| H 6-1 | 1.282 | 1.264 | 1.348 | 1.321 | 1.315 | 1.314 | 1.380 | 1.344 | 1.399 | 1.365 | 1.342 |
| H 9-1 | 1.251 | 1.293 | 1.267 | 1.316 | 1.294 | 1.283 | 1.273 | 1.231 | 1.295 | 1.275 | 1.281 |
| H 12-1 | 1.197 | 1.196 | 1.202 | 1.234 | 1.221 | 1.231 | 1.285 | 1.198 | 1.280 | 1.261 | 1.235 |
| H 3-2 | 1.188 | 1.176 | 1.246 | 1.286 | 1.246 | 1.108 | 1.141 | 1.119 | 1.146 | 1.144 | 1.188 |
| H 6-2 | 2.248 | 1.063 | 1.121 | 1.140 | 1.131 | 3.893 | 1.173 | 1.178 | 1.149 | 1.731 | 1.211 |
| H 9-2 | 1.128 | 1.107 | 1.103 | 1.136 | 1.156 | 1.169 | 1.140 | 1.160 | 1.153 | 1.080 | 1.129 |
| H 12-2 | 1.066 | 1.071 | 1.127 | 1.139 | 1.119 | 1.236 | 1.192 | 1.193 | 1.184 | 1.179 | 1.150 |
| H 3-3 | 1.056 | 1.033 | 1.080 | 1.159 | 1.094 | 1.638 | 1.151 | 1.155 | 1.171 | 1.143 | 1.123 |
| H 6-3 | 1.059 | 1.051 | 1.074 | 1.134 | 0.939 | 1.109 | 1.172 | 1.112 | 1.132 | 1.132 | 1.093 |
| H 9-3 | 1.004 | 1.077 | 1.072 | 1.085 | 1.089 | 1.079 | 1.097 | 1.050 | 1.094 | 1.047 | 1.076 |
| H 12-3 | 1.041 | 1.056 | 1.042 | 1.069 | 1.070 | 1.087 | 1.089 | 1.064 | 1.091 | 1.070 | 1.069 |
| **Batch Average** | see note | 1.132 | 1.162 | 1.192 | 1.164 | see note | 1.212 | 1.186 | 1.212 | 1.238 | **1.187** |
| **Batch Std Dev.** | see note | 0.089 | 0.099 | 0.091 | 0.113 | see note | 0.113 | 0.108 | 0.118 | 0.196 | **0.116** |

**Note batches 1 & 6 had visible resin balls at position 6-2 do not use**

**Table 3-3b Klein Mixer Mixedness Index. Summary of Standard Deviation of LOI for Wedron 530 Sand Mixed in Klein Mixer, Sampled 12 Locations.**

| Position in bowl | Batch number 1 | Batch number 2 | Batch number 3 | Batch number 4 | Batch number 5 | Batch number 6 | Batch number 7 | Batch number 8 | Batch number 9 | Batch number 10 | Position averages |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K 3-1 | 1.405 | 1.362 | 1.382 | 1.391 | 1.397 | 1.371 | 1.297 | 1.278 | 1.287 | 1.286 | 1.345 |
| K 6-1 | 1.310 | 1.296 | 1.299 | 1.345 | 1.332 | 1.253 | 1.299 | 1.297 | 1.369 | 1.248 | 1.305 |
| K 9-1 | 1.421 | 1.260 | 1.295 | 1.259 | 1.290 | 1.325 | 1.307 | 1.327 | 1.424 | 1.303 | 1.321 |
| K 12-1 | 1.233 | 1.221 | 1.195 | 1.246 | 1.183 | 1.270 | 1.222 | 1.229 | 1.251 | 1.196 | 1.225 |
| K 3-2 | 1.227 | 1.186 | 1.225 | 1.259 | 1.208 | 1.140 | 1.121 | 1.080 | 1.180 | 1.080 | 1.171 |
| K 6-2 | 1.172 | 1.218 | 1.172 | 1.142 | 1.124 | 1.170 | 1.175 | 1.146 | 1.218 | 1.123 | 1.166 |
| K 9-2 | 1.180 | 1.123 | 1.147 | 1.203 | 1.143 | 1.203 | 1.183 | 1.143 | 0.959 | 1.154 | 1.144 |
| K 12-2 | 1.114 | 1.171 | 1.146 | 1.154 | 1.167 | 1.110 | 1.144 | 1.124 | 1.125 | 1.094 | 1.135 |
| K 3-3 | 1.140 | 1.198 | 1.205 | 1.181 | 1.153 | 1.194 | 1.088 | 1.144 | 1.127 | 1.076 | 1.151 |
| K 6-3 | 1.086 | 1.146 | 1.124 | 1.136 | 1.138 | 1.079 | 1.144 | 1.140 | 1.141 | 1.116 | 1.125 |
| K 9-3 | 1.144 | 1.227 | 1.173 | 1.208 | 1.156 | 1.249 | 1.121 | 1.118 | 1.172 | 1.125 | 1.169 |
| K 12-3 | 1.078 | 1.124 | 1.090 | 1.118 | 1.114 | 1.141 | 1.068 | 1.063 | 0.953 | 1.088 | 1.084 |
| Batch Averages | 1.209 | 1.211 | 1.204 | 1.220 | 1.200 | 1.209 | 1.181 | 1.174 | 1.184 | 1.157 | **1.195** |
| Batch St. Dev.s | 0.115 | 0.071 | 0.084 | 0.084 | 0.091 | 0.088 | 0.083 | 0.087 | 0.142 | 0.081 | **0.093** |

**Figure 3-2 Data from Tables 3-3a and 3-3b. The Two Mixers are Virtually Indistinguishable.**



### Table 3-4 Cavity Variation: Tensile Strength (psi) for 3 Cavity Corebox by Core Box Cavity for Wedron Sand Mixed in Hobart Mixer. All Cavities are Virtually Indistinguishable.

| Core cavity | North | Middle | South | Ave of Cav ave. |
|---|---|---|---|---|
| Batch #1: 9 Bone Cavity Average | 229.3 | 233.7 | 228.8 | 230.6 |
| Batch #2: 9 Bone Cavity Average | 241.6 | 245.1 | 238.4 | 241.7 |
| Average Difference: 9 bone cavity average from average of cavity averages | -0.7 | 3.2 | -2.6 | |
| Average of cavity std devs | 6.0 | 7.2 | 7.3 | |
| Ave. Diff as % of Ave cavity std devs | -11.4 | 45.2 | -35.0 | |

### Table 3-5 Average and Standard Deviation of Tensile Strength for Dogbones Containing 1.4 % Binder, Made from Wedron 530 Sand Mixed in the Hobart Mixer for 4 Minutes or Mixed in the Klein Mixer for 45 Seconds and Made Within 15-45 Minutes After Mixing in the New Three-On Core Box, Aged 24 Hours and Tested on the Thwing-Albert or Dietert 405 Tensile Tester.

| Break Sequence | Sand Mix Age @ Make hh:mm | Dogbone age @ Break Hours | North Core Weight grams | North Core Tensil psi | Middle Core Weight grams | Middle Core Tensil psi | South Core Weight grams | South Core Tensil psi | dogbone cavity average Tensile |
|---|---|---|---|---|---|---|---|---|---|
| T-A Hobart | | | | | | | | | |
| Average | 0:12 | 24.10 | 111.91 | 303.82 | 111.20 | 307.42 | 112.04 | 293.4 | **301.55** |
| St Dev | 0:04 | 1.26 | 0.53 | 10.73 | 0.27 | 21.72 | 0.14 | 32.4 | **21.62** |
| Reduced St Dev | | | | 0.035 | | 0.071 | | 0.110 | **0.072** |
| 90 % Conf upper limit | 0:19 | 26.21 | 112.79 | 321.84 | 111.66 | 343.91 | 112.27 | 347.8 | **337.87** |
| 90 % Conf lower limit | 0:05 | 21.99 | 111.02 | 285.79 | 110.74 | 270.93 | 111.81 | 239.0 | **265.24** |
| 405 Hobart | | | | | | | | | |
| Average | 0:10 | 26.36 | 111.65 | 236.75 | 111.08 | 243.32 | 111.97 | 233.04 | **237.70** |
| St Dev | 0:04 | 1.52 | 0.34 | 13.87 | 0.38 | 11.54 | 0.21 | 23.18 | **16.20** |
| Reduced St Dev | | | | 0.059 | | 0.047 | | 0.099 | **0.068** |
| 90 % Conf upper limit | 0:18 | 28.92 | 112.22 | 260.05 | 111.72 | 262.70 | 112.32 | 271.99 | **264.91** |
| 90 % Conf lower limit | 0:03 | 23.80 | 111.08 | 213.45 | 110.44 | 223.94 | 111.62 | 194.09 | **210.49** |
| T-A Klein | | | | | | | | | |
| Average | 0:15 | 24.93 | 111.89 | 274.85 | 111.23 | 282.36 | 112.11 | 275.84 | **277.68** |
| St Dev | 0:09 | 0.44 | 0.12 | 17.47 | 0.17 | 17.86 | 0.16 | 13.98 | **16.44** |
| Reduces St Dev | | | | 0.064 | | 0.063 | | 0.051 | **0.059** |
| 90 % Conf upper limit | 0:31 | 25.68 | 112.10 | 304.21 | 111.52 | 312.36 | 112.38 | 299.32 | **305.30** |
| 90 % Conf lower limit | 0:00 | 0.08 | 111.69 | 245.50 | 110.95 | 252.37 | 111.83 | 252.35 | **250.07** |
| 405 Klein | | | | | | | | | |
| Average | 0:17 | 26.05 | 111.85 | 213.60 | 111.28 | 216.57 | 112.03 | 211.07 | **213.74** |
| St Dev | 0:06 | 0.75 | 0.08 | 8.49 | 0.18 | 9.00 | 0.13 | 9.58 | **9.03** |
| Reduced St. Dev. | | | | 0.040 | | 0.042 | | 0.045 | **0.042** |
| 90 % Conf upper limit | 0:28 | 27.31 | 111.99 | 227.87 | 111.58 | 231.69 | 112.26 | 227.16 | **228.91** |
| 90 % Conf lower limit | 0:05 | 24.79 | 111.71 | 199.33 | 110.99 | 201.44 | 111.81 | 194.97 | **198.58** |

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# 4.0 Discussion of Results

In this evaluation every attempt was made to remove all the variables that influence mixing and tensile testing except those created by the machines themselves.

The tensile specimens, the dogbones, were made in a single 3-cavity corebox using the same batches of sand having the same age since mixing, 15-45 minutes .The resulting dogbones from each sand batch were randomized within cavity identifications and distributed to the two tensile test machines.

The mixing effectiveness of the sand mixers was evaluated using the LOI measurement of the binder content for replicated samples from 12 specified locations in the respective mix bowls.

To make sure that the sand was not itself contributing to the variation in the LOI measurement, four (4) sands were pre-evaluated to choose a sand that was least interfering and least variable in LOI measurement.

**Choice of Sand for Making Dogbones for Tensile Testing.**

Table 3-1 demonstrates that Wedron 530 sand had the lowest and least variable indigenous LOI and thus was selected as the sand from which the dogbones were to be made. Figures 3-1a & b show that the Wedron sand statistically stabilized with fewer samples.

**Effect of batch size on Hobart mixer mixedness**

The influence of the batch size on mixer effectiveness for the reference Hobart mixer is shown in Table 3-2. The variability in LOI, used as a measure of "mixedness", was least with a 4000 gram batch. For all sand mixing for dogbone manufacture using the Hobart mixer the batch size was chosen at 4000 grams (about 8-3/4 pounds). The batch size for the Klein mixed sand for dogbones was taken at the manufacturer's recommendation for this mixer at nominally 50 pounds.

**Comparison of Mixedness of Hobart Epicentric and Klein Oscillatory Sand Mixers.**

Each mixer was used to make 10 batches of sand to evaluate the resulting consistency of binder content. The Hobart mixer was run for a total of four (4) minutes for each batch. The sand and binder components were pre-weighed and then charged into the mixer at selected times according a protocol provided by Ashland Chemical Co. for core sand evaluations using a Hobart mixer. The Klein mixer was run for 45 seconds according to the manufacturer's instructions. The sand and binder dispensing rates into the Klein mixer were statistically pre-calibrated. Each batch was sampled at 12 specified locations in the sand bowl. The results shown in Tables 3-3a & b and graphically in Figure 3-2 indicate that binder distribution in sands mixed in either of these mixers was virtually indistinguishable. The mean value of the LOI for each batch from each mixer in was within the value of the standard deviation of the other mixer results.

It was noteworthy that each mixer had a deposit that was not mixed at all. The Klein's dead spot was an annular ring around the foam discharge plug. The Hobart's was at the center bottom of the bowl.

**Core Box Cavity Comparison of Tensile Strengths.**

All dogbones were made in a three (3) cavity end-blown core box. The cavities were rotated 10 degrees about the blow axis so that no draft was required on the dogbone itself. Nine (9) sets of three (3) dogbones were made from each of two sand batches mixed in the Hobart mixer and aged 9-31 minutes during dogbone manufacture. The dogbones were tensile tested after two (2) hours. The binder was 1.4% Ashland Chemical Co. ISOCURE® 305/904 binder and TEA catalyzed. All materials, dogbones, mixers, core blowers, and tensile testers were normalized in temperature to 72-77$^{o}$F. Table 3-4 shows the results by cavity. The central cavity exhibited tensile strengths about 1-2 % higher than the outboard cavities. The outboard cavities were about 1 % different from each other. The differences however were inside the spread of one (1) standard deviation and therefore all cavities must be considered indistinguishable. This pattern persisted throughout all tensile testing.

**Comparison of the Thwing-Albert & Dietert 405 Core Tensile Testers.**

Eight (8) batches of sand were required from the Hobart mixer and 2 batches were required from the Klein mixer so that 60 sets of 3 dogbones from each mixer's sand, a total of 360 dogbones could be made. The dogbones were made with sand that was aged a minimum of 15 minutes but no material was used that was older than 45 minutes from the end of the mixing. The binder was 1.4 % Ashland Chemical Co. ISOCURE® 305/904 binder and TEA catalyzed. All materials, dogbones, mixers, core blowers, and tensile testers were normalized in temperature to 72-77$^{o}$F. The dogbones were tensile tested on both the Thwing-Albert and the Dietert 405 by mixer type and core cavity, twelve (12) sets of thirty (30) dogbones. Within each mixer type and core cavity the dogbones were randomized to convert the make sequence to a tensile test break sequence and distributed between the two tensile test machines. See Appendix Table B6.

The results are shown in Table 3-5. The center cavity again exhibited a 1-2 % higher tensile strength than the end cavities but within the standard deviation. The Thwing-Albert machine gave tensile strength values 64 psi greater than the Dietert machine with cores made from sand mixed with each mixer. Both tensile testers measured tensile strengths to be 24 psi greater for bones whose sand was prepared in the Hobart mixer compared to the sand prepared in the Klein mixer. With sands from both mixers the Dietert machine exhibited a narrower spread of tensile values and the variation was least with the Hobart mixed sand.

# APPENDIX A APPROVED TEST PLAN AND INSTRUCTIONS FOR TEST FX

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# TECHNIKON TEST PLAN

| | | |
|---|---|---|
| > | **CONTRACT NUMBER:** | 1410 **TASK NUMBER**: 6.1 **Test FX** |
| > | **SITE:** | Core Department |
| > | **TEST TYPE:** | Comparative Evaluation of<br>▪ Hobart Epicentric lab mixer and Klein Eccentric Oscillatory sand mixers.<br>▪ Thwing-Albert QC-3A and Dietert 405 Tensile testing machines |
| > | **METAL TYPE:** | N/A |
| > | **MOLD TYPE:** | N/A |
| > | **NUMBER OF MOLDS:** | N/A |
| > | **CORE TYPE:** | 1.4 % Ashland ISOCURE ® 305/904 binder |
| > | **CORE BOX:** | 3-cavity axially blown dogbone. |
| > | **TEST DATE:** | **START:** 26 Apr 2004<br>**FINISHED:** 11 June 2004 |

**TEST OBJECTIVES:**

1. Compare mixing efficiency of sand mixers using variability if LOI of qualified mixed sands as the measure of "mixedness". The reference machine is to be a Hobart Epicentric mixer and the comparative machine is to be Klein eccentric oscillatory mixer.

2. Compare absolute values and consistency of tensile strength measurements on two tensile strength testing machines. The reference machine is to be Dietert 405; comparative machine is to be Thwing-Albert QC-3a tensile tester.

**VARIABLES**

Sand type, Sand homogeneity, LOI value, LOI variability, Binder content consistency, Core box tooling, Core manufacturing technique, Mixed sand age at Dogbone manufacture, Dogbone age at tensile test period. Material and machinery temperature.

**BRIEF OVERVIEW:**

In order to separate the variables that influence the measured tensile strength value of resin bonded sand dogbone tensile test specimens the dogbones must be manufactured in the most

consistent manner possible from homogeneous sand mixed with a constant amount of binder in the most consistent manner feasible. Therefore this test is designed to evaluate each step of dogbone manufacture in reverse order so that the materials, tools, and machinery are demonstrated to be the least variable at each step of preparation. Where the influence of a variable on tensile strength measurement is not fully understood that variable will be maintained within a narrow range for all testing that is in some manner dependent on it. Thus all similar materials, tooling, and machinery will be kept in the same room in the temperature range of 72-77 $^{o}$F. Sand mixing of multiple batches, manufacturing of dogbones, and tensile testing of dogbones will each be done in the shortest span of time practical to minimize time dependent variation...
Since LOI will be the measure of "mixedness" the sand used in the mixing test and follow up tensile dogbone manufacture must exhibit minimal indigenous LOI and minimal LOI variability. Four qualified foundry sands are to be sampled from there respective sources using a tree panning method of obtaining a representative cross section of material. The extracted sands will then each be re-blended using sand splitter techniques to maximize their homogeneity. Final samples will be taken from the re-blended material. Each kind of sand will then have multiple measurements made of its indigenous LOI according to standard AFS procedures. A single kind of sand will be selected for all subsequent processing based on lowest LOI value and least LOI standard deviation.

The optimal batch size for the reference Hobart mixer will then be determined based on the minimal LOI standard deviation over 10 sand batches each for three batch sizes appropriate to the mixer bowl volume.

The "mixedness" will be determined for both the Hobart and Klein mixers by making multiple batches in each mixer using the same sourced sand selected above. The Hobart mixer will be evaluated at its optimal batch size using a 4 minute mixing protocol developed by Ashland Specialties Co. for core sand testing using a Hobart mixer. The Klein mixer will be evaluated using the manufacture's recommended batch size, nominally 50 pounds, and the cycle time, 45 seconds. The binder for the Hobart mixer will be gravimetrically measured for each batch. The sand and binder for the Klein mixer will have to be statistically calibrated to the same nominal binder content as the Hobart. The material feeds to the Klein mixer are by automatic machine cycle.

Dogbones will be manufactured in an axially blown three (3) cavity corebox on a Redford Carver core machine. Bias in the tensile strength based on core cavity will be determined from two (2) nine (9)-dogbone lots from each cavity. Each lot of 9 dogbones from each cavity represents one (1) Hobart sand batch of the selected sand. Based on these results it will be decided whether the cavities can be co-mingled randomly for tensile testing or that they must be segregated by cavity and each cavity being treated as a randomized replication of the tensile test.

Finally, thirty (30) dogbone lots made in the three cavity core box from the selected sand, mixed in each mixer, will be separately tensile tested repeatedly on each tensile test machine to determine the tensile strength mean and standard deviation that each tensile test machine determines. The tensile test portion will include a total of 360 dogbones. The sand batches from each mixer will be aged 15 minutes from the end of mixing before dogbones manufacture commences and no material older than 45 minutes from the end of mixing will be used. Tensile testing will commence 24 hours after completion of the dogbone manufacture.

# Series FX

## Evaluation of Thwing-Albert Tensile Tester
## and
## Klein Sand Mixer

# Process Instructions

**A.** Experiment:

**1)** Measure the accuracy and precision of the Thwing-Albert tensile tester relative to the Deitert 405 Universal tensile tester on qualified core dog bones. Measure by LOI the degree of mixedness of core sands prepared on the Klein mixer relative to a Hobart laboratory mixer.

**B.** Materials & equipment:

**1)** Sands: Wexford W450, Wedron 530, US Silica Oklahoma 90, & Amador 70.
**2)** Ashland Isocure® 305 part I/904 part II core binder system TEA catalyzed.
**3)** Ashland 700 TEA
**4)** Mettler-Toledo SB12001 platform scale.
**5)** Hobart model K45SSWH mixer with open paddle attachment and bowl cover.
**6)** Two 250-500 ml polyethylene dispensing bottles.
**7)** R/C model HBT/CBT core blower with 2 cavity Dogbone core box attached.
**8)** Klein model E101D099 vibratory mixer.
**9)** Deitert Model 405 universal sand tester with dogbone tensile attachment.
**10)** Thwing-Albert Model QC-3A tensile tester.
**11)** ELE model CL-244 gate type sand splitter.
**12)** Thermometer with one (1) oF resolution.
**13)** Stop watch with 1 second resolution and accumulative time capability.
**14)** Vulcan model 3-350 LOI oven with 1800 oF capability and accessories.
**15)** Denver Instruments model XE-100 analytic scale with 0.1 mg readability.
**16)** Four 1-2 gallon Polyethylene pails with sealable lids.
**17)** One (1) inch ID trepanning tool.
**18)** Deitert 276-B Moisture Teller.
**19)** Desiccator storage container.

**Caution:** Observe all safety precautions attendant to these operations as delineated in the pre-production operating and safety instruction manual.

**C.** Overview:

**1)** Measurements are usually relative to a standard rather than absolute. The two machines in question in this evaluation were themselves presented to us as new standards in the industry. They will be evaluated in terms of more historical standards the Deitert 405 universal tensile tester and the Hobart laboratory mixer.

**2)** Quality tensile testing is known to result from a properly designed machine, operated by a well trained person, on consistently manufactured test pieces (sand dog bones), made from uniformly prepared sand in a temperature and time controlled environment. To that end sand and test equipment will be in-solated in a 72-77$^{o}$F environment and the incremental process steps will be held to 30 minutes or less.

**3)** The choice of sand among pre-qualified good foundry sands will be based on the minimal mean and standard deviation of the raw sand LOI. Sand mixing will be evaluated based on standard deviation of the LOI of the binder coated sand. Dog bone preparation will be mechanical and based on the dog bone weight. Tensile testing will be evaluated on 30 sample means and standard deviations of the tensile strength.

**D.** Sand sampling:

**1)** Sample each sand source by trepanning to the center of the lot or bag using a one (1) inch internal diameter by three (3) foot long trepanning tool having twenty-four (24) 3/8 inch diameter holes on 1.0 inch centers. The trepanning sampler shall be inserted so that the highest hole is about two (2) inches below the surface of the sampled material. About 500 grams of material should be gathered for this potion of the evaluation.

**2)** Bag each sample in a labeled Ziploc bag.

**3)** For the Wedron 530 sand that comes in 50 pound bags sample from at least 3 bags per AFS procedure 1104-00-S. Co-mingle the Wedron sand samples so obtained and reduce to about 500 grams using the splitter.

**4)** Dry each sample according to AFS procedure 1125-00-S.

**5)** Run each sample thru the sand splitter per AFS procedure 1120-00-S three times and return it to the Ziploc bag.

**E.** Sand selection:

**1)** The LOI will be used in other parts of the evaluation so the sand with the lowest and most consistent naturally occurring LOI shall be determined to select sand for subsequent use.

- **a)** From each of the four (4) prepared lots weigh twelve (12) nominally 30 gram +/- 0.1 mg LOI samples.
- **b)** Run an 1800 oF LOI according to AFS procedure 5100-00-S, four (4) at a time, one (1) from each source. Randomize location in furnace and record positions.
- **c)** For each material calculate the mean and standard deviation of the LOI.
- **d)** For each material report the individual LOI values, the mean, and standard deviation.
- **e)** Select the one (1) sand with the lowest mean and standard deviation LOI to use in part E of the evaluation.

**F.** Sand mixing.

**1)** Hobart Mixer:

**a)** Batch size:

**i)** This section will determine the Hobart mixer batch size for the balance of the evaluation.

**b)** Mix one (1) 2000 gram, one (1) 3000 gram, and one (1) 4000 gram sand batch constituted as per Table 1.

| **Table 1** | **2000 gram batch** | **3000 gram batch** | **4000 gram batch** |
|---|---|---|---|
| **Sand from part C** | 2000 +/- 0.3 grams | 3000 +/- 0.3 grams | 4000 +/- 0.3 grams |
| **Binder part I** | 15.4 +/- 0.1 grams | 23.1 +/- 0.1 grams | 30.8 +/- 0.1 grams |
| **Binder part II** | 12.6 +/- 0.1 grams | 18.9 +/- 0.1 grams | 25.2 +/- 0.1 grams |

**Note 1**: Weigh the liquid binder parts to be dispensed into the sand by first placing the components into smaller sealed & labeled polyethylene squeezable dispensing bottles. For each sand batch tare weigh the bottle and its contents, dispense binder to the sand then reweigh the bottle and contents until the desired weight loss (dispensed) is achieved. No compensation for residual binder in the dispensing container will be required by this method.

**Note 2:** Construct an easily removable lid for the mixer. The lid is not intended to be air tight but merely inhibit evaporation during mixing.

**c)** Gather approximately 10000 grams of sand from a single source and homogenize by passing through the splitter 5 times.

**d)** Attach the open paddle mixer implement to the mixer head locking it in place.

**e)** Add sand to mixer the bowl and lock the bowl to the mixer.

**f)** Measure and record the sand temperature and ambient temperature.

**g)** Make a dimple in the sand and add part I resin to the sand in the dimple. Cover the resin lightly with sand.

**h)** Lower the mixer head into the sand. Cover the bowl.

**i)** Start a timer and turn the mixer on to "stir" and then to speed setting "2". Mix for one (1) minute. Record the amount of part I dispensed.

**j)** Stop the timer and mixer, remove the lid, raise the mixer head and "turn the sand over" looking for binder stuck to the mixer or for dry spots.

**k)** Lower the mixer head, replace the cover, restart the timer and mixer and mix for one (1) additional minute.

**l)** Stop the timer and mixer, remove the cover, raise the mixer head, and make a dimple in the sand.

**m)** Dispense the required amount of part II co-reactant into the sand dimple.

**n)** Lower the mixer head, cover the bowl, start the timer and mixer on "stir" and then speed "2". Mix for one (1) minute. Record the weight of part II dispensed.

**o)** Stop the timer and mixer, remove the cover, raise the mixer head, and "turn the sand over".

**p)** Lower the mixer head, replace the cover, restart the timer and mixer and mix for one (1) minute.

**q)** Stop the timer and mixer, remove the cover, raise the mixer head, and discharge the mixed sand into a time and contents labeled pail. Seal the lid on the pail.

**r)** Record date, time, and temperature of sand preparation for each sized batch.

**s)** From each size mixed sand batch obtain twelve (12) LOI samples representing the edge (2) and center (2) of the material at three levels (4 top surfaces, 4 mid depth, and 4 bottom surface).

**t)** Calculate and report the average and standard deviation on the sand LOI for each batch size.

**u)** Select the batch size having the smallest LOI standard deviation to be used for the balance of the evaluation using the Hobart mixer.

**v)** Hobart degree of mixedness:

- **i)** Determine the degree of mixedness by mixing sand batches of the size determined in E.1.a.20). Determining the mean sand batch LOI of up to twenty batches of sand by the methods described in section E.1.a.2)-18). The actual number of batches to be measured and the number of samples per batch shall be determined by the standard deviation of the same size batch determined in section E.1.a.
- **ii)** Stop making more determinations when the standard deviation for the aggregation of all determinations ceases to significantly vary.

**2)** Klein mixer:

**a)** Calibrate the Klein mixer sand batch size and binder component deposition rates.

- **i)** Make Ten (10) determinations of the sand batch size with the factory settings for the batch hopper depth probes to determine the mean and standard deviation for the sand batch size.
- **ii)** Record all the sand weight data but calculate and record the mean and standard deviation sand batch weight from the last six (6) determinations.
- **iii)** Recapture the sand and return it to the supply hopper.
- **iv)** Calculate the part I deposition rate to be 0.014 x 0.55 times the mean sand batch weight as determined in E.2.a.1)-3).
- **v)** Calculate the part II deposition rate to be 0.014 x 0.45 times the mean sand weight as determined in part E.2.a.1)-3).
- **vi)** Calibrate the part I and Part II deposition rates based on the calculations of E.2.a.4)-5).
- **vii)** Make six (6) measurements of the binder deposition rates after the last rate adjustment.

**viii)** Record the ambient, binder, & sand temperatures and the binder component weights at each iteration. Calculate and record the mean & standard deviation of the binder component weights.

**b)** Klein degree of mixedness.

**i)** Determine the degree of mixedness by mixing sand batches of the size determined in E.2.a.1).
**ii)** Determining the mean sand batch LOI of up to twenty batches of mixed sand.
**iii)** From each mixed sand batch obtain twelve (12) LOI samples representing the edge (2) and center (2) of the material at three levels (4 top surfaces, 4 mid depth, and 4 bottom surface).
**iv)** Calculate and report the average and standard deviation on the sand LOI for each batch size.
**v)** Calculate the accumulative mean and standard deviation of the sand LOI.
**vi)** Stop making more determinations when the standard deviation for the aggregation of all determinations ceases to significantly vary.

**3)** Select the mixer to be used for preparing sand for dogbones for tensile testing by the Thwing –Albert tensile test machine by choosing the mixer with the lower LOI standard deviation.

**G.** New three cavity core box

**1)** Adjust the core box to make visually good core.
**2)** Make a batch of mixed sand in the Hobart mixer using the batch size determined in Section E.1 & Table 1.
**3)** Exercise the core box.
**4)** Make thirty (30) sets of cores with sand that is 15 – 45 minutes old. Three sand batches may be necessary.
**5)** Identify the batch number, blow number and cavity position on each dogbone.
**6)** Age the cores for 24 hours.
**7)** Randomize the dogbones
**8)** Weigh & record weight of each dogbone
**9)** Run the tensile test on each cavity's cores for all 90 dogbones, on the Thwing-Albert tensile tester.
**10)** Record the test time, sand & ambient temperature, tensile strength, the batch number, the blow sequence number, and cavity number for each dogbone.
**11)** Organize the results by cavity.
**12)** Perform the average and standard deviation on each cavity.
**13)** If the average of either side cavity is no more different from the average of the center cavity than one (1) standard deviation of the center cavity that cavity shall be considered to have no bias.

**14)** If the average of a side cavity is different from the average of the center cavity by more than one (1) standard deviation of the center cavity then the side cavity is biased.

**15)** If either side cavity is biased then the final tensile test results must be segregated by cavity for comparison between the two tensile testers. Each cavity shall be considered a separate 30 piece test run on the tester and 60 sets of dogbones will be required.

**H.** Dogbone tensile test core manufacture.

**1)** Using the chosen mixer and the protocol for that mixer prepare a batch of mixed sand.

- **a)** One day prior to the start of tensile testing set the test room temperature to 73 oF.
- **b)** At the same time turn on the R/C core machine & the Thwing-Albert tensile tester, and the Deitert 405 tensile tester to allow them to thermally stabilize.
- **c)** On the day of the test verify that the room temperature is 72-77$^{o}$F, adjust as necessary. Wait to start the test until temperature is stable in the specified range.
- **d)** Weigh one batch of the selected batch size of the selected sand and calculate the required binder to make a 1.40% Cold box core sand mixture having 55% part I and 45% part II. The total required sand is about 3500 grams.
- **e)** Mix one batch of sand to specification and use the sand to cycle the R/C core blower and the two tensile test machines. Discard the sand.
- **f)** Prepare a second batch of sand to specification for use in the test.
  - **i)** Start a timer at the conclusion of the mix cycle.
  - **ii)** Place the prepared sand in sealed container for test use.
  - **iii)** Record the date, time that the batch is done, the mixing duration, and the component weights.
  - **iv)** Retain each batch of test sand in sealed container for LOI testing at 24 hours after completion of preparation.
- **g)** Subsequent sand batches may be prepared as required to satisfy the core making requirements according to G.1.c-e.

**2)** Make test dogbones.

- **a)** Use three cavity end blown core box.
- **b)** Allow test sand prepared in the selected mixer to age exactly 15 minutes prior to first blow.
- **c)** Fill blow magazine full with sand. Tapping magazine to eliminate gross voids is permissible but do not compact the sand in magazine.
- **d)** Close and seal source prepared sand in pail between fillings and when done.
- **e)** Retain extra prepared sand in sealed container for LOI testing at 24 hours after completion of core sand preparation.
- **f)** Blow a set of cores using the following parameters.

- **i)** Prepared sand mix temperature 72-77°F.
- **ii)** Blow pressure 60 psi (-40°F dew point air).
- **iii)** Blow time 0.5 seconds.
- **iv)** Delay after blow 7 seconds.
- **v)** TEA gas: 1 second @ 20 psi.
- **vi)** Purge: 6.0 seconds @ 40 psi (-40 oF dew point air)

- **g)** Prepared test sand shall not be used to make dogbones beyond 45 minutes after completion of preparation.
- **h)** Make at least 65 dogbones.
- **i)** Place dogbones in order and position of manufacture.
- **j)** Randomize dogbones for tensile testing. Map the reorganization.
- **k)** Set dogbones in tensile test room at 72-77°F.

**I.** Tensile testing.

**1)** Thwing-Albert & Deitert Universal 405.

- **a)** Prepare a set of sixty (60) test dogbones from a common batch of sand as in F.2.
- **b)** Weigh & record each dogbone twenty-three (23) hours after manufacture.
  - **i)** Set aside any bones whose weight varies by more than 5% of the average for the group.
- **c)** Test thirty (30) of the dog bones on each of the two tensile test machines at the same time in rapid sequence 24 hours after start of core manufacture.
- **d)** Calculate, record, & compare the average and standard deviation for cores tested on each machine.

**2)** Klein mixer & Thwing-Albert tensile tester. If the Klein mixer was determined to have the bigger standard deviation in section E.3 make a batch of sand and thirty (30) dogbones using the Klein mixer and the Thwing-Albert tensile tester as in sections G.2.c-k.

Steven M. Knight
Manager Process Engineering

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# APPENDIX B PROCESS DATA DETAILS

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## Table B1. LOI of Raw Sands Considered for Mixing and Tensile Testing.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | **Analyst:** | Matt Prendergast | | | | |
| | | | AFS 5100-00-S | | | | | | | | A70 Sand | OK-90 | 530 | W450 |
| **Sample Date** | **test reference number** | **Oven Batch Number** | **Position in Oven** | **Dish wt. (gms)** | **Dish & Sample wt. (gms)** | **Sample wt. (gms)** | **Time in** | **Time out** | **Dry Wt. (gms)** | **Weight change** | **%LOI @1800* Lost on Ignition** | **%LOI @1800* Lost on Ignition** | **%LOI @1800* Lost on Ignition** | **%LOI @1800* Lost on Ignition** |
| | | | | | | | | | | | **A70 Sand** | **OK 90 Sand** | **Wedron 530 sand** | **Wexford W450 Sand** |
| 4/29/2004 | A701 | 1 | B/L | 52.4438 | 82.4600 | 30.0162 | 12:00 | 2:00 | 82.4279 | 0.0321 | 0.11 | | | |
| 4/29/2004 | OK901 | 1 | F/L | 49.6949 | 79.6712 | 29.9763 | 12:00 | 2:00 | 79.6349 | 0.0363 | | 0.12 | | |
| 4/29/2004 | 5301 | 1 | B/R | 60.343 | 90.3633 | 30.0203 | 12:00 | 2:00 | 90.3451 | 0.0182 | | | 0.06 | |
| 4/29/2004 | W4501 | 1 | B/L | 58.9278 | 89.0028 | 30.0750 | 12:00 | 2:00 | 88.9043 | 0.0985 | | | | 0.33 |
| 5/3/2004 | A702 | 2 | F/R | 67.6637 | 97.689 | 30.0253 | 9:00 | 11:00 | 97.6539 | 0.0351 | 0.12 | | | |
| 5/3/2004 | OK902 | 2 | B/R | 53.8622 | 83.923 | 30.0608 | 9:00 | 11:00 | 83.8811 | 0.0419 | | 0.14 | | |
| 5/3/2004 | 5302 | 2 | F/L | 64.0314 | 94.0703 | 30.0389 | 9:00 | 11:00 | 94.0484 | 0.0219 | | | 0.07 | |
| 5/3/2004 | W4502 | 2 | B/L | 63.3381 | 93.3688 | 30.0307 | 9:00 | 11:00 | 93.2629 | 0.1059 | | | | 0.35 |
| 5/3/2004 | A703 | 3 | F/L | 56.2649 | 86.6519 | 30.3870 | 11:00 | 1:00 | 86.616 | 0.0359 | 0.12 | | | |
| 5/3/2004 | OK903 | 3 | B/L | 66.6072 | 96.5804 | 29.9732 | 11:00 | 1:00 | 96.548 | 0.0324 | | 0.11 | | |
| 5/3/2004 | 5303 | 3 | F/R | 61.134 | 91.1658 | 30.0318 | 11:00 | 1:00 | 91.1409 | 0.0249 | | | 0.08 | |
| 5/3/2004 | W4503 | 3 | B/R | 59.2169 | 89.3008 | 30.0839 | 11:00 | 1:00 | 89.2013 | 0.0995 | | | | 0.33 |
| 5/3/2004 | A704 | 4 | B/R | 52.4417 | 82.48 | 30.0383 | 1:00 | 3:00 | 82.4394 | 0.0406 | 0.14 | | | |
| 5/3/2004 | OK904 | 4 | F/L | 49.6881 | 79.7517 | 30.0636 | 1:00 | 3:00 | 79.7184 | 0.0333 | | 0.11 | | |
| 5/3/2004 | 5304 | 4 | F/L | 60.3444 | 90.5179 | 30.1735 | 1:00 | 3:00 | 90.4938 | 0.0241 | | | 0.08 | |
| 5/3/2004 | W4504 | 4 | F/R | 58.9264 | 88.9988 | 30.0724 | 1:00 | 3:00 | 88.8942 | 0.1046 | | | | 0.35 |
| 5/4/2004 | A705 | 5 | B/L | 61.6223 | 91.1502 | 29.5279 | 11:30 | 1:30 | 91.1153 | 0.0349 | 0.12 | | | |
| 5/4/2004 | OK905 | 5 | F/L | 49.6878 | 79.8081 | 30.1203 | 11:30 | 1:30 | 79.7744 | 0.0337 | | 0.11 | | |
| 5/4/2004 | 5305 | 5 | B/R | 60.3392 | 90.5258 | 30.1866 | 11:30 | 1:30 | 90.5033 | 0.0225 | | | 0.07 | |
| 5/4/2004 | W4505 | 5 | B/L | 59.215 | 89.3271 | 30.1121 | 11:30 | 1:30 | 89.2138 | 0.1133 | | | | 0.38 |
| 5/4/2004 | A706 | 6 | F/R | 56.607 | 86.6166 | 30.0096 | 1:30 | 3:30 | 86.5799 | 0.0367 | 0.12 | | | |
| 5/4/2004 | OK906 | 6 | B/R | 52.4373 | 82.5142 | 30.0769 | 1:30 | 3:30 | 82.4864 | 0.0278 | | 0.09 | | |
| 5/4/2004 | 5306 | 6 | F/L | 67.6607 | 97.6667 | 30.0060 | 1:30 | 3:30 | 97.6508 | 0.0159 | | | 0.05 | |
| 5/4/2004 | W4506 | 6 | B/L | 58.9257 | 89.1289 | 30.2032 | 1:30 | 3:30 | 89.0228 | 0.1061 | | | | 0.35 |
| 5/5/2004 | A707 | 7 | F/L | 64.0254 | 94.1097 | 30.0843 | 7:00 | 9:00 | 94.075 | 0.0347 | 0.12 | | | |
| 5/5/2004 | OK907 | 7 | B/L | 49.6837 | 79.7347 | 30.0510 | 7:00 | 9:00 | 79.7059 | 0.0288 | | 0.10 | | |
| 5/5/2004 | 5307 | 7 | F/R | 53.8464 | 83.8858 | 30.0394 | 7:00 | 9:00 | 83.8644 | 0.0214 | | | 0.07 | |
| 5/5/2004 | W4507 | 7 | B/R | 59.2155 | 89.2497 | 30.0342 | 7:00 | 9:00 | 89.1347 | 0.1150 | | | | 0.38 |
| 5/5/2004 | A708 | 8 | B/R | 61.1207 | 91.1402 | 30.0195 | 9:00 | 11:00 | 91.1077 | 0.0325 | 0.11 | | | |
| 5/5/2004 | OK908 | 8 | F/L | 66.5952 | 96.6326 | 30.0374 | 9:00 | 11:00 | 96.6018 | 0.0308 | | 0.10 | | |
| 5/5/2004 | 5308 | 8 | F/L | 60.3397 | 90.3879 | 30.0482 | 9:00 | 11:00 | 90.3598 | 0.0281 | | | 0.09 | |
| 5/5/2004 | W4508 | 8 | F/R | 63.341 | 93.394 | 30.0530 | 9:00 | 11:00 | 93.2664 | 0.1276 | | | | 0.42 |
| 5/5/2004 | A709 | 9 | B/L | 61.1492 | 91.2647 | 30.1155 | 1:00 | 3:00 | 91.219 | 0.0457 | 0.15 | | | |
| 5/5/2004 | OK909 | 9 | F/L | 66.6049 | 96.6359 | 30.0310 | 1:00 | 3:00 | 96.6007 | 0.0352 | | 0.12 | | |
| 5/5/2004 | 5309 | 9 | B/R | 60.343 | 90.6598 | 30.3168 | 1:00 | 3:00 | 90.6348 | 0.0250 | | | 0.08 | |
| 5/5/2004 | W4509 | 9 | B/L | 63.3364 | 93.4741 | 30.1377 | 1:00 | 3:00 | 93.3747 | 0.0994 | | | | 0.33 |
| 5/6/2004 | A7010 | 10 | F/R | 49.6839 | 79.6558 | 29.9719 | 7:00 | 9:00 | 79.6212 | 0.0346 | 0.12 | | | |
| 5/6/2004 | OK9010 | 10 | B/R | 61.1208 | 91.2519 | 30.1311 | 7:00 | 9:00 | 91.2198 | 0.0321 | | 0.11 | | |
| 5/6/2004 | 53010 | 10 | F/L | 66.5938 | 96.6697 | 30.0759 | 7:00 | 9:00 | 96.6492 | 0.0205 | | | 0.07 | |
| 5/6/2004 | W45010 | 10 | B/L | 63.3429 | 93.4501 | 30.1072 | 7:00 | 9:00 | 93.3507 | 0.0994 | | | | 0.33 |
| 5/6/2004 | A7011 | 11 | F/L | 60.3412 | 90.3619 | 30.0207 | 9:00 | 11:00 | 90.3266 | 0.0353 | 0.12 | | | |
| 5/6/2004 | OK9011 | 11 | B/L | 52.4388 | 82.5377 | 30.0989 | 9:00 | 11:00 | 82.5033 | 0.0344 | | 0.11 | | |
| 5/6/2004 | 53011 | 11 | F/R | 67.6641 | 97.6532 | 29.9891 | 9:00 | 11:00 | 97.6301 | 0.0231 | | | 0.08 | |
| 5/6/2004 | W45011 | 11 | B/R | 59.2166 | 89.2119 | 29.9953 | 9:00 | 11:00 | 89.09 | 0.1219 | | | | 0.41 |
| 5/6/2004 | A7012 | 12 | B/R | 56.6064 | 86.6662 | 30.0598 | 11:00 | 1:00 | 86.6156 | 0.0506 | 0.17 | | | |
| 5/6/2004 | OK9012 | 12 | F/L | 64.0268 | 94.1208 | 30.0940 | 11:00 | 1:00 | 94.0778 | 0.0430 | | 0.14 | | |
| 5/6/2004 | 53012 | 12 | F/L | 53.8489 | 83.8534 | 30.0045 | 11:00 | 1:00 | 83.8206 | 0.0328 | | | 0.11 | |
| 5/6/2004 | W45012 | 12 | F/R | 58.9304 | 88.9119 | 29.9815 | 11:00 | 1:00 | 88.7821 | 0.1298 | | | | 0.43 |
| | | | | | | | | | | **Average** | 0.125 | 0.114 | 0.077 | 0.366 |
| | | | | | | | | | | **Std Dev.** | 0.018 | 0.015 | 0.015 | 0.038 |
| | | | | | | | | | | **Range** | 0.06 | 0.05 | 0.06 | 0.11 |

## Table B2. LOI of 2000, 3000, & 4000 Gram Batches of Wedron 530 Sand Mixed in Hobart Mixer.

| | | | | | | | | | Analyst: | Matt Prendergast | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | AFS 5100-00-S | | | | | | | | | | |
| Sample Date | test reference number | Oven Batch Number | Position in oven | Dish wt. (gms) | Dish & Sample wt. (gms) | Sample wt. (gms) | Time in | Time out | Dry Wt. (gms) | Weight change | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition |
| | | | | | | | | | | | 2000 gram Batch | 3000 gram Batch | 4000 gram Batch |
| 5/10/2004 | 2K 12-1 | 1 | B/L | 49.6891 | 64.6923 | 15.0032 | 1:30 | 3:30 | 64.4858 | 0.2065 | 1.38 | | |
| 5/10/2004 | 3K 12-1 | 1 | F/L | 52.4379 | 67.4794 | 15.0415 | 1:30 | 3:30 | 67.281 | 0.1984 | | 1.32 | |
| 5/10/2004 | 4K 12-1 | 1 | B/R | 67.6639 | 82.683 | 15.0191 | 1:30 | 3:30 | 82.4826 | 0.2004 | | | 1.33 |
| 5/11/2004 | 2K 6-1 | 2 | B/L | 60.6442 | 75.3141 | 14.6699 | 6:30 | 8:30 | 75.1054 | 0.2087 | 1.42 | | |
| 5/11/2004 | 3K 6-1 | 2 | M/L | 53.8492 | 68.9401 | 15.0909 | 6:30 | 8:30 | 68.7394 | 0.2007 | | 1.33 | |
| 5/11/2004 | 4K 6-1 | 2 | F/L | 61.1207 | 76.2039 | 15.0832 | 6:30 | 8:30 | 76.001 | 0.2029 | | | 1.35 |
| 5/11/2004 | 2K 3-1 | 3 | B/R | 66.5964 | 81.6163 | 15.0199 | 6:30 | 8:30 | 81.4086 | 0.2077 | 1.38 | | |
| 5/11/2004 | 3K 3-1 | 3 | M/R | 56.007 | 71.7307 | 15.7237 | 6:30 | 8:30 | 71.5233 | 0.2074 | | 1.32 | |
| 5/11/2004 | 4K 3-1 | 3 | F/R | 59.2171 | 74.2878 | 15.0707 | 6:30 | 8:30 | 74.0859 | 0.2019 | | | 1.34 |
| 5/11/2004 | 2K 9-1 | 4 | B/L | 67.675 | 82.6813 | 15.0063 | 8:30 | 10:30 | 82.4663 | 0.2150 | 1.43 | | |
| 5/11/2004 | 3K 9-1 | 4 | M/L | 49.6869 | 64.7063 | 15.0194 | 8:30 | 10:30 | 64.5097 | 0.1966 | | 1.31 | |
| 5/11/2004 | 4K 9-1 | 4 | F/L | 52.4421 | 67.5569 | 15.1148 | 8:30 | 10:30 | 67.3541 | 0.2028 | | | 1.34 |
| 5/11/2004 | 2K 12-2 | 5 | B/R | 52.2031 | 67.2821 | 15.0790 | 8:30 | 10:30 | 67.0737 | 0.2084 | 1.38 | | |
| 5/11/2004 | 3K 12-2 | 5 | M/R | 64.0325 | 79.0119 | 14.9794 | 8:30 | 10:30 | 78.8098 | 0.2021 | | 1.35 | |
| 5/11/2004 | 4K 12-2 | 5 | F/R | 63.342 | 78.449 | 15.1070 | 8:30 | 10:30 | 78.2479 | 0.2011 | | | 1.33 |
| 5/11/2004 | 2K 6-2 | 6 | B/L | 60.3399 | 75.3372 | 14.9973 | 10:30 | 12:30 | 75.1358 | 0.2014 | 1.34 | | |
| 5/11/2004 | 3K 6-2 | 6 | M/L | 53.8468 | 68.9001 | 15.0533 | 10:30 | 12:30 | 68.7028 | 0.1973 | | 1.31 | |
| 5/11/2004 | 4K 6-2 | 6 | F/L | 61.1222 | 76.2389 | 15.1167 | 10:30 | 12:30 | 76.0383 | 0.2006 | | | 1.33 |
| 5/11/2004 | 2K 3-2 | 7 | B/R | 66.6198 | 81.7019 | 15.0821 | 10:30 | 12:30 | 81.4924 | 0.2095 | 1.39 | | |
| 5/11/2004 | 3K 3-2 | 7 | M/R | 56.6038 | 71.7157 | 15.1119 | 10:30 | 12:30 | 71.5169 | 0.1988 | | 1.32 | |
| 5/11/2004 | 4K 3-2 | 7 | F/R | 59.2118 | 74.3688 | 15.1570 | 10:30 | 12:30 | 74.167 | 0.2018 | | | 1.33 |
| 5/11/2004 | 2K 9-2 | 8 | B/L | 67.6609 | 82.8374 | 15.1765 | 12:30 | 2:30 | 82.633 | 0.2044 | 1.35 | | |
| 5/11/2004 | 3K 9-2 | 8 | M/L | 49.6871 | 64.7643 | 15.0772 | 12:30 | 2:30 | 64.5568 | 0.2075 | | 1.38 | |
| 5/11/2004 | 4K 9-2 | 8 | F/L | 52.4384 | 67.7498 | 15.3114 | 12:30 | 2:30 | 67.5448 | 0.2050 | | | 1.34 |
| 5/11/2004 | 2K 12-3 | 9 | B/R | 52.2019 | 67.2628 | 15.0609 | 12:30 | 2:30 | 67.0582 | 0.2046 | 1.36 | | |
| 5/11/2004 | 3K 12-3 | 9 | M/R | 64.0293 | 78.9889 | 14.9596 | 12:30 | 2:30 | 78.7838 | 0.2051 | | 1.37 | |
| 5/11/2004 | 4K 12-3 | 9 | F/R | 63.3449 | 78.5131 | 15.1682 | 12:30 | 2:30 | 78.3071 | 0.2060 | | | 1.36 |
| 5/12/2004 | 2K 6-3 | 10 | B/L | 60.3447 | 75.4604 | 15.1157 | 6:30 | 8:30 | 75.2542 | 0.2062 | 1.36 | | |
| 5/12/2004 | 3K 6-3 | 10 | M/L | 53.8499 | 68.8443 | 14.9944 | 6:30 | 8:30 | 68.6452 | 0.1991 | | 1.33 | |
| 5/12/2004 | 4K 6-3 | 10 | F/L | 61.1212 | 76.1143 | 14.9931 | 6:30 | 8:30 | 75.9099 | 0.2044 | | | 1.36 |
| 5/12/2004 | 2K 3-3 | 11 | B/R | 66.6059 | 81.657 | 15.0511 | 6:30 | 8:30 | 81.4512 | 0.2058 | 1.37 | | |
| 5/12/2004 | 3K 3-3 | 11 | M/R | 56.611 | 71.5993 | 14.9883 | 6:30 | 8:30 | 71.3912 | 0.2081 | | 1.39 | |
| 5/12/2004 | 4K 3-3 | 11 | F/R | 59.2142 | 74.1909 | 14.9767 | 6:30 | 8:30 | 73.9872 | 0.2037 | | | 1.36 |
| 5/12/2004 | 2K 9-3 | 12 | B/L | 67.6889 | 82.7564 | 15.0675 | 8:30 | 10:30 | 82.5401 | 0.2163 | 1.44 | | |
| 5/12/2004 | 3K 9-3 | 12 | M/L | 52.4419 | 67.4652 | 15.0233 | 8:30 | 10:30 | 67.2594 | 0.2058 | | 1.37 | |
| 5/12/2004 | 4K 9-3 | 12 | F/L | 49.6853 | 64.763 | 15.0777 | 8:30 | 10:30 | 64.5553 | 0.2077 | | | 1.38 |
| | | | | | | | | | | Average | 1.38 | 1.34 | 1.35 |
| | | | | | | | | | | Std Dev. | 0.03 | 0.03 | 0.02 |
| | | | | | | | | | | Range | 0.09 | 0.08 | 0.05 |

**Table B3. LOI determinations from Hobart mixedness evaluations. Column 2 is coded location for 12 samples per run. Alpha, H=Hobart, Numeral=Run number, Numeral=Clock position in mix bowl, Numeral = level position in mix bowl.**

| | | FX HOBART MIXER TEST | | | | | | Analyst: | Matt Prendergast | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AFS 5100-00-S | | | | | | | | | Batch 1 | Batch 2 | Batch 3 | Batch 4 | Batch 5 | Batch 6 | Batch 7 | Batch 8 | Batch 9 | Batch 10 |
| Sample Date | test reference number | oven position | Dish wt. (gms) | Dish & Sample wt. (gms) | Sample wt. (gms) | Time in | Time out | Dry Wt. (gms) | Weight change | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition |
| 5/20/2004 | H1 3-1 | B/L | 60.3283 | 75.5671 | 15.2388 | 6:00 | 8:00 | 75.3848 | 0.1823 | 1.20 | 1.20 | | | | | | | | | |
| 5/20/2004 | H2 3-1 | M/L | 61.1074 | 76.1846 | 15.0772 | 6:00 | 8:00 | 76.004 | 0.1806 | 1.20 | | 1.20 | | | | | | | | |
| 5/20/2004 | H3 3-1 | F/L | 53.8373 | 69.2311 | 15.3938 | 6:00 | 8:00 | 69.0371 | 0.1940 | 1.26 | | | 1.26 | | | | | | | |
| 5/20/2004 | H4 3-1 | B/R | 66.5812 | 81.5642 | 14.9830 | 6:00 | 8:00 | 81.3715 | 0.1927 | 1.29 | | | | 1.29 | | | | | | |
| 5/20/2004 | H5 3-1 | F/R | 57.3529 | 72.363 | 15.0101 | 6:00 | 8:00 | 72.1687 | 0.1943 | 1.29 | | | | | 1.29 | | | | | |
| 5/20/2004 | H6 3-1 | B/L | 57.8808 | 73.1338 | 15.2530 | 8:00 | 10:00 | 72.9347 | 0.1991 | 1.31 | | | | | | 1.31 | | | | |
| 5/20/2004 | H7 3-1 | M/L | 63.7424 | 78.9749 | 15.2325 | 8:00 | 10:00 | 78.754 | 0.2209 | 1.45 | | | | | | | 1.45 | | | |
| 5/20/2004 | H8 3-1 | F/L | 58.926 | 74.0756 | 15.1496 | 8:00 | 10:00 | 73.8601 | 0.2155 | 1.42 | | | | | | | | 1.42 | | |
| 5/20/2004 | H9 3-1 | B/R | 57.2701 | 72.5047 | 15.2346 | 8:00 | 10:00 | 72.2836 | 0.2211 | 1.45 | | | | | | | | | 1.45 | |
| 5/20/2004 | H10 3-1 | F/R | 57.9573 | 73.0064 | 15.0491 | 8:00 | 10:00 | 72.7909 | 0.2155 | 1.43 | | | | | | | | | | 1.43 |
| 5/20/2004 | H1 6-1 | B/L | 67.6547 | 82.8096 | 15.1549 | 10:00 | 12:00 | 82.6153 | 0.1943 | 1.28 | 1.28 | | | | | | | | | |
| 5/20/2004 | H2 6-1 | M/L | 58.9134 | 74.0294 | 15.1160 | 10:00 | 12:00 | 73.8384 | 0.1910 | 1.26 | | 1.26 | | | | | | | | |
| 5/20/2004 | H3 6-1 | F/L | 49.6772 | 64.669 | 14.9918 | 10:00 | 12:00 | 64.4669 | 0.2021 | 1.35 | | | 1.35 | | | | | | | |
| 5/20/2004 | H4 6-1 | B/R | 55.2056 | 70.1882 | 14.9826 | 10:00 | 12:00 | 69.9903 | 0.1979 | 1.32 | | | | 1.32 | | | | | | |
| 5/20/2004 | H5 6-1 | F/R | 59.2002 | 74.2878 | 15.0876 | 10:00 | 12:00 | 74.0894 | 0.1984 | 1.31 | | | | | 1.31 | | | | | |
| 5/20/2004 | H6 6-1 | B/L | 57.8694 | 72.8505 | 14.9811 | 12:00 | 2:00 | 72.6537 | 0.1968 | 1.31 | | | | | | 1.31 | | | | |
| 5/20/2004 | H7 6-1 | M/L | 63.7439 | 78.9053 | 15.1614 | 12:00 | 2:00 | 78.6961 | 0.2092 | 1.38 | | | | | | | 1.38 | | | |
| 5/20/2004 | H8 6-1 | F/L | 58.9253 | 73.923 | 14.9977 | 12:00 | 2:00 | 73.7215 | 0.2015 | 1.34 | | | | | | | | 1.34 | | |
| 5/20/2004 | H9 6-1 | B/R | 57.9567 | 72.9462 | 14.9895 | 12:00 | 2:00 | 72.7365 | 0.2097 | 1.40 | | | | | | | | | 1.40 | |
| 5/20/2004 | H10 6-1 | F/R | 57.2689 | 72.3156 | 15.0467 | 12:00 | 2:00 | 72.1102 | 0.2054 | 1.37 | | | | | | | | | | 1.37 |
| 5/20/2004 | H1 9-1 | B/L | 60.3301 | 75.6134 | 15.2833 | 2:00 | 4:00 | 75.4222 | 0.1912 | 1.25 | 1.25 | | | | | | | | | |
| 5/20/2004 | H2 9-1 | M/L | 61.1092 | 76.0932 | 14.9840 | 2:00 | 4:00 | 75.8995 | 0.1937 | 1.29 | | 1.29 | | | | | | | | |
| 5/20/2004 | H3 9-1 | F/L | 53.8381 | 68.9969 | 15.1588 | 2:00 | 4:00 | 68.8048 | 0.1921 | 1.27 | | | 1.27 | | | | | | | |
| 5/20/2004 | H4 9-1 | B/R | 66.5824 | 81.5486 | 14.9662 | 2:00 | 4:00 | 81.3517 | 0.1969 | 1.32 | | | | 1.32 | | | | | | |
| 5/20/2004 | H5 9-1 | F/R | 57.3541 | 72.3413 | 14.9872 | 2:00 | 4:00 | 72.1473 | 0.1940 | 1.29 | | | | | 1.29 | | | | | |
| 5/21/2004 | H6 9-1 | B/L | 67.6578 | 82.7985 | 15.1407 | 6:00 | 8:00 | 82.6042 | 0.1943 | 1.28 | | | | | | 1.28 | | | | |
| 5/21/2004 | H7 9-1 | M/L | 58.9127 | 73.7186 | 14.8059 | 6:00 | 8:00 | 73.5301 | 0.1885 | 1.27 | | | | | | | 1.27 | | | |
| 5/21/2004 | H8 9-1 | F/L | 49.6748 | 64.8339 | 15.1591 | 6:00 | 8:00 | 64.6473 | 0.1866 | 1.23 | | | | | | | | 1.23 | | |
| 5/21/2004 | H9 9-1 | B/R | 55.2048 | 70.2191 | 15.0143 | 6:00 | 8:00 | 70.0246 | 0.1945 | 1.30 | | | | | | | | | 1.30 | |
| 5/21/2004 | H10 9-1 | F/R | 59.2 | 74.219 | 15.0190 | 6:00 | 8:00 | 74.0275 | 0.1915 | 1.28 | | | | | | | | | | 1.28 |
| 5/21/2004 | H1 12-1 | B/L | 60.3242 | 75.3021 | 14.9779 | 8:00 | 10:00 | 75.1228 | 0.1793 | 1.20 | 1.20 | | | | | | | | | |
| 5/21/2004 | H2 12-1 | M/L | 61.1091 | 76.2008 | 15.0917 | 8:00 | 10:00 | 76.0203 | 0.1805 | 1.20 | | 1.20 | | | | | | | | |
| 5/21/2004 | H3 12-1 | F/L | 53.8385 | 68.9708 | 15.1323 | 8:00 | 10:00 | 68.7889 | 0.1819 | 1.20 | | | 1.20 | | | | | | | |
| 5/21/2004 | H412-1 | B/R | 66.5838 | 81.8251 | 15.2413 | 8:00 | 10:00 | 81.637 | 0.1881 | 1.23 | | | | 1.23 | | | | | | |
| 5/21/2004 | H5 12-1 | F/R | 57.3531 | 72.394 | 15.0409 | 8:00 | 10:00 | 72.2103 | 0.1837 | 1.22 | | | | | 1.22 | | | | | |
| 5/21/2004 | H6 12-1 | B/L | 56.5911 | 71.9224 | 15.3313 | 10:00 | 12:00 | 71.7337 | 0.1887 | 1.23 | | | | | | 1.23 | | | | |
| 5/21/2004 | H7 12-1 | M/L | 52.1891 | 67.5091 | 15.3200 | 10:00 | 12:00 | 67.3123 | 0.1968 | 1.28 | | | | | | | 1.28 | | | |
| 5/21/2004 | H8 12-1 | F/L | 52.4289 | 67.661 | 15.2321 | 10:00 | 12:00 | 67.4785 | 0.1825 | 1.20 | | | | | | | | 1.20 | | |
| 5/21/2004 | H9 12-1 | B/R | 64.0116 | 78.9623 | 14.9507 | 10:00 | 12:00 | 78.7709 | 0.1914 | 1.28 | | | | | | | | | 1.28 | |
| 5/21/2004 | H10 12-1 | F/R | 63.3269 | 78.5016 | 15.1747 | 10:00 | 12:00 | 78.3102 | 0.1914 | 1.26 | | | | | | | | | | 1.26 |
| 5/21/2004 | H1 3-2 | B/L | 67.6481 | 82.6189 | 14.9708 | 12:00 | 2:00 | 82.441 | 0.1779 | 1.19 | 1.19 | | | | | | | | | |
| 5/21/2004 | H2 3-2 | M/L | 58.9137 | 73.7918 | 14.8781 | 12:00 | 2:00 | 73.6169 | 0.1749 | 1.18 | | 1.18 | | | | | | | | |
| 5/21/2004 | H3 3-2 | F/L | 49.6771 | 64.7116 | 15.0345 | 12:00 | 2:00 | 64.5242 | 0.1874 | 1.25 | | | 1.25 | | | | | | | |
| 5/21/2004 | H4 3-2 | B/R | 55.2065 | 70.3438 | 15.1373 | 12:00 | 2:00 | 70.1492 | 0.1946 | 1.29 | | | | 1.29 | | | | | | |
| 5/21/2004 | H5 3-2 | F/R | 59.2009 | 74.162 | 14.9611 | 12:00 | 2:00 | 73.9756 | 0.1864 | 1.25 | | | | | 1.25 | | | | | |
| 5/24/2004 | H6 3-2 | B/L | 56.5944 | 71.6854 | 15.0910 | 6:00 | 8:00 | 71.5182 | 0.1672 | 1.11 | | | | | | 1.11 | | | | |
| 5/24/2004 | H7 3-2 | M/L | 52.1904 | 67.4878 | 15.2974 | 6:00 | 8:00 | 67.3132 | 0.1746 | 1.14 | | | | | | | 1.14 | | | |
| 5/24/2004 | H8 3-2 | F/L | 52.4305 | 67.7048 | 15.2743 | 6:00 | 8:00 | 67.5339 | 0.1709 | 1.12 | | | | | | | | 1.12 | | |
| 5/24/2004 | H9 3-2 | B/R | 64.0135 | 79.2124 | 15.1989 | 6:00 | 8:00 | 79.0382 | 0.1742 | 1.15 | | | | | | | | | 1.15 | |
| 5/24/2004 | H10 3-2 | F/R | 63.3282 | 78.6257 | 15.2975 | 6:00 | 8:00 | 78.4507 | 0.1750 | 1.14 | | | | | | | | | | 1.14 |
| 5/24/2004 | H1 6-2 | B/L | 67.6523 | 82.6957 | 15.0434 | 8:00 | 10:00 | 82.3575 | 0.3382 | 2.25 | 2.25 | | | | | | | | | |
| 5/24/2004 | H2 6-2 | M/L | 58.9126 | 74.1902 | 15.2776 | 8:00 | 10:00 | 74.0278 | 0.1624 | 1.06 | | 1.06 | | | | | | | | |
| 5/24/2004 | H3 6-2 | F/L | 49.675 | 64.8101 | 15.1351 | 8:00 | 10:00 | 64.6404 | 0.1697 | 1.12 | | | 1.12 | | | | | | | |
| 5/24/2004 | H4 6-2 | B/R | 55.2043 | 70.2325 | 15.0282 | 8:00 | 10:00 | 70.0612 | 0.1713 | 1.14 | | | | 1.14 | | | | | | |
| 5/24/2004 | H5 6-2 | F/R | 59.2003 | 74.474 | 15.2737 | 8:00 | 10:00 | 74.3013 | 0.1727 | 1.13 | | | | | 1.13 | | | | | |
| 5/24/2004 | H6 6-2 | B/L | 60.3282 | 75.3737 | 15.0455 | 10:00 | 12:00 | 74.788 | 0.5857 | 3.89 | | | | | | 3.89 | | | | |
| 5/24/2004 | H7 6-2 | M/L | 61.1073 | 76.0444 | 14.9371 | 10:00 | 12:00 | 75.8692 | 0.1752 | 1.17 | | | | | | | 1.17 | | | |

# Table B3 continued.

| Sample Date | test reference number | oven position | AFS 5100-00-S Dish wt. (gms) | Dish & Sample wt. (gms) | Sample wt. (gms) | Time in | Time out | Dry Wt. (gms) | Weight change | %LOI @1800* Lost on Ignition | Batch 1 %LOI @1800* Lost on Ignition | Batch 2 %LOI @1800* Lost on Ignition | Batch 3 %LOI @1800* Lost on Ignition | Batch 4 %LOI @1800* Lost on Ignition | Batch 5 %LOI @1800* Lost on Ignition | Batch 6 %LOI @1800* Lost on Ignition | Batch 7 %LOI @1800* Lost on Ignition | Batch 8 %LOI @1800* Lost on Ignition | Batch 9 %LOI @1800* Lost on Ignition | Batch 10 %LOI @1800* Lost on Ignition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/24/2004 | H9 6-2 | B/R | 66.5823 | 82.229 | 15.6467 | 10:00 | 12:00 | 82.0492 | 0.1798 | 1.15 | | | | | | | | | 1.15 | |
| 5/24/2004 | H10 6-2 | F/R | 57.3525 | 72.3677 | 15.0152 | 10:00 | 12:00 | 72.1078 | 0.2599 | 1.73 | | | | | | | | | | 1.73 |
| 5/24/2004 | H1 9-2 | B/L | 56.5945 | 71.7075 | 15.1130 | 12:00 | 2:00 | 71.537 | 0.1705 | 1.13 | 1.13 | | | | | | | | | |
| 5/24/2004 | H2 9-2 | M/L | 52.191 | 67.7495 | 15.5585 | 12:00 | 2:00 | 67.5773 | 0.1722 | 1.11 | | 1.11 | | | | | | | | |
| 5/24/2004 | H3 9-2 | F/L | 52.4302 | 67.601 | 15.1708 | 12:00 | 2:00 | 67.4337 | 0.1673 | 1.10 | | | 1.10 | | | | | | | |
| 5/24/2004 | H4 9-2 | B/R | 64.0113 | 79.3166 | 15.3053 | 12:00 | 2:00 | 79.1427 | 0.1739 | 1.14 | | | | 1.14 | | | | | | |
| 5/24/2004 | H5 9-2 | F/R | 63.3263 | 78.4504 | 15.1241 | 12:00 | 2:00 | 78.2756 | 0.1748 | 1.16 | | | | | 1.16 | | | | | |
| 5/24/2004 | H6 9-2 | B/L | 67.6495 | 82.678 | 15.0285 | 2:00 | 4:00 | 82.5023 | 0.1757 | 1.17 | | | | | | 1.17 | | | | |
| 5/24/2004 | H7 9-2 | M/L | 58.9121 | 74.2201 | 15.3080 | 2:00 | 4:00 | 74.0456 | 0.1745 | 1.14 | | | | | | | 1.14 | | | |
| 5/24/2004 | H8 9-2 | F/L | 49.676 | 64.7426 | 15.0666 | 2:00 | 4:00 | 64.5678 | 0.1748 | 1.16 | | | | | | | | 1.16 | | |
| 5/24/2004 | H9 9-2 | B/R | 59.2001 | 74.2285 | 15.0284 | 2:00 | 4:00 | 74.0552 | 0.1733 | 1.15 | | | | | | | | | 1.15 | |
| 5/24/2004 | H10 9-2 | F/R | 55.2066 | 70.406 | 15.1994 | 2:00 | 4:00 | 70.2418 | 0.1642 | 1.08 | | | | | | | | | | 1.08 |
| 5/25/2004 | H1 12-2 | B/L | 56.5929 | 71.8315 | 15.2386 | 6:00 | 8:00 | 71.669 | 0.1625 | 1.07 | 1.07 | | | | | | | | | |
| 5/25/2004 | H2 12-2 | M/L | 52.1886 | 67.7055 | 15.5169 | 6:00 | 8:00 | 67.5393 | 0.1662 | 1.07 | | 1.07 | | | | | | | | |
| 5/25/2004 | H3 12-2 | F/L | 52.4286 | 67.757 | 15.3284 | 6:00 | 8:00 | 67.5842 | 0.1728 | 1.13 | | | 1.13 | | | | | | | |
| 5/25/2004 | H4 12-2 | B/R | 64.0092 | 79.0741 | 15.0649 | 6:00 | 8:00 | 78.9025 | 0.1716 | 1.14 | | | | 1.14 | | | | | | |
| 5/25/2004 | H5 12-2 | F/R | 63.3259 | 78.7861 | 15.4602 | 6:00 | 8:00 | 78.6131 | 0.1730 | 1.12 | | | | | 1.12 | | | | | |
| 5/25/2004 | H6 12-2 | B/L | 67.653 | 82.966 | 15.3130 | 8:00 | 10:00 | 82.7767 | 0.1893 | 1.24 | | | | | | 1.24 | | | | |
| 5/25/2004 | H7 12-2 | M/L | 58.9163 | 74.0305 | 15.1142 | 8:00 | 10:00 | 73.8503 | 0.1802 | 1.19 | | | | | | | 1.19 | | | |
| 5/25/2004 | H8 12-2 | F/L | 49.678 | 64.939 | 15.2610 | 8:00 | 10:00 | 64.757 | 0.1820 | 1.19 | | | | | | | | 1.19 | | |
| 5/25/2004 | H9 12-2 | B/R | 59.2047 | 74.2493 | 15.0446 | 8:00 | 10:00 | 74.0712 | 0.1781 | 1.18 | | | | | | | | | 1.18 | |
| 5/25/2004 | H10 12-2 | F/R | 55.2099 | 70.4988 | 15.2889 | 8:00 | 10:00 | 70.3186 | 0.1802 | 1.18 | | | | | | | | | | 1.18 |
| 5/25/2004 | H1 3-3 | B/L | 56.5973 | 71.7907 | 15.1934 | 10:00 | 12:00 | 71.6302 | 0.1605 | 1.06 | 1.06 | | | | | | | | | |
| 5/25/2004 | H2 3-3 | M/L | 52.1892 | 67.5159 | 15.3267 | 10:00 | 12:00 | 67.3576 | 0.1583 | 1.03 | | 1.03 | | | | | | | | |
| 5/25/2004 | H3 3-3 | F/L | 52.4275 | 67.7923 | 15.3648 | 10:00 | 12:00 | 67.6263 | 0.1660 | 1.08 | | | 1.08 | | | | | | | |
| 5/25/2004 | H4 3-3 | B/R | 64.0009 | 79.0798 | 15.0789 | 10:00 | 12:00 | 78.9051 | 0.1747 | 1.16 | | | | 1.16 | | | | | | |
| 5/25/2004 | H5 3-3 | F/R | 63.3243 | 78.376 | 15.0517 | 10:00 | 12:00 | 78.2114 | 0.1646 | 1.09 | | | | | 1.09 | | | | | |
| 5/25/2004 | H6 3-3 | B/L | 60.329 | 75.6792 | 15.3502 | 12:00 | 2:00 | 75.4278 | 0.2514 | 1.64 | | | | | | 1.64 | | | | |
| 5/25/2004 | H7 3-3 | M/L | 61.1092 | 76.2145 | 15.1053 | 12:00 | 2:00 | 76.0406 | 0.1739 | 1.15 | | | | | | | 1.15 | | | |
| 5/25/2004 | H8 3-3 | F/L | 53.8374 | 69.3634 | 15.5260 | 12:00 | 2:00 | 69.184 | 0.1794 | 1.16 | | | | | | | | 1.16 | | |
| 5/25/2004 | H9 3-3 | B/R | 66.5821 | 81.7531 | 15.1710 | 12:00 | 2:00 | 81.5754 | 0.1777 | 1.17 | | | | | | | | | 1.17 | |
| 5/25/2004 | H10 3-3 | F/R | 57.752 | 72.815 | 15.0630 | 12:00 | 2:00 | 72.6429 | 0.1721 | 1.14 | | | | | | | | | | 1.14 |
| 5/26/2004 | H1 6-3 | B/L | 67.6507 | 82.7409 | 15.0902 | 6:00 | 8:00 | 82.5811 | 0.1598 | 1.06 | 1.06 | | | | | | | | | |
| 5/26/2004 | H2 6-3 | M/L | 58.913 | 74.1343 | 15.2213 | 6:00 | 8:00 | 73.9743 | 0.1600 | 1.05 | | 1.05 | | | | | | | | |
| 5/26/2004 | H3 6-3 | F/L | 49.673 | 65.2894 | 15.6164 | 6:00 | 8:00 | 65.1217 | 0.1677 | 1.07 | | | 1.07 | | | | | | | |
| 5/26/2004 | H4 6-3 | B/R | 59.2079 | 74.2439 | 15.0360 | 6:00 | 8:00 | 74.0734 | 0.1705 | 1.13 | | | | 1.13 | | | | | | |
| 5/26/2004 | H5 6-3 | F/R | 52.2081 | 70.3414 | 18.1333 | 6:00 | 8:00 | 70.1712 | 0.1702 | 0.94 | | | | | 0.94 | | | | | |
| 5/26/2004 | H6 6-3 | B/L | 52.1895 | 66.0578 | 13.8683 | 8:00 | 10:00 | 65.904 | 0.1538 | 1.11 | | | | | | 1.11 | | | | |
| 5/26/2004 | H7 6-3 | M/L | 56.5939 | 71.7848 | 15.1909 | 8:00 | 10:00 | 71.6067 | 0.1781 | 1.17 | | | | | | | 1.17 | | | |
| 5/26/2004 | H8 6-3 | F/L | 52.428 | 67.5238 | 15.0958 | 8:00 | 10:00 | 67.356 | 0.1678 | 1.11 | | | | | | | | 1.11 | | |
| 5/26/2004 | H9 6-3 | B/R | 64.01 | 79.1275 | 15.1175 | 8:00 | 10:00 | 78.9563 | 0.1712 | 1.13 | | | | | | | | | 1.13 | |
| 5/26/2004 | H10 6-3 | F/R | 63.3259 | 78.3646 | 15.0387 | 8:00 | 10:00 | 78.1944 | 0.1702 | 1.13 | | | | | | | | | | 1.13 |
| 5/26/2004 | H1 9-3 | B/L | 57.8668 | 73.5031 | 15.6363 | 10:00 | 12:00 | 73.3461 | 0.1570 | 1.00 | 1.00 | | | | | | | | | |
| 5/26/2004 | H2 9-3 | M/L | 63.7417 | 79.336 | 15.5943 | 10:00 | 12:00 | 79.168 | 0.1680 | 1.08 | | 1.08 | | | | | | | | |
| 5/26/2004 | H3 9-3 | F/L | 58.9273 | 73.9681 | 15.0408 | 10:00 | 12:00 | 73.8069 | 0.1612 | 1.07 | | | 1.07 | | | | | | | |
| 5/26/2004 | H4 9-3 | B/R | 57.9578 | 73.0299 | 15.0721 | 10:00 | 12:00 | 72.8664 | 0.1635 | 1.08 | | | | 1.08 | | | | | | |
| 5/26/2004 | H5 9-3 | F/R | 57.2697 | 72.2443 | 14.9746 | 10:00 | 12:00 | 72.0812 | 0.1631 | 1.09 | | | | | 1.09 | | | | | |
| 6/1/2004 | H6 9-3 | B/L | 52.1904 | 67.3382 | 15.1478 | 10:00 | 12:00 | 67.1748 | 0.1634 | 1.08 | | | | | | 1.08 | | | | |
| 6/1/2004 | H7 9-3 | M/L | 56.5936 | 71.7381 | 15.1445 | 10:00 | 12:00 | 71.5719 | 0.1662 | 1.10 | | | | | | | 1.10 | | | |
| 6/1/2004 | H8 9-3 | F/L | 52.4286 | 68.1657 | 15.7371 | 10:00 | 12:00 | 68.0005 | 0.1652 | 1.05 | | | | | | | | 1.05 | | |
| 6/1/2004 | H9 9-3 | B/R | 64.0148 | 78.9965 | 14.9817 | 10:00 | 12:00 | 78.8326 | 0.1639 | 1.09 | | | | | | | | | 1.09 | |
| 6/1/2004 | H10 9-3 | F/R | 63.3251 | 78.4872 | 15.1621 | 10:00 | 12:00 | 78.3284 | 0.1588 | 1.05 | | | | | | | | | | 1.05 |
| 6/1/2004 | H1 12-3 | B/L | 60.3326 | 74.4867 | 14.1541 | 8:00 | 10:00 | 74.3393 | 0.1474 | 1.04 | 1.04 | | | | | | | | | |
| 6/1/2004 | H2 12-3 | M/L | 61.113 | 76.2348 | 15.1218 | 8:00 | 10:00 | 76.0751 | 0.1597 | 1.06 | | 1.06 | | | | | | | | |
| 6/1/2004 | H3 12-3 | F/L | 53.8364 | 69.0898 | 15.2534 | 8:00 | 10:00 | 68.9308 | 0.1590 | 1.04 | | | 1.04 | | | | | | | |
| 6/1/2004 | H4 12-3 | B/R | 66.5834 | 81.627 | 15.0436 | 8:00 | 10:00 | 81.4662 | 0.1608 | 1.07 | | | | 1.07 | | | | | | |
| 6/1/2004 | H5 12-3 | F/R | 57.3532 | 72.8612 | 15.5080 | 8:00 | 10:00 | 72.6953 | 0.1659 | 1.07 | | | | | 1.07 | | | | | |
| 6/2/2004 | H6 12-3 | B/L | 57.8671 | 73.3906 | 15.5235 | 6:00 | 8:00 | 73.2218 | 0.1688 | 1.09 | | | | | | 1.09 | | | | |
| 6/2/2004 | H7 12-3 | M/L | 63.7423 | 79.1298 | 15.3875 | 6:00 | 8:00 | 78.9622 | 0.1676 | 1.09 | | | | | | | 1.09 | | | |
| 6/2/2004 | H8 12-3 | F/L | 58.9269 | 73.9257 | 14.9988 | 6:00 | 8:00 | 73.7661 | 0.1596 | 1.06 | | | | | | | | 1.06 | | |
| 6/2/2004 | H9 12-3 | B/R | 57.9573 | 73.3006 | 15.3433 | 6:00 | 8:00 | 73.1332 | 0.1674 | 1.09 | | | | | | | | | 1.09 | |
| 6/2/2004 | H10 12-3 | F/R | 57.2703 | 72.4642 | 15.1939 | 6:00 | 8:00 | 72.3017 | 0.1625 | 1.07 | | | | | | | | | | 1.07 |
| | | | | | | | | | Average | 1.22 | 1.23 | 1.13 | 1.16 | 1.19 | 1.16 | 1.45 | 1.21 | 1.19 | 1.21 | 1.24 |
| | | | | | | | | | Std Dev. | 0.20 | 0.33 | 0.09 | 0.10 | 0.09 | 0.11 | 0.78 | 0.11 | 0.11 | 0.12 | 0.20 |
| | | | | | | | | | Range | 0.70 | 1.24 | 0.26 | 0.31 | 0.25 | 0.38 | 2.81 | 0.36 | 0.37 | 0.36 | 0.68 |
| | | | | | | | | | | All Batche | Batch 1 | Batch 2 | Batch 3 | Batch 4 | Batch 5 | Batch 6 | Batch 7 | Batch 8 | Batch 9 | Batch 10 |

Sample Position in mixer: mixer, batch number, clock position,level number

LOI furnace position: F=front, M=middle,B= back,L=left,R=right

Note: samples H1-6-2 and H6-6-2 had visible resin balls

## Table B4. LOI determinations from Klein mixedness evaluations. Column 2 is coded location for 12 samples per run. Alpha K=Klein, Numeral=Run number, Numeral=Clock position in mix bowl, Numeral = level position in mix bowl.

| | | | FX KLEIN MIXER TEST | | | | | Analyst: | Matt Prendergast | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | AFS 5100-00-S | | | | | | | | | | | | | | | | |
| Sample Date | test reference number | oven position | Dish wt. (gms) | Dish & Sample wt. (gms) | Sample wt. (gms) | Time in | Time out | Dry Wt. (gms) | Weight change | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition |
| | | | | | | | | | | | Batch number 1 | Batch number 2 | Batch number 3 | Batch number 4 | Batch number 5 | Batch number 6 | Batch number 7 | Batch number 8 | Batch number 9 | Batch number 10 |
| 5/13/2004 | K1 3-1 | B/L | 60.3414 | 75.5613 | 15.2199 | 6:30 | 8:30 | 75.3475 | 0.2138 | 1.40 | 1.40 | | | | | | | | | |
| 5/13/2004 | K2 3-1 | M/L | 53.8532 | 68.8319 | 14.9787 | 6:30 | 8:30 | 68.6279 | 0.2040 | 1.36 | | 1.36 | | | | | | | | |
| 5/13/2004 | K3 3-1 | F/L | 61.1258 | 76.2041 | 15.0783 | 6:30 | 8:30 | 75.9957 | 0.2084 | 1.38 | | | 1.38 | | | | | | | |
| 5/13/2004 | K4 3-1 | B/R | 66.5951 | 81.8482 | 15.2531 | 6:30 | 8:30 | 81.6361 | 0.2121 | 1.39 | | | | 1.39 | | | | | | |
| 5/13/2004 | K5 3-1 | F/R | 57.3659 | 72.5412 | 15.1753 | 6:30 | 8:30 | 72.3292 | 0.2120 | 1.40 | | | | | 1.40 | | | | | |
| 5/13/2004 | K6 3-1 | B/L | 52.1993 | 67.3132 | 15.1139 | 8:30 | 10:30 | 67.106 | 0.2072 | 1.37 | | | | | | 1.37 | | | | |
| 5/13/2004 | K7 3-1 | M/L | 56.6028 | 71.7346 | 15.1318 | 8:30 | 10:30 | 71.5384 | 0.1962 | 1.30 | | | | | | | 1.30 | | | |
| 5/13/2004 | K8 3-1 | F/L | 52.4317 | 67.3982 | 14.9665 | 8:30 | 10:30 | 67.2069 | 0.1913 | 1.28 | | | | | | | | 1.28 | | |
| 5/13/2004 | K9 3-1 | B/R | 64.0133 | 79.0537 | 15.0404 | 8:30 | 10:30 | 78.8602 | 0.1935 | 1.29 | | | | | | | | | 1.29 | |
| 5/13/2004 | K10 3-1 | F/R | 63.6394 | 78.4254 | 14.7860 | 8:30 | 10:30 | 78.2353 | 0.1901 | 1.29 | | | | | | | | | | 1.29 |
| 5/13/2004 | K1 6-1 | B/L | 67.5611 | 82.63043 | 15.0693 | 10:30 | 12:30 | 82.433 | 0.1974 | 1.31 | 1.31 | | | | | | | | | |
| 5/13/2004 | K2 6-1 | M/L | 58.9176 | 73.932 | 15.0144 | 10:30 | 12:30 | 73.7374 | 0.1946 | 1.30 | | 1.30 | | | | | | | | |
| 5/13/2004 | K3 6-1 | F/L | 49.6767 | 64.9916 | 15.3149 | 10:30 | 12:30 | 64.7926 | 0.1990 | 1.30 | | | 1.30 | | | | | | | |
| 5/13/2004 | K4 6-1 | B/R | 55.2066 | 70.2872 | 15.0806 | 10:30 | 12:30 | 70.0844 | 0.2028 | 1.34 | | | | 1.34 | | | | | | |
| 5/13/2004 | K5 6-1 | F/R | 59.2027 | 74.3146 | 15.1119 | 10:30 | 12:30 | 74.1133 | 0.2013 | 1.33 | | | | | 1.33 | | | | | |
| 5/13/2004 | K6 6-1 | B/L | 60.3283 | 75.3433 | 15.0150 | 12:30 | 2:30 | 75.1552 | 0.1881 | 1.25 | | | | | | 1.25 | | | | |
| 5/13/2004 | K7 6-1 | M/L | 53.8373 | 68.853 | 15.0157 | 12:30 | 2:30 | 68.6579 | 0.1951 | 1.30 | | | | | | | 1.30 | | | |
| 5/13/2004 | K8 6-1 | F/L | 61.1172 | 76.1779 | 15.0607 | 12:30 | 2:30 | 75.9825 | 0.1954 | 1.30 | | | | | | | | 1.30 | | |
| 5/13/2004 | K9 6-1 | B/R | 66.6054 | 81.5878 | 14.9824 | 12:30 | 2:30 | 81.3827 | 0.2051 | 1.37 | | | | | | | | | 1.37 | |
| 5/13/2004 | K10 6-1 | F/R | 57.3539 | 72.5038 | 15.1499 | 12:30 | 2:30 | 72.3147 | 0.1891 | 1.25 | | | | | | | | | | 1.25 |
| 5/13/2004 | K1 9-1 | B/L | 67.6843 | 82.711 | 15.0267 | 2:30 | 4:30 | 82.4975 | 0.2135 | 1.42 | 1.42 | | | | | | | | | |
| 5/13/2004 | K2 9-1 | M/L | 58.9132 | 73.9354 | 15.0222 | 2:30 | 4:30 | 73.7461 | 0.1893 | 1.26 | | 1.26 | | | | | | | | |
| 5/13/2004 | K3 9-1 | F/L | 49.6853 | 64.7672 | 15.0819 | 2:30 | 4:30 | 64.5719 | 0.1953 | 1.29 | | | 1.29 | | | | | | | |
| 5/13/2004 | K4 9-1 | B/R | 55.2044 | 70.3516 | 15.1472 | 2:30 | 4:30 | 70.1609 | 0.1907 | 1.26 | | | | 1.26 | | | | | | |
| 5/13/2004 | K5 9-1 | F/R | 59.2064 | 74.1612 | 14.9548 | 2:30 | 4:30 | 73.9683 | 0.1929 | 1.29 | | | | | 1.29 | | | | | |
| 5/14/2004 | K6 9-1 | B/L | 56.5997 | 71.7584 | 15.1587 | 6:00 | 8:00 | 71.5576 | 0.2008 | 1.32 | | | | | | 1.32 | | | | |
| 5/14/2004 | K7 9-1 | M/L | 52.195 | 67.3795 | 15.1845 | 6:00 | 8:00 | 67.181 | 0.1985 | 1.31 | | | | | | | 1.31 | | | |
| 5/14/2004 | K8 9-1 | F/L | 52.4307 | 67.6536 | 15.2229 | 6:00 | 8:00 | 67.4516 | 0.2020 | 1.33 | | | | | | | | 1.33 | | |
| 5/14/2004 | K9 9-1 | B/R | 64.034 | 79.2084 | 15.1744 | 6:00 | 8:00 | 78.9923 | 0.2161 | 1.42 | | | | | | | | | 1.42 | |
| 5/14/2004 | K10 9-1 | F/R | 63.329 | 78.667 | 15.3380 | 6:00 | 8:00 | 78.4672 | 0.1998 | 1.30 | | | | | | | | | | 1.30 |
| 5/14/2004 | K1 12-1 | B/L | 67.6544 | 82.648 | 14.9936 | 8:00 | 10:00 | 82.4632 | 0.1848 | 1.23 | 1.23 | | | | | | | | | |
| 5/14/2004 | K2 12-1 | M/L | 58.9157 | 73.909 | 14.9933 | 8:00 | 10:00 | 73.7259 | 0.1831 | 1.22 | | 1.22 | | | | | | | | |
| 5/14/2004 | K3 12-1 | F/L | 49.6816 | 64.6634 | 14.9818 | 8:00 | 10:00 | 64.4844 | 0.1790 | 1.19 | | | 1.19 | | | | | | | |
| 5/14/2004 | K4 12-1 | B/R | 55.2067 | 70.434 | 15.2273 | 8:00 | 10:00 | 70.2442 | 0.1898 | 1.25 | | | | 1.25 | | | | | | |
| 5/14/2004 | K5 12-1 | F/R | 59.2037 | 74.2096 | 15.0059 | 8:00 | 10:00 | 74.0321 | 0.1775 | 1.18 | | | | | 1.18 | | | | | |
| 5/14/2004 | K6 12-1 | B/L | 60.3379 | 75.4754 | 15.1375 | 10:00 | 12:00 | 75.2832 | 0.1922 | 1.27 | | | | | | 1.27 | | | | |
| 5/14/2004 | K7 12-1 | M/L | 53.8397 | 69.1304 | 15.2907 | 10:00 | 12:00 | 68.9435 | 0.1869 | 1.22 | | | | | | | 1.22 | | | |
| 5/14/2004 | K8 12-1 | F/L | 61.1077 | 76.3029 | 15.1952 | 10:00 | 12:00 | 76.1162 | 0.1867 | 1.23 | | | | | | | | 1.23 | | |
| 5/14/2004 | K9 12-1 | B/R | 66.5882 | 81.5826 | 14.9944 | 10:00 | 12:00 | 81.395 | 0.1876 | 1.25 | | | | | | | | | 1.25 | |
| 5/14/2004 | K10 12-1 | F/R | 57.3531 | 72.3673 | 15.0142 | 10:00 | 12:00 | 72.1878 | 0.1795 | 1.20 | | | | | | | | | | 1.20 |
| 5/14/2004 | K1 3-2 | B/L | 56.6083 | 71.6802 | 15.0719 | 12:00 | 2:00 | 71.4953 | 0.1849 | 1.23 | 1.23 | | | | | | | | | |
| 5/14/2004 | K2 3-2 | M/L | 52.1969 | 67.1699 | 14.9730 | 12:00 | 2:00 | 66.9923 | 0.1776 | 1.19 | | 1.19 | | | | | | | | |
| 5/14/2004 | K3 3-2 | F/L | 52.4318 | 67.6514 | 15.2196 | 12:00 | 2:00 | 67.465 | 0.1864 | 1.22 | | | 1.22 | | | | | | | |
| 5/14/2004 | K4 3-2 | B/R | 64.0208 | 79.147 | 15.1262 | 12:00 | 2:00 | 78.9565 | 0.1905 | 1.26 | | | | 1.26 | | | | | | |
| 5/14/2004 | K5 3-2 | F/R | 63.3281 | 78.613 | 15.2849 | 12:00 | 2:00 | 78.4283 | 0.1847 | 1.21 | | | | | 1.21 | | | | | |
| 5/17/2004 | K6 3-2 | B/L | 56.6065 | 71.7003 | 15.0938 | 6:00 | 8:00 | 71.5283 | 0.1720 | 1.14 | | | | | | 1.14 | | | | |
| 5/17/2004 | K7 3-2 | M/L | 52.191 | 67.2782 | 15.0872 | 6:00 | 8:00 | 67.1091 | 0.1691 | 1.12 | | | | | | | 1.12 | | | |
| 5/17/2004 | K8 3-2 | F/L | 52.4328 | 67.4306 | 14.9978 | 6:00 | 8:00 | 67.2686 | 0.1620 | 1.08 | | | | | | | | 1.08 | | |
| 5/17/2004 | K9 3-2 | B/R | 64.0252 | 79.0824 | 15.0572 | 6:00 | 8:00 | 78.9048 | 0.1776 | 1.18 | | | | | | | | | 1.18 | |
| 5/17/2004 | K10 3-2 | F/R | 63.3274 | 78.523 | 15.1956 | 6:00 | 8:00 | 78.3589 | 0.1641 | 1.08 | | | | | | | | | | 1.08 |
| 5/17/2004 | K1 6-2 | B/L | 57.8804 | 72.9369 | 15.0565 | 8:00 | 10:00 | 72.7604 | 0.1765 | 1.17 | 1.17 | | | | | | | | | |
| 5/17/2004 | K2 6-2 | M/L | 63.7492 | 78.7823 | 15.0331 | 8:00 | 10:00 | 78.5992 | 0.1831 | 1.22 | | 1.22 | | | | | | | | |
| 5/17/2004 | K3 6-2 | F/L | 58.928 | 73.956 | 15.0280 | 8:00 | 10:00 | 73.7799 | 0.1761 | 1.17 | | | 1.17 | | | | | | | |
| 5/17/2004 | K4 6-2 | B/R | 57.2733 | 72.4489 | 15.1756 | 8:00 | 10:00 | 72.2756 | 0.1733 | 1.14 | | | | 1.14 | | | | | | |
| 5/17/2004 | K5 6-2 | F/R | 57.9602 | 73.037 | 15.0768 | 8:00 | 10:00 | 72.8676 | 0.1694 | 1.12 | | | | | 1.12 | | | | | |
| 5/17/2004 | K6 6-2 | B/L | 60.3301 | 75.3694 | 15.0393 | 10:00 | 12:00 | 75.1935 | 0.1759 | 1.17 | | | | | | 1.17 | | | | |

# Table B4 continued.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FX KLEIN MIXER TEST | | | | | | | | Analyst: | Matt Prendergast | | | | | | | | | | | |
| | | | | AFS 5100-00-S | | | | | | | | | | | | | | | | |
| Sample Date | test reference number | oven position | Dish wt. (gms) | Dish & Sample wt. (gms) | Sample wt. (gms) | Time in | Time out | Dry Wt. (gms) | Weight change | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition | %LOI @1800* Lost on Ignition |
| | | | | | | | | | | | Batch number 1 | Batch number 2 | Batch number 3 | Batch number 4 | Batch number 5 | Batch number 6 | Batch number 7 | Batch number 8 | Batch number 9 | Batch number 10 |
| 5/17/2004 | K7 6-2 | M/L | 61.1119 | 76.222 | 15.1101 | 10:00 | 12:00 | 76.0445 | 0.1775 | 1.17 | | | | | | | 1.17 | | | |
| 5/17/2004 | K8 6-2 | F/L | 53.8415 | 69.1135 | 15.2720 | 10:00 | 12:00 | 68.9385 | 0.1750 | 1.15 | | | | | | | | 1.15 | | |
| 5/17/2004 | K9 6-2 | B/R | 66.5865 | 81.7335 | 15.1470 | 10:00 | 12:00 | 81.549 | 0.1845 | 1.22 | | | | | | | | | 1.22 | |
| 5/17/2004 | K10 6-2 | F/R | 57.3525 | 72.4875 | 15.1350 | 10:00 | 12:00 | 72.3175 | 0.1700 | 1.12 | | | | | | | | | | 1.12 |
| 5/17/2004 | K1 9-2 | B/L | 67.6493 | 82.8632 | 15.2139 | 12:00 | 2:00 | 82.6837 | 0.1795 | 1.18 | 1.18 | | | | | | | | | |
| 5/17/2004 | K2 9-2 | M/L | 58.9148 | 74.3312 | 15.4164 | 12:00 | 2:00 | 74.158 | 0.1732 | 1.12 | | 1.12 | | | | | | | | |
| 5/17/2004 | K3 9-2 | F/L | 49.6772 | 64.8842 | 15.2070 | 12:00 | 2:00 | 64.7098 | 0.1744 | 1.15 | | | 1.15 | | | | | | | |
| 5/17/2004 | K4 9-2 | B/R | 55.2065 | 70.3159 | 15.1094 | 12:00 | 2:00 | 70.1342 | 0.1817 | 1.20 | | | | 1.20 | | | | | | |
| 5/17/2004 | K5 9-2 | F/R | 59.2032 | 74.3569 | 15.1537 | 12:00 | 2:00 | 74.1837 | 0.1732 | 1.14 | | | | | 1.14 | | | | | |
| 5/17/2004 | K6 9-2 | B/L | 56.608 | 71.6811 | 15.0731 | 2:00 | 5:00 | 71.4997 | 0.1814 | 1.20 | | | | | | 1.20 | | | | |
| 5/17/2004 | K7 9-2 | M/L | 52.1942 | 67.1315 | 14.9373 | 2:00 | 5:00 | 66.9548 | 0.1767 | 1.18 | | | | | | | 1.18 | | | |
| 5/17/2004 | K8 9-1 | F/L | 52.4325 | 67.433 | 15.0005 | 2:00 | 5:00 | 67.2615 | 0.1715 | 1.14 | | | | | | | | 1.14 | | |
| 5/17/2004 | K9 9-2 | B/R | 61.0193 | 79.0532 | 18.0339 | 2:00 | 5:00 | 78.8803 | 0.1729 | 0.96 | | | | | | | | | 0.96 | |
| 5/17/2004 | K10 9-2 | F/R | 63.3299 | 78.2628 | 14.9329 | 2:00 | 5:00 | 78.0904 | 0.1724 | 1.15 | | | | | | | | | | 1.15 |
| 5/18/2004 | K1 12-2 | B/L | 60.3287 | 75.3422 | 15.0135 | 6:00 | 8:00 | 75.1749 | 0.1673 | 1.11 | 1.11 | | | | | | | | | |
| 5/18/2004 | K2 12-2 | M/L | 61.1083 | 76.1032 | 14.9949 | 6:00 | 8:00 | 75.9276 | 0.1756 | 1.17 | | 1.17 | | | | | | | | |
| 5/18/2004 | K3 12-2 | F/L | 53.8385 | 68.8689 | 15.0304 | 6:00 | 8:00 | 68.6967 | 0.1722 | 1.15 | | | 1.15 | | | | | | | |
| 5/18/2004 | K4 12-2 | B/R | 66.5819 | 81.6478 | 15.0659 | 6:00 | 8:00 | 81.474 | 0.1738 | 1.15 | | | | 1.15 | | | | | | |
| 5/18/2004 | K5 12-2 | F/R | 57.3549 | 72.4404 | 15.0855 | 6:00 | 8:00 | 72.2644 | 0.1760 | 1.17 | | | | | 1.17 | | | | | |
| 5/18/2004 | K6 12-2 | B/L | 57.8705 | 72.8306 | 14.9601 | 8:00 | 10:00 | 72.6646 | 0.1660 | 1.11 | | | | | | 1.11 | | | | |
| 5/18/2004 | K7 12-2 | M/L | 63.7449 | 79.198 | 15.4531 | 8:00 | 10:00 | 79.0212 | 0.1768 | 1.14 | | | | | | | 1.14 | | | |
| 5/18/2004 | K8 12-2 | F/L | 58.9427 | 74.3297 | 15.3870 | 8:00 | 10:00 | 74.1567 | 0.1730 | 1.12 | | | | | | | | 1.12 | | |
| 5/18/2004 | K9 12-2 | B/R | 57.2717 | 72.5238 | 15.2521 | 8:00 | 10:00 | 72.3522 | 0.1716 | 1.13 | | | | | | | | | 1.13 | |
| 5/18/2004 | K10 12-2 | F/R | 57.9576 | 73.1436 | 15.1860 | 8:00 | 10:00 | 72.9774 | 0.1662 | 1.09 | | | | | | | | | | 1.09 |
| 5/18/2004 | K1 3-3 | B/L | 67.6486 | 82.9855 | 15.3369 | 10:00 | 12:00 | 82.8106 | 0.1749 | 1.14 | 1.14 | | | | | | | | | |
| 5/18/2004 | K2 3-3 | M/L | 58.915 | 74.1225 | 15.2075 | 10:00 | 12:00 | 73.9403 | 0.1822 | 1.20 | | 1.20 | | | | | | | | |
| 5/18/2004 | K3 3-3 | F/L | 49.6779 | 64.638 | 14.9601 | 10:00 | 12:00 | 64.4578 | 0.1802 | 1.20 | | | 1.20 | | | | | | | |
| 5/18/2004 | K4 3-3 | B/R | 55.2083 | 70.2853 | 15.0770 | 10:00 | 12:00 | 70.1072 | 0.1781 | 1.18 | | | | 1.18 | | | | | | |
| 5/18/2004 | K5 3-3 | F/R | 59.204 | 74.3004 | 15.0964 | 10:00 | 12:00 | 74.1264 | 0.1740 | 1.15 | | | | | 1.15 | | | | | |
| 5/18/2004 | K6 3-3 | B/L | 56.6159 | 71.6909 | 15.0750 | 12:00 | 2:00 | 71.5109 | 0.1800 | 1.19 | | | | | | 1.19 | | | | |
| 5/18/2004 | K7 3-3 | M/L | 52.1912 | 67.5454 | 15.3542 | 12:00 | 2:00 | 67.3784 | 0.1670 | 1.09 | | | | | | | 1.09 | | | |
| 5/18/2004 | K8 3-3 | F/L | 52.4305 | 67.5754 | 15.1449 | 12:00 | 2:00 | 67.4022 | 0.1732 | 1.14 | | | | | | | | 1.14 | | |
| 5/18/2004 | K9 3-3 | B/R | 64.0973 | 78.6081 | 14.5108 | 12:00 | 2:00 | 78.4445 | 0.1636 | 1.13 | | | | | | | | | 1.13 | |
| 5/18/2004 | K10 3-3 | F/R | 63.3275 | 77.8954 | 14.5679 | 12:00 | 2:00 | 77.7386 | 0.1568 | 1.08 | | | | | | | | | | 1.08 |
| 5/18/2004 | K1 6-3 | B/L | 60.3262 | 75.7889 | 15.4627 | 2:00 | 4:00 | 75.6209 | 0.1680 | 1.09 | 1.09 | | | | | | | | | |
| 5/18/2004 | K2 6-3 | M/L | 61.1093 | 76.0884 | 14.9791 | 2:00 | 4:00 | 75.9167 | 0.1717 | 1.15 | | 1.15 | | | | | | | | |
| 5/18/2004 | K3 6-3 | F/L | 53.8381 | 69.1933 | 15.3552 | 2:00 | 4:00 | 69.0207 | 0.1726 | 1.12 | | | 1.12 | | | | | | | |
| 5/18/2004 | K4 6-3 | B/R | 66.5833 | 81.8926 | 15.3093 | 2:00 | 4:00 | 81.7187 | 0.1739 | 1.14 | | | | 1.14 | | | | | | |
| 5/18/2004 | K5 6-3 | F/R | 57.354 | 72.4413 | 15.0873 | 2:00 | 4:00 | 72.2696 | 0.1717 | 1.14 | | | | | 1.14 | | | | | |
| 5/19/2004 | K6 6-3 | B/L | 57.8685 | 73.2291 | 15.3606 | 6:00 | 8:00 | 73.0634 | 0.1657 | 1.08 | | | | | | 1.08 | | | | |
| 5/19/2004 | K7 6-3 | M/L | 63.7451 | 79.0021 | 15.2570 | 6:00 | 8:00 | 78.8276 | 0.1745 | 1.14 | | | | | | | 1.14 | | | |
| 5/19/2004 | K8 6-3 | F/L | 58.9274 | 74.2605 | 15.3331 | 6:00 | 8:00 | 74.0857 | 0.1748 | 1.14 | | | | | | | | 1.14 | | |
| 5/19/2004 | K9 6-3 | B/R | 57.2722 | 72.2845 | 15.0123 | 6:00 | 8:00 | 72.1132 | 0.1713 | 1.14 | | | | | | | | | 1.14 | |
| 5/19/2004 | K10 6-3 | F/R | 57.9587 | 73.0983 | 15.1396 | 6:00 | 8:00 | 72.9294 | 0.1689 | 1.12 | | | | | | | | | | 1.12 |
| 5/19/2004 | K1 9-3 | B/L | 60.3298 | 75.7017 | 15.3719 | 8:00 | 10:00 | 75.5259 | 0.1758 | 1.14 | 1.14 | | | | | | | | | |
| 5/19/2004 | K2 9-3 | M/L | 61.1124 | 76.3096 | 15.1972 | 8:00 | 10:00 | 76.1231 | 0.1865 | 1.23 | | 1.23 | | | | | | | | |
| 5/19/2004 | K3 9-3 | F/L | 53.8388 | 68.9576 | 15.1188 | 8:00 | 10:00 | 68.7802 | 0.1774 | 1.17 | | | 1.17 | | | | | | | |
| 5/19/2004 | K4 9-3 | B/R | 66.5937 | 81.6231 | 15.0294 | 8:00 | 10:00 | 81.4416 | 0.1815 | 1.21 | | | | 1.21 | | | | | | |
| 5/19/2004 | K5 9-3 | F/R | 57.3557 | 72.3868 | 15.0311 | 8:00 | 10:00 | 72.213 | 0.1738 | 1.16 | | | | | 1.16 | | | | | |
| 5/19/2004 | K6 9-3 | B/L | 56.6277 | 71.8513 | 15.2236 | 10:00 | 12:00 | 71.6612 | 0.1901 | 1.25 | | | | | | 1.25 | | | | |
| 5/19/2004 | K7 9-3 | M/L | 52.1938 | 67.237 | 15.0432 | 10:00 | 12:00 | 67.0684 | 0.1686 | 1.12 | | | | | | | 1.12 | | | |
| 5/19/2004 | K8 9-3 | F/L | 52.432 | 67.8189 | 15.3869 | 10:00 | 12:00 | 67.6468 | 0.1721 | 1.12 | | | | | | | | 1.12 | | |
| 5/19/2004 | K9 9-3 | B/R | 64.0139 | 79.0784 | 15.0645 | 10:00 | 12:00 | 78.9018 | 0.1766 | 1.17 | | | | | | | | | 1.17 | |
| 5/19/2004 | K10 9-3 | F/R | 63.3274 | 78.6038 | 15.2764 | 10:00 | 12:00 | 78.4319 | 0.1719 | 1.13 | | | | | | | | | | 1.13 |
| 5/19/2004 | K1 12-3 | B/L | 67.6486 | 82.8306 | 15.1820 | 12:00 | 2:00 | 82.6669 | 0.1637 | 1.08 | 1.08 | | | | | | | | | |
| 5/19/2004 | K2 12-3 | M/L | 58.9128 | 73.8882 | 14.9754 | 12:00 | 2:00 | 73.7199 | 0.1683 | 1.12 | | 1.12 | | | | | | | | |
| 5/19/2004 | K3 12-3 | F/L | 49.6771 | 65.0483 | 15.3712 | 12:00 | 2:00 | 64.8808 | 0.1675 | 1.09 | | | 1.09 | | | | | | | |
| 5/19/2004 | K4 12-3 | B/R | 55.2068 | 70.2814 | 15.0746 | 12:00 | 2:00 | 70.1129 | 0.1685 | 1.12 | | | | 1.12 | | | | | | |
| 5/19/2004 | K5 12-3 | F/R | 59.2012 | 74.4159 | 15.2147 | 12:00 | 2:00 | 74.2464 | 0.1695 | 1.11 | | | | | 1.11 | | | | | |
| 5/19/2004 | K6 12-3 | B/L | 57.8775 | 73.0387 | 15.1612 | 2:00 | 6:00 | 72.8657 | 0.1730 | 1.14 | | | | | | 1.14 | | | | |
| 5/19/2004 | K7 12-3 | M/L | 63.7403 | 78.7028 | 14.9625 | 2:00 | 6:00 | 78.543 | 0.1598 | 1.07 | | | | | | | 1.07 | | | |
| 5/19/2004 | K8 12-3 | F/L | 58.9247 | 73.9477 | 15.0230 | 2:00 | 6:00 | 73.788 | 0.1597 | 1.06 | | | | | | | | 1.06 | | |
| 5/19/2004 | K9 12-3 | B/R | 57.2697 | 72.5619 | 15.2922 | 2:00 | 6:00 | 72.4162 | 0.1457 | 0.95 | | | | | | | | | 0.95 | |
| 5/19/2004 | K10 12-3 | F/R | 57.9555 | 73.2255 | 15.2700 | 2:00 | 6:00 | 73.0594 | 0.1661 | 1.09 | | | | | | | | | | 1.09 |
| Sample Position in mixer: mixer, batch number, clock position,level number | | | | | | | | | Average | 1.19 | 1.21 | 1.21 | 1.20 | 1.22 | 1.20 | 1.21 | 1.18 | 1.17 | 1.18 | 1.16 |
| LOI furnace position: F=front, M=middle,B= back,L=left,R=right | | | | | | | | | Std Dev. | 0.09 | 0.12 | 0.07 | 0.08 | 0.08 | 0.09 | 0.09 | 0.08 | 0.09 | 0.14 | 0.08 |
| | | | | | | | | | Range | 0.29 | 0.34 | 0.24 | 0.29 | 0.27 | 0.28 | 0.29 | 0.24 | 0.26 | 0.47 | 0.23 |
| | | | | | | | | | | All batched | Batch 1 | Batch 2 | Batch 3 | Batch 4 | Batch 5 | Batch 6 | Batch 7 | Batch 8 | Batch 9 | Batch 10 |

## Table B5. Dogbone core tool cavity tensile strength bias

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3-Cavity core box cavity comparison | | | | | | | Date | 6/7/2004 | |
| Thwing_Albert Tensile machine | | | | | | | | | |
| Tensile test Ambient Temperaure, F | | | | | 77.4 | Strain rate, in/sec | | | 1.2 |
| Mix ambient temperature, | | 76 | | | Sand temperature, F | | | | 76 |
| Binder | and 305/904 | | | | % binder | 1.4 | Ratio part 1:2 | | 55:45 |
| Blow Pressure, psi | | 50 | | | Blow time, sec. | | | | 0.4 |
| A Gas pressure, psi | | 9 | | | A Gas time, sec | | | | 0.4 |
| B Gas pressure, psi | | 30 | | | B Gas time, sec | | | | 1.3 |
| Purge pressure, psi | | 30 | | | Purge time, sec | | | | 55/45 |
| Heat to TEA tank | | NO | | | | | | | |
| Core Number | Core make time | Mix completi on time | | Core mix age at make, | Dogbone make time | Dogbone Brake age after | North Cavity Tensile | Middle Cavity Tensile | South Cavity Tensile |
| | | First batch | Second batch | | | | | | |
| 1 | 10:27 | 10:18 | | 0:09 | 12:50 | 2:23 | 233.3 | 235.1 | 236.1 |
| 2 | 10:30 | 10:18 | | 0:12 | 12:52 | 2:22 | 226.1 | 236.7 | 230.0 |
| 3 | 10:32 | 10:18 | | 0:14 | 12:53 | 2:21 | 235.5 | 229.6 | 236.3 |
| 4 | 10:34 | 10:18 | | 0:16 | 12:54 | 2:20 | 230.5 | 237.3 | 223.7 |
| 5 | 10:35 | 10:18 | | 0:17 | 12:55 | 2:20 | 224.7 | 236.3 | 217.9 |
| 6 | 10:36 | 10:18 | | 0:18 | 12:56 | 2:20 | 227.4 | 243.2 | 219.5 |
| 7 | 10:38 | 10:18 | | 0:20 | 12:58 | 2:20 | 229.8 | 237.3 | 234.9 |
| 8 | 10:40 | 10:18 | | 0:22 | 12:59 | 2:19 | 231.3 | 227.3 | 227.0 |
| 9 | 10:42 | 10:18 | | 0:24 | 13:00 | 2:18 | 225.3 | 220.7 | 233.6 |
| 10 | 10:44 | 10:18 | | Incomplete | core | | | | |
| 11 | 11:31 | | 11:25 | 0:12 | 13:45 | 2:14 | 259.2 | 256.5 | 252.5 |
| 12 | 11:33 | | 11:25 | 0:16 | 13:46 | 2:13 | 237.7 | 247.6 | 235.6 |
| 13 | 11:34 | | 11:25 | 0:18 | 13:47 | 2:13 | 245.9 | 252.3 | 248.4 |
| 14 | 11:35 | | 11:25 | 0:21 | 13:48 | 2:13 | 243.7 | 248.7 | 237.8 |
| 15 | 11:36 | | 11:25 | 0:23 | 13:49 | 2:13 | 241.6 | 245.2 | 235.0 |
| 16 | 11:37 | | 11:25 | 0:25 | 13:50 | 2:13 | 244.6 | 244.6 | 234.4 |
| 17 | 11:38 | | 11:25 | 0:27 | 13:51 | 2:13 | 231.5 | 238.6 | 239.3 |
| 18 | 11:39 | | 11:25 | 0:29 | 13:52 | 2:13 | 237.2 | 241.5 | 228.9 |
| 19 | 11:40 | | 11:25 | 0:31 | 13:53 | 2:13 | 232.9 | 230.5 | 233.6 |
| 20 | Ave batch1 | | | | | | 229.3 | 233.7 | 228.8 |
| 21 | St De batch 1 | | | | | | 3.73 | 6.71 | 7.12 |
| 22 | 90 % Conf upper limit | | | | | | 235.4 | 244.7 | 240.5 |
| 23 | 90 % Conf lower limit | | | | | | 223.21 | 222.71 | 217.1 |
| 24 | Conclusion | | Cavities are indistinguishable | | | | | | |
| 25 | Ave batch 2 | | | | | | 241.6 | 245.1 | 238.4 |
| 26 | St Dev batch 2 | | | | | | 8.32 | 7.66 | 7.49 |
| 27 | 90 % Conf upper limit | | | | | | 255.24 | 257.62 | 250.67 |
| 28 | 90 % Conf lower limit | | | | | | 227.9 | 232.5 | 226.1 |
| 29 | Conclusion | | Cavities are indistinguishable | | | | | | |
| 30 | | | | | | 2:16 | 235.5 | 239.4 | 233.6 |
| Average | | | | | | 0:03 | 8.89 | 9.10 | 8.64 |
| St Dev | 90 % Conf upper limit | | | | | | 250.0 | 254.3 | 247.8 |
| | 90 % Conf lower limit | | | | | | 220.9 | 224.5 | 219.4 |
| | Conclusion | | Cavities are indistiguishable but batches are almost visible | | | | | | |

## Table B6. Worksheet to randomize dogbone make sequence into break sequence for tensile tests.

| Randomized break order | | | TA | Detert | | | | TA | Detert | | TA | Detert | | TA | Detert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Make seq | Random Num | sorted random Num | Break order by make seq | Break order by make seq | Make seq | Random Num | sorted random Num | Break order by make seq | Break order by make seq | Break Order | Break order by make seq | Break order by make seq | Break Order | Break order by make seq | Break order by make seq |
| 1 | 41.20087 | 1.04 | 55 | | 35 | 1.836061 | 25.26 | 3 | | 1 | 55 | 58 | 1 | 55 | 58 |
| 2 | 44.32519 | 1.65 | | 58 | 36 | 23.42218 | 28.31 | | 27 | 2 | 5 | 9 | 2 | 5 | 9 |
| 3 | 2.176586 | 1.84 | 5 | | 37 | 33.71348 | 30.86 | 46 | | 3 | 38 | 56 | 3 | 38 | 56 |
| 4 | 4.720451 | 1.92 | | 9 | 38 | 37.52077 | 31.02 | | 26 | 4 | 40 | 24 | 4 | 40 | 24 |
| 5 | 31.01647 | 2.18 | 38 | | 40 | 22.96506 | 31.16 | 5 | | 5 | 54 | 10 | 5 | 54 | 10 |
| 6 | 41.22225 | 2.37 | | 56 | 41 | 28.315 | 31.18 | | 36 | 6 | 43 | 30 | 6 | 43 | 30 |
| 7 | 31.16431 | 2.65 | 40 | | 42 | 1.036256 | 31.20 | 1 | | 7 | 37 | 34 | 7 | 37 | 34 |
| 8 | 18.14228 | 3.42 | | 24 | 43 | 15.54097 | 32.24 | | 21 | 8 | 61 | 6 | 8 | 61 | 6 |
| 9 | 40.78116 | 4.72 | 54 | | 44 | 40.31964 | 32.87 | 53 | | 9 | 48 | 42 | 9 | 48 | 42 |
| 10 | 6.204437 | 6.20 | | 10 | 45 | 16.67092 | 33.40 | | 23 | 10 | 35 | 32 | 10 | 35 | 32 |
| 11 | 32.2402 | 8.53 | 43 | | 46 | 45.62054 | 33.71 | 59 | | 11 | 13 | 20 | 11 | 13 | 20 |
| 12 | 23.48797 | 8.82 | | 30 | 47 | 38.82457 | 34.18 | | 52 | 12 | 2 | 22 | 12 | 2 | 22 |
| 13 | 30.86461 | 8.85 | 37 | | 48 | 24.57919 | 35.47 | 33 | | 13 | 57 | 65 | 13 | 57 | 12 |
| 14 | 24.78752 | 9.73 | | 34 | 49 | 9.734734 | 35.78 | | 14 | 14 | 44 | 15 | 14 | 44 | 15 |
| 15 | 49.6539 | 10.72 | 61 | | 50 | 11.29318 | 37.05 | 18 | | 15 | 25 | 8 | 15 | 25 | 8 |
| 16 | 2.371959 | 10.99 | | 6 | 51 | 35.77742 | 37.52 | | 49 | 16 | 31 | 66 | 16 | 31 | 11 |
| 17 | 35.47304 | 11.02 | 48 | | 52 | 11.4829 | 38.82 | 19 | | 17 | 3 | 27 | 17 | 3 | 27 |
| 18 | 31.19507 | 11.29 | | 42 | 53 | 11.01939 | 40.32 | | 17 | 18 | 46 | 26 | 18 | 46 | 26 |
| 19 | 25.25946 | 11.48 | 35 | | 54 | 1.916853 | 40.78 | 4 | | 19 | 65 | 36 | 19 | 65 | 36 |
| 20 | 23.66596 | 14.49 | | 32 | 55 | 49.88172 | 41.20 | | 62 | 20 | 1 | 21 | 20 | 1 | 21 |
| 21 | 8.851952 | 15.54 | 13 | | 56 | 56.81575 | 41.22 | 64 | | 21 | 53 | 23 | 21 | 53 | 23 |
| 22 | 14.49172 | 16.24 | | 20 | 57 | 10.98663 | 42.76 | | 16 | 22 | 59 | 52 | 22 | 59 | 52 |
| 23 | 1.649096 | 16.67 | 2 | | 58 | 34.17601 | 44.33 | 47 | | 23 | 33 | 14 | 23 | 33 | 14 |
| 24 | 16.2441 | 18.14 | | 22 | 59 | 37.04701 | 45.62 | | 50 | 24 | 18 | 49 | 24 | 18 | 49 |
| 25 | 42.7628 | 19.35 | 57 | | 60 | 31.18075 | 49.14 | 41 | | 25 | 19 | 17 | 25 | 19 | 17 |
| 26 | 56.88406 | 22.97 | | 65 | 61 | 2.650375 | 49.65 | | 7 | 26 | 4 | 62 | 26 | 4 | 62 |
| 27 | 32.86969 | 23.42 | 44 | | 62 | 55.79836 | 49.88 | 63 | | 27 | 64 | 16 | 27 | 64 | 16 |
| 30 | 10.72079 | 23.49 | | 15 | 63 | 49.13787 | 55.80 | | 60 | 28 | 47 | 50 | 28 | 47 | 50 |
| 31 | 19.34599 | 23.65 | 25 | | 64 | 8.532976 | 56.82 | 11 | | 29 | 41 | 7 | 29 | 41 | 7 |
| 32 | 3.416066 | 23.67 | | 8 | 65 | 8.82384 | 56.88 | | 12 | 30 | 63 | 60 | 30 | 63 | 60 |
| 33 | 23.65303 | 24.58 | 31 | | 66 | 33.40146 | 58.84 | 66 | | | 11 | 12 | | | |
| 34 | 58.83936 | 24.79 | | 66 | | | | | | | | | | | |
| | Step 1 Randomize | first half | | | | Step 1 scond half Randomize | | | | | Step 2 Consolidate | | | Step 3 Eliminate high make numbers | |

## Table B7a. Tensile test results for Hobart mixed sand tensile tested in Thwing-Albert Tensile tester.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tensile Tester Comparison** | | | | Mix/make date | | 8-Aug-04 | | | | Break date | 9-Aug-04 | | |
| **Thwing-Albert Tensile machine** | | | | | | | | **Hobart Sand Mixer** | | | | | |
| Tensile test Ambient Temperaure, F | | | | | | | | Strain rate, in/sec | | | | | |
| Mix ambient temperature, F | | | | | | | Sand temperature, F | | | | | | |
| Binder | | Ashland 305/904 | | | | | % binder | | 1.4 | Ratio part 1:part 2 | | 55:45 | |
| Blow Pressure, psi | | | | | | | Blow time, sec. | | | | | | |
| A Gas pressure, psi | | | | | | | A Gas time, sec | | | | | | |
| B Gas pressure, psi | | | | | | | B Gas time, sec | | | | | | |
| Purge pressure, psi | | | | | | | Purge time, sec | | | | | | |
| Heat to TEA tank | | | | | | | | | | | | | |
| Break Sequence | Mix batch number | Sand Mix Time hh:mm | Core Make Time hh:mm | Sand Mix Age @ Make hh:mm | Core Break Time hh:mm | Dogbone age @ Break Hours | Make sequence number | North Core Weight grams | North Core Tensil psi | Middle Core Weight grams | Middle Core Tensil psi | South Core Weight grams | South Core Tensil psi |
| 1 | 7 | 13:36 | 13:50 | 0:14 | 12:25 | 22.58 | 55 | 111.97 | 298.8 | 111.33 | 310.6 | 112.16 | 291.2 |
| 2 | 1 | 10:44 | 10:58 | 0:14 | 12:28 | 25.50 | 5 | 114.46 | 315.8 | 111.27 | 318.8 | 111.93 | 302.5 |
| 3 | 5 | 13:04 | 13:20 | 0:16 | 12:35 | 23.25 | 38 | 111.79 | 298.6 | 111.21 | 305.0 | 112.03 | 302.7 |
| 4 | 6 | 13:20 | 13:25 | 0:05 | 12:37 | 23.20 | 40 | 112.21 | 288.6 | 111.45 | 300.3 | 112.12 | 297.3 |
| 5 | 7 | 13:36 | 13:49 | 0:13 | 12:39 | 22.83 | 54 | 111.84 | 310.7 | 111.28 | 318.9 | 112.10 | 304.3 |
| 6 | 6 | 13:20 | 13:30 | 0:10 | 12:41 | 23.18 | 43 | 111.93 | 298.6 | 111.19 | 305.4 | 111.99 | 296.4 |
| 7 | 5 | 13:04 | 13:18 | 0:14 | 12:43 | 23.42 | 37 | 111.74 | 300.9 | 111.24 | 206.2 | 111.99 | 298.9 |
| 8 | 8 | 13:47 | 14:01 | 0:14 | 12:45 | 22.73 | 61 | 111.57 | 309.7 | 111.04 | 303.6 | 111.88 | 304.0 |
| 9 | 6 | 13:20 | 13:38 | 0:18 | 12:47 | 23.15 | 48 | 112.34 | 294.7 | 112.15 | 315.4 | 112.37 | 131.0 |
| 10 | 5 | 13:04 | 13:15 | 0:11 | 12:49 | 23.57 | 35 | 111.70 | 297.2 | 111.15 | 302.9 | 111.96 | 274.5 |
| 11 | 2 | 11:05 | 11:13 | 0:08 | 12:51 | 25.63 | 13 | 111.65 | 295.9 | 110.78 | 294.3 | 112.07 | 291.3 |
| 12 | 1 | 10:44 | 10:53 | 0:09 | 12:53 | 26.00 | 2 | 111.79 | 312.9 | 111.37 | 320.7 | 111.88 | 320.5 |
| 13 | 7 | 13:36 | 13:53 | 0:17 | 12:55 | 23.03 | 57 | 111.92 | 288.9 | 111.29 | 303.6 | 112.13 | 296.5 |
| 14 | 6 | 13:20 | 13:32 | 0:12 | 12:57 | 23.42 | 44 | 111.93 | 305.0 | 111.23 | 303.1 | 112.11 | 302.0 |
| 15 | 3 | 11:23 | 11:35 | 0:12 | 12:58 | 25.38 | 25 | 111.38 | 316.6 | 110.71 | 316.5 | 111.79 | 303.2 |
| 16 | 5 | 13:04 | 13:10 | 0:06 | 13:00 | 23.83 | 31 | 111.83 | 295.8 | 110.58 | 297.6 | 112.03 | 291.0 |
| 17 | 1 | 10:44 | 10:55 | 0:11 | 13:02 | 26.12 | 3 | 111.63 | 315.9 | 111.20 | 332.8 | 112.09 | 298.8 |
| 18 | 6 | 13:20 | 13:34 | 0:14 | 13:04 | 23.50 | 46 | 111.68 | 291.6 | 111.17 | 310.8 | 111.91 | 306.9 |
| 19 | 8 | 13:47 | 14:07 | 0:20 | 13:06 | 22.98 | 65 | 111.46 | 290.6 | 111.27 | 288.5 | 111.93 | 293.5 |
| 20 | 1 | 10:44 | 10:51 | 0:07 | 13:08 | 26.28 | 1 | 112.16 | 326.8 | 110.88 | 329.6 | 112.20 | 318.0 |
| 21 | 7 | 13:36 | 13:47 | 0:11 | 13:10 | 23.38 | 53 | 111.95 | 298.6 | 111.29 | 311.5 | 112.15 | 299.0 |
| 22 | 8 | 13:47 | 13:58 | 0:11 | 13:12 | 23.23 | 59 | 111.76 | 312.3 | 111.10 | 304.8 | 112.02 | 293.7 |
| 23 | 5 | 13:04 | 13:13 | 0:09 | 13:14 | 24.02 | 33 | 111.94 | 300.1 | 111.44 | 313.9 | 112.17 | 283.2 |
| 24 | 2 | 11:05 | 11:20 | 0:15 | 13:16 | 25.93 | 18 | 111.78 | 294.3 | 111.07 | 312.3 | 112.01 | 307.2 |
| 25 | 3 | 11:23 | 11:27 | 0:04 | 13:18 | 25.85 | 19 | 111.97 | 325.6 | 111.18 | 331.3 | 112.28 | 322.2 |
| 26 | 1 | 10:44 | 10:56 | 0:12 | 13:20 | 26.40 | 4 | 111.68 | 318.10 | 111.38 | 322.3 | 112.1 | 300.8 |
| 27 | 8 | 13:47 | 14:05 | 0:18 | 13:22 | 23.28 | 64 | 111.53 | 306.5 | 111.07 | 309.7 | 111.84 | 283.1 |
| 28 | 6 | 13:20 | 13:36 | 0:16 | 13:24 | 23.80 | 47 | 111.78 | 293.5 | 111.16 | 312.6 | 111.95 | 291.5 |
| 29 | 6 | 13:20 | 13:27 | 0:07 | 13:26 | 23.98 | 41 | 112.09 | 311.7 | 111.45 | 312.5 | 112.14 | 306.8 |
| 30 | 8 | 13:47 | 14:04 | 0:17 | 13:28 | 23.40 | 63 | 111.74 | 300.2 | 111.15 | 307.0 | 111.83 | 290.6 |
| Average | | | | 0:12 | | 24.10 | | 111.91 | 303.82 | 111.20 | 307.42 | 112.04 | 293.42 |
| St Dev | | | | 0:04 | | 1.26 | | 0.53 | 10.73 | 0.27 | 21.72 | 0.14 | 32.40 |
| Reduced St Dev | | | | | | | | | 0.035 | | 0.071 | | 0.110 |
| 90 % Conf upper limit | | | | 0:19 | | 26.21 | | 112.79 | 321.84 | 111.66 | 343.91 | 112.27 | 347.85 |
| 90 % Conf lower limit | | | | 0:05 | | 21.99 | | 111.02 | 285.79 | 110.74 | 270.93 | 111.81 | 238.99 |
| Conclusion | | | | | | | | | | | | | |

Batch 4 was discarded

## Table B7b. Tensile test results for Hobart mixed sand tensile tested in Dietert 405 Tensile tester.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tensile Tester Comparison** | | | | Mix/make date | | 8-Aug-04 | | | | Break date | 9-Aug-04 | | |
| **Dietert 405 Tensile Tester** | | | | | | | | **Hobart Sand Mixer** | | | | | |
| Tensile test Ambient Temperaure, F | | | | | | | | Strain rate, in/sec | | | | | |
| Mix ambient temperature, F | | | | | | | Sand temperature, F | | | | | | |
| Binder | | Ashland 305/904 | | | | | % binder | | 1.4 | Ratio part 1:part 2 | | 55:45 | |
| Blow Pressure, psi | | | | | | | Blow time, sec. | | | | | | |
| A Gas pressure, psi | | | | | | | A Gas time, sec | | | | | | |
| B Gas pressure, psi | | | | | | | B Gas time, sec | | | | | | |
| Purge pressure, psi | | | | | | | Purge time, sec | | | | | | |
| Heat to TEA tank | | | | | | | | | | | | | |
| Test Sequence | Mix batch number | Sand Mix Time hh:mm | Core Make Time hh:mm | Sand Mix Age @ make hh:mm | Core Break Time hh:mm | Dogbone age @ Break Hours | Make Sequence Number | North Core Weight grams | North Core Tensile psi | Middle Core Weight grams | Middle Core Tensile psi | South Core Weight grams | South Core Tensile psi |
| 1 | 8 | 13:47 | 13:56 | 0:09 | 12:40 | 22.73 | 58 | 111.97 | ND | 111.24 | 279 | 112.09 | 272 |
| 2 | 1 | 10:44 | 11:04 | 0:20 | 12:50 | 25.77 | 9 | 111.68 | 280 | 111.14 | ND | 112.09 | ND |
| 3 | 7 | 13:36 | 13:52 | 0:16 | 13:00 | 23.13 | 56 | 111.93 | ND | 111.27 | 237 | 112.11 | 234 |
| 4 | 3 | 11:23 | 11:34 | 0:11 | 13:10 | 25.60 | 24 | 111.20 | 243 | 110.70 | ND | 111.63 | 247 |
| 5 | 2 | 11:05 | 11:09 | 0:04 | 13:20 | 26.18 | 10 | 112.82 | 226 | ND | 244 | 112.52 | 130 |
| 6 | 5 | 13:04 | 13:09 | 0:05 | 13:30 | 24.35 | 30 | 111.74 | 235 | 111.06 | 241 | 111.87 | 241 |
| 7 | 5 | 13:04 | 13:14 | 0:10 | 13:40 | 24.43 | 34 | 111.80 | 240 | 111.17 | ND | 112.03 | 240 |
| 8 | 1 | 10:44 | 10:59 | 0:15 | 13:47 | 26.80 | 6 | 111.16 | 256 | 111.30 | ND | 111.97 | 235 |
| 9 | 6 | 13:20 | 13:29 | 0:09 | 13:54 | 24.42 | 42 | 111.19 | 233 | 111.97 | 244 | 112.01 | 230 |
| 10 | 5 | 13:04 | 13:11 | 0:07 | 14:01 | 24.83 | 32 | 111.80 | 234 | 111.19 | 229 | 112.00 | 238 |
| 11 | 3 | 11:23 | 11:28 | 0:05 | 14:09 | 26.68 | 20 | 111.40 | 246 | 110.72 | 251 | 111.77 | ND |
| 12 | 3 | 11:23 | 11:31 | 0:08 | 14:16 | 26.75 | 22 | 111.39 | 254 | 110.34 | 244 | 111.61 | 253 |
| 13 | 2 | 11:05 | 11:12 | 0:07 | 14:24 | 27.20 | 12 | 111.52 | 233 | 111.01 | 235 | 111.95 | 241 |
| 14 | 2 | 11:05 | 11:16 | 0:11 | 14:30 | 27.23 | 15 | 111.55 | 216 | 110.87 | 233 | 112.06 | 214 |
| 15 | 1 | 10:44 | 11:03 | 0:19 | 14:37 | 27.57 | 8 | 111.58 | 236 | 111.32 | 265 | 112.08 | 240 |
| 16 | 2 | 11:05 | 11:10 | 0:05 | 14:43 | 27.55 | 11 | 111.72 | 221 | 111.07 | 242 | 111.94 | 219 |
| 17 | 3 | 11:23 | 11:38 | 0:15 | 14:51 | 27.22 | 27 | 111.25 | 233 | 110.49 | 250 | 111.51 | 245 |
| 18 | 3 | 11:23 | 11:37 | 0:14 | 14:58 | 27.35 | 26 | 111.63 | 240 | 110.88 | 249 | 111.80 | 255 |
| 19 | 5 | 13:04 | 13:17 | 0:13 | 15:04 | 25.78 | 36 | 111.82 | 223 | 111.26 | 235 | 111.89 | 231 |
| 20 | 3 | 11:23 | 11:30 | 0:07 | 15:10 | 27.67 | 21 | 111.34 | 232 | 110.37 | ND | 111.81 | 237 |
| 21 | 3 | 11:23 | 11:33 | 0:10 | 15:16 | 27.72 | 23 | 111.44 | 227 | 110.57 | 234 | 111.73 | 238 |
| 22 | 7 | 13:36 | 13:45 | 0:09 | 15:22 | 25.62 | 52 | 111.95 | 216 | 111.30 | 232 | 112.16 | 233 |
| 23 | 2 | 11:05 | 11:14 | 0:09 | 15:28 | 28.23 | 14 | 111.46 | 233 | 110.86 | 237 | 112.01 | 231 |
| 24 | 7 | 13:36 | 13:41 | 0:05 | 15:34 | 25.88 | 49 | 112.21 | 246 | 111.44 | 236 | 112.28 | 236 |
| 25 | 2 | 11:05 | 11:19 | 0:14 | 15:40 | 28.35 | 17 | 111.39 | 232 | 111.95 | 235 | 111.96 | 227 |
| 26 | 8 | 13:47 | 14:02 | 0:15 | 15:46 | 25.73 | 62 | 111.57 | 227 | 111.06 | 242 | 111.84 | 223 |
| 27 | 2 | 11:05 | 11:17 | 0:12 | 15:52 | 28.58 | 16 | 111.63 | 224 | 111.09 | 256 | 112.18 | 226 |
| 28 | 7 | 13:36 | 13:42 | 0:06 | 15:58 | 26.27 | 50 | 111.97 | 246 | 111.31 | 257 | 112.20 | 240 |
| 29 | 1 | 10:44 | 11:01 | 0:17 | 16:04 | 29.05 | 7 | 111.68 | 239 | 111.22 | 242 | 112.11 | 239 |
| 30 | 8 | 13:47 | 13:59 | 0:12 | 16:10 | 26.18 | 60 | 111.72 | 258 | 111.15 | 234 | 111.95 | 230 |
| Average | | | | 0:10 | | 26.36 | | 111.65 | 236.75 | 111.08 | 243.32 | 111.97 | 233.04 |
| St Dev | | | | 0:04 | | 1.52 | | 0.34 | 13.87 | 0.38 | 11.54 | 0.21 | 23.18 |
| Reduced St Dev | | | | | | | | | 0.059 | | 0.047 | | 0.099 |
| 90 % Conf upper limit | | | | 0:18 | | 28.92 | | 112.22 | 260.05 | 111.72 | 262.70 | 112.32 | 271.99 |
| 90 % Conf lower limit | | | | 0:03 | | 23.80 | | 111.08 | 213.45 | 110.44 | 223.94 | 111.62 | 194.09 |
| Conclusion | | | | | | | | | | | | | |

Batch 4 was discarded

## Table B7c. Tensile test results for Klein mixed sand tensile tested in Thwing-Albert Tensile tester.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand Mixer Comparison** | | | | Mix/ make date | | 6/9/2004 | | | Break date | 6/10/2004 | | | |
| **Thwing-Albert Tensile machine** | | | | | | | | **Klein Sand mixer** | | | | | |
| Tensile test Ambient Temperaure, F | | | | | | | | Strain rate, in/sec | | | | | |
| Mix ambient temperature, F | | | | | | | Sand temperature, F | | | | | | |
| Binder | | Ashland 305/904 | | | | | % binder | | 1.4 | | Ratio part 1:part 2 | | |
| Blow Pressure, psi | | | | | | | Blow time, sec. | | | | | | |
| A Gas pressure, psi | | | | | | | A Gas time, sec | | | | | | |
| B Gas pressure, psi | | | | | | | B Gas time, sec | | | | | | |
| Purge pressure, psi | | | | | | | Purge time, sec | | | | | | |
| Heat to TEA tank | | | | | | | | | | | | | |
| Test Sequence | Mix batch number | Sand Mix Time hh:mm | Core Make Time hh:mm | Sand Mix Age @ Make hh:mm | Core Break Time hh:mm | Dogbone age @ Break Hours | Core ID Seq-Cavity | North Core Weight grams | North core Tensile psi | Middle Core Weight grams | Middle Core Tensil psi | South Core Weight grams | South Core Tensil psi |
| 1 | 2 | 11:36 | 11:55:45 | 0:19 | 12:04 | 24.14 | 55 | 111.84 | 279.3 | 111.26 | 285 | 112.04 | 266.8 |
| 2 | 1 | 11:02 | 11:08:30 | 0:06 | 12:07 | 24.98 | 5 | 111.81 | 292.4 | 111.38 | 298.8 | 112.07 | 288.5 |
| 3 | 2 | 11:36 | 11:41:00 | 0:05 | 12:09 | 24.47 | 38 | 111.9 | 283.6 | 111.21 | 291.3 | 112.22 | 287.3 |
| 4 | 2 | 11:36 | 11:42:45 | 0:06 | 12:11 | 24.47 | 40 | 112.09 | 303.8 | 111.1 | 319 | 112.24 | 301.9 |
| 5 | 2 | 11:36 | 11:55:00 | 0:19 | 12:13 | 24.30 | 54 | 111.84 | 219.1 | 111.11 | 244.7 | 112.06 | 268.8 |
| 6 | 2 | 11:36 | 11:45:15 | 0:09 | 12:15 | 24.50 | 43 | 112 | 272.5 | 111 | 281.8 | 112.33 | 282.8 |
| 7 | 2 | 11:36 | 11:40:15 | 0:04 | 12:18 | 24.63 | 37 | 111.82 | 287.1 | 111.27 | 290.9 | 112.35 | 283.8 |
| 8 | 2 | 11:36 | 12:00:50 | 0:24 | 12:20 | 24.32 | 61 | 111.85 | 267.6 | 111.23 | 267.5 | 112.08 | 249.2 |
| 9 | 2 | 11:36 | 11:49:00 | 0:13 | 12:22 | 24.55 | 48 | 111.94 | 268.6 | 111.05 | 287.2 | 112.17 | 259 |
| 10 | 2 | 11:36 | 11:38:40 | 0:02 | 12:24 | 24.76 | 35 | 112.25 | 288.4 | 111.38 | 291.4 | 112.27 | 288.7 |
| 11 | 1 | 11:02 | 11:15:20 | 0:13 | 12:26 | 25.18 | 13 | 111.83 | 266.5 | 111.46 | 284.4 | 112.11 | 286.7 |
| 12 | 1 | 11:02 | 11:06:00 | 0:04 | 12:27 | 25.35 | 2 | 111.88 | 290.9 | 111.35 | 303.3 | 111.97 | 283.9 |
| 13 | 2 | 11:36 | 12:05:50 | 0:29 | 12:28 | 24.37 | 67 | 111.84 | 258.1 | 111.17 | 261 | 112.05 | 262.9 |
| 14 | 2 | 11:36 | 11:46:00 | 0:10 | 13:30 | 25.73 | 44 | 112.01 | 260.7 | 110.97 | 283.2 | 112.35 | 259.1 |
| 15 | 1 | 11:02 | 11:24:50 | 0:22 | 12:32 | 25.12 | 25 | 112.01 | 274.2 | 111.31 | 296.4 | 111.91 | 259.2 |
| 16 | 1 | 11:02 | 11:29:25 | 0:27 | 12:33 | 25.06 | 31 | 111.8 | 257.7 | 111.23 | 264.7 | 111.76 | 272.8 |
| 17 | 1 | 11:02 | 11:07:00 | 0:05 | 12:34 | 25.45 | 3 | 111.84 | 290.5 | 111.42 | 298 | 112.02 | 302.5 |
| 18 | 1 | 11:02 | 11:27:15 | 0:25 | 12:36 | 25.15 | 28 | 111.75 | 267.3 | 111.25 | 259.8 | 111.84 | 258.6 |
| 19 | 2 | 11:36 | 12:04:15 | 0:28 | 12:37 | 24.55 | 65 | 111.94 | 249.5 | 110.91 | 260.7 | 112.19 | 257 |
| 20 | 1 | 11:02 | 11:05:00 | 0:03 | 12:39 | 25.57 | 1 | 112.05 | 305 | 111.43 | 310.9 | 112.15 | 294.3 |
| 21 | 2 | 11:36 | 11:54:20 | 0:18 | 12:40 | 24.76 | 53 | 111.89 | 286.4 | 111.49 | 290.3 | 112.11 | 278.7 |
| 22 | 2 | 11:36 | 11:59:00 | 0:23 | 12:42 | 24.72 | 59 | 112.06 | 264.4 | 111.43 | 288.3 | 112.31 | 276.5 |
| 23 | 1 | 11:02 | 11:31:00 | 0:29 | 12:43 | 25.20 | 33 | 111.83 | 266.7 | 111.35 | 288.6 | 111.92 | 277.3 |
| 24 | 1 | 11:02 | 11:19:30 | 0:17 | 12:45 | 25.43 | 18 | 111.8 | 282.6 | 111.31 | 286.4 | 111.98 | 277.9 |
| 25 | 1 | 11:02 | 11:20:15 | 0:18 | 12:46 | 25.43 | 19 | 111.83 | 274.4 | 111.38 | 276.9 | 112.01 | 272.8 |
| 26 | 1 | 11:02 | 11:07:45 | 0:05 | 12:48 | 25.67 | 4 | 111.77 | 293.8 | 111.36 | 288.5 | 112.01 | 294.9 |
| 27 | 2 | 11:36 | 12:03:10 | 0:27 | 12:54 | 24.85 | 64 | 111.7 | 267.5 | 111.14 | 259.7 | 112.06 | 260.1 |
| 28 | 2 | 11:36 | 11:48:40 | 0:12 | 12:56 | 25.12 | 47 | 111.97 | 285.5 | 110.89 | 271 | 112.3 | 278.4 |
| 29 | 2 | 11:36 | 11:43:25 | 0:07 | 12:58 | 25.24 | 41 | 111.96 | 280.4 | 111.07 | 294.5 | 112.37 | 274.3 |
| 30 | 2 | 11:36 | 12:02:20 | 0:26 | 12:59 | 24.94 | 63 | 111.73 | 261.1 | 111.12 | 246.7 | 111.93 | 270.4 |
| Average | | | | 0:15 | 12:33 | 22:22 | | 111.89 | 274.85 | 111.23 | 282.36 | 112.11 | 275.84 |
| St Dev | | | | 0:09 | 0:18 | 10:40 | | 0.12 | 17.47 | 0.17 | 17.86 | 0.16 | 13.98 |
| Reduces St Dev | | | | | | | | | 0.06 | | 0.06 | | 0.05 |
| 90 % Conf upper limit | | | | 0:31 | 13:05 | 16:18 | | 112.10 | 304.21 | 111.52 | 312.36 | 112.38 | 299.32 |
| 90 % Conf lower limit | | | | 0:00 | 1:00 | 2:00 | | 111.69 | 245.50 | 110.95 | 252.37 | 111.83 | 252.35 |
| Conclusion | | | | | | | | | | | | | |

cores 57 & 46 were faulty and were replaced by cores 67 & 28 respectively

## Table B7d. Tensile test results for Klein mixed sand tensile tested in Dietert 405 Tensile tester.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand Mixer Comparison** | | | | Mix/ make date | | 6/9/2004 | | | Break date | 6/10/2004 | | | |
| **Dietert 405 Tensile Tester** | | | | | | | | **Klein Sand Mixer** | | | | | |
| Tensile test Ambient Temperaure, F | | | | | | | Strain rate, in/sec | | | | | | |
| Mix ambient temperature, F | | | | | | | Sand temperature, F | | | | | | |
| Binder | | | Ashland 305/904 | | | | % binder | | 1.4 | | Ratio part 1: | 55:45 | |
| Blow Pressure, psi | | | | | | | Blow time, sec. | | | | | | |
| A Gas pressure, psi | | | | | | | A Gas time, sec | | | | | | |
| B Gas pressure, psi | | | | | | | B Gas time, sec | | | | | | |
| Purge pressure, psi | | | | | | | Purge time, sec | | | | | | |
| Heat to TEA tank | | | | Operator | | | Operator | | | Operator | | | |
| Test Sequence | Mix batch number | Sand Mix Time hh:mm | Core Make Time hh:mm | Sand Mix Age @ Make hh:mm | Core Break Time hh:mm | Dogbone age @ Break Hours | Core ID Seq-Cavity | Core Weight grams | Core Tensil psi | Core Weight grams | Core Tensil psi | Core Weight grams | Core Tensil psi |
| 1 | 2 | 11:36 | 11:58:10 | 0:22 | 12:20 | 24.36 | 58 | 111.83 | 212 | 111.33 | 218 | 112.18 | 204 |
| 2 | 1 | 11:02 | 11:12:20 | 0:10 | 12:25 | 25.21 | 9 | 111.85 | 230 | 111.32 | 224 | 111.98 | 214 |
| 3 | 2 | 11:36 | 11:56:30 | 0:20 | 12:30 | 24.56 | 56 | 111.95 | 208 | 111.4 | 206 | 112.14 | 198 |
| 4 | 1 | 11:02 | 11:24:00 | 0:22 | 12:35 | 25.18 | 24 | 111.91 | 218 | 111.32 | 214 | 111.95 | 212 |
| 5 | 1 | 11:02 | 11:13:00 | 0:11 | 12:40 | 25.45 | 10 | 111.9 | 222 | 111.48 | 222 | 112.01 | 214 |
| 6 | 1 | 11:02 | 11:28:45 | 0:26 | 12:45 | 25.27 | 30 | 111.9 | 212 | 111.26 | 192 | 111.83 | 188 |
| 7 | 1 | 11:02 | 11:31:40 | 0:29 | 12:50 | 25.31 | 34 | 111.8 | 212 | 111.06 | 214 | 111.88 | 204 |
| 8 | 1 | 11:02 | 11:09:30 | 0:07 | 12:55 | 25.76 | 6 | 111.63 | 186 | 111.34 | 226 | 111.95 | 228 |
| 9 | 2 | 11:36 | 11:44:30 | 0:08 | 13:00 | 25.26 | 42 | 111.92 | 210 | 110.88 | 218 | 112.28 | 222 |
| 10 | 1 | 11:02 | 11:30:10 | 0:28 | 13:03 | 25.55 | 32 | 111.79 | 204 | 111.3 | 216 | 111.82 | 208 |
| 11 | 1 | 11:02 | 11:21:05 | 0:19 | 13:08 | 25.78 | 20 | 111.92 | 214 | 111.37 | 220 | 112.02 | 206 |
| 12 | 1 | 11:02 | 11:22:30 | 0:20 | 13:12 | 25.83 | 22 | 111.76 | 216 | 111.39 | 222 | 111.98 | 218 |
| 13 | 1 | 11:02 | 11:14:35 | 0:12 | 13:22 | 26.12 | 12 | 111.79 | 222 | 111.32 | 236 | 112 | 212 |
| 14 | 1 | 11:02 | 11:17:00 | 0:15 | 13:27 | 26.17 | 15 | 111.95 | 216 | 111.5 | 210 | 112.04 | 214 |
| 15 | 1 | 11:02 | 11:11:20 | 0:09 | 13:32 | 26.34 | 8 | 111.77 | 204 | 111.39 | 224 | 111.95 | 208 |
| 16 | 1 | 11:02 | 11:13:45 | 0:11 | 13:36 | 26.37 | 11 | 111.69 | 226 | 111.34 | 192 | 112.04 | 234 |
| 17 | 1 | 11:02 | 11:26:25 | 0:24 | 13:41 | 26.24 | 27 | 111.87 | 214 | 111.3 | 224 | 111.95 | 202 |
| 18 | 1 | 11:02 | 11:25:35 | 0:23 | 13:46 | 26.34 | 26 | 111.83 | 210 | 111.24 | 210 | 112.01 | 212 |
| 19 | 2 | 11:36 | 11:39:30 | 0:03 | 13:50 | 26.18 | 36 | 111.9 | 222 | 111.49 | 222 | 112.43 | 220 |
| 20 | 1 | 11:02 | 11:21:45 | 0:19 | 13:55 | 26.55 | 21 | 111.86 | 218 | 111.34 | 222 | 111.99 | 220 |
| 21 | 1 | 11:02 | 11:23:15 | 0:21 | 14:00 | 26.61 | 23 | 111.9 | 216 | 111.23 | 210 | 111.83 | 210 |
| 22 | 2 | 11:36 | 11:53:30 | 0:17 | 14:04 | 26.18 | 52 | 111.88 | 216 | 111.18 | 220 | 112.11 | 210 |
| 23 | 1 | 11:02 | 11:16:10 | 0:14 | 14:09 | 26.88 | 14 | 112.01 | 216 | 111.4 | 220 | 112.09 | 220 |
| 24 | 2 | 11:36 | 11:50:50 | 0:14 | 14:15 | 26.40 | 49 | 111.92 | 214 | 110.73 | 220 | 112.16 | 210 |
| 25 | 1 | 11:02 | 11:18:45 | 0:16 | 14:19 | 27.00 | 17 | 111.9 | 212 | 111.39 | 220 | 112.02 | 214 |
| 26 | 2 | 11:36 | 12:01:35 | 0:25 | 14:24 | 26.37 | 62 | 111.79 | 204 | 111.12 | 214 | 112.03 | 210 |
| 27 | 1 | 11:02 | 11:17:45 | 0:15 | 14:29 | 27.19 | 16 | 111.77 | 210 | 111.36 | 210 | 111.96 | 204 |
| 28 | 2 | 11:36 | 11:51:40 | 0:15 | 14:35 | 26.72 | 50 | 111.92 | 208 | 110.98 | 213 | 112.17 | 198 |
| 29 | 1 | 11:02 | 11:10:20 | 0:08 | 14:40 | 27.49 | 7 | 111.73 | 228 | 111.43 | 220 | 112.12 | 198 |
| 30 | 2 | 11:36 | 11:59:50 | 0:23 | 14:46 | 26.77 | 60 | 111.84 | 208 | 111.27 | 218 | 112.12 | 220 |
| Average | | | | 0:17 | | 26.05 | | 111.85 | 213.60 | 111.28 | 216.57 | 112.03 | 211.07 |
| St Dev | | | | 0:06 | | 0.75 | | 0.08 | 8.49 | 0.18 | 9.00 | 0.13 | 9.58 |
| Reduced St. Dev. | | | | | | | | | 0.04 | | 0.04 | | 0.05 |
| 90 % Conf upper limit | | | | 0:28 | | 27.31 | | 111.99 | 227.87 | 111.58 | 231.69 | 112.26 | 227.16 |
| 90 % Conf lower limit | | | | 0:05 | | 24.79 | | 111.71 | 199.33 | 110.99 | 201.44 | 111.81 | 194.97 |

## Table B7e Summary of Tensile test data from tables B7a-d

| | Sand Mix Age @ Make hh:mm | Dogbone age @ Break Hours | North Core Weight grams | North Core Tensil psi | Middle Core Weight grams | Middle Core Tensil psi | South Core Weight grams | South Core Tensil psi | dogbone cavity average Tensile |
|---|---|---|---|---|---|---|---|---|---|
| T-A Hobart | | | | | | | | | |
| Average | 0:12 | 24.10 | 111.91 | 303.82 | 111.20 | 307.42 | 112.04 | 293.4 | **301.55** |
| St Dev | 0:04 | 1.26 | 0.53 | 10.73 | 0.27 | 21.72 | 0.14 | 32.4 | **21.62** |
| Reduced St Dev | | | | 0.035 | | 0.071 | | 0.110 | **0.072** |
| 90 % Conf upper limit | 0:19 | 26.21 | 112.79 | 321.84 | 111.66 | 343.91 | 112.27 | 347.8 | **337.87** |
| 90 % Conf lower limit | 0:05 | 21.99 | 111.02 | 285.79 | 110.74 | 270.93 | 111.81 | 239.0 | **265.24** |
| 405 Hobart | | | | | | | | | |
| Average | 0:10 | 26.36 | 111.65 | 236.75 | 111.08 | 243.32 | 111.97 | 233.04 | **237.70** |
| St Dev | 0:04 | 1.52 | 0.34 | 13.87 | 0.38 | 11.54 | 0.21 | 23.18 | **16.20** |
| Reduced St Dev | | | | 0.059 | | 0.047 | | 0.099 | **0.068** |
| 90 % Conf upper limit | 0:18 | 28.92 | 112.22 | 260.05 | 111.72 | 262.70 | 112.32 | 271.99 | **264.91** |
| 90 % Conf lower limit | 0:03 | 23.80 | 111.08 | 213.45 | 110.44 | 223.94 | 111.62 | 194.09 | **210.49** |
| T-A Klein | | | | | | | | | |
| Average | 0:15 | 24.93 | 111.89 | 274.85 | 111.23 | 282.36 | 112.11 | 275.84 | **277.68** |
| St Dev | 0:09 | 0.44 | 0.12 | 17.47 | 0.17 | 17.86 | 0.16 | 13.98 | **16.44** |
| Reduces St Dev | | | | 0.064 | | 0.063 | | 0.051 | **0.059** |
| 90 % Conf upper limit | 0:31 | 25.68 | 112.10 | 304.21 | 111.52 | 312.36 | 112.38 | 299.32 | **305.30** |
| 90 % Conf lower limit | 0:00 | 0.08 | 111.69 | 245.50 | 110.95 | 252.37 | 111.83 | 252.35 | **250.07** |
| 405 Klein | | | | | | | | | |
| Average | 0:17 | 26.05 | 111.85 | 213.60 | 111.28 | 216.57 | 112.03 | 211.07 | **213.74** |
| St Dev | 0:06 | 0.75 | 0.08 | 8.49 | 0.18 | 9.00 | 0.13 | 9.58 | **9.03** |
| Reduced St. Dev. | | | | 0.040 | | 0.042 | | 0.045 | **0.042** |
| 90 % Conf upper limit | 0:28 | 27.31 | 111.99 | 227.87 | 111.58 | 231.69 | 112.26 | 227.16 | **228.91** |
| 90 % Conf lower limit | 0:05 | 24.79 | 111.71 | 199.33 | 110.99 | 201.44 | 111.81 | 194.97 | **198.58** |

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# APPENDIX C GLOSSARY

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# Glossary

| | |
|---|---|
| **% LOI** | Loss on Ignition: a gravimetric weight change test where a dried sample is weighted before and after being burned in air at 1800$^{o}$F. Weight change is expressed as % of original weight. |
| **Mean** | Average |
| **Mixedness** | A measure of the uniformity of distribution of one set of materials in a matrix of another material. |
| **Standard Deviation** | A statistical measure of dispersion about a mean value |