

Project Title: Energy Saving Melting and Revert Reduction Technology (E-SMARRT)

Project Objective: 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; and Material Properties for Casting or Tooling Design Improvement. This portfolio will significantly reduce metalcasting process energy consumption while improving important capabilities of castings. The Advanced Technology Institute (ATI) provides the project management functions required to lead the project, guided by an Industry Review Board (IRB), and supported by a Technical Advisory Committee (TAC). Table 1: E-SMARRT Work Breakdown Structure

WBS #	Task Description/Title	Lead
3.0	Innovative Casting Processes for Yield Improvement/Revert Reduction	
3.1	Clean Steel Casting Production	CANMET
3.8	Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology	UAB
3.13	Prediction of Wax Pattern Tooling and Final Investment Casting Dimensions	EMTEC/ESI
3.14	Light Metals Permanent Mold Casting	CANMET
5.0	Material Properties for Casting or Tooling Design Improvement	
5.4	Development of Elevated Temperature Aluminum MMC Alloy and Process Technology	Eck
5.11	Aging of Graphitic Cast Irons and Machinability	UMR

Task Objectives and Backgrounds

WBS 3.1 Clean Steel Casting Production

Recipient Organization: CANMMET Materials Technology Laboratory
 Industrial Society Affiliation: American Foundry Society (AFS)
 Technical Contact: Selçuk Kuyucak, (613) 992 2253, Skuyucak@NRCan.gc.ca
 Cost Share Partners: Harrison Steel, Attica, IN, Canada Alloy Castings, Kitchener, Ontario, Maynard Steel, Milwaukee, WI, M E Global, Tempe, AZ, Sivyer Steel, Bettendorf, IO, CMPT LLC, New Berlin, WI, Matrix Metals LLC, Richmond Foundry, TX, Industrial Ceramic Products, Marysville, OH

- 1. Project Objective:** Minimize surface defects in steel castings; especially, those large castings processed by ladle bottom-pouring.
- 2. Background:** Entrained air in ladle bottom pouring operations is the major cause for turbulence and re-oxidation leading to surface defects, in particular, pronounced cope-side defects. These are labor- and energy- intensive to rectify and may also result in scrapped castings. Both, turbulence created by entrained air, and the residual de-oxidizer can contribute to sand / metal reactions at the cope-surface.

Methods to minimize or eliminate entrained air in a pouring box have been developed using water modeling. Two lines of approach have been found promising: a small dam near the sprue outlet of a pouring basin or a submerged ladle-nozzle extension into a pouring basin. These will be tried in steel castings in the lab and in participating industry sponsor sites.

WBS 3.8 Manufacturing Advanced Engineered Components Using Lost Foam Casting Technology

Recipient Organization: The University of Alabama at Birmingham
Industrial Society Affiliation: American Foundry Society (AFS)
Technical Contact: Harry Littleton, (205) 975-8120, hlittleton@uab.edu
Cost Share Partners: Amcan, Exco Engineering, Blue Ridge Pressure Casting, DCD Technologies, Ried and Associates, Ryobi, St. Clair Die Casting, Walkington Engineering, BMW, Bombardier, Carbo Ceramics Inc., Citation Foam Cast, Copeland Corp., ESI Group, Flow Science, Foseco-Morval, Fundilag, General Kinematics, GM Powertrain CDVC, HA International, Lovink Terborg, Magma Technologies, Mercury Marine, Montupet, Mueller Company, Nematik S.A., Southeastern Foundry Products, Styrochem International, Inc., Teksid Aluminum Components Inc., Vulcan Engineering, American Foundry Society

1. **Project Objective:** Through this project, technologies, such as computer modeling, pattern quality control, casting quality control and marketing tool, will be developed to advance the Lost Foam Casting process application and allow greater energy savings. These technologies will improve (1) production efficiency, (2) mechanical properties, and (3) marketability of lost foam castings. All three will reduce energy consumption in the metals casting industry.
2. **Background:** The Lost Foam Casting Process produces high value parts by combining cast components into single castings, improving energy efficiency by achieving better metal yields, reducing materials consumption by eliminating cores, and improving casting dimensional accuracy. All of these process features reduce the energy consumption during manufacturing. However, casting defects such as laps and folds, metal porosity, surface blisters, “orange peel” and lustrous carbon, degrade mechanical properties and limit the application of Lost Foam Castings. This program will further decrease casting scrap and expand the Lost Foam marketplace through addressing the following technical issues:
 - Increased understanding of the metal/pattern replacement process to reduce casting defects and improve computational models
 - Improve pattern quality and consistency to reduce casting defects
 - Develop innovative techniques to expedite pattern pyrolysis product removal to reduce casting defects and improve casting quality
 - Develop techniques and procedures for solidification under pressure to improve casting quality for safety critical applications
 - Develop a design package for casting designers and implement a marketing plan to increase Lost Foam casting applications

WBS 3.13.1 Predicting Pattern Tooling and Casting Dimension for Investment Casting

Recipient Organization: Oak Ridge National Laboratory
Industrial Society Affiliation: American Foundry Society (AFS)
Technical Contact: Adrian S. Sabau, (865) 241-5145, sabaua@ornl.gov
Cost Share Partners: Schrey & Sons Mold, Buycastings.com, Precision Metalsmiths Inc, J&J, A DePuy Company, Precision Colloids, LLC, Precision

Metalsmiths Inc, Minco, JEM Mfg, S&A Consulting Group LLP, Argueso & Co, Precision Castings Inc.

1. **Project Objective:** Developing computational tools and methodologies for predicting pattern tooling and casting dimensions for investment castings in order to enable the production of investment castings to meet blue print nominal during the first casting run.
2. **Background:** Although current predictions show a good qualitative agreement with experimental results for wax pattern distortion, without considering feeding effects during the dwell time, the computed results for wax shrinkage factors are twice as large as those experimentally measured.

WBS 3.13.2 Predicting Pattern Tooling And Casting Dimension For Investment Casting

Recipient Organization: Edison Material Technology Center (EMTEC)
Industrial Society Affiliation: American Foundry Society (AFS)
Technical Contact: Nick Cannell, (216) 408-7706, ncannell@emtec.org
Cost Share Partners: Schrey & Sons Mold, Buycastings.com, Precision Metalsmiths Inc, J&J, A DePuy Company, Precision Colloids, LLC, Precision Metalsmiths Inc, Minco, JEM Mfg, S&A Consulting Group LLP, Argueso & Co, Precision Castings Inc.

1. **Project Objective:** Developing computational tools and methodologies for predicting pattern tooling and casting dimensions for investment castings in order to enable the production of investment castings to meet blue print nominal during the first casting run.
2. **Background:** Although current predictions show a good qualitative agreement with experimental results for wax pattern distortion, without considering feeding effects during the dwell time, the computed results for wax shrinkage factors are twice as large as those experimentally measured.

WBS 3.14 Light Metals Permanent Mold Casting

Recipient Organization: CANMMET Materials Technology Laboratory
Industrial Society Affiliation: American Foundry Society (AFS)
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Cost Share Partners: CANMET-MTL (Investigating Laboratory), Magma Foundry Technologies, Inc., ECK Industries, Inc., Centre Intégré de Fonderie et de Metallurgie, Powercast Manufacturing Inc., Premier Aluminum, Inc., Alcan International Ltd., Grenville Castings Limited

1. **Project Objective:** The main project objectives of this project are to:
 - a. Establish the processing parameters for selected prototype automotive, marine and other components during gravity and low pressure permanent mold casting of Al-Mg alloy 535 and Mg alloys AM50 and a creep resistant alloy (based on suggestion from industrial partners).
 - b. Determine the microstructure and mechanical properties in the as-cast as well as heat-treated of the alloys mentioned above.
 - c. Benchmark the casting processes and alloy properties.
2. **Background:** There is increased interest and emphasis on vehicle weight reduction to improve fuel economy by automakers in North America, Europe and Asia. The use of light alloys based on Al-

and Mg-base alloys that can replace some of the currently used ferrous alloys is one of the strategies being used to achieve better fuel economy. Some of the advantages of permanent mold casting process compared to sand casting processes are better surface finish, precise and consistent dimensional control and improved mechanical properties. The selection of permanent mold cast Al- and Mg-base alloys for more rigorous engineering applications is currently hampered by lack of adequate data on the foundry characteristics and the mechanical properties. There is very limited information in the open literature on the gravity and low-pressure permanent mold casting of Al-Mg alloy 535 and many of the Mg alloys that are of interest to the automotive industry. Currently, high-pressure die-casting is the major production route of magnesium alloy components used in automotive applications. However, due to porosity, most of the high-pressure die cast components cannot be heat-treated. Gravity tilt-pour and low-pressure permanent mold casting of powertrain components from magnesium alloys can lead to reduced porosity defects, and thus allow for the heat treatment of the prototype components for improved performance. It is anticipated that magnesium use in automotive applications may rise to 12.4 kg from the current 4 kg per vehicle, and gradually increase to 100 kg per vehicle by 2020. The use of magnesium in other commercial applications is also expected to increase due to its high-strength-to-weight-ratio.

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

Recipient Organization:	Eck Industries, Incorporated
Industrial Society Affiliation:	American Foundry Society (AFS)
Technical Contact:	Gerald A. Gegel, (309) 266-7533, gegel@dpc.net
Cost Share Partners:	Eck Industries, Incorporated CanMet Materials Technology Laboratory Materials and Process Consultancy

- 1. Project Objective:** The objective of this project is to provide a production capable cast aluminum MMC alloy with an operating temperature capability of 250-300°C. Currently available cast aluminum and magnesium alloys have maximum effective operating temperatures of about 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. Current needs in this temperature range are being satisfied by the use of titanium alloy castings. These have the desired strength properties but the end components are heavier and significantly more costly. Also, the energy requirements for production of titanium alloy castings are significantly higher than those required for production of aluminum alloys and aluminum alloy castings. The first year (Phase I) of this effort will develop the cast Al MMC alloy. The year-two (Phase II) effort involves production-scale (500 pound melts) development of clean melting and casting practices for the developed MMC alloy system and a full evaluation of the alloy's static and dynamic mechanical properties.
- 2. Background:** The aluminum alloys demonstrating high strength at elevated temperature are primarily alloyed with copper and other additions to form intermetallic precipitates that increase alloy strength and hardness. The major strengthening phases of these alloys are η' (Al₂Cu) and S' (Al₂CuMg). Above a metal temperature of about 230°C these strengthening phases precipitates rapidly coarsen or dissolve, and transform into the more stable η (Al₂Cu) and S (Al₂CuMg) phases. These transformations reduce coherency with the matrix resulting in a dramatic reduction of mechanical properties, most specifically ultimate tensile strength and high cycle fatigue strengths.

The challenge is to develop an aluminum alloy system containing thermally stable particles that increase tensile and fatigue strength at elevated temperatures (250°C to 350°C). These strengthening phases must have long term -- greater than 1000 hours -- stability at temperature. Our selected approach is the addition of small, thermally stable ceramic particulates to an Al-Cu-Mg-X matrix alloy. The challenges for this approach include:

- Selection of a ceramic or intermetallic reinforcement that is chemically stable at elevated temperature in an aluminum matrix that does not contain silicon.
- Devising a low-cost, liquid-metal mixing technology that can homogeneously incorporate fine (5 to 8 micron diameter) particulates into an aluminum alloy itself having good elevated temperature mechanical properties, and
- Assuring that the resultant alloy system may be cast into high quality components using cost effective production methods.

Phase I of the project is designed to develop alloy chemistries that provide the desired elevated temperature mechanical properties and evaluate the castability of the resultant alloy(s). The alloy system developed must have both the desired properties and the ability to be cast into near-net or net shape components.

WBS 5.11 Aging of Graphitic Cast Irons and Machinability

Recipient Organization: University of Missouri - Rolla
Industrial Society Affiliation: American Foundry Society (AFS)
Technical Contact: Von L. Richards, (573) 341-4730, vonlr@umr.edu
Cost Share Partners: Rochester Metal Products, Kohler Company, Metals Technology Inc., Federal Mogul, St. Louis, St. Louis Precision Casting, Wayne Nicola (Consultant to UMR), Dalton Foundries, Asama Coldwater, Thyssen-Krupp Waupaca, Wells Durabar, Jencast

- 1. Project Objectives:** The objective of this subtask is to determine whether ductile iron and compacted graphite iron exhibit age strengthening to a statistically significant extent. Further, this effort will identify the mechanism by which gray iron age strengthens and will also identify the mechanism by which age-strengthening improves the machinability of gray cast iron. The results will enable the team to determine whether age strengthening improves the machinability of ductile iron and compacted graphite iron alloys in order to develop a predictive model of alloy factor effects on age strengthening.
- 2. Background:** In strength limited applications of gray, ductile and CG iron, the results of this work will lead to reduced section sizes, and corresponding weight savings. Improved machinability will enhance casting marketability. This research will also lead to yield improvements by allowing the adjustment of casting compositions to more easily processable compositions and will allow reduced scrap production due to shrink and machinability rejects.

The alloys to be studied include gray iron, ductile iron and compacted graphite iron. These alloys are used in automotive, mass transit, heavy transportation (truck, railroad), municipal, energy production (wind, steam) and process plant equipment. Workforce Development will be addressed by having students work in manufacturing facilities to acquire data on casting, production cast materials samples, and acquire data on machinability according to production criteria. This will give the students (both undergraduate and graduate) a firsthand opportunity to look at the technical issues in metals casting and to work alongside technical/professionals in the industry.

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Nicola and Richards (1999) have demonstrated that age strengthening occurs in gray cast iron. Edington, Nicola and Richards (2002) have shown that the machinability of cast iron improves with age strengthening, and have shown evidence of a 0.2-0.4 nm precipitate formation by neutron scattering. The influence of nitrogen (Richards, Van Aken and Nicola, 2003) also suggests a nitrogen-containing precipitate. Considering the body of work in gray iron, it is worthwhile to study the extension of this process to the family of cast irons. Ductile iron and compacted graphite iron are particularly important product areas, since both offer the possibility of significant market growth and enhancement of energy savings from the application of the aging behavior to processes and design.