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**A NATIONAL ASSISTANCE EXTENSION PROGRAM
FOR METAL CASTING: A FOUNDATION INDUSTRY**

Final Report for the Period February 16, 1994 through May 15, 1997

September 1997

Work Performed Under Contract No. FC07-94ID13279

**For
U.S. Department of Energy
Assistant Secretary for
Energy Efficiency and Renewable Energy
Washington, DC**

**By
University of Northern Iowa
Department of Industrial Technology**

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INTRODUCTION

This report describes the activities of the University of Northern Iowa's (UNI) Metal Casting Center (MCC) pursuant to Cooperative Agreement # DE-FC07-94ID13279 (hereinafter referred to as "award") issued by the U.S Department of Energy (DOE). The award follows the 1993 Technology Reinvestment Project (TRP) competition solicited by the Advanced research Projects Agency (ARPA).

The contents of this report include:

An *executive summary* which explains the general intent of the four task items which serve as the foundation of the award. A brief summary of significant events which occurred during the course of the project and affected the award from a programmatic standpoint is also included.

A *task review* which summarily correlates the activities conducted by the MCC to the four task items and supporting subtasks defined in the award document.

A description of the *infrastructure* which was established (in part) as a result of the project and is among the most fundamentally significant results of the award.

A review of *services rendered* to industry outlines and provides summary discussion of activities which were conducted on behalf of the metal casting industry pursuant to the project award.

An explanation of a *solidification modeling consortium* which was started during the award period and will continue on self-sustainable funding generated from industry participants.

A *conclusion* which outlines the MCC's position relative to significant factors affecting the industry, and how the MCC plans to fit in its development.

An *appendix* of published articles, white papers, project reports, case studies, and general publicity which was generated relative to the project award.

EXECUTIVE SUMMARY

The TRP award was proposed as an umbrella project to build infrastructure and extract lessons about providing extension enabling services to the metal casting industry through the national network of Manufacturing Technology Center's (MTC's). It targeted four discrete task areas required for the MCC to service the contemplated needs of industry, and in which the MCC had secured substantial involvement of partner organizations. Task areas identified included Counter-Gravitational Casting, Synchronous Manufacturing, Technology Deployment, and Facility and Laboratory Improvements. Each of the task areas includes specific subtasks which are described in a following section.

The first area, *Counter Gravitational Casting*, was identified as an excellent method for producing thin-walled, clean metal castings which would demonstrate potential for reduced component weight and penetration into new markets. Integral to the project was for the MCC to establish demonstration capability relative to this technology, and to emerge with the capability to provide general deployment activities to the industry. General Motors Corporation owned proprietary rights to the technology, and was the primary cost share sponsor of this task area by waiving usage fees, and providing license to use the technology free of charge. By integrating with the TRP award, the MCC was able to purchase necessary equipment, hire a project manager, develop expertise and process parameters relative to the technology, and begin providing research and deployment services to industry.

The second area, *Synchronous Manufacturing*, targeted the consolidation of several broad-based techniques for improving the process efficiency of small and medium sized metal casters. Such a program would include as its base, the results of a parallel (cost share) project sponsored by the Iowa Energy Center, in which a Process Management System was developed on site at an operating foundry.

Development of the system resulted in a detailed set of procedures (compliant with ISO 9001) for Melting, Molding, Core Making, and Finishing functions. It includes a comprehensive array of daily operating procedures for issues such as equipment maintenance, document control, inspection, corrective action, training, management control, (etc.). Topical issues and project results are summarized in a report ("Turning the Corner at Crane" included in the Appendix of this report), and established in detail in several volumes of material (too extensive to include herein) which can be accessed by contacting the MCC.

Development of the System effectively saved the host foundry, and provides an operating standard which can be adapted by other foundries interested in integrating emerging technologies such as solidification modelling, rapid prototyping, and alternative tooling. As a next step, the MCC is presently establishing an (industry sponsored) solidification modelling consortium that will be carried forward after termination of this award. The installation of a 20-station Sun UNIX training system (provided under this task) furnishes the facility infrastructure necessary for such deployment.

The third task area, *Technology Deployment*, integrated several broadly defined subtasks relative to establishing a deployment network throughout the nation. It is the only task that was carried forward from the first year, through the 39 month award period. At the time of proposal, the (then) seven regional NIST (National Institute of Standards and Technology) Manufacturing Technology Centers (MTC)s were targeted to serve as outreach liaisons to industry. The model proposed would parallel the model used in Iowa, in which foundry consortiums were established in sixteen community college districts located throughout the state. Funding for the in-state program would be provided by annual project agreements with the Wallace Technology Transfer Foundation (WTTF) which was integrated as cost share to supplement the (nationally focused) TRP award. During the time of the agreement, however, the MTC constituency expanded from seven to forty-one, affecting the task definition included in the award language. MCC efforts were adapted accordingly.

The fourth task area, *Equipment/Laboratory* (improvements) called for the installation of several technologies requisite to the TRP award. Although some installations lagged into the second project period, all were completed as planned, and have provided the anticipated improvements. Discussion of current capabilities including those resulting from the TRP award are included in a following section.

After the terms of the award were defined, and the project period was activated, a TRP "Kick-Off" meeting was held on May 17, 1994 at the MCC and attended by both DOE and U.S. Department of Defense (DOD) officials. Project plans were presented by MCC staff, and positive response was indicated by all. A second on-site progress review was conducted on July 18, 1995, and was attended by representatives from DOE, and the Picatinny Arsenal. The meeting included laboratory demonstrations, task reports, and a review of upcoming activities.

The second meeting prompted an award revision which increased interaction with the U.S. Army Ductile Iron Program, added a scope of work addendum, and extended the activity period to May 15, 1997. The addendum was approved by DOE, and fully executed on October 2, 1995. By that time, Tasks 1, 2, and 4 of the original award were either completed or integrated into the Task 3 Statement of Objectives, along with additional task items relative to the work addendum.

On July 31, 1996, the Founding Director of the Metal Casting Center, and the original Principle Investigator of the TRP award, retired. With DOE approval, Mr. Daniel B. Quick was succeeded by Mr. Douglas H. Miller, who assumed his responsibilities on October 21, 1996. In addition to serving on the MCC Board of Advisors, and maintaining an active involvement in the development of the MCC since its inception, Mr. Miller brought with him over 30 years of managerial and foundry related experience from the John Deere Foundry in Waterloo.

TASK REVIEW

This section of the report will correlate significant activities of the MCC to the defined task and subtask issues of the award agreement. Technical discussions and outcomes resulting from services provided by the MCC to industry are included in a following (Services Rendered) section of this report, and/or supported with data, publications, white papers, project reports, and case studies included in the appendix of this report.

The Statement of Objectives, copied from the TRP Project Agreement, is repeated as follows:

During the first budget period (*February 16, 1994 through February 15, 1995*), new applications of synchronous manufacturing techniques to reduce lead times for product design to the marketing of value added product will be applied. These manufacturing techniques will include but not necessarily be limited to the following: counter-gravitational pouring, rapid prototyping of tooling, clean metals technologies, applications of artificial intelligence to metal casting operations, and energy management techniques to improve manufacturing efficiencies. During this phase, the Metal Casting Center will establish relationships with the existing Manufacturing Technology Centers, improve existing facilities, and conduct activities to extract lessons about direct deployment services and direct technology consulting to medium and small sized firms through the Manufacturing Technology Centers.

During the second budget period (*February 16, 1995 extended through May 15, 1997*) the Metal Casting Center will begin to provide extension enabling services to metal casters through the deployment of extension activities in conjunction with its Manufacturing Technology Center partners, industrial partners, and professional society partners. Activities will center around the packaged solutions developed in the first budget period. Activities will follow the conceptual NIST model for a Manufacturing Outreach Center.

TASK 1: COUNTER-GRAVITATIONAL POURING

Subtask 1.1: Install equipment for the demonstration of Counter-Gravitational Pouring Process.

MCC staff conferred with the Hitchiner Corporation of Milford, New Hampshire, (developers of the technology) to determine system requirements, engineering modifications, and related issues regarding the installation of the counter-gravitational casting process at UNI. Engineering to adapt a system to suit the needs of the TRP were initiated, and a purchase order was issued to CSI Industrial Systems Corporation of Grayling, Michigan for the manufacture and delivery of a cell designed specifically for MCC initiatives.

In February of 1995, CSI delivered the unit to the Metal Casting Center and it was installed and operational by the 14th of the same month. The cell is set up to rotate to both a ferrous induction box furnace and a gas fired aluminum and light non-ferrous melt unit. It is capable of 30" Hg of lift, and can be used for both LSVAC and CLA processes. It can also set and record machine and vacuum data.

Subtask 1.2: Develop specialized expertise and implement a program ("packaged solution") for deployment of technology applications of Counter-Gravitational Pouring Process.

An additional staff position with a focus on the Counter-Gravitational Casting Process was created and filled according to UNI hiring procedures.

Conclusive experiments using the LSVAC have successfully generated process variable data relative to casting steel from DSPC (Direct Shell Production Casting) molds, and casting with prototype ceramic molds with insitu cores (in partnership with Ashland Chemical).

Research conducted using the LSVAC includes the examination of fill rates and verification of parameters for solidification modelling configurations, the castability of a thin wall ductile iron sections and a variety of other ferrous and non-ferrous alloys (at 1, 2, 3, and 4 millimeter thicknesses), and ongoing ductile iron magnesium fade testing to determine the influence of post-inoculants. Preliminary investigation of the castability of titanium/magnesium metal matrix composites using LSVAC, testing the permeability of foam coatings, and semi-solid casting has been initiated but not completed. Technical discussion of the results of the aforementioned is included throughout several reports and white papers included in the appendix.

Subtask 1.3: Deploy the Counter-Gravitational Pouring Process through the Manufacturing Technology Centers using interactive media communication (Task 3).

Capabilities and/or research findings relative to the Counter-Gravitational Casting Process has been demonstrated repeatedly during training sessions throughout the course of the project.

TASK 2: SYNCHRONOUS MANUFACTURING

Subtask 2.1: Systematize a Synchronous Manufacturing program for small to medium foundries.

The MCC implemented a project (sponsored in part by the Iowa Energy Center) in which a process management system was developed on-site at Crane Valves in Washington, Iowa. Management procedures defined by the system are designed to help small and medium sized foundries achieve processing benchmarks requisite to modernization. (Before such foundries consider the investments necessary to adopt solidification modelling, rapid prototyping, and alternative (convertible) tooling, they should first ensure balanced, consistent, and controlled material processing within their respective organizations.)

Floor activities for the eighteen month ("proof-of-concept") project were completed on December 31, 1994. The participating foundry, which was previously slated for closure, has subsequently experienced a 67% reduction in scrap, 17% reduction in productive energy consumption, 43% improvement in yield, a shift toward higher quality contract work, and the addition of a second operating shift.

After the results of the initial, on-site work was realized, the Iowa Energy Center (IEC) extended the official completion of the project to December 31, 1995. The extension allowed the MCC to document procedures, and package, duplicate, and distribute a case study of the project to several hundred metal casting operations located throughout the country. Topical issues and project results are summarized in a final report (included as an Appendix to this report), and established in detail in several volumes of material (to extensive to include herein) which can be accessed by contacting the MCC.

Development of the Process Management System was integral (cost share) to this Agreement, and resulted from a synergistic partnership which integrated the resources of DOE, a Public Utility, the Iowa Energy Center, a Community College, an Iowa Extension Office, and the MCC.

Additional "packaged solutions" relative to synchronous manufacturing, which have been studied (and are currently elective) for deployment by the MCC, include "Investment in Excellence for the 90s" offered by Pacific Institute, Shainin Statistical Engineering concepts, various solidification modelling packages, and rapid prototyping techniques available through Sandia National Laboratories and various private organizations. In addition, a design of experiments workshop entitled "Statistical Tools and Technical Strategies" was developed by two consultants hired under UNI contract. Implementation of the (2-day) workshop as well as other "packaged solutions" are discussed in further detail in later sections of this report.

Subtask 2.2: Develop a specialized expertise, and implement a program ("packaged solution") for deployment of technology applications of a Synchronous Engineering program.

An additional MCC staff position with a focus on Synchronous Manufacturing in a Metal Casting environment was created and filled according to UNI hiring procedures.

A computer training facility was constructed within the UNI Industrial Technology Center, and supports a 20-station Sun UNIX-based computer platform which was installed as an integral component of this

project. A computer professional was retained under a professional services agreement to select and interface the expanded computer capabilities (hardware and software) required for ongoing training and deployment initiatives. The UNIX platform supports the MCC Homepage, and modem access to various applications which are being continuously modified.

At the time of this report, a (completely industry sponsored) solidification modelling consortium has been targeted, and contractual arrangements are being established which will open (modem) access to ProEngineer and Flow3D for a group of small and medium foundries for a limited period of time. The success of this initial consortium will serve as a model for future similar efforts targeting other technologies and/or groups of foundries. The MCC will guide the group through several demonstration exercises using each foundries own (product) configurations, and will allow them to establish a learning curve prior to licensing the technology directly.

Subtask 2.3: Develop deployment strategies/methodologies of a Synchronous Engineering program with the Manufacturing Technology Centers.

A self-funded Solidification Modeling Consortium of 17 foundries has been assembled to investigate the parameters of the technology using a centralized platform. Members will be on their own after two years. A subsequent Rapid Prototyping Consortium will be organized next, followed by a Alternative Tooling Consortium. The intent is to initiate an industry move toward digital transfer of tooling configurations.

Subtask 2.4: Deploy the Synchronous Engineering program through the Manufacturing Technology Centers using interactive media communications (Task 3).

TASK 3: TECHNOLOGY DEPLOYMENT

Subtask 3.1: Establish relationships with the seven existing Manufacturing Technology Centers. Their location and the area served by each center are indicated below:

<i>Northeast Center</i>	<i>Troy, NY</i>
<i>Great Lakes Center</i>	<i>Cleveland, OH</i>
<i>Southeast Center</i>	<i>Columbia, SC</i>
<i>Mid-America Center</i>	<i>Lenexa, KS</i>
<i>Midwest Center</i>	<i>Ann Arbor, MI</i>
<i>Upper Midwest Center</i>	<i>Minneapolis, MN</i>
<i>California Center</i>	<i>Hawthorne, CA</i>

Since the original TRP Agreement was executed, several events have transpired which affect the original concept. First, the seven regional MTC's eventually evolved to include 41 located throughout the country. Second, by DOE approved revision, this task was expanded to include several additional subtasks relating to increased interaction with the U.S. Army Ductile Iron Program. Third, the Iowa Manufacturing Technology Center (IMTC) emerged and provided a centralization for the community college based foundry consortiums. Although this was not significant from an operating standpoint, it

did eventually affect the way in which state funding was allocated for this purpose. Fourth, as of July, 1996, the WTTF funding was re-routed as a legislated appropriation to the MCC, through the state Board of Regents.

The MCC is a member of the Modernization Forum based in Dearborn, MI, and MCC staff regularly attend open meetings as they are offered. Routine contact with the following organizations is conducted regarding various issues as they arise: California Manufacturing Technology Center, Casting Development Center, Edison (Ohio) Manufacturing Technology Center, Great Lakes Manufacturing Technology Center, Iowa Manufacturing Technology Center, Massachusetts Manufacturing Partnership, Michigan Manufacturing Technology Center, Mid-America Manufacturing Technology Center, Minnesota (Upper Midwest) Manufacturing Technology Center, New Hampshire Manufacturing Technology Center, New York Manufacturing Extension Partnership, Southeast Manufacturing Technology Center, and the Washington Manufacturing Technology Center.

Similar linkages have been established with the American Metal Casting Consortium, the American Foundrymen's Society, Ames Laboratory, the Cast Metals Coalition, Concurrent Technologies Corporation, Idaho National Engineering Laboratories, Iowa Illinois Nebraska Foundry Management Group, Non-Ferrous Founders' Society, North American Die Casting Association, Rock Island Arsenal, Sandia National Laboratories, Steel Founders' Society of America.

Pursuant to an affiliated (cost share) project sponsored by the Wallace Technology Transfer Foundation of Iowa (WTTF), the MCC has further developed the Iowa Community College (ICC) network of foundry consortiums for pilot level deployment activities pursuant to the TRP. ICC related efforts include preliminary interactive video presentations using the Iowa Communications Network (ICN) and development of an electronic metal casting information bulletin board.

The MCC continues to have daily contact with the operating metal casting industry, primarily in Iowa, through plant visitations, technical society meetings, management group meetings, advisory group meetings, and telephone consultations.

Subtask 3.2: Develop/plan deployment methodologies of the "packaged solutions" with the seven regional Manufacturing Technology Centers.

The MCC regularly uses the Iowa (fiber-optic) Communications Network (ICN), to conduct interactive training programs, primarily through the (Iowa) Community College based Foundry Consortiums. Because it is (primarily) supported by state funding, the ICN is an extremely cost-effective means of reaching out to the small and medium sized foundries *located in the state of Iowa*. As the national communications infrastructure becomes more developed, interacting with MTCs outside of the ICN service region will also become more cost-effective.

An investigation of *currently available* methods (fiber optic, satellite, ISDN, Internet) of providing interaction outside of the ICN service region was conducted in conjunction with Southeast Minnesota Community College, Edison Materials Technology Center, Great Lakes Manufacturing Technology Center, Iowa Manufacturing Technology Center, and the Massachusetts Manufacturing Technology Center.

Subtask 3.3: Develop specialized deployment expertise, and develop "packaged solutions" (for deployment) of current and developing technologies (including Counter-Gravitational Pouring, Synchronous Engineering, sand reclamation, etc.)

An additional MCC staff position with a focus on Technology Deployment to small and medium sized metal casting operations has been created and filled according to UNI hiring procedures. An established position with a focus on Technology Deployment to Iowa Metal Casting operations has remained active through funding provided by WTTF and the State of Iowa.

The TRP award advanced development of the MCC staff and facility infrastructure to maturity. Staff presently consists of a Center Director, Grant Administrator, Secretary, two part time Faculty, four full-time Project Managers (fluent in inter-disciplinary laboratory applications), a Laboratory Assistant, and a varying number of consultants, Graduate Assistants, and Undergraduate Students.

Facilities installed or enhanced during the course of the award include a 20 station UNIX based Sun computing and training facility which includes modem access and Pro-Engineer and Flow 3-D software), and a well equipped foundry laboratory which includes urethane and conventional tooling capabilities, a broad range of molding processes (including isocure cold box), the LSVAC counter-gravitational casting process, and a comprehensive sand testing facility. A more detailed list of MCC facilities is included as a later section of this report.

The MCC has also improved its interactions with other university resources, such as the Iowa Communications Network (ICN), Market Development Program, and Small Business Development Center. The MCC is in a unique position from which to continue to serve as a focal point for the development of targeted (metal casting) industry improvement initiatives.

Throughout the project period, the MCC has maintained direct, daily contact with the operating metal casting industry through short-term consultations, plant visitations, technical society meetings, management group meetings, advisory group meetings, and telephone consultations. Such interaction is requisite to monitoring and maintaining a specialized, grass-roots awareness of true industry needs and issues. Above all else, *this grass roots awareness is considered by the MCC to be the most crucial expertise required for effective technology deployment.*

Subtask 3.4: Train representatives of the seven regional Manufacturing Technology Centers in the technical aspects of packaged solutions and expose them to the Metal Casting Center facilities and capabilities.

A presentation of MCC technical aspects and capabilities was conducted at the Modernization Forum's National Conference in St. Louis Missouri on April 12, 1996. The presentation, entitled "Leveraging National Industry Sector and Service Specific Resources," illustrated the MCC's offerings and what it can do to assist manufacturers in any area that produces or consumes metal castings. A booth was also available to provide personal discussion with MTC field agents about MCC capabilities and resources. The booth generated 15 inquiries regarding specific applications within MTC service areas. Representation of all 42 of the national MTC's was available at the conference. The MCC regularly disseminates information regarding its capabilities and operating position at similar national conventions and meetings.

Subtask 3.5: Implement a sustainable program for technology development of current and developing technologies (including but not limited to Counter-Gravitational Pouring, Synchronous Engineering, and sand reclamation) through the Manufacturing Technology Centers using interactive media.

The MCC has conducted several small scale, fixed fee research projects regarding various issues at the direction of both industry and various other entities (case studies are included in a following section). At the time of this report, a (completely) industry sponsored solidification modelling consortium is being established, which will guide the adoption of the technology by approximately 20 members. In addition, the MCC conducts fee generating training events approximately twice a month on average.

A staff member has developed an overall vision and plan for a comprehensive (fee generating) foundry training program and an organizational scheme which includes over 625 topical areas. Tentative industry testing of the concept has been conducted, and necessary revisions have been implemented. Twenty-five pilot instructional modules on various topics have been completed, and possible areas in which specific courses were needed have been identified. A tentative curriculum of course offerings has been developed and eight complete courses (from the program menu) have been offered to the metal casting industry. Course offerings include aluminum casting design, introduction to ductile iron casting, geometric dimensioning and tolerancing, basic statistics and quality control, aluminum casting technology and iron casting technology.

Subtask 3.6: Conduct (15) eight hour workshops which deploy current and developing technologies through the seven regional Manufacturing Technology Centers using interactive telecommunications systems.

The MCC has conducted numerous technology deployment presentations both on-site as well as interactively using the ICN. The first, pilot-level interactive demonstration was successfully broadcast on the ICN (in conjunction with 2 metal casting technical societies) on May 27, 1994. The initial demonstration was communicated to 53 participants at 14 separate sites (including a high school) located throughout the Iowa Community College Districts.

TASK 4: EQUIPMENT/LABORATORY

Subtask 4.1: Build capacity within the Metal Casting Center facilities by installing equipment/processes required for demonstration of the packaged solutions. Demonstration equipment/processes include but are not limited to: Counter-Gravitational Pouring Process, computer equipment, molding equipment, core room equipment, and sand handling equipment.

In addition to the Counter-Gravitational Casting system and the Sun Computer research and training facility, the MCC has also added cold box molding and coremaking capacity, match-plate molding capacity, requisite office space, and associated renovations.

AWARD ADDENDUM

The following Subtasks were added to the original agreement by addendum executed on October 2, 1995.

Subtask 3.7: To the best of its ability and within the funding provided by Rock Island Arsenal, the contractor shall perform basic services and awarded optional tasks regarding ductile iron and austempered ductile iron for a period up to 12 months from the award date. The Government's intent is to encourage the contractor to adopt practices enabling performance of these services on a self-sustaining basis without further funding from the U.S. Army Ductile Iron program. These practices may include the contractor generating revenue and limiting the services it provides at no charge to the recipient. In any case the contractor's practices shall be consistent with the cooperative agreement.

Studies conducted specifically with the Rock Island Arsenal include a series of single-blow toughness and abrasion tests of ductile iron alloyed with molybdenum and nickel, austempered and normalized to obtain mechanical properties of Grade 1, 2, 3, and 4 Austempered Ductile Iron (ADI). A study of cryogenic treatments of austempered ductile iron to determine the effects on mechanical properties, and a study of the machinability of ADI using laser cutting technology have also been conducted. Results of these studies are included in the appendix to this report. Several other activities associating ductile and austempered ductile irons also are discussed in the appendix.

Subtask 3.8: The basic services shall be for technology transfer and assistance and extension service on a regional and national basis. The contractor shall make arrangements to enable technology transfer and assistance through the NIST/ARPA Manufacturing Technology Centers (MTCs) and Manufacturing Outreach Centers (MOCs) as well as other means. The ductile iron technology to be transferred includes publicly available information, that developed by the contractor, that developed by or for the ductile iron projects or programs of any U.S. Government department or agency, and that obtained from any other means, like from Russian and Soviet sources. Nevertheless, the contractor shall honor intellectual property rights of the owner and shall only release information clearly marked proprietary with approval of the owner. The U.S. government departments shall include the U.S. Army and its Ductile Iron Program contractors. The technology transfer assistance and extension services shall include the actions in subtasks 3.8.1 - 3.8.7 as the need arises.

Subtask 3.8.1: The contractor shall use its technology deployment methods and handle and answer inquiries from domestic ductile iron users or suppliers or referrals from the U.S. Army.

Subtask 3.8.2: The contractor shall coordinate its technology transfer and assistance and extension services with other ductile iron technology sources and service providers.

Subtask 3.8.3: The contractor shall prepare the materials, including papers for presentations, company specific assessments, processing procedures, summaries, announcements, and service providers.

Subtask 3.8.4: Coordinating with Rock Island Arsenal, the contractor shall organize and put on demonstrations at their facility, or other Government or third party facilities. The contractor shall provide within 30 days of the demonstration a short report summarizing the demonstration, listing the attendees and their affiliation and stating any conclusions.

Subtask 3.8.5: The contractor shall consult for business and Government activities including Rock Island Arsenal, industry associations, and other entities, and perform company specific assessments.

Subtask 3.8.6: The contractor shall make presentations and publish papers at conferences.

Subtask 3.8.7: The contractor shall participate in the development of plans for the Army Ductile Iron program, and, upon request, for industry associations and other Government programs.

Subtask 3.8.8: The contractor shall provide written quarterly progress reports summarizing the financial status and categorizing and counting the number of instances of providing technical transfer and assistance. The contractor shall also provide a written final report summarizing the financial status, categorizing and reporting the number of instances of providing technical support, evaluating the effectiveness of the work, and making recommendations from lessons learned.

A presentation of the Effects of Cryogenic Treatment on Austempered Ductile Iron was held publicly on May 2, 1996 in which (40) academic and industry representatives attended. A copy of the report is included in Appendix, Section C.

The MCC has forwarded to the Rock Island Arsenal, copies of the technical progress reports developed pursuant to this award during the period of participation. Copies are included in Appendix, Section C.

Subtask 3.9: By agreement between the contractor and the Government, the contractor shall include other tasks under the basic services which might include the following:

Subtask 3.9.1: The contractor performing experiments or research for the U.S. Army Ductile Iron Program. The contractor shall provide written final reports including financial and technical summaries and containing all the experimental test data and measurements.

Subtask 3.9.2: The contractor preparing materials for a course on ductile iron and/or presenting the course.

Subtask 3.9.3: The contractor preparing a chapter on ductile iron for a book which will be published or preparing manuals.

Subtask 3.9.4: The contractor preparing a computer data base, expert system, and/or neural net program and making it and its user's guide available or accessible to the public.

Subtask 3.9.5: The contractor designing or assisting in the design of ductile iron components.

Subtask 3.9.6: Any other task not explicitly listed with the basic services, but within the scope of either being a technology source for ductile iron or transferring technology for ductile iron.

Description of the activities conducted pursuant to this task are discussed among several published articles, white papers, and project reports included in the Appendix.

INFRASTRUCTURE

THE METAL CASTING CENTER *

Since its official opening in April of 1991, the Metal Casting Center (MCC) has closely followed its mission to improve the productivity and competitiveness of the operating metal casting industry through applied research, technology deployment, training, and direct assistance.

The targeted niche served is the operating metal casting industry. The scope of involvement varies from proactive (large-scale) applied research, to reactive (small-scale) assistance to individual businesses. In short, the MCC concept is to convert theory to practice with a focus on the demand side of the research cycle. In order to provide practical solutions, the MCC maintains strong contacts with (and solicits the concerns of) operating metal casters.

Initial operational funding for the MCC came from the state of Iowa in the form of a three year grant (July, 1989 through June, 1992) of \$463,000 to provide seed capital for start-up of the center. The MCC has since leveraged that funding through a series of cost shared project initiatives, to establish national recognition as a centralized intermediary in the deployment of emerging metal casting technologies.

The TRP award advanced development of the MCC staff and facility infrastructure to maturity. Staff presently consists of a Center Director, Grant Administrator, Secretary, two part time Faculty, four full-time Project Managers, a Laboratory Assistant, and a varying number of consultants, Graduate Assistants, and Undergraduate Students.

LABORATORY **

In support of its mission, the MCC employs a dedicated 5,500 square foot annex to the Industrial Technology Center of the University of Northern Iowa campus. The MCC research and deployment facility includes all equipment, environmental and safety controls (the MCC has established a position of national prominence in this field) needed to perform a wide range of processes and related production techniques commonly utilized in the metal casting industry.

Facilities include a 20 station UNIX based Sun computing and training facility. A well equipped foundry laboratory which includes the LSVAC counter-gravitational casting process, advanced solidification modelling software, comprehensive molding processes, and both urethane and conventional tooling capabilities. Under the same roof, the Department of Industrial Technology (ITD) houses a complete materials processing laboratory, including machining, welding, woodforming, and laser equipment. The MCC also incorporates access to other university resources, such as the Iowa Communications Network (ICN), Market Development Program, and Small Business Development Center in pursuit of its mission. The MCC is in a unique position from which to continue to serve as a focal point for the development of targeted (metal casting) industry improvement initiatives.

Molding processes in which the MCC has staff, equipment, and expertise to work directly with industry include Green Sand (high pressure, match plate, squeezer, hand rammed), No-Bake, Air-Set, Shell, EPC, Investment Casting, Permanent/Semi-Permanent Molding, and Die Casting. Core making processes include cold and hot box core blowing technologies. Melting capacity includes capability for 300 lbs. of ferrous or copper alloys, and 100 lbs. of aluminum or light weight non-ferrous alloys. Specialized technologies include the LSVAC Counter-Gravitational Casting Process and a Hapco Urethane Tooling Cell.

A broad range of standard laboratory instrumentation for mechanical and physical testing, as well as precise chemistry characterization and microstructure evaluation is also available. Instrumentation includes a mass spectrometer, thermal analysis equipment, non-destructive ultrasonic testing equipment, electron microscopy, and a complete sand testing laboratory.

Computing capabilities include a 20 Station Unix-based training facility, supported with a SPARC server 1000E which can be used for direct industry (modem) interactions, as well as on-site deployment and training initiatives for the metal casting industry. To support real-time video telecommunication of training initiatives, the MCC has access to the Iowa Communications network as well as access to affiliated organizations within the university which support digital imaging and educational technologies.

The MCC is in the process of setting up and calibrating an optical emission spectrometer which will provide the capability to analyze gray and ductile iron chemistries. Further work will enable the analysis of copper based, aluminum, and plain and alloyed steels. Such capability is essential for process evaluation/needs assessment, and will also be offered as a discrete service to be provided for a fee by the MCC.

STAFF **

The following summarizes the backgrounds, career strengths, and primary focus of the staff of the MCC during the award period.

Mr. Douglas H. Miller, Center Director (Beginning October 21, 1996), has a B.A. in Accounting and an M.A. in Industrial Technology, both from UNI. He also has over 30 years of experience in Manufacturing, 15 of which were in the metal casting industry. Mr. Miller has demonstrated extensive leadership, primarily in foundry production. He also has also held managerial positions in machining and assembly, at various plants, and has managed purchasing, materials, and sales departments for John Deere Foundry in Waterloo, Iowa.

Mr. Daniel B. Quick, Center Director (Retired July 31, 1996), is an industrial engineer with a B.S. in Industrial Management from Western Michigan University and over 30 years of experience in the automotive sector of the metal casting industry. Mr. Quick has extensive managerial experience and demonstrated leadership in production and experimental tooling development, primarily in advanced engine designs. Mr. Quick's tooling career at Tonawanda, New York, included work as a master mechanic with tool design, procurement, maintenance, process engineering, and prototype experimental casting development responsibilities. The last ten years of Mr. Quick's industrial pursuits were spent in the quality functions of the casting business, included responsibilities for in-plant and customer quality, quality education/training, and quality planning and budgeting at a General Motors foundry affecting 3,000 employees.

Mr. Randal J. Boeckstedt holds a B.T. in Manufacturing Technology and an M.B.A., both from the University of Northern Iowa. He has served as a Business Manager of the MCC since its opening, and has been primarily responsible for defining and communicating business strategies, managing fiscal issues, and reporting technical progress. He was active in defining the mission and operating position of the MCC, and has developed umbrella cost proposals for a \$2.1 million Department of Energy Project, and \$4.0 million Technology Reinvestment Project.

Dr. David D. Bradney, CSIT, CMfgE, has over 35 years of experience in supervisory and managerial assignments, higher education, and computer services. Dr. Bradney holds undergraduate degrees in natural sciences, mathematics and business administration, and Masters and Doctoral degrees in technology. He is permanently licensed in Iowa to teach at the postsecondary level in 12 technical and business areas. He is certified in Manufacturing Technology, Industrial Technology, and Manufacturing Engineering, and is a member of the American Society of Mechanical Engineers, American Foundrymen's Society, Society of Manufacturing Engineers, American Society for Quality Control, ASM International, and others. Dr. Bradney has authored a technical manual entitled Guide to Aluminum Casting Design: Sand and Permanent Mold.

Dr. Scott R. Giese is a Metallurgical Engineer specializing in solidification processing. Dr. Giese has a practical technical degree from Erie Community College and B.S., M.S., and Ph.D. degrees in Metallurgical Engineering from the University of Alabama in Tuscaloosa. His technical concentrations focus on casting processes, solidification science, and process modelling analysis. Dr. Giese has gained practical experience at Hitchcock Industries, a producer of high quality, premium aluminum aircraft structural castings during his academic career.

Dr. Yury S. Lerner is a Professor of Industrial Technology at UNI, and a Faculty Advisor to the MCC. He has more than 30 years of practical experience in the areas of Foundry metallurgy and Metal Casting Processes, and holds B.S. and M.S. degrees in Metallurgical Engineering from the State Polytechnic University of Odessa, Ukraine and a Ph.D. in Metal Casting Technology from the Institute of Foundry Problems of the Ukrainian Academy of Sciences. His career has emerged from Plant Metallurgist, Senior Metallurgist, and Director of Metallurgy at the Research and Development Center for New Casting Techniques and Technology in Russia. He has also held positions of Technical Director at Weatherly Casting and Machine Company, and Manager of Research and Development at Grede Foundries Company. Dr. Lerner is an author and/or co-author of more than 80 publications, and holds 43 patents in Foundry Metallurgy and Metal Casting related fields.

Mr. Jerry R. Thiel, Outreach Project Manager, has over 18 years of managerial experience in the casting of steel, iron, and non-ferrous alloys. Mr. Thiel holds an A.A.S. degree in Material Science, B.T. degree in Manufacturing Technology, and an M.A. in Technology, Manufacturing Process Development. His responsibilities with the MCC are primarily focused on providing direct assistance to foundries located throughout the midwest census region. Jerry has conducted leading research in cryogenic treatment of cast metals.

Dr. L. Fred Vondra holds a B.S. in Industrial Technology/Manufacturing Engineering, M.S. in Industrial Management, and D.I.T. in Industrial Technology. He has worked for J.I. Case Foundry in Racine, Wisconsin in a variety of engineering and supervisory capacities. Dr. Vondra has been involved with the Metal Casting Center since its opening, and has managed projects which include: Ultrasonic/Robotic Inspection of Raw Iron Castings, Mobile Sand Reclamation, Domestic Versus Foreign Pig Iron Evaluation, and the Development of a Wear Factor for the Evaluation of Alternative Tooling Materials (on-going). He has taught numerous university courses in Industrial Materials, Production/Operations Management, Foundry Molding Practices, Organizational Leadership, Metal Casting Technology, and Metallurgy. Currently, Dr. Vondra is managing projects which incorporate the Counter-Gravitational Vacuum Assisted Casting process.

UNI PROGRAMS *

The MCC works in collaboration with the following on-campus industrial outreach programs to provide inter-disciplinary, problem solving services to businesses:

The Market Development Program (MDP) helps small businesses grow by identifying marketing strategies to penetrate new markets. This is accomplished through long-term market research and technical assistance provided by full-time marketing professionals with private industry experience.

The Iowa Waste Reduction Center (IWRC) provides free, confidential on-site environmental assistance to Iowa small businesses. On-site visits are followed by reports regarding regulatory compliance and a pollution prevention plan for the facility. The IWRC is actively involved in applied research, seeking practical solutions for the small business.

The Recycling and Reuse Technology Transfer Center (RRTTC) provides support to the recycling and by-product re-utilization industry through research, education and outreach efforts. The RRTTC provides student opportunities in experiential learning through research projects designed to meet the needs of the recycling industry, thus addressing both the concerns of industry and the needs of students. Targeting of projects and referrals often occurs through close cooperation with other technical assistance programs.

The Small Business Development Center (SBDC) provides technical assistance to small businesses, linking them with resources to identify and resolve issues in marketing, accounting, finance, information management and organizational development.

The John Pappajohn Entrepreneurial Center (JPEC) is to assist entrepreneurs in launching new firms and helping them avoid the pitfalls that reduce their chances for success. The JPEC offers seed grants, primarily to new firms; provides consultative services in cooperation with the Small Business Development Center, both at UNI and its office in Waterloo; and provides a variety of educational program opportunities in partnership with several existing program units, such as the Management and Professional Development Center.

The Management and Professional Development Center (MPDC) provides both on- and off-site education and training tailored to the individual needs of public and private sector organizations. Faculty and staff members have extensive experience in industry, and MPDC programs enroll more than 1,000 each year.

The Institute for Decision Making (IDM) is UNI's economic and community development outreach resource, serving 320 communities statewide. IDM guides the citizens of Iowa as they make decisions and take organized action to improve their communities through results-oriented economic and community development initiatives.

INTERACTIONS *

With the support of the TRP award, the MCC has been able to establish contacts throughout industry as well as several governmental laboratories and academic research institutes which provides access to specialized facilities and expertise in support of MCC initiatives. The following is illustrative of the organizations which were contacted during the award period. It illustrates scope of expertise which can be accessed in support of future MCC initiatives and responsive assistance. These organizations have been involved in personal, face to face meetings with MCC staff, either at the host facility or on-site at the MCC. Several have been involved in more formalized interactions such as signed project agreements. The scope of interaction varies among organizations, and in general is too complex to describe.

The list is offered as an indication of the resource *providers* available to the MCC, and does not include the numerous small and medium foundries in which the MCC has rendered assistance.

Government Affiliated Laboratories/Agencies:

- The Alliance to Save Energy
- American Metal Casting Consortium
- Ames Laboratory
- Concurrent Technologies Corporation
- Defense Logistics Agency
- Edison Materials Technology Center
- Great Lakes Manufacturing Technology Center
- Idaho National Engineering Laboratories
- Iowa Department of Economic Development
- Iowa Energy Center
- Iowa Manufacturing Technology Center
- Miami Valley Manufacturing Extension Center
- The Michigan Manufacturing Technology Center
- Modernization Forum
- The Northeast Midwest Institute
- Rock Island Arsenal
- Sandia National Laboratory
- U.S. Department of Defense
- U.S. Department of Energy
- Upper Midwest Manufacturing Technology Center
- Wallace Technology Transfer Foundation of Iowa

Leading Businesses:

Aluminum Company of America (Alcoa)
Ashland Chemical
CSI Industrial
Caterpillar Tractor
Ford Motor Company
General Motors
Grede Foundries
Hitchiner Corporation
John Deere

Universities:

Case Western University
Iowa State University
Ohio State University
Mississippi State
University of Alabama at Tuscaloosa
University of Alabama at Birmingham
University of Iowa
University of Wisconsin, Madison
Worcester Polytechnic Institute

Technical Societies:

American Foundrymen's Society
The Australian Trade Commission
Iowa, Illinois, Nebraska Foundry Management Group
North American Die Casting Association
Non-Ferrous Founders' Society
Steel Founders Society

SERVICES RENDERED

RESEARCH *

The following summaries outline the applied research activities of the MCC during the course of this award. Where indicated, more specific reports are included in the Appendices of this report.

Casting Design for Permanent Mold

The MCC assisted Rada Manufacturing in designing an aluminum cutlery product that was adaptable with their permanent mold casting facilities. During the design process, the limiting constraint for the cutlery product was the permanent mold size and thermophysical properties of the steel mold. The expectation was to construct the permanent mold tool such that the final product could be easily removed to minimize secondary finishing operations. Computer modeling was used to initially determine casting position in the mold. Next, three gating configurations were designed and resimulated with a coupled heat transfer, fluid flow condition to obtain more realistic casting conditions. From the analysis, one design was recommended that exhibited the best fluid flow and solidification pattern. The final design was chosen based on complete filling of the casting, good solidification with minimal internal shrinkage, easy removal of the sprue for post processing, and the ability to add water cooling lines for future design changes. (No Specific Report).

Casting Design Process

The MCC worked closely with customer organizations to identify simulation expectations. After identifying customer needs, a solid model of casting files was constructed either by the MCC or the customer. The computer generated model was then verified for dimensional size and tolerances. Depending on the prescribed tasks, gating and risering of solid model files were developed using fundamental design principles and assembled to the casting. (No Specific Report).

Casting Yield Improvement

The MCC assisted Bandag with applying computer modeling techniques for an evaluation of the class 20 gray iron tire tread mold. The sponsor desired to increase wear properties and improve dimensional tolerances of their iron molds. The activity was divided into two tasks. The first to evaluate the existing gating and risering system for a small and large tire tread mold. Secondly, the solidification analysis information gathered from phase one was used to design an improved riserless gating system to increase casting yield, improve structural integrity, and maintain dimension stability of the iron tire molds. The results of the activity demonstrated an improvement in casting yield from 31 % to 67 %, along with a 50 % improvement in hardness. Dimensional stability could not be correlated to a specific value, but preliminary indication did show an improvement. (No Specific Report).

Counter-Gravity Casting of Thin Wall Aluminum 356

This study compared the capability of countergravity to produce thin wall aluminum castings and compare with traditional gravity sand molding method. The first series of experiments investigated castability of aluminum 356. The second series studied microstructure, density, thickness and surface roughness variations in conjunction with Mississippi State University. It was found that 356 countergravity castings cast at 1250 F (677C) with a filling vacuum pressure of 5" Hg have thin wall section castability that is comparable to gravity poured castings cast at 1375°F (746°C) at atmospheric pressure. Castability is better at 1350 F (732 C) with a filling vacuum pressure of 5" Hg., when compared to castings made at lower casting temperatures with similar pressure. General comparison with conventional gravity casting established trends of decreasing porosity, improved eutectic silicon particles shape factor, and improved casting yield with the countergravity samples. The ability to cast at lower temperatures and increase yield provide economic benefits with countergravity. (See Appendix C).

Countergravity Crankshaft Research

Twelve experiments were conducted relative to casting a crankshaft with lost foam technology. The patterns were obtained from the Saturn Corporation for purposes of conducting this experimentation. The countergravity process used loose sand surrounding the lost foam pattern and aluminum foil to hold the mold together. Experimentation was unsuccessful at a variety of temperatures and pressures. Further experimentation will probably incorporate a different flask design. This process change will more closely resemble the CLA process incorporated in industry for investment casting purposes. (See Appendix B).

Effects of Post Inoculant Additions on Ductile Iron Fade

This study involved the investigation of three specific, commercially available, post inoculants for ductile iron and their effect on the magnesium fading rate and chill reducing tendency in a low volume production environment. Inoculant A, a foundry grade ferrosilicon 75% alloy, was chosen as the control group. Inoculant B contained a moderate level of barium, while inoculant C contained high levels of calcium and barium. The research focused on two areas, magnesium and inoculation fading effects. Results showed that there was no substantial differences between the three inoculants. Inoculants B and C held the nodule count better during the first 15 minutes after magnesium and inoculation treatment and had positive effects in terms of their chill reducing tendency. The high barium and high calcium containing inoculant C, proved to be the most effective chill reducer by limiting carbide formation in excess of 15 minutes, while maintaining an acceptable nodularity of about 80%. Considering this study, inoculant C will likely be recommended for thin-wall ductile iron castings produced by countergravity processes. (See Appendix C).

Green Sand Burn-in/Penetration Project

A project was conducted with an industry supplier (who requested anonymity) to determine the effect of adding three different percentage amounts of 120 AFS-GFN olivine sand to a 60 AFS-GFN silica green sand. The effect studied was to ascertain if these olivine additions would reduce or prevent penetration type defects in green sand test molds. (See Appendix C).

Investigation of Engineering and Service Properties of Austempered Ductile Irons

The objective of this project was to study impact toughness and wear resistance of austempered ductile iron (ADI) as an alternative material to high alloy and white irons in impact-wear applications. It was conducted in collaboration with Rock Island Arsenal and Albany Research Center of DOE. A series of test specimens with different chemical compositions were developed and cast at the MCC, austempered at Rock Island Arsenal, and shipped to Albany Research Center for specially designed comparison tests. Conventional Charpy Impact testing at -40 C and erosion tests were to be done at UNI. Preliminary results of the abrasion and impact-abrasion study of ADI will be presented at the ASM INTERNATIONAL Conference on Materials Solutions 97 on September 14-18, 1997 in Indianapolis, Indiana. (Report Pending).

Investigation of a Mullite Granular Product as a Foundry Molding Aggregate Substitute

A three month study was undertaken by the MCC and Carbo Ceramics to evaluate the feasibility of substituting a synthetic mullite material for silica sand by the foundry industry. In the evaluation, two commonly used mold binding systems, green sand and phenolic urethane, were selected to compare molding properties between mullite and silica. The green sand results showed that the Carbo products had superior permeability properties, comparable compactability, and good green compression strength at low water content. Core property evaluation indicated lower tensile strength and hardness properties. The study determined that the Carbo products have potential in backing molding aggregate materials because of the exceptional permeability properties it possesses. Future investigation should concentrate on product compatibility with other molding materials and casting surface quality. (See Appendix C).

Mold Wash Project

In April of 1996 an industry supplier (who requested confidentiality) and the University of Northern Iowa's Metal Casting Center conducted an experiment to ascertain the capability of a new graphite mold wash containing olivine sand. This mold wash was to withstand the extreme temperatures and erosive effects of molten ASTM A514B alloy against the graphite mold. The results of this project seem to be favorable with the possibility of future experiments promising. (See Appendix C).

Tooling Material Investigations

Personnel from the MCC have been doing on-going evaluations of potential tooling materials for use as foundry corebox and pattern materials. Impact abrasion is being conducted and test samples are being subjected to molding trials in eleven foundries around the country. The rationale is to compare foundry data received from these trials to data generated in the MCC laboratory. If a correlation exists between the two tests then tooling material manufacturers may have their materials tested at the MCC with reasonable knowledge of how these materials will perform in molding and coremaking processes. (See Appendix A).

TRAINING *

The following training events were offered as part of this award:

<u>Date</u>	<u>Topic</u>	<u>Attendance</u>
05/27/94	Solidification Modeling	53
12/07/94	OSHA Compliance	45
01/07/95	Management Training	45
05/02/95	Supervisory Skills	39
05/09/95	Reducing Sand Related Defects	45
05/16/95	Safety in the Foundry	24
05/25/95	Sand Reclamation	16
07/11/95	Statistical Techniques	46
11/14/95	Using the Internet	8
11/28/95	Gating Systems	17
12/05/95	Cast Iron Metallurgy	7
12/12/95	Cost Analysis	11
02/06/96	Nonferrous Melting	24
03/13/96	Solidification Modeling	14
03/29/96	No-Bake Binders	18
04/02/96	Cleaning and Finishing	16
09/16/96	Aluminum Casting Design	12
09/26/96	Continuous Process Improvement	24
10/15/96	Cooling Curve Analysis	17
01/14/97	Solidification Modeling	38
04/02/97	Rapid Prototyping	24

PUBLICATIONS *

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removed.

Following is a list of published articles. Copies are included in the appendix:

1. Y.S. Lerner, G. R. Kingsbury, "Wear Resistance Property of ADI" (accepted for publication) "Journal of Materials and Performance," ASM International, August , 1997
2. Y. S. Lerner, A.ElSawy, M. Fahmy "Gray Iron Chemistry Optimization for Permanent Mold Molding," Proceedings of the 6-Th. International Conference on Production Engineering, Design and Control, PEDAC'97, Alexandria, Egypt, February 15-17, 1997, pp. 299-310
3. Y. S. Lerner, A.ElSawy, M. Fahmy "NDT Gray Iron Physical and Metallurgical Characteristics," Proceedings of the 6-Th. International Conference on Production Engineering, Design and Control, PEDAC'97, Alexandria, Egypt, February 15-17, 1997, pp. 311-320.
4. Y. S. Lerner, "Titanium Effect on the Structure and Properties of Gray Iron Permanent Mold Castings," AFS Transactions, 1996, Vol.104, pp. 245-255
5. Y. S. Lerner, "Ultrasonic Testing Predicts Casting Properties ", Advanced Materials & Processes, Vol.150, Number 4, November 1996, pp. 39-41.
6. Y. S. Lerner "Another Approach to Iron Casting: The Permanent Mold Process," Modern Casting, November 1996, pp. 48-51.
7. Y. S. Lerner and T.M. Westendorf, "Cooling Systems for Permanent Mold Casting", Foundry Management and Technology, August, 1996, pp. 84 -91.
8. Y.S. Lerner, "An Evaluation of Structure and Properties of Gray Iron Permanent Mold Castings Using Non-Destructive Technique," AFS Transactions, 1995, Vol.103, pp. 151-155.
9. Y. S. Lerner, "Ductile Iron Use in Machine Tool and Hydraulic Components", Foundry Management & Technology, August, 1995, pp.108-115.
10. Vondra, L.F. and Backens, D.J. (1996) Contributing Authors, "Computer Aided Design in Foundry Tooling" Pattern Makers's Manual (3rd edition in print). Des Plaines, Illinois: American Foundrymen's Society.
11. Vondra, L.F. (1996) Contributing Author, "Pattern Material Wear Studies". Pattern Maker's Manual (3rd edition in print). Des Plaines, Illinois: American Foundrymen's Society.
12. Vondra, L.F. (1996) Using Castings to Make Castings. Foundry Management and Technology, 124. (5), 20-22.
13. Vondra, L.F., Formanek, M.C. (1996) A Further Evaluation of Wear Analysis of Foundry Tooling Materials. AFS Transactions, (in print). Received AFS Pattern and Foundry Tooling Division 1996 "Best Paper Award".

SERVICE ***Mock Disaster Exercise**

On April 5, 1996 the Metal Casting Center conducted a mock disaster in the MCC laboratory. The purpose of this exercise was to call attention to the dangerous environment foundries can be and what a conscientious effort should be accorded by management to reduce potential safety problems. Its purpose was also to acquaint local emergency management agencies to the particular potential hazards inherent to the foundry industry. A video tape and written emergency response plan was generated to assist management in constructing their own emergency plan. The event was in response to an actual explosion which occurred in Indiana.

Five local fire departments, three hospitals, the Federal and local Emergency Management Agencies, and staff and students of UNI took part in the simulated explosion in order to test the local emergency response system. The event was nationally publicized in metal casting trade journals to emphasize the importance of being prepared ahead of time, and to stimulate such planning by operating businesses.

Regional Foundry Consortiums

The MCC has established a network of foundry consortiums disbursed throughout the state. The Consortiums are centralized around Iowa Community College Districts and provide primary interaction between the MCC and the industry. There are currently 10 Community College Districts and 16 CIRAS Technology Specialists involved, which provide interaction with 90% of Iowa's metal casting industry.

Foundry Marketing Consortium

The MCC, in conjunction with UNI External Services, has initiated and assisted in development of the Iowa Foundries Group (IFG) to market foundry products on a collective basis. The group is organized to share marketing expenses, such as the costs of a manufacturing representative, and promotional materials, and to jointly market individual capacities and capabilities through the consortium. It is anticipated that additional consortiums will be established in future periods.

Foundry Simulation Activities

A primary component of synchronous manufacturing for the metal casting industry is solid modeling and solidification analysis. In principle, computer aided drafting files of castings are generated to provide assistance in the initial design process.

Non-Profit Service

Metal Casting Center personnel respond, when appropriate, to non-profit organizations in need of castings or foundry expertise. Examples include: plaques for the Waterloo Technical Society, medallions for the University President's office, girders for a scaled down locomotive used by Boone & Scenic Valley Railroad, a central Iowa community, etc.

SOLIDIFICATION MODELING CONSORTIUM

The MCC has initiated a solidification modeling consortium for the foundry industry designed to provide training materials and technical information on the fundamentals of casting simulation. The program approach is structured around the use of present telecommunication technologies enabling each member to access a centralized Silicon Graphics workstation located at the MCC. Working with Concurrent Technology Corporation, multi-user casting simulation software was purchased and installed on the workstation. The simulation software can be accessed by consortium members with UNIX terminal emulation software using Internet connections. Using this methodology, consortium members have the opportunity to learn and practice solidification modeling concepts and techniques at their facilities and on their own pace.

The educational component of the consortium employs an objective approach directed toward training members in solidification modeling theory and methodology. Solidification modeling educational topics include differences between finite difference and finite element methods, efficient meshing schemes, advantages and disadvantages of using constant and variable thermophysical property databases, utilization of post processing results in the design process, application of gating and risering principles coupled with solidification kinetics, process optimization, economic evaluation, and development of experimental verification castings. Assistance in collecting thermophysical casting process information using data acquisition techniques and cooling curve analysis will also be provided.

The role of the MCC is to maintain accessibility of the workstation, train in solidification techniques and post processing analysis, assist members in developing site specific thermophysical property data bases, and demonstrate the benefits of the technology. This innovative activity provides an opportunity for members to learn fundamental concepts of developing reliable and accurate casting simulations. Upon completion, foundries will have developed a sound understanding of techniques and concepts that can then be applied to any commercial simulation package. This will enable them, when purchasing a casting simulation program, to identify the appropriate software and directly implement modeling into their operations.

CONCLUSION

The purpose of this award was to extract lessons about providing extension enabling services to the metal casting industry. At the beginning, extension was interpreted as *responsive* assistance, whereby businesses would approach the MCC with a particular concern, and as an outreach center, the MCC would either provide the assistance, or find someone that could. Industry-wide *continuous improvement* was intended to serve as the catalyst for modernization.

It has been concluded that responsive assistance is *not recommended* to keep pace with the change occurring within the metal casting industry. The MCC has exhausted considerable effort reacting to several patchwork issues, most of which reinforce habits that detract from the larger potential of the industry. To effectively service them would require that the MCC maintain an understanding of details that is superior to that of the operators that deal with them daily.

It is proposed instead that deployment *proactively* stimulate investment in commercial applications of *targeted*, critical technologies emanating from the *creative* work of government supported research laboratories. In addition to recognizing technologies as critical, the MCC's role should include the design of financial transactions that position risk and reward so that providers, investors, and metal casters share equitably in an on-going cycle of commercialization. Linking investors to users should be one of the *primary* efforts.

The mechanical characteristics of the technology, the process, and the industry must be guided by economic principle. From its current position, the MCC needs to cultivate a better awareness of how supply and demand flow on each side of the conversion process, from raw material to *used* component. It needs to stay aware of foundry locations, material sources, how many times castings change hands before end-use, and how long they are in service before being recycled. Such background is essential to provide *placement* of technologies that are critical to the broader purpose of the industry.

CRITICAL TECHNOLOGY *

Although counter-gravitational casting demonstrates potential to benefit the industry, it is not likely *critical* to the central change about to follow digital networking. *Digital tooling*, which integrates solid modelling, rapid prototyping, and disposable tooling material (such as evaporative polystyrene), connected to Internet marketing, opens potential to "fax" components or assemblies *on demand*, anytime, anywhere. This development will likely change how *the business* of metal casting is defined.

Digital networking accommodates a *separation of expertise from facilities*. The benefits of physically *placing* targeted volumes in proximity to several end-use regions, by wire, *on demand*, allows process facilities to amortize *across* markets. A re-shuffled economy-of-scale will emerge that amortizes the enabling technology instead of heavy equipment. Configurations will be stored and transferred *digitally*. Logistics, programmed to end-use will greatly reduce costs associated with storage, handling, obsolescence, and the energy required to physically *transfer mass* through several processing stages over several areas of the globe.

A demand-site orientation will likely emerge that minimizes production risk, localizes material flow (recycling), and services entrepreneurial marketers with niche like processing. The larger, heavily capitalized plant, storing limited tooling will start to compete with several geographically disbursed, smaller franchise shops with unlimited access to *on-line* tooling. Business identities that standardize operations like McDonalds, centralize market development like Kinko's, and dispatch trade like FedEx show potential.

TRADE IDENTITY *

Demand initiates an organization's purpose. It is the consequence of *perceived* need among end users and points to the reason why an effort is organized. Approval is measured by the amount of *surplus* cash an effort generates *after* initial risk has been taken.

How a product is defined, constructed, and priced is reflected by its *trademark*, which in large part, determines the *surplus* cash that it will derive. Compared to the price of the car, the cost of the castings *packaged* in a Jaguar are proportionately less than those in a Geo, yet they could probably be produced for roughly the same cost. A trademark packages *identity* into a quickly defined symbol that *positions* the usefulness and quality of an organization's output.

Casting occurs at the opposite end of the sequence that *initiates demand* for a component. With exception of those that offer engineered castings, the industry consists almost entirely of commodity based *processing* operations. They are sub-tier means to an end, competitive on price, delivery, and to a lesser extent, quality. With the exception of a handful, few casters are identified as component providers like *"Intel" is to microchips*.

Small metal casters are trapped in *established*, saturated, low margin markets. In order to advance, they must learn to *define, develop, and initiate* trade. Instead, they are in some form or another, captive of organizations such as John Deere and Ford, whose *identities* generate revenues on behalf of the industry. A "filter" exists between foundries and the directive politic of cash that follows the *development of trade*.

CULTURE *

In large part, the culture of an industry shapes its operating characteristics. Historically, foundries have been associated with monotony, noise, dirt, foul air, and extreme heat which has caused them an undesirable reputation among new recruits entering the field. By nature, the industry unites a common personality that is tough, tolerant and *biased toward cash* instead of growth. Its basic culture recaptures a vision that is excessively practical, conservative, and independent.

The industry is simply not attractive to creative young talents who, today, have cleaner, easier options. It continues to struggle with high attrition, average age, demand, and labor costs, and has not experienced a significant cultural succession since the smokestack era when *supply ruled demand*. Inward nationalism has the industry reinforcing *its* process, while neglecting the broader role of its *purpose*.

Limited imagination has isolated the industry from the high margin cash flow associated with *creating* trade. Several layers of resale have crept between the industry and the *markets* it serves. The organizations *who apply castings to a purpose* have established an identity for servicing downstream needs, and are harvesting the return necessary to pay investors to sponsor the risks of foundry modernization.

INVESTMENT *

Risk implies lack of confidence in *future* trade. Modernization requires *risk bearing* investment. As modernization guides innovation toward standard, market approval of a technology becomes proven and less prone to risk. Opportunity to claim a share of surplus cash entices investors to *sponsor risk* before an innovation is proven. *Equity* is risk bearing investment *that carries an ownership influence*. It is typically drawn toward potentially higher yielding endeavors than debt instruments.

The saturated markets that metal casters participate in limit margins and their ability to *pay for risk*. Debt financing, which for the most part *guarantees* fixed return for investors is predominant in the industry. It allows metal casters to retain full control of *their* process, but at the same time it requires them to absorb innovative risk *internally*. As a result, not much risk is taken. Evidence of this is illustrated in the requests for assistance that small metal casters had made during the award period. Most involve low-risk *tuning* activities. Few could be considered *innovative*.

Part of the stagnation in the metal casting industry has come about because of a lack of *influence* pushing it to *create* new trade. Risk is currently being absorbed by the competence of individual organizations that are lead by conservative cultures that are inclined to retain equity control of a steady state process. The potential to *influence* trade creating innovation is being drawn away from the industry toward higher yielding alternatives. The paradigm is that cash the small metal caster *cannot* accumulate to invest will increasingly erode its competitive position.

ROLE OF THE METAL CASTING CENTER *

The immediate needs of the Metal Casting Center following completion of this award, is to sustain industry support of activities that draw investment toward the identified critical technology. The (completely industry sponsored) *solidification modeling consortium* identified in previous discussion has an effective beginning date of July 1, 1997, and will run for two years afterward. Prior to termination of this activity, and contingent on available funding, parallel activities focusing rapid prototyping and disposable tooling materials will be proposed to fully integrate digital tooling technology among active members.

Upon satisfactory progress (and with the willingness of active members) an attempt will be made to draw financing toward the technology, through the active participants. A proposal will be made to the consortium to establish a limited liability business identity that will serve as an equity platform to diversify individual risks. Equity in capital equipment (and license to use specific technologies) will be retained by the central identity, and leased to individual members. *Such proposal will require approval of the consortium* and is indicated in this report to illustrate the means by which the MCC will pursue technology deployment following termination of the TRP award. Similar consortiums will be made available to businesses not active in the initial pilot. *Such deployment consortiums* will be the primary focus of MCC efforts.

Pursuant to a separate *cash generating* venture, the MCC is currently initiating several small, responsive projects among a pool of 5-10 businesses, that will position it as a dedicated *hot metals laboratory*. It is anticipated that the project activities will evolve toward a consortium instituted under broadly defined usage agreements that generate fixed-term fees to support the center. The strategic purpose of this effort will be to generate requisite cash to replace that lost with termination of the TRP award.

WHITE PAPERS

White Papers

Advanced Permanent Molding of Ferrous
Alloys

**ADVANCED PERMANENT MOLDING
OF FERROUS ALLOYS**

**Prepared by:
Dr. Yuri Lerner
Professor of Industrial Technology**

**Voice: 319.273.2651
Fax: 319.273.5959**

BACKGROUND

Permanent mold (PM) casting is a practical and competitive method for producing near-net-shape castings using both non-ferrous (aluminum and copper) as well as ferrous metals. Today, the PM process is being successfully used to produce a range of gray and ductile iron castings; from small, thin-wall castings of complex shape weighing from 1-5 pounds, to relatively large thick-walled castings weighing from 500-5000 pounds, with or without cores.

The advantages of the PM process are well known, and the global use of the PM process is on the rise. For example:

(1) The European PM market (excluding Eastern Europe and countries of the former USSR) reportedly includes about 15 foundries with an estimated annual production of 35,000 tons. Parts are being cast for several markets including automotive (brake components) and machine tools (small gears), air compressors (cylinders and crankshafts), hydraulic components, and others.

(2) The Japanese PM market, specializing in high volume castings for air and gas compressors for the refrigeration and automotive industries, is comprised of at least six PM foundries with an annual capacity of about 18,000 tons.

(3) Recently, Japan built two PM foundries in China and Malaysia for the production of cast parts for air-conditioning and refrigeration compressors. These facilities have a combined annual capacity of 6,000 to 8,000 tons.

(4) In India, two foundries are specializing in the low to high volume PM casting of simply shaped, low-weight industrial components in gray and ductile iron.

(5) One foundry in Canada employs the PM process to various fittings and elbows for the sanitary pipe industry.

(6) The German ITT Teves foundry (located in Brazil) is specializing in the production of automotive brake components, hydraulic components, and compressor parts. The annual production is about 12,000 tons of gray iron, and 6,000 tons of ductile iron. Casting weight varies from 250 grams (0.55 lb) to 8 kg (17.6 lb).

(7) In the Eastern European countries (Czechoslovakia, Poland, Hungary, Bulgaria) and countries of the former USSR, the reported annual production of PM castings is about 650,000 tons.

The production of ductile iron castings using the traditional PM process has a number of technical and economic advantages. Some of these are: reduced production time compared to sand casting, reduced casting cleaning costs, elimination of sand and sand handling, and improved dimensional accuracy and stability. Moreover, the amount of magnesium that must be added to the ductile iron melt is reduced, resulting in a lower residual magnesium content in the finished casting due to a higher undercooling rate as compared to sand casting. This results in controlled shrinkage, improved modularity of the ductile iron, enhanced mechanical properties, and better overall casting quality.

The traditional permanent mold casting process does, however, have some limitations. One of the most significant of these problems is heat treatment of finished castings. The traditional method of producing gray and ductile iron permanent mold castings includes extensive heat treatment as a mandatory operation.

The heat treatment of permanent mold castings produced with conventional methods is necessary to ensure and regulate the reproducibility of the microstructure and mechanical properties of the casting. It is also essential in developing the good machining qualities necessary in finished castings.

Of course, the necessity of a high temperature heat treatment is associated with increased energy consumption. This in turn leads to high energy costs that are ultimately reflected in the cost of the casting to the consumer. Other significant problems inherent in the traditional PM process are

a long production cycle contributing to extended production lead-times. This factor is one of the major obstacles restricting the further implementation of PM technology.

Another major obstacle restricting the widespread adoption of PM casting technology is the relatively short mold life encountered in casting the ferrous alloys (irons and steels). This limitation makes it nearly impossible to use this process in the production of steel castings, since mold wear is a significant factor in casting these materials.

Some advances in the PM process have been made in countries of the former USSR. These countries are using a variation of the PM process in which the mold cavity is lined with an appropriate material, either sand or a refractory. The technique is currently being used to pour diesel engine crankshafts and artillery projectiles of ductile iron, and camshafts of gray iron. The annual production using this technique is about 30,000 tons.

PROJECT OBJECTIVES

The purpose of this project will be to explore and develop the new PM process utilizing lined molds. The specific objective to be accomplished are:

- (1) To produce gray and ductile iron castings with improved microstructure and mechanical properties in the as-cast condition, thus eliminating the need for post-casting heat treatment. This will reduce the overall energy consumption associated with the process.
- (2) To study and characterize all important parameters of the lined permanent mold (LPM) casting process.
- (3) To extend the lined permanent mold (LPM) casting process to steel casting.

These objectives will be accomplished through the use of lined permanent molds. The face of

the mold will be lined with a thin (4-6mm) layer of refractory coating or sand mixture, depending upon the type of the alloy to be poured. If a sand mixture is used, it will be applied either by ramming, pouring and vibrating the mixture, or blowing the mixture into the gap between mold and pattern.

RESEARCH PLAN

The research necessary to accomplish the above objectives will be conducted in several distinct phases. These phases are:

Phase 1. Design and fabricate necessary experimental devices and tooling (permanent molds) to produce test castings.

Phase 2. Select permanent mold lining materials for pouring irons and steel. In addition, experiments will be conducted to define and delimit mold lining process parameters; the optimal lining application method, ideal lining thickness, and estimated lining life.

Phase 3. Investigate and evaluate: (1) solidification structure and mechanical properties as a function of thickness in iron and steel castings produced with the LPM technique; (2) the influence of differential lining thickness on the thermal gradient, microstructure, and ability to promote directional solidification in LPM castings; and (3) optimal feeding rates for the LPM process.

Phase 4. Use empirically obtained process parameters and solidification modeling techniques to develop an analytical model that can be used to optimize the pouring process.

Phase 5. As proof-of-concept, produce a number of experimental castings in various iron and steel alloys which will then be evaluated characterized regarding microstructure, mechanical properties, casting surface finish, and overall quality.

Phase 6. Develop and disseminate the information necessary for practical utilization this technology; This will include preparation of the technical program implementation plan, publication of experimental

findings in appropriate journals, and outreach activities and technical assistance to ensure that the technology is effectively transferred to the foundry industry.

White Papers

Advanced Waste Management Assistance
for Foundries

**ADVANCED WASTE MANAGEMENT
ASSISTANCE FOR FOUNDRIES**

**Prepared by:
Mr. John Konefes
Director, Iowa Waste Reduction Center
and
Mr. James Olson
Waste Management Specialist**

**Voice: 319.273.2079
Fax: 319.273.2926
e-mail: olsonj@uni.edu**

BACKGROUND

"In an increasingly environmentally conscious society, management of industrial wastes is becoming a critical economic and sociopolitical challenge." [Quote from a recent DOE workshop summary]. Individual businesses address the management of waste in different ways. The 'art' or 'science' of waste management has evolved from waste reduction/recycling to pollution prevention to a current focus on sustainable manufacturing. Based on the experience of the Iowa Waste Reduction Center during its eight years of providing environmental assistance to small business, our clients are increasingly aware of environmental issues and the benefits associated with proper waste management. Along with this awareness, most businesses have already implemented precursory 'waste reduction/recycling' management practices and are beginning to address pollution prevention. As with any progression, the move from waste reduction/recycling to pollution prevention to the ideals of sustainable manufacturing involves more evaluation, more information and more difficult and costly decision making.

Among other factors, prudent waste management decisions must include consideration of:

- (1) Product design
- (2) Raw material selection
- (3) Production
- (4) Energy
- (5) Regulatory compliance (environmental and health/safety)
- (6) Staff and facility capabilities
- (6) Economics
- (7) Public relations

Changing a waste management practice based on any one of the above criteria is fairly simple and safe to do. Going the next step and eliminating waste at its source (i.e., pollution prevention) by changing processes, product design, and/or raw material selection is significantly more difficult and risky.

PROBLEMS

Are small businesses capable of making prudent pollution prevention decisions? Large companies have in-house staff with the necessary expertise to adequately address waste management issues, or the financial capability to hire consultants. Smaller businesses do not generally have this degree of staff or resources and therefore face far greater obstacles in maintaining competitiveness, meeting regulatory mandates and minimizing their impact on the environment.

Are technical assistance programs keeping up with the needs of small business? Most businesses have access to numerous technical assistance programs. Using Iowa and the metal casting industry as an example, foundries can call upon the Metal Casting Center for specific trade assistance, the Manufacturing Technology Center for research and development assistance, the Small Business Development Center for business planning and financing help, WorkSafe Iowa for OSHA and worker safety consulting and the Iowa Waste Reduction Center for environmental related assistance.

While each of these technical assistance centers realizes the multifaceted aspects associated with waste management decision making, none have expertise in all areas. As a result, the small business owner is potentially deluged with numerous, related decision making tools, with limited time and skills to manipulate these tools into a usable form. In most small businesses the person responsible for waste management and compliance performs a multitude of functions. In very small operations, the owner/manager assumes total responsibility for waste management, inventory, production, shipping and accounting. In larger small businesses, the person responsible for waste management is often a general foreman, accounts receivable clerk, personnel manager or maintenance mechanic. These people are not adequately trained or blessed with the time to evaluate waste management options to the degree necessary to actually convince management to implement the option.

SOLUTIONS

This preproposal is submitted to answer the questions posed above and to develop an advanced waste management technical assistance implementation model.

General steps to answer the question "***Are small businesses capable of making prudent pollution prevention decisions?***" and to provide decision making assistance include:

- (1) Field evaluations of current small business decision making processes for effectiveness in making waste management and related choices.
- (2) Evaluation of existing decision making models (i.e., multi-criteria computer models) for applicability to small business and waste management.
- (3) If necessary, modification of existing models to better serve small business/waste management.
- (4) Distribution of models, training selected participants, and evaluation of effectiveness.

Concurrently with the above activities and to address the question "***Are technical assistance programs keeping up with the needs of small business?***" the following types of activities will also be performed:

- (1) Three to five small foundries will be selected to participate in the project evaluation and pilot testing. The main criteria for selection will be sincere attitude to support project staff and desire to implement cost effective pollution prevention options.
- (2) Assemble a 'project team' from the pool of existing technical assistance programs (i.e., Metal Casting Center, Iowa Waste Reduction Center, Iowa Energy Center, Institute for Decision Making, and the Manufacturing Technology Center). The use of private consultants is not anticipated but could be included if additional expertise is needed.
- (3) Collect facility baseline data.

(4) Collect the necessary data for incorporation into the decision making model discussed above and evaluate waste management options.

(5) Justify pollution prevention related options, assist in obtaining financing, if necessary, and expedite implementation of the option.

(6) Collect post-implementation data to substantiate the effect of the change.

PROJECT DELIVERABLES

Successful completion of this project will result in the following benefits:

(1) Actual pollution prevention at the participating foundries and the basis for cases studies to encourage other foundries to implement similar activities.

(2) Availability of a usable decision making model(s) for use in small foundries and a 'boilerplate' model(s) that can be adapted for other industry sectors.

(3) Evaluation of the effectiveness of the 'team approach' to technical assistance and the basis for expanding the team concept to other industries and state programs.

(4) Opportunity for team members to gain detailed knowledge of the metal casting industry and the services provided by their counterparts.

CONCLUSION

Effective waste management involves complicated and interrelated process, product, energy and other factors. In order to make the best waste management choices, small businesses need:

- (1) Good evaluation criteria
- (2) A workable decision making model, and
- (3) The motivation to make the change.

Secondly, the needs of industry may be changing faster than the services available through existing technical assistance agencies. The effectiveness of a 'jack-of-all trades' is questionable. The capability of small business to assimilate mounds of information provided by 'specialists' appears limited. Integrating service providers into a well managed team, and working directly with business managers, appears to offer the best of both worlds.

The Iowa Waste Reduction Center welcomes the opportunity to provide specific information regarding this project and the qualifications of the service provider agencies that will participate. Please do not hesitate to contact John Konefes (Director) or Jim Olson (Waste Management Specialist) at 800/422-3109 or by fax at 319/273-2926.

White Papers

Cast Steel Crankshaft Research

**CAST STEEL CRANKSHAFT
RESEARCH PROJECT**

**Prepared by:
Dr. L. Fred Vondra
Project Manager**

**Voice: 319.273.6894
Fax: 319.273.5959**

INTRODUCTION

The automobile industry has for years been lightening their vehicles so as to improve fuel economy. One effort that has been investigated is to make engine blocks out of aluminum alloy. Designers feel that in order to utilize aluminum for engine block material they must derive structural strength from other areas. One area that shows significant potential as a structural member is the engine crankshaft. Currently, engine manufacturers have their steel crankshafts made using the forging process. This is a very expensive process however. In order to utilize the advantages of casting some manufacturers make crankshafts in ductile iron. However, making crankshafts in steel is overwhelmingly preferable.

BACKGROUND

There are two primary reasons why steel castings are not currently made successfully: First, the traditional casting process is a very turbulent activity. When turbulence occurs, the molten metal has a tendency to pick up oxygen causing oxide inclusions within the casting. These subsurface inclusions become apparent during machining of the castings.

Second, foundries typically have their melting and holding equipment as separate departments some distance from the molding area. Because of these distances the material handling of the molten metal requires that it be transferred to multiple ladles before the metal is actually poured into the mold. This metal transfer allows the metal to pick up oxygen and causes slag to rise to the ladle surface. Slag and refractory materials may find their way into the casting cavity causing unwanted inclusions.

METHODOLOGY

The MCC has the capability of casting directly from the melting furnace thereby eliminating the material handling problems. It is a process called Loose Sand Vacuum Assisted Casting (LSVAC). This process allows the filling of a casting cavity from the bottom of the mold in a controlled non-turbulent manner.

Because of the very low atmospheric pressure in the casting cavity the molten metal has very little opportunity to pick up oxygen. The University of Northern Iowa's Metal Casting Center (MCC) proposes research in making cast steel crankshafts utilizing the technology.

The pattern media to be utilized in this experimentation will be polystyrene foam. This is a popular metal casting media also known as lost foam casting (LFC). Essentially, foam pattern casting uses a cavityless mold, the pattern stays in the mold during metal pouring. The foam pattern is replaced by molten metal, producing the casting. Historically, LFC has not been used for steel casting because of carbon pick up in the molten metal from the vaporizing foam. However, with the LSVAC system constantly drawing a vacuum in the cavity, the vaporized remains from the foam are drawn out of the mold.

One of the advantages of the lost foam casting process is its dimensional accuracy. The patterns are accurate representations of the desired shape. There is typically less finishing work associated with LFC casting with no fins, parting lines, or draft. Removal of draft, parting lines, and fins is a significant cost to the manufacturing process.

Also, cores are eliminated which allows for more complex casting designs, well controlled wall thicknesses and no coreprints. Also eliminated are fins or shifts, core defects and sand mixing. The process also is very flexible in that multiple levels of castings are possible thus allowing part consolidation. These advantages lead to making near net shaped castings that display significantly improved yields and reduced scrap. The advantages also correspond to reduced energy needed to melt the alloy, and less waste.

Research to be conducted includes process characterization. Process characterization for the LSVAC and LFC includes analyzation in the following areas: sand types and size; lost foam bead type, lost foam coatings; vacuum process parameters such as vacuum levels, dwell times, shakeout times, and gate sizes.

Industry support includes the largest manufacturer of marine engines in the United States. This manufacturer is interested in casting a new generation of crankshafts in steel and discern distinct advantages in using the LSVAC and LFC processes to create these castings. Upon successful experimentation in casting a steel crankshaft using the processes mentioned above other engine manufacturing entities will join the research and apply it toward their products and specifications.

The industrial partner has requested that 1070 high carbon steel be the alloy used for experimentation as a starting point. They are requesting this alloy so as to allow certain areas of the crankshaft to be induction hardened. However, other alloys will be included in the study at a later date as specific needs are better defined. A full metallurgical characterization will be conducted on the steel alloys including chemistry, mechanical and physical testing.

The Metal Casting Center is requesting funding for the above research to address the needs stated in the DOE solicitation Program Notice 96-05. This research would lead to producing castings that would significantly lighten a vehicle thereby improving gas mileage and reducing emissions.

White Papers

Counter-Gravitational Casting of
Aluminum Metal Matrix Composites

**COUNTER GRAVITATIONAL CASTING OF
ALUMINUM METAL MATRIX COMPOSITES**

**Prepared by:
MR. SCOTT R. GIESE
Metallurgical Engineer
Project Manager**

**Voice: 319.273.7083
Fax: 319-273-5959
e-mail: Giese@uni.edu**

INTRODUCTION

Aluminum metal matrix composites (Al-MMC) possess unique material property characteristics for the designer. Discontinuously reinforced Al-MMC offers a range of tailorable mechanical and physical properties achieved by systematic combinations of the ceramic and metal matrix phases. Variables affecting performance are the particulate volume fraction, uniformity in reinforcement distribution, and the matrix mechanical behavior. When properly controlled from the start of liquid metal preparation to the end of solidification, Al-MMC offers higher specific stiffness, better corrosion resistance, superior wear resistance, lower thermal expansion, lower density, and higher thermal conductivity than ferrous casting alloys. Potential applications for the automotive industry include connecting rods, brake rotors, brake drums, suspension elements, drive shafts, and engine blocks.

Metal casting forming processes offers the most direct and shortest route from component design to production. In addition to its economic benefits, Al-MMC discontinuous reinforcement castings rival performance capabilities of powder metallurgy components. Combining the infinite design freedom and integral part of casting, Al-MMC castings offer lightweight, near-net-shape automotive components for the lowest processing cost.

One difficulty in gravity casting Al-MMC is the poor castability ratings of these alloys because of suspended ceramic particulates in the liquid. To compensate for its poor fluidity, foundry designers circumvent this problem by oversizing the gating system. This results in low casting yields, on the order of 40 to 50%, driving production costs higher than normal aluminum castings. A concern for casting Al-MMC is the high oxidation potential and hydrogen absorption during melting and casting resulting in inclusion formation and gas entrapment. Degassing techniques are ineffective for hydrogen gas absorption because of particulate flotation induced by rising degassing bubbles. Filtration schemes for aluminum casting are frequently incorporated into the gating design to remove dross related defects and some oxide inclusions. However, filters can not be used with Al-MMC casting alloys because the intentionally added ceramic particles become trapped in the filters, rendering the alloy with less than expected mechanical properties.

Another problem associated with traditional gravity pouring methods is the turbulent introduction of liquid Al-MMC into the gating system, particularly in areas where the liquid metal abruptly changes direction. Breakup of the metal stream forms small droplets of metal and reoxidation of these droplets inevitably results in macroinclusions. The susceptibility for inclusions is greatly enhanced when the total surface area of the liquid metal is increased. This is particularly true when the liquid metal enters the casting cavity.

Counter gravitational casting processes have emerged to the forefront as a new and innovative casting technique for improving the quality of castings and producing thin walled sections. One process that has potential for producing high quality Al-MMC components is loose sand vacuum assisted casting (LS-VAC), commonly referred as the Hitchner process. In this process, a chemically bonded sand mold is inserted into a vacuum canister surrounded by loose sand, and the canister sealed. The canister is positioned over the melt and slowly lowered until the meniscus of the melt comes in contact with the canister. A vacuum is applied, quiescently siphoning liquid metal into the casting cavity at a controlled rate without disruption of the liquid metal front. After the casting is completely filled and the gates have solidified, the vacuum is released and any residual liquid in the sprue flows back into the furnace. Since the gates do not require removal from a sprue, multiple parts can be assembled resulting in high casting yields on the order of 70-90 percent with minimal post-processing.

The LS-VAC process is ideally suited for applications where intricate and complex coring, thin wall, and close tolerances are required. The controlling factors for filling thin walled sections are the gas pressure and the cooling rate. For traditional casting methods, large metallostatic pressures or heated molds are necessary to completely fill thin sections. The LS-VAC method can overcome this problem by lowering the capillary pressure to completely fill thin sections. The applied vacuum in the casting cavity is beneficial by lowering the external pressure for pore formation in thick sections, minimizing gas porosity formation.

The arrangement and distribution of the ceramic particulates in the metal matrix determine the properties of the cast composite. For sand castings, slow cooling rates allow for buoyant driven

segregation of the particles. The LS-VAC process is unique for production of Al-MMC castings in that lower casting temperatures are used. By decreasing the solidification time with lower casting temperatures, particle segregation is dramatically reduced, encapsulating the particles in the matrix instead of at the grain boundaries. In addition to homogeneous distribution of the particles, fine grains are developed in the metal matrix.

RESEARCH METHODOLOGY

The goal of the proposed research program is to investigate the potential application of the vacuum counter gravitational casting method for Al-MMC alloys. The research strategy of this program is to identify potential casting applications, develop casting design guidelines and process parameters for a variety of commercial Al-MMC casting alloys, and assess specific stiffness and wear resistance properties obtained from counter gravitational casting. The proposed program will evaluate the gating and risering design criteria and process parameters and apply these guidelines to completely fill complex geometric casting shapes while maintaining optimal casting yields. Documentation of mechanical properties will be made available for potential casting designers to provide a technology transfer avenue for automotive applications.

The program is designed to establish casting procedures for Al-MMC counter gravitational casting, comparatively determine the mechanical properties between the LS-VAC process and traditional casting method, and develop initial gating and risering design parameters for the LS-VAC method. Simple geometric castings will be used to evaluate specific stiffness and wear resistance properties for both casting methods. Concurrently, solidification modeling and fluid flow analysis will be used to determine proper gating and risering design to produce a sound experimental casting while maintaining optimal casting yield.

White Papers

Development of Cost Effective and
Reduced Energy Consumption Gating
Systems

**DEVELOPMENT OF COST EFFECTIVE AND
REDUCED ENERGY CONSUMPTION
GATING SYSTEMS FOR METALCASTING**

**Prepared by:
Dr. Yuri Lerner
Professor of Industrial Technology**

**Voice: 319.273.2651
Fax: 319.273.5959**

BACKGROUND

In making a mold for a casting, two structures or systems must be incorporated into the mold along with the mold cavity proper. These are the gating system and the riser system. Both systems are an integral part of the mold, but are external to the mold cavity itself.

Initially, liquid metal is introduced into the mold through the gating system. The molten metal then flows into and through the mold, filling the mold and taking on the actual shape of the casting. To ensure that the mold fills completely, the riser system is attached to the casting downstream of the mold proper.

The riser system provides a liquid metal reservoir that is necessary to compensate for shrinkage which occurs during solidification of the molten metal. After the casting has solidified, it is removed from ("shaken out") of the mold, and the gating and riser systems are detached and remelted. The gating and riser systems are thus waste metal in the sense that they are not a part of the casting itself, but must be present for the casting process to proceed.

Both the gating and riser systems are considered to be part of the casting proper, and are thus included in the calculation of casting yield. Casting yield is defined as the ratio of the weight of casting(s) produced to the total weight of metal poured. Since casting yield includes gates and risers, these systems are a major factor influencing the cost-effectiveness of casting operations. Typically, casting yield varies from 40% to 70%, depending on alloy, process, and mold configuration.

Clearly, any reduction in the size or complexity of the gating and riser systems can reduce the total amount of metal melted, the amount of metal that must be remelted, and the time and energy expended in removing the gating and riser systems from finished castings. Naturally, as these factors are reduced, the costs associated with them also decrease.

Areas in which casting productivity can be improved include the quantity of metal initially melted, the removal of gating and riser systems from finished castings, the weight of waste metal produced,

the handling and recycling of waste metal, and the remelting of the gating and riser systems. Further, reuse of the gating and riser systems (secondary resources) also reduces the quantity of primary resources consumed in casting operations. Hence, any reduction in the number and/or size of gates and risers associated with a casting will directly affect the amount of energy required to produce the casting, the quantity of primary resources consumed, the amount of wastes produced, the overall efficiency of casting operations, and the final cost of the casting to the consumer.

PROJECT OVERVIEW

This project entails the development of direct pouring techniques that will permit the production of both ferrous and non-ferrous castings without the traditional gating system consisting of sprues, runners, and ingates. Current technology in this area combines a ceramic foam filter with insulating sleeves in a pouring cup that serves as a riser feeding the casting during solidification. The ceramic foam filter offers a high filtration efficiency and good control of the flow of liquid metal into the mold.

Currently marketed direct pouring systems exhibit a major disadvantage. This is the premature solidification of the molten metal in the filter pores before the mold has completely filled, resulting in shrinkage-related defects in the finished castings. This problem is most frequently seen in pouring ductile iron and steel castings.

PROJECT OBJECTIVES

The primary objectives of this project are the development of a more efficient direct pouring system that will:

(1) Control the flow rate of the molten metal and slag inclusions by using an appropriate filtration element that will feed the casting more effectively, thus promoting directional solidification to reduce shrink-related defects in finished castings.

(2) Develop a method for calculating the optimal parameters for this type of gating system.

(3) Transform the empirical data gathered into concrete techniques and procedures that can be used by industry to improve casting yield, and significantly reduce energy consumption and waste generation.

RESEARCH PLAN

The research in this project will be carried out in several discrete phases. These phases are:

(1) Phase one. Develop an analytical model of the direct pouring system for optimization of ceramic filters and other parameters

(2) Phase two. Develop both a test casting and an experimental direct pouring device. These will be used to study solidification shrinkage in both ferrous and nonferrous alloys castings poured in both sand and permanent molds.

This phase also includes the development of a series of experiments to evaluate the overall quality of the test castings using X-ray radiography, ultrasonic testing, and visual rating techniques. Pilot runs of the experimental castings will also be conducted.

(3) Phase three. Based on modeling and experimental data, a method for calculating the optimal gating and risering system will be developed. Working from this data, the direct pouring system design will be finalized.

(4) Phase four. This phase is the transfer of technology. Here, the empirical data gathered will be transformed into concrete techniques and procedures that can be used by industry to improve casting yield, and reduce energy consumption and waste generation. In addition, technical assistance in process implementation will be offered to the end users via existing MCC outreach programs.

TECHNICAL AND ECONOMICAL BENEFITS

This project is expected to yield a number of benefits. These are:

- (1) A 20-30 percent improvement in casting yield.
- (2) An overall reduction in energy consumption of from 8-12 percent.
- (3) A 5-8 percent reduction in melting costs.
- (4) An overall increase in casting productivity since more finished castings will be derived from the same volume of melted alloy.
- (5) General improvement in the mechanical properties and quality of castings owing to the removal of non-metallic inclusions by the ceramic filter.
- (6) The reduction of shrink-related defects in finished castings due to a more controlled and less turbulent flow of molten metal through the ceramic filter.
- (7) In permanent mold casting systems, the reduction in size of the gating and risering systems will result in smaller and less expensive molds.

INDUSTRIAL PARTNERS

An initial contact has been made to establish an industrial partnership with one of the major manufacturers of ceramic foam filtration systems. This partner is the Joy-Mark Company of Cudahy, WI.

White Papers

Development of a New Fully Integrated
Pre-Manufacturing Paradigm for Metal
Casting

**DEVELOPMENT OF A NEW AND FULLY INTEGRATED
PRE-MANUFACTURING PARADIGM FOR THE METAL
CASTING INDUSTRY EMPHASIZING ENERGY EFFICIENCY,
WASTE REDUCTION, AND LEAD-TIME COMPRESSION**

**Prepared by:
Dr. David D. Bradney
Certified Manufacturing Engineer
Certified Senior Industrial Technologist
Project Manager**

**Voice: 319.273.7088
Fax: 319.273.5959
e-mail: D. Bradney@aol.com**

BACKGROUND

Historically, manufacturing **processes and methods** have been the primary focus of efforts to reduce overall energy consumption and waste generation. These efforts have been concentrated in the energy consumed directly by manufacturing processes, the type and quantity of materials used in manufacturing, and the downstream pollution generated by manufacturing processes.

Past efforts in reducing energy consumption and waste generation **during** the production process have, to some extent, been successful. However, one consequence of this success is that the **pre-manufacturing** portion of the production cycle has largely been ignored as an additional area in which significant reductions in energy consumption and waste/pollution could be realized.

Pre-manufacturing activities include everything that occurs from the conceptualization of a product and the selection or development of a production process, to the development of a proof-of-concept prototype that is delivered to the customer for final approval. In many production paradigms, pre-manufacturing activities are also called the design and development phase, or the research and development phase.

This portion of the manufacturing cycle is crucial, for it is during this time that far reaching decisions are made—decisions which impact the downstream portion of the production process for years to come. Decisions made at the inception of the manufacturing cycle **directly** determine the type of material used; the quantity of material that must be processed to arrive at a product, the methods that will be used to process the material, and the ultimate recyclability or disposability of both product and the materials used to manufacture the product. Moreover, pre-manufacturing decisions also **directly** influence product end cost, the energy consumed in production, the materials consumed in production, the wastes generated throughout the entire manufacturing cycle, and overall lead-time for product and related components.

While the advantages of a comprehensive and integrated pre-manufacturing paradigm are significant during the pre-manufacturing portion of the production cycle, it must be realized that benefits also accrue downstream of the production cycle as well. For example, in autos and aircraft, lighter and stronger materials produced to near-net shape with little waste will permit weight reductions leading to greater energy efficiency and reduced fuel consumption. This in turn leads to reduced environmental degradation, and enhanced product marketability.

PROJECT OBJECTIVE

The immediate objective of this project is a comprehensive and integrated pre-manufacturing paradigm for the metalcasting industry. The ultimate goal of the project is to provide a design and development paradigm that will influence decision-making relative to energy efficiency and environmental impact **before** production resources are committed. Changing the paradigm by which pre-manufacturing decisions are made will ensure the specification of energy efficient and waste minimizing product configurations, materials, and processing methods.

PROJECT METHODOLOGY

This research will primarily be applied in nature, in that the intent is not the development of new knowledge per se. Rather, the intent is to provide an entirely new configuration for existing technological and scientific knowledge that enables and facilitates the employment of energy efficient and waste minimizing product configurations, materials, and processing methods.

The project is envisioned as occurring over three years in four distinct but overlapping stages. These stages are:

(1) **Technological Assessment.** This is the methodical evaluation of the breadth, depth, applicability, and availability of the information relevant to the project. Because the quantity of information currently available is voluminous, and is expanding daily, the process of assessment can be expected to be ongoing throughout the research process. This will be accomplished through both research in the literature and by close and ongoing interaction with scientific and technical researchers,

metallcasters, manufacturers, governmental agencies, professional and industrial associations; and material and component suppliers.

(2) **"Prototype" Paradigm Development.** In this stage a "prototype" pre-manufacturing paradigm will be developed and evaluated for viability in the current and anticipated manufacturing environment. The prototype paradigm will emphasize techniques and materials that optimize design configurations for near-net shape production methods that reduce manufacturing lead-time.

Specific considerations will include but not be limited to: minimal energy use in production, reduced waste generation in production, increased efficiency in manufacturing processes, reduced downstream pollution, recyclability and disposability of processing by-products; a product life-cycle that enhances recyclability and disposability; near net shape manufacturing technologies, and technologies leading to reduced time-to-market for products. Again, the emphasis will be upon moving the decision-making process to a point early in the pre-manufacturing process, thus defining all activities which follow rather than "adding-on" these considerations after productive resources have already been allocated.

(3) **Final Prototype Development.** In this phase, the full comprehensive and integrated pre-manufacturing paradigm will be developed. It is anticipated that the proof-of-concept for the project will be a multi-volume printed document. However, the form in which the end product of the research is made available to industry will be functions of both need and available technology. At a minimum, the paradigm should be made available via the Web and on CD-ROM, as well as via printed media.

(4) **Technology Transfer.** In the long view, this research is intended to change the way that American industry designs and develops products. This is essentially a process of changing minds, that is, education. It is envisioned that as the new pre-manufacturing paradigm takes hold in industry, it will ultimately move from small-scale commercial use to the industry standard model. That is, the paradigm will become "state-of-the-art". This process will be facilitated through the development

and delivery of training for industry using a variety of modalities including seminars, workshops, correspondence courses, and courseware available via the Internet.

Once the paradigm has been tested and refined in industry, it will ultimately be included in school and college curricula. This is particularly important since it is the educational process that ultimately changes minds, and hence dictates how things will be done for generations to come.

White Papers

Enhancing Energy Efficiency and Waste
Reduction Through Lead Time
Compression

**. ENHANCING ENERGY EFFICIENCY AND WASTE
REDUCTION THROUGH LEAD-TIME COMPRESSION
TECHNOLOGY COUPLED WITH THIN WALL,
NEAR-NET SHAPE CASTING TECHNIQUES**

**Prepared by:
Mr. Daniel B. Quick, BSIE
Director, Metal Casting Center**

**Voice: 319.273.2981
Fax: 319.273.5959**

INTRODUCTION

Through this application, the University of Northern Iowa Metal Casting Center seeks to combine scientific theory and practical industrial technology to make significant advances for the metal casting industry. The goal of this research project is to establish systems in the areas of tool-making technologies and thin wall near net shape casting techniques which will improve vehicular transportation and reduce energy consumption and waste through enhance manufacturing processes.

Since industrial acceptance and application of the techniques, proposed, are pivotal to the results of the research project being accomplished, input from key foundry personnel was followed in the project proposal. The three phase/three year approach to this project will provide **short term** benefits and **long term** changes in the industry approach to the design, production and applications of metal castings.

RESEARCH ACTION PLAN

Phase One deals with lead time compression techniques. The objective here will be to produce an integration of computer engineering techniques by simultaneously linking the design, engineering and production functions.

This will be achieved through the use of electronic data file exchange. This mode of communication will be used to produce rapidly developed three-dimensional models with solidification simulation data integration and integrating production from the beginning rather than at the end.

In Phase Two, these electronic files will be used in conjunction with integration of computer engineering techniques and several rapid prototyping processes to produce the master pattern for composite tooling construction. By addressing the manner in which the tooling is produced, the ability to control dimensions and to begin the casting process with valid tooling provides for additional lead time compression in the cycle to produce castings. By not losing the part tolerance in the tooling, resultant modifications are kept to a minimum. As an additional benefit, modifications are done with less expense than with conventional tooling.

During Phase Three, the counter gravitational vacuum assisted casting technologies will be used to produce thin wall near net shape castings from tooling that was developed and produced in phases one and two. The vacuum assisted casting process provides several benefits besides thin wall castings. Because the metal transfer occurs beneath the surface of the liquid by use of a vacuum to draw the metal into the mold, a new clean metal's technology emerges. Secondly, because the system produces light weight thin walled castings to near net shape dimensions, gating systems are kept to a minimum thereby increasing casting yield and increasing the energy efficiency of the casting process. Facilitating low volume runs and waste reduction, providing direct and immediate benefits to industry, by reducing lead time by at least 50 percent.

This proposal defines a metal casting research activity in Lead Time Compression Technology Coupled With Thin Wall Near Net Shape Metal Casting Techniques/ Design for Energy Efficiency and Waste Reduction. The Metal Casting Center at the University of Northern Iowa will demonstrate that a successful integrated approach to these topics will enhance not only the manufacturing efficiency of this sector, but in the long term, will also significantly enhance the global positioning of the U.S. metal casting industry.

The duality of this proposal will allow the Metal Casting Center to leverage rapidly developed prototype tooling and thin wall casting expertise through a structured R&D project in a three phased approach. Each phase with significant enough impact as to be a project by itself, but as always, the synergy which occurs from the sum of the parts causes a final product that is greater than the whole.

Given that integration of computer engineering techniques and rapid prototyping are currently being used and that the vacuum assisted casting process is an emerging technology then, why is this R & D activity not being done already? The reason is because all of the critical components have not been integrated to form a packaged solution that can be delivered to the metal casting industry which generates industry enthusiasm rather than a simple acceptance as with most R&D activities. Many industries are using integration of computer engineering techniques to compress the design cycle, but not simultaneously in conjunction with the generation of a functional first part casting. The concept

of first part cast as a functional casting rather than as a prototype is key. No longer can manufacturing afford to have castings go through the conventional product design cycle with large amounts of lead time built in for design communication and redesign when the part goes to production.

First part castings are required if integration of computer engineering techniques is to significantly impact the casting market. Simply stated, the casting must be functional from its inception not well into the product life cycle as the industry track record has shown. We must become proactive rather than reactive.

Market research at the Metal Casting Center has shown that the growth market for castings is in the high strength light weight thin wall performance engineered castings of near net proportions, not as commodities, but as value enhanced components. This research was also supported at the DoE/NFS New Orleans Conference of January 1996.

Having these components expected to meet the requirements of dimensional size, while maintaining the mechanical and physical properties of the casting correctly the first time, will open entirely new markets and uses for cast products enhancing vehicular design and weight. This projected result is based upon the significant cost reductions and lead time reductions which will stimulate a corresponding demand from new markets for cast products with a significantly improved final product.

Quite simply, one could compare current practice to a medical operation on a patient with multiple doctors. Each doctor independently works on a different body part at the same time but neglects to view the collective operation as a singular procedure. Each singular procedure is a success, but because there is no collective conscientiousness of the physicians, the patient is never fully functional.

Why then does the Metal Casting Center think that it can succeed where others have failed? The answer is based on the fact that the Metal Casting Center from its inception has used a consultation

and assistance approach to provide services to metal casters in the Midwest census region. Through this project three significant objectives as defined below can be accomplished:

(1) By properly integrating improvements in the design process to produce a product that generates customer enthusiasm, castings will become the choice, rather than the default decision.

(2) By making castings that are lighter and stronger the amount of energy used to produce them and to "push them around" as a finished product is reduced.

(3) By using less product and conserving waste material the industry is able to produce castings that create new markets rather than just satisfy the existing demand, which is already threatened in a global marketplace.

The Metal Casting Center maintains a market driven focus by active ties with the metal casting industry. Five companies, two federal facilities and one professional society have already committed to being project partners. We would expect to significantly increase the number of project participants once this project becomes a formal proposal.

White Papers

**Field Testing the Technology Assessment
Audit and Process Management Method**

**FIELD TESTING OF THE TECHNOLOGY ASSESSMENT
AUDIT AND PROCESS MANAGEMENT METHOD
(TAA/PM²) IN THE METAL CASTING INDUSTRY
FOR THE IMPROVED UTILIZATION OF ENERGY
AND WASTE REDUCTION**

**Prepared by:
JOHN S. BURNINGHAM, D.I.T.
Consultant**

**Voice: 319.373.7091
Fax: 319.273.5959
e-mail: burninj0679@uni.edu**

PROJECT OVERVIEW

The metal casting industry has always been a large user of energy resources because of the heat necessary to transform metals to their liquid state for forming into complex shapes required for economical manufacturing of finished parts. Metal casting has also contributed to landfill waste with the byproducts of the processes. This project proposes two separate, but equally important interrelated tasks for the improved utilization of energy usage and reduction of waste: a Total Assessment Audit (TAA) and implementation of the Process Management Method (PM²). TAA/PM² is soft technology and a management tool for implementing change.

The Metal Casting Center (MCC) at the University of Northern Iowa with sponsorship of the Iowa Energy Center at Iowa State University, developed and *Alpha* tested the TAA/PM² plan over a three year period at the Crane Valve foundry in Washington, Iowa (Crane-Washington). The performance measured at Crane-Washington for the project period Nov 1993 - Oct 1994 was:

Performance Measurement Item	% Change
Number of foundry wage employees	30
Average tons per day poured	78
Good molds poured *	42
Man-hours per ton poured	(27)
Percentage of bad molds **	(28)
Cost of scrap per ton poured **	(39)
Kilowatt hours per ton melted	(29)

* Comparison based on year-to-date daily averages

** Comparison based on year-to-date monthly averages

TAA is not innovative; it is a new proven technique. The PM² technique evolved successfully during the *Alpha* test at Crane-Washington. The marriage of the two techniques into a synchronous packaged solution for energy and waste reduction in the metal casting industry is the **innovation** that must be proven at multiple test sites (industrial partners) so that the "system" will be adopted to the metal casting industry.

RESEARCH OBJECTIVES

The general focus of this project is to field test the TAA/PM² in a number of operating foundries, proving that the adoption of such soft technologies will enhance the value of energy and promote its wise use by metal casters through improved manufacturing efficiencies and a long term program targeted at industrial modernization and growth. Quality improvement and scrap reduction are a significant factor in reducing energy consumption through the savings of energy required to remake parts classified as scrap, with further reductions resulting from equipment improvements and maintenance.

METHODS OF ACCOMPLISHMENT

The TAA of the facility and process has three objectives: productivity improvement, waste reduction, and energy efficiency. The underlying premise to this approach is that the three objectives are interrelated, and that simultaneous evaluation will produce synergistic results. Ultimately, it is felt that the TAA approach can motivate an industry to make improvements it might not otherwise pursue were it focused on singular objectives. Conceived as a "holistic assessment" of a facility or process, the TAA is a formal process to identify targets of opportunity for productivity enhancements and cost reductions.

The PM² phase of the project involves improving foundry efficiencies through process management and quality program initiatives. PM² is integral to organizational structure and job responsibilities; quality audit and testing procedures; raw material specifications; equipment maintenance specifications; and work instructions and employee training.

The *Alpha* test showed that energy usage per ton of shipped castings can be reduced by improving energy efficiency in existing processes and reducing scrap. Waste reduction was best achieved by reducing scrap and minimizing consumption of new materials that will eventually become waste. Every metal casting facility is different. Some are large operations employing hundreds or thousands of employees while other facilities have only a handful of workers. The larger organizations typically have better control and experience in squeezing every last dollar of profit. The smaller and

medium size organizations have not typically developed this expertise. Since energy costs are one of the larger expenses, they are therefore a good target for maximizing profit and at the same time conserving our natural resources.

The TAA/PM² process is a managerial tool for change. It gives the organization the information and techniques necessary for being more profitable. The increase in profits is a result of improved manufacturing efficiencies that utilize energy consumption more efficiently and reduce scrap, a direct result of the synchronous adoption of TAA and PM² techniques into the management tools of the organization.

This project will field test the soft technology in a number of varied foundry operations so as to build a knowledge base of results that can influence the metal casting industry to adopt the TAA/PM² synchronous solution package for the improved utilization of energy resources and reduction in their waste with a bottom line improvement in profits.

White Papers

Initiating Proof of Concept and Lease
Financing Interactions

INITIATING PROOF-OF-CONCEPT AND LEASE FINANCING INTERACTIONS THROUGH THE IOWA FOUNDRIES GROUP

B. 50

The Iowa Foundries Group (IFG) is a centralized marketing alliance of 8 separately owned and operated foundries that employ between 10 to 87 each. Through IFG, the member foundries participate in a joint marketing and sales program which allows them to consolidate a broad array of metal casting capabilities under a single-source identity. IFG was originally formed in December 1994 with assistance and guidance from the University of Northern Iowa's (UNI) Market Development Program (MDP), the Iowa Manufacturing Technology Center (IMTC), and the UNI Metal Casting Center (MCC). IFG has since emerged as a limited liability partnership, operating solely at the direction of its participating foundries.

Proposal Summary

According to a 1993 survey conducted by the MCC (sponsored by the U.S. Department of Energy) access to investment capital was indicated most often as the primary factor limiting the adoption of new technologies by small metal casters. It is proposed herein that, in addition to centralized marketing, IFG also serve (at arms-length from its members) as an *investment* platform to draw financing for commercialization (by members) of emerging process technologies.

IFG has the potential to consolidate a capital base on behalf of its members while at the same time retaining discrete ownership and operation of individual units. IFG associates a united cash flow from which investment identity, economies-of-scale, and risk diversification can be employed to a greater degree than each member can experience individually.

The concept proposed herein integrates university supported proof-of-concept (prior to commercialization), private investment revenue drawn through the IFG platform, and lease-based financing of emerging technologies to individual members of IFG.

Proof-of-Concept

With university support and facilities, it is proposed that IFG members participate in proof-of-concept activities using time-shared access to working technologies that are not commercially common, but are proven beyond a theoretical stage of development. Such access is intended to physically acquaint individual members with the technology *prior to committing any significant capital investment*. During that time, the MCC will implement activities designed to demonstrate the appropriateness of a particular technology for each unique operating environment by allowing members to pre-define operating parameters, advance learning curves, and plan commercialization strategies, without binding them to the risk of long-term capital investment. When applicable, nominal fees paid by IFG members will be leveraged as cost share against potential state or federal modernization programs.

Proof-of-Concept significantly reduces investment risk, and along with it, the cost of financing commercialization. Conceivable loss to any one particular member is proportionately reduced by the number of active participants. The evaluation period also provides a learning curve interval in which members can phase in various applications of the technology, pre-define operating requirements, train staff, and adapt management/marketing strategies which facilitate full commercialization.

The initial period following the introduction of a new process is typically a time when acquisition costs are disproportionately high, as vendors recover development costs and advance their own learning curves. However, it is also a time when commercializing organizations can most readily establish market leadership derived from applying the process. Timing proof-of-concept activities during the initial period of high cost, before the process has become an accepted industry standard, is an essential aspect of the modernization activities proposed herein.

Commercialization Financing

Emerging technologies which demonstrate *proven* returns for individual members (and subsequently IFG) will be commercialized through the member organizations *following* the proof-of-concept period. IFG will finance commercialization by selling sufficient equity *in itself*, to sponsor investment by each individual member. Equity in IFG will be backed by *lease* obligations from its members, and will be periodically sold to raise sufficient revenue for on-going commercialization of other prospective technologies. In effect, IFG will serve at arms-length by selling the rights to (a share of) the revenue obligations drawn from the (combined) commercial applications of each individual member.

Maintaining centralized equity *diversifies* residual investment risk by concurrently distributing it over several detached organizational units and product applications at once. This allows underwriting to be technology specific as opposed to organization specific. It allows IFG to focus a broader asset base on initial commercialization of the *technology*, and simultaneously narrows each member's credit liability to that outlined in the lease obligation.

Because they will be backed by diversified revenue commitments, IFG earnings will be sold at significantly reduced risk, compared to other equity securities. As a result, equity would most probably draw relatively high Price/Earnings. When applicable, debt leveraging and options may also be incorporated.

Lease terms will be defined to sustain a long-term balance which establishes proportionate return for members, while at the same time attracting competitive, low-risk equity capital. Members will retain discretionary authority in determining individualized pricing structures of each specific application. Profit interests will be drawn from increased production efficiencies which will be identified during the proof-of-concept. Tying the individual member's cost of technology to a lease obligation directly correlates payment with cash flows, and at the same time, sustains a general cycle of modernization by limiting the useful life of the technology. In essence, the core business of the members will remain focused on the production of castings, however it will be supported by the core business of IFG which will focus long-term technical, financing, and market positioning for its members.

The following, summarizes a conceptual example of how IFG could leverage the consolidated strength of its members through a commercialization activity.

Long Term Positioning of Digital Tooling

For illustration, assume that the first IFG modernization initiative will focus the proof-of-concept and commercialization of Digital Tooling (analogous to a three-dimensional facsimile) through the integration of solidification modeling, rapid prototyping, and alternative tooling technologies. The components of the technology are presently in early stages, yet they are advanced to a stage where commercialization can begin.

The (combined) technology will facilitate the conversion to production tooling of digitized CAD files which can ultimately be transmitted from globally unlimited Internet sites, storage bins, and archiving entities. In the short-term, not only will it reduce the time and cost of tooling, but it will also stimulate faster conversions, lower-volume production, and establish direct connectivity to a global customer base.

The ability to download tooling will dramatically improve the logistical response of customers in meeting irregular, geographically oriented demand, and will underscore the conceptual advantage that casting holds in producing multilateral full spectrum component designs in a single process conversion. The ability to wire CAD files to a geographic location, and have them cast (by an IFG member) near the demand-site, effectively eliminates the time, cost, and transportation energy that would have been required to ship the weight of value added components. It provides an initial stride toward offering near instant (regionalized) distribution to a globalized customer base (within the constraints of assembly and material handling requirements).

Digital transmission of tooling has revolutionary implications for the metal casting industry and the customer base which supports it. Enhanced tooling efficiencies will facilitate an advance into the arena of low-volume production, and will position liquid forming as one of the most versatile and responsive means of generating complex component designs. As a result, it is envisioned that member foundries will evolve toward smaller multi-locational processing operations, which service demand-sites geographically instead of from a specific product alignment.

Multi-targeted outsourcing by international marketing firms, supported by faster, less expensive tooling conversions, and lower-volume amortizations will more directly correlate supply to demand responsiveness. As the cost of the process is reduced, direct demand response for replacement of existing components also shows potential with the availability of three dimensional scanning equipment (currently available), and anticipated connections to global (CAD design) archiving entities.

By getting involved with digital tooling while it is still a relatively new technology, IFG has the potential of establishing early positioning leads and identity for its members. Establishing initial demand responsiveness and Internet connectivity should precede future modernization efforts by IFG. Completing the product spectrum with high-tolerance components (integrating dimensional control, thin-walled and investment casting techniques) should be investigated after establishing the enhanced versatility and responsiveness of digital tooling.

Conceptual Short-Term Justification of Digital Tooling

The reduction in costs resulting from digital tooling will be both straightforward and dramatic. The ability to generate complex precision patterns in hours instead of weeks, and convert them to plastic tooling in days, will immediately reduce the time associated with skilled craftsmen (or the outsourcing of tooling). Because of the dramatic savings in time, it is assumed that the proof-of-concept will indicate immediate cost savings equal to or in excess of the cost of specialized materials and a correlating amortization of the technology.

A reduction in the amortized tooling margin will result directly from any immediate cost savings, however the savings in time will generate the ability to re-allocate the costs of the technology to a larger base of output. Assuming that the short-term objective is to establish low-volume expansion, and that the cost of converting tooling between configurations will be negligible, maintaining a constant per-unit tooling margin will reduce the volume of each configuration required to break-even. An expansion into lower-volume will begin as a direct result of digital tooling.

A more significant cost advantage will occur in the long term. Because it is primarily a capital intensive process, the cost of incorporating digital tooling will likely decrease with time, as opposed to the cost of maintaining skilled labor, which will likely increase with time (cost of living adjustments). In order to stave off competition, technology vendors will tend to reduce their asking price as they recover initial research costs. (For example, if one platform is put into operation, the cost of development must be recovered exclusively from it. However, if multiple units are put into operation, the development costs are amortized proportionately.)

After the initial development costs are recovered, the costs of the technology will tend toward a margin competitive to the terms of alternative suppliers. Reductions in the cost of the technology will further the trend toward low volume, thus expanding the marketable base of amortization. Theoretically, this cycle could ensue until single unit volume is marketable for low-grade components.

In the early stages, the relative advantages of digital tooling will be more pronounced in the relatively complex design applications. Proportionately, the time required to print complex tooling will not be significantly different than that required to print simple shapes. In comparison, the difference in time and margin required to hand-craft equivalent tooling would be proportionately larger. With digital tooling, the margin on complex shapes could be reduced for competitive purposes, or a proportionately smaller volume could be cast to breakeven.

Proposed Development Scenario of Example Project

It is proposed that IFG (as a whole), enter into a project agreement with the University of Northern Iowa's Metal Casting Center (MCC) to pursue the integration and application of solidification modeling, rapid prototyping, and alternative tooling processes in the commercialization of digital tooling. The components of the technology are available in their early stages of commercialization, and they are advanced to a stage in which integration can begin. The MCC is organized to arrange access to the technologies, provide technical assistance, coordinate usage, and provide general project management.

The MCC currently has capacity to provide the solidification modelling and alternative tooling functions. Various rapid prototyping methods are accessible through private service bureaus, and could be outsourced through the project. The cost to IFG will be negotiated and based on the total level of activity, and the potential to match costs with government funding.

After establishing access channels, research will facilitate learning-curve advances for consortium members in the integration of the technology. Application and adaptation will be emphasized to define operating parameters and tailor the process to each IFG member's individual operating environment. Activities will be documented and reviewed to assist members in determining and justifying individual capacities, specifications, and cost parameters for long-term commercialization of the process.

Existing CAD files of active component designs will be submitted directly by members for solidification analysis using modelling software retained by the MCC. Joint analysis will be conducted to determine tooling specifications such as gating systems, parting lines, etc. Tooling designs will be generated from the solidification analysis and interpreted to digital prototyping code.

The development of physical tooling models will be generated from the digital prototyping code and outsourced to various service bureaus (depending on individual operating requirements) for conversion using rapid prototyping techniques. The model will be converted to production tooling and cast from appropriate tooling materials, contingent on expected production volume, cost and tolerance specifications, cell parameters, etc. Time and cost data will be collected for analysis relative to establishing on-site rapid prototyping and tooling functions at each of the members' facilities.

Feasible technical and financial parameters for individual platforms will be defined through several iterations of the aforementioned procedure. *The measurable technical objective will be to establish internet connectivity by the members, and generate a time reduction of 50-80% (at equal or better cost) for tooling development during the project period.* It is anticipated that revenue expansion generated through low-volume production will pre-cede cost reductions as technology providers amortize development costs and become more competitive. Targeted revenue expansion will be defined as part of the project, prior to commercialization.

Proposed Commercialization Format

Initial project funding will be required from IFG to support proof-of-concept activities which should require approximately one calendar year to complete. Sometime during proof-of-concept, IFG (with MCC support) will approach an investment banking organization for guidance in drafting a preliminary business plan and to begin soliciting investment revenue for commercialization.

Toward the end of the proof-of-concept (after individual cell parameters have been defined), total investment revenue required for commercialization at all sites will be quoted by respective technology sources (based on multiple purchases at conceptually reduced rates). Allowances for underwriting commissions, IFG operating capital, and potential default coverage for individual members will be added in, and individual lease fees will be defined which generate a marketable return on the proposed IFG asset base. The amounts will be integrated into a finalized business plan and

prospectus.

Each member will be asked to sign some form of revenue obligation, expressing commitment to the individualized lease rates. The letters will be used to back an equity issue in IFG to raise the needed amount. Language contained in the obligations will include provisions which shield the member's non-affiliated assets from potential default proceedings.

An equity (or preferred stock) issue will be placed through an investment banking firm to raise the capital required to commercialize the technology. (It may be beneficial to issue a combination of equity, debt, and options, depending on the opinions of members and the banking firm.) Such issue will sell rights to lease revenues in exchange for underwriting the IFG asset base. Because equity will be sold from IFG instead of the individual members, it places the risk of default at an arms-length from the individual member's business and will shield a other assets from foreclosure. It will also open a line of credit that may not otherwise be possible. The revenue obligations from members (including premium coverage for default) will likely generate an aggregated cost of capital comparable to a debt issue. Individual members will be invited to purchase shares of IFG equity.

It is anticipated that each commercialized capital platform will include a modem connection, affiliated hardware and software, a rapid prototyping function, and a plastic tooling cell on-site at each facility. Capacity for solidification modelling will most beneficially be maintained and supported at the IFG level on a fee-for-service basis between IFG and the members. The solidification modelling function will be common to all members, and because it requires significant (computer) processing capabilities, hardware costs would best be shared.

Licensing issues, software updates, and the retention of specialized expertise, can most readily be handled through the centralized IFG organization. Because it is situated in the digital phase of transfer, it can be located virtually anywhere, and accessed by members via modem. In addition, centralizing it facilitates customer interaction and dispatch through a single point of contact. It concentrates development of computing facilities and marketing identity which may eventually include billing services and various other overhead issues.

After an initial asset base is established, it is proposed that the concentrated IFG equity base support leveraged iterations of further modernization focusing development of thin-wall, investment, clean metals, and dimensional control oriented casting procedures prior to conducting customer service and site positioning research. IFG may eventually consider underwriting whole facility expansions for its members.

DEMAND-SITE PROCESSING

- * Contrary to import/export model
 - * As manufacturing migrates toward low-wage areas,
 - Goods are imported to U.S. and
 - Domestic labor rates become less competitive.
 - * As competition for labor in underdeveloped areas increases,
 - Wages rise,
 - Foreign markets expand, and
 - U.S. exports increase.
- * Eventually, a global wage equilibrium will evolve.
 - Increased overall consumption will generate commodity price inflation, and
 - Transportation energy and
 - Raw materials will increase as a percentage of manufacturing cost.
 - Recycling.
- * Also, as technology improves process efficiency,
 - Manufacturing will become less wage dependent.
- * The most efficient value added region will emerge nearest to the end-use (demand) site using
 - Technology intensive,
 - Low volume, convertible output from
 - Less capitalized, process specific facilities which are
 - Geographically organized to service cross market and
 - Minimize transportation, inventory, financing, and obsolescence risk.
- * Emerging technology will
 - Decrease wage dependence, and
- * Increased industrialization will generate
 - Material and energy scarcity.

* Conventional tooling

Intensive skilled Labor
Market restricted casting
Physically housed
Immobile

* Digital Tooling

Three dimensional facsimile

Solidification Modelling defines tooling configuration
Rapid Prototyping converts to physical negative
Expendable Tooling Materials provide variable (cost/benefit) volumes

Reduced duplication cost

Technology intensive
Amortization ripple

Digital archiving

Configurations instantly accessible anywhere (Internet)
Inter-process transportation eliminated
Direct market response

Programmed to end-use
Components instantly, anywhere

Regional casting centers

Less capitalized
Multi-product outsourcing
Volume/tonnage/alloy envelopes

* University/Industry interaction

Instigate
Facilitate
Finance
Support

White Papers

Iowa Communications Network/Industrial
Training

Document Purpose

The purpose of this document is to explain the proceedings of the University of Northern Iowa Metal Casting Center's (MCC) use of the Iowa Communications Network (ICN), satellite transmission, ISDN line, and Internet connection as part of the TRP Technology Deployment program. It is written for the purpose in providing a demonstrative model for advanced telecommunications techniques for future foundry training workshop programs for the National Institute of Standards and Technology Manufacturing Extension Program and associated technical societies. The two year span has brought a greater understanding of the interactive telecommunication technology to expand optional training methods for the foundries to a national level.

The MCC's mission is to improve the productivity and competitiveness of the operating metal casting industry through applied research, technology, education and assistance to business. In keeping with this mission, the ICN is an excellent tool in providing foundries with multidiscipline training programs related to the cast metals industry. Through the experience of using the ICN, the MCC has investigated and developed a methodology in offering telecommunication courses effectively and efficiently. For the next phase of the program, the MCC is expanding training base to the national level.

Interactive Telecommunications

The University of Northern Iowa Metal Casting Center utilized the Iowa Communications Network and alternative telecommunication systems in providing training programs and information seminars to assist small to medium sized foundries with foundry practices, technology transfer, engineering solutions, managerial skills, and environmental issues. By providing educational services for the foundry industry, small to medium sized companies have the ability to adapt and understand innovative technological advancements and principles that are essential to successful business practices.

Four telecommunication systems were investigated with the assistance of the Southeast Minnesota Community College, the Edison Materials Technology Center, the Great Lakes Manufacturing Technology Center, the Iowa Manufacturing Technology Center, and the Massachusetts Manufacturing Technology Center. The first method explored was the fiber optic telecommunication system. With this system, video and audio is transmitted via optical cables, providing clear, uninterrupted images and audio. The second alternative form investigated was satellite transmission. Though very expensive for dual uplinking and downlinking capabilities, satellite can provide equal quality video and audio but on a limited basis. Integrated Service Data Network, or ISDN, is a popular and inexpensive telecommunication system in providing training seminars to multiple intrastate location. Using standard modem and phone line connections, computerized video and audio are transmitted and descrambled at the receiver sites for image processing. Finally, an experimental trial was conducted to assess teleconferencing using Internet access and video emulation software.

The initial phase of the foundry educational program was directed towards a market analysis of the seminars and understanding the technical components of communication network and their

limitations. From the market study, a seminar assessment questionnaire was mailed to approximately 70 foundries located within and 75 miles from the border of Iowa, addressing issues related to sand casting, die casting, and supplier concerns. In this phase of the program, the MCC worked closely with The Cast Metals Institute located in Chicago, IL for assistance in locating high quality presenters. During this time, alternative telecommunication methodologies were investigated to assess the cost effective telecommunication arrangement for providing foundry seminar workshops on a national level.

In developing a training workshop, a seminar task worksheet was utilized to coordinate and streamline scheduling activities. A sample worksheet is provided in Appendix A. After a topic was selected and confirmation of speaker availability was secured, broadcast receiving sites were attained along with determining the mode of teleconferencing transmission with the participating organizations. A mailing brochure was designed to promote the training workshop in addition to organizing promotional activities with key participating MTC personnel. Seminar attendee materials were concurrently developed and produced to provide additional reference training materials for the audience. During the seminar, staff from the MCC provided assistance with operating the presentation equipment, coordinated workshop broadcast production, and managed seminar time to deliver the highest quality teleconferencing workshop. Afterwards, each seminar was evaluated for course material, course content, teleconferencing quality, and speaker skills assess the effectiveness of the training workshop using an evaluation form shown in Appendix B.

Training Benefits

A critical component in providing cost effective training is the distance for travel in sending an employee. This can be translated into savings from increased employee productivity, education cost, and training value. For the state of Iowa, the Metal Casting Center determined from foundry concentration survey that it could service all foundries by strategically securing broadcast sites within a 30 minute drive from any foundry. To illustrate the immediate training benefits from teleconferencing training workshop, a cost analysis is presented accounting for direct training expenditures.

For the cost analysis, it is assumed that the same seminar courses offered by the Metal Casting Center is of the same material content, expenditures, and time as that which could be obtained by the technical societies in Chicago. The chart below shows the cost breakdown for attending a three hour seminar. A registration fee of \$50 per person is charged to compensate for expenditures such as printing, refreshments, site fees at all fiber optic locations, and intrastate telecommunication connections. Travel expense assumes automobile travel calculated at a rate of \$0.25 per mile for an average total driving distance of 540 miles (Waterloo to Chicago). It should be noted that air travel and farther driving distances will increase travel expenses. Since the average travel time from Iowa to Chicago by automobile is approximately five hours, an employee would have to stay at hotel, based on an average weekday rate, the previous night before. For meal expenses, a rate of \$5.00 for breakfast, \$7.00 for lunch, and \$13.00 for dinner was used for the analysis.

Cost Break-Down of ICN and CMI Courses

CMI Course in Chicago

ICN Fee

Registration Fee	\$50.00	Registration Fee	\$50.00
Travel Expense	\$135.00	Travel Expense	\$10.00
Hotel	\$90.00	Hotel	\$0.00
Meals	<u>\$38.00</u>	Meals	<u>\$12.00</u>
Total Cost	\$313.00	Total Cost	\$72.00

For the contract period, fifteen seminars were arranged and coordinated by the Metal Casting Center with the assistance of the Cast Metals Institute and the Manufacturing Technology Centers. The breakdown per seminar is given below using the calculated savings per attendee of \$241. For the year, the total cost savings to the metalcasting industry are estimated to be \$75,521. It should be noted that the estimated savings figure does not include the economic benefits associated in utilizing the presented seminar information in the foundry operation or lost productivity from an absent employee for over night travel.

Estimated Savings By The Foundry Industry			
<i>Presentation Date</i>	<i>Presentation Topic</i>	<i>Attendance</i>	<i>Amount Saved</i>
5/2/95	Supervisory Skills	39	\$9,399
5/9/95	Reducing Sand Related Defects	45	\$10,845
5/16/95	Safety in the Foundry	24	\$5,784
5/25/95	Sand Reclamation	16	\$3,856
11/14/95	Using the Internet	8	\$1,944
11/28/95	Gating Systems	17	\$4,097
12/05/95	Cast Iron Metallurgy	7	\$1,701
12/12/95	Cost Analysis	11	\$2,673
2/06/96	Nonferrous Melting	24	\$5,784
3/29/96	No -Bake Binders	18	\$4,374
4/02/96	Cleaning and Finishing	16	\$3,856
9/26/96	Continuous Process Improvement	24	\$5,784
10/15/96	Cooling Curve Analysis	17	\$4,097
1/14/97	Solidification Modeling	38	\$9,158
4/2/97	Rapid Prototyping	24	\$5,784

Telecommunication Limitations

Through the course of the program, limitations of existing telecommunication technologies were continuously monitored and identified. Today's national telecommunication infrastructure is constructed with a variety of state funded information systems. This attributes to the bulk of encountered limitations when designing and coordinating interactive training workshops.

By far, the fiber optic teleconferencing system provided impeccable broadcast quality. Compressed digital imaging is not impeded from processing equipment and connection limitations. Because a large amount of data can be transferred quickly over fiber optic cables, true interactive teleconferencing can be achieved with superior audio and video clarity at an inexpensive cost.

ISDN lines, an older and inexpensive telecommunication network, provided a cost effective method for conducting interactive workshops with external agencies. Charges for phone connection and long distance phone charges mounted to around \$300 per hour. The limitation of using ISDN line was strongly dependent on image processing equipment. Systems that used slower modem connection speeds resulted in poor image quality, particularly when presenters used on-line drawings and illustrations. As technology for faster modems and microprocessors continues to expand, problems with processing compressed images and bandwidth will become negligible for ISDN lines.

Limitations of satellite transmission were attributed to the large cost associated with providing interactive workshops. To conduct a true interactive workshop program, both the broadcast and receiving sites must be connected to the appropriate satellite. This results in uplinking and downlinking charges for both sites, mounting to over \$2400 per hour. Though cost prohibitive for single receiving sites, satellite transmission was identified as an effective communication tool for outreaching to a large, dispersed audience.

One innovative telecommunication technology that shows promise is Internet accessibility. Presently, video emulation software programs are commercial available for processing compressed transmitted video information. With this method, a workshop attendee can sit in front of a personal computer at their desk and view the seminar. For the PC-based computer, this type of telecommunication methodology is severely restricted to modem speed, computer processing hardware, and Internet connection. Additionally, audio connection with multiple broadcast recipients can not be established and is only technologically feasible for a small, restricted audience.

Summary

The Metal Casting Center is the leading pioneer in employing the Iowa Communication Network for educating the 62 Iowa foundries with best practice principles and emerging technologies. National interest has shifted towards the Iowa Communication Network coupled with alternative teleconferencing systems in providing high quality foundry courses. Keeping current with new communication technologies coupled with Iowa Communication Network will be a critical factor in continuing this type of education for the national foundry industry and the technical societies.

SEMINAR EVALUATION

B. 63

University of Northern Iowa Metal Casting Center

DATE OF PRESENTATION:

TOPIC OF PRESENTATION:

PLACE OF PRESENTATION:

PARTICIPATING ORGANIZATION:

PRESENTERS:

Please help us improve the quality of our seminar presentation by providing your subjective evaluation of each part of the seminar experience. Please circle the appropriate number on the 5-point scale adjacent to each statement shown below. 1 represents ineffective; 5 represents highly effective

1. WORKSHOP PRESENTATION

A. Introduction	1	2	3	4	5
B. Stated Purpose and Objective	1	2	3	4	5
C. Workshop Overview	1	2	3	4	5
D. Sequencing of Presentation	1	2	3	4	5
E. Continuity of Presentation	1	2	3	4	5
F. Use of Visual Aids	1	2	3	4	5
G. Overall Organization of Presentation	1	2	3	4	5

2. SEMINAR CONTENT

A. Organization of Content	1	2	3	4	5
B. Content Relevant to Audience Needs	1	2	3	4	5
C. Content Appropriately Sequenced	1	2	3	4	5
D. Continuity of Content	1	2	3	4	5
E. Appropriate Level of Understandability	1	2	3	4	5

3. INSTRUCTIONAL MATERIALS

A. Quality of Visual Aids	1	2	3	4	5
B. Content of Visual Aids	1	2	3	4	5
C. Quality of Workshop Materials	1	2	3	4	5
D. Content of Workshop Materials	1	2	3	4	5

4. SEMINAR PRESENTERS

A. Professional Appearance	1	2	3	4	5
B. Professional Manner and Deportment	1	2	3	4	5
C. Competence in Subject Matter	1	2	3	4	5
D. Verbal Communication Skills	1	2	3	4	5
E. Workshop Management	1	2	3	4	5
F. Interpreting Audience Questions	1	2	3	4	5
G. Answering Audience Questions	1	2	3	4	5
H. Interaction/Discussion With Audience	1	2	3	4	5

5. OVERALL RATING OF PRESENTATION

1 2 3 4 5

COMMENTS:

UNIVERSITY OF NORTHERN IOWA
METAL CASTING CENTER
SEMINAR/TASK WORKSHEET

B. 64

Seminar Title _____

Seminar Manager _____ Seminar Date _____

Seminar Location _____

TASK	LEAD TIME (weeks)	DUE DATE	DONE- BY login	DATE DONE
12 Weeks Prior To Event, But Not Less Than 8 Weeks				
Determine seminar date	8-12			
Determine seminar location & reserve rooms	8-12			
Confirm availability of speaker(s)	8-12			
Send confirmation letter to speaker(s), reiterating the place, time and topic	8-12			
Obtain speaker agenda	8-12			
Prepare presentation agenda for multiple speakers	8-12			
Determine method of announcement	8-12			
Design brochure (<i>longer lead time required for brochure that goes to printer</i>)	8-12			
Obtain biography information from speaker(s)	8-12			
Determine audience and make provisions to obtain mailing labels	8-12			
Set-up registration process	8-12			
Determine staff member to host event	8-12			
Determine PR to use (<i>advertisements, announcements, press releases, etc.</i>)	8-12			
Develop seminar attendee materials (<i>overheads, binders, etc.</i>)	8-12			
Brochures to printer or to be copied	8			

UNIVERSITY OF NORTHERN IOWA
METAL CASTING CENTER
SEMINAR/TASK WORKSHEET

B. 65

Seminar Title _____

Seminar Manager _____ Seminar Date _____

Seminar Location _____

TASK	LEAD TIME (weeks)	DUE DATE	DONE- BY login	DATE DONE
6 Weeks Prior To Event, But Not Less Than 4 Weeks				
Order seminar materials (<i>binders, tabs, etc.</i>)	4-6			
Mail out brochures, announcements	4-6			
Determine menu	4-6			
Send brochure, other pertinent information to speaker	4-6			
Begin to process registrations, send confirmation letters, etc.	4-6			
Send out press releases, announcements	4-6			
3 Weeks Prior To, But Not Less Than 2 Weeks Before The Event				
Produce attendee materials (<i>make copies, etc.</i>)	2-3			
Obtain master set of overheads, slides, or handouts speaker(s) will use in their presentation	2-3			
Determine room set up	2-3			
Determine audio visual equipment needed and order	2-3			
Mail out second mailing	2-3			
Do telemarketing	2-3			
Order Food	2-3			
Week Prior And Up To Start Of Event				
Make Sign to direct attendees	1			
Make name badges, attendee lists, etc.	1			
Check working condition of AV equipment	1			

UNIVERSITY OF NORTHERN IOWA
METAL CASTING CENTER
SEMINAR/TASK WORKSHEET

B. 66

Seminar Title _____

Seminar Manager _____ Seminar Date _____

Seminar Location _____

TASK	LEAD TIME (weeks)	DUE DATE	DONE- BY login	DATE DONE
Create & copy evaluation form	1			
Put together all attendee materials (<i>include MCC brochure</i>)	1			
Call in "count" to caterer	1			
Finalize registration procedures, check-in, food set-up, etc.	1			
Make arrangements for speaker, if necessary	1			
During Event				
Have registration area, materials and room set-up several hours or night before event (<i>including signage</i>)				
Have promotional information about MCC readily available				
Have host give basic information during introductions (<i>location of phones, restrooms, break times, upcoming events, evaluation forms</i>)				
Follow the agenda and stay on time				
Take pictures of speaker(s) & audience				
Video tape event for future use (optional)				
After Event				
Collect evaluation forms and summarize for feedback				
Send follow-up letter to attendees				
Distribute leads for follow-up				
Send thank you note to speaker				

White Papers

Polyphosphazene Binder Substitute
Investigation

*Research Proposal***Polyphosphazene Binder Substitute Investigation**

*submitted by
Dr. Scott R. Giese
Steve Schneider*

EXECUTIVE SUMMARY

A seven month research effort is proposed by the University of Northern Iowa Metal Casting Center to the Idaho Engineering and Environmental Laboratory for submission to Associated Western Universities Fellowship Program. The proposed research approach builds upon an ongoing Department of Energy funded technology transfer program endorsed by the American Foundrymen's Society and sponsored by the Associated Western Universities. The objective of the research work is to determine and assess the use of polyphosphazene bonded sand cores on casting quality. A comparative analysis will be utilized to ascertain the surface finish, defect formation, and dimensional accuracy for a variety of commercial casting alloys. As a result of the investigation, the research program identifies the feasibility and applicability of substituting the inorganic sand binder for presently used organic sand binder systems.

TECHNICAL BACKGROUND

Ongoing research work by the University of Northern Iowa Metal Casting Center researchers have focused their applied research and technology deployment efforts on performing comparative analysis study of the core tensile strength property between a phenolic urethane organic sand binder system and a polyphosphazene inorganic binder system. In this investigation, the polyphosphazene polymer synthesized by the Idaho National Engineering and Environmental Laboratory was substituted for the phenol functional group in the phenolic urethane organic binder system. For the standard control group, phenolic urethane cores were made with an AFS GFN 58 washed silica sand. The total organic binder used was 1.25% of the total weight of the sand cured with 8% catalyst of the total weight of the mixed binder. For the experimental group, the polyphosphazene resin was combined with the organic isocyanate resin using conventional sand mixing techniques and catalyzed.

Initial testing of the polyphosphazene binder using the same binder and catalyst ratio as used with the phenolic urethane cores showed poor tensile strength properties. The following experiments doubled the resin parts and catalyst and exhibit comparable tensile strength properties as shown in figure 1. As indicated in the figure, development of the tensile strength for the polyphosphazene binder gradually increased at the beginning but showed a similar curing relationship beyond the 12 hour cure time. After a 24 hour cure time, the polyphosphazene binder exhibited approximately 75% of the phenolic urethane binder system core tensile strength property.

Figure 1. Graph shows the core tensile strength as a function of curing time for a phenolic urethane sand binder system and phenol substituted polyphosphazene sand binder system.

PROPOSED RESEARCH PROGRAM

The proposed research work is directed toward evaluating and determining the effect of the polyphosphazene sand binder on surface finish, defect formation, and dimensional accuracy for several commercial casting alloys. Laboratory experiments are designed to assess the inorganic binder compatibility with the following casting alloys: class 35 gray iron, 80-55-06 ductile iron, low carbon steel, A356 aluminum, and Sebiloy low lead brass. A comparative analysis study is proposed using a phenolic urethane organic binder as the standard experimental control group to ascertain casting quality of the polyphosphazene inorganic binder.

A cylindrical core positioned symmetrically in a cylindrical mold print is employed in the proposed experimental design to explore the casting quality of the polyphosphazene binder. To form the cylindrical mold cavity, the green sand (silica sand, clay, and water) molding technique using a jolt squeeze molding machine is proposed. After completing the green sand mold, the experimental core is inserted into the formed core print prior to the final assembly of the flask. Depending on the casting alloy, the water content of the appropriate green sand mixture can be adjusted for maximum compatibility and hardness, minimizing potential distortion of the final cast cylinder. During experimentation, three standard core tensile strength dogbone specimens will be produced to characterize the core properties during casting.

After casting, the cast cylinder will be removed with the tested core intact. The core material will then be removed and initial observation for sand penetration will be done. Sand blasting of the cylindrical casting to remove any remaining core material will be performed and visually inspected for surface quality. The casting will then be transferred to a coordinate measuring machine to assess dimension stability of the core. If warranted, the casting can be sectioned to perform a detail defect inspection for veining and blowhole defects. An industrial sponsor will be solicited to determine nitrogen and phosphorus absorption from the decomposition of the core for ferrous castings only.

Upon completion of the experimental work, a detail report will be submitted to the Idaho National Engineering and Environmental Laboratory discussing the experimental procedures employed in the proposed research work, a discussion of results, and significant conclusions and recommendations for substituting the polyphosphazene inorganic sand binder. The final report

will be submitted for presentation at the American Foundrymen's Society Casting Congress to develop a research relationship with foundry resin producers and consumers.

STATEMENT OF WORK

The following statement of work outlines the activities, milestone and deliverables for the collaborative research program with the Idaho National Engineering and Environmental Laboratory and the University of Northern Iowa Metal Casting Center.

1. Collection of Experimental Equipment and Materials

- 1.1. Construct pattern and core box tooling.
- 1.2. Synthesize polyphosphazene binder (INEEL).
- 1.3. Secure casting alloys.
- 1.4. Develop appropriate green sand mixtures for corresponding alloys.
- 1.5. Condition green sand mixtures and perform standard AFS mold quality tests.

2. Laboratory Trials

- 2.1. Develop experimental methodology approach for cylindrical cores
 - 2.1.1. Surface finish
 - 2.1.2. Casting surface defect analysis
 - 2.1.3. Dimensional accuracy using coordinate measuring machine
- 2.2. Conduct laboratory trials
 - 2.2.1. Polyphosphazene binder
 - 2.2.2. Phenolic urethane binder
- 2.3. Analyze casting quality data

3. Reporting

- 3.1. Program monthly status reports to INEEL
- 3.2. Final Report to INEEL and AWU

White Papers

**Semi-Solid Casting of Fiber-Reinforced
Mg Composites**

Semi-Solid Casting of Fiber - Reinforced Mg Composites

A proposal for a cooperative program between university, industry, and government laboratory personnel.

Prof. Scott Chumbley, Ames Laboratory / Iowa State University

Prof. Alan Russell, Iowa State University

Dr. Scott R. Giese, Dr. Yury Lerne, Dr. Fred Vondra, University of Northern Iowa

Mr. Ken Clark, Fansteel-Wellman Dynamics

Mr. Roger DeBruyne, Bekaert Fibre Technologies

Introduction

Automobiles of the future are expected to contain increasing amounts of light-weight alloys to meet performance objectives. While today's automobiles rely primarily upon ferrous alloys for the majority of structural and engine components, increased usage of aluminum and magnesium alloys is desirable in the transportation vehicles of the future to reduce weight and increase fuel economy. Current Al and Mg alloys do not possess the same attractive combination of strength, formability, ease of joining, recyclability, and low cost as do iron-based alloys. Gains must be made in these areas if Al and Mg alloys are to be successfully utilized.

Mg is an attractive candidate for castings due to its high fluidity and its very low density. Use of Mg alloys to produce large rotating components such as wheels or gears could potentially achieve large improvements in vehicle efficiency. However, traditional Mg castings have lower than desired mechanical properties and poor performance at elevated temperatures.

We believe the technology now exists to produce Mg-castings of superior mechanical properties suitable for elevated temperature use. This process must be relatively simple to produce large numbers of castings cost-effectively.

Collaborations and Expertise

The proposed work is a collaborative research effort between the University of Northern Iowa Metal Casting Center (UNI), Iowa State University (ISU), Ames Laboratory (AL), Fansteel-Wellman Dynamics Inc. (FS-WD), and Bekaert Fibre Technologies (BFT) of Belgium. Personnel at ISU and AL have been investigating fiber-reinforced composites for a number of years with considerable success. FS-WD is a commercial Mg casting facility located in Creston, Iowa that manufactures high-grade Mg parts for military aircraft. BFT is a primary manufacturer and supplier of metallic fibers.

In anticipation of the successful completion of the first phase of this project, discussions have already taken place between the UNI and ISU investigators and personnel at the Idaho National Engineering and Environmental Laboratory to extend the scope of the program. The goal of this additional collaborative effort would be to establish process monitoring techniques to control the proposed casting method, making it more suitable for introduction into a manufacturing environment.

Background

Researchers at AL have been investigating the production of deformation processed metal matrix composites (DMMC) based on a number of alloy systems [1-4]. Exploratory studies on Mg-based composites found that the strength of Mg could be improved by producing castings containing an immiscible fiber material (Ti, Nb, or Fe) as a second phase. Most notable in these studies was the discovery that the strength of these alloys remained high, especially for the Ti-reinforced composites, even after prolonged exposure to temperatures of 400° C for 500 hours (see Figure 1) [3,4]. These studies suggest that if suitable fibers could be introduced into cast Mg parts and if a fine dispersion is obtained, a superior casting would result. Solid fibers added to a molten Mg bath would settle rapidly; however, a suitable dispersion might be obtained if the fibers could be introduced into Mg in the semi-solid state.

The rheocasting (or thixocasting) process is a potential method to incorporate and uniformly distribute fibers for producing a reinforced magnesium matrix composite. In this process, the strengthening phase would be introduced into a metallic slurry by mechanically entrapping the fibers amongst the primary solid particles. A semi-solid can then be processed into a final part by simple casting or by a combination of casting and forging techniques.

Figure 1 - Change in ultimate tensile strength for Mg-20Ti deformation processed composite ($\eta = 4.5$) after exposure to 300° C and 400° C for 500 hours. Similar results were obtained with Nb and Fe fibers.

Several processing variables control the distribution of the particulates within the matrix. Even though experiments have shown excellent wettability properties between the particles and Mg matrix, the rate of addition and stirring still plays a significant role in preventing agglomeration of the particulates. Particle entrapment can be enhanced by refining the size of the primary solid particles in the slurry or by holding the initial melting temperature. Numerous process parameters need to be investigated to determine the viability of this method for the high volume manufacture of reproducible castings.

Experimental Approach

Because of the reactive nature of magnesium with oxygen, special precautions will be considered during the processing and transferring of magnesium matrix composites. Since semi-solid casting is possible with large freezing range, two-phase alloys, commercial alloys supplied by FS-WD will be used for the investigation. For the initial tests, the Mg alloy AZ91 (9.0% Al, 1.0% Zn, 0.2% Mn, remainder Mg) and commercial titanium fibers supplied by BFT will be used. To ensure good wetting of the fibers they will be cleaned at AL, sealed in an argon atmosphere to prevent water contamination and oxidization, and delivered to UNI. Due to their considerable experience, personnel at FS-WD will lend technical assistance to UNI during the casting phase of the program.

In the proposed work, a continuous slurry mixer located at the Metal Casting Center at UNI will be utilized to manufacture magnesium-titanium fiber reinforced billets. A schematic illustration of the continuous slurry mixer is shown in Figure 2. A two chamber heating furnace will be modified to melt within the furnace chamber to eliminate atmospheric exposure of the molten magnesium in transfer. Melting will be prepared in a steel crucible in an induction furnace under a protective atmosphere. A resistance heating furnace is positioned above the induction furnace to assist in maintaining temperature control during the slurry mixing cycle.

After the metal is melted and superheated to 700°C, the furnace temperature controller will be adjusted to gradually cool by 5°C/min from the preheated state to the partially solidified state. The experimental solid to liquid ratio will be determined and maintained constant at this temperature through completion of titanium particle addition. After the desired solid fraction is reached, the predetermined volume fraction of titanium fiber particles will be introduced into the melt using the protective atmosphere flow stream as the carrier agent. The addition rate can be regulated by the flow of gas. The particulates will be mechanically stirred with a stainless steel rotor at a predetermined mixing rate. The semi-solid composite

material will then be cast into a steel ingot mold with a flux cover positioned under the furnace chamber nozzle. Experiments will be conducted to assess the processing variables of titanium particle size, particulate addition rate, and primary solid volume fraction to study the effect of solidification processing on the microstructure of the composite ingots.

Mechanical testing and microstructural examination will be performed at ISU and AL. The as-cast ingots will be sectioned, polished, and metallographically examined to characterize the microstructure and particle distribution. Since a commercial AZ91 alloy will be used, it will be necessary to subject the as-cast specimens to a T4 solution heat treatment for dissolution of the eutectic β phase to reveal the grain boundaries. Scanning and transmission electron microscopy (SEM, TEM) equipped with energy dispersive spectrometers (EDS) will be employed to analyze the castings and study possible particle/matrix interfacial reaction products. Beside conventional material characteristic tests, nondestructive sound frequency tests for Young's Modulus and Poisson ratio determination will be conducted. FS-WD will also conduct standard industry tests on parts supplied to them for that purpose.

Figure 2. Schematic illustration of continuous semi-solid furnace and mixing chamber.

References

1. J.D. Verhoeven, W.A. Spitzig, L.L. Jones, H.L. Downing, C.L. Trybus*, E.D. Gibson, L.S. Chumbley, L.G. Fritzemeier, and G.D. Schnittgrund, "Development of Deformation Processed Copper-Refractory Metal Composite Alloys," *J. Mater. Eng.* (1990) 12:127-139.
2. A.M. Russell*, T.W. Ellis*, and L.S. Chumbley, "In-situ Strengthening of Titanium with Yttrium", *J. Mater. Sci.*, 30 (1995) 2070-2076.
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4. J.A. Jensen, A.M. Russell, T.W. Ellis, and L.S. Chumbley, "HCP Matrix In-situ Composites", *Trace and Reactive Metals: Processing and Technology*, TMS/ASM, Las Vegas, NV, Feb 1995. Also published in *Light Metals 1995*, TMS, Warrendale, PA, 1995.

Budget

B. 75

The estimated costs for the program are shown below. A three year program is proposed with all the participants agreeing to provide some services and salary support as in-kind cost sharing contributions. In addition, we will seek industrial support in exploring the engineering potential of the titanium-magnesium matrix composite can be secured through a state supported grant sponsored by the Edison Materials Technology Center.

Budget Item	Year 1		Year 2		Year 3	
	costs	in-kind	costs	in-kind	costs	in-kind
a) Personnel						
Principal Investigators (S. Chumbley, A. Russell, S. Geise, Y. Lerner, F. Vondra)	30K	20K	32K	20K	15K	20K
Graduate Students (2)	40K		42.5K		45K	
Industrial Assistance (K. Clark)		10K		15K		20
b) Benefits						
≈ .21 x faculty salary	6.3K		6.7K		3.2K	
\$750 / grad student	\$1.5K		\$1.5K		\$1.5K	
c) Materials, Services, and Travel						
alloys melt stock	5K	2K	6K	3K	6K	5K
fiber material	5K	2K	6K	3K	6K	5K
microscope time	2K	5K	4K	5K	6K	5K
analytical services	5K	2K	2K	2K	2K	2K
Travel	3K		3K		2K	
d) In-direct Costs (Overhead)	40K		42.5K		35.5	
≈ .41 x (a+b+c)						
Equipment						
Modifications to semi-solid caster	15K		5K			
Project Funding						
Cost-Sharing		41K		48K		57K
Requested	152K		151K		122K	
TOTAL MATCHING (three years)	146K					
TOTAL REQUESTED (three years)	425K					

Cost sharing from FS-WD and BFT will be in the form of at-cost alloy and fiber material, technical assistance, and production and evaluation of industrial castings. These contributions are expected to increase during the course of the project, as are increased cost sharing for microscope and analytical services. The experimental work at UNI to develop the casting process is anticipated to be completed in the first two years of the project, requiring capital equipment expenditures and additional salary support during these years.

White Papers

Summary of State wide economic impact

*University of Northern Iowa
Metal Casting Center*

During the seven year period of initial formation of the Metal Casting Center (MCC), the State of Iowa has contributed through seed capital, project funding, and general appropriation, direct cash funding of \$1,441,046. The MCC has leveraged that to include an additional \$2,974,716 in federal cash revenues over the most recent five year period, which required over \$1,877,573 of in-kind support. Total direct investment to date has been \$6,293,335.

Available is a spread-sheet analysis outlining the calculations used to determine the economic impact that the MCC has had on the State of Iowa. It singles out two areas affecting the state's economy; the impact of stimulated economic activity resulting from MCC operations, and the impact of job creation.

Stimulated \$8.15 in Economic Activity for Each State Dollar Spent

Activity resulting from the influx of state and federal revenues into the local economy creates spending on goods and services, which gets spent and re-spent within the local economy, until its effect eventually fades. Various output multipliers, defined by source of revenue (state or federal civilian output), were provided by Iowa State University (ISU), and applied to determine aggregate economic impact. In aggregate, it was determined that *spending on MCC operations has stimulated approximately \$11.7 million in economic activity throughout the state, which represents approximately \$8.15 for every dollar of state support.* Initial state support is essential to providing the focal point for stimulating federal and industry spending, which amplifies the initial state investment.

Created 208 Jobs at an Average Cost to the State of \$6,908 Each

Aside from MCC staff jobs, it is estimated that, as a result of MCC activities, approximately 77 jobs have been directly created or retained within the state's metal casting industry. (A substantial proportion of these jobs were result of a single project funded by the Iowa Energy Center.) Using employment multipliers provided by ISU, it was determined that these jobs led to *total creation of 208 private-sector jobs, at an average cost to the state of \$6,908 per job.* Using the December, 1995 All Private Sector Average wage indicated in "Iowa Economic Trends," it was determined that \$3.8 million in *taxable* income was added to the state's payroll, generating *increased payroll tax revenues of \$203,389 each year.* Standard and estimated deductions were accounted for in the estimate.

Generate Annualized Return on Investment of 33.6%

Annualized cash funding provided to the MCC averaged \$198,764 from state sources during the initial seven year period of MCC development and growth, and \$585,574 from federal sources during the most recent five year period. Total liquid investment in the MCC averaged \$784,338 annually during the most recent five year period. When applying the ISU multipliers, average MCC funding spent within the state creates annualized economic activity of approximately \$1.5 million each year. Assuming that the state recovers 4% of this activity (through sales taxes, property taxes, MCC staff payroll taxes, etc.), it is estimated that *spending on MCC operations in itself generates an additional \$62,118 in state tax revenues each year.* When combining the increase in (private-sector) payroll tax revenue with the additional revenue resulting from MCC operational spending, it is estimated that *\$265,507 in tax revenues are added to the state treasury each year as a result of MCC activities. This equates to a 33.6% return on an average annual investment of \$198,764.* In other words, for every dollar invested in the MCC by the state of Iowa, a \$1.34 in revenues are recovered by the state's treasury.

White Papers

Topical Training Guide for the Foundry
Industry

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**UNIVERSITY OF NORTHERN IOWA
METAL CASTING CENTER
FOUNDRY TRAINING PROGRAM**

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White Papers

Use of Cryogenic Treatment to Enhance
Properties of Austempered Ductile Irons

**THE USE OF CRYOGENIC TREATMENT TO
ENHANCE THE MECHANICAL PROPERTIES OF
COMMERCIALY PRODUCED AUSTEMPERED
DUCTILE IRONS USED IN AUTOMOTIVE APPLICATIONS**

**Prepared by:
Mr. Gerard R. Thiel
Project Manager**

**Voice: 319.273.7085
Fax: 319.273.5959
e-mail: Thiel@Cobra.uni.edu**

OBJECTIVES

The primary objective of this research is to investigate the process of using cryogenic treatments (CT) to enhance the mechanical properties of commercially produced austempered ductile irons to be used in automotive applications as a lower cost, lower weight replacement of steel castings presently used. These conventional materials that only need refinement and optimization may serve as some valuable intermediate materials until high technology nonferrous composite alloys or other advanced materials can be fully developed.

BACKGROUND INFORMATION

Research programs conducted on cryogenic treatments for austenitic iron alloys have shown that dramatic mechanical property improvements of 25-40% are possible without an associated increase in hardness. Further studies have suggested that wear resistance of cryogenically treated materials have been improved in excess of 500% over non treated metals. Compiled data on various wear properties and case studies from actual industry applications show promising results of CT on both ferrous and non-ferrous alloys. In spite of the dramatic improvements in mechanical properties obtainable with CT, continued research and resulting industry acceptance has been limited to only a few selected alloys.

Utilizing cryogenic treatment, tensile properties and wear resistance of many materials can be improved to add to the range of applications these materials can fill. This improvement in mechanical properties has only recently been documented as the formation of submicroscopic carbides that neither raises the hardness of the material nor degrade the machinability.

Austempered Ductile Iron (ADI) is an alloyed and heat treated ductile cast iron with a similar composition to that of conventional ductile iron. Alloying elements such as nickel, copper and molybdenum are added to the ADI to enhance the matrix structure and enable the material to better respond to heat treat. The properties of the material are obtained by austempering (a specialized isothermal heat treatment) to impart a high degree of hardness, toughness and wear resistance to the cast parts. Although commercialized in the 1970's, ADI has failed to make a significant impact in terms

of usage. Originally developed to replace steel castings in many applications because of its lower production costs, lighter weight and superior castability, conventionally produced ADI has failed to match the mechanical properties of steel castings or forgings it was meant to replace.

RESEARCH TASKS / METHODOLOGY

A number of heats of austempered ductile iron will be cast and evaluated with respect to their mechanical properties in several conventionally treated conditions. Cryogenic treatments of these materials will then be preformed and the tests repeated. Enhancements to the chemical composition of the austempered ductile iron will be made to optimize the effects of the cryogenic treatments. Optimized mechanical properties for the cryogenically treated samples will be compared to commercially available steel castings and forging to evaluate possibilities for replacement.

ANTICIPATED RESULTS

It is expected that changes to the conventional manufacture and subsequent processing of austempered ductile iron will be required to maximize the full potential of the combined technologies. The successful completion of the project would allow automotive designers greater options for replacements of steel castings to reduce vehicle weight while lowering overall costs in near term applications.

FACILITIES AVAILABLE

The University of Northern Iowa has developed an extensive research facility on its campus. The industrial program began in 1904 and the foundry program, in 1956. In the last six years, the program has taken a quantum step forward in the building and equipping of our new Metal Casting Center. These newly acquired resources, combined with the other university support facilities, are available to support our proposed research projects.

In 1988, the MCC was founded and funds were dedicated to a new facility completed in 1991. Those contributing to the Center were UNI, which provided \$622,500; the State of Iowa, which granted \$465,000; and private industry, which supplied \$1,500,000 in equipment. With 5,500 square feet of

floor space, the Center for Metal Casting is located in a new building attached to the Industrial Technology Center at UNI.

The facility can utilize such current technology as green sand molding, shell molding, investment casting/lost wax molding, evaporative polystyrene molding along with die casting, permanent molding and the V-process and H-process. The melting capacity of the plant is 100 pounds of nonferrous material and 300 pounds of ferrous material. For more information <http://iscssun.uni.edu/metalcst/web>

INDUSTRY SUPPORT

For the last six years the Metal Casting Center has been an integral part of the foundry industry in Iowa and the Midwest. Direct assistance in consultation and technology integration to these foundries keep the center's staff "in tune" as to the needs and concerns of the industry we support. Applied research projects that address these needs have been supported by this industry with monies, donations and in-kind match. To date private industry has supported the center by providing an industry advisory board for center direction and planning, cost share funds, and more than two million dollars of donated equipment.

RESEARCH PARTNERS

Ames Laboratory is a government-owned, contractor-operated U. S. Department of Energy laboratory seeking solutions to energy-related problems through the exploration of chemical, engineering, materials, mathematical and physical sciences. Established in the 1940s with the successful development of the most efficient process to produce high-purity uranium metal for atomic energy, Ames Lab now pursues much broader priorities than the materials research that has given the Lab international credibility. Responding to issues of nation concern, Lab scientists are actively involved in environmental research, innovative scientific education programs, the development of applied technologies and the quick transfer of such technologies to industry. Ames Laboratory is managed by Iowa State University. Because of our relationship with ISU, the Lab atmosphere stimulates creative thought and encourages scientific discovery, providing solutions to complex

problems and educating tomorrow's scientific talent. All operations are conducted so as to maintain the health and safety of all workers and with a genuine concern for the environment. For more information <http://ams.ameslab.gov/ameslab/index.html>.

The Materials Preparation Center (MPC) is a DOE User Facility recognized for its unique capabilities in the preparation, purification, and characterization of rare-earth, alkaline-earth, and refractory metal materials. Established in 1981, the Center consolidates and makes available to scientists at university, industry, and government facilities the capabilities related to synthesis, processing, and characterization of advanced materials developed at Ames Laboratory during the course of its 40 years of basic research. The MPC is sponsored by the Materials Sciences Branch of the Division of Basic Energy Sciences, US Department of Energy. For more information http://www.ameslab.gov/mat_ref/mpc.html.

White Papers

**Wear Analysis of Foundry Tooling
Materials**

The Next Step - A Pilot Study

Introduction

For well over 30 years foundry personnel have been testing tooling materials to analyze their wear resistance to the harsh environment of molding and core making. Gouwens, Maier & Wallace, Helzer and Vondra have all made significant contributions to the study of materials and their resistance to wear phenomenon. Historically, most of the experimentation has been conducted in a laboratory setting although Gouwens attempted to correlate his laboratory data with actual information from a core blowing operation. Since then most of the experimentation has been done strictly in a laboratory setting. Also, it is only fair to mention that individual companies have conducted their own wear studies. However, this information is not readily available to the public.

Currently, a project is beginning where testing is to be conducted on the foundry floor as well as the laboratory to ascertain if the wear data generated in these two areas correlate. A test specimen has been designed, materials have been designated and the test patterns constructed. The AFS Pattern and Tooling (Division 7) Committee contributed toward the management, design of the test specimen and material list for this study. A host of foundries, pattern shops and suppliers also contributed toward this project. Funding for the project comes from the U.S. Department of Energy through the Cast Metals Coalition (CMC) and from contributions from the ten participating foundries, CMI - International and foundry suppliers in the form of cost share.

This pilot project is the beginning of what should be a more intensive project over time. New materials, especially non-metallics, are being formulated over time. Some may have a place as a tooling material and should be considered for testing. Based on the results of this pilot a more extensive project involving more foundries, materials, foundry processes and resources will be investigated.

Review of Literature

In a review of literature it was found that there are many current applications for polymer tooling. In the extremely competitive field of auto making, polymers have made inroads in the front end of the manufacturing process. They have been used for master models, stamping dies, and even for short run production tooling. Patterns made from numerical control (NC) machined polyurethane modeling board have been used extensively to help reduce lead times. One manager of an automotive prototype facility maintains that polyurethane modeling materials provide the accuracy needed for patterns.

In the foundry industry, managers are specifying polyurethane elastomers for pattern and corebox construction. This is a result of the emphasis and developments made by urethane manufacturers to provide a material that can compete with metal in tooling applications. In the past, it was believed that production tooling had to be metal in order to survive the severe environment of a production foundry. Steadily increasing metal tooling costs are changing this perception (Crowley, 1988).

One foundry, the Brillion Iron Works, maintains that they can achieve maximum dimensional accuracy in its castings by using low cost urethane tooling. This foundry uses several thousand patterns and coreboxes. A large percentage of these tools are now made out of urethane. They claim that by using urethane instead of metal in their tooling, a worn pattern can be replaced in a matter of days versus the weeks required for metal tooling (Dahl, 1985).

Wear is another important concern with foundry tooling. When a pattern or corebox wears, resulting castings can be of poor quality, lose their dimensional accuracy, and even cause defects. This can result in downtime for the foundry, increased scrap, and more capital investment for replacements. Being able to evaluate the rate at which a material wears becomes an important consideration based on these reasons (Helzer, 1988).

Several tests have been developed to help determine the wear characteristics of pattern and corebox materials. One highly used test was developed by Gouwens (1967). This test utilized an impact abrasion device for high velocity impact by silica sand. Test samples were subjected to abrasive wear in this testing device and then exposed to a typical oil-sand core blowing system in a production foundry. The field results from this test were compared to the results from the initial test. The laboratory test and the field test did not correlate perfectly with one another. However, after considering both results, Gouwens (1967) decided that the impact test was a close simulation of the field test.

Maier and Wallace modified Gouwens test in 1977 (Helzer, 1988). For their test, they employed the use of dry sub-angular silica sand cascading inside of a Pyrex glass sleeve onto selected test samples. Each sample was tested for three 4-hour periods and was weighed between each cycle.

Another test (Helzer, 1988) simulated pattern wear on selected specimens by impact abrasion of sand grains against the pattern material. This type of test also simulated the wear experienced in a typical cold box core blower. In this test, dry sub-angular silica sand cascades inside a Pyrex sleeve onto selected samples that are rotating at a certain velocity. These specimens were mounted on a shaft acting as blades inside the glass sleeve. Test cycles were for three 4-hour periods with each specimen being weighed in between periods.

Vondra (1992) then reproduced the testing conducted by Helzer. Tests were conducted using impact abrasion testing utilizing the device mentioned above on 30 non-metallic and four metallic materials. Included in his study was the development of a wear factor which predicted the life of a material compared to a standard using the same test.

All material reviewed indicated that plastics could indeed act as a viable substitute for metal tooling in some instances. Previous tests indicated that some plastics have excellent wear characteristics. It was also apparent that plastic tooling could be both less expensive and less time consuming to build than metal tooling.

Project Objective

It is the intent of this project to ascertain the wearability of different tooling materials, both metallic and non-metallic, in actual on the floor foundry tests. Impact abrasion testing will also be conducted on samples of the same materials to ascertain any correlation of data generated between the two tests. Measurements will be conducted at CMI International, Ferndale, MI. and testing will occur at 10 foundries. Impact abrasion testing will be conducted at the University of Northern Iowa's (UNI) Metal Casting Center (MCC).

Scope of Work

Based on input from the AFS Pattern and Tooling Committee (Division 7) a test specimen was designed to be mounted on production plates for purposes of conducting this test (See Appendix A). This design incorporates two radii (.5 and .25 inches), assorted filets along with a 60 degree face. Also, the specimen includes 2 degree draft on all four sides. The first phase of this project will consist of identifying, constructing, testing and measuring potential tooling materials for wear analysis. The analysis will consist of using two measurement techniques: 1. Measurement of the test patterns using the EOS Optical Imaging system to scan and compare the contour changes of the test pieces. 2. Taking percentage weight loss measurements on a before and after basis. Both of these measurements will be conducted at CMI International.

The test patterns will then be subject to 20,000 cycles on Disamatic Molding Machines.

Disamatics were chosen based on their perceived aggressiveness toward tooling and their extreme speed in accomplishing the number of cycles desired.

Concurrently, test specimens will be constructed of the same materials used in the production testing, to the desired size specifications and subject them to impact abrasion testing at UNI. Measurements of the test pieces will consist of percentage weight loss measurements only as to measure the specimens using a CMM would be impractical.

A variety of materials will be tested consisting of both metallics and non-metallics. The ultimate objective of this study is to compare the test results of impact abrasion experimentation (UNI) with testing conducted at CMI International and on the foundry floor. The desired output of this experimentation is that the wear comparisons will allow a validation of the impact abrasion testing at UNI. The breakdown of the materials to be tested is as follows:

Class 40 Gray Iron (standard)	12 samples
D2 Steel	8 samples
D2 Steel Wear Coated	8 samples
303-304 Stainless Steel	4 samples
Ciba-Geigy RP 6444	4 samples
Hapco 665 Hapflex	4 samples
6061 Aluminum	5 samples
6061 Aluminum Wear Coated	6 samples

Industry Participation and Cost Share

Ten foundries have volunteered to run test patterns at their facilities. Industrial representatives will provide the testing materials, conduct on-site testing, and construct the test specimens. CMI International will also do the EOS optical imaging measurements prior to and after testing. The UNI will write up the study and final report.

Justification and Economic Significance

The current tool manufacturing/creation procedure presents a problem to industry because it is costly and time consuming. It is costly because the current process is labor intensive and requires extensive hand finishing (metallics). Also, many modifications tend to shorten the life of the tool. The process requires substantial lead time and therefore reduces a company's flexibility to respond to market trends and changes. One of the major problems metal casters face in the international marketplace is how to be competitive when tooling lead time places restraints on industry flexibility. Domestic firms could capture markets with the help of improved tooling technology.

An important implication of this project is the impact it will have on the expansion of current firms and the potential for new domestic industry. If the domestic pattern making industry in the U.S. is on the cutting edge of tooling technology it will have significant economic benefits for the casting industry.

The best estimates show that by tightening up the tolerances of this type of tooling and holding the casting dimensions a reduction of scrap from 15-30% will result. It will also reduce the weight of good castings shipped. If we use a very conservative .6% reduction of casting weight due to tighter tolerances this translates into 55,661 tons of iron saved per year. To translate this into a dollar figure we used the following formula:

Total tonnage of iron produced in 1991 was 9,869,000 tons (1992 Annual Forecast of Casting Demand, AFS).

Using a typical scrap rate of 6% for foundries, we extrapolate:

6% scrap rate of 9,869,000 tons = 592,140 tons of scrap

15% savings of 592,140 tons = 88,121 tons saved

.6% savings of 9,276,860 tons shipped = 55,661 tons saved (tons shipped)

Total tons saved = 144,473

2000 lbs. X 144,473 tons = 288,946,000 lbs of scrap saved

Cost of iron @ \$.50/lb x 177,642,000 lbs scrap = \$88,821,000 saved/year

Using the industry accepted rate of 70% of casting cost as devoted to energy used in the melting process it can be extrapolated that the energy cost savings could be in a range of \$101,131,100 if the savings were 15% or \$202,262,200, if the savings were 30%. It is important to note that these numbers reflect only iron poured. Further savings will be incurred from other castable alloys, i.e., Aluminum, Copper and Steel.

Research Procedure

After the test specimens have been weighed and measured they will be mounted on a Disamatic Plate and run through 20,000 cycles. Each test pattern will be labeled and weighed prior to and after the 20,000 cycle run. Also, each test pattern will be measured using the EOS Optical Imaging system prior to and after the 20,000 cycle run. The specimens will be subjected to 20,000 cycles runs until any appreciable wear can be determined. The EOS system will allow the researchers to analyze where and by how much the specimens were worn.

The abrasion testing equipment to be used in the University phase of this research utilizes a Pyrex drum, filled with 5 pounds of sand, rotating at 82 rpm causing a cascading of the sand onto a fixture which holds the test specimens. The specimens are mounted at a 45 degree angle so as to act as an impeller to the cascading sand. The fixture itself rotates at approximately 1400 rpm in the same direction as the drum. As the sand cascades onto the spinning fixture, impact abrasion occurs to the test specimens. This apparatus was devised for Gouwens' study in the 1960s. Wear studies were continued using the same apparatus by Maier & Wallace in the 1970s, Helzer in the 1980s, and Vondra in the 1990s.

Each specimen will be tested for three four-hour cycles in the fixture. Two specimens of each sample material will be tested at different times to conform with testing parameters designed earlier for previous studies. The material weights will be recorded before the test begins and after each four hour cycle. An Ohaus Type GT 450 balance will be used to weigh the samples. This balance is a 400 gram capacity unit calibrated every six months to NIST #732/246690-

#523/240932 standards. The 5 pounds of sand contained in the drum will be replaced after each cycle to ensure that new media will be impacting the specimens. This eliminates any fractured or rounded sand grains which may lose abrasiveness during the cycle. The molding material to be used for this research will be a 58-62 AFS GFN sub-angular to round silica sand.

The University phase will also include an in-depth review of the latest advanced pattern materials available worldwide. Currently, a literature review is being conducted to ascertain what has been recently published, regarding tooling materials, in the metal casting industry. However, a more concerted effort from industry to release information regarding tooling materials needs to be accomplished.

Participating Foundries that will run the test patterns and their molding equipment:

<u>Foundry & Location</u>	<u>Molding Machine</u>
Wagner Casting Co. Decatur, IL	Disamatic
Wheland Foundry Chattanooga, Tn	Disamatic
Waupaca Foundry, Inc. Waupaca, WI	Disamatic
Grede Foundry Iron Mountain Div. Iron Mountain, MI	Disa Forma 1500 molds/8 hrs
Reedsburg Foundry Div. Of Grede Reedsburg, WI	Disamatic

Northern Casting Corp. Hibbing, MN	Disamatic
Briggs & Stratton Corp. Milwaukee, WI	Disamatic
Neenah Foundry Co. Neenah, WI	Disamatic
Brillion Iron Works Brillion, WI	Disamatic
Navistar International Waukesha, WI	Herman Matchmaster

Flask size 18 x 24 8/8 & 24 x 24 10/10,
4000 molds per day. Will run 2 patterns
of the same material, one for cope and one for drag.
Will run 3 types of pattern materials
A. 2 cast iron--Class 40
B. 2 Aluminum
C. 2 Aluminum wear coated

Following is the written procedure that each foundry is to follow regarding the test they will be conducting.

Each foundry will be sent a copy of the pattern wear test study form (See Appendix B), a letter with the type of pattern material to be tested, and the corresponding numbers engraved on the plate side. We will also send a copy of the Briggs & Stratton drawing (See Appendix C) showing the location of the test pattern on their plate as an example. Each foundry must provide a drawing showing the location of the test pattern on their plate.

The goal is to run a minimum of 20,000 impressions for each test. The foundry must record the exact number of impressions that are conducted on each material. When the foundry has run at least 20,000 impressions the test pattern is to be removed and returned to the tooling consultant.

The tooling consultant will send it to CMI International to weigh and measure this pattern and then will return it for another 20,000 cycles. Also, it is important that all pertinent information, such as mold hardness, sand type, etc., be included on the accompanying form.

A form will travel with each test pattern, which includes; pattern I. D. number, material, cycles, etc. The foundries will run a test pattern 20,000 molds then run the control pattern, class 40 gray iron, 20,000 molds and keep alternating until we can measure changes due to wear. The control pattern will accompany each different pattern and will run in conjunction with that material.

The list of test pattern materials and where they were constructed follow:

1. Iron Class 40 12 patterns
Cast at St. Louis Precision Casting Co. Machined CNC at Caterpillar (Cat) Mapleton.
(Same as Cat. Spec 1660 gray iron class 40).
2. D2 Steel 8 patterns
Cast at St. Louis Precision Casting Co. Machined CNC at Cat - Mapleton.
3. D2 Steel (Wear coated) 8 patterns
Cast at St. Louis Precision Casting Co. Machined CNC at Cat - Mapleton
Wear coating was done at Wear - Cote International Inc. in electroless nickel plating
4. Stainless Steel 303-304 6 patterns
Cast at St. Louis Precision Casting Co. Machined CNC at Cat - Mapleton.
5. RP 6444 4 patterns
REN:C:O-THANE Polyurea Elastomer. Shore 60 +/- 5D Elastomer, light amber
Ciba-Geigy Corporation; East Lansing, MI
Cast at Cat - Mapleton
6. 665 Hapflex 4 patterns
Elastomeric polymer alloy 65 Shore D
Hapco Inc; Hanover, MA

The two urethanes above are two-component liquid castable polyurethane elastomers. John

Deere Product Engineering Center, Waterloo, Iowa made a 4-cavity mold, in which to cast the polyurethanes.

7. 6061 Aluminum 5 patterns
Furnished by Finn Pattern, Cudahy, WI. Machined at Cat - Mapleton
(Finn Pattern also supplied the measuring fixture)

8. 6061 Aluminum (wear coated) 6 patterns
Furnished by Finn Pattern, Machined at Cat - Mapleton

The plan to correlate foundry results with laboratory tests will be as follows:

It is anticipated that CMI International will work with the tooling consultant and the University of Northern Iowa to design a plan to correlate the foundry test results with the laboratory test data.

Also, it is further anticipated that a "Pattern Wear Test Study" paper is to be submitted for presentation at the AFS Casting Congress in 1998.

Following is a starting time schedule for each task in the project.

A. Cut Patterns from 6061 bar stock	Completed
Metal - Aluminum	
Cast Non-Metallics	Completed
B. Machine 12 metal patterns - aluminum	Completed
C. Wear coat 6 aluminum and 8 D2 patterns at;	Completed
Wear-Coat International, Inc.	
P.O. Box 4177	
Rock Island, IL 61204-4177	

D. Measure all patterns at CMI International Inc. Ferndale, MI. November, 1996

- measure surface dimensions using EOS before and after testing
- measure percent weight loss before and after testing

E. Send patterns to participating foundries including instructions

and the "Pattern Wear Test Study" form.

December, 1996

AFS Pattern and Tooling (Division 7) Monitoring Committee

Roy Evers (Chair)	St. Louis Precision Casting
Bob Allen	Bloomfield Foundry
Gladwyn Doughman	Casting Design & Service
Ron Gustafson	Clinkenbeard and Associates

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WEAR STUDY TEST SPECIMEN

APPENDIX A

AMERICAN
FOUNDRYMENS
SOCIETY, INC.

METAL CASTING CENTER
UNIVERSITY OF NORTHERN IOWA
DEPT. OF IND. TECHNOLOGY
CEDAR FALLS, IA 50614-0178

*AFS PATTERN AND FOUNDRY TOOLING DIVISION VII
IN CONSORTIUM WITH THE UNIVERSITY OF NORTHERN IOWA*

B. 134

PATTERN WEAR TEST STUDY

1. FOUNDRY NAME AND ADDRESS BELOW

2. CONTACT PERSON

3. TYPE OF MOLDING MACHINE _____

4. MOLD OR FLASK SIZE _____ COPE AND DRAG HEIGHT _____

5. MOLD PARTING: _____ HORIZONTAL _____ VERTICAL

6. TYPE OF MOLDING SAND: _____

AVERAGE GRAIN FINENESS _____

ANGULAR GRAINS _____ ROUND GRAINS _____

RANGE OF MOLD HARDNESS _____ TO _____ SQUEEZE PRESSURES _____

SAND TEMPERATURES FAHRENHEIT: LOW _____ HIGH _____

7. PATTERN TEMPERATURE _____

8. MOLD SPRAY OR MOLD RELEASE:

WHAT TYPE; OIL BASE _____ WATER BASE _____ SILICON BASE _____

FREQUENCY; EVERY MOLD _____ 1/5 _____ 1/10 _____ 1/15 _____ 1/20 _____

NONE _____ OTHER _____

9. ATTACH SKETCH (LOCATION OF TEST PATTERN IN THE MOLD)

APPENDIX B

APPENDIX C

Appendix A - Wear Study Test Specimen (Page 16)

Appendix B - Pattern Wear Test Study Form (Page 17)

Appendix C - Example of where to mount the test specimen on a pattern plate (Page 18)