Arnold Schwarzenegger
Governor

Acoustic Stimulation for Aluminum Castings To Conserve Metal & Electricity

PIER FINAL PROJECT REPORT

Prepared For:
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Public Interest Energy Research Program

Prepared By:
California Cast Metals Association

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ACOUSTIC STIMULATION FOR ALUMINUM CASTINGS TO CONSERVE ELECTRICTY

CALIFORNIA CAST METALS ASSOCIATION

Fall 2004

STATE OF CALIFORNIA ENERGY COMMISSION

Project Funded By: PIER-CEC

ACKNOWLEDGEMENTS

The California Cast Metals Association would like to acknowledge the CCMA Board of Directors for their time and talent put into this study. Also, we would like to thank William Funderburk of Stanzler, Funderburk and Castellon, the local foundries that donated materials for the testing, the consulting group CAPS, LLC, and those at the Energy Commission who helped make this project a success.

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grant Program
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally-Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

What follows is the final report for the California Energy Commission (PIER), 500-02-024, conducted by the California Cast Metals Association. The report is entitled Acoustic Stimulation for Aluminum Castings to Conserve Electricity. This project contributes to the Industrial/Agricultural/Water End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Energy Commission's Web site at: http://energy.ca.gov/research/index.html or contact the Energy Commission's Publications Unit at 916-654-5200.

ABSTRACT

Metal melting is the most electric-intensive process at foundries, accounting for 55% of total energy use. It takes approximately 650 kWh to melt one ton of aluminum. A typical foundry melts 250 tons of aluminum per month. This project examines acoustic stimulation technology commercially for aluminum foundries. The technology consists of an audio device vibrating lower than ultrasound frequencies, at high amplitudes, and inserted into the risers of the mold. The goal is to keep the metal more fluid and improve liquid flow, which will allow smaller volume risers for filling the cavity of the mold. The Project succeeded in demonstrating energy savings and waste metal reduction from lower pour temperatures in commercial casting pours using acoustic stimulation, but further research is needed to apply the technology on thin wall pattern sand molds.

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EXECUTIVE SUMMARY

Preliminary tests on the acoustic stimulation process at Iowa State University and selected test foundries suggested the potential of reducing electricity consumption in the commercial melting of aluminum at foundries by 12-17%. The research done at Iowa State University focused on the mechanical properties of aluminum using standard aluminum test bars to verify that acoustically stimulated molten aluminum would not be harmed or degraded by the acoustic treatment process. This research indicated that not only was the metal not harmed, but in some cases the mechanical properties such as elongation were improved.

But more research and further verification would be needed to insure that the casting end users' minimum specified commercial mechanical properties are always met in order for the process to be accepted by foundry owners and operators. Test bars poured at Iowa State University were not castings that would be accepted by the industry as research for commercial applications. Research was executed through this project in California to expand on the test bar findings. The data and findings established would be the basis for applications in real California foundries for true energy savings.

This project, titled: *Acoustic Stimulation for Aluminum Castings to Conserve Metal and Electricity*, was an eight-month study that included research at three metal casting facilities under the direction of Mr. Jim Furness, Furness-Newburge, Inc. The research facilities included:

- Technikon (a full production foundry within a laboratory setting, near Sacramento)
- California State Polytechnic University, Pomona (Industrial Department)
- California State University, San Luis Obispo (Industrial Department)

Objectives

The goal of this project was to move in the direction of maintaining the 30% amount of metal needed in the riser liquid long enough to allow for proper feeding, thus reducing the amount of metal that needs to be melted for the riser. As an example, a typical 100 pound casting may produce 40 lbs of the liquid metal usually destined for the riser. Optimistically 12 lbs will actually feed into the casting. Of this 40 lbs, the remaining 28 lbs of metal were melted and did not end up as part of the final product.

With acoustic stimulation it may be possible to stimulate only 12 lbs of metal, keep it liquid, and effectively feeding the casting while saving 28 lbs or 28% of the energy required to produce a 100 lb. casting. This will be demonstrated by designing the acoustic stimulator in such a way that the stimulator takes up space in the center of the riser normally containing the excess metal. After the time needed to feed the casting the riser metal reserve into the casting, the stimulator probe will be removed leaving a hollowed riser or a riser of reduced metal volume if liquid metal flows into the space taken up by the acoustic stimulator.

Currently, the test equipment used requires manual operation, including manual "tracking" of heat-induced resonate frequency changes of the stimulator assembly. This manual operation was conducted with operational assistance of Jim Furness, Furness-Newburge, Inc.

Approach

At each metal casting facility, different commercial sand molds were created. One set of molds was used for aluminum castings without the acoustic stimulation. While another set of molds were poured with the acoustic stimulation. Smaller or hollow risers, thinner wall capabilities, casting yield improvement, and delay in solidification were among the areas of research. An audio device vibrating lower than ultrasound frequencies, at high amplitudes is inserted into the risers of the mold. The goal is to keep the metal more fluid and improve liquid flow, which will allow smaller volume risers for filling the cavity of the mold. Risers must be large enough and at high temperatures to keep the metal liquid. Hence, smaller risers means less total metal poured per casting. Less metal poured per casting can be directly equated to energy savings. Each area contributed to the overall goal of energy savings in aluminum foundries.

Outcomes

The comparison of an acoustically stimulated riser versus a non-stimulated riser was a clear demonstration of the metal saved per casting. In the tests conducted at Cal Poly, San Luis Obispo, reports showed that the riser accounted for 50% of the casting; and the amount of metal displaced by the stimulator probe accounted for approximately 40% of the riser volume; this would translate into a *20% reduction in the melt energy* used to produce this casting.

Conclusions

Energy savings were demonstrated in commercial casting pours using acoustic stimulation. Studies showed that with better placement of the stimulator probe, the thinnest parts of the casting can be successfully filled.

Commercialization Potential

Several foundries are working currently to explore ways to implement this technology in full-scale production applications. The potential energy savings as well as improved mold filling possibilities and the possible use of alloys, now difficult or impractical due to filling issues, keeps interest levels very high in this technology. Overflow and alternative manufacturing sources have been identified in the event they are needed.

Benefits to California

Any new technological procedures that could help in melting aluminum more efficiently will significantly benefit the entire aluminum foundry industry, as well as relieve pressure on California's electric generation facilities and transmission grid.

1.0 Introduction

A *metal casting* is commonly defined as a metal object produced by pouring molten metal into a cavity. The cavity is located within a *mold*, generally made of chemically or resin bonded sand, and the molds are destroyed upon solidification of the metal. Fluid flow and heat transfer are important to consider, as is the design of the mold and gating system to ensure proper flow of the metal into the mold cavities. Overall, once the molten metal has solidified, it takes the desired shape of the mold to create a metal casting.

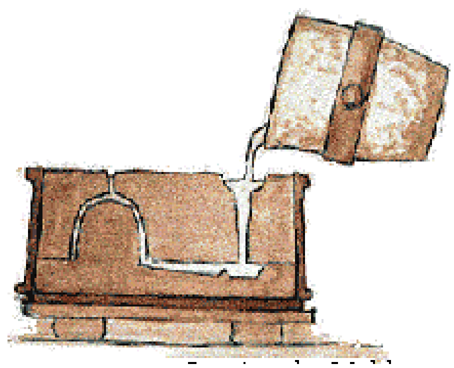

Figure 1 Pouring the Mold

The metal casting industry is one of the nation's largest consumers of energy. And the most energy intensive process in metal casting is the *melting of metal*. Melting consumes approximately 55% of total energy costs. Other energy intensive processes include: core making, mold making, heat treatment, and post-cast activities. To gain perspective, the amount of energy used by the U.S. metal casting industry is equivalent to that used by the residents of Massachusetts, New Hampshire, New Mexico, Rhode Island, Wyoming, and Hawaii.

1.1 Background and Overview

California's metal casting industry is comprised of approximately 400 companies, and represents over 20,000 employees. Because of the energy-intensive manufacturing process of metal casters, this industry is one of California's largest consumers of energy. In all, the average metal foundry can consume as much electricity as 650 residential homes.

The largest concentration of foundries in California is aluminum foundries. There are at least 70 aluminum foundries in the state of California, representing approximately 40% of sand casting foundries in the metal casting industry. It takes approximately 650 kwh (kilowatt hours) to melt 1 ton of aluminum. Each aluminum foundry in the state of California melts about 250 tons of aluminum per month. The aluminum foundry industry as a whole accounts for nearly 20,000 tons of aluminum melted per month. Hence, aluminum foundries account for 13,000,000 kwh of electricity per month in metal melting alone. This is a significant amount of electricity.

Figure 2 Pouring of Molten Aluminum

Any new technological procedures that could help in melting aluminum more efficiently will significantly benefit the entire aluminum foundry industry, as well as relieve pressure on California's electric generation facilities and transmission grid.

ABOUT CCMA:

The California Cast Metals Association (CCMA) was founded in 1972 and has since operated as the statewide trade association for California's metal casting industry—encompassing foundries, die casters, rolling mills, and smelters. CCMA is a not-for-profit California corporation. One of its key missions is to advance the knowledge of its members in matters related to the containment of costs in order to keep California metal casters competitive with metal casters in other states and abroad.

In 2000, CCMA began collaborating with foundryman Mr. Jim Furness of Furness-Newburge, Inc. on an aluminum melting technology that was becoming ready for transfer to commercial operations. Mr. Furness has over 35 years experience with acoustics—beginning in 1965 with the U.S. Navy.

The technology encompasses the ***acoustic stimulation*** of aluminum typically through the riser of the mold to keep the metal fluid longer—thus allowing for greater metal flow, lower risers, less metal used, and potential thin-walled castings.

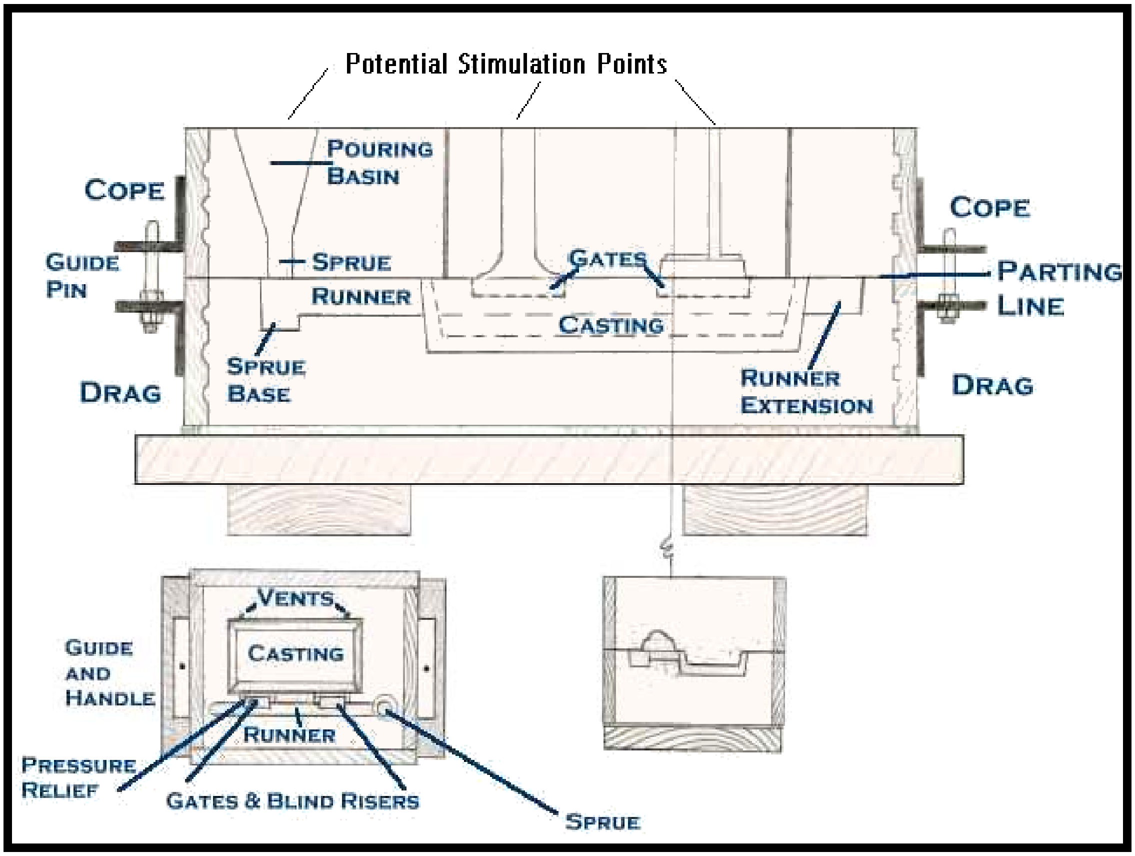

Figure 3 Potential Acoustic Stimulation Points

Using less metal in the pour means less metal must be melted, and electricity is thus saved. Additionally, castings may be produced with thinner walls by utilizing the acoustic stimulator process. This translates into a lighter casting and requires less metal per part.

1.2 Project Objectives

The goal of this project was to move in the direction of maintaining the 30% amount of metal needed in the riser liquid long enough to allow for proper feeding, thus reducing the amount of metal that needs to be melted for the riser. As an example, a typical 100 pound casting may produce 40 lbs of the liquid metal usually destined for the riser. Optimistically 12 lbs will actually feed into the casting. Of this 40 lbs, the remaining 28 lbs of metal were melted and did not end up as part of the final product.

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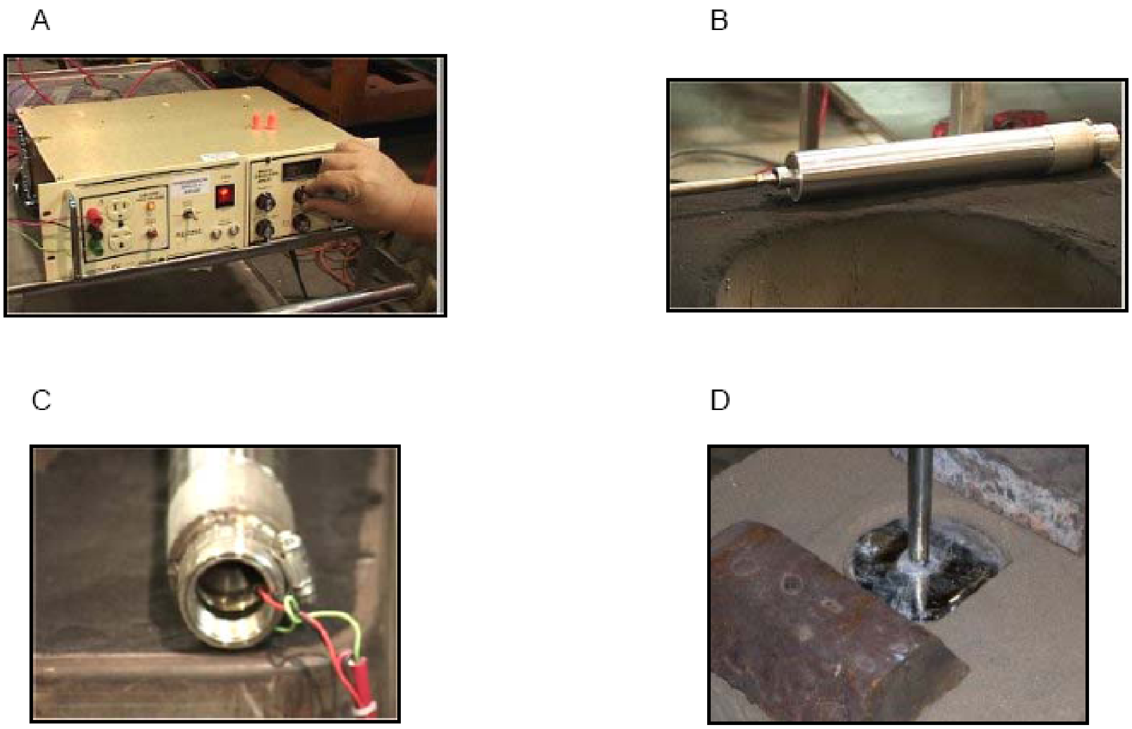

Figure 4 A-Manual Control of the Acoustic Stimulator B-Stimulator Probe C-Connection of Control Device to Rod D-Stimulator in Riser with Molten Metal

1.3 Report Organization

This report is organized as follows:

Section 1.0 Introduction
Section 2.0 Project Approach
Section 3.0 Project Outcomes
Section 4.0 Conclusions and Recommendations

There are 4 appendices:

Appendix A: Technikon Field Test I
Appendix B: California State Polytechnic, Pomona, Field Test
Appendix C: Cal Poly San Luis Obispo Field Test
Appendix D: Technikon Field Test II
Appendix E: How Magnetostrictive Actuators Work

2.0 Project Approach

Four individual field tests were conducted as part of this grant project. This report reviews the results from each of the four field tests in the appendices. The reports are as follows:

1. Technikon Field Test I
2. California State Polytechnic, Pomona, Field Test
3. Cal Poly San Luis Obispo Field Test
4. Technikon Field Test II

Previous literature and experiments indicate the possibility of transferring or "pumping" energy through a fluid medium using sound waves. Two potential mechanisms explaining acoustically affected delay of solidification of molten metal are known:

1.) Sound waves can disrupt or delay the formation "flow inhibiting" dendrite structure.

2.) Heat can be pumped or redistributed by sound energy. Ultrasonic refrigeration works on a "heat pumping" principle and has been a reality for several years. Greatly simplified, the energy of a sound wave travels through molten metal in the form of a pressure wave. When a gas or liquid is compressed by a pump or compressor in a conventional heating or cooling system, it "heats". Conversely, during the reduced pressure portion of the heating/cooling process, the "negative" pressure "cools". This process is commonly known as a "heat pump". A sound wave, being a positive and negative pressure wave can also "pump" heat. An increase in the "blackening" or burning of the organic phenolic based resin coated sand grains in the localized area of the stimulator probe can be clearly seen in Field Trials 1, 2 and 4. Field Trial 3 used an inorganic silicate resin that did not discolor with heating.

While dendrite formation delay is also most likely involved in the delay of solidification, the initial intent of this project is to see if heat from the riser of the casting (hottest part of the mold) can be transferred to the leading edge of the metal to keep it molten and thus aid filling.

In thin sections, filling of the mold is limited by the large surface area around the feature that extracts heat very quickly, causing the metal to freeze prior to filling the cavity. Because of this, minimum-wall thicknesses are specified in the design of cast components so they can be produced. However, many times the needed mechanical properties can be met with a thinner wall and thus the extra metal is not necessary from a functional standpoint. Thicker walled castings lead to additional use of energy by melting more metal than necessary to fill the thicker sections. Thus, if a method could be developed that allowed thinner sections to be filled, thinner and better castings could be designed, resulting in substantial reductions in energy consumption.

Much of this project's focus occurred in controlling the delay in solidification and filling of thinner walled castings. As a thinner walled casting would contain less metal than a standard casting, less metal per casting would be needed and thus energy would be saved.

Moreover, when risers were acoustically stimulated, the risers had more "shrinkage" than non-stimulated risers on the same casting. And if the stimulator probe was left in the riser until just before solidification, the riser could become hollow. A hollow riser that fed metal to the casting equally or better than a solid riser the hollow riser would contain less metal to make the same casting. This would also reduce the energy required to produce castings.

The research conducted in this project was necessary because while the science indicates that heat will flow to the leading edge of molten metal filling the mold, quantification or simulation of the phenomena are not yet reliable due to the difficulties of the transient nature of the mold filling process making modeling of the dynamics of mold filling is not accurate enough. Thus, the only way to find if the heat flux from the riser to the leading edge is greater than the heat flux from the thin section to the mold (a condition necessary for success of this method) is by experimentation and research.

Frequency has also been determined to influence the behavior of the heat transfer on different fluid media. Since the optimum frequency values for molten aluminum have not been established, it is necessary to explore these as well in the experiments.

Risers are a key point where metal/energy can be saved. Riser effectiveness is measured by the total volume of liquid metal in the riser that actually goes into feeding the casting. The total amount of melted metal required for risers to produce an aluminum casting can be up to 60% of the total metal poured into the mold. It is not unusual to have risers use less than 30% of the metal to actually feed the casting. This means that 70% or more of the metal in the riser is used to simply keep that last 30% liquid until it is needed. In turn, keeping the metal liquid longer through the acoustic stimulator process will result in less metal needed in the riser. And less metal directly translates into less electricity consumed per casting.

Other methods have been developed to improve riser-feeding efficiency such as "firecracker" riser core inserts, insulating and exothermic sleeves, and insulating and exothermic riser covers. Unfortunately the covers, while beneficial, only produce a small improvement. The sleeves in combination with covers provide a better solution, yet their high cost and inability to be used in high pressure molding situations make them limited in the volume of castings in which they can be used. Acoustic stimulation has been used in the past to thermally stimulate materials. This principle was used to maintain the risers liquid for a longer period of time which will allow them to remain liquid and continue feeding the casting. Using the acoustic stimulator process rather than sleeves or riser covers saves the facility material costs and provides a greater opportunity to conserve electricity.

3.0 Project Outcomes

The comparison of an acoustically stimulated riser versus a non-stimulated riser was a clear demonstration of the metal saved per casting. In the tests conducted at Cal Poly, San Luis Obispo, reports showed that the riser accounted for 50% of the casting; and the amount of metal displaced by the stimulator probe accounted for approximately 40% of the riser volume; this would translate into a *20% reduction in the melt energy* used to produce this casting.

More evidence was shown at the first Technikon test, where positive results were obtained in reducing the volume of metal in the risers due to the stimulation rod displacing metal. General estimates can be made conservatively at *4-6% savings*.

And in the final test at Technikon, studies showed that with better placement of the stimulator probe, the thinnest parts of the casting can be successfully filled.

4.0 Conclusions and Recommendations

4.1. Conclusions

The objectives of this PIER project were met as energy savings were demonstrated in commercial casting pours using acoustic stimulation. Most notably, the comparison of an acoustically stimulated riser versus a non-stimulated riser (bottom of page 52) was a clear demonstration of the metal saved per casting. In the tests conducted at Cal Poly, San Luis Obispo, reports showed that the riser accounted for 50% of the casting; and the amount of metal displaced by the stimulator probe accounted for approximately 40% of the riser volume; this would translate into a *20% reduction in the melt energy* used to produce this casting.

More evidence was shown at the first Technikon test, where positive results were obtained in reducing the volume of metal in the risers due to the stimulation rod displacing metal. General estimates can be made conservatively at *4-6% savings*.

And in the final test at Technikon, studies showed that with better placement of the stimulator probe, the thinnest parts of the casting can be successfully filled.

The energy savings demonstrated during this testing varied from 0% to 20%. In test #4 we finally demonstrated the potential to acoustically assist in the filling of thinner walled casting and the associated potential energy savings.

4.2. Recommendations

But for commercial integration and widespread industry implementation to occur, this emerging technology would need to be demonstrated further as an *automated* procedure, rather than stimulating each casting *manually* as done in this research. Although this research showed that metal/electricity could be saved, automation would be the basis for commercial implementation. Commercial businesses produce hundreds of castings per day and may lose production time with manual use of the acoustic stimulation process. Future research would likely entail automation and improvement in thin-walled castings

- Automation of the process should at a minimum include a stimulator holding and withdrawal mechanism, electronic tracking of heat-induced changes in mechanical resonance and timing/tracking PLC or computer. For commercial facilities, manual operation is too cumbersome, induces unnecessary variables and poses risk of burns from spilled molten metal.
- The acoustic actuators need additional cooling near molten metal. Failures of stimulation occurred during field tests when overheating of actuators were experienced.
- The size, composition and method of manufacturing of the ceramic probe tips needs more refinement. Again, this will better move the technology towards standardized usage.
- Actuators with additional/wider frequency response windows need to be tested.

- Individual companies seeking to integrate this technology will require on-site analysis as each foundry is different and entail different engineering specifications.
- Test ceramic and refractory coatings to prevent cavitation erosion and excess metal buildup on the probe tips need to be further examined.
- Test mold coatings with the overall process.
- Test the use of both exothermic and insulating riser sleeves outside acoustically hollowed risers to potentially produce even further-improved energy savings potential.

4.3. Benefits to California

Several foundries are working currently to explore ways to implement this technology in full-scale production applications. The potential energy savings as well as improved mold filling possibilities and the possible use of alloys, now difficult or impractical due to filling issues, keeps interest levels very high in this technology. Overflow and alternative manufacturing sources have been identified in the event they are needed.

4.4. On Going Research

- Prevention or reduction of warping in this walled Stainless Steel castings via stimulation of pouring basin, not riser. *Commercial castings have been made in MN.*
- Prevention of cracking and higher yields in iron castings. *Ongoing with a WI foundry group with a division in CA.*
- Improvement in detail in lost wax investment casting for reduced cost of finish detailing. *Commercial castings have been made in IL.*
- Self-tuning power supplies with much higher kilowatt capacities are under development at the Furness-Newburge, Inc. facility in KY.
- More robust gas cooled actuators designed specifically for foundry application are under development at the Furness-Newburge, Inc. facility in KY.
- The potential phenomena of acoustically affected dendrite structure delay and changes in dendrite spacing are being investigated in a joint project between Furness-Newburge, Inc. and Penn State University.

GLOSSARY

Acoustics: The branch of physics dealing with sound, especially in its transmission.

Alloy: A metallic material formed by mixing two or more chemical elements. Usually possesses properties different from those of the components.

Alloying: Procedure of adding elements other than those usually comprising a metal or alloy to change its characteristics and properties.

Aluminum: One of the chemical elements. A silvery, lightweight, easily worked metal that resists corrosion and is found abundantly.

Binder: Material to hold the grains of sand together in molds or cores. May be cereal, oil, clay resin, etc.

Binder, plastic/resin: Synthetic resin material used to hold grains of sand together in molds or cores. May be phenol formaldehyde or urea formaldehyde thermosetting types.

Casting: (n.) Metal poured into a mold to form an object. (v.) Act of pouring molten metal into a mold.

Cavity, mold or die: Impression or impressions in a mold or die that give the casting its shape.

Cope: The upper part or topmost section of a mold or pattern.

Core: Separable part of the mold, usually made of sand and generally baked, to create openings and various shaped cavities in the castings. Also used to designate the interior portion of an iron-based alloy which after hard-casing is substantially softer than the surface later or case.

Core Binder: Any material used to hold the grains of core sand together.

Drag: The lower or bottom section of a mold or pattern.

Eutectic: The alloy which has the lowest melting point possible for a given composition.

Fin: A thin piece of metal projecting from a casting at the parting line or at the junction of cores or mold.

Flask: Container in which a mold is made.

Gates: The point at which molten metal enters the casting cavity. Also a general term to indicate the entire assembly of connected columns and channels carrying the metal from the top of the mold to the casting.

Heat Transfer: Transmission of heat from one body to another by radiation, convection, conduction or other.

Holding Furnace: Usually a small furnace for maintaining molten metal at the proper pouring temperature, and which is supplied from a larger melting unit.

Hot Spots: Term applied to gray iron castings to denote chilled areas or inclusions that are harder than the surrounding iron and that cause machining difficulties.

Hot Tears: Cracks in castings formed at elevated temperatures; usually by contraction stresses.

Inclusions: Particles of slag, sand, or other impurities such as oxides, sulfides, silicates, etc., trapped mechanically during solidification or formed by subsequent reaction of the solid metal.

Ingot: Commercial pig mold or block in which copper, copper-base, aluminum, aluminum alloys, magnesium, magnesium alloys, and other nonferrous materials are made available to the foundry.

Ladle: Metal receptacle lined with refractory for transportation of molten metal. Types include hand, trolley, crane, bottom-pour and teapot.

Matchplate: A metal or other plate on which patterns split along the parting line are mounted back to back with the gating system to form an integral piece.

Metallurgy: Science dealing with the constitution, structure, and properties of metals and alloys, and the processes by which they are obtained from ore and adapted to the use of the foundryperson.

Mold: The form, usually of sand, containing the cavity into which molten metal is poured to make the casting.

Pattern: Model of wood, metal, plaster, or other material used in making a mold.

Porosity: Unsoundness in castings appearing as blowholes and shrinkage cavities.

Riser: Reservoir of molten metal attached to the casting to compensate for the internal contraction of the casting during solidification.

Riser Gating: Gating system in which molten metal from the sprue enters a riser close to the mold cavity and then flows into the mold cavity.

Runner: The portion of the gate assembly which connects the sprue with the casting.

Sprue: The vertical portion of the gating system where the molten metal first enters the mold.

Vent: An opening in a mold or core to permit escape of steam and gases; also called a vent hole.

Viscosity: Resistance of hot fluid substance to flowing. A measurable characteristic for an individual substance at a given temperature and under definite conditions.

Yield: In production of castings, a value expressed as a percentage indicating the relationship of the weight of a casting to the total composite of a casting and its gating system. Example: If the casting and gating system weigh 125lbs. and the casting weighs 100lbs., the yield is 80%.

APPENDIX A: TECHNIKON FIELD TEST I

FIELD TEST 1

Acoustic Stimulator

Commercial Testing/Research

Technikon, LLC

McClellan, CA

Acoustic Stimulation of Cast Aluminum

30 September 2003

CEC Research- 2003

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.

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

Process Engineering Manager:	*// Original Signed //*	10/1/03
	Steven Knight	Date
VP Measurement Technologies:	*// Original Signed //*	10/1/03
	Clifford Glowacki, CIH	Date
VP Operations:	*// Original Signed //*	10/1/03
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President:	*// Original Signed //*	10/1/03
	William Walden	Date

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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.

Although this test was designed specifically to investigate thin wall section filling, the following observation was obvious. 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 poured into the riser did not adversely affect the casting quality.

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.

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

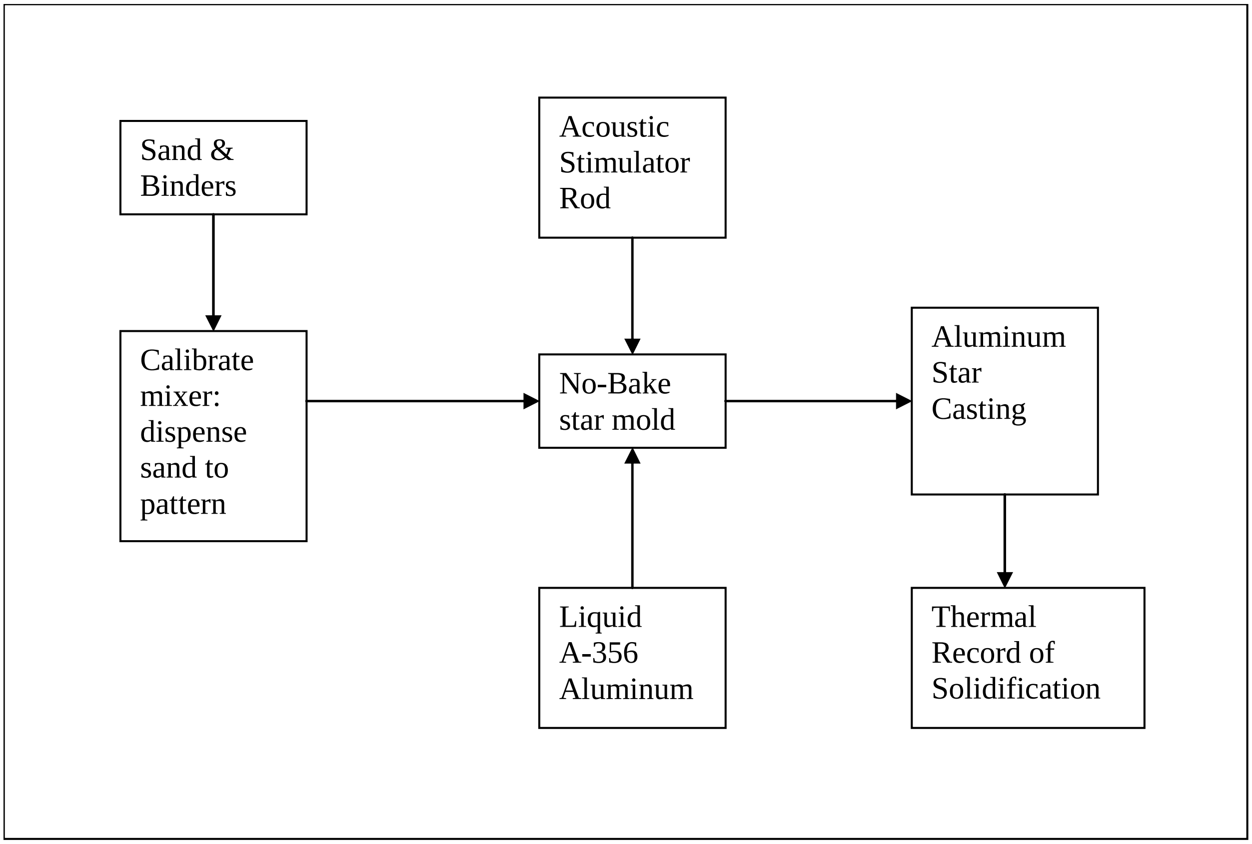
	Test FG
Type of Process Tested	Optimization of Aluminum Casting Resulting from Acoustic Stimulation
Binder System	Phenolic Urethane No-Bake HA-International TECHNISET ® 20-665; 23-635; 17-727
Number of Molds	16: 8 for Stimulation , 8 for non-stimulated comparison
Process Parameters Measured	No-Bake binder 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. **Test Plan Review and Approval:** The proposed test plan was reviewed by the Technikon staff and the CERP Steering Committee, and approved.

2. **Sand Preparation:** 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. **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 Gatina

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. **Report Preparation and Review:** 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

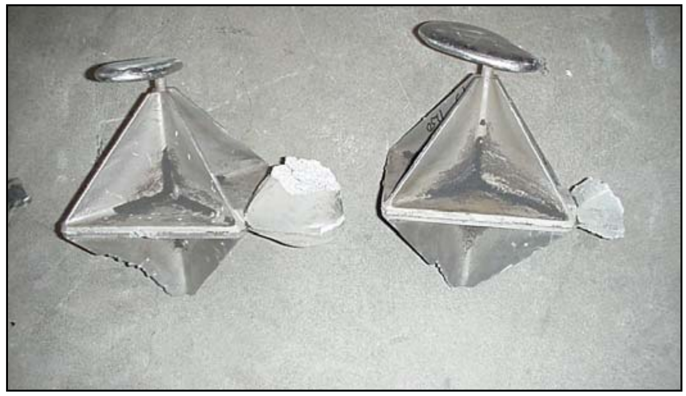
Metal being acoustically stimulated. Stimulation continued after pouring was done until the casting was solidified.

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.

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.

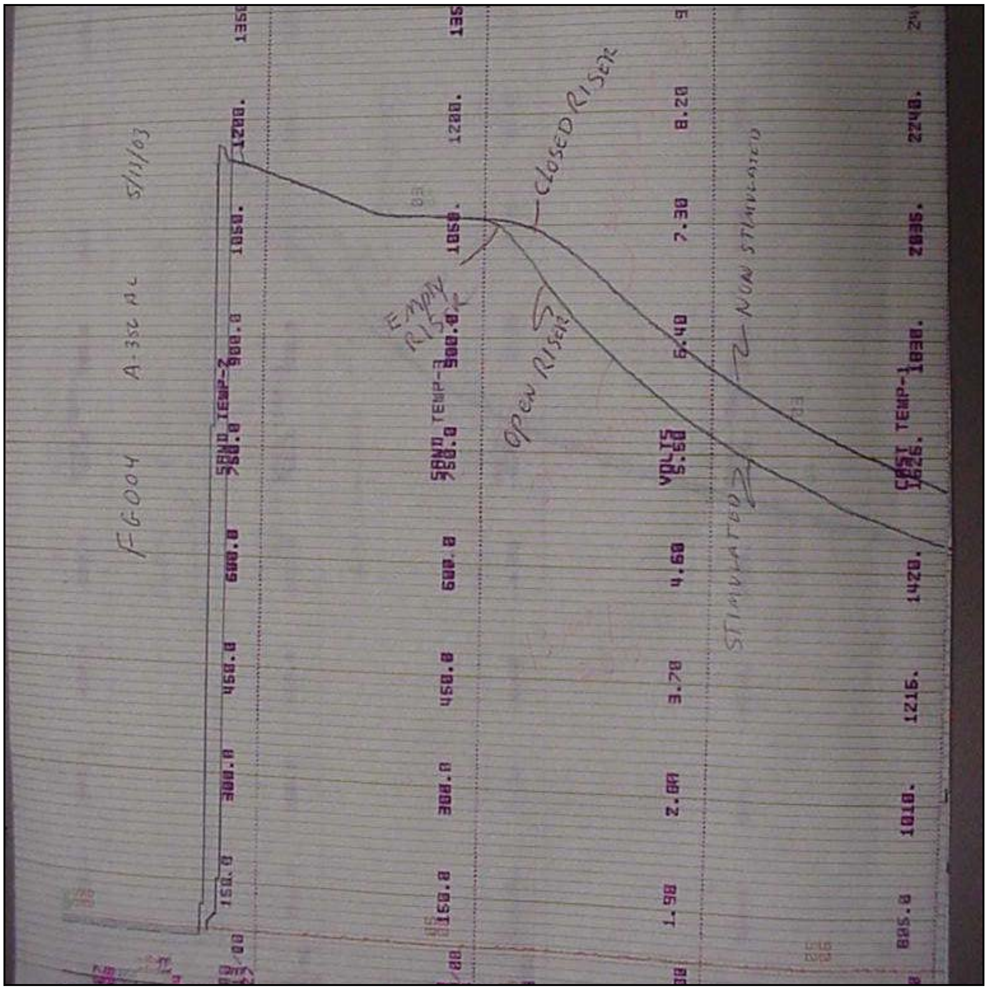
Figure 3-3 Castings FG003P and FG003S

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 thermocouples failed. The pour temperature was raised 50^{o}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

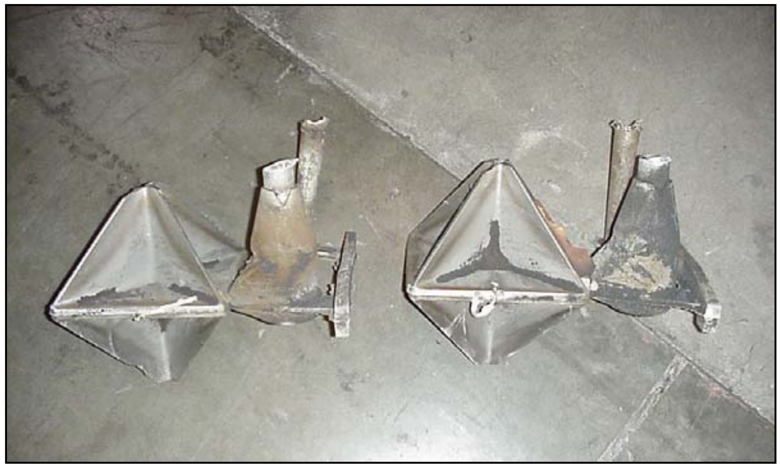
Castings FG004P (left) and FG004S (right) were cast upright as shown. Both drag cavities had misrun due to interrupted metal jetting across the shallow based riser. Metal entered the cavity before the exciter touched the metal in the riser. Both casting risers had simple thermocouples successfully embedded 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.

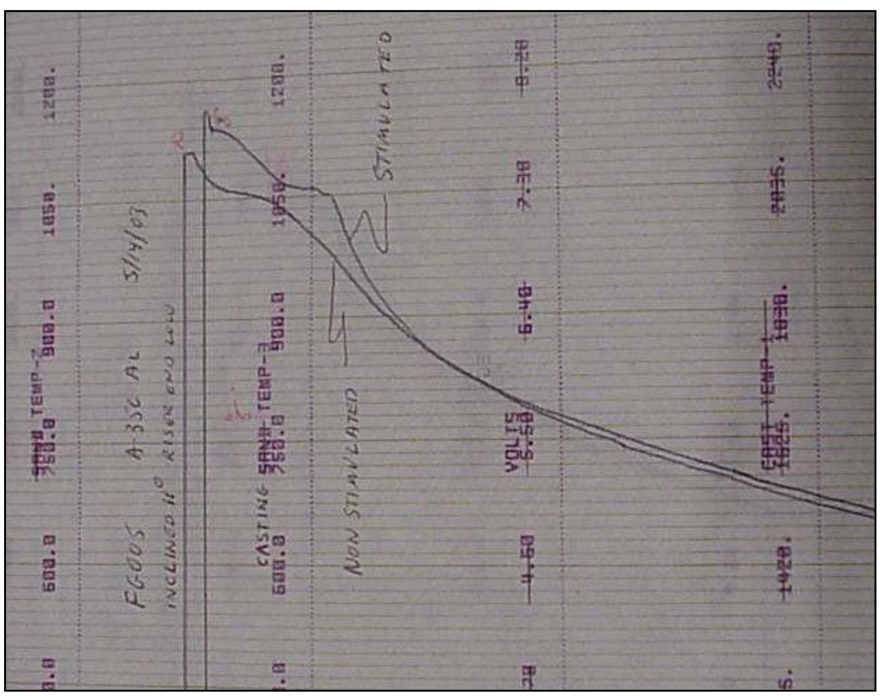
Neither of the drag cavities had a misrun. FG005P had cope misrun but FG005S did not. Neither cavity exhibited any surface evidence of shrinkage. Both casting had simple thermocouples successfully embedded in the center of their respective castings via the parting line.

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 location 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.

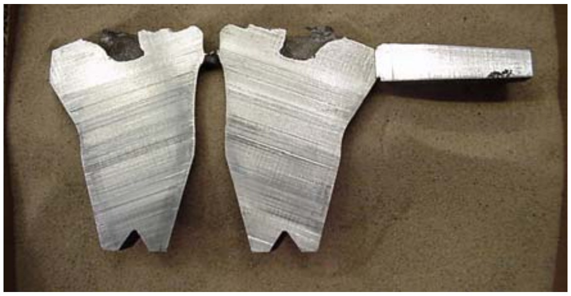
Figure 3-10 Castings FG006S and FG006P

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^{o}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.

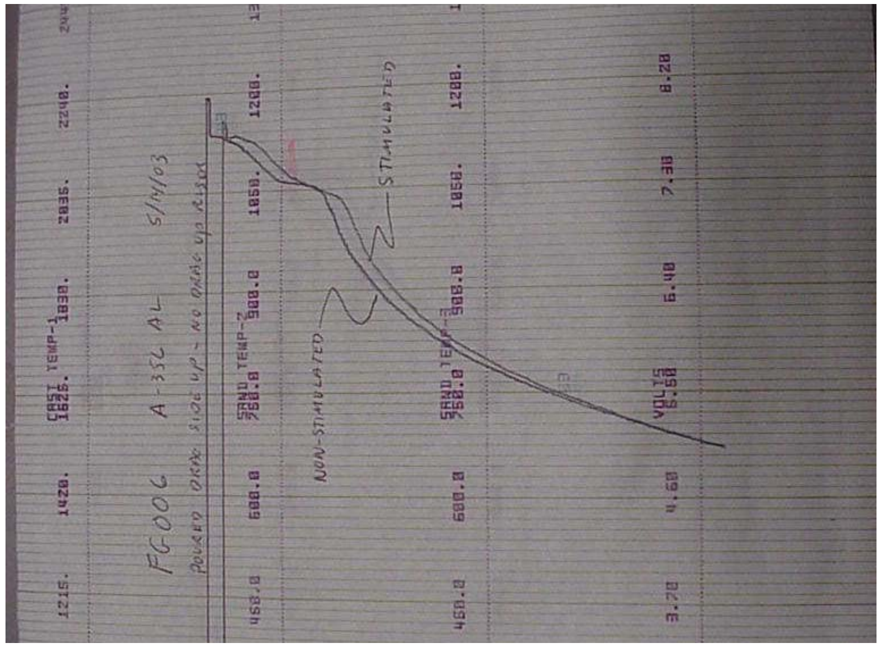
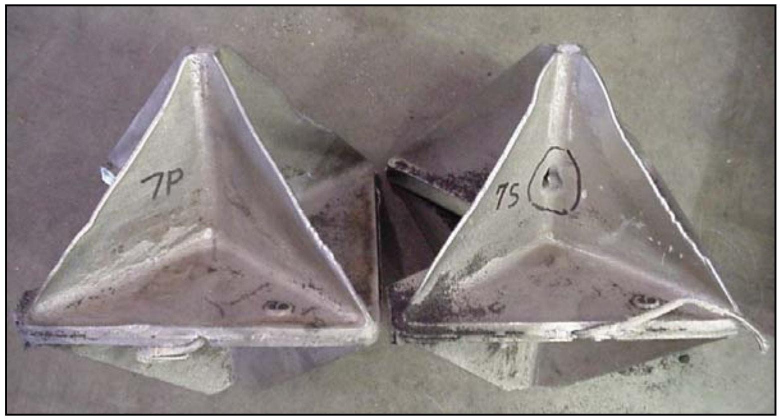


Figure 3-14 Castings FG007S and FG007P

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.

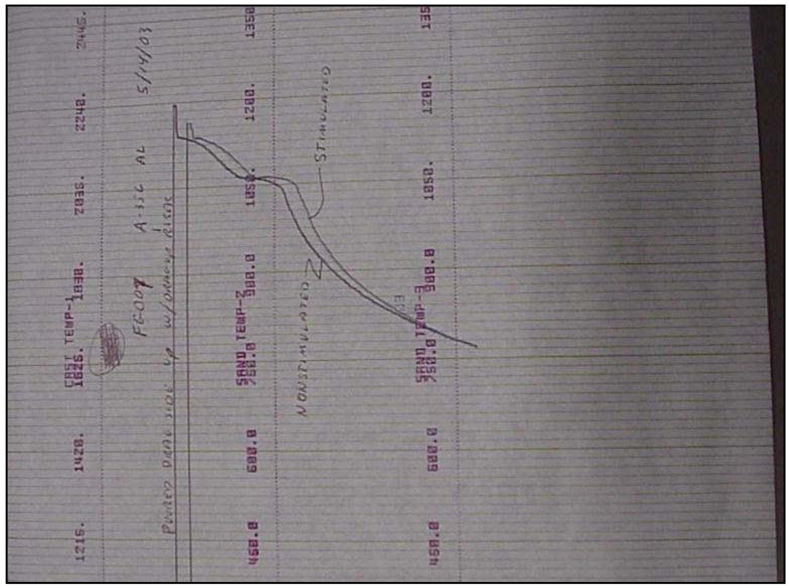


Figure 3-18 FG008P and FG008S

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^{o}F, stimulation frequency 1384-1577 Hertz.

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.

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 did not adversely affect the casting quality. Reducing the volume of metal in the risers was 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. The test conditions during Field Trial 1 did not result in “successful” castings in this initial work. However, careful observations of heat transfer changes in the sand and the delay of solidification near the acoustic probe dictated a rethinking of the experimental conditions. Ultimately, the potential of reduced energy consumption via hollow risers and better filling of thin walled castings was achieved in Field Trials 3 and 4.

APPENDIX A

TECHNIKON TEST PLAN

> **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

TESTING: **2004**

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.

APPENDIX B POURING LOG

Acoustic Stimulation of Aluminum During Solidification

TEST SERIES FG

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

All risers are open risers except as noted.

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
9/03	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.
9/03	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.
9/03	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.

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
9/03	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.
9/03	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.
9/03	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.

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
9/03	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.
9/03	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.

APPENDIX B: CALIFORNIA STATE POLYTECHNIC, POMONA, FIELD TEST

FIELD TEST 2

Acoustic Stimulator

Commercial Testing/Research

California State Polytechnic University, Pomona

Industrial Manufacturing and Engineering Department

September 2003

Effects of Acoustic Stimulation on Thin Section Filling of Aluminum

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1. INTRODUCTION

The intent of this experiment is to see if heat from the riser of the casting (hottest part of the mold) can be transferred to the leading edge of the metal to keep it molten and thus aid filling.

The experiment is necessary because while the science indicates that heat will flow to the leading edge of molten metal filling the mold, quantification or simulations of the phenomena are not yet reliable due to the difficulties of the transient nature of the mold filling process making modeling of the dynamics of mold filling is not accurate enough. Thus, the only way to find if the heat flux from the riser to the leading edge is greater than the heat flux from the thin section to the mold (a condition necessary for success of this method) is by experimentation.

2. OBJECTIVE

Evaluate the effect of acoustic stimulation on the mold fill distance of A356.1 Aluminum.

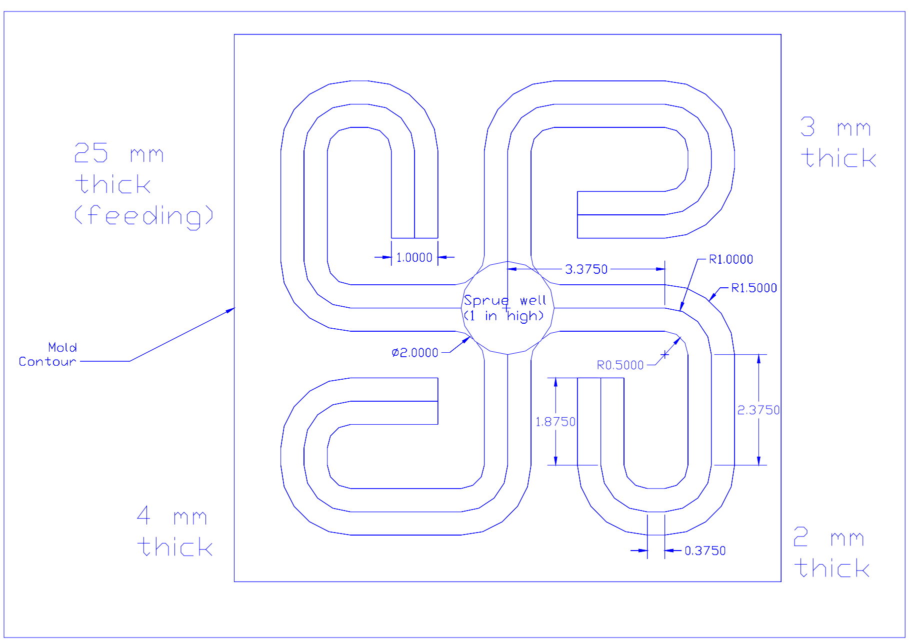
3. PROCEDURE

3.1 Equipment

The facilities were provided by California State Polytechnic University – Pomona and their foundry laboratory. The facility is equipped with a 75 KW induction furnace and the associated tools for pouring operations. An Electro Nite immersion pyrometer was used to monitor pouring temperatures. The variable frequency power supply, variable frequency transducer, and various actuating rods were provided by Furness-Newburge, Inc.

3.2 Pattern design

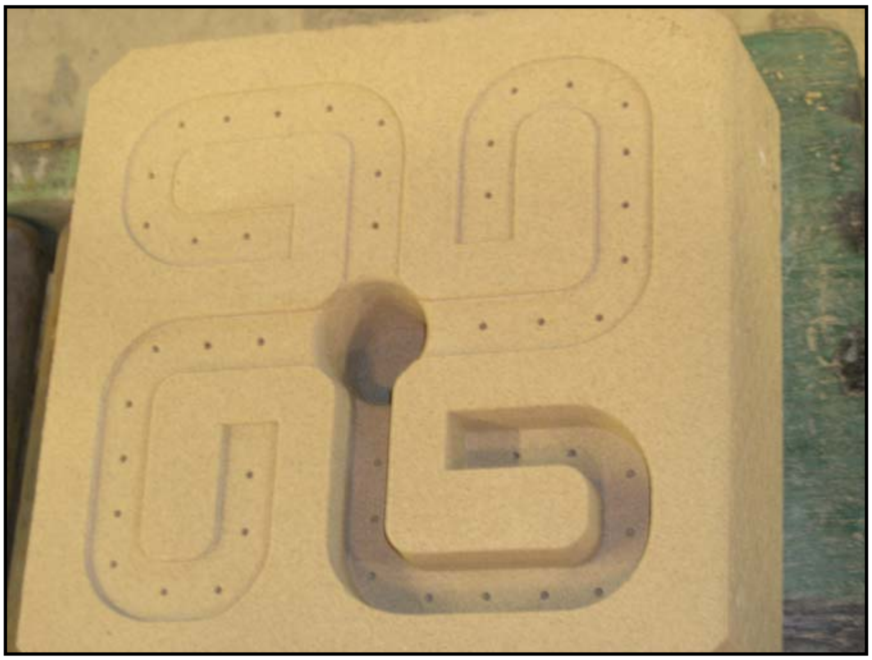
The pattern, illustrated below in Diagram 1 consists of a four-arm pattern with radial symmetry and is similar to an industry standard fluidity pattern. Each arm has a uniform thickness. Of the four arms, the first is 2mm thick, the second is 3mm thick, the third is 4mm thick and the fourth is 25mm thick.



(Above) Diagram 1: Pattern geometry for fluidity experiment.

3.3 Materials

The molds were made of phenolic-urethane bonded sand (Diagram 2). The alloy used was A356.1 Aluminum.



(Above) Diagram 2: Drag portion of experimental mold.

3.4 Experimental design

The experiment was organized to determine the following: an optimal pouring temperature and then measure the effect of varied frequencies of acoustic stimulation, the possible heat sink effect of the actuator, the effect of wall thickness, the effect of actuator shape and the effect of ladle stimulation during mold pouring.

Number of Molds	Temperature (˚F)	Frequency (Hz)	Pouring Date: 9/03 Notes:
1	1250	-	establish pouring temperature
1	1200	-	establish pouring temperature
1	1150	-	establish pouring temperature
2	1250 *	-	confirm baseline pouring temperature
3	1250 *	-	determine effect of actuator as heat sink
3	1350 *	-	determine effect of actuator as heat sink at 1350 F (Note: transducer failure prevented further trials @ 1350 F)
3	1250 *	915 – 950	
3	1250 *	1610-1630	
3	1250 *	3600-3650	
3	1250 *	5300-5600	
3	1250 *	5300-5600	Transducer in ladle
3	1250 *	12600	
* Pouring temperature determined from analysis of the first three molds.			

3.5 Procedures:

The general pouring procedure went as follows: For one mold at a time, the mold was positioned on the pouring carrousel, then the transducer was hung at a height such that the actuating tip would be past the parting line of the mold to establish the proper height. Once this was accomplished, the actuator was removed and ready for preheating in the ladle. Then the metal would be transferred to a ladle from the holding furnace and the actuator's tip was placed in the metal to preheat. The metal was allowed to cool in the ladle until it reached the proper pouring temperature within 10 degrees F. At about 5-10 seconds prior to pouring the actuator was removed from the ladle, placed in the mold and activated and then the mold was poured.

Exceptions to this pouring procedure: In the trials where the temperature was being determined, there was no actuator involved. In the trials to determine the “heat sink” effect, the transducer was not turned on. On one set of trials the actuation begun at the ladle and then as pouring took place was moved to the mold.

(Photo): Experimental Set up.

4. RESULTS AND DISCUSSION

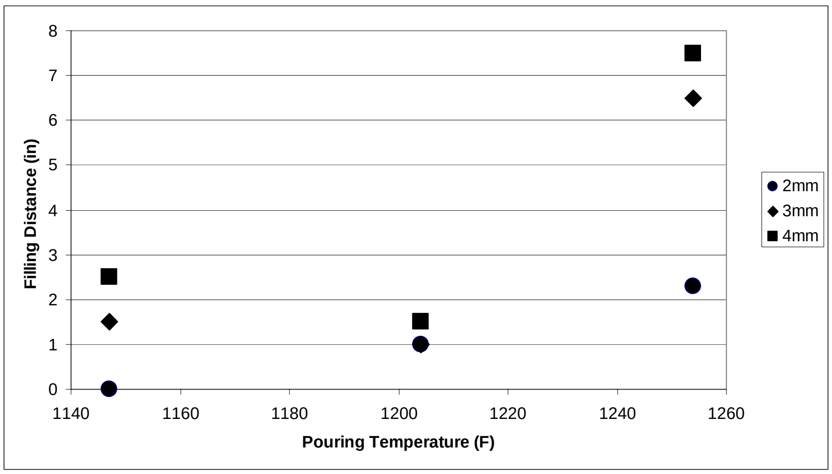
4.1 Results

The following data represents length of fill with and without acoustic stimulation and the effect of a heat sink.

Actual Temp. (˚F)	Actual Frequency (Hz)	Target Temp. (˚F)	Target Frequency (Hz)	2 mm arm fill length (in)	3 mm arm fill length (in)	4 mm arm fill length (in)	Pouring Date 9/03; Notes:
1254	-	1250	-	2.3	6.5	7.5	establish pouring temperature
1204	-	1200	-	1.0	1.0	1.5	establish pouring temperature
1147	-	1150	-	0.0	1.5	2.5	establish pouring temperature
1250	-	1250	-	3.0	8.0	10.5	baseline pouring temp
1250	-	1250	-	2.5	7.5	10.3	baseline pouring temp
1253	-	1250	-	1.5	8.0	9.0	heat sink effect
1258	-	1250	-	1.8	6.0	9.0	heat sink effect
1258	-	1250	-	3.5	7.0	8.3	heat sink effect
1343	-	1350	-	2.0	3.0	12.0	heat sink effect
1345	-	1350	-	6.0	10.5	12.0	heat sink effect
1350	-	1350	-	8.0	12.0	12.0	heat sink effect
1250	923-950	1250	915-950	0.0	0.0	1.0	
1250	950	1250	915-950	1.0	4.0	7.5	
1252	915-923	1250	915-950	2.0	7.0	7.2	
1250	1615	1250	1610-1630	1.5	6.5	9.5	
1250	1612	1250	1610-1630	2.0	7.5	9.5	
1350	1600	1250	1610-1630	5.0	4.0	12.0	
1253	3600	1250	3600-3650	1.3	6.3	7.5	
1246	5400	1250	5300-5600	2.0	6.5	8.5	
1254	5500	1250	5300-5600	2.0	9.0	10.5	
1225	5600	1250	5300-5600	1.7	6.0	7.7	actuator in ladle
1229	5600	1250	5300-5600	2.0	3.5	5.0	actuator in ladle
1250	5600	1250	5300-5600	2.0	7.5	8.5	actuator in ladle
1248	12650	1250	12600	1.3	8.5	7.5	metal degassing
1250	12000	1250	12600	2.0	4.0	8.5	metal degassing
1253	11800	1250	12600	3.0	9.5	12.0	metal degassing

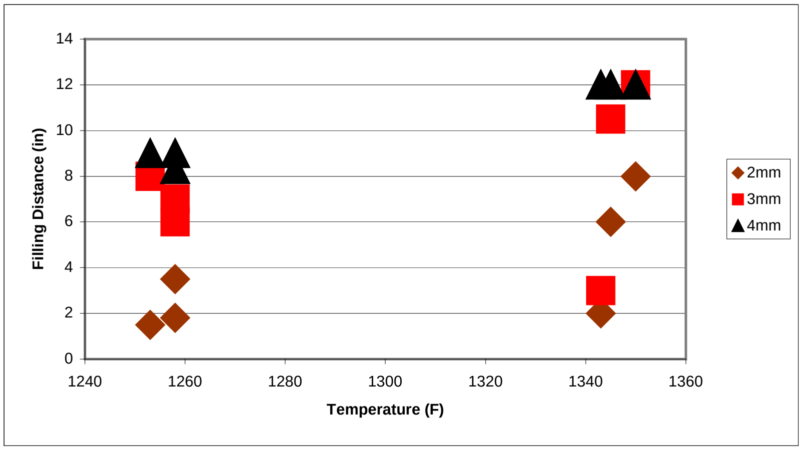
4.2. Pouring temperature determination and verification

Molds were poured at the various temperatures of 1150˚F, 1200˚F, 1250˚F and 1350˚F. As can be seen in Diagram 3, 1250˚F provided the greatest sensitivity over the 1150˚F and 1200˚F pouring temperatures. A pouring temperature of 1350˚F did not provide any significant increase in experiment sensitivity to changes in fill distances. 1250˚F was chosen as the optimal pouring temperature. This pouring temperature provided a large degree of sensitivity. As expected, we noted a statistically significant relation between the pouring temperature and the fill distance of each thin wall arm.



(Above) Diagram 3: Pouring Temperature vs. Filling Distance (Establish experimental pouring temperature)

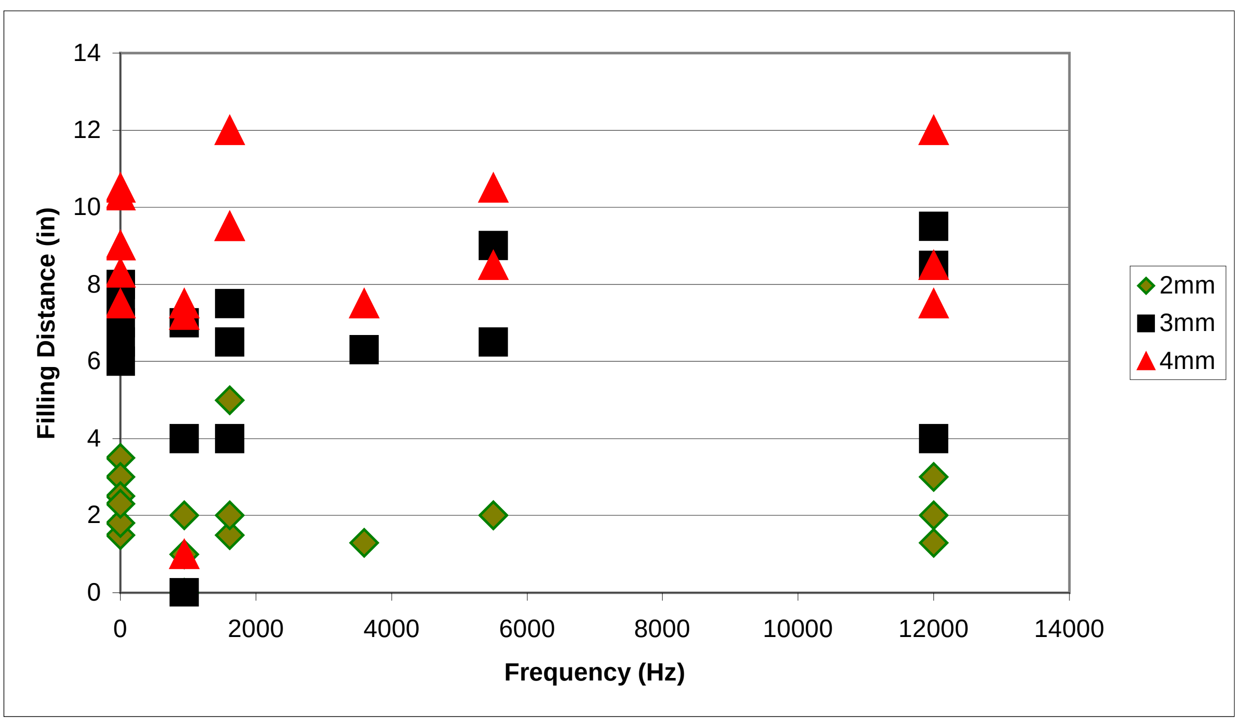
In order to verify the pouring temperature of 1250˚F, six additional molds were poured. Three molds were poured at 1250˚F and three at 1350˚F to determine if any significant increase in experiment sensitivity could be established. A pouring temperature of 1350˚F did not provide any significant increase in experiment sensitivity. The results of the effect of an elevated pouring temperature are illustrated below in Diagram 4.



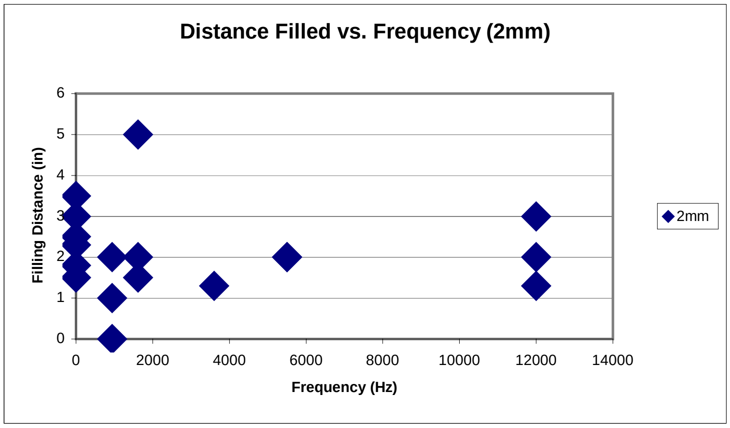
(Above) Diagram 4: Effect of Pouring Temperature (No actuation).

4.3 Acoustic effect

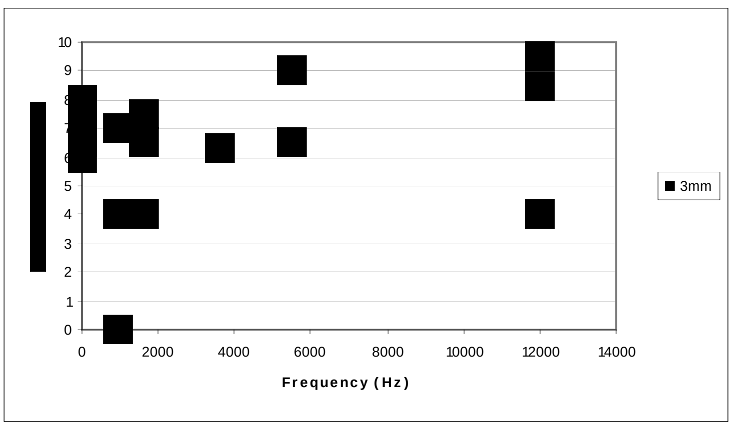
As illustrated, the effect of acoustic stimulation over all tested frequencies had no effect on the fill distance on any of the wall thickness. Statistical analysis corroborated this result. Diagrams 5-8 illustrate the various frequencies effect on each of the individual wall thickness.



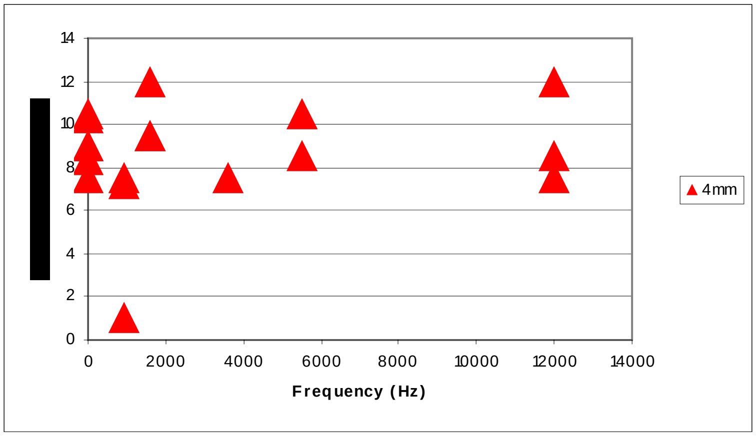
(Above) Diagram 5: Filling Distance vs. Frequency for all thicknesses.



(Above) Diagram 6: Filling distance vs. frequency, 2mm arm only.



(Above) Diagram 7: Filling distance vs. frequency, 3mm arm only.



(Above) Diagram 8: Filling distance vs. frequency, 4mm arm only.

Acoustic Coupling:

It is important to note that there was coupling between the actuator and the molten metal. The coupling of energy into the material is evidenced by the burn-in on the sprue and a noticeable delay in solidification (Diagram 9).

(Above: Diagram 9): The part on the left was not acoustically stimulated while the part on the right was. The burn in of the sand on the sprue is evidence of the thermal effect from actuation due to increased exposure of the sand to metal at high temperature.

Heat sink effect:

The heat sink effect studied consisted in observing whether the mass of the actuator was taking heat from the metal and cooling it. There was no significant heat sink effect noticed as illustrated below in Diagram 10.

(Diagram 10): Comparison of Heat Sink vs. No Heat Sink

Effect of wall thickness:

As illustrated in Diagrams 5 through 8 the distance filled by the different thickness arms increased with thickness of the arm. This corroborates many previous studies to this effect.

During the 12600 Hz trials, visual degassing of the material was noted in the vicinity of the actuator, prior to solidification.

5. CONCLUSIONS

- Acoustic stimulation did not increase the distance flow in the thin sections of the casting. However, in a few instances there seemed to be a positive response to actuation when resonance was maintained. Overall though, it was difficult to maintain resonance and thus a feedback controlled system may overcome this difficulty.

- The acoustic stimulation seemed to have a small sphere of influence as evidenced by the amount of sand burn in. It may be possible to positively affect mold fill if the stimulation takes place closer to the leading edge of metal.
- Electricity savings are definitely possible, but a transfer to commercial applications could not be fully attained at this test.

APPENDIX C: CAL POLY SAN LUIS OBISPO FIELD TEST

FIELD TEST 3

Acoustic Stimulator

Commercial Testing/Research

California State Polytechnic University, San Luis Obispo

Industrial Manufacturing and Engineering Department

October 2003

ACOUSTIC STIMULATION EXPERIMENTS AT CAL POLY - SAN LUIS OBISPO

Martin Koch, Professor

Industrial and Manufacturing Engineering Department

Introduction:

As discussed, riser effectiveness is measured by the total volume of liquid metal in the riser that actually goes into feeding the casting. It is not unusual to have risers use less than 30% of the metal to actually feed the casting. This means that 70% or more of the metal in the riser is used to simply keep that last 30% liquid until it is needed. The idea in this project is to move in the direction of maintaining the 30% amount of metal needed in the riser liquid long enough to allow for proper feeding, thus reducing the amount of metal that needs to be melted for the riser.

As an example, if a typical 100 pound casting is produced 40 lbs (40%) of the liquid metal is usually destined for the riser. Of this 40 lbs, optimistically 12 lbs (40 x 30%) will actually feed into the casting. Thus, the remaining 28 lbs of metal were melted and did not end up as part of the final product. With acoustic stimulation it may be possible to stimulate only 12 lbs of metal, keep it liquid, and effectively feeding the casting while saving 28 lbs or 28% of the energy required to produce the casting. These numbers are conservative as energy savings have the potential of being somewhat better.

Test Plan

Ten Sodium Silicate no-bake molds (see Illustration 1) using a long wedge pattern were made in order to enhance directional solidification. In addition, this pattern would be sensitive to the riser not feeding properly.

(Illustration 1 Above): 10 molds were made with Sodium Silicate bonded sand

The molds will be stimulated with a 1.25 inch diameter refractory probe (see Illustration 2) attached to a titanium resonator rod attached to a 1200-1500 Hz acoustic actuator. The stimulating probe diameter was increased to 1.25 inch to displace a larger volume of the riser metal than previous experiments. The rationale for this size probe is to simulate a 40%-50% reduction in riser volume. The stimulator will be hand held in the center riser section until just prior to solidification of the molten aluminum. One non-stimulated mold will be poured. The acoustic amplitude will be controlled manually by continuously adjusting the frequency of the actuator to compensate for heating of the device.

Risers will be sawed in half in order to examine and photograph the effect of stimulation. As it will be difficult to hold the device at a constant depth and radial position inside the riser, this will result in variable “hollowness”, or cavity size. As the percentage risers account for the total about metal required to make a commercially viable casting varies in this alloy from ~10% to 50%, the amount of energy saved could vary from 5% to 25% in savings.

Procedure:

A long wedge pattern was made in order to enhance directional solidification. In addition, this pattern would be sensitive to the riser not feeding properly. Prior to the molds will be poured at approximately 1300 F directly through the riser while the acoustic probe is stimulating the riser. The probe will stimulate until the riser is nearly completely solidified and then withdrawn.

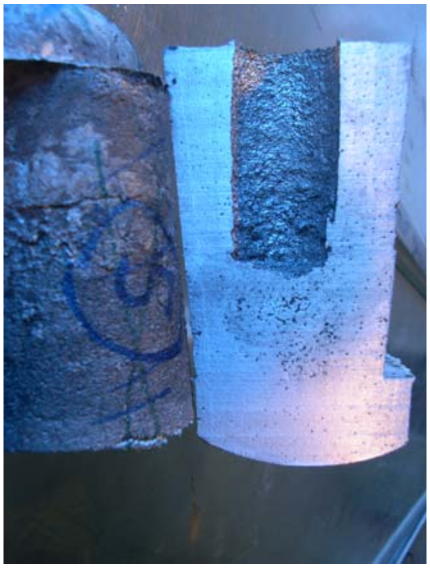
(Above Illustration 2): Probe Used in Cal Poly San Louis Obispo Experiments, 1 ¼ inch diameter.

(Above Illustration 3): Pointed probe used in Cal Poly Pomona experiments.
Probe used in Technikon experiments was ½ inch diameter.

The frequencies used to stimulate the metal in the risers were varied from ~1300 hz to ~5000 hz. Riser stimulation frequency did not significantly matter in this limited experimentation. All frequencies seemed to stimulate equally for purposes of this research.

(Above Illustration 4) Larger 1.25 inch diameter probe stimulating. Note liquid metal “wave” near probe.

(Left Illustration 5A) A non-stimulated riser.



(Left Illustration 5B) Acoustically stimulated riser.

Results:

The risers were maintained liquid for a longer period of time when acoustically stimulated. Note the liquid metal wave near the probe in Illustration 4. In addition, the amount of metal that was displaced by the actuator probe was approximately 35% to 50% of riser volume (See Illustration 5A, 5B). The power input to the actuator was approximately 0.65 kW.

(Above Illustration 6): Castings poured with hollow risers

Discussion:

The first point that is important to make is that the risers were kept liquid and feeding for a substantially longer time when stimulated than when not stimulated. Most of the metal in risers simply keeps the metal that will eventually feed the casting from solidifying before it is needed. With acoustic stimulation it is possible to obtain the same objective and simply not melt the unnecessary metal.

This experiment used limited riser/transducer configurations. The risers used were designed using standard principles for determining the shape, essentially a cylinder with a similar height as diameter. This geometry is used to minimize the surface area to volume of the riser to keep the center hot as long as possible. If the castings are acoustically stimulated a different shape riser could be used to optimize the acoustic effect: most likely tall and thin. In this manner the actuator would also displace more metal from the riser in greater proportion as seen in the previous illustrations.

Energy Savings Potential

The amount of metal displaced by the stimulator probe accounted for approximately 40% of the riser volume. This riser volume was approximately 50% in this casting. This would translate into a 20% reduction in the melt energy used to produce this casting.

Future work:

Acoustic stimulation works to keep risers liquid until needed to feed metal. Research now should focus on optimizing transducer geometry and riser geometry for acoustic stimulation. Effects on feeding distance should also be researched.

APPENDIX D: TECHNIKON FIELD TEST II

FIELD TEST 4

Acoustic Stimulator

Commercial Testing/Research

Technikon, LLC

McClellan, CA

October 2003

Experiment to Test Theory of Acoustic Heat Affected Zone

Jim Furness, President

Furness-Newburge, Inc.

Versailles, KY

1. INTRODUCTION

The previous experiments indicated an area of burned sand in the localized area of the stimulator probe. In the non-stimulated castings, this phenomena was reduced or non-existent. This indicated the possibility of a heat affected zone heat where energy was being “pumped” into the sand. The intent of this experiment is to see if acoustic heat pumping from the “heat affected zone” can be transferred to the leading edge of the metal as it enters the thin section thereby keeping the advancing metal front molten longer and thus aid in the filling of the thin sections.

Test Plan

Three phenolic urethane no-bake molds using the test one star pattern. The molds will be stimulated through an access hole with a probe attached to a titanium resonator rod attached to a 1200-1500 Hz acoustic actuator. The molds will be stimulated above, in the middle and just below the hard to fill 2.5 mm section. The acoustic amplitude will be controlled manually by continuously adjusting the frequency of the actuator to compensate for heating of the device. The castings will be visually inspected for fill potential.

(Above, Image 1): No blackened sand adhering to the casting without acoustic stimulation

(Above, Image 2): Blackened sand adhering to the riser after stimulation

(Above, Image 3) Blackened sand adhering to the riser after stimulation

2. OBJECTIVE

Evaluate the effect of acoustic stimulation on the mold fill distance of A356.1 Aluminum when the stimulator probe was placed just below the advancing metal front in a hard to fill thin wall area.

(Above, Image 4) Casting did not fill when probe was placed in the center of the hard to fill thinnest section.

(Above, Image 5): The final casting of the project showing acoustic probe just below the hard to fill area has filled the casting.

Conclusion:

In this final experiment we showed that placement of the probe is critical when trying to improve metal feed in thin walled aluminum sections. At previous test sites, the probe was most likely outside the “heat affected zone” of acoustic influence.

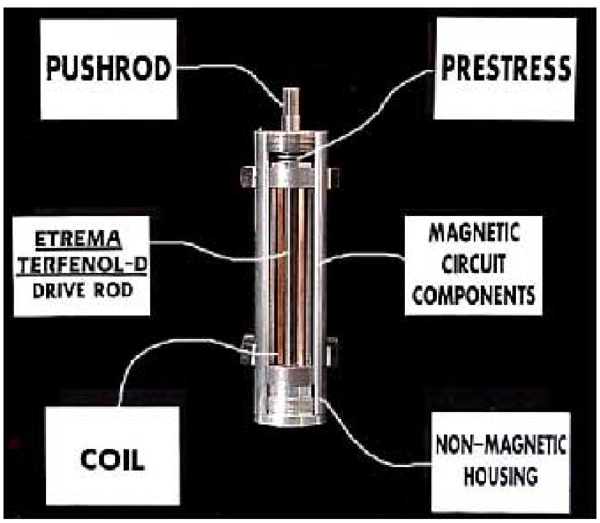
Potential Energy Savings:

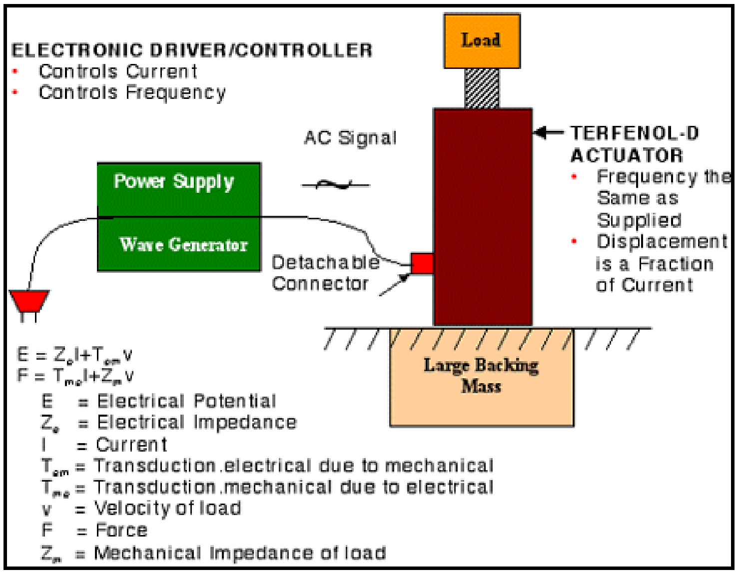
No additional energy was actually saved in this experiment as much of the focus was on the positioning of the probe. But the potential for filling thinner walled castings was demonstrated. As discussed in previous research, this potential can result in 1% to 20% of the metal melted to produce a casting. This decrease in overall metal poured would directly translate into energy savings.

APPENDIX E: HOW MAGNETOSTRICTIVE ACTUATORS WORK

HOW MAGNETOSTRICTIVE ACTUATORS WORK

TERFENOL-D actuators have few moving parts, contributing to high reliability. The figure at left shows the essential parts of a typical actuator. A properly magnetically biased magnetostrictive actuator will operate at the frequency of the input current. A prestress system will optimize output and efficiency. The most important design consideration is careful engineering of the "magnetic circuit". The magnetic circuit consists of the solenoid coil to provide the oscillating field, permanent magnets for bias, and careful selection and shaping of the other parts through which the magnetic field passes. A good magnetic circuit ensures the highest magnetic flux density in the TERFENOL-D, and very uniform magnetic flux in all phases of the actuator operating cycle. Basic configuration and equations for a magnetostrictive actuator system are shown below. Models are continuously refined, based on results with successful actuators. Custom actuators always take advantage of the latest engineering and manufacturing techniques.
(Contributing Source: http://www.etrema-usa.com/products/terfenol/)





ELECTRONIC DRIVER/CONTROLLER
• Controls Current
• Controls Frequency
Load
AC Signal
TERFENOL-D ACTUATOR
• Frequency the Same as Supplied
• Displacement is a Fraction of Current
Power Supply
Wave Generator
Detachable Connector
Large Backing Mass
E = Z_e I + T_em v
F = T_me I + Z_m v
E = Electrical Potential
Z_e = Electrical Impedance
I = Current
T_em = Transduction.electrical due to mechanical
T_me = Transduction.mechanical due to electrical
v = Velocity of load
F = Force
Z_m = Mechanical Impedance of load