Final Report

Energy-Saving Melting and Revert Reduction Technology

(E-SMARRT)

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List of Acronyms

AFS – American Foundry Society

CMC – Cast Metals Coalition

E-SMARRT – Energy Saving Melting and Revert Reduction Technology

NFFS – Non-Ferrous Founders' Society

NADCA – North American Die Casting Association

SFSA – Steel Founders' Society of America

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Executive Summary

Energy-Saving Melting and Revert Reduction Technology (E-SMARRT) is a balanced portfolio of R&D tasks that address energy-saving opportunities in the metalcasting industry. E-SMARRT was created to:

- Improve important capabilities of castings
- Reduce carbon footprint of the foundry industry
- Develop new job opportunities in manufacturing
- Significantly reduce metalcasting process energy consumption

and includes R&D in the areas of:

- Improvements in Melting Efficiency
- Innovative Casting Processes for Yield Improvement/Revert Reduction
- Instrumentation and Control Improvement
- Material properties for Casting or Tooling Design Improvement

The energy savings and process improvements developed under E-SMARRT have been made possible through the unique collaborative structure of the E-SMARRT partnership. The E-SMARRT team consisted of DOE's Office of Industrial Technology, the three leading metalcasting technical associations in the U.S: the American Foundry Society; the North American Die Casting Association; and the Steel Founders' Society of America; and SCRA Applied R&D, doing business as the Advanced Technology Institute (ATI), a recognized leader in distributed technology management. This team provided collaborative leadership to a complex industry composed of approximately 2,000 companies, 80% of which employ less than 100 people, and only 4% of which employ more than 250 people. Without collaboration, these new processes and technologies that enable energy efficiencies and environment-friendly improvements would have been slow to develop and had trouble obtaining a broad application.

The E-SMARRT R&D tasks featured low-threshold energy efficiency improvements that are attractive to the domestic industry because they do not require major capital investment. The results of this portfolio of projects are significantly reducing metalcasting process energy consumption while improving the important capabilities of metalcastings. Through June 2014, the E-SMARRT program predicts an average annual estimated savings of 59 Trillion BTUs per year over a 10 year period through Advanced Melting Efficiencies and Innovative Casting Processes. Along with these energy savings, an estimated average annual estimate of CO_2 reduction per year over a ten year period is 3.56 Million Metric Tons of Carbon Equivalent (MM TCE).

1. Introduction

Energy-Saving Melting and Revert Reduction Technology (E-SMARRT) is a balanced portfolio of tasks to address energy-saving opportunities in the metalcasting industry, including:

- Improvements in Melting Efficiency
- Innovative Casting Processes for Yield Improvement/Revert Reduction
- Instrumentation and Control Improvement
- Material properties for Casting or Tooling Design Improvement

E-SMARRT is a collaboration between the Department of Energy (DOE), the three leading metalcasting industry associations (American Foundry Society, North American Die Casting Association, Steel Founders Society of America) and their members, the leading U.S. metalcasting research institutions, and SCRA, a leader in consortia management.

The results of this portfolio of projects are significantly reducing metalcasting process energy consumption while improving the important capabilities of metalcastings. The E-SMARRT Work Breakdown Structure (WBS) with the portfolio of projects and the lead research institution is contained in the table below:

Table 1 E-SMARRT Work Breakdown Structure

WBS #	Task Description/Title	Lead
1.0	**Project Management**	ATI
2.0	**Improve Melt Efficiency**	
2.1	Improvements in Efficiency of Melting for Die Casting	CWRU
2.2	Melting Efficiency Improvement	UMR
3.0	**Innovative Casting Processes for Yield Improvement/Revert Reduction**	
3.1	Clean Steel Casting Production	CANMET
3.2	Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys	CANMET
3.4	Improved Die Casting Process to Preserve the Life of the Inserts	CWRU
3.5	Development of Thin-Section Zinc Die Casting Technology	ILZRO
3.7	Design Support for Tooling Optimization	OSU
3.8	Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology	UAB
3.9	Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings	UI
3.10	Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings	UI
3.11	Precision Castings	UMR
3.12	Innovative Semi-Solid Metal (SSM) Processing	WPI
3.13	Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions	ORNL/ EMTEC
3.14	Light Metals Permanent Mold Casting	CANMET
4.0	**Instrumentation and Control Improvement**	
4.1	Energy Efficiency Instrumentation	ISU
5.0	**Material Properties for Casting or Tooling Design Improvement**	

5.1	The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: *Towards a "Smart" Die Coating*	CSM
5.3	Casting Porosity-Free, Grain Refined Magnesium Alloys	CWRU
5.4	Development of Elevated Temperature Aluminum MMC Alloy and Process Technology	Eck
5.6	Development of CCT Diagrams	ISU
5.7	Corrosion Testing Practices – High Alloy Corrosion Program	Lehigh
5.8	Mechanical Performance of Dies	OSU
5.9	The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management	OSU
5.10	Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications	UAB
5.11	Aging of Graphitic Cast Irons and Machinability	UMR

The following projects were never started due to funding restrictions:

3.3	Improved Yield & Production Rates in Metal Mold Casting Processes by Advanced Thermal Management	CWRU
3.6	Investigation of Flow Regimes in High Pressure Die Casting	OSU
5.2	Improvement in Die Design to Improve Die Life as Affected by Thermal Fatigue Cracking, Erosion and Soldering	CWRU
5.5	Conformal Cooling in Die Casting and Permanent Mold Casting	INEEL

E-SMARRT was created to:

- Improve important capabilities of castings
- Reduce carbon footprint of the foundry industry
- Develop new job opportunities in manufacturing
- Significantly reduce metalcasting process energy consumption

These E-SMARRT R&D tasks feature low-threshold energy efficiency improvements that are attractive to the domestic industry because they do not require major capital investment. The results of this portfolio of projects are significantly reducing metalcasting process energy consumption while improving the important capabilities of metalcastings. Through June 2014, the E-SMARRT program predicts an average annual estimated savings of 59 Trillion BTUs per year over a 10 year period through Advanced Melting Efficiencies and Innovative Casting Processes. Along with these energy savings, an estimated average annual estimate of CO_2 reduction per year over a ten year period is 3.56 Million Metric Tons of Carbon Equivalent (MM TCE).

Advanced Technology International (ATI), dba SCRA Applied R&D, provided the project management functions required to lead the program, guided by an Industry Review Board (IRB) and supported by a Technical Advisory Committee (TAC).

In November 2008, DOE cancelled the Cast Metals Coalition (CMC) Technology Transfer program, which provided the metalcasting industry associations with funds to monitor the performance of E-SMARRT tasks and transition the program's results into industry. DOE allowed for a portion of the E-SMARRT GFY2009 funds to be allocated to the three CMC metalcasting industry associations (American Foundry Society, North American Die Casting

Association, and Steel Founders' Society of America) to review E-SMARRT results and promote the deployment into industry.

2. Background

The metalcasting industry is expanding in Brazil, Eastern Europe, India, and China. These countries are focused on producing castings at dramatically lower prices using older technology. Because of these lower prices, U.S. metalcasters are unable to invest in R&D or capitalize major equipment installations. Low labor cost and below cost foreign price competition have severely reduced profitability of U.S. metalcasters. Over the last 10 years, over 600 metalcasters have gone out of business, and in 2013 only 2,001 remain. It is hard for the industry to raise capital for plant, equipment or R&D.

Growth in light metalcasting applications dominates the current U.S. technology landscape. Simulation and rapid tooling technologies, based on computer-generated solid models, have greatly reduced design-to-market cycle times for metalcastings. Advances in Lost Foam and metal mold processes in the aluminum industry segment are examples of adaptation of existing melting equipment, processing equipment, and facilities. Some new melting technologies, such as infrared and microwave, are beginning to be developed and implemented. The Energy SMARRT Team, including people from government, industry, and academia, identified the Energy SMARRT research needs through the Metalcasting Vision 2002 and resulting Technology Roadmap.

Over 100 metalcasters, engineering firms and suppliers contributed over $11,000,000 in cost share to Energy SMARRT. These organizations provided labor, expertise, oversight, facilities, material and equipment. Many of these industry partners participated in the Metalcasting Vision 2002 and resulting Technology Roadmap. Energy SMARRT actively evaluated the development of these technologies and assisted in their deployment.

The management structure of the program allowed the partners to monitor progress of the R&D tasks, terminating any that are under performing and initiating new, or augmenting those that show additional promise. The criterion for each task's progress and success was early energy and dollar savings. Energy SMARRT targeted the needs identified by the industry, reflecting their cost pressures and energy efficiency problems. This approach attacked most of the significant energy-saving opportunities and had a high probability of reducing metalcasting energy consumption. Energy SMARRT addressed fundamental problems across a broad industry base to assure adoption and savings. The innovative and bold nature of Energy SMARRT's technology is its ability to save 49 Trillion BTU's/Year on average, while requiring minimal capital investment and saving approximately $335M per year.

The overarching goal of the Energy SMARRT program is to improve metalcasting processes to achieve an average annual reduction in energy use of 14%, saving $335M per year. The program scope addresses both Advanced Melting and Innovative Casting Processes through a balanced portfolio. This approach will identify processes and technological advances able to deliver economic benefits beginning as soon as two years from the program start.

The Energy SMARRT research addressed the more important energy saving opportunities across the industry. It avoided the pitfall of pursuing a single technology that, even if successful, would improve only one segment of the industry. The Energy SMARRT research portfolio was developed by industry and presents an innovative program that addresses requirements identified in the Metalcasting Vision 2002 and resulting Technology Roadmap.

3. Results and Discussion

The specific tasks for E-SMARRT, the Principal Investigator, and the Office of Scientific and Technical Information (OSTI) final report number are listed in Table 2. The detailed results and discussions on each specific Energy SMARRT task are in the OSTI final reports and listed in Appendix B.

Table 2 E-SMARRT Tasks, Principal Investigators, and OSTI Final Report Number

WBS #	Task Description/Title	Lead	OSTI #
1.0	**Project Management**	ATI	NA
2.0	**Improve Melt Efficiency**		NA
2.1	Improvements in Efficiency of Melting for Die Casting	CWRU	1057665
2.2	Melting Efficiency Improvement	UMR	1051407
3.0	**Innovative Casting Processes for Yield Improvement/Revert Reduction**		
3.1	Clean Steel Casting Production	CANMET	1126492
3.2	Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys	CANMET	1131409
3.4	Improved Die Casting Process to Preserve the Life of the Inserts	CWRU	1057028
3.5	Development of Thin-Section Zinc Die Casting Technology	ILZRO	1111101
3.7	Design Support for Tooling Optimization	OSU	1025584
3.8	Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology	UAB	1024103
3.9	Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings	UI	1022073
3.10	Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings	UI	1022074
3.11	Precision Casting of Steel	UMR	1028211
3.12	Innovative Semi-Solid Metal (SSM) Processing	WPI	1057874
3.13	Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions	ORNL/ EMTEC	1024605
3.14	Light Metals Permanent Mold Casting	CANMET	1126472
4.0	**Instrumentation and Control Improvement**		NA
4.1	Energy Efficiency Instrumentation	ISU	1123312

5.0	**Material Properties for Casting or Tooling Design Improvement**		NA
5.1	The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: *Towards a "Smart" Die Coating*	CSM	1050628
5.3	Casting Porosity-Free, Grain Refined Magnesium Alloys	CWRU	1097772
5.4	Development of Elevated Temperature Aluminum MMC Alloy and Process Technology	Eck	1131418
5.6	Development of CCT Diagrams	ISU	1022742
5.7	Corrosion Testing Practices – High Alloy Corrosion Program	Lehigh	1045448
5.8	Mechanical Performance of Dies	OSU	1025587
5.9	The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management	OSU	1135793
5.10	Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications	UAB	1123477
5.11	Aging of Graphitic Cast Irons and Machinability	UMR	1054341

The technical objective and approach for each E-SMARRT task is listed below:

2.1 Improvements in Efficiency of Melting for Die Casting: This task evaluated multiple aspects of the aluminum melting and handling in die casting operations, with the objective of increasing the energy efficiency while improving the quality of the molten metal.

2.2 Melting Efficiency Improvement: This task studied steel foundry melting operations to understand energy use and requirements for casting operations, define variations in energy consumption, determine technologies and practices that are successful in reducing melting energy and develop new melting techniques and tools to improve the energy efficiency of melting in steel foundry operations.

3.1 Clean Steel Casting Production: This task focused on the mold filling aspects to examine the effects of pouring methods and gating designs on the steel casting cleanliness through water modeling, computer modeling, and melting/casting experiments.

3.2 Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys: This task developed appropriate lost foam casting technology for near-net shape prototype engineering components from selected aluminum- and magnesium-base alloys, and investigated the effects of vacuum molding and pouring techniques and low pressure on the quality of the prototype thin-wall components produced during lost foam casting.

3.4 Improved Die Casting Process to Preserve the Life of the Inserts: This task studied the combined effects of die design, proper internal cooling and efficient die lubricants on die life and developed methods of optimized process control for extended die life.

3.5 Development of Thin-Section Zinc Die Casting Technology: This task developed a new high fluidity zinc high pressure die casting alloy, termed the HF alloy, during laboratory trials and proven in industrial production. The HF alloy permits castings to be achieved with section thicknesses of 0.3 mm or less.

3.7 Design Support for Tooling Optimization: This task involved design assessment and support for high pressure die casting and similar processes using a permanent mold. The focus was on thermal management of the die and cooling system with the objective of developing optimization techniques to aid in the die cooling system design. A second objective was to improve the CastView program to visualize the filling of the die cavity, specifically extending the techniques to gravity and slower fill processes. A third objective was to extend the Castability Assessment work to include "wizards" that incorporate industry-wide (NADCA) or company design standards.

3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology: This task developed technologies that advanced the Lost Foam Casting process application and allow greater energy savings. These improvements included (1) production efficiency, (2) mechanical properties, and (3) marketability of lost foam castings.

3.9 Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings: This task developed and implemented a model into existing casting simulation software (MagmaSOFT) that predicts distortion and residual stress development during heat treatment of steel castings.

3.10 Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings: This task developed a combined model for predicting dimensional changes and hot tears in steel castings and implemented the model in commercial MagmaSOFT casting simulation software.

3.11 Precision Casting of Steel: This task focused on two areas of study in the production of steel castings to reduce scrap and save energy:

1. Reducing the amount of shell cracking in investment cast steel production
2. Investigating the potential of lost foam steel casting

3.12 Innovative Semi-Solid Metal (SSM) Processing: This task had four parts:

1. Optimize the continuous rheoconversion process (CRP) scale up for commercial applications
2. Develop optimum alloys for SSM/CRP processes
3. Establish optimum heat treatment schedules for various commercial SSM alloys
4. Develop a comprehensive constitutive mathematical model that includes the internal microstructural dynamics of SSM slurries and allows better simulation of die filling during the production of SSM parts.

3.13 Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions: This task developed computational tools and methodologies for predicting pattern tooling and casting dimensions for investment castings and incorporating them into ProCAST simulation software in order to enable the production of investment castings to meet blue print nominal during the first casting run.

3.14 Light Metals Permanent Mold Casting: This task established the processing parameters for gravity and low pressure permanent mold casting of Al-Mg alloy 535 and high strength aluminum alloy 206.0 (Al-Cu alloy). The microstructure and mechanical properties were also determined for the as-cast as well as heat-treated conditions of these alloys.

4.1 Energy Efficiency Instrumentation: This task developed better tools and strategies to collect and manage process and product information. Based on industry feedback, five areas were selected based on the amount of variation caused by this source or the potential for improvement in terms of energy, emissions and competitiveness:

1. Heat Treatment Control Strategies
2. Semi-Automated Grinding
3. Surface Mapping Software
4. Study of Impact of Repairs via Weld Gouges
5. Rapid Pattern Making Machine

5.1 The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating: This task designed and developed an optimal coating system that extends die life and performance by minimizing premature die failure.

5.3 Casting Porosity-Free, Grain Refined Magnesium Alloys: This task identified causes for micro-porosity in magnesium alloys and developed remedies to be implemented in production.

5.4 Development of Elevated Temperature Aluminum Metal Matrix Composite (MMC) Alloy and Process Technology: This task developed a production-capable cast aluminum MMC alloy with an operating temperature capability of 250-300°C.

5.6 Development of Continuous-Cooling-Transformation (CCT) Diagrams: This task characterized the solid-solid phase transformations seen in cast superaustenitic stainless steels to improve corrosion and / or mechanical properties.

5.7 Corrosion Testing Practices – High Alloy Corrosion Program: This task developed new heat treatment practices for high ally steel castings that improve corrosion resistance and mechanical properties comparable to their wrought counterparts.

5.8 Mechanical Performance of Dies: This task improved the ability to model the mechanical characteristics of the interactions that occur between the die casting machine and the dies to improve productivity, die performance, and part quality.

5.9 The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management: This task evaluated the feasibility of designing, fabricating, and testing high pressure die casting tooling having properties equivalent to H13 on the surface in contact with molten casting alloy - for high temperature and high velocity molten metal erosion resistance – but with the ability to conduct heat rapidly to interior water cooling passages. The tooling was fabricated by traditional machining of the copper substrate, and H13 powder was deposited on the copper via the Laser Engineered Net Shape (LENS) process.

5.10 Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications: This task characterized surface/near surface indications located and evaluated the effectiveness of current surface quality standards in predicting the actual size and shape of indications and their effect on part performance.

5.11 Aging of Graphitic Cast Irons and Machinability: This task determined:
1. Whether ductile iron and compacted graphite iron exhibited age strengthening
2. The mechanism by which cast gray iron age strengthens
3. The mechanism by which age-strengthening improves the machinability of gray cast iron.

4. Benefits Assessment

2.1 Improvements in Efficiency of Melting for Die Casting: The results of this research will produce energy savings through the improved process and handling of the aluminum melt used in the die casting process. In addition, this work focused on improving the quality of the melt. The results of this work were predicted to bring about an average energy savings of 4.4 trillion BTU's/year over a 10 year period. The average annual estimate of CO_2 reduction per year through 2022 is 0.084 Million Metric Tons of Carbon Equivalent (MM TCE).

2.2 Melting Efficiency Improvement: Industrial trials proved that:
- energy optimization in induction furnaces can save between 5 and 15% in the melting operation from improvements in scheduling and improved melting practices.
- the use of chemical energy in electric arc furnace operations can save between 6 and 15% electrical energy consumption
- the tapping temperature can be reduced by 50 to 100^{o}F with improved ladle operations, saving an additional 3 – 5% electrical energy.

3.1 Clean Steel Casting Production:
- bottom-pouring with new basin designs (dam), submerged nozzle, and nozzle extension effectively improved the large steel casting cleanliness
- radial-choke gating design resulted in the reduction of casting tree weight by 12%.
- radial-choked gating can produce clean steel castings without resorting to the ceramic filters in gating, which would have huge potential savings for the metalcasting industry.

3.2 Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys: The potential energy savings at pouring temperatures of 1250^{o}F (677^{o}C) compared to 1450^{o}F (788^{o}C) are very large. The estimated savings for this temperature reduction is 17 - 19%. In addition, CO_2 emissions are significantly reduced and melting and holding furnace life is extended. Furthermore, the use of non-traditional higher strength aluminum alloys would alloy designers to produce either lighter weight components at current stress levels or higher performance parts at current part weight.

3.4 Improved Die Casting Process to Preserve the Life of the Inserts: Improving die life by means of optimized cooling line placement will reduce die temperatures during processing, saving energy associated with production. The utilization of optimized die lubricants will also reduce heat requirements in addition to reducing waste associated with soldering and washout. Annual energy saving estimates is 2012, based on commercial introduction in 2010, a market penetration of 70% by 2020 is 1.26 trillion BTU's/year.

3.5 Development of Thin-Section Zinc Die Casting Technology: The new high fluidity (HF) zinc alloy can significantly improve upon the energy and cost savings already inherent in zinc alloys, including fast production rates and net shape casting that eliminates the need for subsequent machining operations. The low melting temperature (385°C) alloy reduces energy requirements for metal melting and holding, and increases die life, while the weight reduction achieved through ultra-thin wall casting capability reduces energy use throughout the life of the cast part from melting and casting, transportation of finished parts, during use and final collection for end of life recycling.

3.7 Design Support for Tooling Optimization: Annual energy saving estimates is 2011 over a ten year period, based on commercial introduction in 2012, a market penetration of 30% by 2015 is 1.89 trillion BTU's/year by 2022. Along with these energy savings, reduction of scrap and improvement in yield will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO_2 reduction per year through 2022 is 0.037 Million Metric Tons of Carbon Equivalent (MM TCE).

3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology: Typical casting scrap rates for both aluminum and iron castings have been reduced to less than 2% for simple shapes and less than 6% for complex castings with intricate passages. This is a significant improvement from the 25% - 30% scrap rates that were common fifteen years ago. Annual energy saving estimates based on commercial introduction in 2011 and a market penetration of 97% by 2020 is 5.02 trillion BTU's/year and 6.46 trillion BTU's/year with 100% market penetration by 2023. Along with these energy savings, reduction of scrap and improvement in casting yield will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO_2 reduction per year through 2020 is 0.03 Million Metric Tons of Carbon Equivalent (MM TCE).

3.9 Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings: Due to the premature termination of this project, the commercial model to predict distortions and residual stresses that develop during heat treatment of steel castings has not yet been fully validated. However, the comparisons between predictions and experiments performed for this project show reasonable agreement thus far. When validation is complete, this model will provide the steel casting industry with a tool that will result in increased casting yield from reduced scrap, more efficient use of heat treatment resources, significant casting weight savings, as well as longer service lives for steel castings. This new technology was predicted to result in an average energy savings of 2.44 trillion BTU's/year over a 10 year period (with full funding). With only 32.5% of proposed funding, 2011 annual energy saving estimates, based on commercial introduction in 2012, a market penetration of 29% by 2020, and 10% reduction in energy usage per year, is 2.15 trillion BTU's/year. Along with these energy savings, reduction of scrap and improvement in casting yield will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO_2 reduction per year through 2020 is 0.03 Million Metric Tons of Carbon Equivalent (MM TCE).

3.10 Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings: The development of a commercial model to predict dimensional changes and hot tears during solidification of steel castings will provide the steel casting industry with a tool that will result in a reduction of scrapped castings and re-work/repair due to dimensional changes or hot tears, and also an increase in casting yield due to a reduction in the use of padding and improved placement of risers, leading to better riser efficiency. With 86.6% of proposed funding, current (2011) annual energy saving estimates, based on commercial introduction in 2012, a market penetration of 29% by 2020, and 10% reduction in energy usage per year, is 2.15 trillion BTU's/year.

3.11 Precision Casting of Steel: With potential 20% of castings used for transportation applications, or 100,000 year steel casting produced, novel processing will potentially save 7, 200,000 X 10, 000 = 0.72 trillion Btu per year or 7.2 trillion Btu during 10 years.

3.12 Innovative Semi-Solid Metal (SSM) Processing: SSM technology uses 80% of the energy used in conventional aluminum casting technology. Over a period of 10 years, it is predicted that SSM technology will capture 24% of the die casting and permanent mold aluminum market. Estimated savings from this data is 2.1×10^{12} Btu.

3.13 Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions: This new modeling data is predicted to save an estimated 2.4 trillion BTU's/year with 50% market penetration by 2020. Along with these energy savings, reduction of scrap and improvement in casting yield will result in an average annual estimate of CO_2 reduction per year through 2020 of 0.41 Million Metric Tons of Carbon Equivalent (MM TCE).

3.14 Light Metals Permanent Mold Casting: It is estimated that energy savings of about 250 kWh per ton of castings can be realized by switching from sand to permanent mold casting. In addition, the environmental problems associated with sand disposal and working conditions in the foundries would also be improved.

4.1 Energy Efficiency Instrumentation:

- For Heat Treatment Control Strategies, current (Dec 2013) annual energy saving estimates based on commercial introduction in 2013 and a market penetration of 60% by 2024 is 0.16 trillion BTU's/year. Along with these energy savings, reduction of scrap will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO2 reduction per year through 2024 is 0.003 Million Metric Tons of Carbon Equivalent (MM TCE).

- For Semi-Automated Grinding, current (Dec 2013) annual energy saving estimates based on commercial introduction in 2014 and a market penetration of 20% by 2024 is 1.3 trillion BTU's/year. Along with these energy savings, reduction of scrap will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO2 reduction per year through 2024 is 0.02 Million Metric Tons of Carbon Equivalent (MM TCE).
- For Surface Mapping Software current (Dec 2013) annual energy saving estimates based on commercial introduction in 2013 and a market penetration of 50% by 2024 is 4.5 trillion BTU's/year. Along with these energy savings, reduction of scrap will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO2 reduction per year through 2024 is 0.07 Million Metric Tons of Carbon Equivalent (MM TCE).
- For Impact of Repairs via Weld Gouges current (Dec 2013) annual energy saving estimates based on commercial introduction in 2013 and a market penetration of 25% by 2024 is 1.1 trillion BTU's/year. Along with these energy savings, reduction of scrap will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO2 reduction per year through 2024 is 0.02 Million Metric Tons of Carbon Equivalent (MM TCE).
- For Rapid Pattern Making current (Dec 2013) annual energy saving estimates based on commercial introduction in 2013 and a market penetration of 20% by 2024 is 0.9 trillion BTU's/year. Along with these energy savings, reduction of scrap will result in a reduction of the environmental emissions associated with the melting and pouring of the metal which will be saved as a result of this technology. The average annual estimate of CO2 reduction per year through 2024 is 0.01 Million Metric Tons of Carbon Equivalent (MM TCE).

For the entire project, by 2024 the average annual energy savings estimate is 7.96 trillion BTU's/year and the average annual estimate of CO2 reduction per year 0.123 Million Metric Tons of Carbon Equivalent (MM TCE).

5.1 The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating: The technology offers energy savings through reduced energy use in the die casting process from several factors such as greatly increased life of the tools and dies, reuse of the dies and die components, reduction or elimination of lubricants, and reduced machine down time. Use of the optimized coating system will also result in the reduction of Al solder sticking on the die and die component surface and therefore reduce the energy involved in the cleaning process of the dies. The combination of the depositions of the CrN/AlN superlattice coating and the AlN piezoelectric thin film using one deposition technique in one deposition system also reduced energy use in the processing equipment. Current (2012) annual energy saving estimates, based on initial dissemination to the casting industry in 2010 and market penetration of 80% by 2020, is 3.1 trillion BTU's/year

5.3 Casting Porosity-Free, Grain Refined Magnesium Alloys: It is estimated application of predictive porosity computer simulation methods and best practices of gating and risering can reduce scrap by at least 2%. Using American Foundry Society -esitimated 100 thousands of tons of magnesium casings produced in the US as a base-line, the 2% reduction in scrap translates into 2,000 tons/year (4.41 Million pounds/year). At an average melting energy of 1,800 BTU/lb (33) the energy savings resulting from this scrap reduction are $7.93x10^9$ BTUs. The cost of the energy savings assuming an average cost of $5/MMBTU is almost $39.6 million/year.

5.4 Development of Elevated Temperature Aluminum MMC Alloy and Process Technology: The total energy savings of 532 million BTU per ton of Ti alloy castings replaced by the newly developed elevated temperature capable AlCuMgSc alloy, which is a 77% savings in energy requirements.

5.6 Development of CCT Diagrams: The main benefits of this research has been in identifying the scientific reasons why castings may fail due to poor fracture toughness and / or poor corrosion resistance and providing guidelines to follow to avoid such failures. By identifying the reasons for failure, namely, intermetallic formation on grain boundaries and the time / temperature regimes under which harmful intermetallics can occur, companies can now use advanced heat-flow software to determine whether any particular casting, or part of a large casting, will be subject to cooling conditions that would lead to precipitate formation. The experimental results obtained relating specific intermetallic formation to composition can also provide guidance in determining solution heat treatment times and temperatures to improve casting quality. These results can produce significant energy savings in two ways. Firstly, by reducing the number castings that need to be scrapped savings are generated by eliminating costs associated with completely remaking a casting. Secondly, by identifying the time / temperature ranges at which precipitation is a problem, heat treatment schedules can be more efficiently planned and executed.

5.7 Corrosion Testing Practices – High Alloy Corrosion Program: The development of high alloy steel heat treatment guidelines will provide the steel casting industry with enhanced process controls that will result in a reduction of scrapped castings and rework/repair and improved energy efficiencies resulting from accurate heat treatment practices. Current (2012) annual energy saving estimates, based on initial dissemination to the casting industry in 2010 and market penetration of 99% by 2020, is 0.25 trillion BTU's/year. The average annual estimate of CO_2 reduction per year through 2020 is 0.005 Million Metric Tons of Carbon Equivalent (MM TCE).

5.8 Mechanical Performance of Dies: The results of this study were predicted to result in an average energy savings of 2.03 trillion BTU's/year over a 10 year period.

5.9 The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management: Commercial implementation of LENS™ fabricated Cu/H13 bi-metallic tooling technology will reduce overall energy consumption, along with its affiliated greenhouse gas emissions, and also reduce other aerosol emissions and effluent water quality from die casting operations.

5.10 Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications: Accurate numerical simulations of casting service performance allow designers to use the geometric flexibility of castings and the superior properties of steel to produce lighter weight and more energy efficient components for transportation systems (cars and trucks), construction, and mining. Accurate simulations increase the net melting energy efficiency by improving casting yield and reducing rework and scrap. Conservatively assuming a 10% improvement in yield, approximately 1.33 x 10^{12} BTU/year can be saved with this technology. In addition, CO_2 emissions will be reduced by approximately 117,050 tons per year.

5.11 Aging of Graphitic Cast Irons and Machinability: Estimated energy savings in ten years is 13.05 trillion BTU, based primarily on yield improvement and size reduction of castings for equivalent service. Also it is estimated that the heavy truck end use of lighter castings for equivalent service requirement will result in a diesel fuel energy savings of 131 trillion BTU in ten years.

5. Commercialization

For a summary of the Technology Transfer efforts performed by the industry associations (American Foundry Society, North American Die Casting Association, and Steel Founders' Society of America) under the Energy SMARRT program after the cancellation of the Cast Metals Coalition (CMC) Technology Transfer program in November 2008, see Appendix A.

2.1 Improvements in Efficiency of Melting for Die Casting: The Principal Investigator, Case Western Reserve university, worked with many die casters to benchmark the energy efficiency of a wide range of aluminum melting and holding furnaces, including: Spartan Light Metal, Sparta IL; Mercury Marine, Fond du Lac WI; Empire Die Casting, Macedonia OH; Ryobi Die Casting, Shelbyville, IN; Honeywell, San Diego CA; Pressure Cast Products, Oakland CA; Eck Industries, Manitowoc WI; General Die Casters, Peninsula OH; and Gibbs Die Casting, Henderson, KY.

2.2 Melting Efficiency Improvement: The technologies developed in this project are commercially available and have already been implemented in part or whole by several industrial foundries, including

- American Cast Iron Pipe Company
- American Centrifugal
- Atlas Castings
- Bahr Bros. Mfg., Inc.
- Magotteaux
- Pacific Steel Casting Company
- Richmond Foundry Co.
- Southern Alloy Corporation

- Spokane Industries
- Stainless Foundry & Engineering, Inc.

3.1 Clean Steel Casting Production: The bottom-pouring new gating designs developed in this project are commercially available and have already been implemented at Harrison Steel and Wescast Industries.

3.2 Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys: This project provided quarterly status reports and has directly interacted with the American Foundry Society (AFS) Division 11 committee (Lost Foam Committee), which is comprised of industry members. An aluminum lost foam foundry has expressed an interest in vacuum assisted pouring (VAP) as a potential remedy to a filling defect that is a major contributor to their scrap rate.

3.4 Improved Die Casting Process to Preserve the Life of the Inserts: Results from this task have been incorporated at St. Clair Die Casting, Empire die Casting, General Metal die Casters, and Twin City Die Casting.

3.5 Development of Thin-Section Zinc Die Casting Technology: Commercialization leadership has been taken by Joyner's Die Casting in Minneapolis, MN and Brillcast in Grand Rapids, MI. These companies have been proactive in seeking new jobs that could be manufactured to advantage in the HF alloy, including conversions from brass and steel stampings where parts consolidation, such as the hinges on the legacy locket, lead to savings in materials, processing, cost and energy. A brochure describing the HF alloy, its advantages and potential applications has been produced by NADCA. Five "live" seminars and a webinar were conducted for industry.

3.7 Design Support for Tooling Optimization: This work will be incorporated into CastView die casting design software and as a web-based application that can be accessed from the NADCA design tools web site.

3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology: Transfer of the developed technology to the production floor was accomplished through meetings held at four month intervals that included industry partners. The new Lost Foam book, "Lost Foam Made Simple" is available through AFS. The Pattern Permeability Apparatus is available through UAB along with servicing and recalibration. Instructions for using this apparatus are included in the Lost Foam book. Presentations were also made at AFS-sponsored Lost Foam Conferences and annual Metalcasting Congresses/CastExpos.

3.9 Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings: Because this project was terminated before the originally planned project duration expired, the heat treatment residual stress/distortion model had not been completely verified and validated. Although additional work is required to fully validate the heat treatment residual stress/distortion model, completion of this additional work will automatically result in a commercially available product, since the model utilizes the commercial software packages DANTE and ABAQUS. In addition, technology transfer occurred in the form of the publication of papers describing the residual stress/distortion model.

3.10 Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings: The hot tear predictor is in the form of a user subroutine that can be utilized in conjunction with the commercial casting simulation package MAGMAsoft, via the MAGMAsoft API (applications programming interface). The final visco-plastic stress model with damage is implemented using the commercial software package ABAQUS. In addition, technology transfer occurred in the form of the publication of papers describing the hot tear/dimensional changes model, which are available in conference proceedings and journals (see detailed report).

3.11 Precision Casting of Steel: Thanks to intensive involvement of an industrial cosponsors group hosted by SFSA, many of the findings about autoclave conditions, pouring practice, and shell thickness variation were adopted very quickly by SFSA members.

3.12 Innovative Semi-Solid Metal (SSM) Processing: The following companies have adopted their practices to incorporate SSM processing technologies and also have made use of the concepts of CRP to enhance nucleation: Aluminium Rheinfelden, Mercury Marine, Nemak, Premier Tool & Die Cast, THT Pressses, and Buhler.

3.13 Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions: The results from this task were incorporated into the commercial casting analysis software ProCAST.

3.14 Light Metals Permanent Mold Casting: Industry partners are taking advantage of these results to expand their use of alloy 206 in current and new applications where its higher tensile properties provide clear economic advantage over other alloys in heavy-duty transportation applications (e.g. automotive chassis, gear housings, and suspension components) where high tensile and yield strengths and moderate elongation are needed.

4.1 Energy Efficiency Instrumentation:

- The Heat Treatment Control was utilizing different sensors as well as an innovative control strategy to better control the heat treatment operation. This approach was demonstrated via a case study at two steel foundries by the researchers, and furthermore assisted another company in implementing this strategy. The results were publicized via conference proceedings and presentations at two different venues. One company, Falk Corporation reported their implementation in 2006. [Nitz 2006].
- A proof of concept system was developed for the Semi-Automated Grinding System which demonstrated that the approach and algorithms were workable for the semi automation of grinding operations. The results were published in conference proceedings and being reworked for a journal publication. There was some interest in commercializing the approach, but the large investment into a full scale system was a hindrance.
- The Surface Mapping Software has been provided to several industry users and their input has been very useful in improving the product. The results of using the software have not only been reported via conference presentations, proceedings and workshops by the project team, but an industry user has also presented their results at a conference.

Initial requests through Iowa State University to fund the next commercialization steps have not been successful, but the project team has been receiving advice from a software entrepreneur on how to better secure funding to take this product to market. Funding to take the software to full scale commercialization remains the final hurdle. Another commercialization option that is being explored is to part with a solidification software company as this tool could be used to interface with their solidification results (in particular the inclusion and hot tear prediction).

- The results of the Weld Gouge Analysis study were well received by the industry via a conference presentation and publication. These results have been requested by industry personnel since the publications. The true benefit of these results is in the producer's ability to better demonstrate to their customers on the importance of adequately and appropriately specifying the surface quality necessary.
- The Rapid Pattern Making Machine has been updated and made more reliable through this project. At the time of this report, case studies to demonstrate the use of the technology are underway with industry. Talks are also underway with economic development officials to help jumpstart this technology. One of the research team is seriously considering taking this technology to found a startup company.

5.1 The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating: Colorado School of Mines is currently working with NADCA on a commercialization and in-plant validation in an effort to achieve full commercialization of the coating systems. Two commercial coating companies, Phygen and Swiss-Tek, are part of this transition project.

5.3 Casting Porosity-Free, Grain Refined Magnesium Alloys: Activities to commercialize best magnesium casting practices have been initiated at Thompson Aluminum. The results of the project were also disseminated among magnesium foundries in collaboration with the American Foundry Society to further promote the adoption of best practices.

5.4 Development of Elevated Temperature Aluminum MMC Alloy and Process Technology: Eck Industries, Inc. worked with three different domestic and international customers to assess technical needs and produce prototype parts for customers in aviation, ventilation and stationary power generation. To establish commercial availability of this casting alloy system, the project team worked with AMG Aluminum and Thermal Transfer Composites to develop a commercial production base. And finally as part of this development effort, proposed SAE AMS standards for the AlCuMgSc casting alloy and its derivative MMC alloy have been written.

5.6 Development of CCT Diagrams: Dissemination of the results will be made to the US steel casting industry through presentations, industry review committees, technical societies associated with steel casting such as the Steel Founders Society of America (SFSA), and publication of data in trade and refereed journals.

5.7 Corrosion Testing Practices – High Alloy Corrosion Program: The results of this investigation have been presented at numerous professional meetings held by the Steel Founders Society of America (SFSA) in order to disseminate the technology to end users. SFSA has taken action to modify the existing specifications for these alloys in order to improve their performance in demanding applications on a more consistent basis. In addition, several foundry members of SFSA have already modified their heat treating schedules for these alloys.

5.8 Mechanical Performance of Dies: This work has been incorporated into NADCA's Productivity Improvement Suite. The "How to Model the Die/Machine System" report is available from the NADCA web site. The work was reviewed twice a year in NADCA committee meetings. The committees are composed of members of industry provide a mechanism to disseminate the information.

5.9 The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management: Additional technological development is required for commercialization of the LENS^{TM} fabricated Cu/H13 bi-metallic tooling. Specifically, the technology of depositing H13 on copper substrates via the LENS^{TM} process is not sufficiently robust to support commercialization.

5.10 Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications: Numerous presentations and papers of this work have been presented at the annual Steel Founders' Society of America's Technical & Operating Conferences. SFSA is the largest trade association representing steel foundries in North America and has specific committees for ASTM, NACE, ISO and interface with the US Government.

5.11 Aging of Graphitic Cast Irons and Machinability: A number of the active foundry / machining co-sponsors implemented the results of this task in their plant operations immediately after plant trials. These include Dalton Foundry, Metals Technology Inc., Rochester Metal Products, Asama Coldwater Manufacturing, Eaton Corporation, and Bremen Foundry. The guidelines for application were published through the American Foundry Society (AFS) to make them available to all foundries that have interest.

6. Accomplishments

A list of one-page Success Stories used to promote the E-SMARRT accomplishments are contained in Appendix C.

A list of publications / presentations can be found in each specific E-SMARRT task final report. Each specific tasks' final reports has been uploaded to the Department of Energy (DOE) Energy Link system (E-Link), developed and maintained by the DOE Office of Scientific and Technical Information (OSTI). The list of specific reports and their OSTI number can be found in Appendix B.

One task filed for patent, Task 5.1, "The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating":

- J. J Moore, D. Zhong, J. Lin, "Functionally Graded Alumina-based Thin Film System", No. US2005/0263261 A1.

One patent was granted for the CRP process in Task 3.12, "Innovative Semi-Solid Metal (SSM) Processing". The patent is not licensed yet, but the prospects are high as interest is high by industrial sector.

- D. Apelian, A de Figueredo, M. Findon, N. Saddock, "Alloy Substantially Free of Dendrites and Methods of Forming the Same", US Patent No. 7,513,962.

Specific Task Highlights:

2.1 Improvements in Efficiency of Melting for Die Casting: The project was successful in benchmarking various melting, holding and molten metal transfer types of equipment. It also collected information on melt losses of these furnaces. The project also conducted a series of one-day workshops under NADCA sponsorship at various die casting plants.

2.2 Melting Efficiency Improvement: There have been 12 publications and 5 graduate students that reflect the work from this project (see Section 6 in task final report for details).

3.1 Clean Steel Casting Production: There have been three published papers, numerous presentations and a series of technical reports (see Section 6 in task final report for details).

3.2 Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys: Seven journal and conference proceeding publications were developed from the outcome of this task. A presentation was given at the 2014 AFS Casting Congress.

3.4 Improved Die Casting Process to Preserve the Life of the Inserts: An electronic tool incorporating the design guidance for the placement of cooling lines within dies has been incorporated into the North American Die Casting Association (NADCA) website.

3.5 Development of Thin-Section Zinc Die Casting Technology: A new high fluidity zinc casting alloy has been developed that is compatible with existing production equipment. The alloy is 40% more fluid than existing alloys and has the capability of filling sections of 0.3 mm (0.011 in.) thickness.

3.7 Design Support for Tooling Optimization: This work has developed simple models and extended existing models that support design decision making by part designers, die casters and die builders. The most important feature of all of this work is that the computational burden is very low encouraging the exploration of more design options within the available time. In addition, four papers were developed, one of which received the Die Casting Congress Best Paper Award for 2011.

3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology: A book titled "Lost Foam Made Simple" was written and published by AFS. A Pattern Permeability Apparatus was developed and commercialized. Gating of Lost Foam castings has been improved to prevent unfed metal shrinkage.

3.9 Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings: A model to simulate residual stress development and distortion during heat treatment of steel castings was tested, although not yet fully validated. This model is commercially available. The work detailed in this task resulted in the publication of three papers available in SFSA technical conference proceedings. See detailed report.

3.10 Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings: A model to simulate hot tears and dimensional changes during casting solidification has been successfully developed and implemented in commercial casting simulation software. This model advances the state-of-the-art in the prediction of hot tears and dimensional changes. The hot tear/dimensional changes model has also been successfully applied to predict hot tears and dimensional changes in squeeze cast magnesium alloy control arms.

3.11 Precision Casting of Steel: Thirteen articles were published in several scientific magazines/trade journals/conference proceedings (see report for details). Five graduate students supported the effort and produced thesis based on portions of this work. The SFSA Wikipedia on investment casting contains the results at www.SFSA.org.

3.12 Innovative Semi-Solid Metal (SSM) Processing: One patent was granted for the CRP process. The patent is not licensed yet, but the prospects are high as indicated by the industrial sector interest. Numerous articles were published and presentations made (see detailed report). Six graduate students and two post-docs supported this effort.

3.13 Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions: The transfer of validated wax material property data from its raw form into separate temperature-dependent thermophysical and mechanical property datasets into ProCast.

3.14 Light Metals Permanent Mold Casting: Unique processing techniques were developed and six journal and conference proceeding publications were developed from the outcome of completed tasks.

4.1 Energy Efficiency Instrumentation

- Heat Treatment Control strategies were readily picked up by industry, implemented and further implementation was spurred by industry representatives reporting on their implementation success.
- A prototype system for the Semi-Automation of the Grinding Process for large castings was developed and demonstrated in the laboratory. While there was some initial interest from industry, commercialization has currently stalled because of the investment threshold.
- A robust software system for the collection, management and analysis of casting Surface Mapping data was taken from a prototype stage to a beta rollout to several industrial users.
- The consequences of making Weld Repairs on the casting surfaces was investigated via a study conducted at three steel casting producers. This information is now available to help producers educate their customers on the implications of excessive surface

requirements.

- An automated system for Rapid Pattern Making was advanced to the point of conducting case studies to demonstrate its effectiveness with industry. Commercialization through state economic development routes is currently under investigation.

5.1 The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating: The project successfully developed a multifunctional smart coating system containing a CrN/AlN superlattice based tribological layer and an AlN piezoelectric thin film sensor for die casting dies. The commercialization efforts with Phygen LLC have led to the production of the CrN/AlN superlattice coatings in industrial coaters. Two Ph.D. students were supported by the research project and graduated in the project period. One US patent has been applied for the design coating system (*J. J Moore, D. Zhong, J. Lin, 'Functionally Graded Alumina-based Thin Film System', Pub. No. : US2005/0263261 A1*). More than 30 research papers have been published in peer reviewed journals and more than 10 presentations have been given in international conferences to publicize the major outcomes of the research.

5.3 Casting Porosity-Free, Grain Refined Magnesium Alloys: The results of the project have been disseminated through presentations at the regular meetings of the Magnesium Division of the American Foundry Society. Presentations on the subject matter were also made at the Annual Metalcasting Congress and published in the proceedings as "Shrinkage Behavior of AM50, AM60 and AZ91, Transactions of the American Foundry Society V 113 Paper 05-028(06) P 849 – 855. The best practices developed as part of the project have been implemented and are used by commercial magnesium foundries involved in the project.

5.4 Development of Elevated Temperature Aluminum MMC Alloy and Process Technology: An aluminum alloy capable of maintaining strength at high temperatures, up to 250°C, was developed. This alloy contains copper, magnesium, silicon, nickel, manganese and scandium as alloying additions. This alloy composition is amenable to casting using either sand or permanent molds. AMS specifications for AlCuMgSc alloy castings and AlCuMgSc MMC alloy castings were drafted.

5.6 Development of CCT Diagrams: The major project accomplishment is in providing for the first time accurate and easily accessible data concerning the phase transformations present in specific cast alloys CN3MN and CK3McuN as a function of time and temperature to reduce scrap and improve heat treatment efficiencies. Other accomplishments include one M.S. degree granted, three published papers in international journals, and four papers published in the proceedings of meetings of the Steel Founders Society of America.

5.7 Corrosion Testing Practices – High Alloy Corrosion Program: Three graduate students participated in this research and thirteen papers were published.

5.8 Mechanical Performance of Dies: This work resulted in the improvements of modeling procedures used to represent the casting/die interface which is very important in extending the structural modeling of the die and machine to modeling the development of stresses in the cast part. Two PhD dissertations were derived from the task and ten papers were published.

5.9 The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management: Accomplishments include the development and evaluation of two approaches to the fabrication of bi-metallic Cu/H13 die casting tooling via the LENS™ process.

5.10 Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications: Finding an indication of reasonable length (1/4") with one inspection is at best a 50/50 proposition. It is also unlikely that an inspector can discriminate an indication length to a 1/16", perhaps 1/8". Removing false positives increased repeatability and reproducibility by 10% or more. Seven papers were published.

5.11 Aging of Graphitic Cast Irons and Machinability: American Foundry Society (AFS) Metalcasting Congress Cast Iron Division Best Paper Awards in 2004, 2005, 2007, 2008, 2009, and 2010. Twelve papers were published. One PhD student and two MS students participated in the research.

7. Conclusions

2.1 Improvements in Efficiency of Melting for Die Casting: The coreless induction furnace is clearly the most efficient means of melting the aluminum. However, it has to be complemented by a holding furnace to fulfill the needs of a die casting operation.

2.2 Melting Efficiency Improvement:

- Electrical energy can be reduced during melting in induction furnaces by an average of 15% on the first heat of production through improved preheating practices.
- There is an average decrease of 8% in electrical consumption with the addition of chemical energy provided by SiC additions in an electric arc furnace.
- Using chemical energy in the form of a door oxy-fuel burner and sidewall Co-Jet in an electric arc furnace resulted in decreased average electrical consumption by 10%.
- Using low thermal conductivity "sandwich" linings resulted in a reduced tap temperature of 60^{o}F from standard castable ladles, a reduction in melting energy by 3%. The energy loss through the sidewalls is reduced by 40% with the sandwich lining when compared to common alumina castable linings.

3.1 Clean Steel Casting Production: New bottom-pouring designs consisting of a submerged ladle nozzle extension, pour basin, dam, and choked sprue at the sprue base resulted in significant reduction in air entrainment and flow turbulence in the gating system. In lip-pouring, it was observed that the pressurized gating had the most surface macro inclusions and the radial choke gating had the least macro inclusions among the molds without gating filters.

3.2 Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys: The casting trials demonstrated that lost-foam casting process can be a viable manufacturing route for prototype components poured from magnesium alloys AZ91D/E, AM50 and ZE41A. For aluminum LFC, net shape thin walled engineering components can be successfully cast with A356, A206, 535 and modified 319 aluminum alloys at 110^{o}F (43^{o}C) above liquidus temperatures using the VAP process.

3.4 Improved Die Casting Process to Preserve the Life of the Inserts: Improving die life by means of optimized cooling line placement reduce die temperatures during processing, saving energy associated with production. The utilization of optimized die lubricants will also reduce heat requirements in addition to reducing waste associated with soldering and washout. Cooling lines could be placed as close as 0.5” from the surface of the die to improve die life. Graphite and boron nitride die lubricants are capable of completely eliminating soldering and washout. However, because of cost and environmental considerations these materials are not widely used in industry. The best water-based die lubricants evaluated in this program were capable of providing similar protection from soldering and washout.

3.5 Development of Thin-Section Zinc Die Casting Technology: The new zinc die casting alloy capable of producing castings with thinner sections than achievable before, termed the high fluidity (HF) alloy, was successfully developed and ready for commercial development.

3.7 Design Support for Tooling Optimization: This task successfully extended and demonstrated modeling capabilities that support design decision making for high pressure die casting. It has also developed fill visualization tools suitable for slow fill processes that enable very fast assessment of the fill pattern associated with these processes.

3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology: Mechanical properties of A319, A356 and A206 can be significantly improved using pressure solidification. Mechanical properties of A319 and A356 can be significantly improved using vacuum assisted pouring.

3.9 Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings: The predicted distortions were in reasonable agreement with the experimentally measured values.

3.10 Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings: A model that predicts hot tears and dimensional changes during steel casting solidification has been successfully developed and implemented in commercial casting and stress analysis software. This model is based on a visco-plastic constitutive model with damage, where the damage begins to form when feed metal is cut off to a solidifying region.

3.11 Precision Casting of Steel: Conclusions based on scientific/ technical findings shell cracking:

- High heating rate in the autoclave (high steam temperature/pressure) lowers the stress and cracking incidence.
- Mold cooling control can limit oxidation due to cracking after pouring, by delaying the silica phase transformation that causes the mold shell to crack.
- Drain patterns should be controlled to eliminate local high thickness regions in individual slurry layers

Conclusions based on scientific/ technical findings lost foam steel:

- EPS foam generally decomposes by the collapse mode in steel casting.
- There is an accumulation of carbon pick-up at the end of the casting opposite the gate.

3.12 Innovative Semi-Solid Metal (SSM) Processing: This work has categorically confirmed the viability of SSM processing by copious nucleation and distribution of nuclei to attain non-dendritic cast structures. The results obtained in the laboratory as well as in commercial trials have demonstrated the benefits of SSM processing from energy savings as well as a resultant cast structure that is far superior to conventional castings.

3.13 Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions: The results between analysis and reality compared very well, and the results were successfully implemented in a usable and accurate simulation tool for modeling the deformation of wax patterns during the solidification and cooling stages of wax manufacturing.

3.14 Light Metals Permanent Mold Casting:

- The utilization of intensive solidification modeling to aid mold and casting design was effective in predicting the areas on a cast component that could produce hot cracking where the die hit certain maximum temperatures based on the wall thickness and casting geometry.
- Die cycle dwell time of 200 to 230 second and initial mold preheating temperature from 460°C to 480°C provided the best results.
- Optimization of the grain structure and good control of casting cycle time are critical to producing hot tear free components. Effective thermal management of the mold by location of temperature sensors and controlled heating and/or cooling at the right time in hot spots are critical to producing hot tear free components.
- The castability of A206 with 50% primary ingot plus 50% in-house scrap as the charge material was similar to that observed for A206 and B206 100% primary ingots. This could lay groundwork for future work on developing appropriate charge material primary/scrap ratio for alloy 206. Achieving that goal should make the casting of alloy 206 more economically viable and wider industry acceptance.
- The areas prone to mechanical hot cracking is driven by the casting design related to variation in section thickness that could cause premature solidifications in some areas of the component. Controlled localized heating elements in those hot spots of the mold can reduce the hot tearing.

4.1 Energy Efficiency Instrumentation: This project made inroads in tackling some particular areas of the metalcasting process that can help the industry reduce variability of their operations, and hence, reduce the labor and energy inputs needed and be more responsive to their customers' needs. The heat treatment control efforts were immediately adopted by some casting producers as there were no commercialization hurdles. The grinding automation system, while successfully demonstrated via a laboratory prototype, has the largest chasm to cross before it can be commercially viable because of the risk of investment in the system development. The analysis of the metallurgical effects of the weld gouges was well received by industry. The Mapping software and rapid pattern making system are being adopted by industry and further commercialization efforts are ongoing.

5.1 The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating: A 'Smart' coating design based on thin film piezoelectric sensor embedded within a tribological coating system has been introduced. The structure and properties of the coating system have been optimized using a Closed Field Unbalanced Magnetron Sputtering (CFUBMS) deposition system to achieve the maximum performance in terms of superhardness (>40 GPa), excellent wear resistance, good toughness, excellent adhesion, and high thermal stability.

5.3 Casting Porosity-Free, Grain Refined Magnesium Alloys: Predicting porosity using a casting and solidification software is key in ensuring a porosity free casting. Best gating practices and modifications in the gating and risering of the casting should be pursued until the porosity in the model is eliminated.

5.4 Development of Elevated Temperature Aluminum MMC Alloy and Process Technology: The developed AlCuMgSc alloy extends the operational temperature capability of AlCu casting alloys to 250°C. The manufacture of castings from this alloy instead of the currently used Ti alloy castings would reduce manufacturing costs and reduce energy requirements. The additional strength (about 14%) attained by the MMC version of the developed alloy system would allow even greater penetration of the applications currently manufactured from Ti alloy castings. The result would be even greater reductions in manufacturing costs and energy requirements. Equivalent or better castability of the developed alloy as compared to currently used A201 and A206 aluminum castings may reduce manufacturing costs for the more difficult part configurations.

5.6 Development of CCT Diagrams: The results of the microstructural investigation showed that the equilibrium transformation kinetics of both CN3MN and CK3MCuN are extremely sluggish. Equilibrium conditions were not reached in either alloy after 2040 hours at 700 to 900ºC. The transformations occurred fastest at 900ºC, indicating the maximum transformation rate could be at temperatures higher than 900ºC. Two dominant intermetallic phases were seen to precipitate from the austenitic matrix, BCT- σ and HCP-Laves phases as determined by TEM. Theses phases formed at all temperatures studied in both alloys.

5.7 Corrosion Testing Practices – High Alloy Corrosion Program: The corrosion resistance of optimally heat treated (1205 °C/4 hours) CN3MN and CK3MCuN were shown to be comparable to the corrosion resistance of their wrought counterparts AL6XN and 254SMO. Corrosion resistance was optimized for CF-3-HF and CF-8-HF alloys utilizing a heat treatment of 2200°F for 4 hours.

5.8 Mechanical Performance of Dies: The task successfully extended the capability to model the die casting die/machine system and has made the use of this technology more accessible to the industry.

5.9 The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management: The two processes investigated for LENS™ fabricated Cu/H13 bi-metallic tooling represent creative and novel approaches to a difficult technical problem. Both show promise, but further development of these two approaches is necessary to enable commercialization of this technology.

5.10 Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications: The number of non-linear and linear indications rapidly decreased in number after the first 0.010" of metal removal but stabilized to a constant value. Hot tears and/or cracks typically had length to width ratios greater than 3. Removing false positives while inspecting increased repeatability and reproducibility by 10% or more.

5.11 Aging of Graphitic Cast Irons and Machinability:

- Age strengthening was demonstrated to occur in gray iron ductile iron and compacted graphite iron.
- Machinability was demonstrated to be improved by age strengthening when free ferrite was present in the microstructure, but not in a fully pearlitic microstructure.
- Age strengthening only occurs when there is residual nitrogen in solid solution in the Ferrite, whether the ferrite is free ferrite or the ferrite lamellae within pearlite.
- Age strengthening can be accelerated by Mn at about 0.5% in excess of the Mn/S balance.

8. Recommendations

2.1 Improvements in Efficiency of Melting for Die Casting: At this time there is no standard for evaluating the melt losses of various furnaces. Such a standard would go a long way in facilitating better decisions in purchasing and operating melting equipment and should be developed.

2.2 Melting Efficiency Improvement: Provide foundry support in the installation of electrical consumption meters and controls.

3.1 Clean Steel Casting Production: None.

3.2 Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys: Current lost foam engineering models for filling and solidification do not incorporate either vacuum assisted pouring (VAP) or solidification under pressure (SUP) into the calculations. For these processes to gain wider acceptance to designers, engineering models must account for the effects of VAP and SUP and verify the modelling results to actual data.

3.4 Improved Die Casting Process to Preserve the Life of the Inserts: Well formulated water-based die lubricants can effectively eliminate or significantly reduce soldering. When using superior die steels with high toughness, cooling lines can be placed closer to the cavity surface. Depending on the configuration, cooling lines can be drilled as close as 0.5" from the cavity. The hardness of the tooling should be kept in the 44-46HRC range to lower the risk of gross cracking

3.5 Development of Thin-Section Zinc Die Casting Technology: Industry organizations serving the zinc and die casting industries are expected to continue technology transfer and market development activities, and should be encouraged these industries in the usage of the HF alloy.

3.7 Design Support for Tooling Optimization: The utility of the program would be greatly improved if the analysis and display functions were updated to take advantage of newer hardware capabilities.

3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology: The production of Compacted Graphite engine blocks without the gray iron skin could transform the diesel engine market in the US. This breakthrough provides the opportunity to design the next generation of diesel engines to include the benefits of the Lost Foam Process such as part consolidation, weight savings due to the improved mechanical properties of CGI and stiffer cylinder bores resulting in reduced emissions. Second, the next step in maturing the Lost Foam Casting Process could be the implementation of techniques to eliminate variable pattern permeability.

3.9 Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings: It is recommended that further validation of the software be performed with the aid of additional experiments with large production steel castings that experience significant heat treatment distortions.

3.10 Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings: The predictive capability of the model will improve further with the development of more accurate high-temperature mechanical properties.

3.11 Precision Casting of Steel: Work is needed on large scale investment castings, particularly with pattern materials that are compatible with limited production quantity.

3.12 Innovative Semi-Solid Metal (SSM) Processing: It is strongly recommended that the following efforts need to be pursued:

- SSM/CRP to produce nanostructured metals
- SSM/CRP to make thin castings in the range of less than 2-3 mm
- Study the effect of composition on viscosity of liquid metals as well as the effect of shear.

3.13 Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions: Additional research would provide for further material property data acquisition, testing, and building of a complete (including "filled" waxes) wax database.

3.14 Light Metals Permanent Mold Casting: a follow-up project where casting, mold, and tooling design are optimized for A206 to take full advantage of its superior tensile properties for a selected structural component. The results of such study should expand the use of A206 by the automotive industry where thinner-wall and lighter structural components can be poured from A206.

4.1 Energy Efficiency Instrumentation:

- The Heat Treatment Control strategies were the first of the technologies developed here that was adopted by industry users. Further improvements could be incorporated as technology devices become more prevalent and less expensive.
- The Grinding Automation System was successful as a laboratory prototype, but failed to gain acceptance from industry because of the risk and investment hurdle. The opportunity still exists to pick up the control strategies and system architecture and build a full scale system.
- The Surface Mapping Software continues to gain success. Further research is required to develop a full scale commercialization plan.
- The study on the material effects of the Weld Gouges on the casting surface should be used in conjunction with ongoing efforts to look at the effects of defects to develop a more robust casting surface specification strategy that would better serve the casting user.
- The Rapid Pattern Making machine has been advanced to the stage that commercialization is possible.

5.1 The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a "Smart" Die Coating: Continue to work the optimized smart die coating system, especially the AlN piezoelectric thin film remote measurement, for different applications.

5.3 Casting Porosity-Free, Grain Refined Magnesium Alloys: The most important step in future work would be to find a bulk method for testing for porosity location. Possibilities for this include eddy current analysis or ultrasonic inspection. This ability would greatly enhance the accuracy with which porosity content could be quantified. Simulations and casting trials should be performed to correlate the simulations results with real foundry results. A wider variety of casting geometries and feeding conditions should be studied to give these gradient results wider applicability. Such conditions include feeding through a reduced section, or castings with unfavorable tapers. Thin section castings should be studied to determine the applicability, if any, of these minimum gradients.

5.4 Development of Elevated Temperature Aluminum MMC Alloy and Process Technology:

- Investigate longer aging times to see if additional high temperature strengthening phases can be precipitated.
- Investigate replacing a portion of the scandium with zirconium or adding nickel to reduce alloy cost.
- Investigate smaller particle size for the alumina to improve strength at both room and elevated temperature.
- Due to the strong effect of alumina on elevated property strength, investigate higher alumina contents, perhaps as a substitute for some of the scandium.

5.6 Development of CCT Diagrams: It is recommended that a final study be undertaken employing Transmission Electron Microscopy (TEM) to completely characterize the nature of the intermetallics that form in the initial stages of precipitation. Based on these results experiments could run, in conjunction with computer thermodynamic simulations, to determine which alloying additions are most critical in causing precipitation to occur. Advanced alloys could then be developed where these elements are either tightly controlled to reduce precipitation of additional alloying is used to mitigate the harmful effects.

5.7 Corrosion Testing Practices – High Alloy Corrosion Program: Further corrosion testing is required for CF-3-LF, CF-3M, CF-8-LF, and CF-8M in order to gain a better understanding of the corrosion performance of these alloys.

5.8 Mechanical Performance of Dies: While structural modeling of the die/machine system is relatively mature, extension of the modeling to include the effects of the die and machine on the part dimensions and stress state after cooling is not. There are still major issues in capturing the macroscopic behavior of the casting/die interface during and immediately after filling. As the capabilities of generic fluid structure interaction improve, perhaps the modeling of the casting properties can be improved. The second major impediment is the lack of high temperature material properties. The mechanical properties of the cast alloy are needed up to the solidus temperature and over a wide range of strain rates. Such data are virtually non-existent today and must be developed in the very near future.

5.9 The Use of Laser Engineered Net Shaping for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management: The logical follow-on to this research project would be to investigate the viability of using the heated substrate method employed by Northern Illinois University, along with the nickel interfacial layer demonstrated by Lehigh University for LENS™ fabricated Cu/H13 bi-metallic die casting tooling. Tooling fabricated successfully by this method should be evaluated for its longevity in service and cooling proficiency in a commercial die casting demonstration.

5.10 Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications: Further testing and research is required to validate the method correlating safety factor, elongation, and indication length. In addition, the relationship between fatigue properties and surface indications in steel castings needs to be further developed.

5.11 Aging of Graphitic Cast Irons and Machinability: None.

9. Appendices

Appendix A

Technology Transition Efforts Conducted by The Metalcasting Industry Associations (American Foundry Society, North American Die Casting Association, and Steel Founders' Society of America) after cancellation of the Cast Metals Coalition Technology Transfer program in November 2008

<u>Q1 – 2009</u>

AFS:

- AFS Division 11 meeting (webex) hosted by AFS, March 11
    i. Planning for presentations, including many E-SMARRT projects, at 113th Metalcasting Congress Tuesday April 7-10, in Las Vegas, NV
    ii. D. Caulk (GM R&D) receiving AFS Award of Scientific Merit for lost foam work
    iii. D. Caulk & M. Barone (GM R&D) receiving Howard F. Taylor Award for AFS Best Paper, "Analysis of Mold Filling in Lost Foam Casting of Aluminum : Methods & Examples – Part I & II (08-090 & 08-091)
- Lost Foam Consortium webex meeting hosted by AFS March 12
    iv. Reviewed latest work on vacuum assisted filling of aluminum
    v. Reviewed lab and in plant trials of lost foam casting CGI
    vi. Defect analysis of lost foam casting ductile iron
    vii. Future research plans and contract extension activities
- CMC Technical Committee conference call on March 13.

NADCA:

- The NADCA Board of Governors meeting was held on January 30 at NADCA Headquarters in Wheeling, IL.
- A Die Materials Task Force meeting at NADCA Headquarters in Wheeling, IL on February 10.
- A Die Materials Committee meeting at NADCA Headquarters in Wheeling, IL on February 11.
- An R&D Committee meeting at NADCA Headquarters in Wheeling, IL on February 12.
- A NADCA CEO Conference was held at the Rancho Las Palmas Resort in Rancho Mirage, California on Mar. 8-10.
- CMC Technical Committee conference call on March 13.

SFSA:

- Updated the SFSA Board of Directors on the status of ESMARRT projects.
- The ESMARRT projects were reviewed by the SFSA Carbon and Low Alloy Research Committee at Missouri University of Science and Technology.

- Clarification of objectives for Lehigh project (Task 5.7) with Ron. Bird, Stainless Foundry and Machine and John Dupont, Lehigh University.
- Determined extent of testing program with Scott Chumbley (Task 5.6), Iowa State University and Ron Bird, Stainless Foundry and Machine.

<u>Q2 – 2009</u>

AFS:

- 113th Metalcasting Congress, Las Vegas, NV. April 7-9, 2009
    i. Coordinated presentations for AFS-sponsored tasks at 2009 Metalcasting Congress, Las Vegas, NV
    ii. D. Caulk (GM R&D) received AFS Award of Scientific Merit for lost foam work
    iii. D. Caulk & M. Barone (GM R&D) received Howard F. Taylor Award for AFS Best Paper, "Analysis of Mold Filling in Lost Foam Casting of Aluminum : Methods & Examples – Part I & II (08-090 & 08-091)
- Distributed minutes and attachments for Lost Foam Consortium webex meeting hosted by AFS March 12 and AFS Division 11 meeting
    i. Reviewed latest work on vacuum assisted filling of aluminum
    ii. Reviewed lab and in plant trials of lost foam casting CGI
    iii. Defect analysis of lost foam casting ductile iron
    iv. Future research plans and contract extension activities
- Research Updates
    i. Initial investigation into production of CGI (Compacted Graphite Iron) using lost foam appears very promising. This avoids the flake skin which can reduce fatigue life typically observed in products like CGI block produced in chemically bonded molds. This would be a focus area if the current contract could be extended for additional year. Since GCI blocks are being considered for new higher strength passenger car, diesel and truck engine applications this has tremendous potential.
    ii. Use of vacuum for higher silicon aluminum alloys to reduce defects and also pour colder showing promise with potential to reduce pouring temperatures by 150^{o}F and save 15% in energy.
    iii. Continuing to work on common defects observed in pouring lost foam ductile iron for highly machined parts in clutch-less transmission.
- Technology Transfer Activities
- Current Quarter Activities & meetings
    - See activities listed above
    - AFS Energy Committee webex meeting May 27th, reviewed activities of E-SMARRT projects and energy saving potentials.
    - Conducted Energy Webinar Series:
        - Tues., May 12, 11:00 a.m. EST - Getting Started: Understanding the Issues (Module 1)
        - Thurs., May 14, 11:00 a.m. EST - Utilities (Module 2)
        - Tues., May 19, 11:00 a.m. EST - Controlling Melting Costs: Ferrous Alloys (Module 3)
        - Thurs. May 21, 11:00 a.m. EST - Controlling Melting Costs: Non-Ferrous Alloys (Module 4)
        - Tues., May 26, 11:00 a.m. EST - Managing Compressed Air Systems (Module 5)

- Thurs., May 28, 11:00 a.m. EST - Plant Environment and Equipment (Module 6)
- Thurs., June 4, 11:00 a.m. EST - Implementation Plans: Energy Assessments and Best Practices (Module 7)

NADCA:

- Coordinated presentations for NADCA-sponsored tasks at 2009 Metalcasting Congress, Las Vegas, NV
- The NADCA Board of Governors held a meeting on April 10 at the Paris Hotel in Las Vegas, Nevada.
- A NADCA Computer Modeling Task Force Meeting was Held at OSU on April 23.
- NADCA Die Materials Task Force meetings were held at NADCA Headquarters in Wheeling, IL on June 9.
- NADCA held a Die Materials Committee meeting at NADCA Headquarters in Wheeling, IL on February 10.
- NADCA held an R&D Committee meeting at NADCA Headquarters in Wheeling, IL on February 11.
- A brief training video on green house gas was developed and added to the list of NADCA on-line training videos.

SFSA:

- The High Alloy Research Committee reviewed High Alloy Projects at Penn State University, April 15.
- Arranged for Monett Metals to present a paper at the SFSA National T&O on the significant improvements in melting efficiency as a result of the MS&T / Kent Peaslee work (Task 2.2).
- Verified industrial success of new heat treatment procedure developed by Lehigh in May. Procedure now adopted by Stainless Foundry.
- Determined priorities in the Iowa State University / Scott Chumbley (Task 5.6) program with Ron Bird of Stainless Foundry, in preparation for meeting in July at Ames, IA.
- Updated SFSA Board of Directors on the progress of the ESMARRT program.

<u>Q3 – 2009</u>

AFS:

- A paper on Aging Iron (Task 5.11) was published in the Fall 2009 International Journal of Metalcasting (IJMC)
- An AFS Energy Webinar series is now available online for replay
- AFS participated in the Midwest Energy Exchange Conference, Detroit, MI, on September 9-10. Efforts included a table top display with posters explaining benefits and energy savings of ITP sponsored projects, like the Lost Foam activities. A CD that contained papers from the AFS library on energy savings and the presentations from the first module of the Energy webinar were handed out at this conference. These activities were reviewed at the meeting with Doug Kaempf and Scott Hutchins, DOE-ITP SEN (Save Energy Now) program office.
- An AFS Energy Webinar meeting is being planned for the fall
- The Aging Iron Project (Task 5.11) was reviewed on September 9 (AFS 5I – Ductile & CGI Research) and September 16 (AFS 5H Gray Cast Iron Research) at AFS

- Coordinated the updated SOW's for Mod 3 funding

NADCA:

- An article on the 2010 NADCA R&D Strategic Plan and Roadmap was featured in the July issue of Die Casting Engineer Magazine.
- NADCA coordinated the logistics for the second Die Casting Energy Efficiency Workshop, held at Ryobi Die Casting, Shelbyville, IN, on August 5.
- Information on NADCA sponsored E-SMARRT tasks was presented in St. Louis for the NADCA Chapter 17 meeting on September 15, 2009.
- A NADCA Computer Modeling Task Force Meeting was held at OSU on April 23.
- Energy and technology information from the E-SMARTT program was presented and discussed at the NADCA Plant Management Conference, September 24-25, 2009.
- A preliminary selection of E-SMARRT papers was made for presentation at CastExpo 2010, March 20-23, Orlando, FL.
- Coordinated with CWRU to find a site for the next Die Casting Energy Efficiency Workshop, to be held at Mercury Marine, Fond du Lac, WI, November 17.

SFSA:

- Conducted a meeting at Iowa State University with PI Scott Chumbley (Task 5.6) and Ron Bird of Stainless Foundry. Developed a plan for the determination of intermetallic formation at grain boundaries.
- Conducted the Carbon and Low Alloy Research Review at Chicago, IL on July 15-16. Researchers presented information to SFSA committee members on the progress of the projects funded by the ESMARRT program.
- Conducted the High Alloy Product Group meeting at Miamisburg, OH. Researchers presented information to SFSA members on the progress of the projects funded by the ESMARRT program. Scott Chumbley (Task 5.6) followed up on the plan developed in July at ISU meeting.
- Held the Western Division T&O meeting at Salt Lake City, UT on August 13-14. An overview of the ESMARRT research program was given to the attending SFSA members.
- The SFSA Annual Meeting was held at Sun River, OR on September 19-22. SFSA member management personnel were given an overview of the ESMARRT program and project results to date.

<u>Q4 – 2009</u>

AFS:

- Reviewed aging iron work (Task 5.11) at Ductile Iron Society, October 1.
- AFS Division 11 – Lost Foam Committee, conference call, October 7.
- Discussed E-SMARRT program updates at AFS TDC (Technology Development Council)
- Meeting, AFS, October 14.
- AFS 2F (Metal Matrix Composite) Committee conference call and discussion on Task 5.4

- Reviewed resumption of Task 5.2 at AFS Division 6 Magnesium Meeting, October 21
- Discussed E-SMARRT program updates at AFS Research Board meeting, AFS, November 11.
- AFS Energy Committee meeting, November 11.
- Div. 11 – Lost Foam Committee conference call, November 17.
- AFS EnergyStar and Energy Webinar, November 17
- AFS Energy 101 webinar, Decmber 9
- Attended UAB IAC meeting, Birmingham, AL, December 15.

NADCA:

- The NADCA Board of Governors held a meeting on October 2 at NADCA Headquarters in Wheeling, IL
- Information on NADCA sponsored E-SMARRT projects was presented in Stevensville, MI at the NADCA Chapter 39 meeting on October 8.
- NADCA Die Materials Task Force meetings were held at Purdue University in West Lafayette, IN on October 13.
- NADCA held a Die Materials Committee meeting at Purdue University in West Lafayette, IN on October 14.
- NADCA held an R&D Committee meeting at Purdue University in West Lafayette, IN on October 15.
- Energy Workshop conducted at Mercury Marine on November 17.
- Information on NADCA sponsored E-SMARRT projects was presented in Lansing, MI at the NADCA Chapters 1 and 3 meeting on November 30.
- The Innovative SSM Project was reviewed at WPI on December 1.
- Information on NADCA sponsored E-SMARRT projects was presented in Toronto, Canada at the NADCA Chapter 10 meeting on December 1.

SFSA:

- Teleconference on October 13 between the Chairman of the High Alloy Research Committee (Ron Bird) and SFSA (Malcolm Blair) with John Dupont of Lehigh University to discuss progress of current ESMARRT project.
- Iowa State University meeting on October 20 to discuss the status of the projects at ISU (Tasks 4.1 and 5.6) and determine the next steps in this work
- Discussions with SFSA Executive Committee of Board of Directors on November 16 regarding scope and progress of research programs.
- SFSA Technical & Operating Conference on December 9-12, Chicago, Il. Over 150 representatives from industry, and academia. Reported on progress and discussed future action on research projects.

<u>Q1 – 2010</u>

AFS:

- AFS Div. 5 Cast Iron meetings, January 13-14, AFS, Schaumburg, IL
  - Review of project updates by Prof. Von Richards
  - Discussion of upcoming quarter activities

- E-SMARRT Technical Committee Conference call, January 22
- AFS Division 2 Aluminum meeting, January 26, AFS, Schaumburg, IL, to review Task 5.3
- AFS Energy Webinar Part 2, January 27
- AFS Research Board meeting, February 17
  - Review of AFS E-SMARRT projects
- AFS Lost Foam Consortium and Division 11 Lost Foam WebEx meeting, February 25
- Meeting at DOE – Wind Energy Sector group, discussed E-SMARRT, March 4
- CastExpo 2010, March 20-23 Orlando, FL, presentations:
  - 10-062 Vacuum Assisted Filling of Lost Foam Castings
  - 10-161(panel) Lost Foam Casting
  - 10-035 Aging Effect on Gray Cast Iron Machinability: Importance of Microstructure
  - 10-036 Aging & Machinability of Irons with Compact & Spherical Graphite
  - 10-084 Energy Efficient Melting, Transportation& Holding in Aluminum Casting
  - 10-106 (carbon footprint session)
  - 10-110 (Climate Change session)
  - Metal Technology Theatre, March 20, Bob Eppich
  - Metalcasting Advancement Center, March 21, Melting Practice, and March 22, Steel Melting and Cleaning
- IJMC (International Journal of Metalcasting Vol.4 Issue 2 , Spring 2010
  - Age Strengthening of Cast Irons: review of Research and Literature, J Teague and V. Richards pp 45-57

NADCA:

- NADCA held a Die Materials Task Force meeting at NADCA Headquarters, Wheeling, IL on February 16.
- NADCA held a Die Materials Committee meeting at NADCA Headquarters, Wheeling, IL on February 17.
- NADCA held an R&D Committee meeting at NADCA Headquarters, Wheeling, IL on February 18.
- The 2010 CastExpo was held at the Orange County Convention Center in Orlando, FL on March 20-23.
- The NADCA Board of Governors meeting was held on March 23 in Orlando, FL.
- The 2010 NADCA CEO Conference was held at Disney's Grand Floridian Resort & Spa in Orlando, FL March 23-25.

SFSA:

- Meeting of High Alloy Research Committee at Lehigh University on March 11 to discuss corrosion testing. The committee decided that SFSA should contact a user group to prioritize the alloys to be corrosion tested. MTI have been contacted and will help in this task.
- Meeting of the Carbon and Low Alloy Research Committee on March 31 at University of Alabama, Birmingham. It was decided that there should be a joint meeting with the High Alloy Research Committee to discuss the UAB work. The committee identified a number of potential candidates to increase the size of the Gage R&R study. It appears from the

initial wore that given the current probability of detection the existing inspection standards may be too restrictive.

Q2 – 2010

AFS:

- CMC Conference call April 16
- Participation in Illinois Industrial Energy Efficiency Forum at UIC, April 21
- UAB-IAC meeting, UAB, to review Lost Foam Consortium activities
- AFS Div. 5 Cast Iron meetings, April 27-28 at AFS, review Task 5.11
  - Review of project updates by Prof. Von Richards
  - Discussion of upcoming quarter activities
- Heat Treatment Workshop, May 26-27 at AFS
- AFS Research Board meeting (June 8) and Division Council meeting (June 9), part of which consisted of review of AFS-sponsored E-SMERRT projects
- AFS Wisconsin Regional, June 15-16, with Wisconsin Focus On Energy
- AFS Div. 2 Aluminum meeting, June 22 at AFS, part of which was to review Task 5.3
- AFS Energy Committee (1G) meeting, June 30 at AFS.
- Publishing the AFS Transactions 2010 Vol. 118 114th Metalcasting Congress
  - 10-062 Vacuum Assisted Filling of Lost Foam Castings
  - 10-035 Aging Effect on Gray Cast Iron Machinability: Importance of Microstructure
  - 10-036 Aging & Machinability of Irons with Compact & Spherical Graphite
  - 10-084 Energy Efficient Melting, Transportation& Holding in Aluminum Casting
- IJMC (International Journal of Metalcasting Vol.4 Issue 2 , Spring 2010
  - Age Strengthening of Cast Irons: review of Research and Literature, J Teague & V. Richards pp 45-57

NADCA:

- A NADCA Computer Modeling Task Force meeting was held at OSU on April 28 to review the OSU projects.
- WPI project reviews were held during the Advanced Casting Research Center (ACRC) consortium meeting on June 2 at WPI in Worcester, MA.
- An Energy Workshop was held at Nemak in Sylacauga, AL on June 2.
- NADCA Die Materials Task Force meetings were held at NADCA Headquarters in Wheeling, IL on June 15.
- NADCA held a Die Materials Committee meeting at FISA North America in Elk Grove Village, IL on June 16.
- NADCA held an R&D Committee meeting at NADCA Headquarters in Wheeling, IL on June 17.
- The NADCA Board of Governors held a meeting on June 25 at NADCA Headquarters in Wheeling, IL.

SFSA:

- On Task 5.6 with Iowa State University, SFSA helped obtain material from members to assist in the determination of the critical times and temperatures at which the intergranular precipitate forms. This intergranular precipitate has a detrimental effect on the toughness of the 6%Mo superaustenitic grades and may also be an indicator of corrosion resistance.

- SFSA helped recruit five additional members to assist in the Gage R&R study with UAB on Task 5.10.

<u>Q3 – 2010</u>

AFS:

- Lost Foam Consortium & AFS Div. 11 meetings, August 23-24, at UAB during Materials Processing and Application Development (MPAD) Dedication and Open House
- AFS Research Board meeting, August 26
- CMC Conference call, August 27
- AFS Div. 5 Cast Iron meetings September 14-15 at AFS, review Task 5.11
    - Review of project updates by Prof. Von Richards
    - Discussion of upcoming quarter activities
- AFS Div. 2 Aluminum meeting, September 28 at AFS, to review Task 5.3
- AFS Foundry Executive Conference, Park City, UT. September 19-21
- AFS Energy Webinar meeting
- IJMC (International Journal of Metalcasting) Vol.4 Issue 3 , Summer 2010

NADCA:

- An overview article on the 2011 NADCA R&D Strategic Plan and Roadmap was featured in the July issue of Die Casting Engineer Magazine and the full plan was posted on the NADCA website in August.
- A date has been set for another Die Casting Melting Efficiency Workshop. It will be held on November 12, 2010 in Hemet, CA.
- A presentation, including information on the NADCA R&D Program and DOE funded projects, was provided for NADCA Chapter 3 in Grand Rapids, MI on September 9.
- A presentation, including information on the NADCA R&D Program and DOE funded projects, was provided for NADCA Chapter 25 in Indianapolis, IN on September 15.
- The 2010 NADCA Plant Management Conference was held on September 22-24 in Grand Rapids, MI.

SFSA:

- A meeting was held in Pittsburgh to discuss the problems with current corrosion tests. The meeting was attended by the High Alloy Research Committee and John Dupont (Lehigh University) along with the following guests; John Grubb ATI (Allegheny), Jim Gossett Fisher Controls, Carl University of Tennessee and Annemarie Appleton Chairman of ASTM Subcommittee A01.14. The meeting discussed problems that had been experience with the current ASTM test methods and the progress of the revision of ASTM A262.
- A later conference call between Ron Bird Chairman of the High Alloy Research Committee, Malcolm Blair and John Dupont developed an outline of the future work to be carried out in

this program. Malcolm Blair is to make a presentation on this topic to MTI who have shown an interest in this work.

- Work at UAB has moved forward with additional foundries having taken part to increase the data collection in the Gage R&R study for detection of surface indications. This work will be discussed at a joint meeting of the High Alloy and Carbon Low Alloy Committees meeting at Iowa State University, Ames in October.
- The work at Iowa State University under the direction of Scott Chumbley has proceeded with the Charpy testing of the sub-size specimens aimed at determining the location of the "nose" indicating the conditions under which the detrimental grain boundary precipitates form. This data will be analyzed and discussed by the High Alloy Research Committee at Iowa State University in October.

<u>Q4 – 2010</u>

AFS:

- AFS Energy Committee Webinar meeting, October 26
- Plant tour and visit at Aesir Metals (Lost Foam Steel), Youngstown, OH
- Project update review at AFS Division Council meeting, November 9, Schaumberg, IL
- Project update review at AFS Research Board meeting November 10, Schaumberg, IL
- E-SMARRRT Technical Committee Conference Call, November 12
- Lost Foam Consortium and AFS Division 11 meeting, December 7-8, with plant tours of ACH Foam and Mercury Marine, Fond-du Lac, WI
- UAB – IAC meeting, UAB, Birmingham, AL, December 15
- Prepared IJMC (International Journal of Metalcasting) Vol.5 Issue 1 , Winter 2011 article
- Conducted discussions with CANMET about E-SMARRT FY12 projects

NADCA:

- NADCA Board of Governors meeting, October 2, NADCA Headquarters, Wheeling, IL.
- NADCA Die Materials Task Force meetings, NADCA Headquarters, Wheeling, IL, October 12.
- NADCA Die Materials Committee meeting, NADCA Headquarters, Wheeling, IL, October 13.
- NADCA R&D Committee meeting, NADCA Headquarters, Wheeling, IL, October 14
- Conducted a Die Casting Energy Workshop on November 12 in Hemet, CA
- Reviewed WPI research project activities at WPI on December 1
- A presentation, including information on the NADCA-sponsored E-SMARRT R&D Program and DOE funded projects, was provided for NADCA Chapter 7 in Newark, NJ on December 2.
- A presentation, including information on the NADCA-sponsored E-SMARRT R&D Program and DOE funded projects, was provided for NADCA Chapter 15 in Greenville, SC on December 8.

SFSA:

- Discussions at the ASTM meeting in San Antonio in November with the ASTM committee on corrosion testing and follow up discussions with the Chairman of the High Alloy Alloy

Research Committee identified that a full factorial study of the most commonly produced grades of stainless steel would be required to obtain meaningful results. A foundry member has agreed to supply the necessary maerials for this work.

- The additional data required by UAB has been supplied and was reprted on at the SFSA Technical & Operating Confeence in December.
- Discusions with Kent Peaslee at MS&T has identified where the plant work to examine the extended use of chemical fuels and a trial of the new refractory on a larger ladle will be carried out.

<u>Q1 – 2011</u>

AFS:

- Lost Foam technology review meeting with Caterpillar
- AFS Research Board Meeting, Schaumburg, IL, February 9
- CMC Conference Call, February 18
- DOE-ORNL Advanced Materials for Heavy Duty & Light Duty Vehicle Workshop, March 8-9, Dearborn, MI
- Prepare IJMC (International Journal of Metalcasting) Vol.5 Issue 2 , Spring 2011 article

NADCA:

- Presentations, including information on the NADCA DOE funded projects, was provided at the following NADCA Chapter Meetings:
- NADCA Chapter 29 Meeting, Lewisburg, TN, January 26
- NADCA Chapter 16 Meeting, Minneapolis, MN, February 9
- NADCA Chapter 5 Meeting, Chicago, IL, February 10
- NADCA held a Die Materials Task Force meeting at NADCA Headquarters in Wheeling, IL on February 15
- NADCA held a Die Materials Committee meeting at NADCA Headquarters in Wheeling, IL on February 16
- NADCA held an R&D Committee meeting at NADCA Headquarters in Wheeling, IL on February 17
- The NADCA Board of Governors meeting was held on March 4 at NADCA in Wheeling, IL.
- NADCA held its annual Executive Conference at the Omni Tucson National Resort in Tucson, AZ on March 20-23. An R&D Projects Update presentation was provided during this conference.

SFSA:

- Per task 3.10 (Hot Tears), attempts are being made to refine the hot-tearing model by carrying out some further trials on a modified casting which minimizes the restraint on the test specimen caused by the casting design.
- Data Mapping Software has been sent for trial to one foundry (Harrison Steel). Some minor software bugs need to be dealt with. It is planned that Iowa State will receive feedback from the foundry on the ease of operation of the software at regular intervals. Currently only one foundry can use the software, as the data will be stored on the Iowa

State server. If multiple users were to use the software as currently configured this would companies to view all of the entered data regardless of its source. Attempts will be made to develop some case studies using the rapid patternmaking equipment.

- Although the GFY2011 funding has not been received at this time, SFSA and MS&T are planning on:
  1. Running a series of trials of the new ladle refractory on medium sized ladles at three foundries.
  2. Improving melting efficiency through supplemental chemical energy/scrap type and method – plants will be revisited and more locations recruited.
  3. Effects of furnace and ladle stirring – more information will be acquired from users.
  4. Modeling of energy efficiency – a self-contained spreadsheet model will be developed.

Q2 – 2011

AFS:

- Held the 2011 Metalcasting Congress on April 5-8 in Schaumburg, IL. The following papers associated with ESMARRT were presented:
  - Vacuum Assisted Filling of A356 Aluminum Alloy, Engine Blocks Using the Lost Foam Casting Process (11-044) – Lost Foam Casting
  - Advantages of Pouring Compacted Graphite Iron Castings Using the Lost Foam Casting Process (11-045) – Lost Foam Casting
  - Development of Cast Al Alloys for Elevated Temperature (250°C) Service (11-017) – Aluminum
  - Effect of Alloying Elements on Gray Iron Natural Aging. Part 1. Manganese (11-022) – Cast Iron
- Conducted the AFS Cast Iron Research Committee meeting, May 4. Task 5.11, Aging Iron, was reviewed.
- Conducted the AFS Research Board meeting on June. 14
- Conducted the AFS Aluminum Division meeting on June 16 where Task 5.3 (Casting Porosity-Free Magnesium) and 5.4 (Elevated Temperature Aluminum MMCs) were reviewed
- Held the AFS Energy Conference on June 28-29
- Prepareed IJMC (International Journal of Metalcasting) Vol.5 Issue 3 , Summer 2011 article

NADCA:

- Information was given on NADCA-sponsored ESMARRT projects during a NADCA course presented to NADCA Chapter 17 on June 2, 2011 in Sikeston, MO.

SFSA:

- There will be a review of the current ESMARRT research at the Carbon & Low Alloy Research Review meeting on July 12-13 in Chicago, il. Approximately 45 people are expected to attend this meeting.
- Discussions have taken place over the last few months with respect to the progress of the work at Lehigh. Material has been obtained from a member foundry and a separate foundry has agreed to carry out the heat treatment of this material. In total 32 test pieces

will be heat treated and the corrosion testing trials carried out at Lehigh using a variation based on ASTM G48.

<u>Q3 – 2011</u>

AFS:

- GIFA 2011 (International Metalcasting Exposition), Dusseldorf, Germany, June 28 – July 2
- USAMP/USCAR Magnesium Roadmapping meeting, USCAR Southfield, MI, July 10
- AFS Research Board meeting, Schaumburg, IL, August 23
- AFS Aluminum Division meeting, including reviews of Task 5.3 and Task 5.4, Schaumburg, IL, September 15
- AFS Cast Iron Research Committee meeting, including review of Task 5.11, Schaumburg, IL, September 22
- IJMC (International Journal of Metalcasting) Vol.5 Issue 4 , Fall 2011 article

NADCA:

- An overview article on the 2012 NADCA R&D Strategic Plan and Roadmap was featured in the July issue of Die Casting Engineer Magazine.
- A one-hour webinar on Die Casting Energy Efficiency was conducted on August 24.
- A State-of-the-Industry webinar was conducted on August 25.
- The NADCA Die Surface Engineering Task Force held web meetings on August 26 and September 30.
- The Die Casting Congress and Tabletop Exposition was held on September 19-21 at the Greater Columbus Convention Center in Columbus, OH.
- The NADCA Computer Modeling Task Force held a meeting on September 21 in Columbus, OH.
- The NADCA Board of Governors held a meeting on September 21 in Columbus, OH.
- A one-hour webinar on Designing the Die for the Machine was conducted on September 28
- A presentation, including information on the NADCA R&D Program and DOE funded projects, was provided for NADCA Chapter 3 in Grand Rapids, MI on September 29.
- The NADCA Technology Administration Group held a meeting via telecom on September 29.

SFSA:

- Review of the current SFSA-sponsored E-SMARRT research (Tasks 2.2, 3.9, 3.10, 3.11, 4.1, and 5.10) at the Carbon & Low Alloy Research Review meeting, July 12-13, Chicago, IL. Approximately 45 people from industry, academia, and government attended this meeting.
- Discussions have taken place over the last few months with respect to the progress of the work at Lehigh. Material has been obtained from a member foundry and a separate foundry has agreed to carry out the heat treatment of this material. In total 32 test pieces

will be heat treated and the corrosion testing trials carried out at Lehigh using a variation based on ASTM G48.

- Southern Division meeting, July 20-21, Muskogee, OK
- Human Resources and Safety Meeting, August 9-10, Spokane, WA
- Eastern Division meeting, August 17-18, Bay City, MI
- SFSA Annual Meeting, September 10-13, Laguna Beach, CA

Q4 – 2011

AFS:

- AFS Aluminum Energy & Melt Efficiency Conference, October 10-12, in Dayton, OH. This included a presentation by Dave Neff, "Benchmarking Energy Use in Melting" based on the E-SMARRT Task 2.1 led by CWRU. There is also a workshop CD and a copy of this presentation will be supplied to ATI and DOE.
- AFS Division 11 Lost Foam conference call meetings were conducted on November 1 and December 1.
- Met with CFA (Chinese Foundry Association) at AFS November 4, including their Secretariat of their Lost Foam Division
- AFS Research Board and Division Council meeting on November 15-16.
- International Journal of Metalcasting Vol. 5 Issue 4, Fall 2011 Article

NADCA:

- NADCA Die Materials Task Force meetings were held at NADCA Headquarters in Wheeling, IL on October 11.
- NADCA held a Die Materials Committee meeting at NADCA Headquarters in Wheeling, IL on October 12.
- NADCA held an R&D Committee meeting at NADCA Headquarters in Wheeling, IL on October 13.
- A one-hour webinar on coatings for zinc die castings was presented on October 19.
- A one-hour webinar on coatings for reducing die solder was presented on October 26.
- A one-hour webinar on controlling porosity was presented on November 16.
- Information on the NADCA R&D Program and DOE funded projects was provided during plant visits in the NADCA Chapter 30 region (Los Angeles) on November 29-30.
- A one-hour webinar on thermal control of dies was presented on November 30.
- Information on the NADCA R&D Program and DOE funded projects was provided during plant visits in the NADCA Chapter 12 region (Milwaukee) on December 7-8.
- WPI research project activities were reviewed at WPI on December 7.
- Information on the NADCA R&D Program and DOE funded projects was provided during plant visits in the NADCA Chapter 16 region (Minneapolis) on December 15-18.

SFSA:

- A meeting of the Carbon and Low Alloy Committee was held at Iowa State University on October 13. There was a practical demonstration of the rapid patternmaking equipment, which aroused significant interest. A progress report on the data mapping software was also made which now has six foundries utilizing this software on a trial basis.

- The current status of all of the E-SMARRT projects were reported on at the SFSA Technical and Operating (T&O) Conference in Chicago December 7 -10. The meeting was attended by 226 people from 51 member plants providing an opportunity for member foundries to gain insight into this work and provide input into the direction of the projects.

<u>Q1 – 2012</u>

AFS:

- Conducted discussions with CANMET for the restart of Task 3.1 (Clean Steel Casting Production, Task 3.2 (Lost Foam Thin Wall Castings in Aluminum and Magnesium), Task 3.2, and Task 3.14 (Light Metals Permanent Mold Castings).
- Attended DOE Manufacturing Demonstration Facility (MDF) Workshop in Chicago on March 12. Had a nice discussion with DOE Advanced Manufacturing Office Director Leo Christodoulou on using the existing E-SMARRT consortium as a castings MDF.
- Developed plans for 116th Metalcasting Congress, scheduled for April 17-20 in Columbus, OH. Many of the E-SMARRT tasks will be briefed.
- Visited University of Alabama – Birmingham to discuss technology transfer from the completed Lost Foam task (Task 3.8)

NADCA:

- Provided three (3) webinars on extending die life (each one part of a three-part series) on January 11, January 25, and February 15.
- Presented information on the NADCA R&D Program and DOE E-SMARRT projects during plant visits in the NADCA Chapter 17 region (St. Louis) on January 16-18.
- Conducted NADCA Die Materials Task Force meetings at NADCA Headquarters, Wheeling, IL on February 7.
- Conducted NADCA Die Materials Committee meeting at NADCA Headquarters, Wheeling, IL on February 8.
- Conducted NADCA R&D Committee meeting at NADCA Headquarters, Wheeling, IL on February 9.
- Presented information on the NADCA R&D Program and DOE E-SMARRT projects during a NADCA Chapter 3 region (Grand Rapids) meeting on February 15 and during plant visits in this region on February 15-16.
- Presented information on the NADCA R&D Program and DOE E-SMARRT projects during plant visits in the NADCA Chapter 6 region (Cleveland) on February 20-22.
- Presented a one-hour webinar on reducing die soldering on February 22.
- The NADCA Board of Governors held a meeting on February 24 at NADCA, Wheeling, IL.
- Presented information on the NADCA R&D Program and DOE E-SMARRT projects during a plant visit in the NADCA Chapter 39 region (SW Michigan) on March 8 and during a Chapter 39 meeting.
- Presented information on the NADCA R&D Program and DOE E-SMARRT projects during plant visits in the NADCA Chapter 25 region (Indianapolis) on March 19 and 20 and during a Chapter 25 meeting on March 20.

- NADCA held its annual Executive Conference at the Naples Beach Hotel in Naples, FL on March 25-28. A presentation on energy efficiency in aluminum melting was provided during this conference.
- Part 1 of a 3 part die life webinar series was provided for NADCA Chapter 17 (St. Louis) on March 20.
- A one-hour webinar on thin wall casting was presented on March 28.

SFSA:

- Updates on the progress of the E-SMARRT projects were given at the meeting of the SFSA Board of Directors, Marco Island, FL, January 14-15
- The SFSA Technical & Operating (T&O) Committee developed the program outline for the 2012 T&O Conference to be held in Chicago in December 2012. Updates of the E-SMARRT projects will be included at the meeting.
- A Southern Division meeting was held on March 13-14 in Longview, Texas where updates on the projects were discussed with industry representatives.
- Visited Missouri University of Science & Technology, Rolla, MO and Iowa State University, Ames, IO the week of March 26 to review and discuss progress on their E-SMARRT tasks and how industry might assist in their progress.

Q2- 2012

AFS:

- IJMC (International Journal of Metalcasting) Vol. 6 Issue 2, Spring 2012 article
- 116th Metalcasting Congress, April 17-20, Columbus, OH
- AFS Div. 11 Lost Foam meeting during 116th Metalcasting Congress, April 17-20, Columbus, OH
- AFS Div. 6 Magnesium meeting during 116th Metalcasting Congress, April 17-20, Columbus, OH
- AFS Div. 9 Steel meeting during 116th Metalcasting Congress, April 17-20, Columbus, OH
- AFS Automotive Materials & Casting Process seminar during SAE 2012 World Congress, April 24, Detroit, MI
- AFS Government Affairs Conference, May 2-4, Washington, DC
- AFS CMI Gray and Ductile Process Metallurgy & Metalcasting Practice Course, May 15-16, WMU
- Conference Call with Canmet on restart of projects, May 22
- Casting Process and Materials seminar at SME Rapid2102, May 23-24, Atlanta, GA
- AFS Research Board and Division Council June 12-13.
- AFS Div. 11 Lost Foam meeting, UAB, June 21, Birmingham, AL
- AFS Div. 2 Aluminum meeting, Wolverine Bronze, June 26-27, Roseville, MI– Task 5.3 and 5.4 reviews

NADCA:

- A one-hour webinar on reducing shot sleeve distortion was presented on April 11.

- Information on the NADCA R&D Program and DOE funded projects was provided during plant visits in the NADCA Chapter 14 region (Dayton, OH region) on April 17-19 and during a Chapter 14 meeting on April 17.
- Information on the NADCA R&D Program and DOE funded projects was also provided during plant visits in the NADCA Chapter 10 region (Toronto, Canada) on May 2 and 3 and during a Chapter 10 meeting on May 2.
- NADCA held its annual Plant Management Conference at the Birmingham Marriott Hotel in Birmingham, Alabama on May 16-18. R&D Project information was provided during this conference.
- The NADCA Board of Governors held a meeting on June 1 at NADCA in Wheeling, IL.
- The WPI ACRC project review meeting was held on June 6 in Worcester, MA.
- NADCA held a Die Materials Task Force meeting at Twin City Die Casting Company on June 12.
- NADCA held a Die Materials Committee meeting at Twin City Die Casting Company on June 13.
- NADCA held an R&D Committee meeting at Twin City Die Casting Company on June 14.

SFSA:

- The High Alloy Research Committee met at Lehigh U to discuss the work of John Dupont and an extension to the work of Scott Chumbley ISU April 4.
- The Technical and Operating Committee discussed the incorporation of the current ESMARRT projects in the National T&O Conference program April 19.
- At the ASTM A01.18 meeting the incorporation of the findings of the Lehigh U work was agreed and will be balloted to become part of the ASTM steel castings standards May 5.
- The Eastern Division of the SFSA T&O met where the ESMARRT project findings were discussed with industry May 23.
- A CMC meeting was held at AFS to discuss the progress and funding of the ESMARRT projects May 30.
- Updates on the progress of the ESMARRT projects were given at the meeting of the SFSA Board of Directors June 12.
- At the ISO TC17SC11 meeting the incorporation of the findings of the Lehigh U work was agreed and will be balloted to become part of the ISO steel castings standards June 19 - 20.

<u>Q3 – 2012</u>

AFS:

- AFS Division 2 (Aluminum) meeting, September 20, 2012, Schaumburg, IL. Updates to industry committee members provided by Dr. David Schwam of CWRU (Task 5.3), Dave Weiss of Eck (Task 5.4), and Yemi Fasoyinu of Canmet (Task 3.14)

NADCA:

- An overview article on the 2013 NADCA R&D Strategic Plan and Roadmap was featured in the July issue of Die Casting Engineer Magazine.
- A one-hour webinar on optimizing die casting with PQ2 was presented on August 22.

- A one-hour webinar on why properties vary in die castings was presented on September 5.

SFSA:

- The Western Division of the SFSA T&O met on July 12-13. ESMARRT project findings were discussed with industry participants.
- Updates of the ESMARRT projects were given by the researchers at the SFSA Carbon and Low Alloy Research Review, July 17-18, Chicago, IL.
- Findings from the ESMARRT project were discussed with industry in a seminar addressing foundry operations and technology on August 14-15.

Q4 – 2012

AFS:

- International Journal of Metalcasting (IJMC), Vol. 6, Issue 4, Fall and Vol. 7 Issue 1 Winter
- The Minerals, Metals, and Materials Society (TMC) Materials Genome Meeting, Pittsburgh, PA, October 10
- AFS International Ferrous Melting Conference, Hilton Garden Inn Vanderbilt, Nashville, TN October 10-12
- AFS Div. 11 Lost Foam meeting, BRP, Spruce Pine, NC, October 17
- China Foundry Week 2012, Shuzou, China, October 22-25
- AFS Research Board and Division Council Meeting, AFS, Schaumburg, IL, October 12-13

NADCA:

- The NADCA Die Casting Congress & Exposition was held at the Indiana Convention Center in Indianapolis on October 8-10, 2012.
- The NADCA Board of Governors held a meeting on October 10 at the Indiana Convention Center during the NADCA Die Casting Congress & Exposition.
- The NADCA Die Materials Specification Task Force held a meeting at NADCA, Wheeling, IL, on October 23.
- The NADCA Die Materials Committee held a meeting at NADCA on October 24.
- A meeting of the Computer Modeling Task Force and Die Materials Development Task Force was held after the Die Materials Committee meeting on October 24.
- NADCA held an R&D Committee meeting at NADCA on October 25.
- The NADCA Die Surface Engineering Task Force held web meetings on October 19 and November 16, 2012.
- A three-part webinar series on shot profiles was presented on November 13, November 28, and December 19.

SFSA:

- December 12, National T&O Workshop, Chicago practical demonstration of Data Mapping software to over 50 industry representatives who provided feedback and suggestions for additional applications.

- December 13 - 15, National T&O Conference, updates of the ESMARRT projects were presented to over 175 industry, government, and academic attendees.

<u>Q1 – 2013</u>

AFS:

- IJMC (International Journal of Metalcasting), Vol. 7, Issue 1, Winter, and Vol. 7, Issue 2, Spring.
- AFS Div. 2 Aluminum meeting, January 17, AFS, Task 3.2, 3.14, 5.3 and 5.4 reviews
- Integrated computational materials engineering (ICME) Conference Call, (TMS/ASM) Materials Genome, March 4
- AFS International Ferrous Melting Conference, Nashville, TN, October 10-12
- AFS Research Board, AFS, February 12
- AFS Div. 11 Lost Foam meeting, Vulcan Engineering, Pelham, AL, February13, Task. 3.2
- CMC/E-SMARRT Technical Committee conference call, February 14
- Visit to Canmet, Hamilton, Ontario, February 21, to review Tasks 3.1, 3.2 and 3.14

NADCA:

- A webinar on die soldering was presented on January 10.
- On January 15, a presentation including NADCA sponsored R&D Projects was provided in St. Louis, Missouri for NADCA Chapter 17.
- A three part webinar series on aluminum alloy development was presented on January 16, 23, and 30.
- NADCA Die Materials Specification Task Force meeting, NADCA Headquarters, February 5.
- NADCA Die Materials Committee meeting, NADCA, February 6.
- Die Materials Development Task Force meeting, NADCA, February 6.
- NADCA R&D Committee meeting, NADCA, February 7.
- NADCA Die Surface Engineering Task Force web meeting, February 13.
- On February 19, a presentation including NADCA sponsored R&D Projects was provided in Cleveland, Ohio for NADCA Chapter 6.
- The first two parts of a four-part webinar series on control of porosity was presented on February 27 and March 6.
- NADCA Board of Governors meeting, March 1, NADCA.
- A shot sleeve distortion webinar was presented on March 13.
- NADCA Executive Conference, March 17-20, Marco Island, Florida.
- The first of a three-part webinar series on extending die life was presented on March 27.

SFSA:

- SFSA Board meeting, January 11, strategic direction of research projects and acquisition of Task 4.1 metering equipment
- SFSA Investment Casting Group meeting, February 13, Conbraco, Conway, SC
- SFSA Carbon & Low Alloy Research Committee meeting, March 26, University of Iowa, Iowa City, industry oversight of ISU’s Task 4.1 research project

Q2 – 2013

AFS:

- IJMC (International Journal of Metalcasting) Vol. 7 Issue 2 Spring and Vol. 7 Issue 3 Summer
- AFS 117th Metalcasting Congress and CasExpo'13, St. Louis, MO, April 6-9
- Visited Eck on Project 3.14 and 5.4
- AFS Aluminum Division 2 meeting June 6 at AFS – Task 3.2, 3.14, 5.3 and 5.4 reviews
- AFS Division 11 Lost Foam meeting at Styrochem, Montreal, CA, June 19, Task. 3.2
- AFS Research Board June 13
- CMC ESMARRT call June 21

NADCA:

- The third and fourth parts of a four-part webinar series on control of porosity were presented on April 3 and 10.
- On April 9, a presentation including NADCA sponsored R&D Projects was provided in Batavia, New York for Companies in the NADCA Chapter 9 region. In attendance were 12 students from Alfred State College.
- The second and third parts of the three-part webinar series on extending die life were presented on April 17 and 24.
- On April 24, a presentation including NADCA sponsored R&D Projects was provided in Newark, New Jersey for NADCA Chapter 7.
- NADCA held its annual Plant Management Conference at the Dayton Marriott Hotel in Dayton, Ohio on May 15-17. R&D Project information will be provided during this conference.
- A webinar on thin wall zinc was presented on May 29.
- The NADCA Board of Governors held a meeting on June 19 in Washington, DC during the NADCA Government Affairs briefing.
- NADCA held Die Materials Task Force meetings at Therm-Tech in Waukesha, Wisconsin on June 11.
- A NADCA Die Materials Committee meeting was held at the Country Springs Hotel in Waukesha, Wisconsin on June 12.
- A NADCA R&D Committee meeting was held at the Country Springs Hotel in Waukesha, Wisconsin on June 13.
- A three-part webinar series on advanced die design was presented on June 5, 12, and 26.

SFSA:

- April 4 presented the data mapping to Eglin AF base designers
- April 8 SFSA Lunch at AFS Casting Congress discussed energy of melting and data mapping.
- April 25 Presented Data mapping at the AFS NW regional in Vancouver
- May 21 shared the Data mapping developments with AF as a part of the JDMTP review
- June 11 SFSA Board meeting reviewed research portfolio

Q3 – 2103

AFS:

- AFS Committee 1G (Energy) Conference Call, July 30
- Foundry Environmental Seminar, August 11-12, Pittsburgh, PA
- AFS Research Board Committee meeting, August 13, Schaumburg, IL
- AFS Board of Directors meeting, August 21, Schaumburg, IL
- Foundry Executive Conference, September 23, Napa, CA

NADCA:

- 2013 NADCA R&D Strategic Plan and Roadmap article featured in July issue of Die Casting Engineer Magazine
- Webinar on why properties vary in die castings, July 17
- Three-part webinar series on die care and maintenance, August 14, 21 and 28
- Porosity management series of webinars, September 4, 11, and 25
- NADCA Congress and Tabletop, September 16-18, Louisville, KY

SFSA:

- SFSA Research Review presented current program status to industry, July 16-18, Chicago, IL
- SFSA Western Division meeting, with presentation of research, August 22, Portland, OR
- SFSA Annual Meeting, September 7-10, Half Moon Bay, CA

Q4 – 2013

AFS:

- IJMC (International Journal of Metalcasting), Vol. 7, Issue 4, Fall 2013 article
- AFS Division 2 Aluminum Meeting, October 8, Schaumburg, IL, AFS updated results of Task 5.4 (Elevated Temperature Aluminum MMC Alloy)
- AFS Division 11 Lost Foam Meeting to review/discuss Task 3.2 (Lost Foam), included tours of ACH and Mercury Marine, October 22, Fondulac, WI
- Advanced Foundry Waste Seminar, October 22–23, 2013, Atlanta, GA

NADCA:

- Bi-Metallic Tooling Webinar, October 30
- Resource Conservation and Recovery Act Webinar, November 7
- Thermal Lines Webinar, December 11

SFSA:

- North Central Technical & Operating and Future Leaders Group, October 1-4, Milwaukee, WI
- Southern Division Technical & Operating Meeting, November 12-14, Birmingham, AL
- SFSA National Technical & Operating Conference, December 11-14, Chicago, IL

Q1 2014

AFS:

- AFS Molding and Melting Methods and Materials Committee Meetings, January 21-23, Schaumburg, IL
- AFS Board of Directors Meeting, January 27, 2014, Rancho Mirage, CA
- Lost Foam Division Committee Meeting and Plant Tour, February 5, University of Alabama, Birmingham
- AFS Wisconsin Regional Conference, February 12 – 14, Milwaukee, WI
- AFS Molding Methods and Materials Committee Meeting, February 18-19, Schaumburg, IL
- Webinar: Enhancing Aluminum Castings for Structural Applications, March 6, 2014

NADCA:

- Die Materials and R&D Committee Meetings, February 12-13, Arlington Heights, IL
- Die Casting Executive Conference, February 23-26, Marco Island, FL
- Process Monitoring Webinar, March 11
- Influence of Process Parameters and Maintenance on Die Life Webinar, March 12
- Applying New Technologies Webinar, March 19
- Thermal Design Theory Webinar, March 21

SFSA:

- SFSA Technical & Operating Conference Committee Meeting, January 14, Rosemont, IL
- SFSA Board of Directors Meeting, January 17 – 19, Half Moon Bay, CA
- Research Review Meetings, University of Iowa, March 26-27, Iowa City, IA
- Research Review Meetings, Iowa State University, March 27, Ames, IA

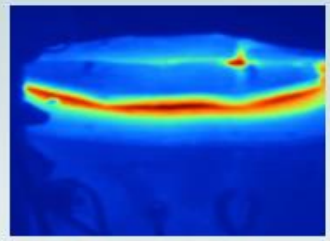
Appendix B
List of Detailed E-SMARRT Reports and DOE Office of Scientific and Technical Information (OSTI) Number

1. Task 2.1, "Improvements in Efficiency of Melting for Die Casting", OSTI Number 1057665
2. Task 2.2, "Melting Efficiency Improvement", OSTI Number 1051407
3. Task 3.1, "Clean Steel Casting Production", OSTI Number 1126492
4. Task 3.2, "Feasibility of Producing Lost Foam Castings in Aluminum and Magnesium Based Alloys", OSTI Number 1131409
5. Task 3.4, "Improved Die Casting Process to Preserve the Life of the Inserts", OSTI Number 1057028
6. Task 3.5, "Development of Thin-Section Zinc Die Casting Technology", OSTI Number 1111101
7. Task 3.7, "Design Support for Tooling Optimization", OSTI Number 1025584
8. Task 3.8, "Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology", OSTI Number 1024103
9. Task 3.9, "Simulation of Distortion and Residual Stress Development During Heat Treatment of Steel Castings", OSTI Number 1022073
10. Task 3.10, "Simulation of Dimensional Changes and Hot Tears During Solidification of Steel Castings", OSTI Number 1022074
11. Task 3.11, "Precision Castings", OSTI Number 1028211
12. Task 3.12, "Innovative Semi-Solid Metal (SSM) Processing",OSTI Number 1057874
13. Task 3.13, "Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions", OSTI Number 1024605

14. Task 3.14, “Light Metals Permanent Mold Casting”, OSTI Number 1126472
15. Task 4.1, “Energy Efficiency Instrumentation”, OSTI Number 1123312
16. Task 5.1, “The Development of Surface Engineered Coating Systems for Aluminum Pressure Die Casting Dies: Towards a “Smart” Die Coating “,OSTI Number 1050628
17. Task 5.3, “Casting Porosity-Free, Grain Refined Magnesium Alloys”, OSTI Number 1097772
18. Task 5.4, “Development of Elevated Temperature Aluminum MMC Alloy and Process Technology”, OSTI Number 1131418
19. Task 5.6, “Development of CCT Diagrams”, OSTI Number 1022742
20. Task 5.7, “Corrosion Testing Practices – High Alloy Corrosion Program”, OSTI Number 1045448
21. Task 5.8, “Mechanical Performance of Dies”, OSTI Number 1025587
22. Task 5.9, “The Use of Laser Engineered Net Shaping (LENS) for Rapid Manufacturing of Dies with Protective Coatings and Improved Thermal Management”, OSTI Number 1135793
23. Task 5.10, “Surface/Near Surface Indications – Characterization of Surface Anomalies from Magnetic Particle and Liquid Penetrant Indications”, OSTI Number 1123477
24. Task 5.11, “Aging of Graphitic Cast Irons and Machinability”, OSTI Number 1054341

Appendix C
E-SMARRT Success Stories

METALCASTING
E-SMARRT
Energy-Saving Melting and Revert Reduction Technology



Benchmarking of Melting Operations helps Die Casters Improve Energy Efficiency

Melting efficiency is an important part of aluminum die casting operations. Die casters need to make informed decisions when selecting melting equipment to maximize operating efficiencies. The capital cost of new melting equipment with higher efficiency can be recovered relatively quickly when it replaces old melting equipment with lower efficiency. However energy efficiency is not the only factor in optimizing melting operations, as melt losses and metal quality are also very important. Selection of melting equipment has to take into consideration the specific conditions at each die casting facility, such as available floor space, average quantity of metal used, as well as the ability to supply more metal during peaks in demand.

SUCCESS STORY

Problem: There was a lack of reliable data of energy use and melt losses for aluminum melting furnaces within the die casting industry.
Solution: Case Western Reserve University, partnering with the Cast Metals Coalition (CMC) on E-SMARRT and in cooperation with the North American Die Casting Association (NADCA) and their members, worked to benchmark the energy efficiency of a wide range of aluminum melting and holding furnaces. Shown above (from left to right) are three of the benchmarked furnaces - reverberatory, stack, and induction furnaces.
Benefits: Based on the detailed benchmarking work, workshops were conducted on melting efficiency through the coordination of NADCA. An average of fifty people attended each workshop at various locations across the United States, including Empire Die Casting (Macedonia, OH), Edelbrock (Hemet, CA), Nemak Die Casting (Sylacauga, AL), Ryobi Die Casting (Shelbyville, IN), and Mercury Marine (Fond du Lac, WI). Methods for approaching the theoretical aluminum melting energy of 500 BTU/lb where covered in detail.

"As Energy Efficiency Team Leader, I found the Workshops and benchmarking information generated by the CWRU project very useful in evaluating our own melting operation and making improvements."
Mike Evans, Gibbs Die Casting

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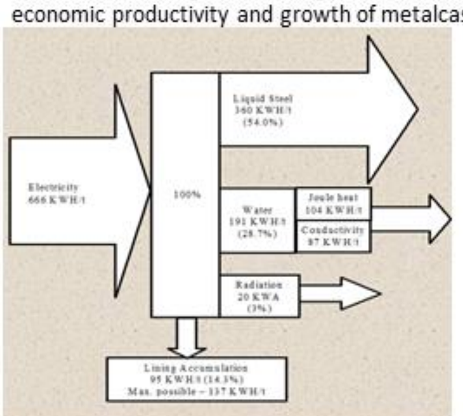
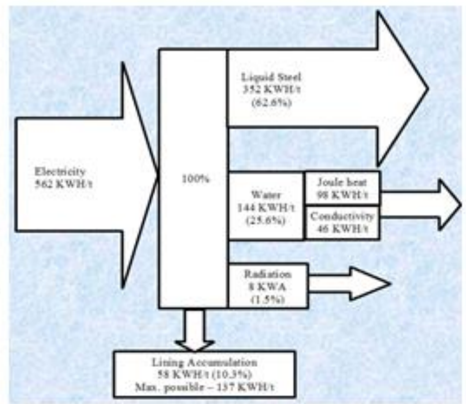
Saving Energy Through More Efficient Melting

The Missouri University of Science and Technology (MS&T), partnering with the Cast Metals Coalition on the E-SMARRT program, evaluated energy use and requirements for steel foundry operations to develop melting techniques and practices that improved melting energy efficiency. This effort resulted in reductions in energy use, operation costs, greenhouse gases and other emissions, while increasing productivity which will stimulate the economic productivity and growth of metalcasting manufacturing.



Electrical Energy Use Before Changes



Electrical Energy Use After Changes (preheat + covers)

SUCCESS STORY

Problem: An induction melting foundry averaged electrical consumption between 500 and 666 KWh/ton for melting on hot and cold linings, respectively. Heat losses during steel melting included heat accumulation and conduction to the cold lining and radiation from the open surface. Energy efficiency was 30 - 50% during heating of the molten bath to tap temperature.

Solution: Gas preheating of the induction lining prior to the first heat reduced the energy requirements of the first heat and radiation losses were reduced by using covers during melting in the furnaces. New alloying practices reduced the time the liquid steel was in the furnace.

Benefits: The foundry realized a 16% reduction in electrical energy on the first heat of the day and 5-10% reduction in energy on heats melted in hot linings.

"Improving efficiency in melting has helped us significantly reduce our energy and operating costs and improve quality and safety without new capital investments. We were fortunate to be able to work with the group from Missouri S&T on this project."

Jay Triplett, President
Monett Metals, Inc.

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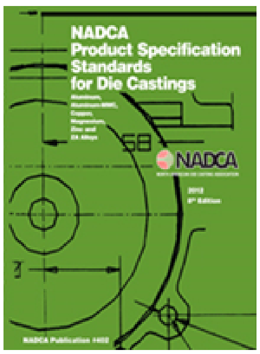
High Fluidity Zinc Die Casting Alloy Reduces Part Cost and Improves Energy Efficiency

As a partner in the Energy-Saving Melting and Revert Reduction Technology (E-SMARRT) program, the North American Die Casting Association (NADCA) has sponsored the development of new technologies for improving energy efficiency. One such technology is the high fluidity (HF) zinc die casting alloy developed by the International Lead and Zinc Research Organization (ILZRO). This HF alloy has 40% higher fluidity than Zamak 7 – the previous commercially available zinc die casting alloy of highest fluidity. Information on this alloy has been transferred to the industry through the NADCA Product Specification Standards for Die Castings document. ILZRO is also providing design assistance to companies for proper implementation of the new alloy. The benefits of this technology include:



- **Casting of thinner walls**
- **Fill of more complex geometries**
- **Minimization of scrapped unfilled parts**
- **Shorter cycle times**
- **Higher productivity**
- **Enhanced energy efficiency**

SUCCESS STORY

Problem: There was an excessive and unacceptable 20 minute cycle time to machine the front and back of each HTC One V Windows-based cell phone made from forged 6000 series aluminum blanks.

Solution: The front and back components of the case were redesigned as die castings utilizing the HF zinc alloy. Dies for the two castings were designed for a 4-slide zinc die casting machine to accommodate undercuts and other details of the configurations not achievable with current aluminum and magnesium die casting alloys. Based on computer simulations showing acceptable flow and fill analyses, die sets were fabricated and cast cell phone cases were successfully produced. With a higher yield strength and ultimate strength than the original forged aluminum alloy, the ability to be cast to the desired 0.4 mm wall thickness (slightly less than 0.016 inch), and an estimated machining time of only 2 minutes, the HF zinc alloy was a game changer.

Benefits: Converting the HTC cell phone case to die cast HF zinc alloy from machined aluminum forgings provided large cost and energy savings. Based on a production level of one million cell phones per month, the cost savings for machining alone is $60,000 per month or $720,000 per year. The energy savings for machining, coupled with the savings in melting zinc for die casting versus melting aluminum for forging stock, is estimated to be 3.8 billion BTU per month or 45.6 billion BTU per year.

> *"Brillcast has had the privilege of running the initial test tools with HF alloy and were very pleased with the increased fluidity. We recently modified the wall stock of a retired tool from .045" to .022" to gain further knowledge of the alloys capabilities. We produced thousands of castings at .022" wall over a 4" x 2.5" plate. The finish was class A acceptable. We are excited at the prospect of what the HF alloy can mean for opening up new applications for zinc die castings."*
>
> --Brad Doornbos, President / CEO, Brillcast Inc.

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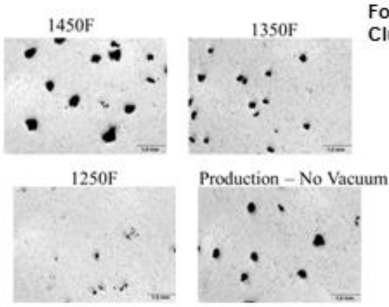
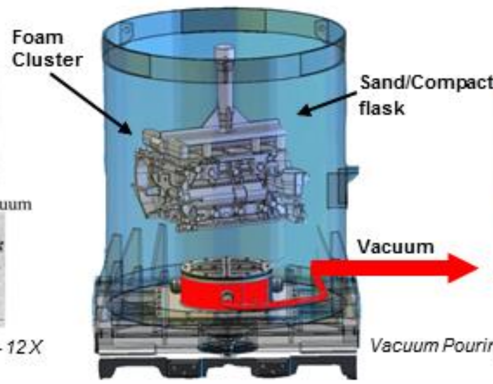
Improvements is the Lost Foam Casting Process

Problem: The aluminum casting process may produce components with lower mechanical properties than other forming processes, such as forging and machining, due to porosity formed by the release of hydrogen during solidification. The Lost Foam Casting Process (LFCP), a type of evaporative-pattern casting process that is advantageous for very complex castings, can produce additional porosity and folds when there is inefficient removal of gas formed during the degradation of the foam pattern. Process improvements were needed to increase mechanical properties while reducing porosity and the incidence of folds.



Typical Porosity from Main Bearing Blanks – 12 X



Vacuum Pouring Schematic

Engine Bed Plate Cast Using Vacuum Assisted Pouring

Casting *Pattern*

SUCCESS STORY

Solution: The University of Alabama at Birmingham (UAB), partnering with the Cast Metals Coalition on the E-SMARRT program, incorporated the Vacuum Assisted Pouring (VAP) process into the aluminum LFCP. VAP reduces porosity by allowing significantly lower pouring temperatures where the hydrogen content of the molten metal is reduced. VAP also provides a more uniform pressure gradient of the casting and allows for a more timely removal of gases from the casting cavity. This timing is critical in the removal of all gases before solidification.

Benefits: Casting trials at UAB using VAP have illustrated that metal porosity and the incidence of folds can be significantly reduced in automotive engine blocks using A319 and A356 aluminum. Porosity values in the main bearing areas of A319 engine blocks were reduced from 2.0 % to less than 0.5 %. In addition, ductility (% elongation) increased from 0.8 % to 1.5%. Increased ductility is an indicator of improved fatigue strength. Similar results were obtained for samples removed from an engine block poured using A356. Energy saving calculations indicate that the 200°F reduction in pouring temperature for aluminum alloys will reduce manufacturing energy usage by 17-29%.

"We are taking advantage of the Vacuum Assisted Pouring to reduce our gas consumption of the melting furnaces pouring at a lower pour temp resulting in ~ 6% savings in natural gas".

Tom McMahon
Senior Lost Foam Process Engineer,
Nemak

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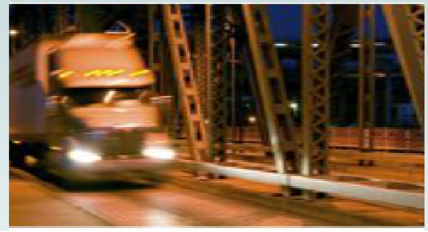


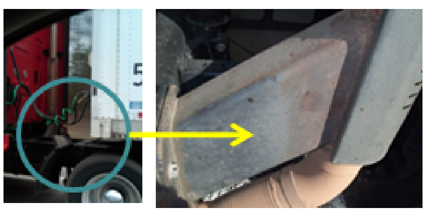
"Improving the Lost Foam Casting Process Yields Better Casting Solutions"

Many technical issues inhibit the production and growth of the U.S. lost foam castings industry. The issues were studied and practical solutions developed by the Lost Foam Consortium under E-SMARRT. Grede-Columbiana (formerly Citation Foam Casting) was a major contributing partner throughout the program. The resulting technology was developed and verified in production, and directly contributed to the growth and success of Grede and other lost foam foundries. The research was conducted by the University of Alabama at Birmingham (UAB) partnering with the Cast Metals Coalition on the E-SMARRT program.

SUCCESS STORY

Problem: Lost foam casting has not significantly improved the major controlling parameters since its inception in 1959. As a result, there have been several casting facility failures and limited market applications of this innovative energy-saving casting process.

Solution: The Lost Foam Consortium was formed by UAB under the E-SMARRT program to identify lost foam controlling parameters, develop solutions, and implement them in production. The areas of research were identified by consortium participants such as Grede. Casting trials at UAB and other Lost Foam Consortium foundries resulted in new procedural manuals and instrumentation that improves the production of lost foam castings while reducing the number of defects. All solutions were validated in production facilities.



- **Reduced weight by 20%**
- **Totally as-cast - no machining required**
- **Replaced a 3-piece steel fabrication**
- **Eliminated 108 inches of welding**

Benefits: Lost foam improvements resulting from this effort include:

- Foam coating (permeability and viscosity) quality control
- Pattern quality control
- Improved gating guidelines for improved metal flow
- Pattern shrinkage data to improve tool design
- Sand expansion data that increases the dimensional accuracy of castings
- Flask filling and compaction to reduce pattern distortion

These improvements directly contributed to the growth and success of lost foam castings at Grede. Grede-Columbiana is the world's largest manufacturing facility for ferrous lost foam castings used by leading industrial and transportation manufacturers. Lost foam castings include transmission components, driveline slip yokes, chassis brackets, complex differential carrier housings, towing components and suspension assemblies, axle tube assemblies, bed plates, engine blocks, cylinder heads, and turbocharger housings.

"With robust training and implementation of the Lost Foam Consortium body of knowledge, Grede continues to grow in a market with ever increasing demands."
-- Tom Walton, Business Development Manager, Lost Foam, Grede Holdings

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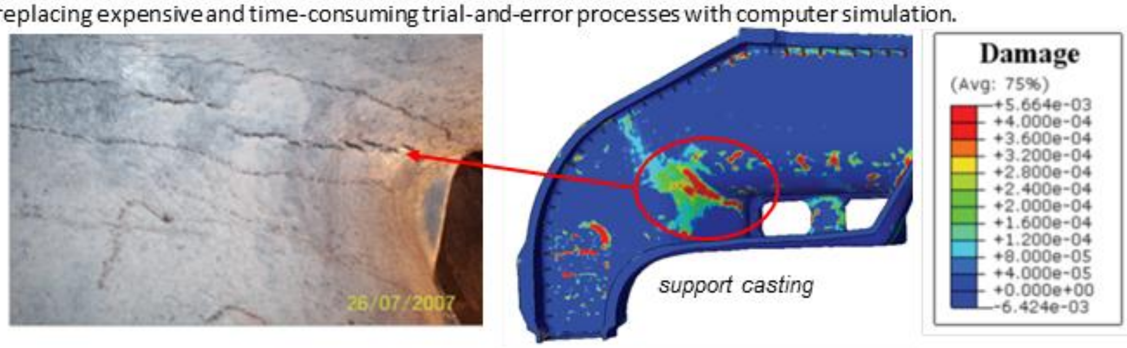
Simulation of Hot Tears in Steel Castings Reduces Costly Rework

During steel casting solidification, contractions and distortions can cause final product dimensions to vary significantly from the original pattern. Casting cracks that form late in solidification, called hot tears, occur when tensile strains can no longer be accommodated by liquid metal flow. Dimensional changes and hot tears are major problems in the steel casting industry, resulting in costly scrap or repair work. Correcting these problems required a tedious trial-and-error process. The University of Iowa, partnering with the Cast Metals Coalition on the E-SMARRT program, developed a casting simulation model that predicts dimensional changes and hot tears, replacing expensive and time-consuming trial-and-error processes with computer simulation.



SUCCESS STORY

Problem: Initial casting trials for a prototype casting used in a Caterpillar off-highway truck frame resulted in hot tears at internal corners.

Solution: The new hot tear/dimensional change simulation model was able to successfully predict the hot tear location. Hot tears were eliminated by systematically modifying casting parameters and geometry, and then re-simulating until the predicted hot tears were alleviated.

Benefits: This new model is estimated to save 24,430 million BTU per year per unit affected by this new technology. A unit is defined as 1% of the total U.S. steel foundry production tonnage per year. The model has been implemented in MAGMAsoft, the worldwide leading casting simulation software.

"Caterpillar has implemented the hot tear model developed at the University of Iowa into its suite of casting modeling and simulations tools. This pioneering research is routinely utilized to solve complex hot tear problems observed in first article castings. Having a model that can be used earlier in the casting development process is helping to avoid costly hot tear problems through improved design." - ***Rick Huff, Manufacturing Technology, PD&GT, Caterpillar, Inc.***

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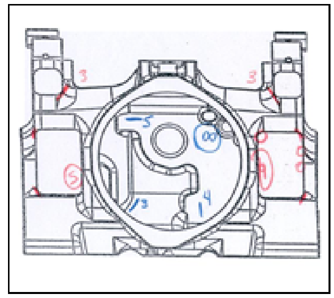
Surface Mapping Software



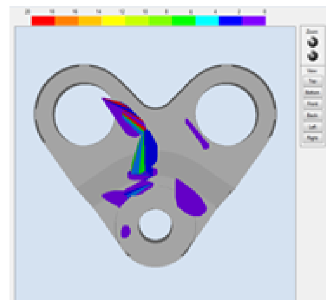
Example of manual data collection of surface anomalies for one view of one casting.

Program Overview

Surface inspection is an important step in the production of metalcastings. During this inspection, areas that need additional processing are identified which are addressed via grinding or other processes. Important process control decisions can be made based on this surface inspection data if it were more easily accessible. For instance, the long term effects of gradual process changes or the effect of a new gating system design could be investigated.

Problem

This surface inspection information is rarely available for analysis since it is recorded directly on the casting. The data needed for quality control decisions in the casting process is often difficult to obtain. This is especially true when referring to the surface quality of the part as it undergoes multiple inspections. A typical inspection involves identifying the location of anomalies and marking them for further processing in the cleaning room. Each time an inspector views a casting, information on the part surface quality is conveyed. Often the information is not recorded. If it is, the data is collected manually on paper inspection sheets. Manual recording is time intensive and access to this information is very difficult.



A frequency map showing the occurrence of surface anomalies across a range of castings, as output from the software.

SUCCESS STORY

Solution: As part of the Energy-Saving Melting and Revert Reduction Technology (E-SMARRT) program, Iowa State University developed Anomaly Mapping Software that provides an easy to use interface for recording anomaly type and location on a 3D model. Analysis modules designed for this data include histograms, frequency plots, and area calculations. By linking this database with other process information, correlations between other process variables can be conducted. Metalcasting producers now have a way to collect and analyze real data to improve casting production.

Benefits:

- Reduction in the amount of energy by proactively reducing rework and scrap through informed process control decisions
- Able to identify critical process variables
- Higher quality parts delivered with shorter lead times

> *"The anomaly mapping software allows us to objectively observe and monitor the causes of rework and scrap, which quickly helps us determine a permanent corrective action to improve casting quality and customer satisfaction."*
>
> **--AJ Menefee, Quality & Engineering Manager, Eagle Precision Cast Parts, Inc.**

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High Temperature Aluminum Metal Matrix Composite (Al-MMC) Alloy

As part of the Energy-Saving Melting and Revert Reduction Technology (E-SMARRT) program, Eck Industries is developing a production-capable cast Al-MMC alloy with an operating temperature capability of 250-300°C. Al-MMCs consist of nonmetallic reinforcements incorporated into an aluminum matrix. Al-MMCs have better stiffness, wear resistance and thermal conductivity than base aluminum alloys. Currently available cast aluminum alloys have maximum effective operating temperatures of approximately 200°C. While this temperature capability is adequate for traditional applications, demands from important industrial sectors as well as the military require lightweight alloys that can operate in temperature ranges of 250-300°C.

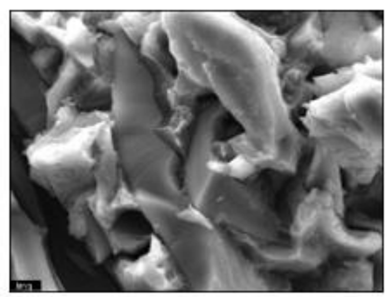
SUCCESS STORY

Problem: Current high-temperature casting needs are being met by the use of titanium alloy castings. Titanium castings have the desired strength, but the end components are heavier and significantly more costly. In addition, the energy requirements for production of titanium alloy castings are significantly higher than those required for the production of aluminum alloy castings.

Solution: Eck successfully developed a process to cost-effectively produce a high temperature Al-MMC alloy. The technology was demonstrated on a light aircraft engine cylinder head part.

Benefits:

- Weight reduction for improved fuel economy with current powertrains
- No loss in strength / material properties
- Eck already has a potential customer for the material developed



"The development of a reliable, high temperature, light-weight material that is easy to cast and has good fatigue properties has generated significant interest from customers in the aerospace and air control markets. Improved alloy performance drives innovative designs that improve overall energy efficiencies."

--David Weiss
VP Engineering/R&D, Eck Industries, Inc.

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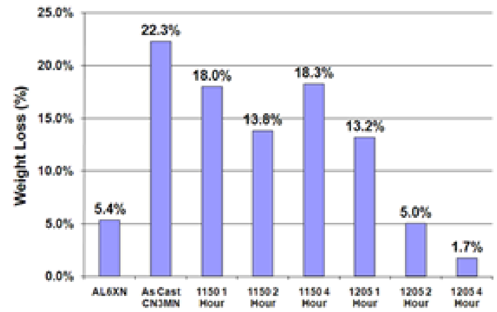
New Heat Treating Schedules Lead to Dramatic Improvements in Corrosion Resistance of Cast Stainless Steels

Program Overview & Objective: High alloy stainless steels are used in many applications where there is a need for components to have good corrosion resistance and high impact toughness. Fabrication of such components by casting is often desirable from an economic standpoint, since complicated shapes can be made in fewer steps with reduced costs compared to other manufacturing processes. However, the use of cast stainless steel components is often limited by poor corrosion resistance relative to counterpart wrought alloys. The objective of this project was to develop heat treatments for cast stainless steels that could provide dramatic improvements in corrosion resistance. Successful design of such heat treatments would pave the way for increased use of cast stainless steel alloys in demanding applications.

Problem: High alloy stainless steels can contain significant amounts of segregation in the as-cast condition that reduces corrosion resistance. Current heat treatment standards were not effective at eliminating the segregation. Thus, there was a need to determine if new heat treatments could be designed that would eliminate segregation and restore corrosion resistance.

Graphs explanation: *Variation in weight loss due to corrosion as a function of sample condition for (A) CN3MN and (B) CK3McuN. Comparison is made with the matching wrought stainless steel alloys – AL6XN and 254SMO.*



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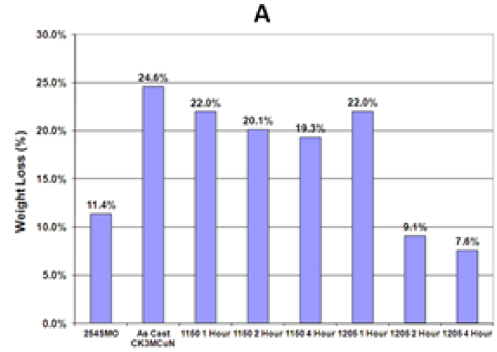

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SUCCESS STORY

Solution: Two commercial versions of high alloy cast stainless steels (CN3MN and CK3McuN) were subjected to a wide variety of heat treatment times and temperatures, and then used for corrosion testing. Comparisons were made with the matching wrought stainless steel alloys (AL6XN and 254SMO). The results showed that dramatic improvements in corrosion resistance were possible to the point where the corrosion resistance of the cast alloys was equivalent to that of the matching wrought materials.

Benefits: These dramatic improvements in corrosion resistance will open the door to new applications for cast stainless steels in applications that were previously not possible. As a result of this work, the heat treatments in several ASTM standard specifications for castings (which includes Standard A351/A351M, A743/A743M, and A744/A744M) are being modified.

> *"When the results of the work at Lehigh University became available, the heat treatment was modified accordingly. The use of the revised treatment has resulted in only 5% of the lots failing the initial corrosion test – and none of these lots have required re-heat treatment"*
>
> -- Ron Bird, Stainless Foundry & Engineering, Milwaukee, WI

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