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Final Report

on

# Task 7: Die Soldering During Host Site Testing

OSURF Project 729390

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## DISCLAIMER

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# EXECUTIVE SUMMARY

Task 7 — Die Soldering During Host Site Testing

To provide industrial confirmation of laboratory results produced in Task 6 of this project, five industrial trials were organized with cooperative die casters in the USA. Components cast during these trials ranged from functional electronic heat sinks to decorative household plumbing components. Whereas laboratory work indicated that die temperature and draft angle were the most important process factors influencing solder accumulation, it was not possible to vary draft angle on the established production dies used for these trials. Substantial variations in die temperature were realized however and also die surface conditions were varied, confirming the influence of a secondary variable in the laboratory investigation.

Substantial evidence from the trials indicated that die surface temperature is the most important factor for controlling solder build up. It is very desirable that die temperature be controlled precisely in some way. During the trials, several die casters systematically controlled die temperature by using die spray, the only temperature control tool often available on the production floor. With good control, it is possible to minimize the incidence of die soldering on tooling where die soldering has been experienced in prior production.

The surface roughness of the die casting die greatly influenced the number of castings that could be run before solder initially appeared. A shot peened cavity began showing solder build up after 253 shots, whereas a highly polished cavity avoided solder build up until 4256 castings had been run in the campaign.

Development of careful thermal management techniques, now judged to be beyond the capabilities of most United States die casters, will be necessary to control incidences of die soldering found in typical production. Thermal control will involve both control of the bulk die temperature through use of thermally controlled cooling lines, and also regulation of surface temperature by well controlled die spraying (lubrication) techniques. Further research, development and technology transfer to enhance thermal control capabilities of United States die casters is recommended.

INTRODUCTION:

Many die casters, especially those producing decorative parts for which good surface finish is critical, from time to time experience a build up of the cast metal inside the die casting tool cavity that is commonly referred to as die soldering (or "build-up"). Over the years, practices to minimize die soldering had been empirically worked out by several die casters, however this problem can never be completely avoided, and practices were found to be inconsistent from one die casting facility to another. Under the auspices of the North American Die Casting Association Research and Development Committee, ILZRO agreed to jointly fund a research program with the US Department of Energy that would determine the causes of die soldering in zinc die casting dies. ILZRO served as the primary contractor for this project. Subcontracts were let to Noranda Technology Centre and William G. Walkington to carry out laboratory research and to provide consulting services, respectively.

The laboratory research at Noranda began in October 1994 and consisted of two phases: I. A Literature Review and Casting Trial and II. Further Casting Trials to Investigate Secondary Process Variables. The Noranda laboratory research was completed in August 1996 after which the third stage: III. Verification Trials at Commercial Die Casters, was begun.

The purpose of this report is to provide a summary of work carried out under Phase III, including activities with candidate and participating die casters, the common methods used during the industrial trials, specific reports on each participating die caster, and a discussion and general conclusions concerning the industrial validation trials.

*Phase I*

The results of the Noranda laboratory work done in phase I were based on the most popular zinc die casting alloy, Alloy 3; and they found that die soldering was a deposition type mechanism rather than a "galvanizing reaction" as had been reported widely in the subject literature. The deposition mechanism results in a very thin Al rich, Fe free layer next to the die steel, contrary to a galvanizing reaction which would produce an Fe containing layer on the surface of the die steel. The results of the Noranda laboratory trials are summarized in two progress reports that were previously submitted in fulfillment of the requirements for this project.[1,2]

The Noranda laboratory work concluded that high die temperatures and low (approaching zero) draft angles separately or together promote moderate to severe die soldering. A significant interaction was found between die temperature and draft angle, viz. low (near zero) draft angles can be tolerated only if the die temperature is kept low, and low draft angles and high die temperatures can lead to severe die soldering. The laboratory trials indicated that die surface roughness was one of the factors that contributed to soldering, although this variable had not been examined within the structure of the laboratory research. Observations during these laboratory trials indicated that surface roughness could play an important role (especially in areas of low draft angle) in promoting die soldering, at least during the initial stages. This observation was consistent with observations by die casters that once die soldering begins, and then roughened the surface on its own, it must be eliminated completely or it will quickly return. Thus, one of the purposes of the industrial trial was to examine the effect of die surface roughness on the propensity of a die to solder.

The Noranda laboratory work determined that gate velocity was not an important factor in promoting die soldering, therefore this variable was not considered in any of the industrial trials. However, the work did indicate that if the draft angle is low and the gate velocity high enough so that erosion can occur, soldering will more than likely result because of a physical attachment mechanism. High velocity metal spray during subsequent shots can remove previously-formed solder and cause further erosion. During the Noranda laboratory work, variations in the Al content of the casting alloy were used to determine the effect of Al content on the tendency of the die to solder. No effect of this variable was seen in the relatively short laboratory trials and it was desired to determine whether an effect of Al composition became important during extended campaigns typical of industrial production. However, there were many difficulties in changing casting alloy composition during industrial production; and in spite of several efforts being made, it was not possible to get this option included during the industrial confirmation trials.

The industrial confirmation trials investigated the effect of the following primary variables:

- Die surface roughness (as machined vs. highly polished)
- Die surface treatment (shot peening and other finishes or coatings)
- Die temperature
- Die lubrication
- Draft angle

Details on the effects of each of these variables are given in the respective individual company reports and the results are summarized at the conclusion of this document.

## CHAPTER 2 — METHODS OF INVESTIGATION:

Recruitment of industrial participants for the confirmation trials was carried out by Dr. Frank E. Goodwin, principal investigator, and William G. Walkington, project consultant. Presentations on the results of the Noranda laboratory research were made to the following companies who had indicated an interest in joining the project:

- Amerock, Rockford, IL
- Brillcast, Holland, MI
- Crecocast, Seville, OH
- Diemakers, Monroe City, MO
- Kippcast, Madison, WI
- Moen, Sanford, NC
- National Manufacturing, Sterling, IL

In addition, the following companies received complete information on the project, however all found it impossible to join the confirmation trials:

- Chicago White Metal, Bensenville, IL
- Kennedy Die Casting, Worcester, MA
- Wright Products, Rice Lake, WI

A condition to join the industrial confirmation trials was that the die caster nominate a test component for his industrial trial. A "baseline datasheet" was prepared so that the nature of the die soldering problem with this component could be better understood. A blank baseline datasheet is shown in Appendix 1.

Upon meeting with the first group of die casters noted above, the baseline datasheet was reviewed and the machinery used to manufacture the component observed, especially the details of the die casting dies. A set of "procedure guidelines" was also developed so that all die casters could follow the same procedures during their die soldering trials to the extent possible, given limitations of each company's equipment. A copy of the procedure guidelines is shown as Appendix 2.

After organizing the trials, it became apparent that detailed methods for evaluation of die soldering on the produced castings needed to be developed, therefore a "sample and evaluation procedure" shown in Appendix 3 was developed. Some of the die casters used the "grid technique" developed to determine the severity of soldering on sampled castings. A copy of the grid with its 1/16" squares used by such die casters is shown as part of Appendix 3. Other die casters used a numeric rating system consistent with their own internal rating system.

Five companies ultimately participated in the industrial validation trials:

Brillcast
Diemakers
Kipp Cast
Moen
National Manufacturing

These companies participated in these trials on the condition that all results would be coded to avoid divulging their identity. Therefore, they are referred to as companies A-E in the remainder of this report.

Reflecting the differences in management of each company, different levels of documentation were prepared by each participant, from very detailed, including printouts of machine variable histories, to informal or anecdotal. All five companies were regularly contacted by telephone by either Dr. Goodwin or Mr. Walkington to assess progress and give guidance on the direction of work.

The first die casting trial in all cases was a "baseline trial" which used the normal process conditions for the castings selected by each of the die casters. In this trial, the process variables and part quality were to be monitored according to the method agreed to for each company. The baseline trial was to provide a quantitative confirmation of the experiences of each of the die casters in a manner which would allow comparison of the baseline trials between the die casters.

All trials were conducted using Alloy 3, whose composition is shown in Table 1. Details of the confirmation trials held at each company are shown in the following chapter.

## CHAPTER 3 — INDIVIDUAL COMPANY CONFIRMATION TRIALS:

The details of the casting process were checked at each company to be sure there were not major problems with other parameters. The $PQ^2$ calculations, which determine how well the die is matched to the die casting machine, were checked, and the die conditions were reviewed to be sure the die was not deteriorated enough to cause problems that would interfere with the testing.

Since the casting shapes that were to be used in the trials could not be changed, the chance to change the draft angle was minimal. Therefore, the draft angles tested depended on the solder location in the parts that were available. The largest part of the effort was concentrated on managing the process controls available to the die caster as they affect the soldering.

### *A. Company A*

Company A runs very high quality surface finish parts. The part selected was a faucet escutcheon, which has to have an extremely high quality finish. The part soldered on the side, and a picture of the soldering is shown in Figure 1. The solder was not always noticeable unless the part was polished and then it may only show as a slight rough spot noticeable when the light is reflected just right; however this would show up as a small imperfection after plating. A photograph of this casting is shown in Figure 2.

The part was run as a single cavity in a 400 ton machine. The machine and the die were completely instrumented (which is the normal method for operating in this plant), with the die temperature control being done with buried thermocouples controlling the water flow in the die. Vacuum was not used on this die. Normal operating conditions were used for the initial baseline data. The filled-in baseline data sheet for Company A is shown in Appendix 4.

The baseline data shows that the average die temperature taken at the solder site just after the machine opened was 388°F, which would generally be considered a little cool considering the good finish requirement. The soldering is in an area away from the gate not in the direct metal flow path, thus gate velocity was not considered a factor. (This was also the case on the other parts.)

As requested, profilometer readings were taken on the die. These readings are for a die that had normal tool room preparation, and were from about 9 to 15 µin in the area where the solder accumulated. The holding furnace temperature was set at 805°F, and the variation was small; ±2°F.

The die had to be polished an average of six times over three shifts to remove solder during the baseline run (which was run at normal production conditions). A 6000 piece lot was run during the baseline.

The experimental plan for Company A was to conduct die soldering trials at die temperatures 20°F above and below the baseline die temperature of 338°F with a nitrided surface treatment, Dynablue that had shown promise in past production. The experimental plan is shown graphically in Figure 7.

The next trial was with a cavity that had a surface treatment to give it a smoother surface. In this case, a commercial treatment that was reported to have been successful at this diecaster was used. The surface finish was measured at 2μin to 4μin after treatment. The second run was made with the same conditions as the first, except for the surface treatment. A 5000 piece run was made. The result was that the same polishing (six times in a three shift period) was required as with the normal finish. The die caster also used the grid system to record the amount of the solder.

A trial with a higher die temperature was the next trial run to be set up. Given that the die had to be run under production conditions, the trial was to be run at the highest die temperature that would allow continuous production.

During this trial, the die temperature could only be stabilized at a temperature about 20°F higher than the normal production run without causing other problems - even this small change caused some increase in scrap from causes other than solder. During the time these conditions were being established, the soldering was about the same as noted before. The trial was then terminated because of the expensive scrap being generated and the lack of any apparent benefit to the soldering problem. A low temperature run was also attempted, with very similar results.

Thus the temperature changes desired for the experimental work could not be run because of the very critical surface finish requirements for this part, even with the very careful process control that existed in this plant. However, the surface roughness information was considered very valuable.

### *B. Company B*

The part chosen was a heat sink, run as a two cavity die in a 60 ton machine. There were occasional problems with "build-up", or solder on the fins of the sink in normal operation. The die normally runs about 15,000 parts per month, about a 8 or 10 day run. The die is cleaned up between runs with acid, and polished on the floor as needed. A photograph of their part is shown in Figure 3.

The metal temperature in the furnace was 800°F. The die will sometimes run for some time before polishing is required the first time, but will need polishing more often once it starts. The die caster installed two thermocouples in the die to run the tests; these were installed under the cavity in the only location available. A copy of their filled-in baseline data sheet is shown in Appendix 5.

The first baseline run was intended to be a run with the settings used in normal production. The experimental plan is shown in Figure 7B. A cavity (cavity #1) had already been sent out for shot peening with Metalife, and so it was decided to run this cavity in combination with a cavity that was "bright polished," which was considered the normal cavity The normal cavity (cavity #2) had a polished surface finish, which was the normal situation in the tool room when a die was cleaned and made ready for another casting run.

The profilometer reading on the normal cavity was about 25μin, and about 75 to 80μin on the cavity that had been treated with Metalife.

The results showed that the normal cavity (cavity 2) did not show any solder build up for 4256 shots, while the shot peened cavity (cavity 1) showed some build up from shot #253 on. The number of .06 inch grid squares on the casting surface that were observed as rough (and hence had some solder on the die) ran from 6 squares at first; and increased to 20 squares at shot number 6257. The die was polished at about that point. The fact that there was some soldering present did not mean that the part had to be scrapped; unlike the first part, some roughness could be tolerated on this part.

There was no visible soldering on the part for cavity 2 until a small amount appeared shortly after 4256 shots, and this increased a little until polishing for cavity 1. It remained essentially at zero after polishing through about 10,000 shots.

A profilometer reading on the casting after soldering had occurred gave a reading of about 100 μin to 135 μin on the casting surface.

The second run for this die was delayed, and is now in progress, but the data were not available for this report. A lower temperature will be used for this run, with the temperature being set by lowering the cycle speed. The temperature will be set as low as possible without making rejected parts. The surface finish on the die for both cavities is now at the normal production surface finish, so just the temperature will be changed.

### *C. Company C*

The part to be run was an electrical switch housing with an occasional soldering problem. The die contained a core with a .5630 diameter that was 2 inches long, and tolerance allowed .002 inches total dimensional variation on the diameter including draft, making it essentially a zero draft situation. This core occasionally soldered up and required polishing, and because of the tight tolerances, it did not take much polishing to take the core out of tolerance. A photograph of this casting is shown in Figure 4.

The core contained a small water line to control the core temperature, which had been added at some point in the production history (this part had been in production for over 12 years, and details of when the water was added were not available). The water flow was set to be continuous when the die started production.

Temperature monitoring was needed to run the soldering tests, and a thermocouple was added to the die. The area of interest was the movable core that had zero draft, but it was too small to add a thermocouple internally, so a thermocouple was added in the die on the stationary side such that it would touch the core when the die was closed. This arrangement is shown in Figure 8. A small stationary core in the cover die already existed that shut off against the movable core, and the thermocouple was added in this small stationary core. This would provide a surface temperature measurement of the core when the die was closed. There was concern that the temperature measurement would be incorrect because of flash build up between the thermocouple and the core, but the thermocouple was spring loaded slightly, so this worked quite well.

There had been surface finish problems on the core in the past as well as soldering problems. It was suspected that the water line in the core would over-cool it, and this would cause poor finish problems. The operator's reaction would be to turn the water off to help the surface finish, however, then the core would get too hot, and then soldering problems would appear. A copy of Company C's filled-out baseline data sheet is shown in Appendix 6. A drawing of the die used for the study is shown in Figure 8. A graphical representation of the experimental plan for Company C is shown in Figure 7C.

During the baseline run, the core temperature was adjusted to get the best operating temperature. A setting of about 350°F gave the best balance between a good surface finish but still no soldering; and this was used as the base line test. Unfortunately, some of the test data was misplaced and so exact numbers are no longer available. Interviews with the operators and engineers produced these data.

The set up engineer reported that with the water off, the core temperature would approach 400°F, and solder would start to appear. When the temperature was lowered to about 300°F, then cold finish problems and lubricant build up would appear. The lubricant was mixed at 40:1, and applied for about 0.5 seconds; but a setting that was right for the higher temperatures would be excessive at the lower temperatures and cause some lubricant build up problems. A setting between these of about 350°F gave the best results, and this is where they ran the base line test.

In order to maintain the temperature setting, the thermocouple was hooked to a controller that turned the water flow on and off so as to maintain a set temperature. The thermocouple installation was judged a success by the die caster, who is adding similar controls to another die.

The second trial run was to be run at a higher temperature; however, a part of the core was broken off shortly after the test was initiated, and the test was terminated.

### *D. Company D*

The part selected was a cover for a screen door handle, and is shown in Figure 5. The part had very high quality requirements and was a new die that was being developed for production. There were continual soldering problems that affected the surface finish just enough to make the parts non-usable. The solder appeared as a line of solder just above the gate (and with some on the side of the cavity opposite the gate).

The company agreed to run a baseline and then more trials; however a short time later they reported that they had solved the problem by adding a small amount of die spray just at the point of soldering, and that they could no longer afford to participate in the study. The experimental plan that would have been followed is shown in Figure 7D.

However, the fact that they solved the problem by adding cooling directly on the area where there was a soldering problem was considered significant.

### *E. Company E*

The part selected was a very high quality surface finish part that was a base (or deck) for a faucet. This casting had three holes for use is a kitchen faucet assembly, and is shown in Figure 6. The defect could not be seen until after polishing and viewing at the proper angle in the light.

The soldering occurred on the side of the cover side of the die, opposite the gate at the end of the metal flow path. The solder occurred in an area that caused frequent shut downs in the run for polishing. Some dies had been polished so much that part of the die surface was polished away, and the casting wall thickness had increased from .05 inches to as much as .08 inches.

The baseline experiment was run and the process variables were monitored carefully. Some of the data from the base line test is shown in Appendix 7. These results are consistent with the remarks shown in the above paragraph. Before further data could be obtained, the problem was corrected by some modifications to the spray system that allowed the spray to be applied directly to the solder area. (The company also elected to discontinue U.S. casting operations and purchase castings from U.S. and overseas suppliers).

## CHAPTER 4 — DISCUSSION AND CONCLUSIONS:

### *A. Discussion*

The laboratory work indicated that die temperature and draft angle were the most important process factors influencing solder accumulation, and that the surface finish also could be important on a sustained production run. However, the laboratory work could only be done with trials that ran for about 300 shots, and evidence from production operations was that soldering often did not appear until after several thousand shots; and that it could be removed but would come back and would need continual die polishing or other maintenance (acid etching) to keep the die surface clean once it started.

Thus the need for field confirmations of the laboratory results with field trials. However, as can be seen from the discussions about the individual trials, it was very difficult to establish the necessary conditions for trials in continuous production situations.

One of the problems was the trials of lower aluminum content alloy; these could not be run in the field as they were in the laboratory. Scheduling a special alloy into the commercial systems was a problem because most die caters used central metal delivery systems. In this case, running a trial with a special alloy required all machines to be switched; even though only one machine needed to run the trial alloy. Those that had individual melting systems could not change schedules enough to use a special alloy. The aluminum variation proposed was well within Zamak 3 specifications, Table 1, and would not have affected customers.

This trial was desired because the laboratory results indicated that aluminum plays some role in the deposition of zinc on the die [1,2] and lowering aluminum content may have some long-term effect on soldering. Also, this is a practice done in some overseas operations. It should also be mentioned that lowering the aluminum content will also reduce the fluidity of the zinc; this may not be a problem on many castings, but it could easily be significant on those that require the very high quality surface finish.

Also, economics make it difficult for participants to run long trial runs (on the order of 5,000 to 10,000 shots) at settings that are marginal and that produce extra scrap. As noted in the comments on each company, some trials were terminated early for economic reasons even though the company involved was anxious to help as much as possible. Mostly the trials were terminated when the soldering was eliminated or reduced during the trial.

### *B. Conclusions*

Even though not every trial was completed, there is enough data to establish some important conclusions. These would essentially corroborate the initial phase I and II work done in the laboratory.

1. The surface roughness of the die has a definite influence on the time before the initial appearance of the solder and on the amount of solder build up. This was most evident in the trial using a two cavity die where one cavity had a rough finish (75μin to 80μin) and the other had a smooth finish (9μin to 15μin). It was also evident in the laboratory trials (1,2). However, a very smooth finish, on the order of 2μin to 4μin, did not improve results over the normal die polishing. The "normal" finishes were from about 15μin to 25μin in these trials. This confirms earlier work(3) that indicated that some roughness is desirable in die casting die cavities.

2. There is substantial evidence that the die surface temperature is the most important factor for controlling solder. Trials from three of the five companies indicated this to be the case. It is also apparent that the die surface temperature at the location of the solder is the variable to be controlled, which may be difficult to measure. Certainly this is true for the variables available for control once the die reaches the production floor. It appears very desirable that the die temperature be controlled precisely some way, as was particularly evident in the Company C trials.

   The die surface temperature at the location of the solder may not react in quite the same way as the bulk die temperature and may be difficult to measure. One of the most common methods of controlling this is using die spray, which was very important in two of the trials. The die spray can change the surface temperature on a spot basis very quickly; also it is often the only temperature control tool available on the production floor. However, it is subject to a number of critical judgment factors (i.e. direction, volume, velocity and time of spray). Interior temperature control with thermocouples controlling water or oil lines provides a very predictable and effective control (as with the Company C trial).

   The role of the coating developed by the die lubricant is also an unknown at this point, and probably is a significant factor. However, it should be noted that the die sprays being used had at least 97% water content; which would undoubtedly cause the cooling effect of the water to be a very strong influence in die surface temperature regardless of the type of lubricant.

3. An important conclusion is that very careful temperature management is required to keep the die surface temperature at the optimum point to prevent soldering and not cause other problems (which is probably different for different

shapes of castings). The temperature should be high enough to get a good surface finish and low enough to reduce the onset of soldering. At present, it is felt that the necessary process engineering and control needed for a substantial reduction of die soldering in zinc is not at the necessary level for most die casters. Again, it should be noted that the exact role of the coating applied by the lubricant is not well documented.

Two die casters already had thermocouple control of water flow on the trial die because of other needs for stringent finish requirements, two had to add it, and the third terminated before adding thermocouple control. In one case, Company C, controlling the water lines with a thermocouple in the die allowed the soldering problem to be eliminated and surface finish improved.

The type of control anticipated for good control would come not only from having thermocouples in the die to control the surface temperatures; but also by controlling the spray system precisely and repeatedly for direction, volume, velocity and time (to 0.01 second intervals) of spray; and also by thermally engineering the die initially, mostly with software simulation of the thermal conditions.

## CHAPTER 5 — ACKNOWLEDGMENTS:

The authors of this report wish to acknowledge the following individuals and companies for their very significant contributions to this project. These include members of the industrial monitoring team which gave guidance to the project over its duration.

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- Jim Verburg, Brillcast
- Scott Kirkman, Brillcast
- John Coates, Diemakers
- Mark Utterback, Diemakers
- Justin West, Diemakers
- Roger Johnson, Kippcast
- Bill Evans, Kippcast
- Bob Bronson, Kippcast
- Mike Lendman, National Mfg.
- Dennis Behr, National Mfg.
- Paul Kennedy, Kennedy Die Casting
- Jack Berkseth, Wright Products

## CHAPTER 6 REFERENCES

1. Final Progress Report on Task 6, Phase I, "Cooperative DoE/NADCA Die Soldering Program," ILZRO Project ZM-415, October 1994 - September 1995, Issued September 1995.

2. Final Progress Report on Task 6, Phase II, "Cooperative DoE/NADCA Die Soldering Program," ILZRO Project ZM-415, October 1995 - January 1997, Issued January 1997.

3. J.M. Birch and S.E. Booth, "The Relationship Between Casting Parameters and the Surface Quality of Zinc Alloy Castings," Proceedings of NADCA 15th Die Casting Congress & Exposition, October 16-19, 1989, St. Louis, MO, Paper G-T89-093.

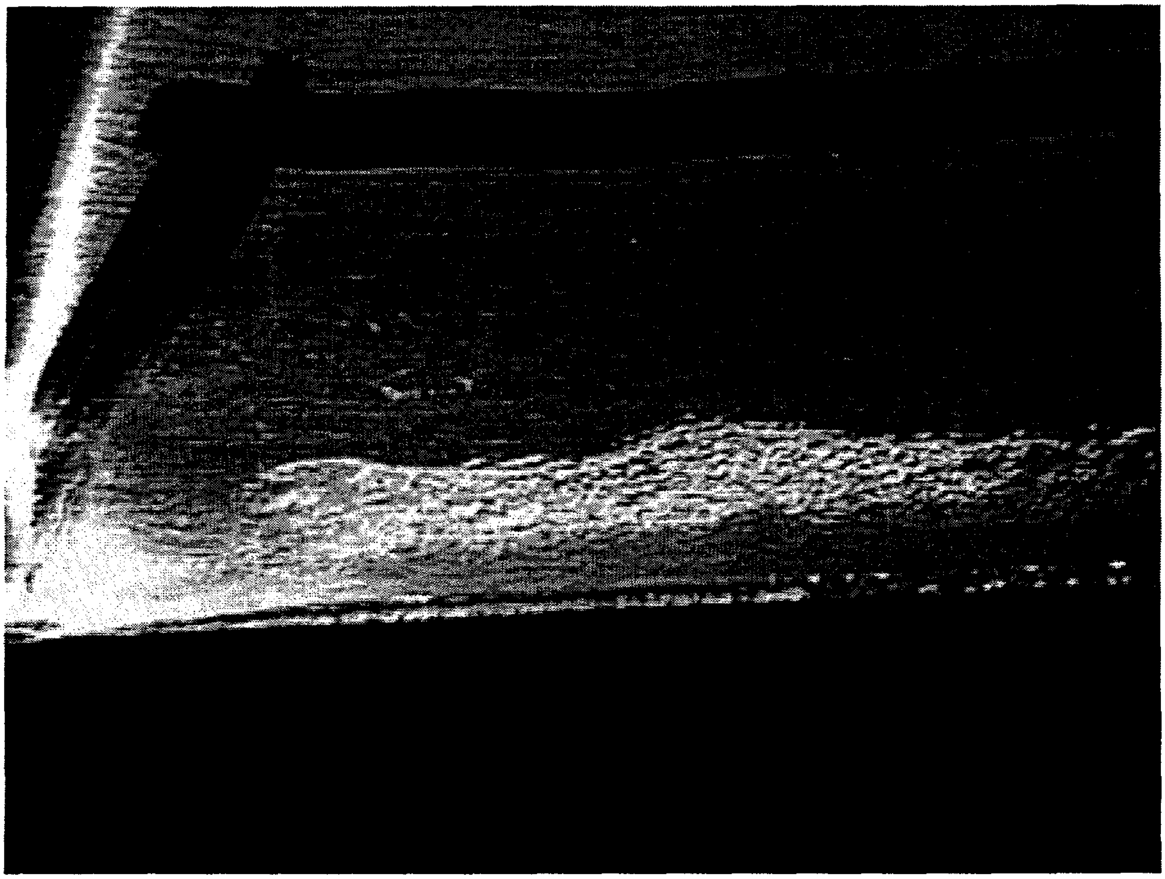


Figure 1. Close-up view of soldered area on casting shown in Figure 2.

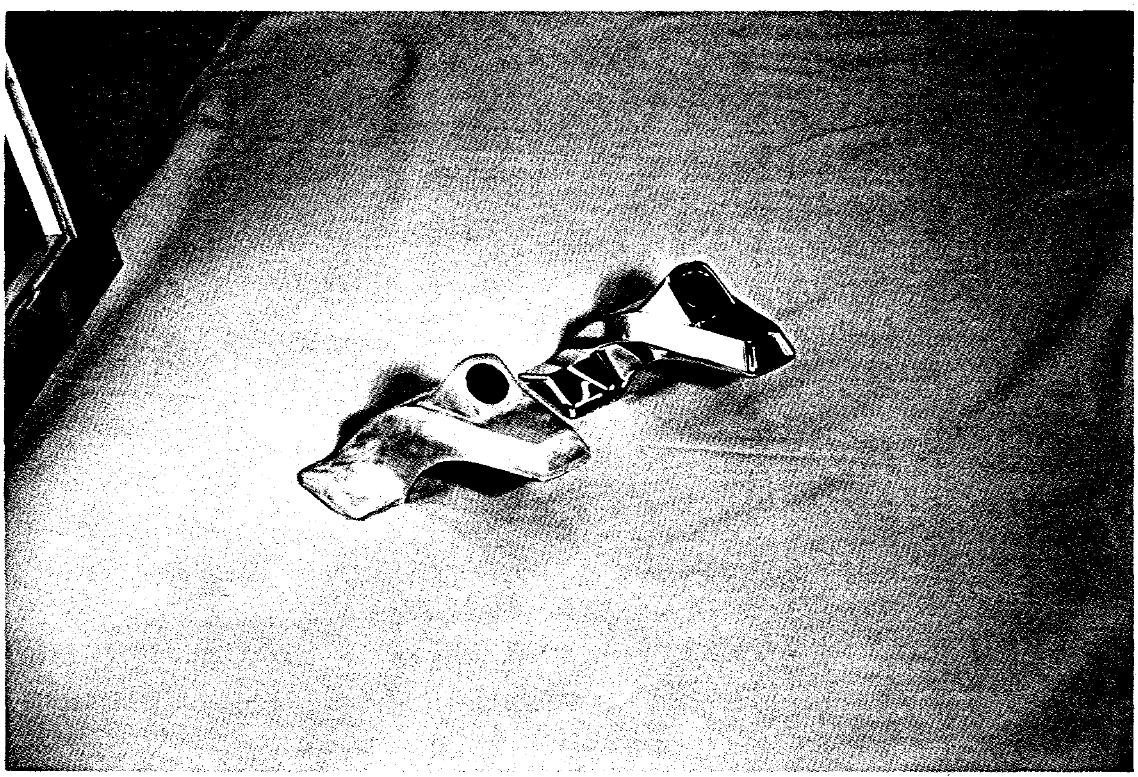


Figure 2. As-cast (left) and plated (right) faucet casting produced by Company A for die soldering confirmation trials.

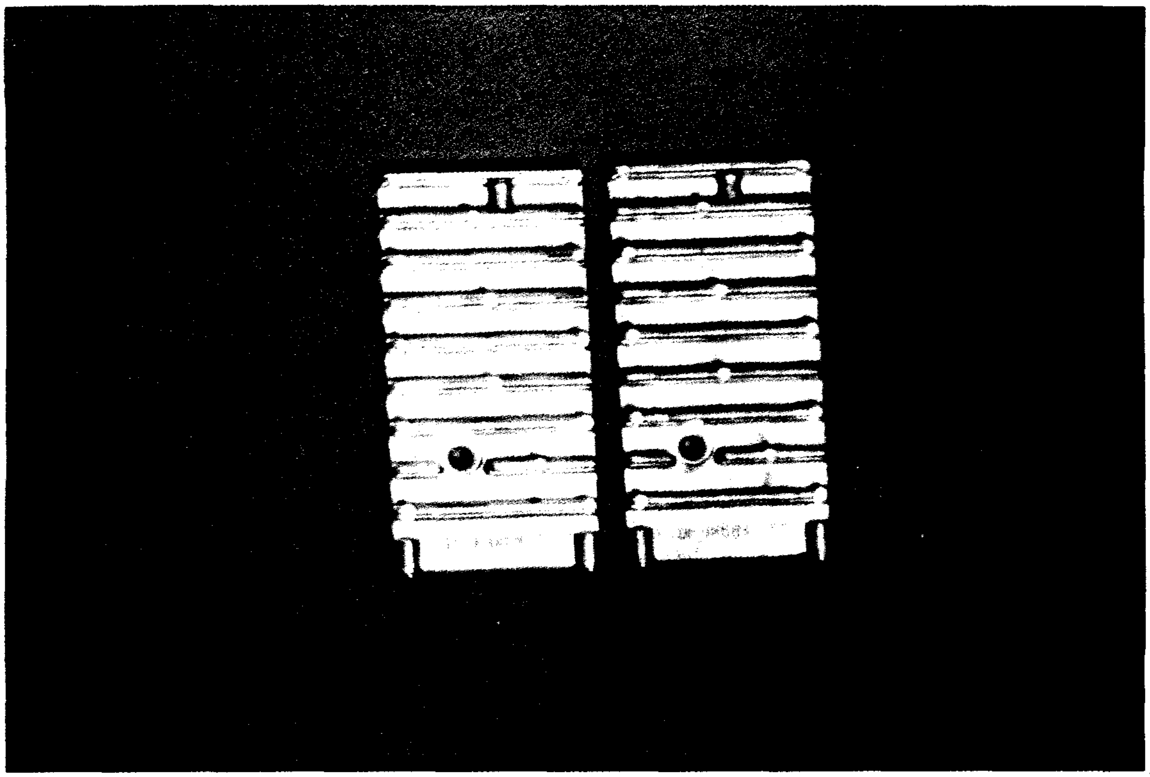


Figure 3. Electronic heat sink castings produced by Company B for die soldering confirmation trials.

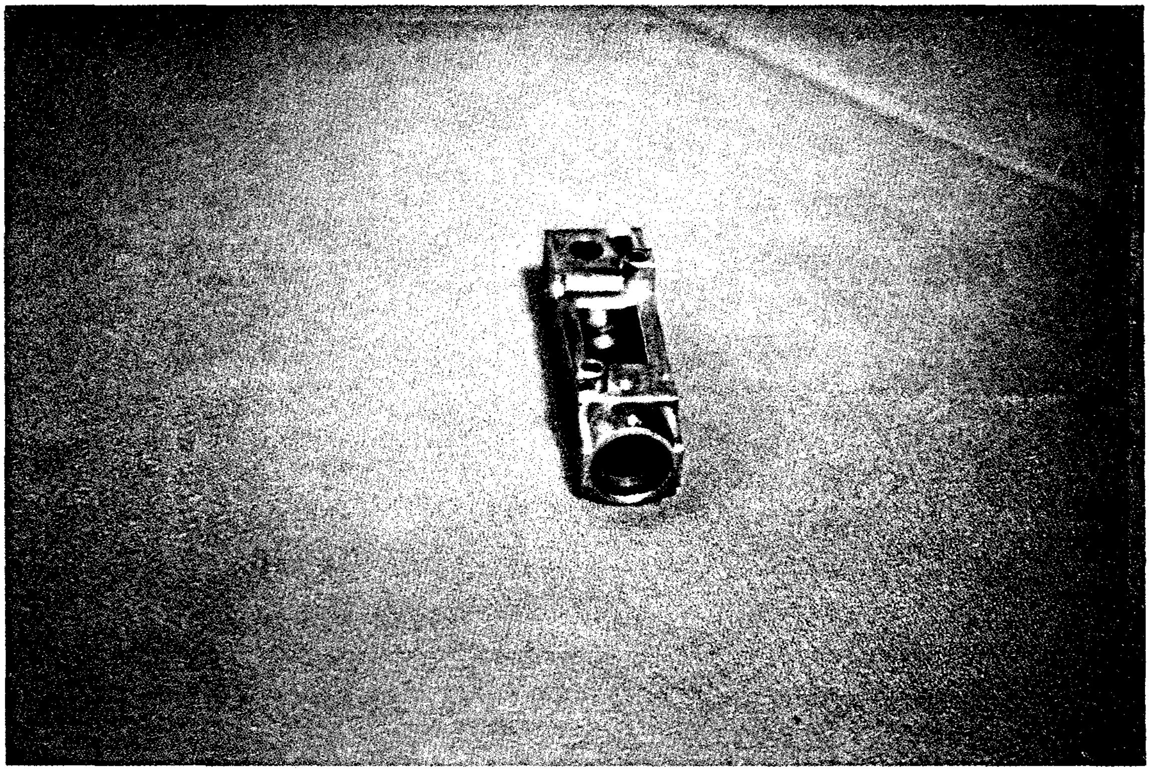


Figure 4. Electronic switch housing casting produced by Company C for die soldering confirmation trials.

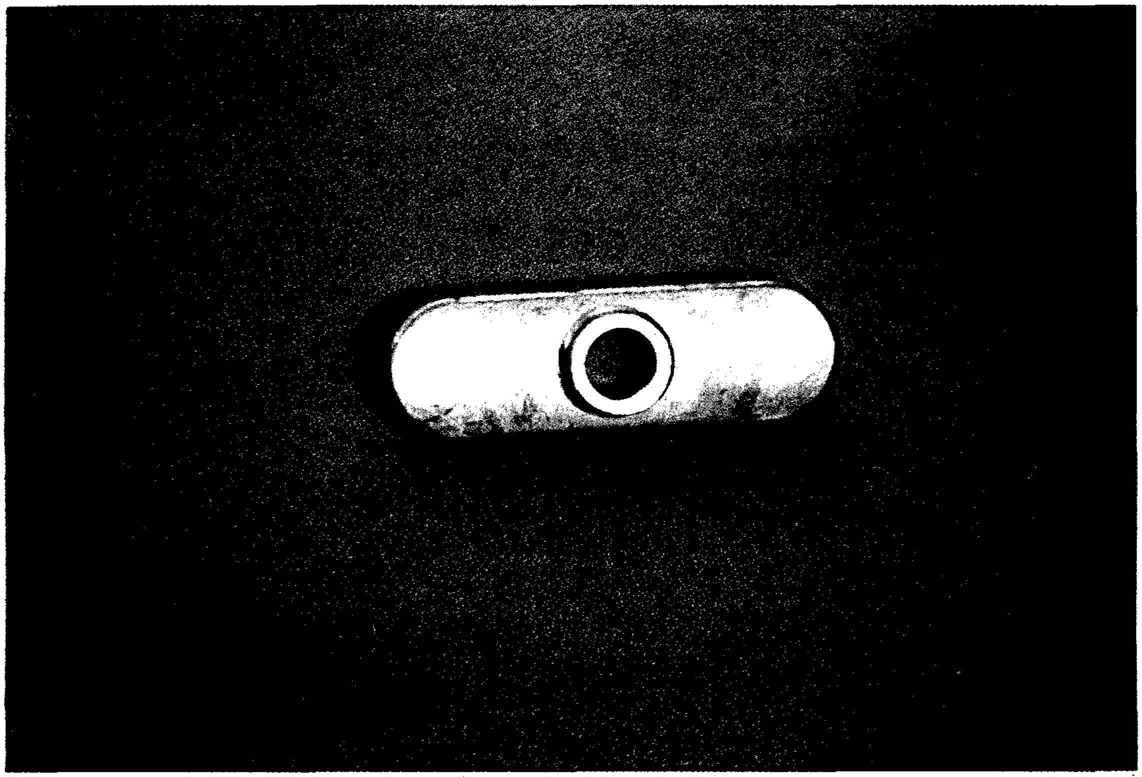


Figure 5. Screen door latch cover produced by Company D for die soldering confirmation trials.

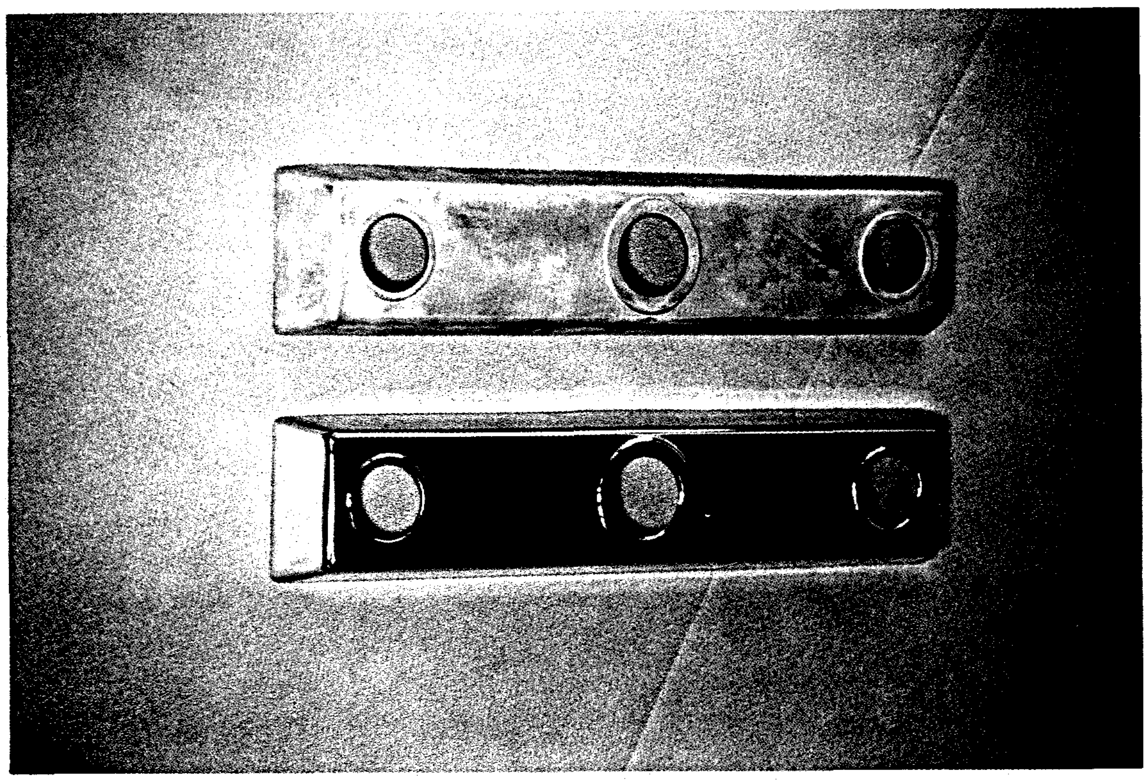


Figure 6. As-cast (top) and electroplated (bottom) kitchen faucet base castings produced by Company E for die casting confirmation trials.

| Die Temp. °F | Regular Polish | Nitrided Surface |
|---|---|---|
| | 358 | High [✔] |
| | Baseline [✔] | 338 [✔] |
| | 308 | Low [✔] |

Die Surface

**A. Company A**

| Die Temp. °F | Regular Polish | Shot Peened |
|---|---|---|
| | High | High |
| | Normal Baseline [✔] | Normal |
| | Low Polished [✔] | Low |

Finish Surface

**B. Company B**

| Die Temp. °F | |
|---|---|
| | High |
| | 350 Baseline [✔] |
| | Low |

**C. Company C**

| Die Spray | |
|---|---|
| | High Spray |
| | Normal Spray Baseline |
| | |

**D. Company D**

| Die Spray | |
|---|---|
| | High |
| | Baseline [✔] |
| | Low |

**E. Company E**

[✔] Indicates Trial Performed.

Figure 7. Chart of Planned Process Variables for Investigation During Industrial Confirmation Trials.

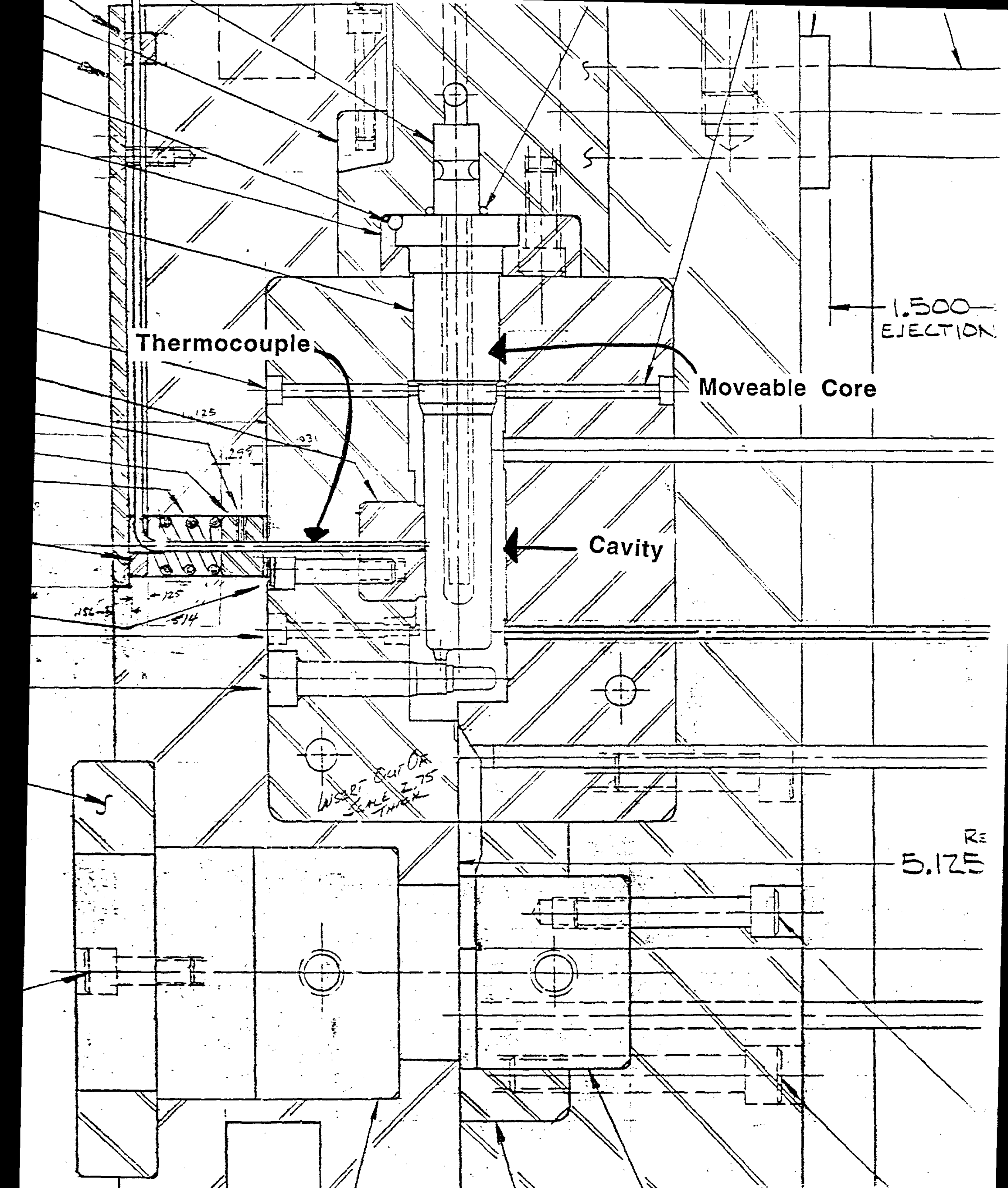



Figure 8. Die drawing across parting line, COMPANY "C" casting.

## APPENDIX 1

# Cooperative ILZRO/DoE/NADCA Die Soldering Program
## Baseline Data Sheet for Trial Component

COMPANY: ____________________

NAME: ____________________

PLANT LOCATION: ____________________

CONTACT PERSON FOR THIS PROJECT: ____________________

CONTACT NNUMBERS: TELEPHONE: ____________________ FAX: ____________________

DESCRIPTION OF PART SELECTED: ____________________

PART NO.: ____________ WEIGHT: ____________ ALLOY: ____________

FILL TIME: ____________ VELOCITY: ____________ PLUNGER SIZE: ____________

PLUNGER SPEED: ____________ POT TEMPERATURE: ____________

DESCRIPTION OF SOLDER PROBLEM: ____________________

LOCATION: ____________________

NUMBER OF SHOTS BEFORE ACTION IS REQUIRED: (Action would be polishing the die, or changing the core or die part. Use average numbers and list minimum and maximum shots if known).

AVE: ____________ MINIMUM: ____________ MAXIMUM: ____________

WHAT ACTION WAS NORMALLY TAKEN AT THAT TIME? ____________________

HOW LONG DOES IT TAKE TO FIX THE PROBLEM WITH THIS ACTION, AND RETURN THE MACHINE TO PRODUCTION? (TOTAL MACHINE DOWNTIME BECAUSE OF SOLDER PROBLEM): ____________________

A sample part of the die with soldering on it is needed. If a soldered die part is not available, then photographs and measurements of the amount of the soldered area will be needed. Comments: ____________________

____________________

FOR A NEW DIE PART AT THE LOCATION OF THE SOLDERING, WHAT WOULD THE FOLLOWING BE:

Draft on the die at the point where solder occurred: ____________________

Surface finish on the die at the soldered point: ____________________

Die temperature at the solder point: Average: ____________________

Temperature just **after** die opens: ____________ Temperature just **before** die closes: ____________

Date filled out: ____________ By: ____________________

# # # # #

# APPENDIX 2

ZM-415, "Cooperative Department of Energy/NADCA Die Soldering Program"
Industrial Confirmation Trials

## Procedure Guidelines

*Note: All results will be coded to avoid divulging of your company's name.*

1. Choose a die with history of soldering.

2. Determine present die and casting conditions:
   - Surface Finish (roughness, use of coatings) in Soldered Area
   - Draft
   - Die Temperature
   - Casting Alloy - Al %
   - Use of Die Lubricant, Coatings, Release Agents
   - Shot Conditions — Gate Velocity, $PQ^2$ Characteristics
   - Spray Practices (Die Surface Cooling)
   - How Many Shots are Usually Run Until Die Solders?

3. Determine how to modify die based on project recommendations:
   - Die Temperature
   - Draft in Soldered Area
   - Roughness in Soldered Area (including coating)
   - Possibly Al Composition

4. Run the die using shot conditions similar to those shown in Step 2.
   - If run conditions progressively (one change at a time) run at least as many shots as in Step 2.
   - If you can only do one trial, then change all variables at once; run die until soldered, or 5,000-10,000 shots.

5. Characterizing Soldered Surfaces:
   - Dimension Change
   - Extent of Surface Soldering — Photos, Grid Overlay and Counting

6. Reporting of Results — All Items Shown Above Plus Number of Shots in Each Trial.

7. Time Table:
   - Die casters are asked to conduct an organization meeting with their own personnel during September 1996 using these guidelines. Bill Walkington, as a consultant to this project, is also available for up to three days free-of-charge, including attendance at the die casting trials.
   - All trials should be completed by the end of March 1997.

ZM-415, "Cooperative Department of Energy/NADCA Die Soldering Program"
Industrial Confirmation Trials

# Sample and Evaluation Procedure

Running and Sampling:

Please measure and record the surface roughness of the die in the area that solders before each run of castings, including the baseline run.

There should be a minimum of 5,000 castings produced for each set of process conditions chosen for this project. If this is too many or too difficult, please contact Bill Walkington or Frank Goodwin.

A good sampling procedure would be to take five sequential castings after each 250 shots. For a 5,000 casting run, this would give 100 samples. If this is too many, a minimum size of 40 samples should be taken.

If there is enough soldering so that the die needs to be polished frequently, then five samples should be taken just before one of the times the die is polished. The number of shots since the last polishing should be recorded.

If the conditions chosen give consistently bad castings, the run can be stopped after it is obvious that casting quality is poor. Samples should be kept and evaluated to provide the data needed for the project.

Evaluation of Castings:

There are several ways to evaluate die soldering:

- A grid technique. In this procedure a grid of 1/16" squares is laid over the soldered area and the number of squares covering the soldered area is counted and recorded. If you need transparencies for this, please let Bill Walkington know and he will send you some.

- A numeric rating system, for example, from 1 (bad) to 5 (good). This require that the same person conduct all ratings, and that examples of castings from each rating be sent to Bill Walkington or Frank Goodwin so that the rating can be calibrated against the grid measurement system described above.

## APPENDIX 3
*(Page 2)*

•A system your company has already established. This system must be able to measure soldering as a separate quality issue and not as part of another quality attribute. It should also be capable of measuring the small changes that might result from one run to another. Examples of castings from each rating should be sent to Bill Walkington or Frank Goodwin so that the rating can be calibrated against the grid measurement system described above.

<u>Reporting:</u>

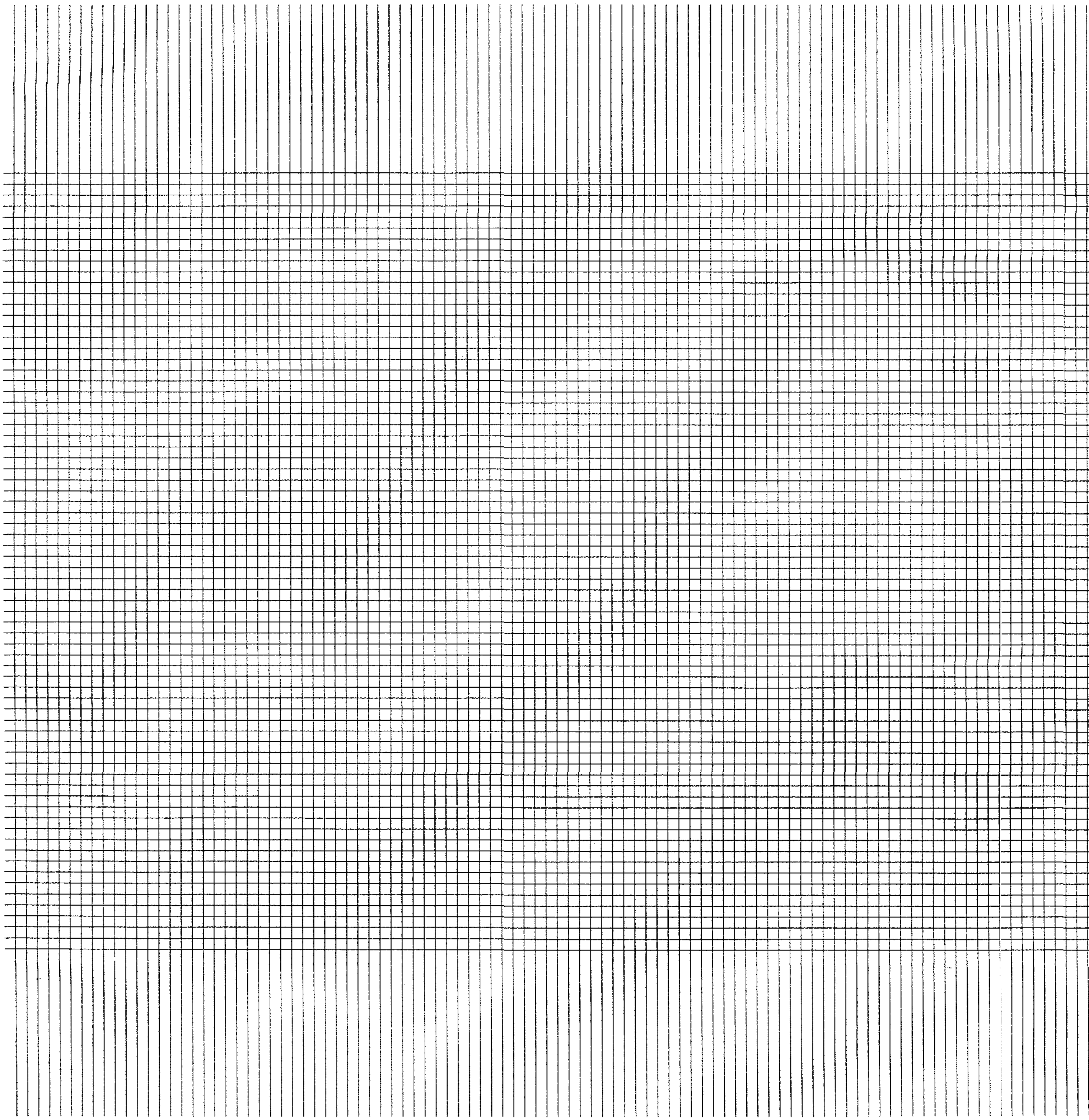
Because each companies experiments will be different, the reporting method will also be different in each case, but will always include die surface roughness and soldering severity data (grid measurements or ratings). All measurements described above, together with a complete list of the casting conditions used in each run, should be sent to Bill Walkington or Frank Goodwin upon completion of this work.

1/97

APPENDIX 3

*(Page 3)*

# Transparent Rating Sheet Used



APPENDIX 4

## Cooperative ILZRO/DoE/NADCA Die Soldering Program
## Baseline Data Sheet for Trial Component

COMPANY: COMPANY A

NAME: ____________________

PLANT LOCATION: ____________________

CONTACT PERSON FOR THIS PROJECT: ____________________

CONTACT NNUMBERS: TELEPHONE: ____________________ FAX: ____________________

DESCRIPTION OF PART SELECTED: Faucett Eschutsion

PART NO.: 100988C WEIGHT: .66 ALLOY: Zamak 3

FILL TIME: .018 VELOCITY: 101 PLUNGER SIZE: 3.6

PLUNGER SPEED: 30 POT TEMPERATURE: 795

DESCRIPTION OF SOLDER PROBLEM: Alloying to cavity surface

LOCATION: Either nose end; vertical wall adjacent to parting line

NUMBER OF SHOTS BEFORE ACTION IS REQUIRED: (Action would be polishing the die, or changing the core or die part. Use average numbers and list minimum and maximum shots if known).

AVE: 5-6 X/shift MINIMUM: 4 X/shift MAXIMUM: 7-8 X/shift

WHAT ACTION WAS NORMALLY TAKEN AT THAT TIME? Polish out

HOW LONG DOES IT TAKE TO FIX THE PROBLEM WITH THIS ACTION, AND RETURN THE MACHINE TO PRODUCTION? (TOTAL MACHINE DOWNTIME BECAUSE OF SOLDER PROBLEM): 10 min to polish - 10 min prod. part

A sample part of the die with soldering on it is needed. If a soldered die part is not available, then photographs and measurements of the amount of the soldered area will be needed. Comments: ____________________

FOR A NEW DIE PART AT THE LOCATION OF THE SOLDERING, WHAT WOULD THE FOLLOWING BE:

Draft on the die at the point where solder occurred: 14°

Surface finish on the die at the soldered point: Class A

Die temperature at the solder point: Average: 306.5°F

Temperature just **after** die opens: 401.5°F Temperature just **before** die closes: 210.6°F

Date filled out: 7 Nov. 1996 By: ____________________

# # # # #

APPENDIX 5

## Cooperative ILZRO/DoE/NADCA Die Soldering Program
## Baseline Data Sheet for Trial Component

COMPANY: COMPANY B

NAME: 

PLANT LOCATION: 

CONTACT PERSON FOR THIS PROJECT: 

CONTACT NNUMBERS: TELEPHONE: FAX: 

DESCRIPTION OF PART SELECTED: Heat Sink

PART NO.: 34771 WEIGHT: .311 lbs. ALLOY: #3 Zinc

FILL TIME: 31.00 MSEC VELOCITY: 32.32 IPS PLUNGER SIZE: 1.75

PLUNGER SPEED: 38.16 IPS POT TEMPERATURE: 800 Degrees

DESCRIPTION OF SOLDER PROBLEM: Metal Load up (Solder)

LOCATION: On Fin Areas

NUMBER OF SHOTS BEFORE ACTION IS REQUIRED: (Action would be polishing the die, or changing the core or die part. Use average numbers and list minimum and maximum shots if known).

AVE: 75% 5,600 25% between 20,000 and 40,000 MINIMUM: 330 MAXIMUM: 43,936

WHAT ACTION WAS NORMALLY TAKEN AT THAT TIME? Clean-Up With Acid/Remove With Pick/Polish

HOW LONG DOES IT TAKE TO FIX THE PROBLEM WITH THIS ACTION, AND RETURN THE MACHINE TO PRODUCTION? (TOTAL MACHINE DOWNTIME BECAUSE OF SOLDER PROBLEM): 3 Hrs. With Acid/Polishing - 24 Hrs.

A sample part of the die with soldering on it is needed. If a soldered die part is not available, then photographs and measurements of the amount of the soldered area will be needed. Comments: 

FOR A NEW DIE PART AT THE LOCATION OF THE SOLDERING, WHAT WOULD THE FOLLOWING BE:

Draft on the die at the point where solder occurred: 1.5 Degrees All Ribs Bothsides

Surface finish on the die at the soldered point: 

Die temperature at the solder point: Average: 

Temperature just <u>after</u> die opens: . Temperature just <u>before</u> die closes: 

Date filled out: 12-16-96 By: 

CPM 5.0 #####

# APPENDIX 6

## Cooperative ILZRO/DoE/NADCA Die Soldering Program
## Baseline Data Sheet for Trial Component

COMPANY: COMPANY C

NAME: ______

PLANT LOCATION: ______

CONTACT PERSON FOR THIS PROJECT: ______

CONTACT NNUMBERS: TELEPHONE: ______ FAX: ______

DESCRIPTION OF PART SELECTED: Housing Micro Switch

PART NO.: 530790 WEIGHT: .520 ALLOY: #3 Zinc DJ

FILL TIME: ______ VELOCITY: ______ PLUNGER SIZE: ______

PLUNGER SPEED: ______ POT TEMPERATURE: ______

DESCRIPTION OF SOLDER PROBLEM: ______

LOCATION: ______

NUMBER OF SHOTS BEFORE ACTION IS REQUIRED: (Action would be polishing the die, or changing the core or die part. Use average numbers and list minimum and maximum shots if known).

AVE: ______ MINIMUM: ______ MAXIMUM: ______

WHAT ACTION WAS NORMALLY TAKEN AT THAT TIME? Polish/Scrape

HOW LONG DOES IT TAKE TO FIX THE PROBLEM WITH THIS ACTION, AND RETURN THE MACHINE TO PRODUCTION? (TOTAL MACHINE DOWNTIME BECAUSE OF SOLDER PROBLEM): ______

A sample part of the die with soldering on it is needed. If a soldered die part is not available, then photographs and measurements of the amount of the soldered area will be needed. Comments: Sample Avail.

FOR A NEW DIE PART AT THE LOCATION OF THE SOLDERING, WHAT WOULD THE FOLLOWING BE:

Draft on the die at the point where solder occurred: ______

Surface finish on the die at the soldered point: ______

Die temperature at the solder point: Average: ______

Temperature just **after** die opens: ______ Temperature just **before** die closes: ______

Date filled out: 1-14-97 By: ______

# # # # #

COMPANY E Shotscope Data for Casting Trials

| SHOT NO. | DATE | TIME | PEAK VELOCITY | FILL TIME | GATE VELOCITY | CYCLE TIME | COVER 1 TEMP. | COVER 2 TEMP | SPRAY VOLUME | QUALITY CAV 1 | RATING CAV 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 315 | 2/13/97 | 12:51:14 | 93.01 | 15.00 | 127 | 23.85 | 459 | 526 | 0.74 | 2 | 2 |
| 316 | 2/13/97 | 12:51:38 | 95.02 | 15.00 | 124 | 23.89 | 458 | 526 | 0.69 | 2 | 2 |
| 317 | 2/13/97 | 12:52:02 | 96.89 | 15.00 | 129 | 23.82 | 459 | 528 | 0.67 | 3 | 2 |
| 318 | 2/13/97 | 12:52:26 | 90.03 | 15.00 | 121 | 23.77 | 457 | 526 | 0.69 | 2 | 2 |
| 319 | 2/13/97 | 12:52:50 | 96.96 | 15.00 | 127 | 23.63 | 463 | 526 | 0.71 | 2 | 2 |
| | | | | | | | | | | | |
| | | AVG | 94.38 | 15.00 | 126 | 23.79 | 459 | 526 | 0.70 | 2.20 | 2.00 |
| | | RANGE | 6.93 | 0.00 | 7.67 | 0.26 | 5.26 | 2.61 | 0.07 | 1.00 | 0.00 |
| | | | | | | | | | | | |
| 331 | 2/13/97 | 12:57:34 | 91.41 | 15.00 | 127 | 23.83 | 459 | 528 | 0.64 | 2 | 2 |
| 332 | 2/13/97 | 12:57:58 | 92.45 | 15.00 | 134 | 23.73 | 460 | 530 | 0.59 | 2 | 2 |
| 333 | 2/13/97 | 12:58:22 | 95.23 | 15.00 | 124 | 23.71 | 460 | 527 | 0.62 | 2 | 2 |
| 334 | 2/13/97 | 12:58:46 | 95.09 | 15.00 | 127 | 23.54 | 459 | 527 | 0.65 | 2 | 2 |
| 335 | 2/13/97 | 12:59:10 | 91.28 | 15.00 | 124 | 23.88 | 459 | 528 | 0.58 | 2 | 2 |
| | | | | | | | | | | | |
| | | AVG | 93.09 | 15.00 | 127 | 23.74 | 460 | 528 | 0.61 | 2.00 | 2.00 |
| | | RANGE | 3.95 | 0.00 | 9.21 | 0.34 | 0.88 | 2.61 | 0.07 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 588 | 2/13/97 | 17:27:12 | 98.14 | 15.00 | 126 | 23.59 | 434 | 492 | 1.49 | 2 | 3 |
| 589 | 2/13/97 | 17:27:36 | 94.74 | 15.00 | 123 | 23.55 | 436 | 489 | 0.68 | 1 | 3 |
| 590 | 2/13/97 | 17:27:58 | 98.34 | 15.00 | 127 | 23.66 | 435 | 489 | 0.57 | 1 | 3 |
| 591 | 2/13/97 | 17:28:22 | 94.67 | 15.00 | 129 | 23.71 | 437 | 486 | 0.49 | 1 | 3 |
| 592 | 2/13/97 | 17:28:46 | 94.19 | 15.00 | 124 | 23.51 | 436 | 486 | 0.47 | 1 | 3 |
| | | | | | | | | | | | |
| | | AVG | 96.02 | 15.00 | 126 | 23.60 | 436 | 489 | 0.74 | 1.20 | 3.00 |
| | | RANGE | 4.16 | 0.00 | 6.14 | 0.20 | 3.51 | 6.12 | 1.02 | 1.00 | 0.00 |
| | | | | | | | | | | | |
| 1106 | 2/13/97 | 21:18:00 | 92.45 | 15.00 | 127 | 23.41 | 454 | 501 | 0.78 | 1 | 4 |
| 1107 | 2/13/97 | 21:18:24 | 90.86 | 15.00 | 120 | 23.54 | 456 | 495 | 0.80 | 1 | 4 |
| 1108 | 2/13/97 | 21:18:46 | 91.97 | 15.00 | 120 | 23.44 | 453 | 495 | 0.78 | 1 | 4 |
| 1109 | 2/13/97 | 21:19:10 | 93.91 | 15.00 | 127 | 23.52 | 454 | 496 | 0.74 | 1 | 4 |
| 1110 | 2/13/97 | 21:19:34 | 92.94 | 15.00 | 126 | 23.76 | 454 | 495 | 0.69 | 1 | 4 |
| | | | | | | | | | | | |
| | | AVG | 92.43 | 15.00 | 124 | 23.53 | 454 | 496 | 0.76 | 1.00 | 4.00 |
| | | RANGE | 3.05 | 0.00 | 7.67 | 0.35 | 2.63 | 6.11 | 0.11 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 1353 | 2/14/97 | 1:30:10 | 92.59 | 15.00 | 134 | 23.44 | 408 | 465 | 1.08 | 3 | 3 |
| 1354 | 2/14/97 | 1:30:34 | 94.53 | 15.00 | 124 | 23.31 | 410 | 468 | 1.05 | 2 | 3 |
| 1355 | 2/14/97 | 1:30:58 | 92.94 | 15.00 | 123 | 23.33 | 412 | 469 | 1.04 | 2 | 3 |
| 1356 | 2/14/97 | 1:31:20 | 94.26 | 15.00 | 129 | 22.69 | 413 | 471 | 1.02 | 2 | 3 |
| 1357 | 2/14/97 | 1:31:44 | 95.57 | 15.00 | 127 | 23.42 | 414 | 471 | 1.03 | 2 | 3 |
| | | | | | | | | | | | |
| | | AVG | 93.98 | 15.00 | 127 | 23.24 | 412 | 469 | 1.04 | 2.20 | 3.00 |
| | | RANGE | 2.98 | 0.00 | 10.74 | 0.75 | 6.16 | 6.13 | 0.06 | 1.00 | 0.00 |
| | | | | | | | | | | | |
| 1500 | 2/14/97 | 3:05:58 | 96.47 | 15.00 | 126 | 23.34 | 435 | 486 | 0.49 | 1 | 4 |
| 1501 | 2/14/97 | 3:06:22 | 92.11 | 15.00 | 167 | 23.57 | 438 | 486 | 0.48 | 1 | 4 |
| 1502 | 2/14/97 | 3:06:46 | 93.63 | 15.00 | 126 | 23.42 | 435 | 490 | 0.32 | 1 | 4 |
| 1503 | 2/14/97 | 3:07:08 | 96.82 | 15.00 | 126 | 23.26 | 435 | 485 | 0.33 | 1 | 4 |
| 1504 | 2/14/97 | 3:07:32 | 93.84 | 15.00 | 124 | 23.22 | 437 | 485 | 0.37 | 1 | 4 |
| | | | | | | | | | | | |
| | | AVG | 94.57 | 15.00 | 134 | 23.36 | 436 | 486 | 0.40 | 1.00 | 4.00 |
| | | RANGE | 4.71 | 0.00 | 42.98 | 0.35 | 3.51 | 5.25 | 0.17 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 1556 | 2/14/97 | 3:31:18 | 94.95 | 15.00 | 127 | 23.41 | 428 | 476 | 0.35 | | 4 |
| 1557 | 2/14/97 | 3:31:42 | 93.15 | 15.00 | 124 | 23.19 | 424 | 475 | 0.42 | | 4 |
| 1558 | 2/14/97 | 3:32:06 | 94.95 | 15.00 | 123 | 23.33 | 426 | 476 | 0.40 | | 4 |
| 1559 | 2/14/97 | 3:32:28 | 94.39 | 15.00 | 126 | 23.34 | 424 | 476 | 0.44 | | 4 |
| 1560 | 2/14/97 | 3:32:52 | 95.36 | 15.00 | 129 | 23.35 | 424 | 478 | 0.38 | | 4 |
| | | | | | | | | | | | |
| | | AVG | 94.56 | 15.00 | 126 | 23.32 | 425 | 476 | 0.40 | #DIV/0! | 4.00 |
| | | RANGE | 2.22 | 0.00 | 6.14 | 0.22 | 4.39 | 3.50 | 0.09 | 0.00 | 0.00 |

COMPANY E Shotscope Data for Casting Trials

| SHOT NO. | DATE | TIME | PEAK VELOCITY | FILL TIME | GATE VELOCITY | CYCLE TIME | COVER 1 TEMP. | COVER 2 TEMP | SPRAY VOLUME | QUALITY CAV 1 | RATING CAV 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1577 | 2/14/97 | 3:39:28 | 95.23 | 15.00 | 123 | 23.30 | 428 | 478 | 0.38 | 1 | 3 |
| 1578 | 2/14/97 | 3:39:52 | 95.57 | 15.00 | 124 | 23.15 | 426 | 482 | 0.38 | 1 | 3 |
| 1579 | 2/14/97 | 3:40:14 | 98.28 | 15.00 | 120 | 23.17 | 426 | 478 | 0.48 | 1 | 3 |
| 1580 | 2/14/97 | 3:40:38 | 98.28 | 15.00 | 121 | 23.47 | 428 | 478 | 0.37 | 1 | 3 |
| 1581 | 2/14/97 | 3:41:02 | 96.27 | 15.00 | 124 | 23.23 | 430 | 478 | 0.49 | 1 | 3 |
| | | AVG | 96.72 | 15.00 | 122 | 23.26 | 428 | 479 | 0.42 | 1.00 | 3.00 |
| | | RANGE | 3.05 | 0.00 | 4.60 | 0.32 | 4.39 | 4.38 | 0.11 | 0.00 | 0.00 |
| 1750 | 2/14/97 | 4:46:50 | 93.49 | 15.00 | 130 | 23.16 | 434 | 481 | 0.52 | 3 | 5 |
| 1751 | 2/14/97 | 4:47:14 | 94.05 | 15.00 | 123 | 23.40 | 430 | 485 | 0.50 | 3 | 5 |
| 1752 | 2/14/97 | 4:47:36 | 94.39 | 15.00 | 121 | 23.31 | 434 | 482 | 0.57 | 2 | 5 |
| 1753 | 2/14/97 | 4:48:00 | 93.22 | 15.00 | 123 | 23.55 | 431 | 482 | 0.54 | 2 | 5 |
| 1754 | 2/14/97 | 4:48:24 | 93.49 | 15.00 | 124 | 23.33 | 430 | 482 | 0.52 | 2 | 5 |
| | | AVG | 93.73 | 15.00 | 124 | 23.35 | 432 | 482 | 0.53 | 2.40 | 5.00 |
| | | RANGE | 1.17 | 0.00 | 9.21 | 0.39 | 3.51 | 3.50 | 0.08 | 1.00 | 0.00 |
| 1795 | 2/14/97 | 5:04:24 | 95.50 | 15.00 | 129 | 23.21 | 433 | 483 | 0.49 | 1 | 2 |
| 1796 | 2/14/97 | 5:04:46 | 96.13 | 15.00 | 127 | 23.29 | 430 | 483 | 0.47 | 1 | 2 |
| 1797 | 2/14/97 | 5:05:10 | 94.60 | 15.00 | 124 | 23.10 | 430 | 483 | 0.50 | 1 | 2 |
| 1798 | 2/14/97 | 5:05:32 | 93.70 | 15.00 | 126 | 23.27 | 435 | 482 | 0.48 | 1 | 2 |
| 1799 | 2/14/97 | 5:05:56 | 96.68 | 15.00 | 124 | 23.30 | 431 | 483 | 0.50 | 1 | 2 |
| | | AVG | 95.32 | 15.00 | 126 | 23.23 | 432 | 483 | 0.49 | 1.00 | 2.00 |
| | | RANGE | 2.98 | 0.00 | 4.60 | 0.20 | 4.39 | 0.87 | 0.02 | 0.00 | 0.00 |
| 1814 | 2/14/97 | 5:11:48 | 96.40 | 15.00 | 121 | 23.43 | 430 | 483 | 0.50 | 3 | 4 |
| 1815 | 2/14/97 | 5:12:10 | 96.06 | 15.00 | 127 | 23.31 | 430 | 482 | 0.54 | 3 | 4 |
| 1816 | 2/14/97 | 5:12:34 | 95.92 | 15.00 | 130 | 23.35 | 435 | 482 | 0.57 | 3 | 4 |
| 1817 | 2/14/97 | 5:12:58 | 94.19 | 15.00 | 121 | 23.45 | 431 | 484 | 0.54 | 4 | 4 |
| 1818 | 2/14/97 | 5:13:22 | 94.39 | 15.00 | 126 | 23.50 | 431 | 483 | 0.43 | 3 | 4 |
| | | AVG | 95.39 | 15.00 | 125 | 23.41 | 431 | 483 | 0.51 | 3.20 | 4.00 |
| | | RANGE | 2.22 | 0.00 | 9.21 | 0.19 | 4.39 | 1.75 | 0.15 | 1.00 | 0.00 |
| 2046 | 2/14/97 | 8:34:12 | 96.13 | 15.00 | 126 | 23.32 | 451 | 491 | 0.51 | 1 | 3 |
| 2047 | 2/14/97 | 8:34:36 | 93.01 | 15.00 | 127 | 23.36 | 450 | 494 | 0.45 | 1 | 3 |
| 2048 | 2/14/97 | 8:34:58 | 97.24 | 15.00 | 124 | 23.32 | 451 | 492 | 0.47 | 1 | 3 |
| 2049 | 2/14/97 | 8:35:22 | 92.73 | 15.00 | 121 | 23.29 | 451 | 494 | 0.48 | 1 | 3 |
| 2050 | 2/14/97 | 8:35:46 | 96.20 | 12.00 | 132 | 23.43 | 450 | 489 | 0.47 | 1 | 3 |
| | | AVG | 95.06 | 14.40 | 126 | 23.34 | 451 | 492 | 0.47 | 1.00 | 3.00 |
| | | RANGE | 4.51 | 3.00 | 11.13 | 0.14 | 1.75 | 5.24 | 0.06 | 0.00 | 0.00 |
| 2264 | 2/14/97 | 10:18:08 | 95.92 | 15.00 | 127 | 24.67 | 439 | 467 | 0.41 | 2 | 2 |
| 2265 | 2/14/97 | 10:18:30 | 93.28 | 15.00 | 132 | 24.68 | 439 | 471 | 0.43 | 3 | 2 |
| 2266 | 2/14/97 | 10:18:56 | 92.38 | 15.00 | 132 | 24.66 | 443 | 468 | 0.42 | 3 | 2 |
| 2267 | 2/14/97 | 10:19:20 | 93.91 | 15.00 | 126 | 24.81 | 440 | 469 | 0.39 | 3 | 2 |
| 2268 | 2/14/97 | 10:19:46 | 96.89 | 15.00 | 123 | 24.67 | 442 | 469 | 0.42 | 3 | 2 |
| | | AVG | 94.48 | 15.00 | 128 | 24.70 | 441 | 469 | 0.41 | 2.80 | 2.00 |
| | | RANGE | 4.51 | 0.00 | 9.21 | 0.15 | 4.39 | 4.38 | 0.04 | 1.00 | 0.00 |
| 2295 | 2/14/97 | 10:30:54 | 96.47 | 15.00 | 117 | 24.83 | 448 | 475 | 0.45 | 3 | 5 |
| 2296 | 2/14/97 | 11:25:02 | 30.56 | 15.00 | 1 | 25.00 | 295 | 383 | 0.38 | 3 | 5 |
| 2297 | 2/14/97 | 11:25:28 | 89.33 | 12.00 | 144 | 25.03 | 299 | 382 | 0.55 | 3 | 5 |
| 2298 | 2/14/97 | 11:25:54 | 91.28 | 15.00 | 124 | 25.00 | 303 | 384 | 0.42 | 3 | 5 |
| 2299 | 2/14/97 | 11:26:16 | 93.22 | 15.00 | 123 | 24.81 | 310 | 388 | 0.45 | 3 | 5 |
| | | AVG | 80.17 | 14.40 | 102 | 24.93 | 331 | 402 | 0.45 | 3.00 | 5.00 |
| | | RANGE | 65.91 | 3.00 | 142.68 | 0.22 | 152.44 | 93.14 | 0.17 | 0.00 | 0.00 |

COMPANY E Shotscope Data for Casting Trials

| SHOT NO. | DATE | TIME | PEAK VELOCITY | FILL TIME | GATE VELOCITY | CYCLE TIME | COVER 1 TEMP. | COVER 2 TEMP | SPRAY VOLUME | QUALITY CAV 1 | RATING CAV 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3140 | 2/14/97 | 18:55:20 | 92.18 | 15.00 | 126 | 24.43 | 450 | 485 | 0.86 | 3 | 4 |
| 3141 | 2/14/97 | 18:55:44 | 98.28 | 15.00 | 120 | 24.26 | 449 | 485 | 0.85 | 3 | 3 |
| 3142 | 2/14/97 | 18:56:10 | 91.62 | 15.00 | 126 | 24.44 | 449 | 484 | 0.84 | 3 | 3 |
| 3143 | 2/14/97 | 18:56:34 | 93.98 | 15.00 | 138 | 24.50 | 449 | 489 | 0.84 | 3 | 3 |
| 3144 | 2/14/97 | 18:56:58 | 91.69 | 15.00 | 134 | 24.52 | 449 | 484 | 0.85 | 3 | 3 |
| | | | | | | | | | | | |
| | | AVG | 93.55 | 15.00 | 129 | 24.43 | 449 | 485 | 0.85 | 3.00 | 3.20 |
| | | RANGE | 6.65 | 0.00 | 18.42 | 0.26 | 1.75 | 5.25 | 0.02 | 0.00 | 1.00 |
| | | | | | | | | | | | |
| 3170 | 2/14/97 | 19:07:34 | 94.95 | 18.00 | 123 | 24.59 | 449 | 484 | 0.80 | 2 | 5 |
| 3171 | 2/14/97 | 19:07:58 | 92.94 | 15.00 | 117 | 24.45 | 448 | 484 | 0.79 | 2 | 5 |
| 3172 | 2/14/97 | 19:08:22 | 95.29 | 12.00 | 144 | 24.34 | 449 | 485 | 0.79 | 2 | 5 |
| 3173 | 2/14/97 | 19:08:46 | 98.20 | 15.00 | 121 | 24.36 | 450 | 485 | 0.81 | 2 | 5 |
| 3174 | 2/14/97 | 19:09:10 | 89.54 | 15.00 | 121 | 24.45 | 449 | 484 | 0.83 | 2 | 5 |
| | | | | | | | | | | | |
| | | AVG | 94.18 | 15.00 | 125 | 24.44 | 449 | 484 | 0.80 | 2.00 | 5.00 |
| | | RANGE | 8.66 | 6.00 | 27.24 | 0.25 | 2.63 | 0.87 | 0.04 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 3551 | 2/14/97 | 20:57:50 | 91.90 | 15.00 | 135 | 24.47 | 455 | 486 | 0.90 | 2 | 5 |
| 3552 | 2/14/97 | 20:58:14 | 92.31 | 15.00 | 126 | 24.52 | 450 | 485 | 0.85 | 2 | 5 |
| 3553 | 2/14/97 | 20:58:38 | 91.41 | 15.00 | 127 | 24.34 | 450 | 486 | 0.85 | 2 | 5 |
| 3554 | 2/14/97 | 20:59:02 | 92.31 | 15.00 | 120 | 24.24 | 450 | 486 | 0.81 | 3 | 5 |
| 3555 | 2/14/97 | 20:59:26 | 90.51 | 15.00 | 127 | 24.43 | 450 | 485 | 0.82 | 2 | 5 |
| | | | | | | | | | | | |
| | | AVG | 91.69 | 15.00 | 127 | 24.40 | 451 | 486 | 0.85 | 2.20 | 5.00 |
| | | RANGE | 1.81 | 0.00 | 15.35 | 0.28 | 4.39 | 0.87 | 0.09 | 1.00 | 0.00 |
| | | | | | | | | | | | |
| 3801 | 2/15/97 | 0:17:44 | 93.22 | 12.00 | 129 | 24.20 | 441 | 470 | 0.98 | 2 | 5 |
| 3802 | 2/15/97 | 0:18:08 | 98.62 | 12.00 | 130 | 24.40 | 440 | 469 | 0.88 | 2 | 5 |
| 3803 | 2/15/97 | 0:18:32 | 94.19 | 15.00 | 130 | 24.35 | 441 | 471 | 0.91 | 2 | 5 |
| 3804 | 2/15/97 | 0:18:58 | 95.29 | 15.00 | 126 | 24.32 | 444 | 471 | 0.90 | 3 | 5 |
| 3805 | 2/15/97 | 0:19:22 | 95.92 | 15.00 | 135 | 24.25 | 440 | 470 | 0.88 | 2 | 5 |
| | | | | | | | | | | | |
| | | AVG | 95.45 | 13.80 | 130 | 24.30 | 441 | 470 | 0.91 | 2.20 | 5.00 |
| | | RANGE | 5.40 | 3.00 | 9.21 | 0.20 | 4.39 | 2.63 | 0.09 | 1.00 | 0.00 |
| | | | | | | | | | | | |
| 4051 | 2/15/97 | 1:59:06 | 89.68 | 12.00 | 150 | 24.26 | 447 | 483 | 0.89 | 3 | 5 |
| 4052 | 2/15/97 | 1:59:30 | 88.64 | 12.00 | 150 | 24.30 | 452 | 482 | 1.02 | 3 | 5 |
| 4053 | 2/15/97 | 1:59:54 | 93.42 | 15.00 | 121 | 24.31 | 448 | 482 | 0.96 | 3 | 5 |
| 4054 | 2/15/97 | 2:00:18 | 87.32 | 18.00 | 120 | 24.31 | 448 | 483 | 0.90 | 3 | 5 |
| 4055 | 2/15/97 | 2:00:44 | 92.25 | 15.00 | 146 | 24.16 | 447 | 482 | 0.96 | 4 | 5 |
| | | | | | | | | | | | |
| | | AVG | 90.26 | 14.40 | 137 | 24.27 | 448 | 482 | 0.95 | 3.20 | 5.00 |
| | | RANGE | 6.10 | 6.00 | 29.42 | 0.15 | 5.26 | 0.87 | 0.14 | 1.00 | 0.00 |
| | | | | | | | | | | | |
| 4280 | 2/15/97 | 3:34:48 | 90.23 | 15.00 | 124 | 24.44 | 448 | 485 | 0.98 | 3 | 5 |
| 4281 | 2/15/97 | 3:35:14 | 88.78 | 15.00 | 121 | 24.30 | 448 | 484 | 1.01 | 3 | 5 |
| 4282 | 2/15/97 | 3:35:38 | 97.03 | 15.00 | 114 | 24.50 | 448 | 484 | 1.09 | 3 | 5 |
| 4283 | 2/15/97 | 3:36:02 | 88.23 | 12.00 | 102 | 24.38 | 449 | 484 | 0.99 | 3 | 5 |
| 4284 | 2/15/97 | 3:36:26 | 98.34 | 12.00 | 146 | 24.34 | 450 | 483 | 1.00 | 3 | 5 |
| | | | | | | | | | | | |
| | | AVG | 92.52 | 13.80 | 121 | 24.39 | 448 | 484 | 1.01 | 3.00 | 5.00 |
| | | RANGE | 10.12 | 3.00 | 44.13 | 0.20 | 1.75 | 1.75 | 0.11 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 4840 | 2/15/97 | 9:37:54 | 95.29 | 15.00 | 123 | 24.63 | 448 | 486 | 0.81 | 2 | 4 |
| 4841 | 2/15/97 | 9:38:20 | 96.68 | 15.00 | 130 | 24.62 | 445 | 487 | 0.87 | 2 | 4 |
| 4842 | 2/15/97 | 9:38:44 | 88.98 | 15.00 | 134 | 24.71 | 443 | 487 | 0.79 | 2 | 4 |
| 4843 | 2/15/97 | 9:39:08 | 91.21 | 12.00 | 140 | 24.69 | 443 | 487 | 0.75 | 2 | 4 |
| 4844 | 2/15/97 | 9:39:34 | 94.74 | 15.00 | 118 | 24.67 | 444 | 486 | 0.86 | 2 | 4 |
| | | | | | | | | | | | |
| | | AVG | 93.38 | 14.40 | 129 | 24.66 | 445 | 487 | 0.82 | 2.00 | 4.00 |
| | | RANGE | 7.70 | 3.00 | 21.87 | 0.09 | 4.39 | 0.87 | 0.12 | 0.00 | 0.00 |
| | | | | | | | | | | | |

COMPANY E Shotscope Data for Casting Trials

| SHOT NO. | DATE | TIME | PEAK VELOCITY | FILL TIME | GATE VELOCITY | CYCLE TIME | COVER 1 TEMP. | COVER 2 TEMP | SPRAY VOLUME | QUALITY CAV 1 | RATING CAV 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5043 | 2/15/97 | 11:51:08 | 96.68 | 15.00 | 144 | 24.31 | 347 | 385 | 0.77 | 3 | 5 |
| 5044 | 2/15/97 | 11:51:30 | 87.74 | 15.00 | 140 | 24.41 | 354 | 391 | 0.71 | 3 | 5 |
| 5045 | 2/15/97 | 11:51:56 | 94.05 | 12.00 | 138 | 24.34 | 359 | 396 | 0.68 | 3 | 5 |
| 5046 | 2/15/97 | 11:52:20 | 95.02 | 12.00 | 140 | 24.35 | 364 | 405 | 0.65 | 3 | 5 |
| 5047 | 2/15/97 | 11:52:44 | 94.46 | 12.00 | 142 | 24.15 | 372 | 406 | 0.69 | 3 | 5 |
| | | | | | | | | | | | |
| | | AVG | 93.59 | 13.20 | 141 | 24.31 | 359 | 396 | 0.70 | 3.00 | 5.00 |
| | | RANGE | 8.94 | 3.00 | 6.14 | 0.26 | 25.58 | 20.25 | 0.12 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 5365 | 2/15/97 | 14:13:28 | 94.32 | 15.00 | 120 | 24.07 | 485 | 482 | 0.68 | 1 | 1 |
| 5366 | 2/15/97 | 14:13:52 | 96.20 | 15.00 | 121 | 24.21 | 487 | 483 | 0.62 | 1 | 1 |
| 5367 | 2/15/97 | 14:14:18 | 92.18 | 15.00 | 134 | 24.07 | 488 | 483 | 0.61 | 1 | 1 |
| 5368 | 2/15/97 | 14:14:40 | 88.99 | 15.00 | 121 | 24.12 | 489 | 486 | 0.69 | 1 | 1 |
| 5369 | 2/15/97 | 14:15:04 | 89.96 | 15.00 | 126 | 24.05 | 490 | 485 | 0.67 | 1 | 1 |
| | | | | | | | | | | | |
| | | AVG | 92.33 | 15.00 | 124 | 24.10 | 488 | 484 | 0.66 | 1.00 | 1.00 |
| | | RANGE | 7.21 | 0.00 | 13.81 | 0.16 | 4.37 | 4.37 | 0.08 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| 5676 | 2/15/97 | 19:09:42 | 95.50 | 12.00 | 157 | 24.23 | 499 | 479 | -0.15 | 1 | 2 |
| 5677 | 2/15/97 | 19:10:06 | 92.80 | 15.00 | 127 | 24.41 | 499 | 480 | -0.15 | 1 | 2 |
| 5678 | 2/15/97 | 19:10:30 | 86.15 | 18.00 | 129 | 24.12 | 499 | 484 | -0.15 | 1 | 2 |
| 5679 | 2/15/97 | 19:10:54 | 93.91 | 15.00 | 123 | 24.35 | 499 | 483 | -0.15 | 1 | 2 |
| 5680 | 2/15/97 | 19:11:18 | 99.52 | 12.00 | 134 | 24.15 | 500 | 483 | -0.15 | 1 | 2 |
| | | | | | | | | | | | |
| | | AVG | 93.58 | 14.40 | 134 | 24.25 | 499 | 482 | -0.15 | 1.00 | 2.00 |
| | | RANGE | 13.38 | 6.00 | 34.53 | 0.29 | 1.75 | 4.37 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | |
| | | AVG AVG | 93.35 | 14.70 | 126.77 | 23.93 | 437.67 | 479.17 | 0.64 | #DIV/0! | 3.59 |
| | | AVG RANGE | 7.85 | 1.50 | 20.89 | 0.26 | 10.75 | 7.82 | 0.13 | 0.38 | 0.04 |

Table 1

Composition of Zinc Die Casting Alloy 3
ASTM Standard B86

| | |
|---|---|
| Aluminum | 3.5-4.3% |
| Magnesium | 0.2-0.5% |
| Copper | 0.25% Max. |
| Fe | 0.10% Max |
| Pb | 0.005% Max. |
| Cd | 0.004% Max. |
| Sn | 0.003% Max. |
| Zn | Balance |