

**DIE CASTING RESEARCH:
DIE CAVITY INSTRUMENTATION**

Final Report, Tasks 2 through 5

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**C. E. Mobley
J. Brevick**

December 1997

Work Performed Under Contract No. DE-FC07-94ID13233

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

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**By
The Ohio State University
Columbus, OH 43210**

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DIE CASTING RESEARCH: DIE CAVITY INSTRUMENTATION

Final Report for Tasks 2-5

- Executive Summary, Final Report
- Analysis of In-Cavity Thermal and Pressure Characteristics in Aluminum Alloy Die Casting
A Masters Thesis by V. K. Venkatasamy
- An Evaluation of Direct Pressure Sensors for Monitoring the Aluminum Die Casting Process
A Masters Thesis by X. Zhang

Executive Summary

For

U.S. Department of Energy-Sponsored Project

“Die Cavity Instrumentation”

Contract No. DE-FC07-94ID13233

Tasks 2,3,4, and 5

C. E. Mobley & J. Brevick

Ohio State University

OSU Research Foundation Project # 730198

December 31, 1997

The primary objective of this Department of Energy Sponsored-project was to evaluate the performance characteristics and usefulness of near cavity temperature, liquid pressure, and gas flow rate sensors for improved monitoring and control of die casting processes. Three types of near cavity sensors were evaluated:

A multi-thermocouple probe used for determining the surface and near-cavity thermal history of the die;

A commercially available direct cavity pressure sensor for measuring the pressure history of the liquid and solidifying alloy in the die cavity;

and A vent gas flow sensor for monitoring whether gas exits the cavity vent during cavity filling.

As part of the evaluation of the above near or in-cavity process sensors, die casting experiments were conducted during 1996 at the Manufacturing Laboratory of the Ohio State University's Engineering Research Center for Net Shape Manufacturing. A beta site die casting campaign was also performed at the GM Casting Advanced Development Center (CADC), at Bedford, Indiana on April 17, 1997. One hundred and fifty six rear axle aluminum alloy transmission cases were die cast during the GM CADC beta site experimental campaign. Detailed shot profile, die temperature, and cavity pressure data were collected for each shot. The cycle time for each of the 156 shots in the campaign was 121 seconds and there were no operating delays or breaks during the campaign. The volumes, densities, and weights of the individual castings were determined and correlated with the measured casting variables. The complete data for the GM beta site campaign are given as Appendices A and B in Xueheng Zhang's Master's Thesis prepared during this project.

The following observations, conclusions, and recommendations were reached from the OSU and GM CADC Bedford die casting experiments

Thermal Probes:

Thermal sensors located at the die cavity surface demonstrated sufficient response time to successfully measure gate freezing time as well as near-surface heat fluxes from molten alloy entering the cavity and from spray cooling of the die surfaces. These data can be extremely useful to die designers, in terms of validating their approach for thermal management of the die. Data gathered from the near-cavity temperature sensors were consistent with thermal analysis results from computer programs (BINORM and MagmaSoft) for the experimental die and casting cycle. The experiments with the thermal probes were short duration tests accomplished on an experimental die, so the longevity of the thermal sensors is unknown.

Longer duration Beta-site tests were conducted with multiple thermocouple sensors located throughout the die, but not at or near the cavity surface. The "composite" die temperature based on these temperature sensors was found to be one of the principal process variables needed to predict the volume and weight of the die castings produced. The variation of the composite die temperature based on the 14 thermocouples with shot number throughout the GM CAD/CAM experimental campaign is shown in Figure 1.

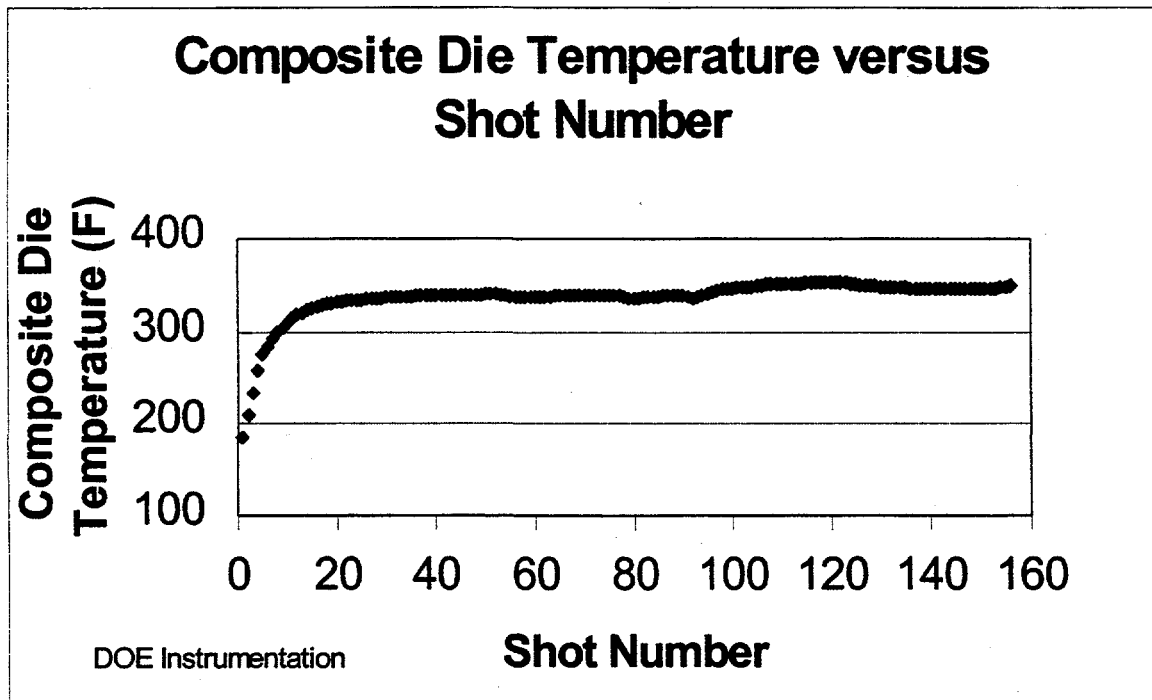


Figure 1: Composite Die Temperature versus Shot Number

In-Cavity Direct Pressure Sensors:

The in-cavity direct pressure sensors evaluated in this project were manufactured by Kistler Instrument Corporation (Kistler Instrument Corporation part # 6175A2).

The Kistler direct pressure sensors demonstrated sufficient response time capability to measure the metal pressure in its local cavity region during cavity filling and intensification. However, once a skin solidified on the surface of the pressure sensor, the reported sensor pressure decreased in comparison with the metal pressure inferred from the hydraulic records.

The direct pressure sensors provide complimentary data to the machine hydraulic record. Specifically, the hydraulic pressure sensors on die casting machines are of limited value for measuring the inertial pressure spike that occurs in the cavity at the end of filling. However, the direct pressure sensors were able to monitor the pressure during the final stages of cavity filling, the pressure spike at the end of filling, and the pressure during the onset of intensification. These data are very useful during initial trials with a new die to determine the preferred injection system parameters as part of machine set-up to produce the desired casting quality without flashing the die.

Data from 156 shots at the GM CADC beta site experimental campaign of April 17, 1997 were collected using the Kistler direct pressure sensors with no reliability problems with the sensors or the associated data acquisition equipment. The variation of the hydraulic pressure and the cavity pressure with shot number during the GM CADC experimental campaign is shown in Figure 2.

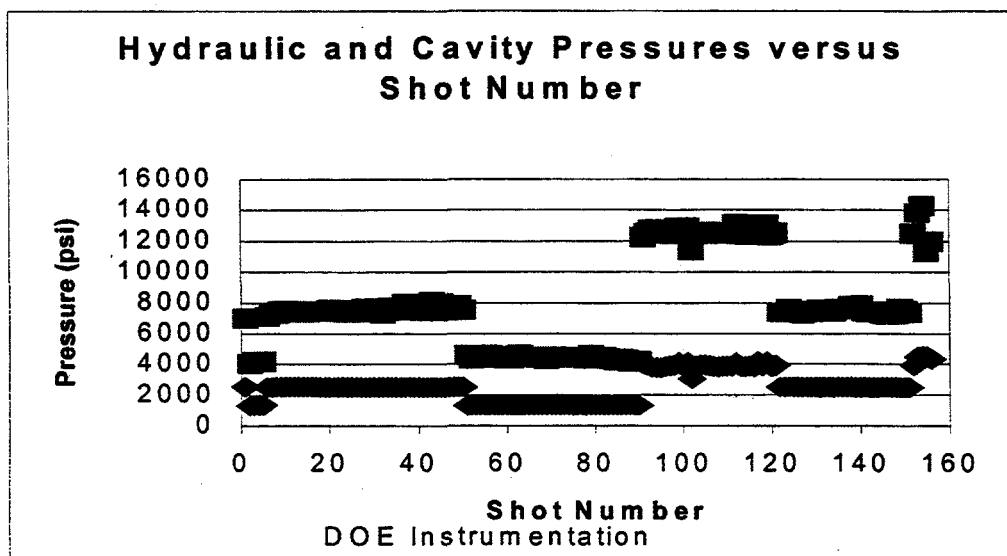


Figure 2. Hydraulic and Cavity Pressure versus Shot Number for GM Beta-site Campaign

Vent Gas Flow Sensors

OSU experiments indicated that thermocouples and microphone transducers are adequate to determine if a die cavity vent is open or closed during a given shot. However, the need exists to develop robust sensors and/or systems which can be used for multiple sequential determinations. Access to the vent exhaust location is a major problem in attempting to utilize the vent gas flow sensors on dies currently in use. If vent gas sensors are to be used to monitor the gas flow from the cavity during filling, their placement should be considered in the early design of the die vent and means provided for the sensor placement and replacement. Additional effort is required to demonstrate the robustness of the thermocouple or microphone transducer type vent flow sensors.

Correlation of Near Cavity Sensor Data with Part Properties

The volume, density, and weight of the trimmed castings produced during the GM CADC beta site campaign were determined using the Archimedes' method. All three characteristics (volume, density, and weight) were determined to five significant figures.

Volume: The volumes of the aluminum alloy rear axle transmission cases die cast during the GM CADC campaign are plotted as a function of the shot number in Figure 3.

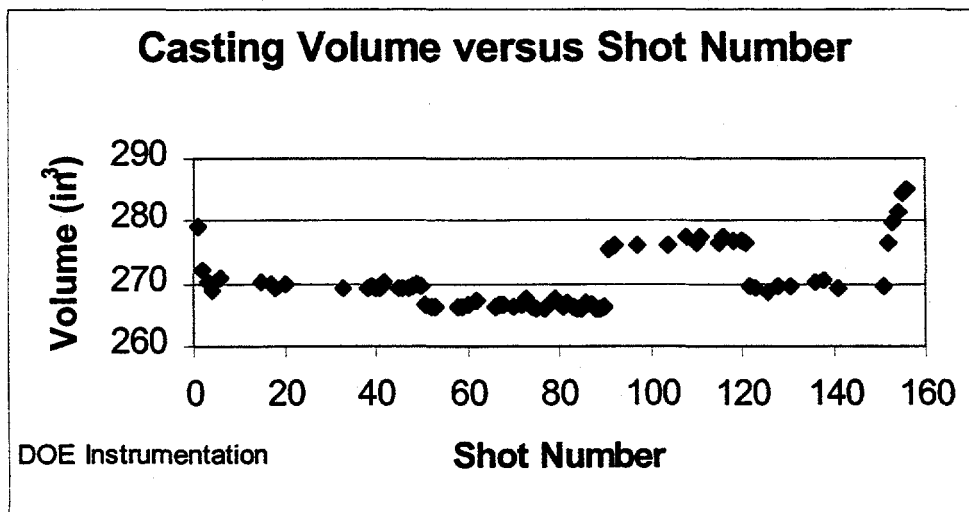


Figure 3. Casting Volume versus Shot Number for GM Beta-site Campaign

It was anticipated that the volume of the casting is primarily a function of die cavity temperature and the liquid pressure in the die cavity. The casting volume is unique or specific to a given machine and die, as it depends on the dimensional stability/response of the die casting system.

For the GM CADC die and machine system used in the beta site campaign, the volume of the die castings, V_c , was related to the die casting conditions by the expression:

$$V_c = 281.088 - 0.0524 T + 0.0003862 P_{\text{mean}} + 6 \times 10^{-8} P_{\text{mean}}^2 \quad [1]$$

where T is the composite die temperature (in degrees Fahrenheit) at the start of a given shot and P_{mean} is the mean or average pressure in the liquid during solidification (in pounds per square inch, psi). The R^2 correlation coefficient for the relation given in Equation [1] is 0.970.

The die temperature significantly influences the volume of the die casting. This is consistent with the observation that casting volumes and weights differ significantly during startup and during or following production stoppage or delays. The volume of the casting is greater when the die is cold and decreases with increasing die temperature.

The volume of the castings correlated well with the intensification stroke length or plunger travel past impact. The variation of intensification stroke length with shot number for the GM CADC campaign is shown in Figure 4. Linear regression analysis indicated that the volumes of the GM beta site castings were also given by the relation:

$$V_c = 281.911 - 0.052327 T + 14.6116 \delta \quad [2]$$

where T is the composite die temperature (in degrees Fahrenheit) and δ is the intensification stroke length (in inches), and the casting volume is in units of cubic inches. The R^2 correlation coefficient for the Equation [2] fit was 0.973.

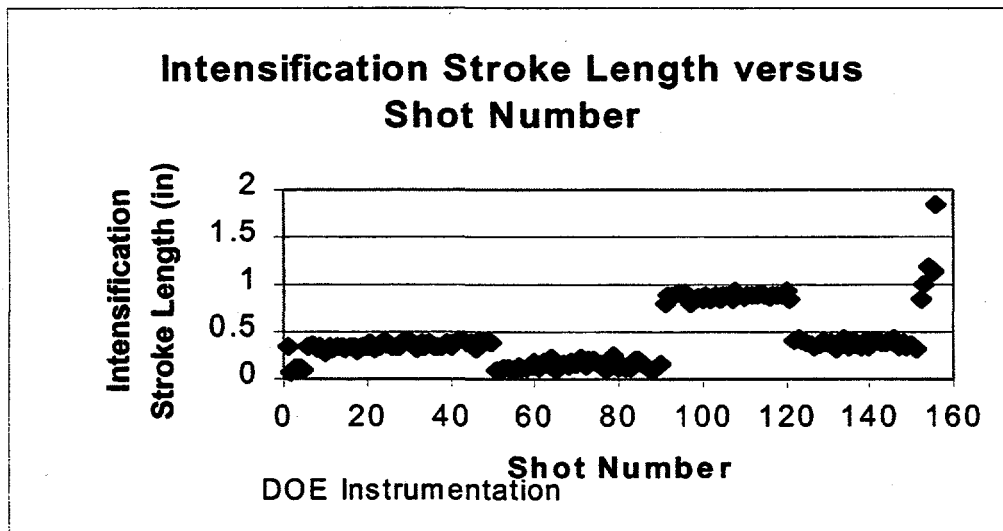


Figure 4. Intensification Stroke Length versus Shot Number For GM Beta-site Campaign

Density: The measured densities of the GM CADC castings as a function of shot number are shown in Figure 5.

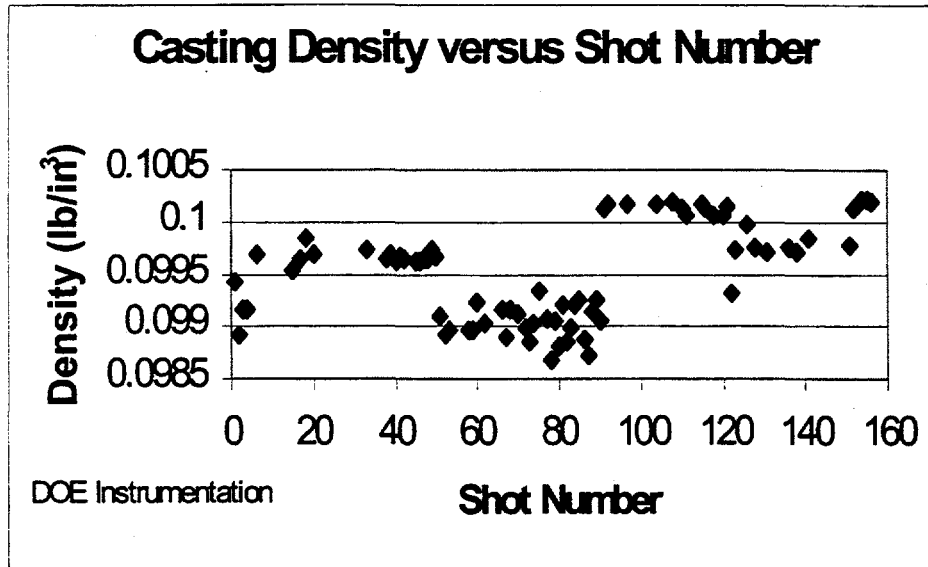


Figure 5. Casting Density versus Shot Number for GM Beta-site Campaign

Based on the model presented in the 1993 NADCA Transactions paper entitled "Equations for Predicting the Percent Porosity in Die Castings", it was anticipated that the density of the castings would depend primarily on the quantity of gas contained in the casting, the pressure applied during solidification, and the amount of liquid fed to the die cavity during intensification. Thus it was expected that the density of the casting would be given by an equation of the type:

$$\rho = \rho_o [1 - \beta - 59.7 v/P_{\text{mean}} + (\pi D^2/4)\delta f/V_c] \quad [3]$$

where ρ_o is the theoretical density of the solid alloy,

β is the solidification shrinkage fraction for the alloy,

v is the quantity of gas contained in the liquid alloy in the die cavity,

P_{mean} is the mean pressure in the liquid during solidification,

D is the diameter of the plunger tip,

δ is the intensification stroke length,

f is the fraction of liquid alloy moved during intensification which reports to the die cavity,

and V_c is the volume of the casting cavity or casting.

For the GM CDCA beta site castings, the density of the individual trimmed cases was fit by the expression:

$$\rho = 0.0988 - 4.0345/P_{\text{mean}} + 0.4470 \delta^{0.19}/V_c \quad [4]$$

with all of the variables expressed in English units (density in pounds per cubic inch; pressure in pounds per square inch; intensification stroke length in inches, and casting volume in cubic inches). The R^2 correlation coefficient for the Equation [4] fit was 0.933.

Weight: The weight of the GM CDCA beta site castings as a function of the shot number is shown in Figure 6.

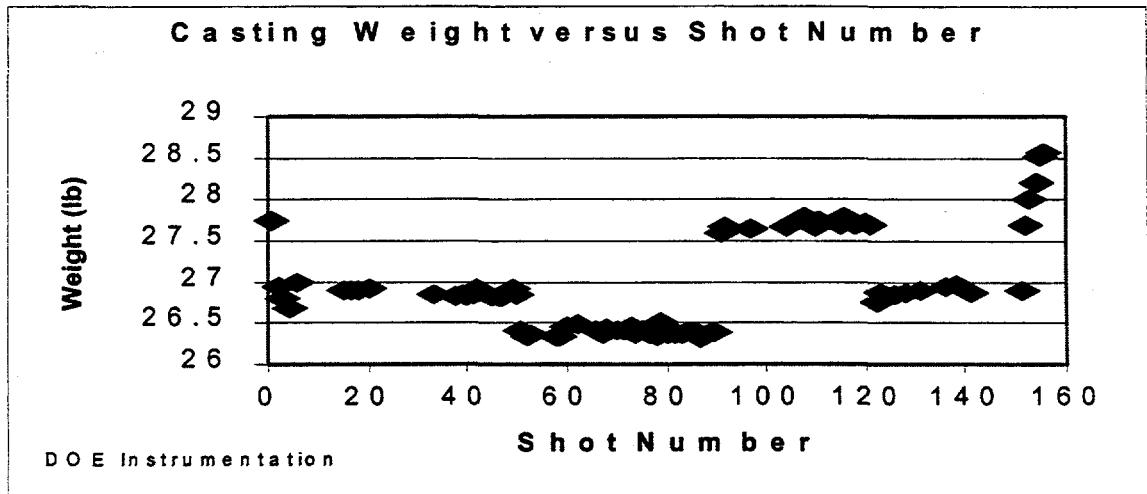


Figure 6. Casting Weight versus Shot Number for GM Beta-site Campaign

The weight of the casting is the product of its density and volume, that is:

$$W = \rho V_c \quad [5]$$

As the volume of the casting depends on the die temperature and mean pressure applied to the liquid during solidification (and/or the intensification stroke length), and the density depends on the mean pressure and intensification stroke length, the weight of the casting (for a completely filled and non-flashed cavity) is expected to depend primarily on the die temperature, mean applied pressure, and intensification stroke length. A regression analysis for the trimmed casting weight gave the best fit relation:

$$W = 28.303 - 0.00515 T - 1713.5/P_{\text{mean}} + 1.4962 \delta \quad [6]$$

All the variables in Equation [6] are expressed in English units. The R^2 correlation coefficient for Equation [6] was 0.985.

The observed relations between casting weight, volume, and density with die temperature, mean cavity pressure during solidification, and intensification stroke length clearly show the value of using existing and near cavity measurements to better monitor and understand the die casting process and resultant parts. The observed dependence of casting weight with the selected process variables also suggests the monitoring and use of weight data as part of a process and product quality control procedure as the weighing of castings does not require complex equipment and/or long time measurement procedures.

Disclaimer

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