LLNL-TR-741698

LAWRENCE LIVERMORE NATIONAL LABORATORY

Design and Product Optimization for Cast Light Metals (USCAR/AMP) Final Report CRADA No. TC-1061-94

K. W. Dolan, R. J. Osborne, G. S. Cole, B. Cox

November 14, 2017

Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Design and Product Optimization for Cast Light Metals (USCAR/AMP)

Final Report
CRADA No. TC-1061-94
Date National Labs Technical Work Ended: April 10, 2000

Date: March 7, 2001 Revision: 4

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory (ORNL) and Sandia National Laboratories (SNL), General Motors, Ford and Chrysler (now DaimlerChrysler Corporation).

University of California
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550
Kenneth W. Dolan
Principal Investigator
Telephone: (925) 422-7971
Fax: (925) 422-3834

General Motors Corporation
MC 480-205-314, Dock 17
30007 Van Dyke
Warren MI 48090-9065
Richard J. Osborne
Telephone: (810) 575-7039
Fax: (810) 492-5115

Ford Motor Company
20000 Rotunda Drive
Dearborn, MI 48121-1860
Gerald S. Cole
Telephone: (313) 322-1860
Fax (313) 390-0514

Chrysler Corporation (now DaimlerChrysler Corporation)
800 Chrysler Drive East
Auburn Hills, MI 48326
Bruce Cox
Telephone: (248) 576-0235
Fax: (248) 576-7288

B. Project Scope

The objective of the United States Automotive Partnership (USAMP) program was to develop information and technology for the U.S. automotive industry to optimize design and improve product capabilities for light weight, high strength, cast structural aluminum and magnesium components. Sandia National Laboratory and Oak Ridge National Laboratory were also involved with this CRADA. This report covers only the work done by LLNL.

The objectives of the USAMP project "Design and Product Optimization for Cast Light Metals" had five specific tasks:

Task 1: Development of a cast light metal material design property database
The existing body of casting design property data for aluminum, and magnesium alloys was scarce and poorly documented. As the automotive industry moved into lighter weight, higher strength, cast structures, it was necessary to provide the design engineer with information needed to successfully design components with light metal alloys. The data would also be useful for the development of process monitoring, non-destructive evaluation (NDE) techniques and predictive property modeling.

Task 2: Publication of standardized material manufacturing guidelines and component evaluation methodologies
The identification and/or development of alloy composition, component evaluation procedures, and key process variables would advance the automotive industry to a point where they would be able to standardize their test methods and specifications. This standardization would result in significant savings by minimizing separate quality systems. This would also allow the industry to minimize system variation and further qualify their suppliers.

Task 3: Management and reporting of program activities
This task greatly enhanced the value of the overall program. The program's success was determined by the ability of the management team to interweave the task results. The type of reports and guidelines that were generated from this program would have a significant impact on the design and engineering operations of the automotive industry and their suppliers.

Task 4: Development of on-line process monitoring, feedback control, and non-destructive evaluation technique(s) to assure cast component consistency and quality
The supplier-to-supplier and casting-to-casting consistency was of significant interest to the automotive industry. As their reliance on cast structural components increased, so did their need to assure consistent quality of cast products. The traditional role of NDE as a screening tool to reject unacceptable cast products did not assure quality from the beginning. A wide range of process monitoring and NDE technologies were available at reasonable cost, including: radiography, ultrasonics, infrared imaging, computed

tomography, and various sensor techniques. Application of these technologies for on-line process monitoring and non-destructive techniques to assure cast component quality would assist the automotive supplier industry with process feedback control and assure quality prior to shipment.

The techniques could also be used to qualify suppliers and determine the consistency of their products. The development of such techniques could, however, be greatly enhanced by knowledge obtained during product development and process evaluation phases. Early process monitoring and NDE involvement would serve to understand critical process parameters and verify the accuracy of computer modeling activities.

Task 5: Evaluation and development of numerical modeling techniques to predict mechanical properties throughout cast component sections

The transition to cast structural automotive components created the need to predict the properties of the component in all sections of the design. This need arose because of the necessity to provide mass efficient product design and reduce development lead time. The automotive industry required a higher degree of certainty that its property requirements had been met from supplier to supplier and from component to component. Current solidification and fluid flow modeling methods could only be used to identify potential macrostructure problem areas. The development of a property prediction model would provide the capability to identify design changes and manufacturing methods that optimize component properties. Both cyclic and monotonic properties were included in the prediction model.

Deliverables and Products:

(See Technical Accomplishments Section below for deliverables per year)

In addition to the technical milestones and deliverables listed under each year's activities, the following reports and abstracts were required:

1. An initial nonproprietary abstract suitable for public release
2. Other abstracts (final when work was complete, and others as substantial changes in scope and dollar occurred)
3. An annual progress report containing no Proprietary Information or Protected CRADA information so that the report can be openly distributed
4. A final report
5. Other topical/periodic reports where the nature of the research and magnitude of dollars justify

C. Technical Accomplishments

First Year

Participant	Date	Milestone
USAMP	11-30-94	Completed plans for micro structural and property characterization
USAMP	12-31-94	Selected USAMP facility for making plate castings
USAMP	4-30-95	Casted plate castings for generation of property and micro structural database
USAMP	6-1-95	Developed component acceptance criteria
USAMP	6-1-95	Identified critical process variables to be monitored that influence cast microstructure and properties
LLNL	6-1-95	Assessed on-line process monitoring and control techniques for cast components
LLNL	9-30-95	Reported on sensitivity of NDE techniques used to characterize supplied castings

Second Year

Participant	Date	Milestone
USAMP	12-31-95	Casted and coordinated characterization of mule castings of 356 alloy
USAMP	6-1-96	Defined discontinuities in 356 alloy castings relevant to NDE, and process & property models
USAMP	9-30-96	Casted and coordinated characterization of 356 alloy plate castings with varying process parameters
LLNL	3-31-96	Completed plans for fielding process monitoring & NDE techniques for sand casting of 356 alloy
LLNL	9-30-96	Established baseline NDE for 356 alloy castings

Third Year

Participant	Date.	Milestone
USAMP	12-31-96	Selected casting processes for which process monitoring tools needed to be established
USAMP	9-30-97	Completed database development for 356 alloy for a wide range of process conditions
LLNL	3-31-97	Completed plans for fielding process monitoring and NDE techniques for selected processes
LLNL	9-30-97	Demonstrated sensor techniques for monitoring critical variables for selected processes

Fourth Year

Participant	Date	Milestone
USAMP	10-31-97	Provided process line for demonstration of process monitoring and NDE equipment
USAMP	12-31-97	Characterized mule castings of 356 alloy poured under various process conditions
USAMP	9-30-98	Selected two production castings for validation and provide solid models to ORNL and SNL
USAMP	9-30-98	Coordinated characterization of two production castings for validation of LLNL, ORNL and SNL models and techniques
LLNL	9-1-98	Demonstrated and validated process monitoring and ND tools and techniques for production line

Fifth Year

Participant	Date	Milestone
USAMP	10-1-98	Provided production facility for evaluation of process monitoring and NDE tools and techniques
USAMP	12-31-98	Coordinated characterization of Mg alloy castings alloy poured under various process conditions
LLNL	9-1-99	Validated process monitoring and NDE tools in production environment for production castings

D. Expected Economic Impact

D.1 Specific Benefits:

The benefits derived from the successful completion of this CRADA include

- Vehicle mass savings for ground and air transportation leading to reduction in fuel consumption and emission levels: less dependence on foreign oil, improved trade balance and environmental response
- Reduced manufacturing energy consumption (melting, machining, handling, and transportation energy requirements) as light metal usage increases
- Light metal alloys have greater recycling value with reduced energy consumption.
- The CRADA participants competitive global posture would increase as a result of manufacturing vehicles offering greater consumer value
- Manufacturing health and environmental issues would be reduced for light metal casting operations when compared to ferrous foundries
- Provided National Laboratories with valuable manufacturing development experience

E. Partner Contribution

This USAMP project consisted of five overall tasks. The consortium of researchers that was established included several of the National Labs, and technologists from the Big Three auto makers.

The specific task responsibilities for the National Laboratories part in the program enabled the Labs to conduct CRADA specific research in Tasks 1,4 & 5 in cooperation with the Big Three automakers or their suppliers. Microstructural characterization and mechanical property determination tasks were conducted as part of a cooperative agreement between DOE and USAMP and its selected subcontractors. However, as part of the research consortium, the National Labs were informed of the activities and results in all of the tasks.

The five USAMP program tasks were:

Task 1: The generation of a cast light metal material property database

1.1 Identified required design data (USAMP)
1.2 Conducted literature survey of required data (USAMP)
1.3 Conducted critical analysis of information (USAMP, LLNL)
1.4 Identified data inconsistencies or "gaps" (USAMP, LLNL)
1.5 Conducted studies to develop data (USAMP, LLNL)
1.6 Published design guidelines (USAMP)

Task 2: Definition and publication of standardized material manufacturing guidelines and component testing methodologies.

2.1 Identified materials of interest (USAMP)
2.2 Identified and standardize performance test methods (USAMP, LLNL,)
2.3 Standardized material chemistry requirements (USAMP)
2.4 Standardized heat treatment cycle requirements (USAMP)
2.5 Published standard specifications which govern testing of components (USAMP)

Task 3: Management and reporting of program activities.

3.1 Held biannual review meetings (USAMP, LLNL, ORNL, SNL)
3.2 Collected monthly subcontract status reports (USAMP)
3.3 Conducted task force and steering committee meetings (USAMP)
3.4 Distributed reports (USAMP)
3.5 Conducted educational and technology transfer activities (USAMP)

Task 4: Development of on-line process monitoring and non-destructive techniques to assure cast component consistency and quality.

4.1 Identified critical variables to be quantified (USAMP, LLNL)
4.2 Developed acceptance criteria for components (USAMP, LLNL)
4.3 Demonstrated application of existing tools and techniques (LLNL)
4.4 Developed new tools and techniques for process monitoring and NDE (USAMP, LLNL)
4.5 Tested quantitative accuracy of new and existing tools and techniques (USAMP, LLNL)
4.6 Validated tools and techniques in production line (LLNL)

Task 5: Development of a numerical model capable of accurately predicting cast component properties through the input of product geometry, and alloy and process parameters.

5.1 Identified existing software tools (USAMP)
5.2 Reviewed software application to castings (USAMP)
5.3 Predicted the effect of process variables (USAMP)
5.4 Predicted the influence of material composition (USAMP)
5.5 Predicted the effect of cast structure and morphology (USAMP)
5.6 Validated process and property models on production components (USAMP, LLNL)

F. Documents/Reference List

Material Properties Database, USAMP/Westmoreland Testing and Research, Inc. (*)

USCAR-USAMP/AMD Design Guidelines, USAMP/Entelechy (*)

Reports

K. W. Dolan, "Quality Assurance: Nondestructive Evaluation and Process Monitoring Sensors - Executive Summary", April 15, 2000, UCRL-JC-139594 (unlimited distribution).

K. W. Dolan, "Quality Assurance: Nondestructive Evaluation and Process Monitoring Sensors - Final Report", December 2000, UCRL-ID-139594 (limited distribution).

Patent/Copyright Activity
None by LLNL

Subject Inventions
None by LLNL

Background Intellectual Property
None by LLNL

G. Acknowledgement

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Richard J. Osborne — 3/29/01

Richard J. Osborne — Date
General Motors Corporation

Bruce Cox — Date
Chrysler Corporation (now DaimlerChrysler Corporation)

Gerald S. Cole — Date
Ford Motor Company

Kenneth W. Dolan — 5/24/01

Kenneth W. Dolan, Principal Investigator — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

G. Acknowledgement

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

____
Richard J. Osborne — Date
General Motors Corporation

[signature] — 3/26/01
Bruce Cox — Date
Chrysler Corporation (now DaimlerChrysler Corporation)

____
Gerald S. Cole — Date
Ford Motor Company

[signature] — 5/24/01
Kenneth W. Dolan, Principal Investigator — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

G. Acknowledgement

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Richard J. Osborne — Date
General Motors Corporation

Bruce Cox — Date
Chrysler Corporation (now DaimlerChrysler Corporation)

5-5-01

Gerald S. Cole — Date
Ford Motor Company

5/24/01

Kenneth W. Dolan, Principal Investigator — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

Design and Product Optimization for Cast Light Metals (USCAR/AMP)

Final Abstract (Attachment I)
CRADA No. TC-1061-94

Date: March 7, 2001 Revision: 4

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory (ORNL) and Sandia National Laboratories (SNL), General Motors, Ford and Chrysler (now DaimlerChrysler Corporation).

University of California
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550
Kenneth W. Dolan
Principal Investigator
Telephone: (925) 422-7971
Fax: (925) 422-3834

General Motors Corporation
MC 480-205-314, Dock 17
30007 Van Dyke
Warren MI 48090-9065
Richard J. Osborne
Telephone: (810) 575-7039
Fax: (810) 492-5115

Ford Motor Company
20000 Rotunda Drive
Dearborn, MI 48121-1860
Gerald S. Cole
Telephone: (313) 322-1860
Fax (313) 390-0514

Chrysler Corporation (now Daimler Chrysler Corporation)
800 Chrysler Drive East
Auburn Hills, MI 48326
Bruce Cox
Telephone: (248) 576-0235
Fax: (248) 576-7288

B. Project Scope

The objective of the United States Automotive Partnership (USAMP) program was to develop information and technology for the U.S. automotive industry to optimize design and improve product capabilities for light weight, high strength, cast structural aluminum and magnesium components. The objectives of the USAMP project "Design and Product Optimization for Cast Light Metals" had five specific tasks:

Task 1: Development of a cast light metal material design property database
The existing body of casting design property data for aluminum, and magnesium alloys was scarce and poorly documented. As the automotive industry moved into lighter weight, higher strength, cast structures, it was necessary to provide the design engineer with information needed to successfully design components with light metal alloys. The data would also be useful for the development of process monitoring, non-destructive evaluation (NDE) techniques and predictive property modeling.

Task 2: Publication of standardized material manufacturing guidelines and component evaluation methodologies
The identification and/or development of alloy composition, component evaluation procedures, and key process variables would advance the automotive industry to a point where they would be able to standardize their test methods and specifications. This standardization would result in significant savings by minimizing separate quality systems. This would also allow the industry to minimize system variation and further qualify their suppliers.

Task 3: Management and reporting of program activities
This task greatly enhanced the value of the overall program. The program's success was determined by the ability of the management team to interweave the task results. The type of reports and guidelines that were generated from this program would have a significant impact on the design and engineering operations of the automotive industry and their suppliers.

Task 4: Development of on-line process monitoring, feedback control, and non-destructive evaluation technique(s) to assure cast component consistency and quality
The supplier-to-supplier and casting-to-casting consistency was of significant interest to the automotive industry. As their reliance on cast structural components increased, so did their need to assure consistent quality of cast products. The traditional role of NDE as a screening tool to reject unacceptable cast products did not assure quality from the beginning. A wide range of process monitoring and NDE technologies were available at reasonable cost, including: radiography, ultrasonics, infrared imaging, computed tomography, and various sensor techniques. Application of these technologies for on-line process monitoring and non-destructive techniques to assure cast component quality would assist the automotive supplier industry with process feedback control and assure quality prior to shipment.

The techniques could also be used to qualify suppliers and determine the consistency of their products. The development of such techniques could, however, be greatly enhanced by knowledge obtained during product development and process evaluation phases. Early process monitoring and NDE involvement would serve to understand critical process parameters and verify the accuracy of computer modeling activities.

Task 5: Evaluation and development of numerical modeling techniques to predict mechanical properties throughout cast component sections

The transition to cast structural automotive components created the need to predict the properties of the component in all sections of the design. This need arose because of the necessity to provide mass efficient product design and reduce development lead time. The automotive industry required a higher degree of certainty that its property requirements had been met from supplier to supplier and from component to component. Current solidification and fluid flow modeling methods could only be used to identify potential macrostructure problem areas. The development of a property prediction model would provide the capability to identify design changes and manufacturing methods that optimize component properties. Both cyclic and monotonic properties were included in the prediction model.

Deliverables and Products:

In addition to the technical milestones and deliverables listed under each year's activities in the Final Close-out report, the following reports and abstracts were provided:

- An initial nonproprietary abstract suitable for public release
- Other abstracts (final when work was complete, and others as substantial changes in scope and dollar occurred)
- An annual progress report containing no Proprietary Information or Protected CRADA information so that the report can be openly distributed
- A final report
- Other topical/periodic reports where the nature of the research and magnitude of dollars justify

C. Benefit to Industry

The benefits derived from the successful completion of this CRADA include:

- Vehicle mass savings for ground and air transportation leading to reduction in fuel consumption and emission levels: less dependence on foreign oil, improved trade balance and environmental response
- Reduced manufacturing energy consumption (melting, machining, handling, and transportation energy requirements) as light metal usage increases
- Light metal alloys have greater recycling value with reduced energy consumption.
- The CRADA participants competitive global posture would increase as a result of manufacturing vehicles offering greater consumer value
- Manufacturing health and environmental issues would be reduced for light metal casting operations when compared to ferrous foundries

D. Benefit To DOE/LLNL

This project provided National Laboratories with valuable manufacturing development experience such as; on-line process monitoring, feedback control, and non- destructive evaluation, and numerical modeling techniques in support of DOE's mission objectives.

E. Project Dates

Project start: April 1995
Project close: April 2000