Casting Emission Reduction Program

Prepared by:

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Acoustic Stimulation of Cast Aluminum

Technikon #1409-132FG

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Acoustic Stimulation of Cast Aluminum

1409-132-FG

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

Process Engineering Manager:	*// Original Signed //* Steven Knight	Date
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VP Operations:	*// Original Signed //* George Crandell	Date
President:	*// Original Signed //* William Walden	Date

The data contained in this report were developed to assess the relative metal feeding characteristics of an acoustically stimulated A-356 aluminum casting produced at the Technikon casting facility. You may not obtain the same results in your facility. Data was not collected to assess casting cost, manufacturing methodology, or environmental impact.

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Executive Summary

This report contains the results of acoustic stimulation of A-356 aluminum castings as they are solidifying. The castings were prepared in No-Bake molds made at the Technikon, LLC production foundry using the No-Bake mold making facility.

The objective of this test was to determine if acoustic stimulation during solidification promoted improved feeding of the metal to remote portions of the casting or improved internal feeding of the casting from the riser to reduce porosity.

A pattern was made as a star casting that had progressively thinner fin sections on the drag (bottom) pattern half. Eight pairs of No-Bake molds were poured with A-356 aluminum. One of each pair was stimulated with resonant frequency acoustic energy while the other was not. Eight pairs of the molds were poured to develop a methodology that, based on the results, optimized the opportunity to provide acoustic energy at critical periods of cavity filling and solidification.

The metal was poured at a temperature where success would be marginal so as to demonstrate whether the acoustic stimulation was having an effect on the filling and feeding characteristics.

The castings were instrumented with thermocouples to monitor the solidification. The pairs of molds were poured sequentially from the same heated ladle in order to make the pouring conditions as identical as possible.

The castings were sectioned through the various riser configurations and along the casting feed path leading to the heavier section in the center of the casting. There was some indication that the solidification in the casting was delayed by acoustic stimulation.

No pair of castings showed a systematic improvement in feed capability, as evidenced by a more complete casting, with acoustic stimulation compared to no stimulation.

Some castings had surface shrinkage at the casting center indicative of isolation from the riser but the acoustic stimulation, as performed, did not mitigate this defect.

This testing failed to demonstrate that acoustic stimulation promoted better metal feeding capability by acoustic thermal pumping and/or acoustic breakdown of dendrite growth. However, these aspects were promising enough to suggest that further experimentation should be planned.

The risers on the acoustic stimulated casting contained less metal – indicating metal was displaced by the acoustic stimulation probe. This displaced metal translates to less energy being used to produce the test casting. All castings were free of internal porosity throughout the feeder to the casting center, showing this decrease in metal in riser didn't affect the casting quality.

It must be noted that the reference and product testing performed is not suitable for use as emission factors or for purposes other than evaluating the relative emission reductions associated with the use of alternative materials, equipment, or processes. The emissions measurements are unique to the specific castings produced, materials used, and testing methodology associated

with these tests, and should not be used as the basis for estimating emissions from actual commercial foundry applications.

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 Technikon Objectives

The primary objective of Technikon is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was designed to evaluate alternate materials and production processes designed to achieve significant air emission reductions, especially for the 1990 Clean Air Act Amendment. The facility has two principal testing arenas: a Pre-Production Foundry designed to measure airborne emissions from individually poured molds, and a Production Foundry designed to measure air emissions in a continuous full scale production process. Each of these testing arenas has been specially designed to facilitate the collection and evaluation of airborne emissions and associated process data.

The Production 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 Production 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.

It must be noted that the results from the reference and product testing performed are not suitable for use as emission factors or for other purposes other than evaluating the relative emission reductions associated with the use of alternative materials, equipment, or manufacturing processes. The emissions measurements are unique to the specific castings produced, materials used, and testing methodology associated with these tests. These measurements should not be used as the basis for estimating emissions from actual commercial foundry applications.

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 corrosion rate for thin wall castings. Section 2 of this report includes a summary of the methodologies used for data collection and analysis and data management. Specific data collected during this test are summarized in Section 3 of this report. Appendix B of this report includes the complete pouring log.

1.4 Specific Test Plan and Objectives

The Test Plan to make the molds and castings is included in Appendix A. The objectives of this testing were to determine whether the acoustic stimulation of liquid aluminum during filling of the casting cavity and during solidification would:

a) Cause the metal flow farther at a given temperature and thereby reduce the thermal energy to successfully pour aluminum castings.
b) Cause the metal in the riser to feed for a longer period of time allowing reduced riser size to back fill internal shrinkage in the casting and thereby reducing the amount of energy necessary to produce porosity free aluminum castings.

Table 1-1 provides a summary of the test plan for the No-Bake mold making. The details of the approved test plans are included in Appendix A.

Table 1-1 Test Plan Summary

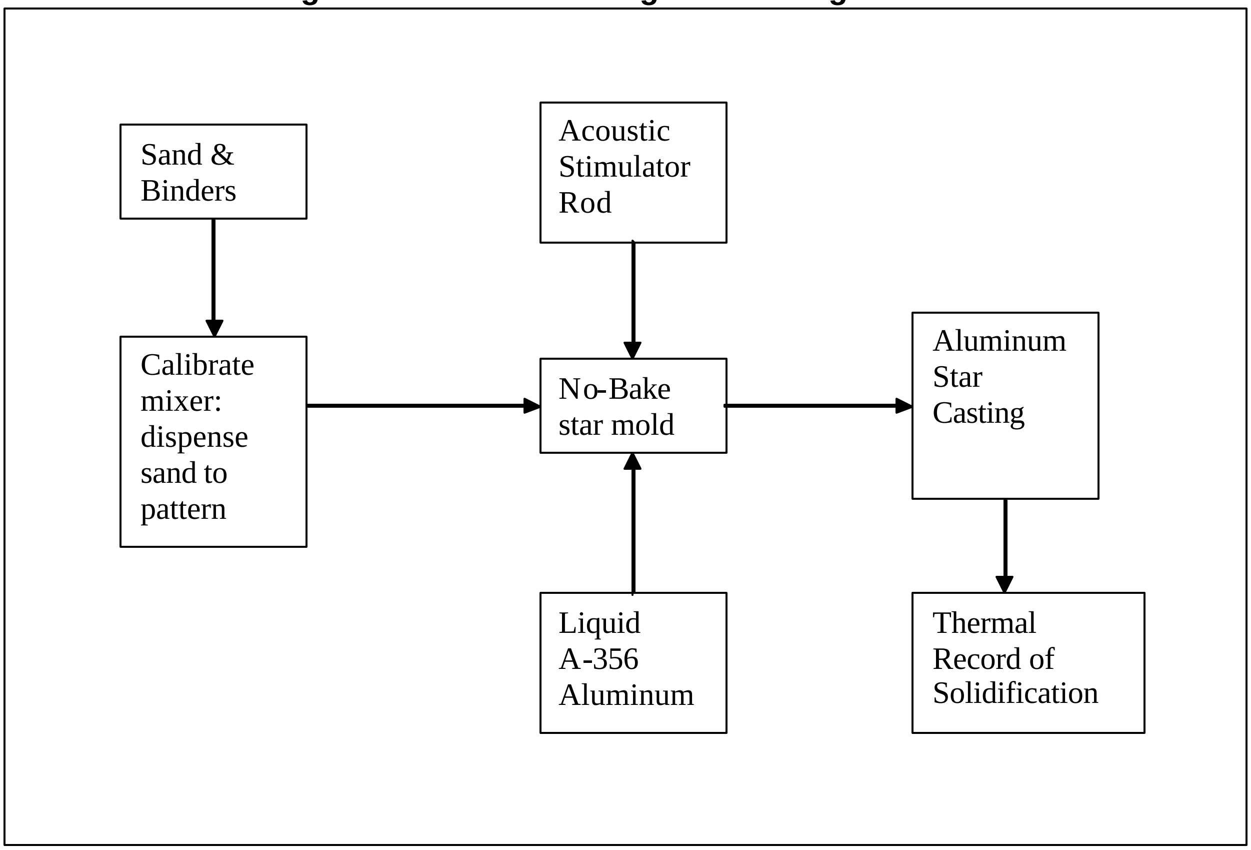
	Test FG
Type of Process Tested	Optimization of Aluminum Casting Resulting from Acoustic Stimulation
Test Plan Number	1409-132-FG
Binder System	Phenolic Urethane No-Bake HA-International TECHNISET ® 20-665; 23-635; 17-727
Number of Molds	16: 8 for Stimulation , 8 for non-stimulated comparison
Foundry Test Date	5/13/03 > 5/14/03
Process Parameters Measured	No-Bake binder content, Metal weight, Aluminum pour temperature, pour time, Thermal solidification data

2.0 Test Methodology

2.1 Description of Process and Testing Equipment

Figure 2-1 is a diagram of the No-Bake mold making process and testing equipment.

Figure 2-1 Mold Making and Testing Process



2.2 Description of Testing Program

The specific steps used in this sampling program are summarized below:

1. **<u>Test Plan Review and Approval:</u>** The proposed test plan was reviewed by the Technikon staff and the CERP Steering Committee, and approved.

2. **<u>Sand Preparation</u>:** Sands were mixed with quantities of designated binders in a Kloster paddle mixer. The sand was preheated or cooled as required to a standard temperature

range. The sand was mixed thoroughly and then dispensed at approximately 100 lbs/min into a pair of 12 x 16 x 6 inch flasks containing a 1-on star matchplate pattern.

3. **Mold Preparation:** No-Bake molding line. Mixed sand was dispensed into snap-flasks. Once the flasks were about one-half full, the vibration table was started to compact the mixed sand and it continued for an additional five (5) seconds after the flask was full. The excess sand was struck off and removed from the test enclosure.

No-Bake Mold Line with Total Enclosure

4. Where new core materials are being evaluated, initial core emissions base-line data are gathered by placing five step-block cores under an**Process Parameter Measurements:** Table 2-1 lists the process parameters that are monitored during each test. The analytical equipment and methods used are also listed.

Table 2-1 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Binder Weight (mixing)	Mettler PJ8000 Digital Scale (Gravimetric)
Sand Weight (mixing)	OHAUS 110# digital platform scale
Sand Temperature (mixing)	Stem type dial thermometer
Cycle Time	Digital elapsed time clocks
Mold Weight	Cardinal 748 Digital Platform Scale
Cooling curve	Thermocouple and multi-channel recorder

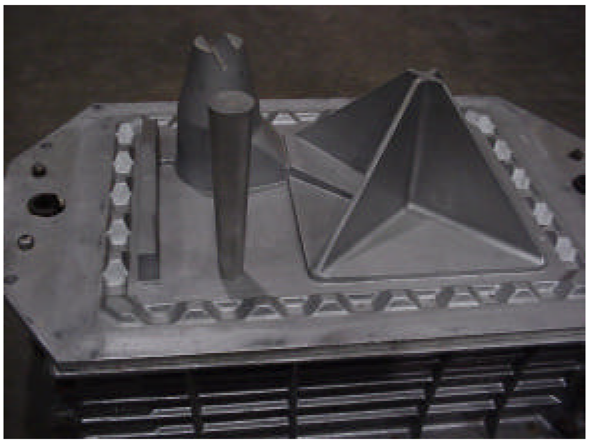
5. **Casting Process:** A single one-on Star pattern was built to be used in this test that had variable fin thickness in the drag pattern. These thicknesses were 2.5 millimeters, 3.0 millimeters, 3.5 millimeters and 4 millimeters measured along the free edge. The standard fin thickness in the cope pattern is 5.3 millimeters

Variable finned Star Casting with Riser and Gating

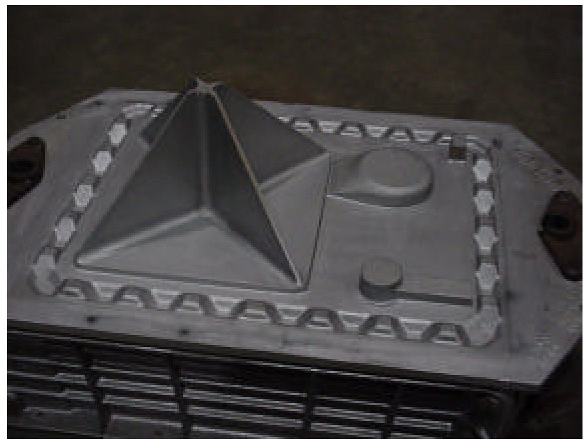
6. **Metal Stimulation:** Sixteen molds were prepared and poured with aluminum in pairs. One of each pair was

acoustically stimulated from the start of pour to the end of solidification. The castings were lightly cleaned with a wire brush.

7. **<u>Report Preparation and Review</u>:** The Preliminary Draft Report is reviewed by the Manager, Process Engineering 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 and the Vice President-Operations. Comments are incorporated into a Final Report prior to final signature approval and distribution.



Single Star Cope Pattern with Fixed Thickness Fins



Single Star Drag Pattern with Variable Thickness Fins

Metal being acoustically stimulated. Stimulation continued after pouring was done until the casting was solidified

Mold after being poured and stimulated. Shows stimulation hole in rear where stimulator was and flow off vent in front. Aluminum was poured in box and drained to level of top of mold

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3.0 Test Results

In the descriptions of the following figures, in the casting identification, a "P" indicates plain un-stimulated and an "S" indicates a stimulated casting

Figure 3-1 Castings FG001P and FG001S

Castings FG001P (left) and FG001S (right) were cast upright as shown. The risers were broken off during shakeout due to the metal having barely solidified. The drag cavities both had misrun due to interrupted metal flow jetting across the shallow based riser. Metal entered the cavity before the exciter was touching the metal in the riser. FG001P had a vented riser. The riser for FG001S was necessarily open to accommodate the stimulator rod. Poured at 1252 Deg F.

Figure 3-2 Castings FG002P and FG002S

Castings FG002P (left) and FG002S (right) were cast upright as shown. Both drag cavities had misrun due to interrupted metal jetting across the shallow based riser. Metal entered the cavity before the exciter touched the metal in the riser. FG002P had a vented riser. The riser for FG002S was necessarily open to accommodate the stimulator rod. FG002S had surface shrinkage on the riser neck. Poured at 1258 Deg F.

Figure 3-3 Castings FG003P and FG003S

Castings FG003P (left) and FG003S (right) were cast upright as shown. Both drag cavities had misrun due to interrupted flow. Metal entered the cavity before the exciter touched the metal in the riser. A Data Cast thermocouple cup was imbedded in the respective risers to record the solidification of the riser. Both thermo-

couples failed. The pour temperature was raised 50°F to make the casting less prone to misrun. The extra heat was ineffective indicating that the misrun was due to internal splashing of the initial metal. FG003P had a vented riser. The riser for FG003S was necessarily open to accommodate the stimulator rod. Poured at 1314 Deg F.

Figure 3-4 Castings FG004P and FG004S

Castings FG004P (left) and FG004S (right) were cast upright as shown. Both drag cavities had misrun due to interrupted metal jetting across the shallow based riser. Metal entered the cavity before the exciter touched the metal in the riser. Both casting risers had simple thermocouples successfully embedded in the center of their respective risers to profile the riser solidification. FG004P was a closed riser. The riser for FG004S was necessarily open to accommodate the stimulator rod. Poured at 1273 Deg F.

Figure 3-5 Thermal Profile from FG004P and FG004S

Thermal Profile of the center of the risers from castings FG004P and FG004S. The better insulation of the closed riser in FG004P is apparent in the elongated final solidification. FP004P was poured about 35 seconds earlier than FG004S. The vertical time lines are seven minutes apart.

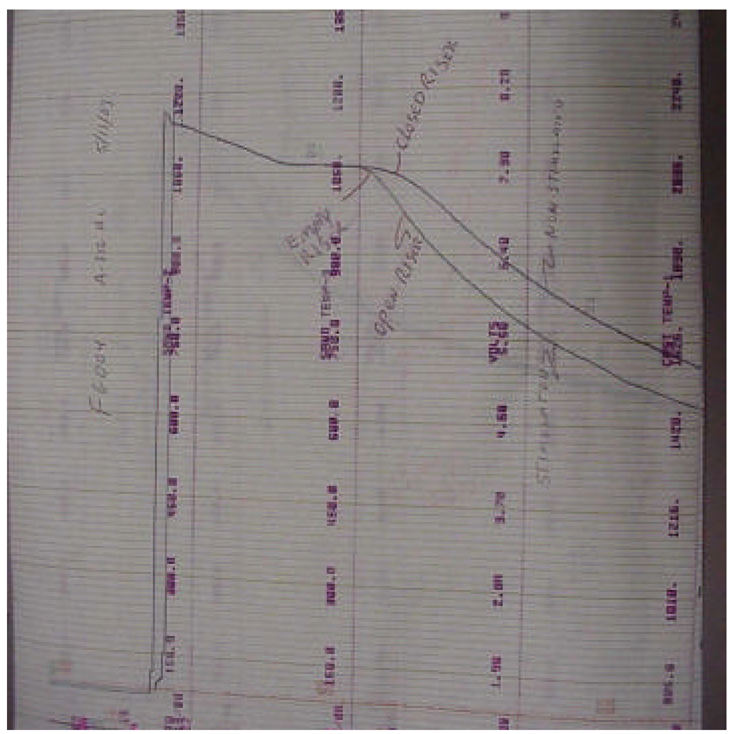
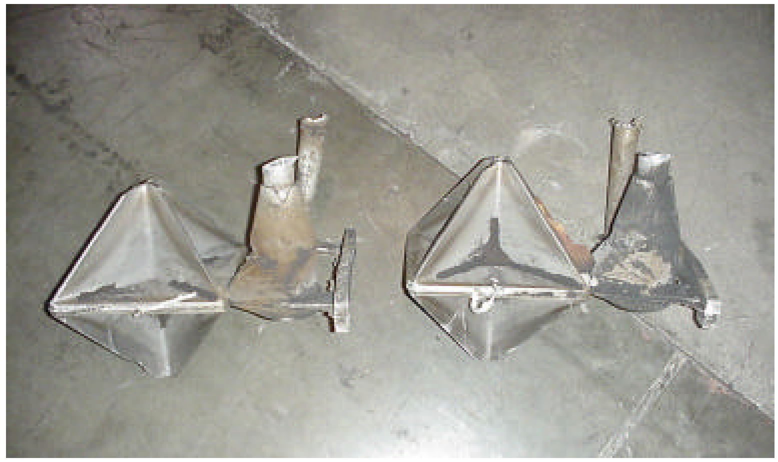


Figure 3-6 Castings FG005P and FG005S



Castings FG005P (left) and FG005S (right) were cast upright as shown. However both molds were inclined 11 degrees with the riser end down so that metal would not jet across into the cavity to cause a misrun and the stimulator rod could contact the metal before the metal entered the cavity. There is no residual evidence, one way or the other, that the stimulator actually contacted the metal before the metal entered the cavity. FG005P had a vented riser. The riser for FG005S was necessarily open to accommodate the stimulator rod. Poured at 1284^{o}F, stimulator frequency 1520-1530 Hertz.

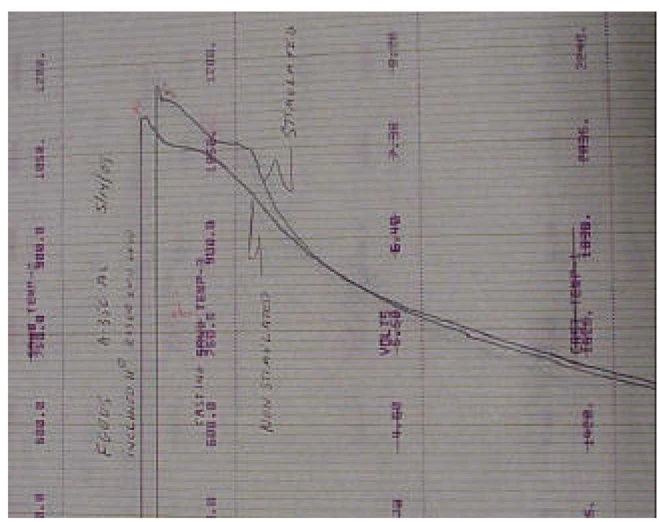
Figure 3-7 FG005P and FG005S.

Neither of the drag cavities had a misrun. FG005P had cope misrun but FG005S did not. Neither cavity exhibited any surface evidence of shrinkage. Both casting had simple thermocouples successfully embedded in the center of their respective castings via the parting line.

Figure 3-8 Risers and Gating Connection to Casting for FG005P and FG005S

FG005P (top) was a vented riser. The cavity for the tip of the stimulating rod is apparent in FG005S (bottom) and demonstrates where the rod was at the end of the riser solidification. At the end of pouring the riser cavities were initially full. Except for the good shrinkage cavity, the porosity free casting, neck, and riser are evidence of the correct solidification order.

Figure 3-9 Thermal Profile of the Center of the Castings - FG005P and FG005S



FP005P was poured about 35 seconds earlier than FG005S. Differences in curve shape are partially due to the effects of stimulation. They also reflect the speed at which the mold filled to the thermocouple location and the actual geometric position of the thermocouple relative to the thermal center of the casting. The lack of the initial arrest at the beginning of the un-stimulated FG0005P is evidence that at the location of the thermocouple metal freezing had begun before the thermocouple had caught up to the metal temperature. The slope of the curves at the end of solidification could be interpreted as either effects of stimulation or geometric asymmetry. For example, in FG005P the more gradual transition at the end of solidification could be interpreted as the freezing front passing through the thermocouple bcation towards the location of the last metal to solidify, whereas, for FG005S the thermocouple was at the location of the last metal to solidify. The vertical time lines are seven minutes apart.

Figure 3-10 Castings FG006S and FG006P

Castings FG006S (left) and FG006P (right) were cast up-side-down as shown. The original riser configuration was pointing down so that metal would not jet across into the cavity to cause a misrun and the stimulator rod could contact the metal long before the metal entered the cavity. There is clear residual evidence (see Figure 12) that the stimulator actually contacted the metal before the metal entered the cavity. FG006P was a vented riser. The riser for FG006S was necessarily open to accommodate the stimulator rod. This pair of casting and all subsequent castings were poured after some metal had been pigged from the ladle to preheat the ladle spout in order to have the pour temperature more nearly the same for both castings. Poured at 1306°F, stimulator frequency 1480-1520 Hertz.

Figure 3-11 Castings FG006P and FG006S

Castings FG006P (left) and FG006S (right) were cast up-side-down as shown. Both drag cavities acting as copes had slight misrun. Both cavities exhibited surface shrinkage as would be expected without the pressure head of the riser. Both castings had simple thermocouples successfully embedded in the center of their respective castings via the parting line.

Figure 3-12 Risers and Gating Connections to Castings FG006P and FG006S

FG006P (top) had a vented riser. The cavity for the tip of the stimulating rod is apparent in FG006S (bottom) and demonstrates where the rod was at the end of the riser solidification. This demonstrates the potential of using stimulation to reduce the amount of metal in risers, therefore saving energy used in melting. At the end of pouring the riser cavities were initially full. Except for the small shrinkage cavity, the porosity free nearby casting, neck, and riser are evidence of the correct solidification order. The shrinkage in the castings, however, is evidence that the up-side-down riser, as the metal source, had inadequate head pressure. The risers froze off from the center of the castings before the casting completely froze causing the castings to feed upon their selves.

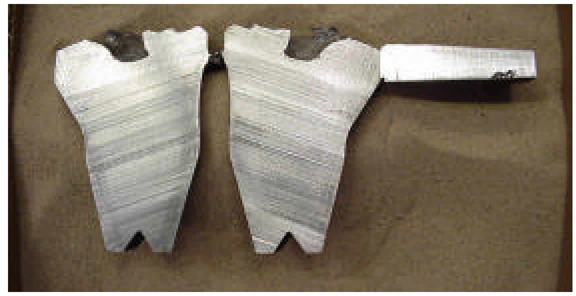


Figure 3-13 Thermal Profile of the Center of Castings -FG006P and FG006S

FP006P was poured about 35 seconds earlier than FG006S. Differences in curve shape are mostly from this time shift. The vertical time lines are seven minutes apart.

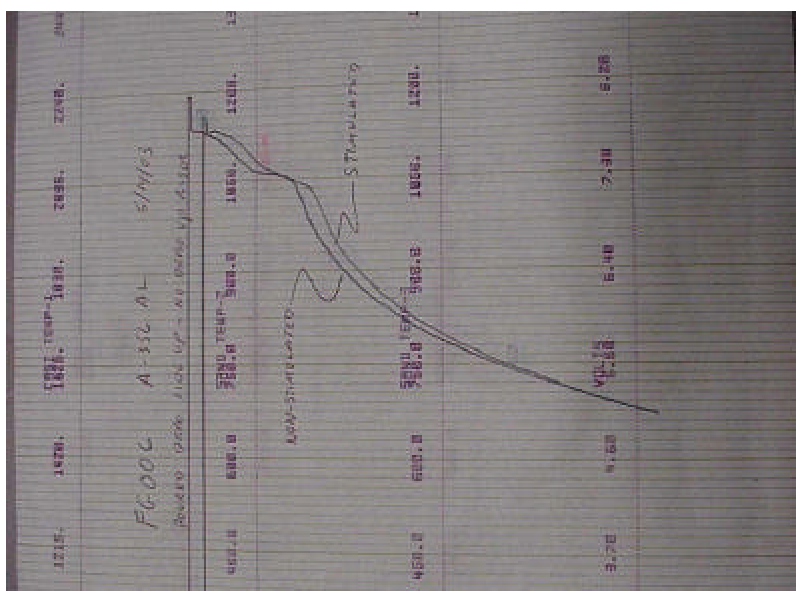
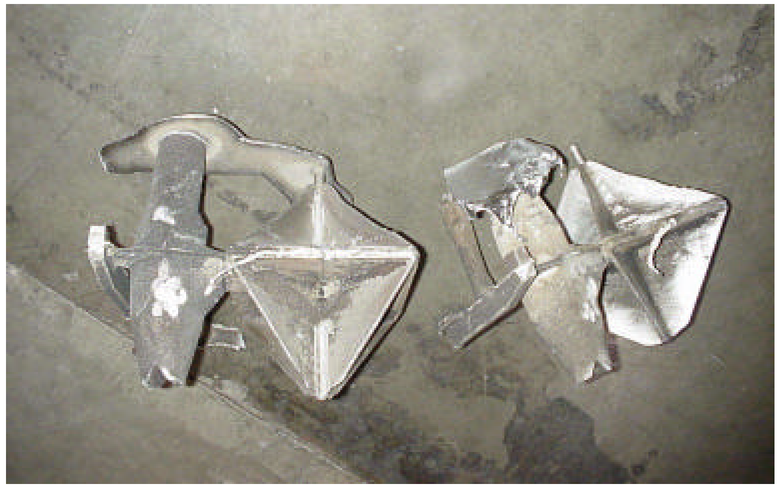
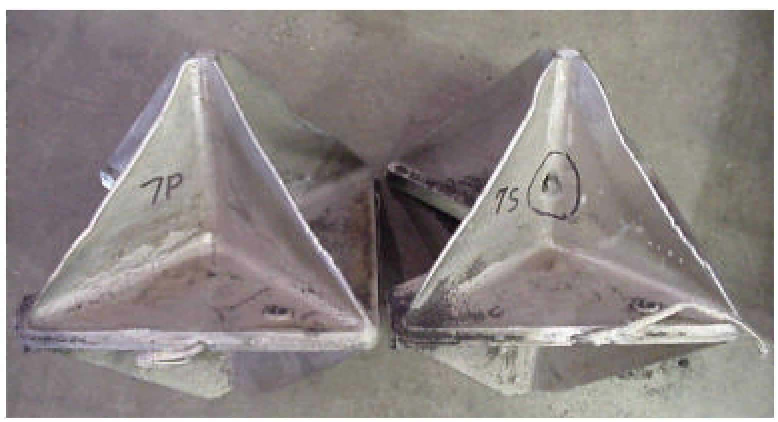


Figure 3-14 Castings FG007S and FG007P



Castings FG007S (left) and FG007P (right) were cast up-side-down as shown The original riser configuration was pointing down so that metal would not jet across into the cavity to cause a misrun and the stimulator rod could contact the metal long before the metal entered the cavity. A similar hand cut riser was added into the upward-pointing drag (acting as a cope) to provide a functioning riser. The new riser addition was not fully sized to the casting requirements as was the original riser. FG007P had a vented riser. The riser for FG007S was necessarily open to accommodate the stimulator rod. Poured at 1279°F, stimulator frequency 975-985 Hertz.

Figure 3-15 Castings FG007P and FG007S



Castings FG007P (left) and FG007S (right) were cast up-side-down as shown. Both drag cavities acting as copes had slight misrun as shown above. FG007S unexpectedly exhibited surface shrinkage. It is possible that the hand cut riser being smaller than the original riser froze too early causing the casting to feed on itself. Both castings had simple thermocouples successfully embedded in the center of their respective castings via the parting line.

Figure 3-16 Risers and Gating Connections to Castings - FG007P and FG007S

For castings FG007P (top) and FG007S (bottom) at the end of pouring the riser cavities were initially full. There is no clear residual evidence that the stimulator did actually contact the metal before the metal entered the cavity. The cavity for the tip of the stimulating rod at the end of the riser solidification is not apparent but lies in the right side of the FG006S riser at the large holes under the purple line. The shrinkage in this casting was fed from the location of the tip of the stimulator rod. This riser suggests that significant cavitation was occurring creating a de-facto vent to atmosphere. Except for the good shrinkage cavity on FG007P and the multitude of bubble cavities in FG007S, the porosity free nearby casting, neck, and riser are evidence of the correct solidification order. But the shrinkage in the FG0007S casting is evidence that the riser addition as a metal source had frozen off from the center of the casting before the casting completely froze causing the casting to feed upon itself.

Figure 3-17 Thermal Profile of the Center of Castings - FG007P and FG007S

FP007P was poured about 35 seconds earlier than FG007S. Differences in curve shape are mostly from this time shift. The vertical time lines are seven minutes apart.

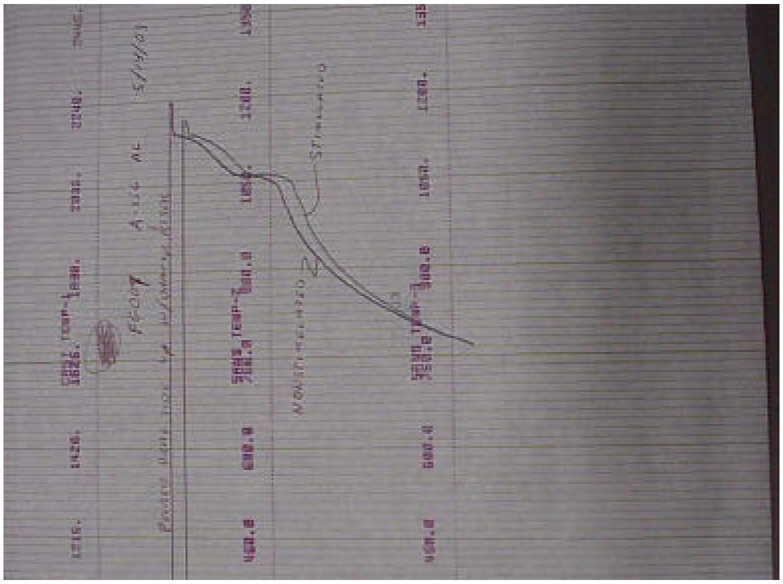


Figure 3-18 FG008P and FG008S

FG008P is on the left and FG008S is on the right. FG008P is shown inverted to the pour orientation. FG008S is shown as poured. Casting set 8 repeated set 7 but with slightly larger diameter riser additions to eliminate premature riser freeze off, was poured hotter to eliminate misrun, and the stimulation frequency was altered to increase the coupled power to the metal. The misrun was not eliminated but the shrinkage was. Poured at 1350°F, stimulation frequency 1384-1577 Hertz.

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4.0 Discussion of Results

This report contains the results of acoustic stimulation of A-356 aluminum castings as they are solidifying. The castings were made in No-Bake molds made at the Technikon, LLC production foundry using the No-Bake mold making facility.

The objective of this test was to determine if acoustic stimulation during solidification promoted improved feeding of the metal to remote portions of the casting or improved internal feeding of the casting from the riser to reduce porosity. Additionally, the reduction of riser size or volume was also to be reviewed.

A pattern was made for the star casting that had progressively thinner fin sections on the drag (bottom) pattern half. Eight pairs of No-Bake molds were poured with A-356 aluminum. One of each pair was stimulated with resonant frequency acoustic energy while the other was not. Four pairs of the molds were poured to develop a methodology that, based on the results, optimized the opportunity to provide acoustic energy at critical periods of cavity filling and solidification.

The metal was poured at a temperature where success would be marginal so as to demonstrate whether the acoustic stimulation was having an effect on the filling and feeding characteristics. The castings were instrumented with thermocouples to monitor the solidification. The pairs of molds were poured sequentially from the same heated ladle in order to make the pouring conditions as identical as possible.

The castings were sectioned through the various riser configurations and along the casting feed path leading to the heavier section in the center of the casting to demonstrate any internal porosity. None was found.

No pair of castings showed a systematic improvement in filling with acoustic stimulation as evidenced by a more complete casting.

All castings were free of internal porosity through out the feeder to the casting center.

Some castings had surface shrinkage at the center indicative of isolation from the riser but the acoustic stimulation, as performed, did not mitigate this defect.

Positive results were obtained in reducing the volume of metal in the risers due to the stimulation rod displacing metal. The size of the rod used in these tests was 3/8”. Further testing needs to be done with larger rod sizes to determine the potential in reducing volume of metal needed in this riser design.

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APPENDIX A APPROVED TEST PLAN FOR TEST FG

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TECHNIKON TEST PLAN

> **CONTRACT NUMBER:** 1409 **TASK NUMBER:** 1.3.2 **Series:** FG

> **WORK ORDER NUMBER**: 1181

> **SAMPLE EVENTS:** No emission sampling

> **SITE**: X **PRE-PRODUCTION** ___ **FOUNDRY**

> **TEST TYPE:** Process optimization study: Improving cast metal feeding with acoustic stimulation.

> **METAL TYPE:** A-356 Aluminum

> **MOLD TYPE:** 1-on No-Bake star mold made with HA 7211/7206 binder with 17-727 activator

> **NUMBER OF MOLDS**: 20.

> **CORE TYPE:** None

> **TEST DATE:** **START:** 7 May 2003

FINISHED: 12 May 2003

TEST OBJECTIVES:

Make a side by side comparison of metal feed capability at various temperatures and riser & feed pad geometries for castings made with acoustically stimulated metal versus castings made without acoustic stimulation. This was to be demonstrated by pouring a thin wall casting to determine if stimulation would fill thin casting sections. Additionally the testing was to demonstrate if less metal was required in casting risers; therefore reducing energy requirements.

VARIABLES:

The pattern will be the 1-on star. The mold will be made with Amador A-70 sand, & 1.3 % HA International 7211/7706 binder and 17-727 activator. The metal will be poured with three (3) levels of superheat, the riser will be made at three (3) diameters at constant height, and the feed pad will be made at three (3) thicknesses.

BRIEF OVERVIEW:

Factors affecting metal feeding distance are well documented in the literature and include heat distribution during cooling as delineated by geometry, temperature, mold conductivity, pouring rate, and gating design as well as metallurgical characteristics crystal growth patterns and influence on them by alloying and trace elements. In this experiment acoustic stimulation of the riser and gating system will be explored to demonstrate any beneficial affects from thermal pumping and interruption of dendrite growth.

SPECIAL CONDITIONS:

Identical molds will be simultaneously poured from the same ladle in pairs, one stimulated and the other not to negate the influence of temperature, pouring rate, gating, geometry, and metallurgical uniqueness. For this purpose a common pouring cup will be used.

Process Engineering Manager (Technikon)	Date
V.P. Measurement Technology (Technikon)	Date
V.P. Operations (Technikon)	Date
Test Design Committee Representative	Date
Emission Committee Representative	Date

APPENDIX B POURING LOG FOR TEST FG

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Acoustic Stimulation of Aluminum During Solidification

TEST SERIES FG

In this test the metal temperature was knowingly chosen to be on the edge of misrun failure, in order to allow the acoustic stimulation to demonstrate failure prevention.

Date	Time	Sample ID	Exciter Rod Length in.	Mold Pour Time, sec.	Pre-Pour Metal Temp, F	Post-Pour Metal Temp, F	Freq. Hz.	Comments
5/13/03	10:15	1P, 1S	25	12	1252	1241		Stimulation 2 minutes. Both castings had metal lapping misrun on the drag fins due to jetting across the shallow riser drag base. Metal entered the cavity before the exciter was touching the metal in the riser.
5/13/03	1:10	2P, 2S	25	12	1258	1248		Both castings had metal lapping misrun on the drag fins the due to jetting across the shallow drag riser base. Metal entered the cavity before the exciter was touching the metal in the riser. 2S had surface shrinkage on the riser neck.
5/13/03	1:45	3P, 3S	25	12	1314	1302		Both castings had metal lapping misrun on the drag fins due to jetting across the shallow drag riser base. 3P was minimal. Metal entered the cavity before the exciter was touching the metal in the riser. Data Cast T/C cup was imbedded in both 3P & 3S risers to map riser solidification: T/C failed.
5/13/03	3:00	4P, 4S	25	12	1273	1261		Both castings had metal lapping misrun on the drag fins due to jetting across the shallow drag riser base. Metal entered the cavity before the exciter was touching the metal in the riser. T/C imbedded in both 4P, 4S risers to map riser solidification. 4P had closed riser. See chart.
5/14/03	9:40	5P, 5S	25	14	1300	1284	1520-1530	Molds inclined 11 degrees end-to-end, riser low, to allow exciter to be submerged before metal enters cavity and to prevent metal from jetting into cavity. Drags OK. 5P had cope misrun 5S did not. T/C @ casting center via parting line to map casting solidification.

Date	Time	Sample ID	Exciter Rod Length in.	Mold Pour Time, sec.	Pre-Pour Metal Temp, F	Post-Pour Metal Temp, F	Freq. Hz.	Comments
5/14/03	11:06	6P, 6S	25	13-14	1306	1301	1480-1520	Poured drag side up to provide metal pool (cope riser) for stimulation before metal enters cavity. Cope (down) good, misrun in drag (up) fins. Casting had center, drag (up), shrinkage extending to surface. Surface shrinkage on both drag (up) riser bases. T/C @ casting center via parting line to mape casting solidification. Pigged first metal to heat ladle spout.
5/14/03	1:40	7P, 7S	40	12-14	1303	1279	975-985	Poured drag side up. Ground mold to make smaller riser on drag (up) side in addition to mold-in cope (down) riser. Cope (down) good, drag (up) misrun on fins. 4P showed side surface shrinkage on drag (up) riser. 4S drag (up) riser showed erosion marks from exciter contact. T/C @ casting center via parting line to map casting solidification. Pigged first metal to heat ladle spout.
5/14/03	2:45	8P, 8S	21.75	13-14	1350	1321	1384-1577	Pour drag side up with hotter metal. Ground mold to make smaller riser on drag (up) side in addition to mold-in cope (down) riser. Cope (down) good, drag (up) misrun on fins. No T/C. Pigged first metal to heat ladle spout.

All risers are open risers except as noted.