Final Report

Project Title: A New Direct-Pour In-Mold (DPI) Technology for Producing Ductile and Compacted Graphite Iron Castings.

Covering Period: 9/1/02 to 8/31/05
Date of Report: 1/12/06

Recipient: Comanche Technologies, LLC
Award Number: DE-FG36-02GO12060

Working Partners: Jay R. Hitchings, Dr. Doru Stefanescu, Dr. Frank Juretzko, Jason Hitchings
Cost-Sharing Partners: Comanche Technologies, University of Alabama, DONSCO Foundries

Contact: **Jay R. Hitchings**, Director R&D, Comanche Technologies LLC, 610-269-4513, JayRHitchings@msn.com, General Manager – Jason Hitchings, 804-598-8998 JHitchings@performancespectrum.com

Project Team: DOE HQ Program Manager – Lisa Barnett, DOE Field Project Officer – Deborah Weems.

Executive Summary

The end findings of the Direct-Pour In-Mold (DPI) technology development project prove the concept's viability, and show that its widespread implementation could have a significant energy and cost savings impact on the US ferrous casting industry. Our testing produced *exceptional* nodular iron, and met all of our original objectives:

- High Magnesium Recovery
- Zero Magnesium Fume Emission
- High Graphite Nodular Count (high quality end casting)
- Accurate and Consistent Flow Rates

The technology is both economically feasible as well as immediately advantageous to the foundries that will be open to employing it in their casting operations. They should realize cost savings through more consistent outputs from their production lines (significantly reduced scrap rates), higher return on casting inputs (a higher Magnesium recovery rate equates to a much more efficient utilization of an expensive ingredient), drastic reductions in noxious Magnesium fume emissions (reducing the need for constant air venting and pollution emissions), and a higher quality end casting that will exceed customer expectations and ultimately make the DPI foundry a stronger competitor in both the domestic and global casting industry. At this point, we do not have enough commercial foundry testing data for the DPI technology to apply it within the context of a business case that would dollarize the projected cost savings for an end user. However, we are now working towards that end and should have enough data for a compelling business case by June of 2006.

Project Description

Technology Application Background: The DPI concept combines two proven foundry techniques; in-mold magnesium treatment and the direct pour method, to produce a unique new technology, "Direct Pour In-Mold" (DPI). This technology solves several problems associated with the standard in-mold treatment, plus it adds the considerable benefits of direct pour. DPI benefits include a significant energy savings, increased mold yields, very high magnesium recovery with zero fume emitted, and no requirement for post-inoculation. The use of a thin cast magnesium treatment alloy assures consistent, repeatable, treated metal that produces quality ductile and CGI (compacted graphite iron) castings.

Original Project Goal and Objectives: The DPI project team's overall goal was to prove the feasibility of this new technology, particularly in a cost-efficient application. The objectives supporting this goal were; optimize the end design of the DPI unit(s), conduct extended foundry testing for performance data collection, and capture the foundry cost-savings data for the end value proposition that will be carried to potential customers.

Project Task	Challenges	Solutions	Progress Notes
Finalize DPI Unit Internal Design Structure	1. How to achieve accurate flow rates and pour times in a vertical gating system. 2. How to direct all incoming molten metal across the horizontal surface of the treatment alloy, at the bottom of the reaction chamber (in a laminar flow pattern) to achieve a uniform dissolution of the alloy.	The team employed a flow modeling software program from Novacast called "NovaFlow". Although the initial trial runs had some difficulty in getting the internal dimensions of the DPI container correct, the problem was later corrected and the simulations were matched quite accurately by the actual pour tests conducted.	The final internal design has provided consistent flow rates and pouring times. A critical parameter of the treatment alloy is its placement in the bottom of the internal reaction chamber. The alloy should be sealed in a plastic bag and tamped into the bottom of the chamber to produce a horizontal top surface for the incoming molten metal to contact. Styrofoam cups will be a consideration for commercial production to hold the alloy. Thinner walled containers should be explored and also larger containers for producing larger weights of treated metal.
DPI Sleeve Testing and Alloy Calibration	Accurately coordinating the flow rate with treatment alloy dissolution, and to the base metal with regard to its Sulfur content.	We achieved optimal results by holding the base metal composition as constant as possible, while varying the weight of the treatment alloy until acceptable microstructures and Magnesium residual levels were attained for the target initial grade of iron. Additional data on matching appropriate sulfur percentages for the rest of the desired grades of iron will be captured during additional commercial foundry testing.	Further actual foundry extended testing should be conducted using different base metal compositions corresponding to various grades of iron in order to prove consistency of results. Also, further testing should be done to establish what the range of base metal Sulfur levels can be tolerated in order to achieve good microstructures using the two commercial treatment alloys that have been used in the project.
Apply and Modify DPI Technology for other applicable casting techniques	A large percentage of our target market utilizes Disamatic casting machines, which pose a unique challenge in fitting our DPI sleeve into their vertical parted molds. We need to explore the best way to incorporate the placement of the DPI sleeve into an automated vertical parted mold setup.	All of our flow modeling and lab testing focused on horizontally parted molds, so we're confident in our results for that segment. However, we still need to invest more time in understanding how to implement a DPI sleeve placement within an automated coresetter environment (Disa)	The two main types of molding or casting systems that the DPI technology is aimed at are the highly automated Disamatic, vertically parted molds, and the horizontally parted molds used by jobbing shop foundries. All of our research has been done on the horizontally parted molds, and with very good success. We have produced a little over one hundred extra containers for future extended testing in a jobbing type foundry, but testing the technology in a Disamatic shop will require several hundred more containers. Disamatics can run 300 to 450 molds per hour.
Project Management	The change in lab testing subcontractor from Penn State University to the University of Alabama was made due to the University of Alabama's higher level of expertise in ferrous metals as well as their willingness to conduct more in-depth testing for the project. However, we "paid" for these benefits when our project was significantly delayed by the University of Alabama. But in the end, we were pleased with their work.	The variance in project management was minimal and only occasionally affected the technical status reporting to the DOE. Since the main project timeline delays stemmed from the University of Alabama getting "off-task", we felt the project management aspect of the DPI testing was mostly on-target.	The overall reporting process went relatively smoothly, save for the occasional late report to DOE due to the delays on the part of the University of Alabama.

Conclusions and Recommendations for Future Work:

The compacted graphite iron (CGI) phase of the project will need additional time and testing, due to the extreme demands on the homogeneity of the treatment alloy with regard to its Magnesium content. We are using a blended mixture of crushed 4% Magnesium ferrosilicon and 75% ferrosilicon to get a lower Magnesium content which isn't as homogenous with respect to Magnesium as a crushed alloy of the proper composition would be. Our prediction is that a lower content Magnesium alloy, lower than 4%, will most likely be required for the compacted graphite iron production. This continued work will be fully funded by Comanche Technologies.

Supplemental Information

Attachment 1 – The DPI Lab testing summary report from the University of Alabama team (separate PDF file).
Attachment 2 – The Appendix for the lab testing summary report from the University of Alabama team (separate PDF File).

Appendices

Appendix A.   Final Task Schedule
Appendix B.   Final Spending Schedule
Appendix C.   Final Cost Share Contributions
Appendix D.   Energy Savings Metrics

Appendix A

Final Task Schedule

Final Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	Finalize DPI Unit Internal Design Structure	11/1/03	8/15/05	8/11/05	100%	Completed.
2	DPI Sleeve Testing and Alloy Calibration	07/1/04	9/30/05	11/15/05	85%	Additional testing will take place within a commercial foundry environment that will enable the team to capture the range of sulfur levels vs. weight of the treatment alloy that will produce a 100% spherical graphite microstructure.
3	Apply and Modify DPI Technology for other applicable casting techniques	1/1/05	11/25/05	12/10/05	70%	While the team is satisfied with the DPI application within horizontally parted mold applications, there remains significant work to be done on the optimal placement of the DPI within a vertically-parted DISA-matic casting operation. This testing will continue in 1 & 2Q 2006.
4	Project Management	2/15/05	1/15/06	1/15/06	100%	Completed.

Appendix B

Final Spending Schedule

Final Spending Schedule **Project Period:** 9/1/02 to 8/31/06

Task	Approved Budget	Final Project Expenditures
Task 1 Finalize DPI Unit Internal Design Structure	193,082	193,082
Task 2 DPI Sleeve Testing and Alloy Calibration	39,711	51,711
Task 3 Apply and Modify DPI Technology for other applicable casting techniques	24,046	13,500
Task 4 Project Management	10,940	8,940
Total	267,779	267,233
DOE Share	200,000	200,000
Cost Share	67,779	67,233

Appendix C

Final Cost Share Contributions

Final Cost Share Contributions

Funding Source	Approved Cost Share		Final Contributions	
	Cash	In-Kind	Cash	In-Kind
Comanche Technologies	6,085	33,706	6,085	33,160
University of Alabama	7,000	16,516	7,000	16,516
Donsco Foundry		4,472		4,472
Total	13,085	54,694	13,085	54,148
Cumulative Cost Share Contributions				67,233 *

** the $546 difference between approved and final cost share contributions will be remedied as there is additional project work that will continue under the full funding of Comanche Technologies.*

Appendix D
Energy Savings Metrics

Unit Definition

For the purpose of making an accurate comparison of the current technology (Covered Tundish) and the proposed technology (Direct Pour In-Mold) in terms of "units", we used *a single ton of treated ductile iron* as our comparison metric. As an example, you can compare the Btu requirements for one unit (one ton of treated ductile iron) as follows:

Covered Tundish Technique:	**650,612,576 Btu** (650.6 Mil.)
Direct Pour In-Mold Technique:	**563,668,058 Btu** (563.7 Mil.)
Energy Savings:	**86,944,518 Btu (87 Mil.)**

Discussion of Energy Savings

Energy savings are calculated and compared on the production of one ton (2000lbs) of ductile iron by both the DPI technology and the current technology, the standard Covered Tundish Technique. The Covered Tundish Technique is most similar to the DPI technology due to its comparable low Magnesium fume emission and relative high Magnesium recovery.

Comparison	DPI	Covered Tundish
Magnesium Recovery	70% - 90%	40% - 75%
Treatment Alloy (6%MgFeSi)	.7% - 1.0%	1.5% - 2.0%
Post Inoculation	0%	1.0% (75%FeSi)
Base Metal Treatment Temperature	1450°C – 1460°C	1500°C – 1520°C

Both techniques can use the same 6%MgFeSi treatment alloy. The DPI technology does not require post inoculation, whereas the Covered Tundish requires a 1% addition of 75%FeSi and many times an additional proprietary inoculant in the mold down sprue. The DPI technology can use a 50°C lower pour temperature, as well as reduce the weight of the metal poured by subtracting the weight of the eliminated or shortened runner system.

Validation of Energy Savings Metrics via Testing

The key energy savings claims that we projected the DPI technology would attain, as illustrated in the chart above, were validated through our in-lab testing. The documented details for the Magnesium recovery, treatment alloy used, and the base metal treatment temperatures for both the Ductile Iron and Compacted Graphite Iron heats are illustrated on pages 4-44 and 5-44 of ***Attachment 1*** (the University of Alabama Team's DPI project PHASE II Report).

Energy Units

1.) 1 KWH = **3413 Btu** (Chemical Handbook)
2.) 1 Ton (2000lb) gray iron melted in a medium frequency induction furnace to 1520°C equals 500-800 Mil. Btu/ton. Assume mid-range of 650 Mil. Btu/ton divided by 2000lbs = **.325 Mil. Btu/lb** of gray iron. (E&E profile for Metal Casting)
3.) Smelting 1 Ton (2000lb) of 50% FeSi, used in (6% MgFeSi) treatment alloy = 4500-4700 KWH/ton. Assume mid-range of 4600 KWH/ton X 3413 Btu/KWH = 15.7 Mil. divided by 2000lb = **7850 Btu/lb.** of 50% FeSi.
4.) Smelting 1 Ton (2000lb) of 75%FeSi, used in post inoculant alloy = 8000-8200 KWH/ton. Assume mid range of 8100 KWH/ton X 3413 Btu/KWH = 27.7 Mil. Btu/ton. 27.7 Mil. Divided by 2000lb = 13.823 Btu/lb of 75% FeSi. (Smelting data for submerged arc furnace provided by Globe Metallurgical)
5.) Molten salt electrolysis for Magnesium metal = 10-12 KWH/kg of metal. Assume a mid-range of 11 KWH/kg divided by 1kg = .01 KWH/gm, one pound of Magnesium = .01 KWH/gm X 454 gm = 4.9 KWH/lb of Magnesium. 4.9 KWH/lb X 3413 Btu/KWH = 17,065 Btu/lb of Magnesium metal. (ASM Metal Handbook)

Technique Energy Comparison Breakdown

Current Technology: Covered Tundish Treatment

Covered Tundish @ 2% addition of (6% MgFeSi) Treatment Alloy
2% of 2000lbs = .02X2000 = 40lb, less 6% Mg = 37.6lbs; 7850 Btu/lb of 50% FeSi X 37.6lb = 295,160 Btu. 2.4lb of Magnesium metal X 17,065 Btu/lb = 40,956 Btu. 40,956 + 295,160 = **336,116 Btu** is required to produce 40lb of (6% MgFeSi) treatment alloy for one ton of ductile iron using the Covered Tundish treatment technology.

Covered Tundish @ 1% addition of 75% FeSi Post-Inoculant
1% of 2000lbs = .01X2000 = 20lbs. 13,823 Btu/lb 75% FeSi X 20lbs = 276,460 Btu. **276,460 Btu** is required to produce 20lb of post-inoculant alloy for one ton of ductile iron using the Covered Tundish technique.

Covered Tundish Treatment Summary

Total Btu required to produce 1 ton of ductile iron:

Treatment alloy (6%MgFeSi) @ 2% addition	336,116 Btu
Post Inoculation alloy (75%FeSi)@1% addition	276,460 Btu
Melt 1 Ton iron in induction furnace at 1520°C	650,000,000 Btu
TOTAL	**650,612,576 Btu (650.6 Mil.)**

Proposed Technology: Direct Pour In-Mold Technology

DPI Technology @1% addition of (6% MgFeSi) Treatment Alloy
1% of 2000lbs = .01X2000 = 20lb, Less 6% Mg = 18.8lbs; 7850 Btu/lb 50% FeSi X 18.8lb = 147,580 Btu. 1.2lbs of Magnesium metal X 17,065 Btu/lb = 20,748 Btu. 20,478 + 147,580 = **168,058 Btu** is required to produce 20lb of (6% MgFeSi) treatment alloy for one ton of ductile iron using the DPI technology.

50°C lower iron pouring temperature for DPI Technology
Assume mid-range of energy to melt one ton of iron in a medium frequency induction furnace to 1520°C: 650 Mil. Btu/ton iron divided by 1520°C = .43 Mil Btu/degree C; 50C X .43 Mil Btu/degree C = 21.5 Mil. Btu
21.5 Mil. Btu saved by reducing the necessary iron melt temperature by 50°C.

Reduction in weight of metal poured by DPI – Direct Pour
Assume: 650 Mil. Btu/ton; 650 divided by 2000lbs = .325 Mil. Btu/lb
Assume: 20 molds @ 100lbs each of poured metal. 10% of poured weight is runner weight to be eliminated by direct pour technique. .10X100lbs = 10lb/mold, 10lbs X 20 molds = 200lbs of eliminated runner weight. Therefore, .325 Mil.Btu/lb X 200lbs = 65 Mil. Btu are saved by using the direct pour technology (DPI).

Direct Pour In-Mold Technology Summary
Total Btu required to produce 1 ton of ductile iron:

Treatment alloy (6% MgFeSi) @ 1% addition		168,058
Post Inoculation (not required with DPI)		0
Melt 1 ton iron in induction furnace at 1520°C		650,000,000
	Total	650,168,058
Savings: 50°C lower pouring temperature		(21,500,000)
Savings: Elimination of runner metal		(65,000,000)
	Total Btu	**563,668,058 (563.7 Mil.)**

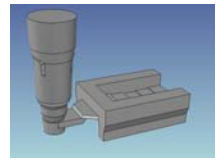
Annual Savings Metrics Calculations

Starting with the FY 2005 annual tonnage of Ductile Iron produced in the US as provided by the American Foundry Society's market report data (reported on page 21 of the January 2006 issue of *Modern Casting* magazine) of **4.69** Mil. Tons, we apply the **45%** market share projection for the Covered Tundish production method. This shows an annual production tonnage for the Covered Tundish of **2.11** Mil. Tons. To come up with the Btu per year per unit (Tons in this case) for Covered Tundish, we refer back to the number of Btu required to produce a single ton of ductile iron using this technology, which is **650.6** Mil Btu. Using those two key data points we arrive at our input for column A in the Energy Savings Metrics block for the chart below.

Energy Savings Metrics

Type of Energy Used	A Current Technology (Btu / yr / unit)	B Proposed Technology (Btu / yr / unit)	C=A-B Energy Savings (Btu / yr / unit)	D Estimated Number of Units in U.S. by 2010 (units)	E=CxD Energy Savings by 2010 (Btu / yr)
Oil / Gasoline					
Natural Gas					
Coal					
Electricity (@ 10,500 Btu / kWh)					
Other Energy 1 (1 KWH @ 3414 Btu*)	*Covered Tundish* **650.6 Mil** Btu/yr/ton	*DPI* **563.7 Mil** Btu/yr/ton	**86.9 Mil** Btu/yr/ton	**.734 Mil tons** Ductile Iron	**63.8 Trillion** Btu/yr
Other Energy 2 (Explain)					
Other Energy …n (Explain)					
Total Per Unit	*Covered Tundish* **650.6 Mil** Btu/yr/ton	*DPI* **563.7 Mil** Btu/yr/ton	**86.9 Mil** Btu/yr/ton	**.734 Mil tons** Ductile Iron	**63.8 Trillion** Btu/yr

Market projections for the year 2010 – Reflecting our commercialization strategy of licensing a leading foundry consumables manufacturer, we project that within at least four years (given sufficient partner investment in marketing and sales efforts) the DPI technology can capture approximately 15% (.734 Mil. Tons) of the total US ductile iron market.



Final report of the DPI project PHASE II

Project Director: **Dr. F.R. Juretzko**
Students: **Wes Nicholson**

Director, Solidification Laboratory: **Dr. D.M. Stefanescu**

Table of Content

Executive Summary 4
Introduction 6
Casting re-design task list 6
New design 6
Simulation efforts 7
Settings for DPI simulation 7
DPI2 container manufacturing 9
Sleeve 9
Inserts 10
Pattern 11
Alloy additions to the DPI container 11
1st heat with DPI2 containers 12
Mold fabrication 12
Results 15
Pouring performance 15
Castings after shake-out 16
Microstructures 18
2nd heat 21
Changes in container production 21
Changes in alloy addition 21
Pouring performance 22
Castings after shake-out 23
3rd heat 24
Changes in container production 24
Changes in alloy addition 24
Pouring performance 25
Microstructures 26
4th heat 28
Changes in alloy addition 28
Pouring performance 28
Castings after shake-out 28
Microstructures 30
5th heat 32
Changes in container production 32
Changes in alloy addition 32
Changes in molding 32
Pouring performance 32
Castings after shake-out 33
Microstructures 35
6th heat 36
Changes in container production 36
Changes in alloy addition 36
Changes in molding 36
Pouring performance 36
Castings after shake-out 37
Microstructures 39
Investigation of the presence of the flake graphite domains 40
Conclusions 43
Appendix – simulation results .... **Error! Bookmark not defined.**
050617-container 075 .... **Error! Bookmark not defined.**

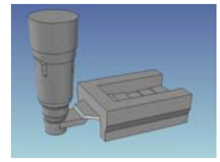
050620-container 075-opposite .... **Error! Bookmark not defined.**
050620-container 100-center .... **Error! Bookmark not defined.**
050621-container 100-center .... **Error! Bookmark not defined.**
050617new container 070-off center .... **Error! Bookmark not defined.**
050622container 060 .... **Error! Bookmark not defined.**
050623 DPInew rev4_1 .... **Error! Bookmark not defined.**
050625 DPInew rev4_1 .... **Error! Bookmark not defined.**
050627 DPInew rev4_1no lip30 .... **Error! Bookmark not defined.**
050627 DPInew rev4_1no lip35 .... **Error! Bookmark not defined.**
050711_DPI2 complete2 .... **Error! Bookmark not defined.**
050713_DPI2 complete .... **Error! Bookmark not defined.**
050720_DPI2 complete .... **Error! Bookmark not defined.**
Appendix –Technical drawings .... **Error! Bookmark not defined.**
Appendix - Alloy calculation .... **Error! Bookmark not defined.**
Appendix - DPI2-A CGI casting microstructures-end section .... **Error! Bookmark not defined.**
Appendix - DPI2-A CGI casting microstructures-ingate section .... **Error! Bookmark not defined.**
Appendix - DPI2-B CGI casting microstructures-ingate section .... **Error! Bookmark not defined.**
Appendix - DPI2-B CGI casting microstructures-end section .... **Error! Bookmark not defined.**
Appendix - DPI2-C CGI casting microstructures-ingate section .... **Error! Bookmark not defined.**
Appendix - DPI2-C CGI casting microstructures-end section .... **Error! Bookmark not defined.**
Appendix - DPI2-D CGI casting microstructures-ingate section .... **Error! Bookmark not defined.**
Appendix - DPI2-D CGI casting microstructures-end section .... **Error! Bookmark not defined.**
Appendix - Ingate microstructures for CGI trials .... **Error! Bookmark not defined.**
DPI2-A .... **Error! Bookmark not defined.**
DPI2-B .... **Error! Bookmark not defined.**
DPI2-C .... **Error! Bookmark not defined.**
DPI2-D .... **Error! Bookmark not defined.**
Appendix - Filling sequence of simulation 050720 .... **Error! Bookmark not defined.**
Time step 0.5 seconds .... **Error! Bookmark not defined.**
Time step 2 seconds .... **Error! Bookmark not defined.**

Executive Summary

This final report contains the container development effort, the fabrication steps of the container, the execution of the test heats and their analysis. In the first casting trials the DPI container was used to produce ductile iron (DI) castings while the second set of trials was geared towards the production of compacted graphite iron (CGI) castings. The report is organized along the time line the tasks were completed. The heats are individually listed with their respective processing parameters and analysis. Lessons learned were incorporated into the next heat.
A total of 10 DI and 6 CGI castings have been poured with the newly developed test pattern.
The DI heats yielded good results with complete treatment of the metal by using 255±5g of IM6 addition. To achieve sound castings in the thin sections the pouring temperature window had to be raised from 1460±15 ºC to 1470±15 ºC. A complete overview of the DI heats poured is given in Table 1.
The treatment of the base metal to obtain CGI was not as complete as desired. Since the processing window for CGI is much smaller, this was not unexpected. A small amount of grey iron persisted to be present in some location of the casting. A this stage the attempt to produce CGI has to be viewed as not complete, even though good results were obtained in the majority of the casting volume. A complete listing of CGI heats is given in Table 2

Table 1 Compilation of DPI2 DI heats

	Target	**DPI2-1**		**DPI2-2**		**DPI2-3**		**DPI2 - 4**		**DPI2 – 5**		**DPI2 - 6**	
Alloy		IM6		IM6		IM6		IM6		IM6		IM6	
Amount [%]		1.00		1.00		1.50		1.10		1.20		1.20	
Amount [g]		181.0		181.0		218.0		215.0		235.0		235.0	
Pouring temperature	1445 – 1475 ºC	1433 ºC		1461 ºC		1451 ºC		1464 ºC		1452 ºC		1475 ºC	
Note						Run out							
Spec sample		top	bot	top	bot	top	bot	top	bot	top	bot	top	bot
%C [Leco]	3.3-3.8	3.43	3.38	3.35	3.3	3.26	3.3	3.52	3.43	3.52	3.4	3.53	3.45
%Si	2.2-2.8 base melt	3.43	3.79	3.68	3.69	3.82	3.84	3.42	3.33	3.61	3.59	3.4	3.82
%Mg	0.04 residual	0.0196	0.0418	0.0369	0.0325	0.049	0.0442	0.0348	0.0299	0.0412	0.0373	0.0323	0.0486
%Mn	~ 0.1 or less	0.105	0.107	0.109	0.108	0.11	0.11	0.0978	0.0958	0.0998	0.0984	0.0977	0.101

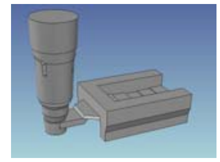


DPI Phase 2

	Target	DPI2 – 7		DPI2 – 8		DPI2 – 9		DPI2 – 10		DPI2 – G	
Alloy		IM6		IM6		IM6		IM6		IM6	
Amount [%]		1.20		1.40		1.30		1.35			
Amount [g]		234.5		273.6		254.1		263.9		235	
Pouring temperature	1445 – 1475 ºC	1474 ºC		1448 ºC		1459 ºC		1481 ºC		1462	
Note								Visible reaction in the opening of the top insert.		Good reaction, after 1 to 2 minutes, side wall of cope busted and emptied the casting.	
Spec sample		top	bot	top	bot	top	bot	top	bot	top	bot
%C [Leco]	3.3-3.8	3.29	3.27	3.33	3.2	3.25	3.23	3.23	3.22	n/a	n/a
%Si	2.2-2.8 base melt	3.38	3.49	3.28	3.2	3.38	3.65	3.38	3.5	3.5	4.15
%Mg	0.04 residual	0.096	0.066	0.039	0.037	0.067	0.076	0.046	0.061	0.069	0.098
%Mn	~ 0.1 or less	0.074	0.079	0.079	0.079	0.066	0.066	0.063	0.065	0.115	0.114

Table 2 Compilation of DPI2 CGI heats

CGI Heats	Target	DPI2 - A		DPI2-B		DPI2-C		DPI2-D		DPI2-E		DPI2-F	
Alloy IM4 [g]		200		180		160		140		200		160	
Alloy FeSi75 [g]		60		80		100		120		60		80	
Pouring temp		1457 ºC		1464 ºC		1448 ºC		1460 ºC		1471 ºC		1491 ºC	
Note						No metal up through the vents				Small run out on opposite side of container, casting filled completely		Run out after complete filling, casting appears to be sound	
Spec sample		top	bot	top	bot	top	bot	top	bot	top	bot	top	bot
%C [Leco]	3.3-3.8	3.24	3.24	3.39	3.37	3.4	3.37	n/a	3.36	n/a	n/a	n/a	n/a
%Si	2.2-2.8 base melt	3.57	3.61	3.87	4.03	4.35	4.38	4.08	4.18	3.99	4	3.67	4.01
%Mg	0.04 residual	0.053	0.054	0.042	0.044	0.063	0.059	0.054	0.056	0.063	0.054	0.044	0.043
%Mn	~ 0.1 or less	0.064	0.061	0.065	0.066	0.065	0.063	0.064	0.064	0.117	0.121	0.112	0.114

Introduction

DPI Phase 2 is the continuation of the proof of concept study completed in the spring of 2005. It contained a large number of casting and container design with its respective simulation effort. It culminated in the actual pouring of regular grey iron of a standard composition and produced ductile iron castings with the standard step test pattern. After completion of Phase 1, the technology development and commercialization was the next logical step. It should improve on the economic side of container production and also be able to demonstrate repeatability. It further aimed at expanding the DPI container treatment to the production of compacted graphite iron.

Casting re-design task list

The initial step test casting had to be redesigned to yield sound mechanical samples and demonstrate thin wall capabilities. The total casting weight needed to be maintained at 40 lbs.

The traditional test casting used in Phase 1 showed some deficiencies in terms of complete filling and occasional run outs, since the main casting weight was located in the drag. It furthermore did not provide for simple extraction of test samples for mechanical testing. Therefore a new test casting was proposed to incorporate the following considerations:

- Maintain overall casting weight of 40 lbs.,
- Provide thin sections within the casting to demonstrate thin wall capabilities,
- Provide areas for easy mechanical test samples of 3 to 6 mm thickness,
- A Y-block for machined samples is considered,
- Maintain vents,
- Design the pattern in a compact manner,
- The main casting weight should be in the cope,
- Maintain spectrometer sample inserts,
- Test casting should be a relevant design for demonstration to industry,
- Simulate test casting performance by simulation.

New design

The newly designed test casting was designed to incorporate the listed considerations. The design features a basic U-shape with two Y-block areas in the drag. These Y-block parts will be sound and can be used for machined tensile bars. Between the long sides of the U-shape are five plates with thicknesses ranging from 2 to 10 mm thickness to demonstrate the thin wall capabilities, Fig. 1. The order of plate thickness from the bottom of the U-shape is 10, 8, 2, 4 and 6 mm. The plates are individually mounted to allow for changing positions if necessary.

The overall casting weight for ductile iron (density approximated as 7.1 g/cm^3) was calculated to be 26 lbs, being close to the old design weight of 23.6 lbs.

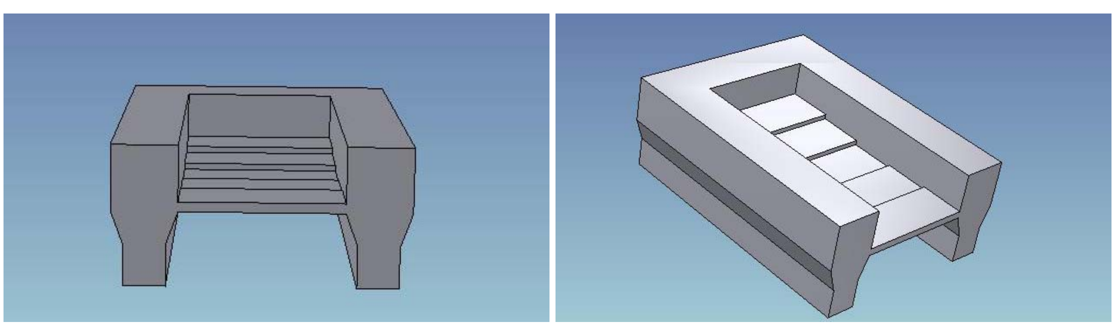
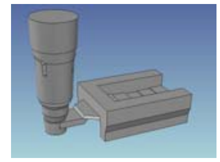


Fig. 1 3D Views of new test casting

The overall appearance of the casting with DPI container is shown in Fig. 2. Not shown are the vents and the spectrometer sample inserts. It is planned to add two vents, one on top of each leg of the U-shape and for the



spectrometer inserts to be in similar positions as the old casting, thus sampling of the first liquid to fill and the last. In the current view the pouring cup of the container seems very large, but depending on the height of the vents, this volume will not be completely filled after pouring.

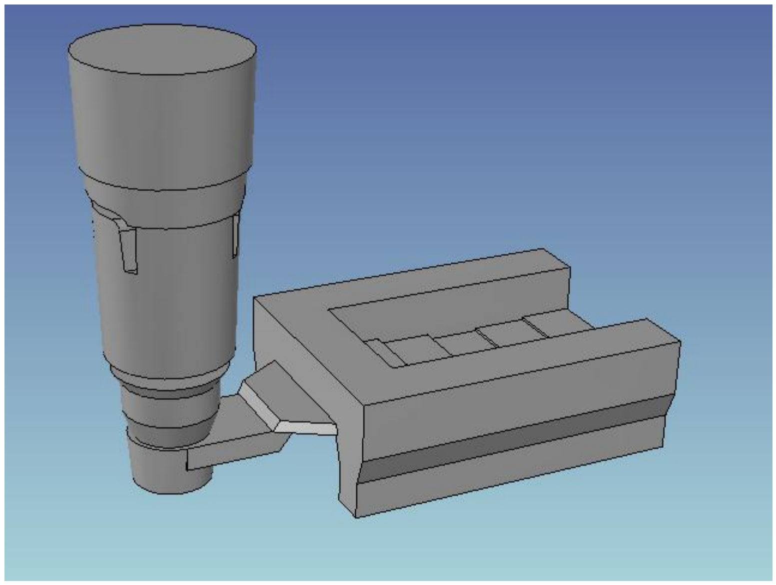


Fig. 2 New casting design with redesigned DPI container

Simulation efforts

The following simulations were performed in order to ascertain the proper simulation conditions to achieve a filling time of close to 20 seconds, as observed during the actual pours. The simulations were initially performed with the original DPI_98 3D model, which was created in IronCAD from measurements of the DPI 98 container of the Phase 1 trials. The DPI 98 container had an opening at the bottom of the pouring basin with a diameter of 1.06in.

Modifications included the removal of the spiral segment and the reduction of the pouring basin opening to 0.75in diameter, and the presence of filter elements. The most influential parameter has been the pouring height. This parameter directly influences the flow rate into the simulated pouring basin.

It has to be noted that the simulations do not account for the back pressure created by the Mg reaction.

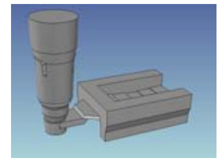
Settings for DPI simulation

For the simulation of the DPI casting a number of input variables are to be selected. The materials are given in the material selection section, while the simulation descriptions are contained in a three sheet descriptor file, reproduced below. Some of the simulation parameters are explained in detail.

Material selection

Cast material: HiSiMo, which is the entry for ductile cast iron

Heat conduction W/m/C		Specific heat, J/kg/C	
37	@100 ºC	550	@100 ºC
34	@500 ºC	600	@500 ºC
32	@1100 ºC, 1150 ºC	800	@1150 ºC
		900	@1175 ºC
		950	@1600 ºC
Density, kg/m^3		CLE 10^{-6} /C	
7000	@500 ºC	12	@500 ºC
7000	@1150 ºC	15	@1175 ºC
6830	@1180 ºC	28	@1400 ºC



		47	@1600 ºC
T liq	1186 ºC	Q cr, kJ/kg	160.0
T sol	1149 ºC	Q eut, kJ/kg	260.0
Chemical composition			
Fe 93.83	C 3.40	Si 2.4	Mn 0.3
P 0.02	S 0.01	Mg 0.04	

Initial temperature: 1450°C
Mold material: Furan sand, initial temperature: 20°C

File name: c:\program files\NFSolid\SimFiles\Results\comanche_12_apr.00.psp

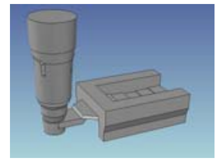
MESH			
	Box dimensions	Casting position	Number of cells
Along X, mm	246.65	124.46	198
Along Y,mm	350.04	175.26	281
Along Z, mm	260.35	131.32	209
Min. mould thickness, mm	10.16	Total cells	11,628,342
Size cell, mm	1.25	Casting cells	1,255,573
Boundary conditions	Low	High	
YZ plane	Normal conditions	Normal conditions	
XZ	Normal conditions	Normal conditions	
XY	Normal conditions	Normal conditions	

Rigging			
Shrinkage calculation model		Air Gap	
CLFu, %	70.00	Temperature, C	1172.93
CLFd, %	70.00	Contact gap, µm	1.00
			Coeficcient, %
Medium gravity influence		V upper	100.00
Solver 0 without convection		V lateral	100.00
No friction parameters		V lower	100.00

The model of shrinkage defects formation is based upon the percolation theory. **CLF** stands for the critical fraction of percolation, with CLFd denoting the lower threshold and CLFu the upper threshold. Using the same value for CLFu and CLFd divides the liquid into two parts, i.e. feeding possible and feeding impossible because of dendritic coherency. Other options are the assignment of a lower level of CLFd, usually 0.3 for the onset of the mushy zone.

In the model of **Medium gravity influence** the system energy represents the sum of surface energy and potential energy of liquid in the gravity field. The place of shrinkage distribution is determined by minimality of this sum.

Gatings			
In all	1	Section, mm^2	4479.91
Boundary conditions at gating point		Normal conditions	
Pouring type	Gravity casting		
Pressure height, mm	80.000		
Friction factor	0.90	Normal values range from 0.8 to 0.9	
Flow, kg/s	34.544		



Deviation from real life scenario:

Use if the single CLFu and CLFd, simulation software is capable of dealing with different values to account for influence of mushy zone on solidification, is not really needed if only flow is considered. All other values are deemed correct for this particular simulation. Fine tuning can be done by the friction factor, however, that is not considered to have a significant impact on the final simulation results.

A total of 13 simulations were performed with the Phase 1 DPI container design in an attempt to recreate the filling time. This proved to be not possible. The most obvious reason is the fact that the simulation does not account for backpressure created by the Mg reaction in the reaction chamber. This back pressure in conjunction with the narrow opening in the pouring cup led to an increase of pouring time which could not be successfully simulated with the available software.

During the development effort of the new design 12 simulations were performed, with a variety of changed dimensions and performance variables, such as filling rate and pouring height, Table 3. See appendix – Simulation for details.

Table 3 Compilation of simulation variables for the DPI 2 design effort

	Pressure height	Flow	Section	Filters	Filling time	Sustained flow	Max flow
	[in]	[lbs/s]	[in2]	# and factor	[s]	[lbs/s]	lbs/s]
050617-container 075	1	2.9	0.5	0	14.6	3.2	3.2
050620-container 075-opposite	1	3.0	0.5	0	14.0	3.3	3.3
050620-container 100-center	1	5.1	0.8	0	8.2	5.7	5.7
v050621-container 100-center	3.15	9.0	0.8	0	6.4	~6.25	9.4
050617new container 070-off center	1	4.5	0.4	0	16.1	2.8	2.8
050622container 060	1	1.9	0.3	0	22.0	2.1	2.1
050623 DPInew rev4_1	1	92.6	14.6	0	5.4	6.6	118.6
050625 DPInew rev4_1	1	92.6	14.6	4, F:1.0	5.4	6.6	118.6
050627 DPInew rev4_1no lip30	1	92.6	14.6	0	5.3	6.6	118.6
050627 DPInew rev4_1no lip35	1	92.6	14.6	0	5.2	6.9	118.0
050713_DPI2 complete	1.57	115.9	14.6	0	5.4		
050720_DPI2 complete	1.97	123.1	14.6	3 F:1.0	6.2	5.7	63.1

With the design of the container completed and checked by simulations, the next step was the manufacturing of the new container pieces.

DPI2 container manufacturing

Sleeve

The core box for the DPI container sleeve was machined out of aluminum with a split-mold design, a vented base plate and a solid insert. The manufacturing was done at Reich companies in Trussville, AL with a cold box L25 core machine. A total of 14 good sleeves were produced. The gassing of the sand core with catalyst made it necessary to retain a ¼" of material at the bottom, Fig. 3 left. The visible hole is a result of the insert removal. This thin piece of sand can easily be removed. The whole container is shown in Fig. 3 right.

The complete technical drawings are supplied in Appendix –Technical drawings.

Fig. 3 Close-up shot of the inside (left) and overall view (right).

Inserts

The inserts were designed to snuggly fit into the container, such as to minimize the use of core paste or other sealant. The initial pieces were fabricated on a 3D thermojet rapid prototype machine. This machine uses a successive wax deposition method to build the parts, Fig. 4. Using these two prototype parts, the core boxes were fabricated by UA’s College of Engineering machine shop with wood and a pourable plastic pattern making material, using the wax samples as performs. The core boxes yielded exact replicas from the initial 3D prototypes. Two sands were used to produce these inserts, GFN 47 and GFN 97 sand. While the GFN 97 provides a smoother surface, it is the GFN 47 that did perform better in terms of core blowing and feel of sturdiness, Fig. 5.

Table 4 Current settings for the L1 core machine

Parameter	Key on control panel	Part 1- Bottom insert	Part 2-Top insert
Gassing time	F 1	8	5
Pre-dosing	F 2	18	7
Post-dosing	F 3	0	0
Time to final purge pressure	F 4	1.0	1.0
Final pressure of purge air	F 5	2.0	1.5
Shoot time	F 7	2.0	2.0
Shoot exhaust time	F 8	2.0	2.0
Pressure setting		2.75	2.0
		Good filling for GFN 47 1% Iso-Cure binder Sand feels soft, rubs off easily	Good filling for GFN 47 1 % Iso-Cure binder Sand feels soft, rubs off easily
			

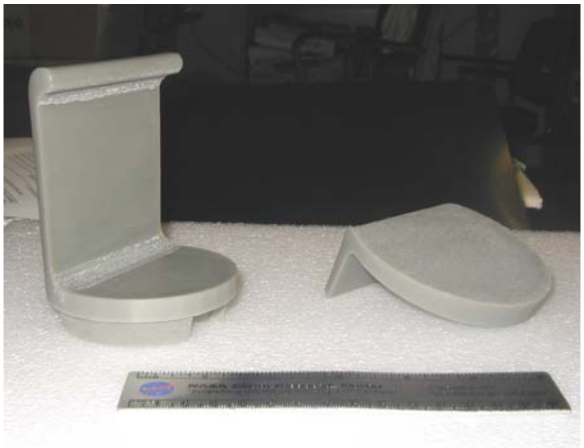


Fig. 4 Prototype pieces from the 3D systems thermojet.

Fig. 5 Fabricated inserts with GFN 47 (left) and GFN 97 (right).

Pattern

The pattern of Phase 1 was modified by removal of the step casting and its replacement with the new casting design. In an attempt to keep the remanufacturing costs low, small bridges were added to connect the spectrometer inserts to the casting, Fig. 6. The plates in the center of the U shape casting are interchangeable.

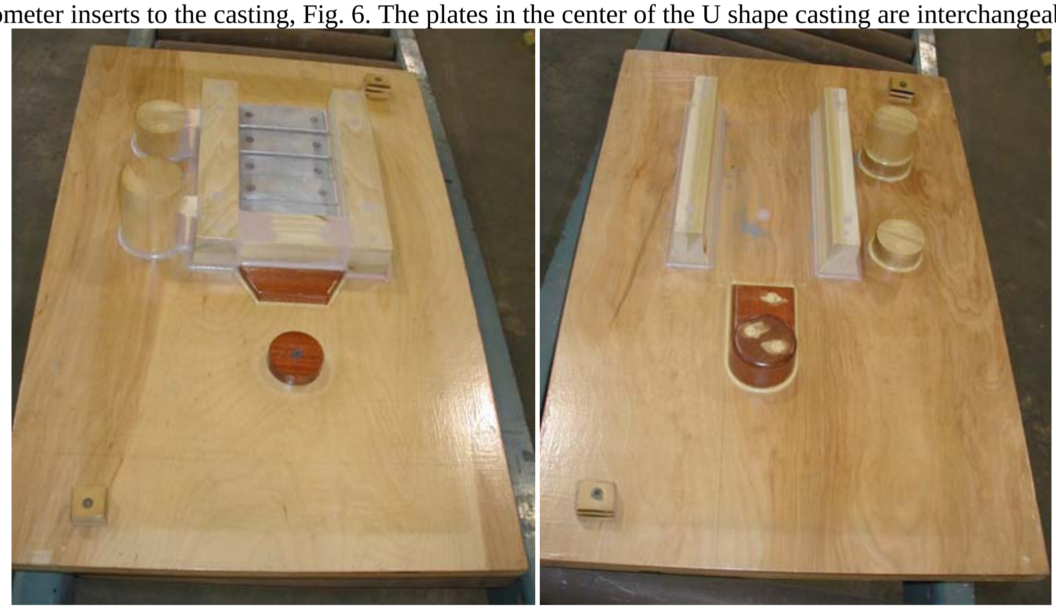


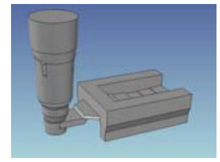
Fig. 6 Picture of the match plate pattern cope (left) and drag (right).

Alloy additions to the DPI container

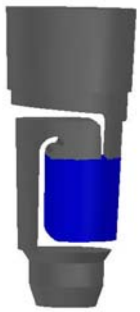
The alloy additions were received. The chemical composition of the additions is given in Table 5.

Table 5 Chemical composition of alloy additions

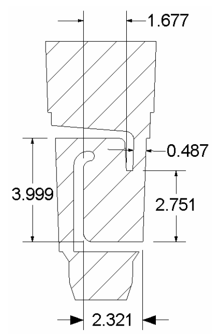
Alloy	Si [%]	Mg [%]	Al [%]	TRE [%]	Ca [%]
IM-6 MgFeSi	44.25	5.95	0.66	0.52	0.44
IM-4 MgFeSi	44.38	4.60	0.68	0.54	0.42
High purity 75%FeSi	75.14	-	0.36	-	0.19



Following a conversation between Jay Hitchings and Dr. Juretzko it was decided that UA will bag the alloys in order to shorten the adjustment time. The alloy additions are calculated based on the *Inmold Process Installation Manual* from Materials and Methods LTD, Reigate, England, 1974. The necessary chamber data were obtained by analysis of the final design volume, Fig. 7.



Volume of reaction chamber (blue) is 18.306 in^3



Cross-section of container with dimensions (in) for reaction chamber

Fig. 7 Basic numbers for the reaction chamber.

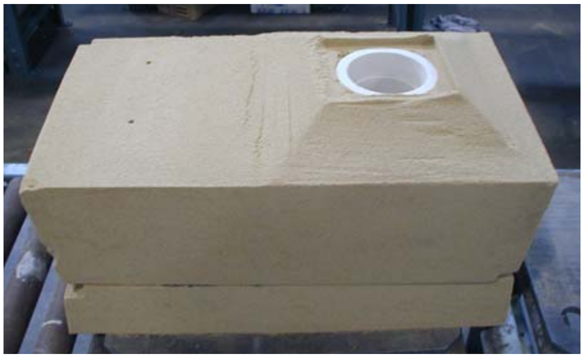
1st heat with DPI2 containers

The first heat with the new DPI container was conducted on Sept 13 2005. A total of three molds were prepared.

Mold fabrication

The mold halves were produced by resin bonded GFN 47 sand, using the same flasks as employed during the DPI phase 1 project. Removal of the pattern was easier than for the previous casting design. The sleeve was added onto the top of the match plate and the sand hand packed around it to secure it in place. Two venting rods were inserted at the end of each leg of the U-shape, Fig. 8. The mold halves were assembled with the aid of some core paste around the perimeter of the lower half, **Fig. 9**. A close-up of the insert and the pouring area is shown in **Fig. 10**.

Fig. 8 Open mold halves with DPI2 sleeve and spectrometer inserts in place.



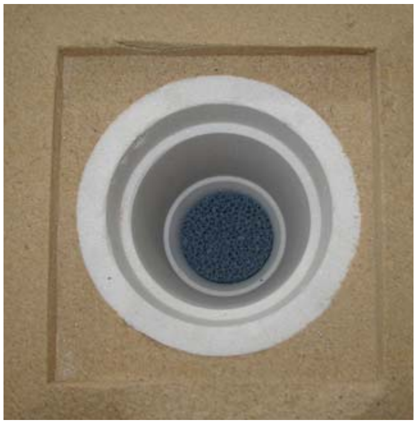


Fig. 9 Closed mold **Fig. 10 Detail of the DPI2 sleeve without filling.**

After completion of the mold assembly, the DPI sleeves were loaded with a round 15ppi Selee foam filter, the inserts to create the chamber and the pouring cup, and the alloying additions. The alloy additions were weighted out and placed into small re-sealable bags, Fig. 11 (left). After placement of the bag, the top inserts was secured in place by core paste applied to the area adjacent to the handle, Fig. 11 (right).

The alloy additions were calculated by following the outline of the Inmold process guidelines, based on a casting weight of 40 lbs, see Appendix - Alloy calculation.

Table 6 Alloy additions

	DPI2-1	DPI2-2	DPI2-3
Alloy	IM6	IM6	IM6
Amount [%]	1.0%	1.0%	1.5%
Amount [g]	181 g	181 g	218 g

Fig. 11 Detail of alloy bag (left) and top view of completed sleeve (right).

The molds with their respective inserts and alloy additions are shown in Fig. 12, Fig. 13, and Fig. 14. The filter elements are not shown. **Fig. 15** shows the three molds weighted down and ready to be poured.

Fig. 12 Inserts for DPI2-1 (filter not shown), GFN 47 inserts, 1% addition

Fig. 13 Inserts for DPI2-2 (filter not shown), GFN97 inserts, 1% addition

Fig. 14 Inserts for DPI2-3 (filter not shown), GFN 47 inserts, 1.2% addition.

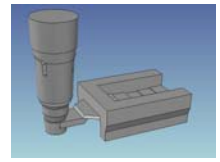


Fig. 15 Molds ready to be poured (l DPI2-1, mid. DPI2-2, r DPI2-3). **Fig. 16 Detail of pouring basin**

Results

The melt chemistry as determined by spectroanalysis is given in Table 7. It is seen that the carbon level was within the target range. The attempted residual of 0.04% Mg was not achieved with the first spec sample was well within the range for the third. It large scatter of Mg values for DPI2-1 could be the result of inhomogeneous mixing in the chamber, which was not observed in the second casting that contained the same amount of alloy.

Table 7 Melt chemistry of 1st DPI2 heat

Sample	%C [Leco]	%Si	%Mg	%Mn
Target	3.3-3.8	2.2-2.8 base melt	0.04 residual	~ 0.1 or less
DPI2-1 top	3.43	3.43	0.0196	0.105
DPI2-1 bottom	3.38	3.79	0.0418	0.107
DPI2-2 top	3.35	3.68	0.0369	0.109
DPI2-2 bottom	3.26	3.69	0.0325	0.108
DPI2-3 top	3.30	3.82	0.049	0.110
DPI2-3 bottom	3.30	3.84	0.0442	0.110

Pouring performance

The castings were poured from a preheated 100lbs ladle. The pouring basin did work properly and a good pouring rate could be maintained. For DPI2-3 it was observed that the reaction of the alloy bag resulted in some sparks exiting the chamber at the top insert. This could be a result of the higher alloy additions.

Table 8 Pouring temperatures

	Pouring temperature	Note
Target	1445 – 1475 ºC	
DPI2-1	1433 ºC	Slightly below
DPI2-2	1461 ºC	Run out
DPI2-3	1451 ºC	

Minutes after pouring, the molds and especially the containers were inspected. It was observed that for DPI2-1 the inserts did disintegrate and were floating to the top, Fig. 17, providing another explanation for the scatter of the spectrometer data. This was not observed during pouring. DPI2-2 did have a run-out and after the pour the top insert was still in place, Fig. 17. During pouring of DPI2-3, the same observations were made as for DPI2-1, i.e. is the proper performance of the top insert during pouring and the subsequent flotation of the sand inserts after completion, Fig. 18.

Fig. 17 DPI2-1 minutes after pouring (left), DPI2-2 minutes after pouring (right)

Fig. 18 DPI2-3 minutes after pouring

Castings after shake-out

The castings were removed from the molds the next day.
DPI2-1 had a low pouring temperature. Resulting in the formation of a cold shot at the 2m plate, **Fig. 19** and **Fig. 20**. The hollow of the lower insert of the container is visible.

Fig. 19 DPI2-1 after shake-out. Note cold shot at 2mm plate.

Fig. 20 Detail of cold shot in DPI2-1

Even though DPI2-2 had a run-out, the spectrometer samples did fill, as did all the plates of the casting, Fig. 21. Based on the skin formation at the lower part of the U-shape, the run out occurred after the cope was partly filled.

Fig. 21 DPI2-2 after shake-out. Note complete filling of all plates.

DPI2-3 did fill completely and the pouring temperature was about 1451 ºC, Fig. 22. The 2 mm plate showed a cold shot with a fold, Fig. 23.

Fig. 22 DPI2-3 after shake out.

Fig. 23 Detail of DPI2-3. Cold shot and skin formation.

With respect to the thin wall sections, especially the 2mm plate, the application of an insulating coating or raising the pouring temperature window was considered.
The castings weight for DPI2-1 was 44 lbs 10oz and for DPI2-3 was 43 lbs 2oz.

Microstructures

Castings have been sectioned according to Fig. 24.

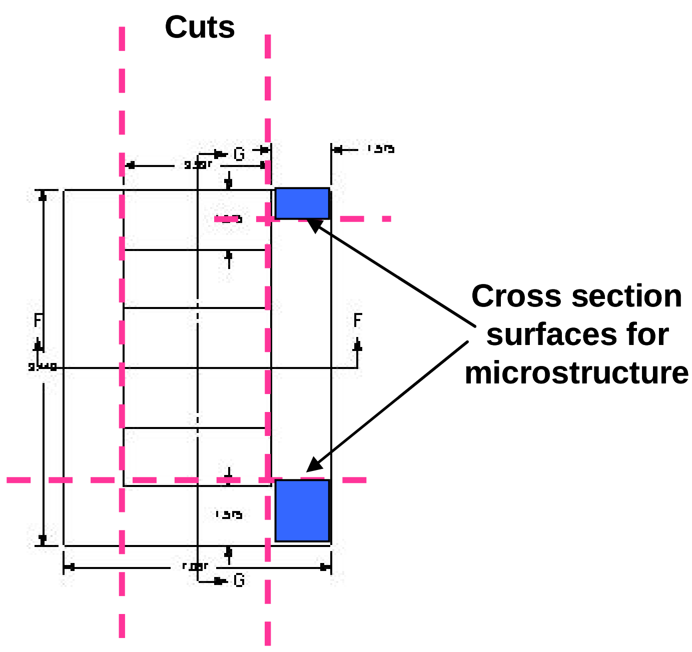


Fig. 24 Sectioning scheme for the castings. Dotted lines are band saw traces, blue segments are samples.

Casting 1: Predominant ductile structure, small areas of grey, complete microstructure is pending.
Casting 2: Run out but all microstructure is ductile.
Casting 3: Small areas of grey, predominantly ductile.

Casting 3 has been investigated more closely. The following micrographs in **Fig. 25**, **Fig. 26** and Fig. 27 are from the end section. The order is from top to middle to bottom. All three figures show a completely spheroidal graphite shape, with slight variations in the amount of nodularity.

The inlet section was not as homogeneous in graphite shape and the areas of the microstructures are given in Fig. 28.

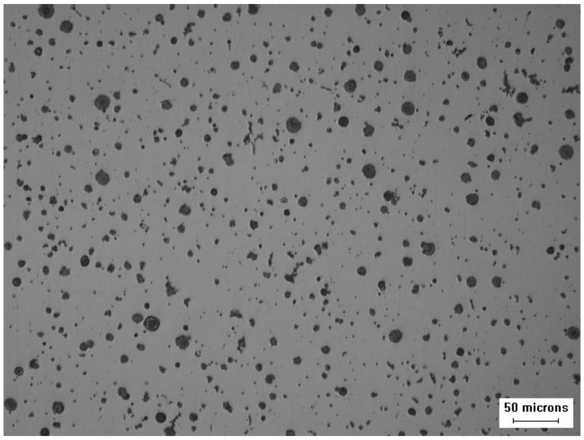


Fig. 25 End section – top, fully ductile

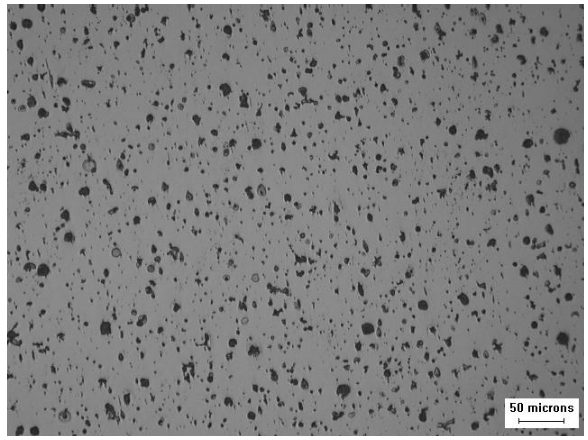


Fig. 26 End section – middle, fully ductile

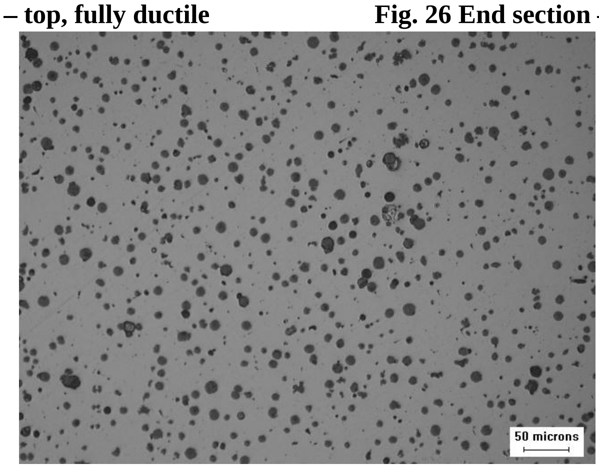


Fig. 27 End section – bottom, fully ductile

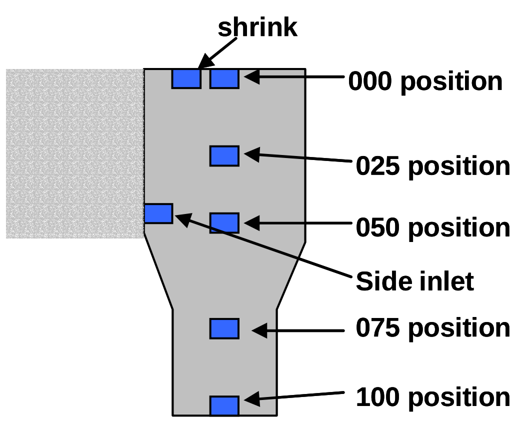


Fig. 28 Locations of the micrographs for Fig. 29 through Fig. 33**.**

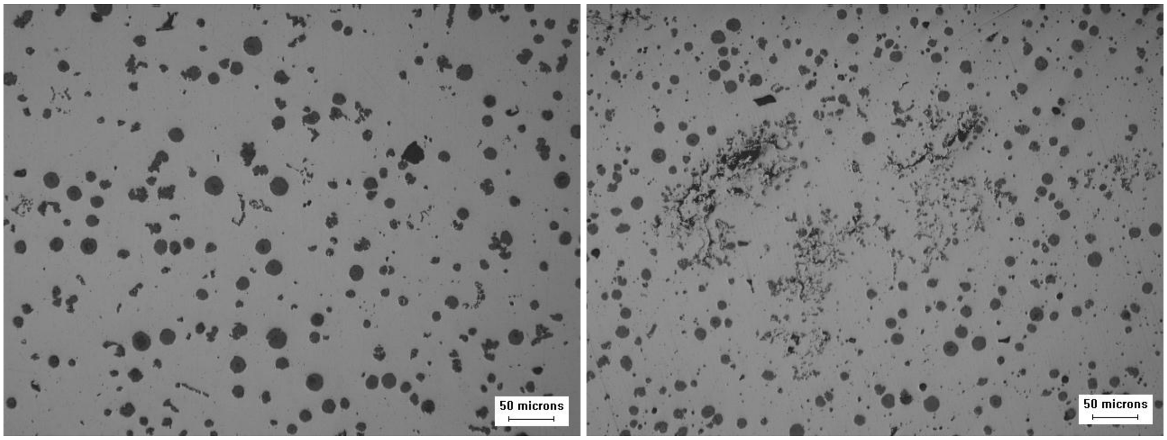


Fig. 29 Inlet section – left:000 position ductile, right: shrink below surface ductile.

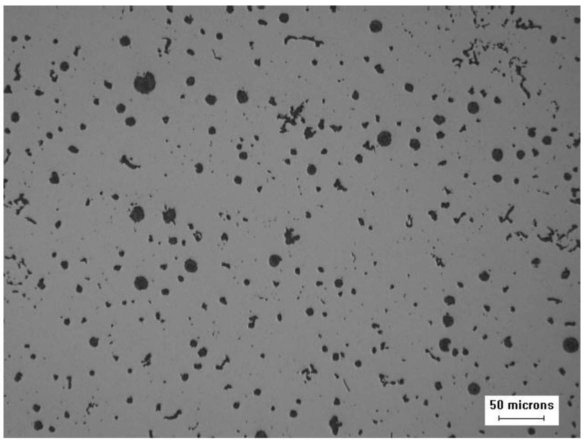


Fig. 30 Inlet section – 025 position, ductile with traces of compacted.

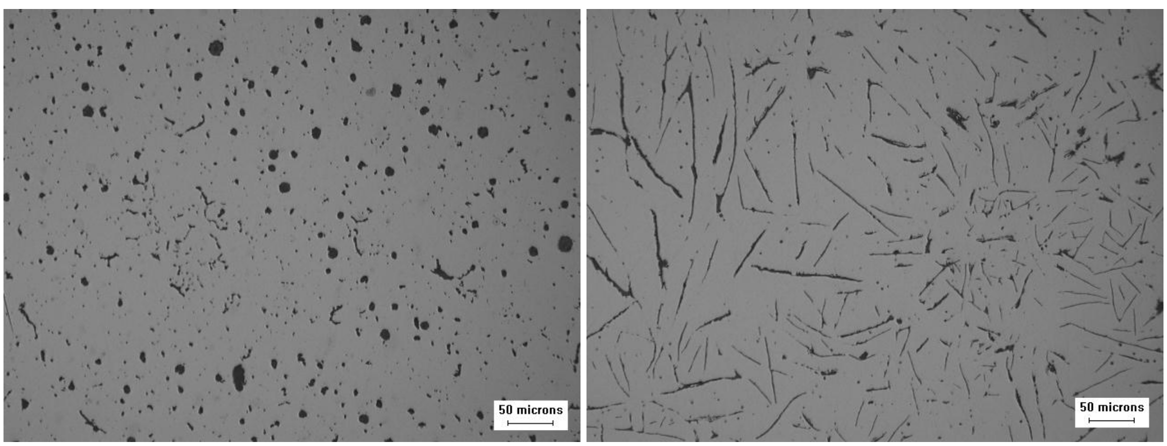


Fig. 31 Inlet section – 050 position ductile/compacted, side towards inlet grey/compacted.

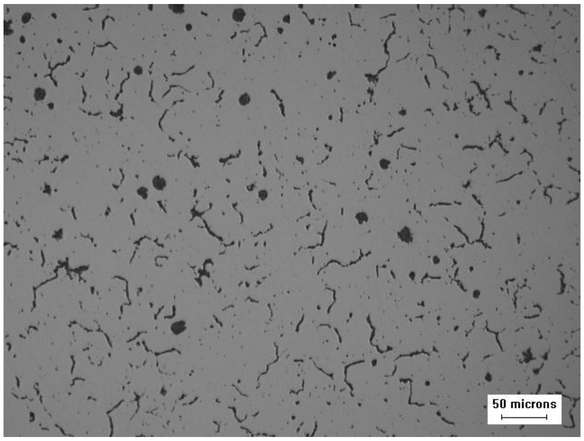


Fig. 32 Inlet section – 075 position, some compacted

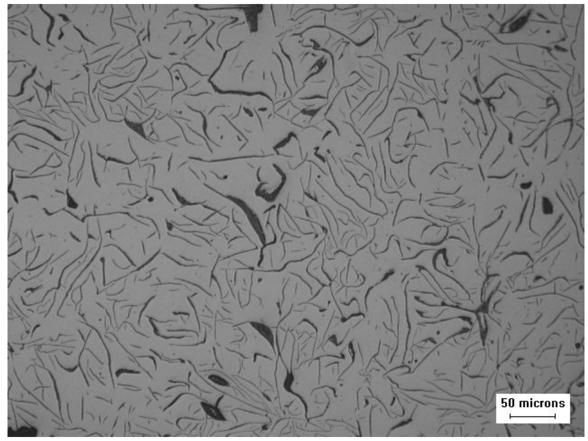


Fig. 33 Inlet section – 100 position, fully grey

2nd heat

Changes in container production

The inserts were replaced with new ones, since it was found that the “feel” of the inserts was soft and not as smooth and hard when compared to the sleeves. To remedy this problem, after consulting with Mr. Tommy Horton from Reich Companies, the binder amount was raised from 1% to 1.3 %. 20lbs of sand with 47 GFN were mixed in a bucket with an industrial mixer attachment. The binder was *SigmaCure* from HA Inc. Blow pressure for the inserts was 2.7 bar. The insert pieces produced were of similar quality as the sleeves produced by Reich Companies.

Changes in alloy addition

The initial alloy additions for the 1st heat were based on a 40 lbs casting weight. After the heat the casting weight was found to be closer to 43-44 lbs. Therefore the initial alloy additions had to be increased. In addition, the microstructure of DPI2-1 and DPI2-3 showed some untreated areas. After consulting with Jay Hitchings, it was agreed to boost the alloy additions to 1.1 and 1.2 %. The alloy additions are given in Table 9.

Table 9 Alloy additions for the 2nd heat

Mold	Alloy addition [%]	Alloy addition [g]
DPI2 - 4	1.1	215
DPI2 – 5	1.2	235
DPI2 - 6	1.2	235

Table 10 Chemistry of 2nd DPI2 heat

Sample	%C [Leco]	%Si	%Mg	%Mn
Target	3.3-3.8	2.2-2.8 base melt	0.04 - residual	
DPI2-4 top	3.52	3.42	0.0348	0.0978
DPI2-4 bottom	3.43	3.33	0.0299	0.0958
DPI2-5 top	3.52	3.61	0.0412	0.0998
DPI2-5 bottom	3.40	3.59	0.0373	0.0984
DPI2-6 top	3.53	3.40	0.0323	0.0977
DPI2-6 bottom	3.45	3.82	0.0486	0.101

Pouring performance

After observing the cold shots in the first DPI2 heat, the pouring temperature window was raised by 10ºC. The pouring temperatures are given in Table 11. The pouring was constant and no run-outs were observed. DPI2-4 and DPI2-5 were filled from a preheated 100 lbs ladle, while DPI2-6 was filled with the remains of the furnace. All pours were recorded by video.

Table 11 Pouring temperatures of DPI2 heat on Sept 30th 05

Mold	Pouring temperature	Note
Target	1455-1475 ºC	
DPI2 - 4	1464 ºC	
DPI2 – 5	1452 ºC	
DPI2 - 6	1475 ºC	

The top inserts were secured in place by a ring of core paste, Fig. 34 left. The inserts did withstand the pour without problems as identified by the pictures taken minutes after the pour, Fig. 34 right and Fig. 35.

Fig. 34 Left: top insert glued into position by core paste, right: DPI2-4 minutes after pouring with top insert slowly disintegrating

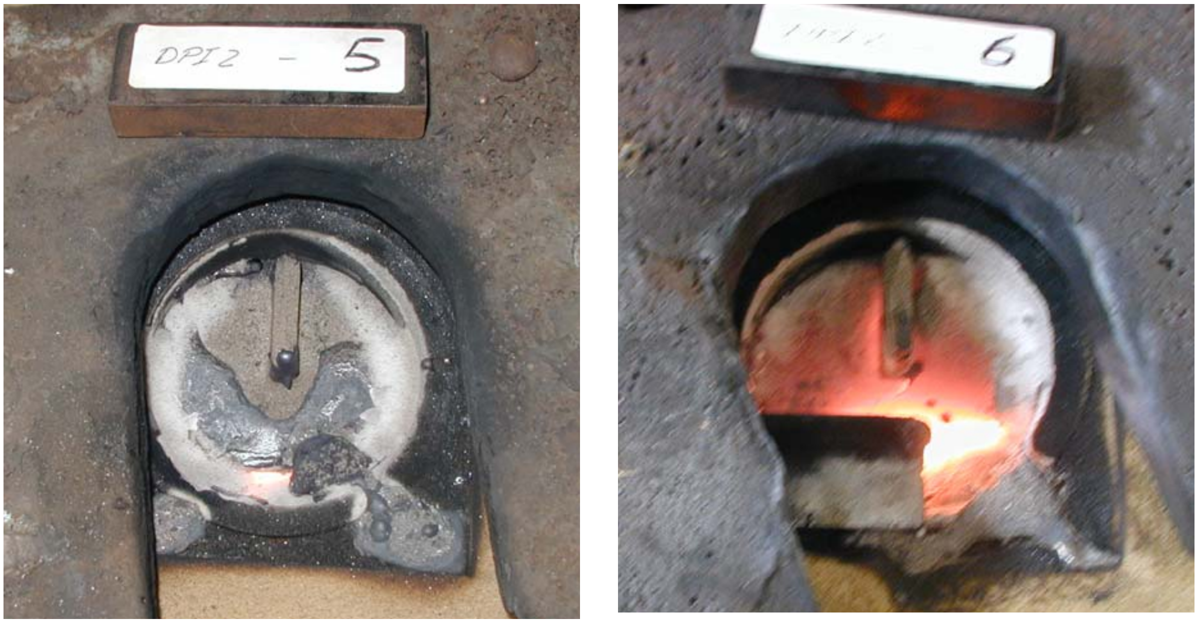


Fig. 35 DPI containers minutes after pouring. In both cases the top insert remained intact

Castings after shake-out

After shake out, the castings showed complete filling and only DPI2-5 showed a small fold in the 2mm thin section. The castings were sectioned as described in Fig. 24.

The container did perform as expected and no damages were observed. Fig. 36 shows the side view of two containers. The hollow area of the lower insert is clearly visible. The reason that no traces of the top insert are observed lies in the fact that the level of the vents is lower than the position of the top insert, thus when pouring stops at the emergence of the liquid through the vent, a small portion still flows out of the vents and leaves no metal on top of the top insert.

Fig. 36 Side view of container DPI2-4 and DPI2-6 after shake out.

The reoccurrence of grey iron inside the casting, presumably stemming from the last metal flowing through the chamber, led to the investigation of the ingates of all three castings for the second heat. The castings were sectioned as shown in Fig. 37. A minimum of three sparks were done on each sample. The results of the spectro analysis are given in Table 12. It is clear from the residual Mg level present in the ingate that the alloying additions were not sufficient for the complete treatment of the metal. Even though the spectrometer discs of the main casting showed sufficient residual Mg level to produce ductile iron (see Table 10), the evidence of the ingates and small areas of the casting itself showed the presence of grey iron.

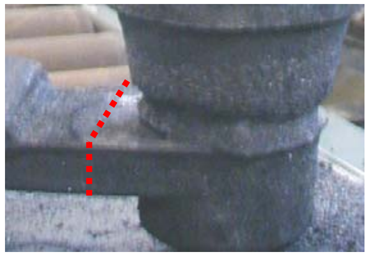


Fig. 37 Indication of the cut surface used for spectro analysis.

Table 12 Spectrometer results of the ingates of DPI2 heat 4, 5 and 6.

	#1	#2	#3	#4	Avg.	std dev
DPI2-4	0.0133	0.00771	0.0103	0.00647	0.009445	0.003025
DPI2-5	0.0286	0.0174	0.0171	-	0.021033	0.006555
DPI2-6	0.0205	0.0135	0.0143	0.0178	0.016525	0.003242

The spectrometer results were also plotted to asses the homogeneity of the residual Mg levels, Fig. 38. DPI2-4 had a 1.1% alloy addition while 5 and 6 had 1.2% additions. This is consistent with the higher levels measured in the ingate. However, it is obvious that the ingate should have a higher Mg level to assure the complete treatment of the metal flowing through the container.

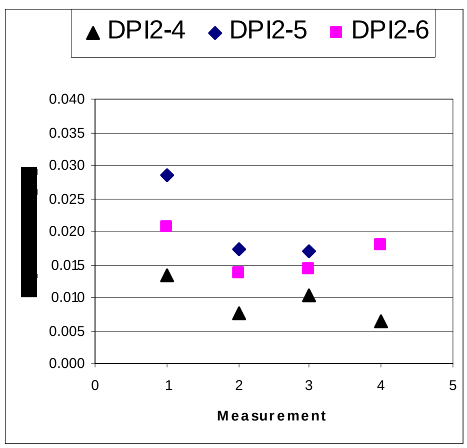


Fig. 38 Mg level variation in the ingates.

3rd heat

A third heat was performed on Oct 18th 2005 with two molds. The goal of this heat was to asses the necessary level of alloy addition to achieve complete treatment. To this effect the alloy additions were set at a level of 1.2 and 1.4 %. The alloy was placed into a thin plastic bag and tamped into the bottom of the container chamber.

Changes in container production

No changes were made to the container.

Changes in alloy addition

The alloy additions were raised to 1.2 for DPI2-7 and 1.4% for DPI2-8, Table 13.

Table 13 Alloy additions for the 3rd heat

Mold	Alloy addition [%]	Alloy addition [g]
DPI2 – 7	1.2	234.5
DPI2 – 8	1.4	273.6

Pouring performance

The pouring temperature for DPI2-7 was 1474ºC and for DPI2-8 1448ºC. They were poured from the same completely filled 100 lbs ladle. The first casting filled completely and a good and constant pouring rate could be established. For the second casting it was observed that after initial establishing a good pouring rate, the Mg reaction took place, leading to the movement of the top insert from its seat. Both top inserts were glued into place by a bead of core paste covering the whole perimeter of the insert.
The chemistry of the spec samples are given in Table 14. It is seen that the carbon level is at the lower limit of the desired target. The mg residual is too high for DPI2-7 while it is at the target for DPI2-8. This is rather surprising since DPI2-7 contained less alloy addition.

Table 14 Chemistry of 3rd DPI2 heat

Sample	%C [Leco]	%Si	%Mg	%Mn
Target	3.3-3.8	2.2-2.8 base melt	0.04 - residual	
DPI2-7 top	3.29	3.38	0.096	0.074
DPI2-7 bottom	3.27	3.49	0.066	0.079
DPI2-8 top	3.33	3.28	0.039	0.079
DPI2-8 bottom	3.32	3.20	0.037	0.079

In addition to the spectrometer samples, DPI2-7 and DPI2-8 were sectioned at the ingate to asses if any treated metal was present at the ingates. For DPI2-7 an additional section was cut as illustrated in Fig. 39.
The spectrometer results are given in Table 15. The data given are the low and high values from three sparks per sample.

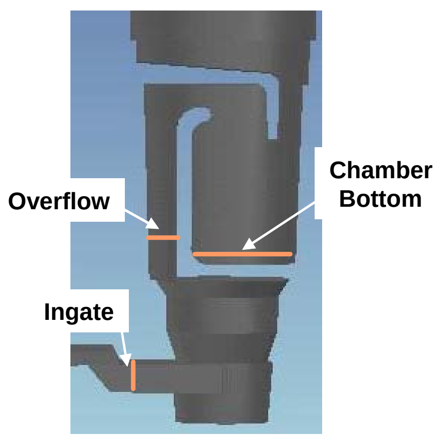


Fig. 39 Cut lines for spectrometer readings for DPI2-7.

It is seen that for DPI2-7 at the chamber bottom the Si level is that of the base melt. Additionally the Mg level is very low, both levels indicating a complete consumption of the alloying elements. However, moving towards the overflow, the Si and Mg level both increase slightly. The ingate readings are again closer to the desired levels, even though the Mg level is short of the desired 0.04% residual. This clearly shows that the 1.2% alloy addition was completely consumed by the end of the pour and that the amount was not sufficient to produce the desired 0.04% residual Mg in the ingate.
For DPI2-8 the ingate readings showed a very high Mg level, which was unexpected.

Table 15 Spectrometer results on selected areas in DPI2-7 and DPI2-8.

Sample	%Si	%Mg	%Mn
DPI2-7 chamber bottom	2.37-2.83	0.00244-0.0141	0.0592-0.0671
DPI2-7 overflow	2.65-3.40	0.0120-0.0221	0.0526-0.0597
DPI2-7 ingate	3.88-4.09	0.0251-0.0281	0.0512-0.0525
DPI2-8 ingate	3.91-4.2	0.0793-0.110	0.0424-0.0460

Microstructures

DPI2-7

The overall microstructure is ductile with only a small area of flake present in the lower part of the inlet area of the Y-block. An etched micrograph is shown in Fig. 40.

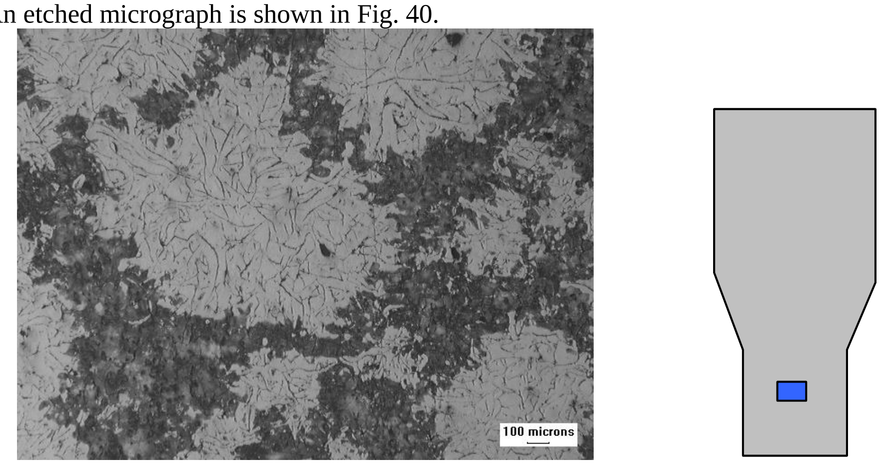


Fig. 40 Presence of Flake graphite in the lower part of the inlet area (blue area in schematic).

DPI2-8

As in DPI2-7 the overall microstructure was spheroidal. Only a small area showed some compacted graphite, Fig. 41 and Fig. 42.

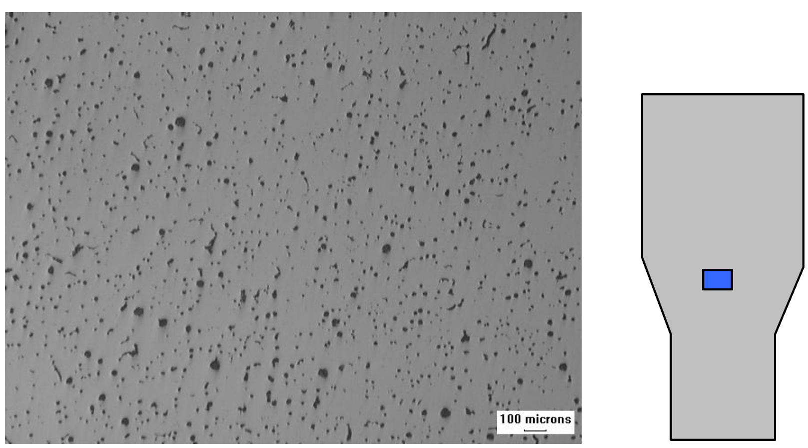


Fig. 41 Mid section of the inlet area (blue area in schematic)

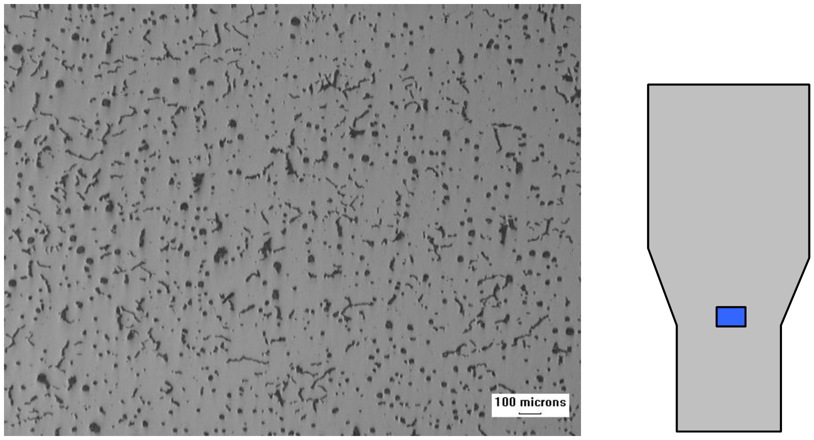


Fig. 42 Lower section of the inlet area (blue area in schematic)

Interestingly, for all investigated samples, the lower part of the Y-block area contained either grey or compacted, depending on the level of additions. Reviewing the filling pattern of the simulations, no clear indication could be obtained to explain this effect. However, it seems that is has to be an area which receives the most recently treated metal to show this effect.

Combining the findings of the spectrometer analysis and the microstructures, it can be concluded that the necessary amount for completely treat the metal for spheroidal iron has to be more than 1.2% and less than 1.4%. In addition, the tampering of the alloy additions into the bottom of the chamber provided for a better treatment. Therefore it is planned to use one mold with a 1.3% addition to fine tune the process for ductile iron.

4th heat

The fourth DPI2 heat was conducted on November 2nd 2005. A total of three molds were produced. The first two were used to fine tune the alloying amounts for the ductile iron series, based on the findings of the third heat. The third mold was the first attempt to use the DPI2 container to produce compacted graphite iron (CGI).

Changes in alloy addition

The alloy additions were changed to 1.3% and 1.35% for DPI2-9 and DPI2-10. The third mold was the first of the CGI trials, indicated by the letter A, Table 16.

Table 16 Alloy additions for the 4th heat

Mold	Alloy addition [%]	Alloy addition [g]
DPI2 – 9	1.3	254.1
DPI2 – 10	1.35	263.86
DPI2 - **A**		200 g IM4, 60 g Fe-Si 75

The chemistry of the spectrometer samples is given in Table 18 .

Pouring performance

The first casting was poured from a preheated 100lbs ladle. Because the temperature was at the lower end of the desired temperature range, the metal was transferred back into the furnace and reheated. The second and third mold was poured from the same ladle. Besides the stronger reaction and subsequent slow down in filling rate of DPI2-10, no problems were observed with the three molds. All bottom and top inserts remained in place and appeared undamaged, Fig. 43. This is supported by the container shape after shake-out, Fig. 46.

Table 17 Pouring temperatures of the 4th DPI2

Mold	Pouring temperature	Note
Target	1455-1475 ºC	
DPI2 – 9	1459 ºC	
DPI2 – 10	1481 ºC	Visible reaction in the opening of the top insert.
DPI2 - **A**	1457 ºC	

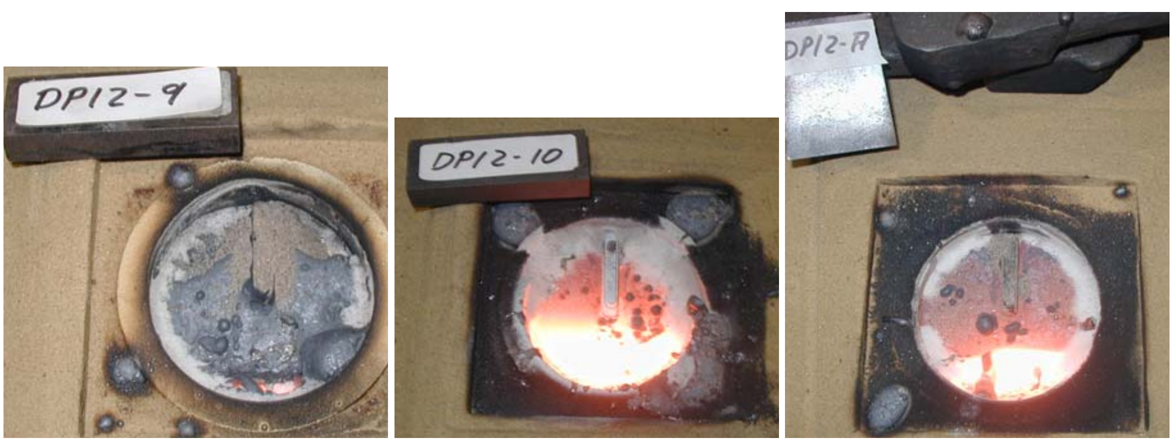


Fig. 43 View of the top inserts after pouring. All inserts retained their shape.

Castings after shake-out

The castings were allowed to cool overnight and were cleaned the next morning. The castings filled completely. DPI2-9 showed a cold metal fold in the 4mm plate while DPI2-10 showed a cold shut in the 2mm plate. DPI2-A did not show any defects, Fig. 44 and Fig. 45.

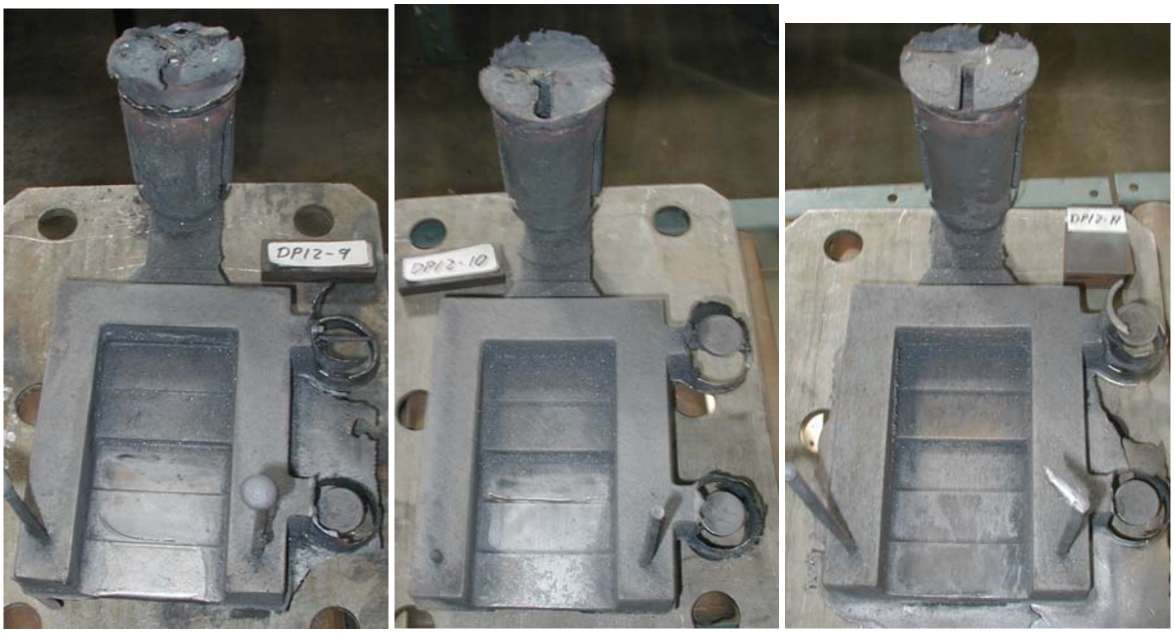


Fig. 44 View of the castings after shake out. LeftDPI2-9, middle DPI2-10, right DPI2-A. Note the shape of the metal on top of the top insert, especially the opening created by the handle piece.

Fig. 45 Detail of the plates of #9 and #10.

Fig. 46 Side view of the containers of the 4th heat. All inserts performed as planned.

The chemistry analysis of the 4th heat is given in Table 18. It is seen that the carbon level is at the lower limit of the target value. The Si level is consistently higher for the bottom spec sample, indicating that the alloying addition and reaction does indeed diminish some during the filling. The residual Mg level is above the target value, but it indicates complete treatment of the metal. The analysis of the container spectrometer data shows that indeed treatment alloy was still present. However, for the ductile treatment, the ingate values are very low, indicating that some incompletely treated metal could have entered the casting cavity.

Table 18 Chemistry of 4th DPI2 heat

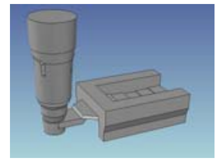
Sample	%C [Leco]	%Si	%Mg	%Mn
Target	3.3-3.8	2.2-2.8 base melt	0.04 - residual	
DPI2-9 top	3.25	3.38	0.067	0.066
DPI2-9 bottom	3.23	3.65	0.076	0.066
DPI2-10 top	3.23	3.38	0.046	0.063
DPI2-10 bottom	3.22	3.50	0.061	0.065
DPI2-**A** top	3.24	3.57	0.053	0.064
DPI2-**A** bottom	3.24	3.61	0.054	0.061

Table 19 Max. and Min. Spectrometer data of the ingates and the chamber bottom of the 4th heat.

Sample	%Si	%Mg	%Mn
DPI2-9 chamber bottom	~4.20	0.0330 - 0.0453	0.0446 - 0.0493
DPI2-9 ingate	2.32 - 2.43	0.00524 - 0.00768	0.0483 - 0.0526
DPI2-10 chamber bottom	3.11 - 4.2	0.0176 - 0.0402	0.0412 - 0.0458
DPI2-10 ingate	2.46 - 2.53	0.0183 - 0.0276	0.0490 - 0.0530
DPI2-A chamber bottom	2.94 - 3.37	0.0185 - 0.0206	0.0436 - 0.0469
DPI2-A ingate	2.67 - 3.07	0.0231 - 0.0359	0.0426 - 0.0461

Microstructures

The microstructures of DPI2-9 and DPI2-10 were ductile. As with previous microstructures, a small area at the ingate side of the section showed a consistent pattern of small areas of grey, which is discussed here Investigation of the presence of the flake graphite domains.



The microstructure of DPI2-A, the first attempt at compacted graphite iron, has been investigated in more detail. Fig. 47 shows the areas of which microstructures were obtained. The end section is predominately ductile, while the ingate section is mostly compacted. The complete set of micrographs is given in Appendix - DPI2-A CGI casting microstructures-end section and Appendix - DPI2-A CGI casting microstructures-ingate section.

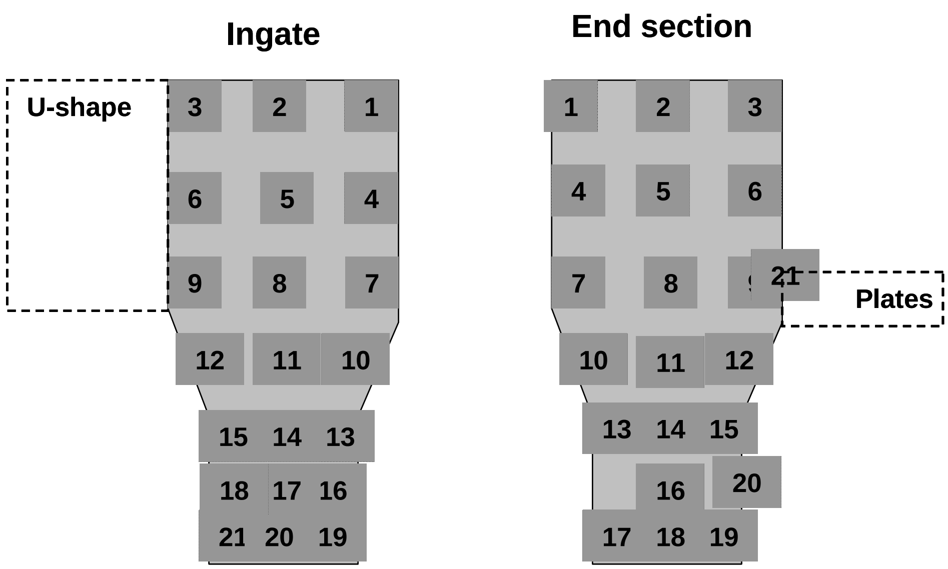


Fig. 47 Areas of the DPI2-A casting for microstructures.

In addition to the overview pictures, a small series of micrographs were taken to the right side of image 15 of the Ingate section. It clearly shows the area of untreated metal entering the side wall of the sample. This particular pattern has been observed in the previous ductile trials and is believed to be a peculiar phenomenon of the casting design. No satisfactory explanation has yet been given as to why this area is repeatedly present, even though the presence of sufficient treatment alloy in the chamber has been established.

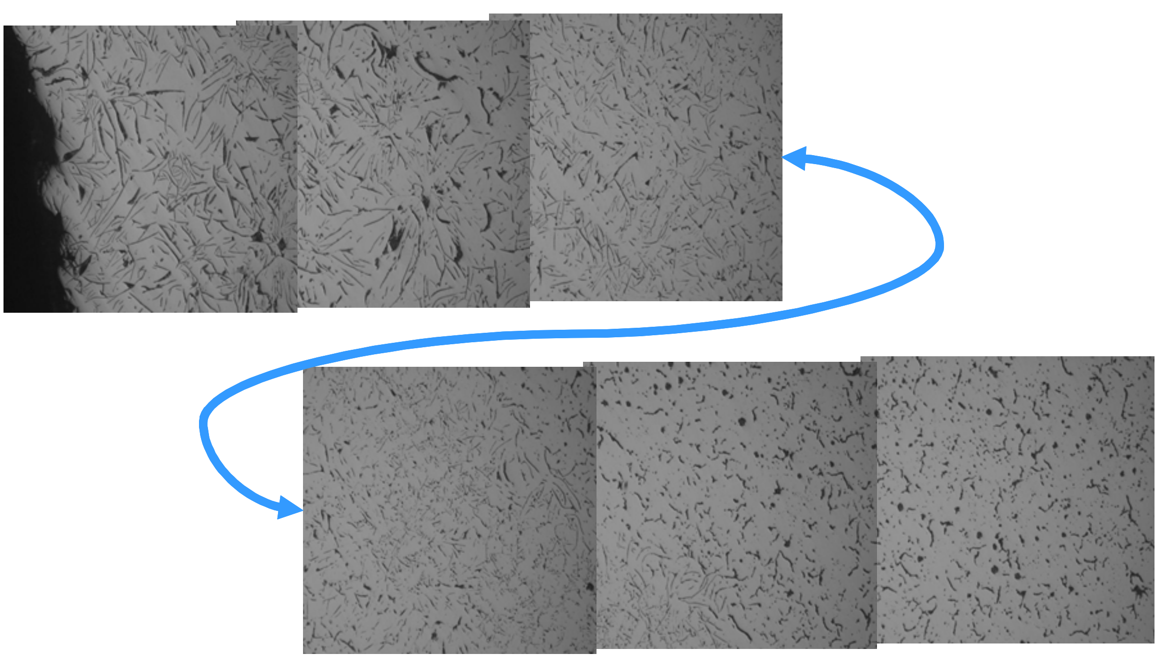


Fig. 48 Composite image of the transitional area at the ingate. Magnification is 100x.

5th heat

Changes in container production

No changes were made to the container. However, since the initial batch of sleeves was exhausted, two more sleeves were fabricated with the GFN 47 sand as was used for the inserts and the mold.

Changes in alloy addition

After characterization of the first CGI mold, it was decided to lower the amount of the IM 4 treatment addition, while maintaining the overall amount of addition, Table 20.

Table 20 Alloy addition for 5th heat

Mold	Amount IM4 [g]	Amount FeSi75 [g]
DPI2-B	180	80
DPI2-C	160	100
DPI2-D	140	120

Changes in molding

In an attempt to reduce the chilling tendency of the thin plates, all three molds were coated with Velvacoat (Ashland Chemicals), Fig. 49. Only the 2, 4 and 6mm plates were coated. The coating was applied with a soft brush and allowed to dry. Any uneven surfaces caused by the brush were smoothed over by gently rubbing over the coated surface.

Fig. 49 Coated cope (left) and drag (right) of molds for the 5th heat.

Pouring performance

The pouring was steady and a good fill rate could be established. The pour was captured on tape and has been converted to an .avi format. The pouring temperatures are given in Table 21 and the chemistry is given in Table 22. The residual Mg content appears too high to have only CGI present in the casting. The C and Si levels were within range.

Table 21 Pouring temperature for 5th heat

Mold	Pouring temp [ºC]	Note
DPI2-B	1464	
DPI2-C	1448	No metal up through the vents
DPI2-D	1460	

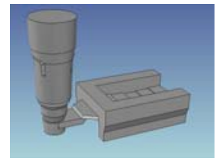



Table 22 Chemistry of 5th DPI2 heat from the spectrometer inserts

Sample	%C [Leco]	%Si	%Mg	%Mn
Target	3.3-3.8	2.2-2.8 base melt	0.01 – 0.02 residual	
Final				
DPI2-**B** top	3.39	3.87	0.042	0.065
DPI2-**B** bottom	3.37	4.03	0.044	0.066
DPI2-**C** top	3.40	4.35	0.063	0.065
DPI2-**C** bottom	3.37	4.38	0.059	0.063
DPI2-**D** top	n/a	4.08	0.054	0.064
DPI2-**D** bottom	3.36	4.18	0.056	0.064

The analysis of the container elements previously identified shows that the Mg residual in the chamber bottom is nearly complete, even though the range of spectrometer data indicates that a good mixing was not established for DPI2-B and DPI2-C. The last casting DPI2-D showed the least amount of Mg variation, even though all containers were identical and were filled the same way.

Table 23 Max. and Min. Spectrometer data of the ingates and the chamber bottom of the 5th heat.

Sample	%Si	%Mg	%Mn
DPI2-**B** chamber bottom	2.70-3.33	0.0001-0.0141	0.0437-0.0844
DPI2-**B** ingate	3.49->4.2	0.0131-0.0232	0.0379-0.0441
DPI2-**C** chamber bottom	2.76->4.2	0.0040-0.0202	0.0440-0.0512
DPI2-**C** ingate	>4.2	0.0333-0.0445	0.0401-0.0408
DPI2-**D** chamber bottom	3.22-3.90	0.0137-0.0275	0.0397-0.0467
DPI2-**D** ingate	> 4.2	0.0569-0.0990	0.0438-0.0573

Castings after shake-out

All three castings filled completely, even though DPI2-C did not show metal emerging from the vents. It turned out that the vents were partially filled. The castings after shake out and a close up of the plates are given in Fig. 50, Fig. 51, and Fig. 52.

DPI2-B showed a cold shut in the 2, 4 and 6mm plate, indicating the filling pattern of the casting. Apparently the coating was not sufficient to prevent the cool down for the pouring temperature of 1464ºC. Surprisingly, the temperature defect is much reduced for DPI2-C, which was poured at a lower temperature. This casting shows only a small defect in the 2mm plate, running across the long side of the plate.

DPI2-D did not exhibit any surface defects, even though the pouring temperature was again lower than the first casting. All three castings benefited from the core wash in the appearance of the thin plates.

Fig. 50 Casting DPI2-B

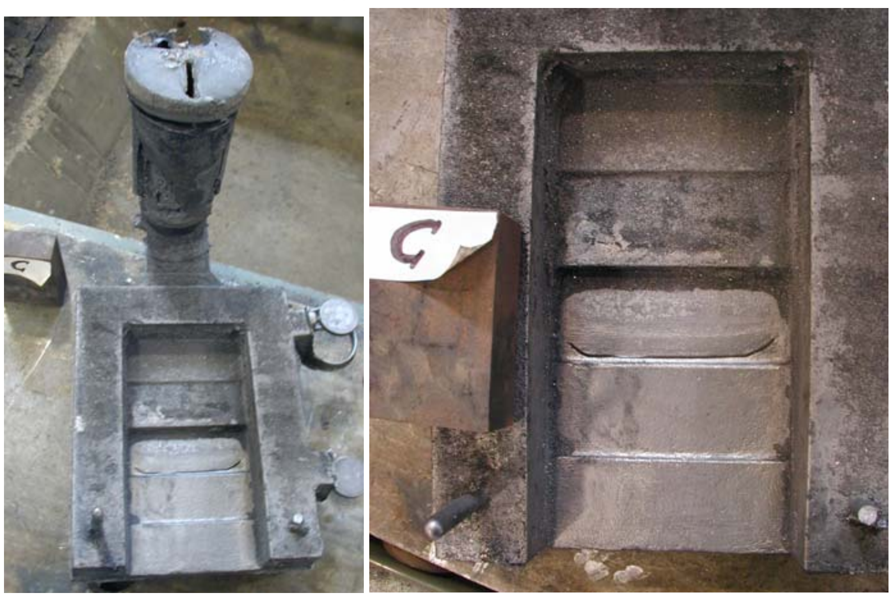


Fig. 51 Casting DPI2-C

Fig. 52 Casting DPI2-D

Microstructures

The castings have been cut in the same fashion as the previous castings (see Fig. 24 and Fig. 39.) All segments have been polished and the microstructures are given in the appendices
Appendix - DPI2-B CGI casting microstructures-ingate section
Appendix - DPI2-B CGI casting microstructures-end section
Appendix - DPI2-C CGI casting microstructures-ingate section
Appendix - DPI2-C CGI casting microstructures-end section
Appendix - DPI2-D CGI casting microstructures-ingate section
Appendix - DPI2-D CGI casting microstructures-end section
They show a significant amount of spheroidal graphite shapes with more compacted towards the container side. However, some flake graphite domains are present in the casting at the bottom area of the Y-block section. See the chapter Investigation of the presence of the flake graphite domains for a thorough investigation of these observations.

6^th heat

A total of three molds were produced and poured. Two molds were of the standard DPI2 pattern with CGI alloy additions, while the third was a modified step pattern. This was to demonstrate the usefulness of the DPI container with DI treatment on a different casting design as previously produced, Fig. 53. The casting weight was assumed to be comparable to the DPI2 test casting.

Fig. 53 Picture of the step casting before assembly.

Changes in container production

No changes were implemented with the DPI containers.

Changes in alloy addition

The furnace charge consisted of 50 lbs pig iron, 100 lbs internal returns and 50 lbs DI returns from Citation Marion. The alloy additions are given in Table 24.

Table 24 Alloy additions for the 6^th heat

Mold	Amount IM4 [g]	Amount IM6 [g]	Amount FeSi75 [g]
DPI2-E	200	-	60
DPI2-F	160	-	80
DPI2-G	-	235	

Changes in molding

DPI2-G was the modified step pattern. To check the chemistry, the pattern was equipped with two spectrometer sample cups. The placement cavities for the inserts were hand drilled into the resin-bonded mold, as was the ingate.

Pouring performance

The standard method of 100 lbs ladle pouring was used. No video recordings were done. The pouring temperatures are given in . The amount of residual Mg seems very high and is not supported by the additions to the alloying chamber. Microstructure analysis has to used to confirm these levels.

Table 25. The chemical analysis from the spectrometer inserts is given in Table 26. The amount of residual Mg seems very high and is not supported by the additions to the alloying chamber. Microstructure analysis has to used to confirm these levels.

Table 25 Pouring temperatures for 6th heat

Mold	Pouring temp [ºC]	Note
DPI2-E	1471	Small run out on opposite side of container, casting filled completely
DPI2-F	1491	Run out after complete filling, casting appears to be sound
DPI2-G	1462	Good reaction, after 1 to 2 minutes, side wall of the cope busted and emptied the casting, cope was containing the pattern, spec samples are good.

Table 26 Chemistry of 6th DPI2 heat from the spectrometer inserts

Sample	%C [Leco] *	%Si	%Mg	%Mn
Target	3.3-3.8	2.2-2.8 base melt	0.01 – 0.02 residual	
Final				
DPI2-**E** top	-	3.99	0.063	0.117
DPI2-**E** bottom	-	4.00	0.054	0.121
DPI2-**F** top	-	3.67	0.044	0.112
DPI2-**F** bottom	-	4.01	0.043	0.114
DPI2-**G** top	-	3.50	0.069	0.115
DPI2-**G** bottom	-	4.15	0.098	0.114

** The Leco carbon analyzer that was used in this study was not available for these samples, because of technical problems.*

Castings after shake-out

During pouring, run outs were observed with the DPI2-E and F castings. After shake-out it was observed that the casting did indeed fill completely. This indicates that it was the metallostatic pressure that eventually forced the liquid metal out. All spectrometer samples were filled, Fig. 54. The castings did not show any grave defects in the plate area. The only notable casting defect was veining on the inside of the U-shape, as clearly visible in Fig. 54. Sand being chafed off during assembly of the mold halves is considered to be the main reason for the presence of the flash and subsequent partial run-out.

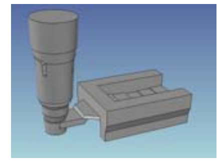


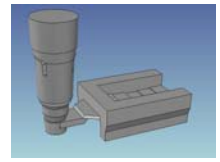
Fig. 54 Castings DPI2-E and DPI2-F after shake-out.

The step casting DPI2-G was molded in resin bonded sand as were all other test castings. In order to incorporate the spectrometer inserts and the DPI container, the flask space became a concern. Therefore the spectrometer sample receiving the later treated metal was located on the backside of the casting, Fig. 55. The DPI container was situated to the side of the casting. After complete filling, one side wall gave under the metallostatic pressure in conjunction with the weakening of the sand by thermal exposure. This led to the emptying of the casting on the grated floor. However, filling was achieved as demonstrated by the filled spectrometer samples. Only the two upper steps were affected by the run out. The thinnest step filled only partially, which is in accordance to the observations of the first DPI step casting. Because the openings for the spectrometer samples were hand carved, excess metal is seen at both positions.

Fig. 55 Casting DPI2-G after shake-out.

Microstructures

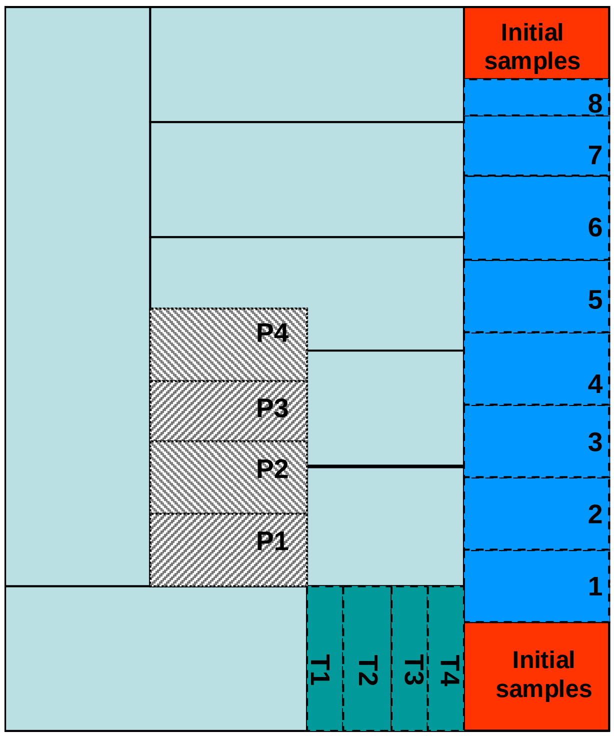
Pending.



Investigation of the presence of the flake graphite domains

The continuous presence of flake graphite domains in the DPI2 test castings presents a problem for the evaluation of the effectiveness of the DPI treatment. While some samples of the long side of the U-shape have been found without flake graphite, most samples close to the ingate contain flake graphite domains, especially in the lower section of the Y-block cross section.

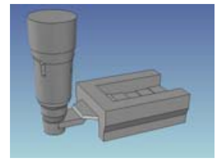
The CGI casting DPI2-B casting has been selected to study the extent of these flake graphite domains. Fig. 56 shows the areas which have been sectioned. Numbered 1 through 8 are the slices of the long side section, T1 through T4 are the lower section of the U-shape, and P1 through P4 are sections of the 10, 8 and 2 mm plates. The areas labeled "initial samples" refer to the segments used for the microstructure evaluation as given in Appendix - DPI2-B CGI casting microstructures-ingate section and Appendix - DPI2-B CGI casting microstructures-end section.



Section of DPI2-B

Fig. 56 Schematic of the sectioned areas of the casting DPI2-B The ingate is located at the title below the schematic.

The row of cut samples 1 through 8 was evaluated by optical means. That is to say, the grey iron areas are visually distinct from the ductile/compacted areas by their more lustrous appearance. Using this distinction, the extent of the flake graphite was measured. Fig. 57 shows the areas of flake graphite in the lower part of the cross section. It is apparent that the domain reaches across the entire length. Even though, towards the end the domain starts to shrink, but is still centrally situated. With the exception of number 1, no flake graphite domain was observed at the side. This indicates that the grey iron had to flow from the ingate across the bottom of the lower part of the U-shape and then flow downwards into the Y-block area of the casting towards the upper side of the U-shape.



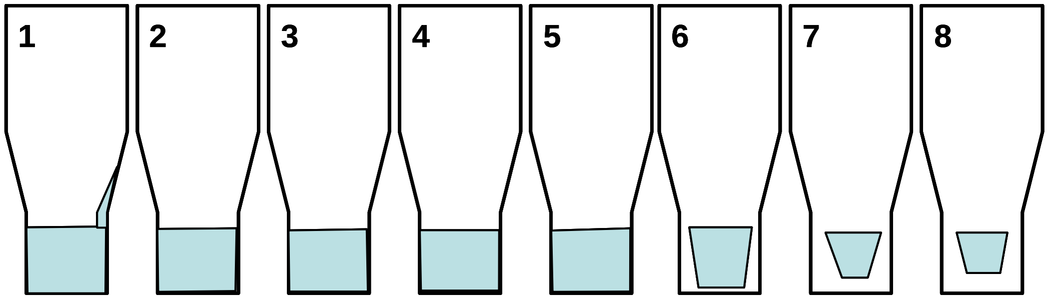


Fig. 57 Schematic of the flake graphite domain in the long leg of the U-shape.

From the initial sample close to the ingate in DPI2-B it was confirmed that the side area of a grey iron domain exists, as shown in No.1 of Fig. 57. In the following section, No.2 through 8, no such side areas were observed. This leads to the suggestion that the grey iron domains are created during the initial filling by untreated or insufficiently treated metal. Following the grey iron domain through the leg of the casting, it is observed that up to No 5 no change in size is observed. Towards the end of the leg, the domain is seen tapering into a smaller area, consistent with increased filling from the top as well as from initial metal splashing back from the back wall.

Microstructure analysis of the samples T1 through T4 showed a thin layer of grey iron at the bottom of the cross section, again an indication of the initial presence of insufficiently treated metal entering the casting. A schematic is given in Fig. 58. *Ingate* denotes the area where the metal entered the casting while plate *refers* to the adjacent 10mm plate. It is seen that the amount of grey iron on the cross section is larger towards the side of the U-shape, which is initially surprising. The simulation results have shown that the initial liquid flows across the flat part adjacent to the ingate and only when the flow gets obstructed by the thin plates, does the liquid back fill. At the same time some amount of liquid flows down into the Y-block section near the ingate. See Appendix - Filling sequence of simulation 050720 for a sequence from the simulation video.

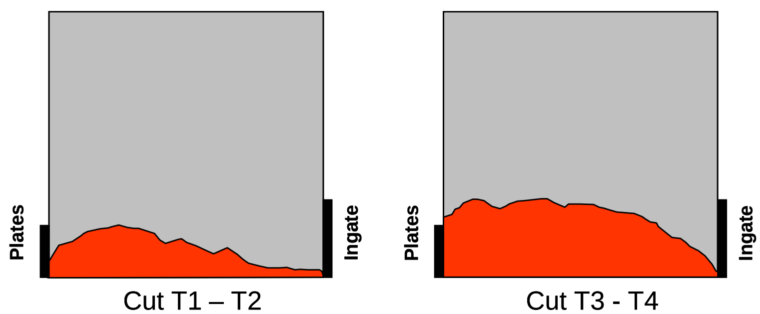


Fig. 58 Schematic of T sample cross section of Fig. 56.

Comparing the evidence of the microstructure with the simulation results, it is very difficult o come to a unified conclusion of when and where the metal is coming from.

Assuming it originates from the beginning of mold filling by untreated metal, which is supported by the thin layer flowing down the side of the Y-block section and the continuous presence in the lower part of the Y-block, one has to wonder why it tapers down towards the end of the long side of the U-shape. Clearly the filling stems from the ingate side of the long section. It further is puzzling that the layer at the ingate is so thick, which is contradicting this assumption, since it is almost as thick as the ingate itself. As for why it tapers, the simulation clearly shows the back washing and thus an increase in turbulence, which could account for the tapering. Why then is the lower section not disturbed further as seen by the liquid being diverted when encountering the thinner plates in the middle of the plate section of the casting, leading to turbulence in the middle section of the Y-block?

Assuming the grey iron originates towards the end of the filling by depleting the alloying additions, its presence at the bottom of the Y-block is not explained. Only the presence at the ingate can account for that.

However, it could be possible that a combination of both factors is at play. But to this end the spectrometer data do not support this as the residual Mg levels of the DPI2-B ingate are between 0.01 and 0.02.

Further investigations of other castings seem to be in order to be able to unequivocally determine the source of the grey iron.

Conclusions

The DPI Phase 2 project was aimed at bridging the gap between the proof of concept stage and the technology being applicable and useable in a foundry environment. To this end the container has been redesigned and in doing so, reduced the number of pieces from 7 - 8 to 3. All pieces can be mass produced using standard corebox technology. The resin amount needs to be above 1.2% to assure a hard core and eliminate the danger of sand removal. The improved cores did perform well during the pouring operation, holding their shape until the casting was filled and the metal started to solidify.

The design of the new container was supported by computer simulation with the software package NovaCast. It allowed for the virtual testing of a variety of parameters to minimize the filling time, while at the same time obtaining sound castings.

The test casting was also redesigned to eliminate some of the problems encountered during Phase 1of this project. In addition, the casting was designed to demonstrate thin wall capabilities and deliver sound samples for mechanical testing.

The treatment for ductile iron was done with IM-6 alloy addition. It was found that an addition level of 1.3% or 255±5g is sufficient to produce ductile iron. The attempt to produce compacted graphite iron was more troublesome. It as found that in numerous castings flake graphite domains persisted, whose origin has yet to be completely understood. CGI has by nature a very tight processing window and to sustain the exact amount of treatment during the pouring operation is a challenging task indeed.

Appendix – simulation results

050617-container 075

Full scale simulation, no symmetry shortcut, new design, fill area 0.75 in diameter
DPInew_fillarea075_050617.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.620**	**7.310**	
Along Z	**11.895**	**6.12**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 846 949**
Size cell	**0.081 in**	**Casting cells**	**286 147**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**0.45 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**2.869**		

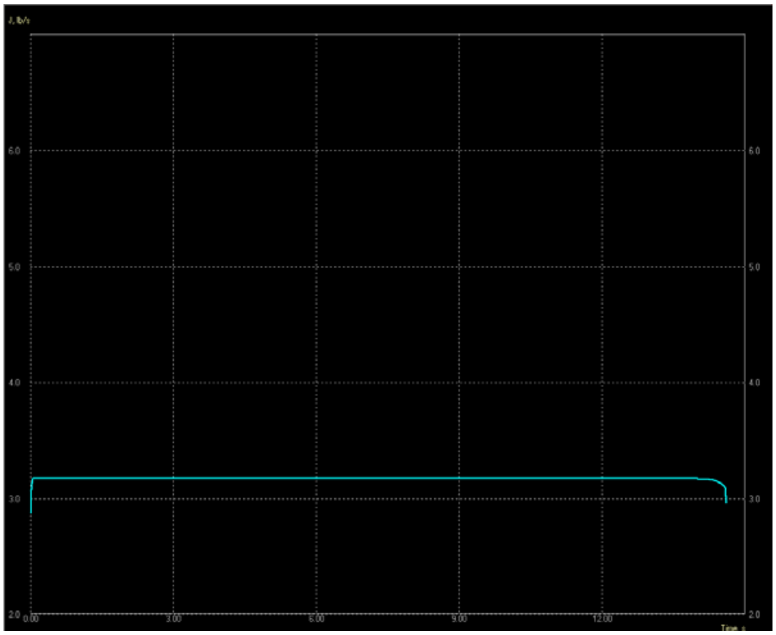
File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05 s**	**7 sensors temp, vel, press, flow**

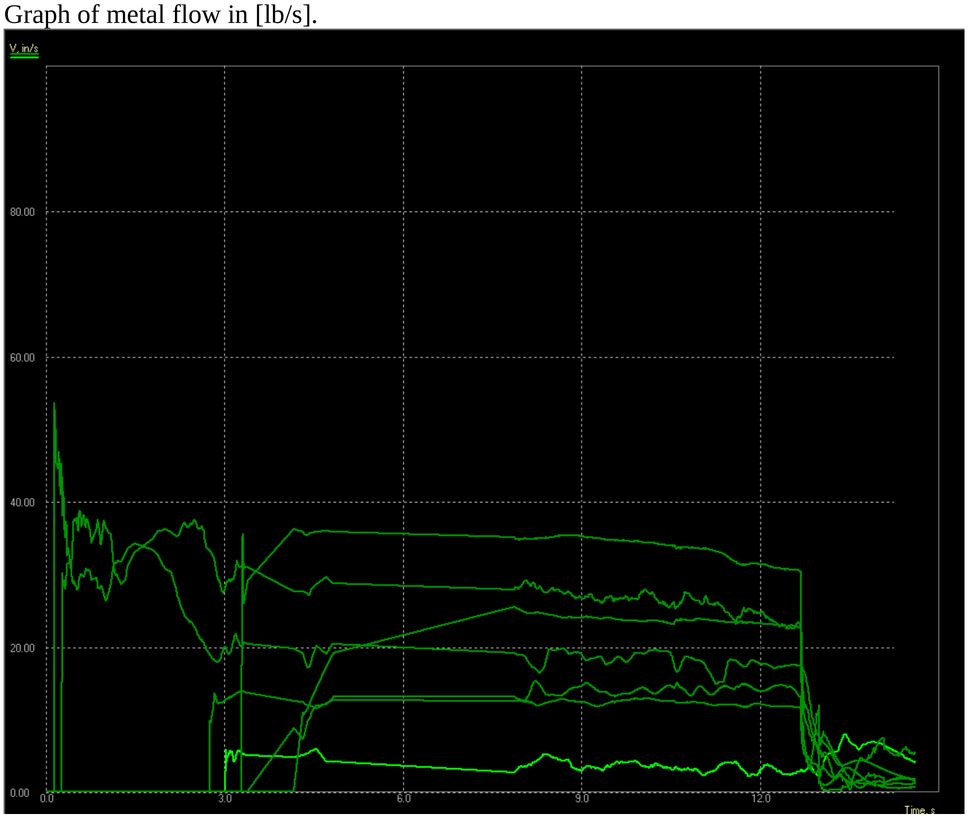
Results

Filling time	**14.604**
Sustained flow, lb/s	**3.17**
Max flow, lb/s	**3.17**

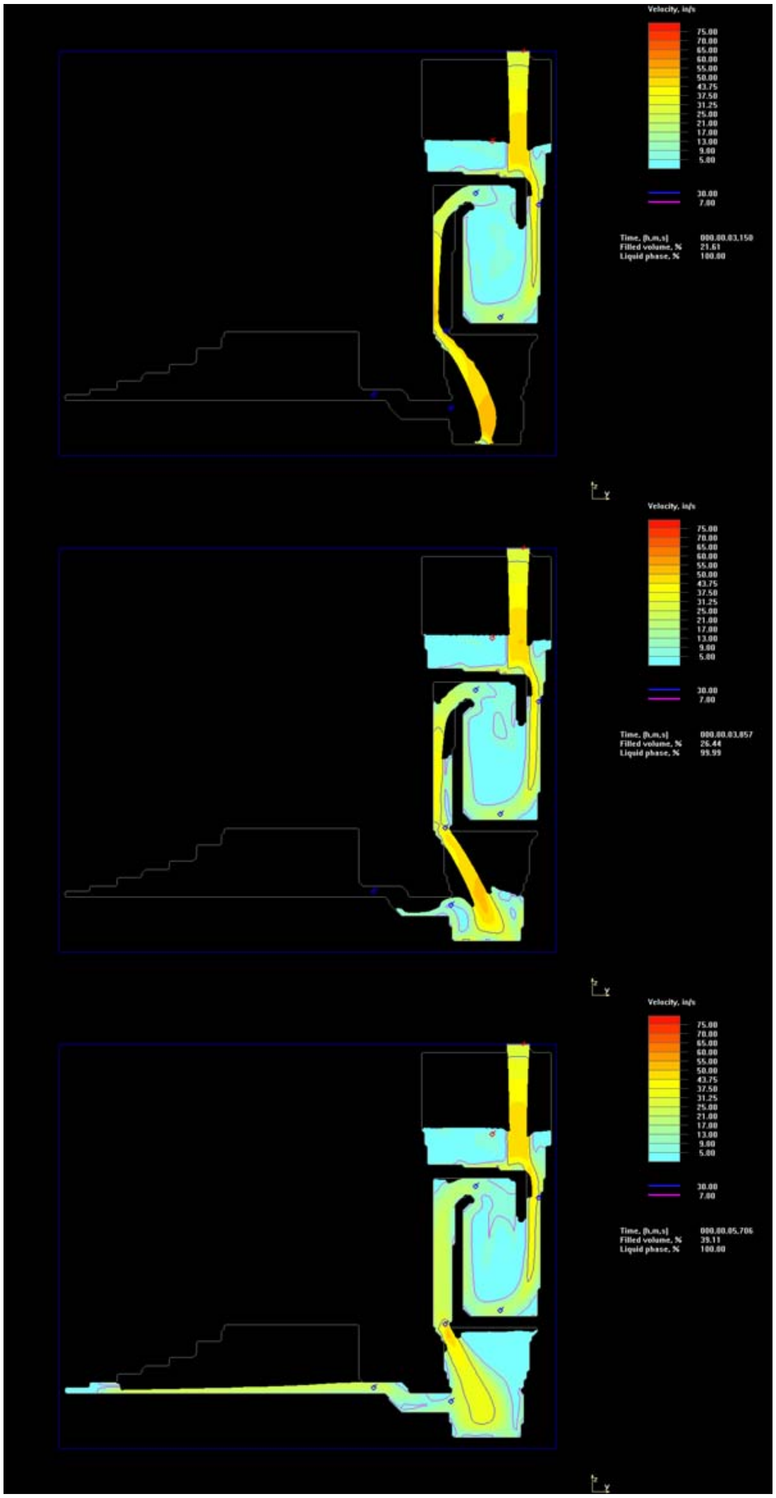
Results



Graph of metal flow in [lb/s].



Virtual sensor data of velocity in [in/s].



Screen shots of filling progress with sensor elements.

050620-container 075-opposite

Full scale simulation, no symmetry shortcut, new design, fill area 0.75in opposite
050629-container 075-opposite.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.620**	**7.310**	
Along Z	**11.895**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 846 949**
Size cell	**0.081 in**	**Casting cells**	**286 147**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**0.47 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**2.993**		

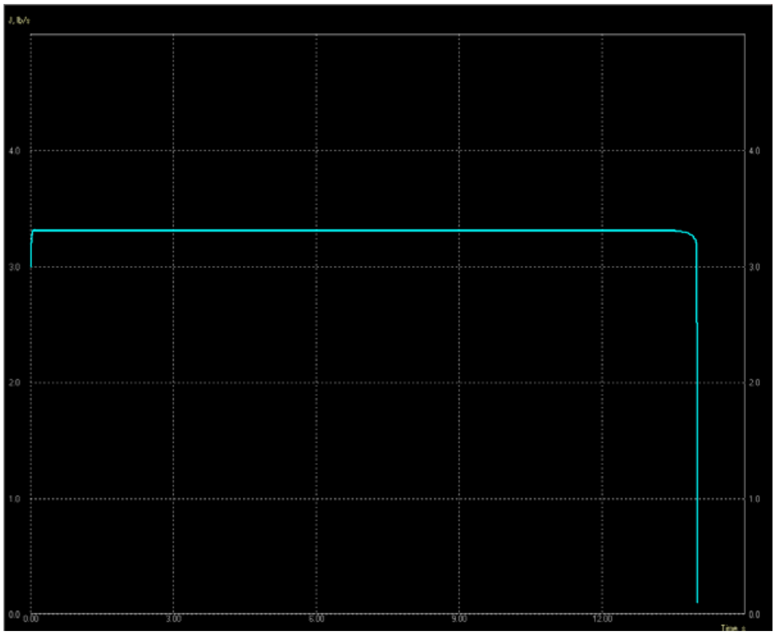
File information

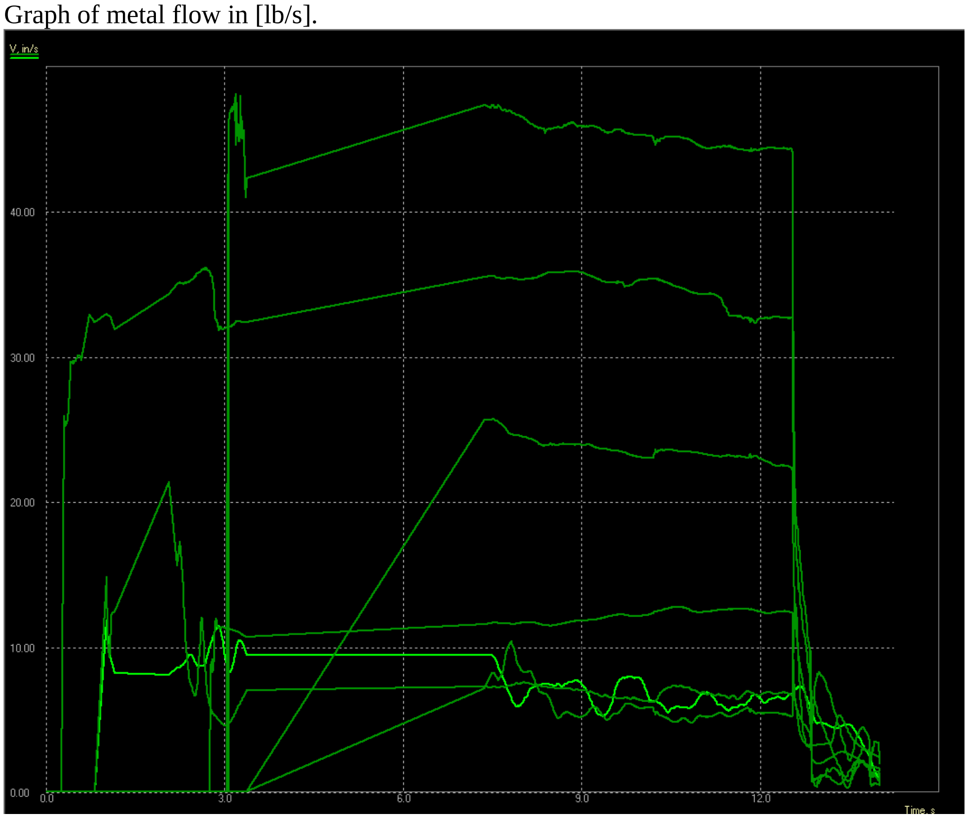
Autostop	**100% filled**	**Velocity**
Autosave	**0.05 s**	**7 sensors temp, vel, press, flow**

Results

Filling time	**13.995**
Sustained flow, lb/s	**3.30**
Max flow, lb/s	**3.30**

Results



Graph of metal flow in [lb/s].


Virtual sensor data of velocity in [in/s].

050620-container 100-center

Full scale simulation, no symmetry shortcut, new design, fill area 1.00in center
050620-container 100-center.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	Casting position	Number of cells
Along X	**8.670 in**	**4.335**	
Along Y	**14.620**	**7.310**	
Along Z	**11.895**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 846 949**
Size cell	**0.081 in**	**Casting cells**	**286 147**

Boundary conditions	Low	High
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**0.80 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**5.072**		

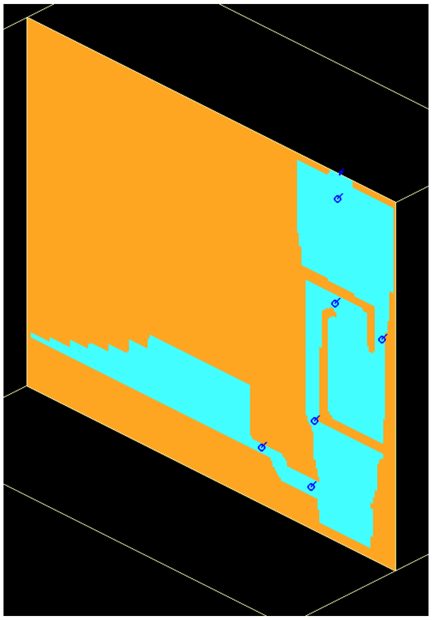
File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05 s**	**6 sensors temp, vel, press, flow**

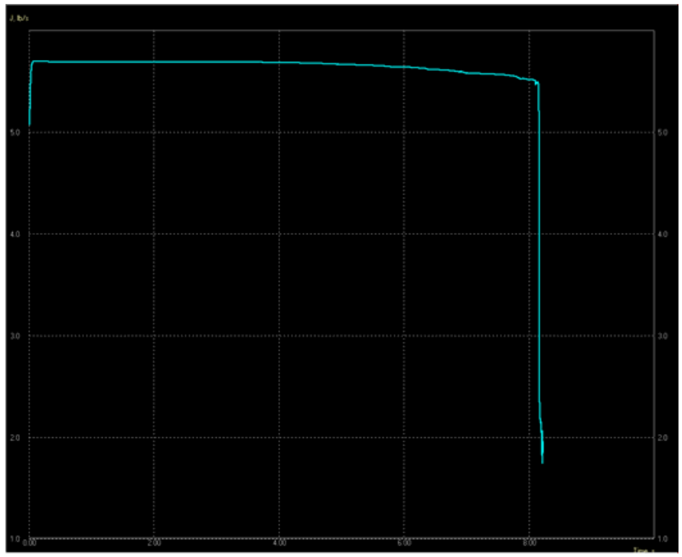
Results

Filling time	**8.230**
Sustained flow, lb/s	**5.68**
Max flow, lb/s	**5.68**

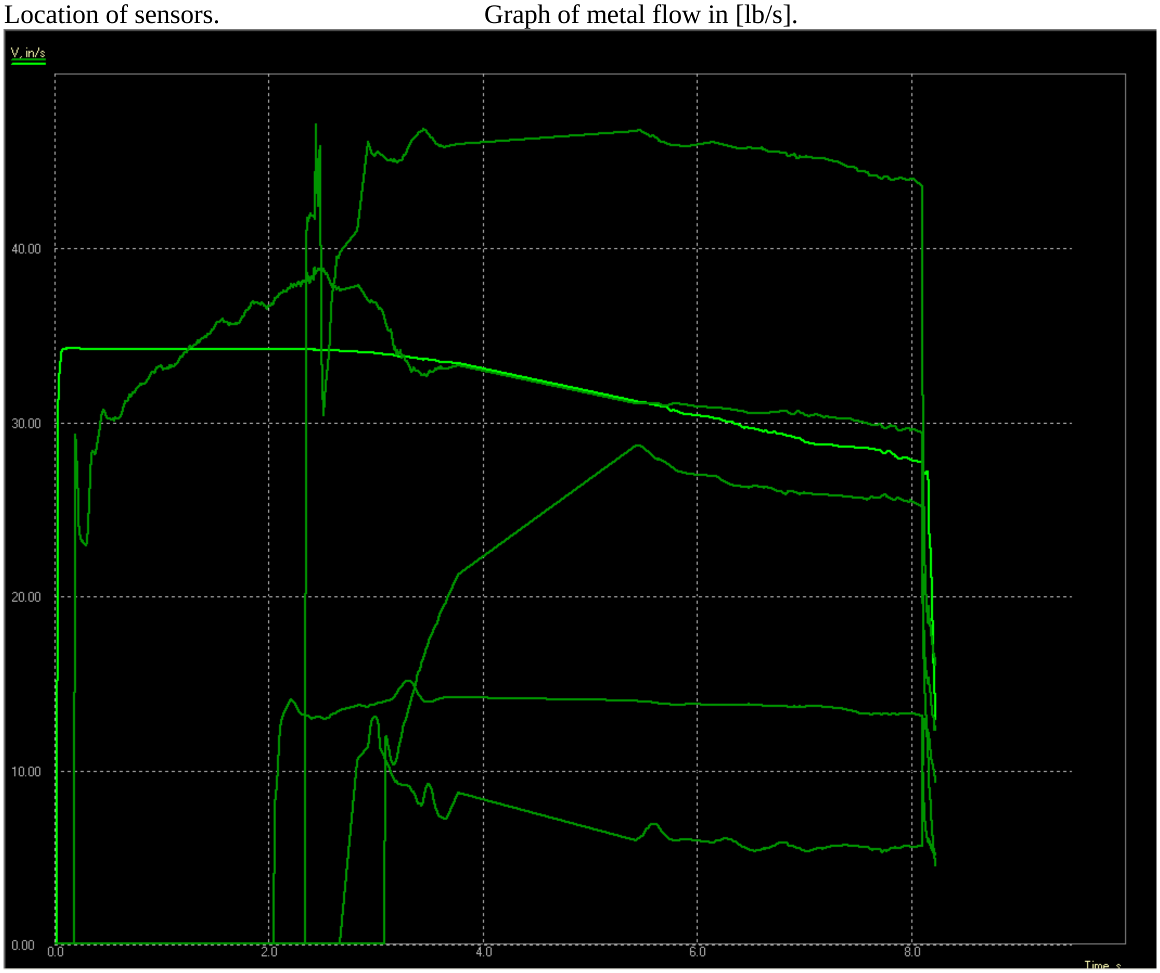
Results



Location of sensors.



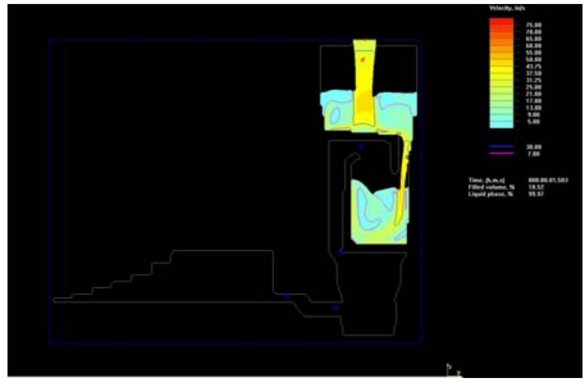
Graph of metal flow in [lb/s].



Virtual sensor data of velocity in [in/s].

Filling sequence of the new DPI container with 5lb/s filling rate

Initial filling of pouring basin

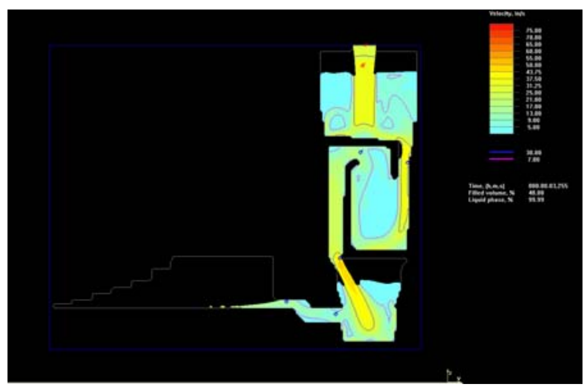


Continuous filling of reaction chamber with good metallostatic head in pouring basin

Fill of reaction chamber complete

Initial run into the container basin

Backfill of the overflow chamber, opening of lower insert acting as choke



DPI container is completely filled while casting is at beginning of filling

050621-container 100-center

Full scale simulation, no symmetry shortcut, new design, fill area 1.00in center
050620-container 100-center.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.620**	**7.310**	
Along Z	**11.895**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 846 949**
Size cell	**0.081 in**	**Casting cells**	**286 147**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**0.80 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**3.15**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**9.001**		

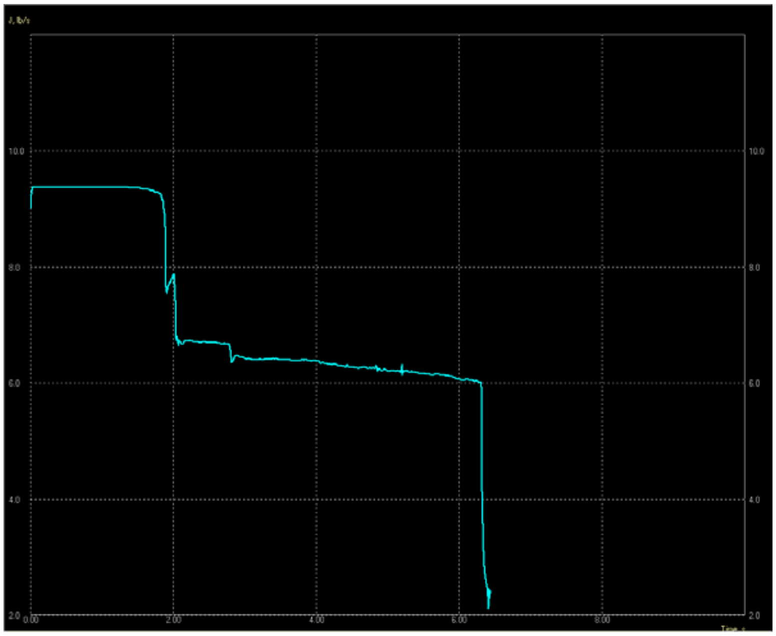
File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05 s**	**6 sensors temp, vel, press, flow**

Results

Filling time	**6.439**
Sustained flow, lb/s	**~6.25**
Max flow, lb/s	**9.37**

Results



Graph of metal flow in [lb/s].

Virtual sensor data of velocity in [in/s].

Screen shots of filling progress with sensor elements. The lines inside the liquid are iso-velocity lines, with blue denoting 30in/s and red 7 in/s.

050617new container 070-off center

Full scale simulation, no symmetry shortcut, new design, fill area center 0.70in, area located halfway between center and rim, opposite inlet

050621 new container 070.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.620**	**7.310**	
Along Z	**11.895**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 972 103**
Size cell	**0.081 in**	**Casting cells**	**286 147**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**0.40 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**4.524**		

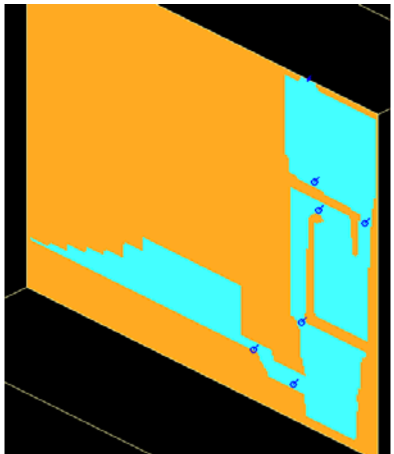
File information

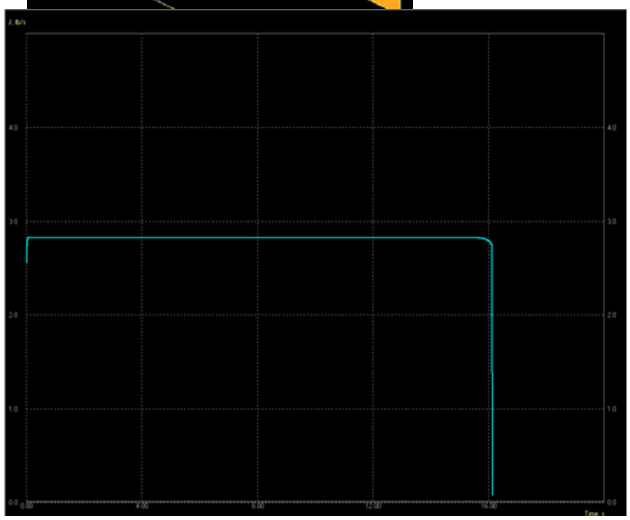
Autostop	**100% filled**	**Velocity**
Autosave	**0.05 s**	**6 sensors temp, vel, press, flow**

Results

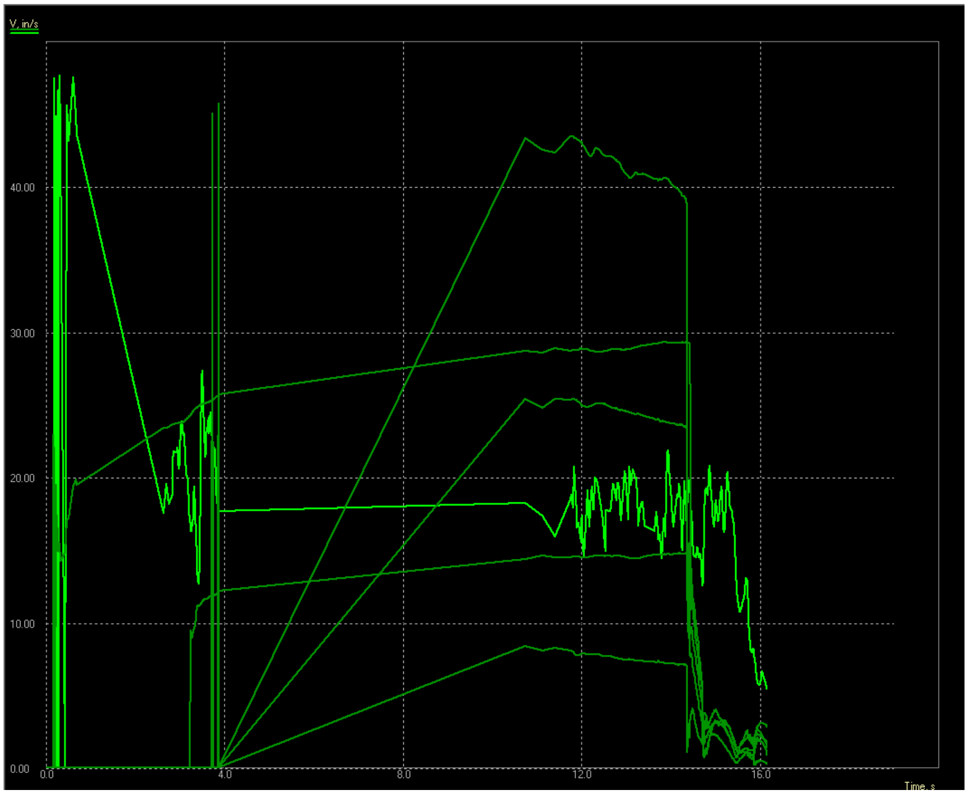
Filling time	**16.131**
Sustained flow, lb/s	**2.82**
Max flow, lb/s	**2.82**

Results





Location of sensor elements. Graph of metal flow in [lb/s].



Virtual sensor data of velocity in [in/s].

050622container 060

Full scale simulation, no symmetry shortcut, new design, fill area center 0.70in, area located halfway between center and rim, opposite inlet
050622 new container 060.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.620**	**7.310**	
Along Z	**11.895**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 846 949**
Size cell	**0.081 in**	**Casting cells**	**286 147**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**0.30 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**1.912**		

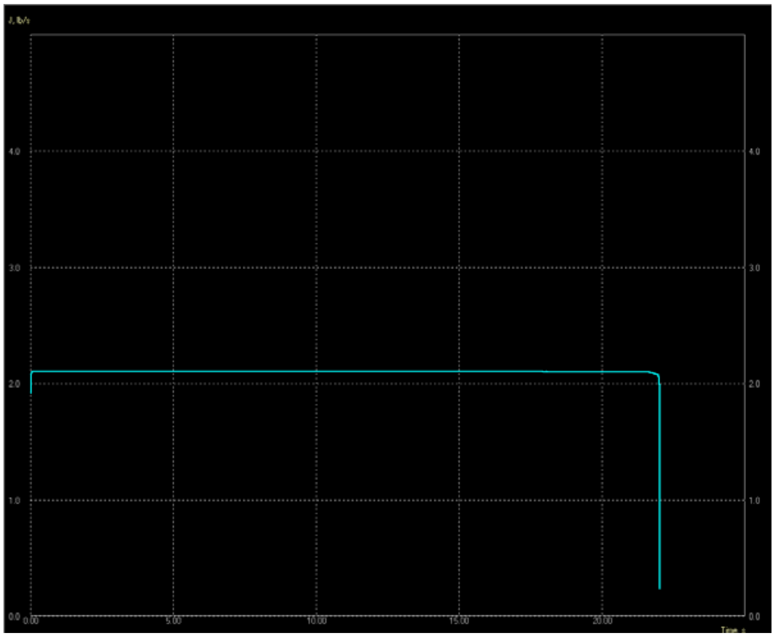
File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05 s**	**6 sensors temp, vel, press, flow**

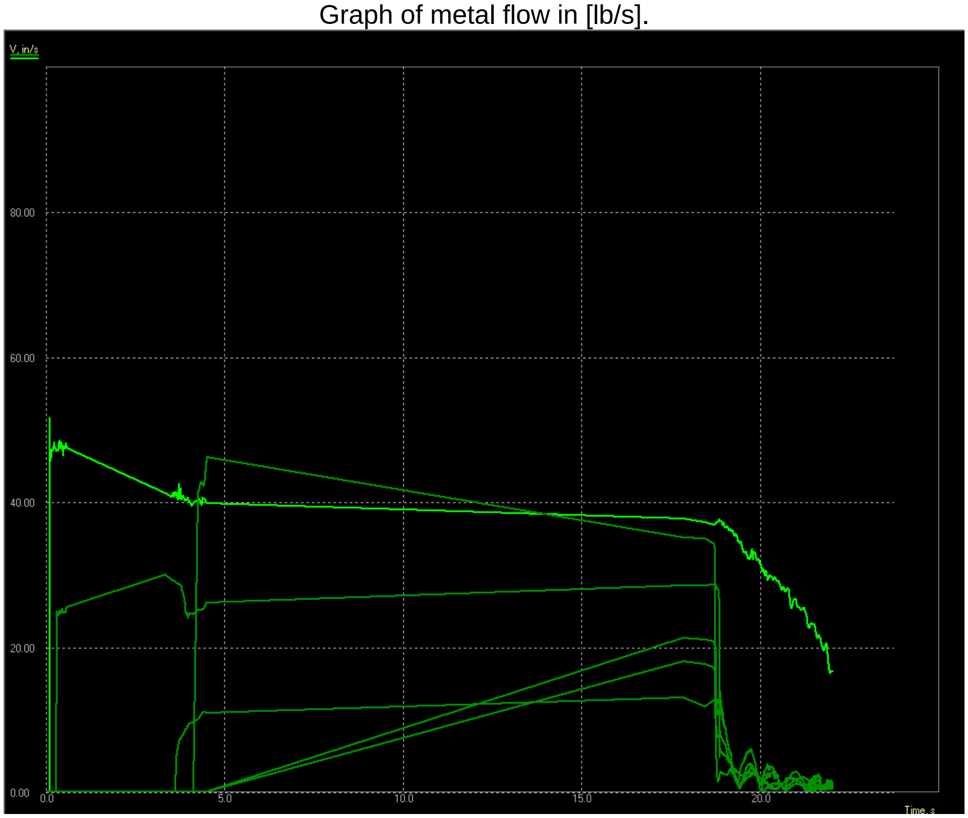
Results

Filling time	**22.011**
Sustained flow, lb/s	**2.10**
Max flow, lb/s	**2.10**

Results



Graph of metal flow in [lb/s].



Virtual sensor data of velocity in [in/s].

050623 DPInew rev4_1

Full scale simulation, no symmetry shortcut, rev4 design,

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	Casting position	Number of cells
Along X	**8.670 in**	**4.335**	
Along Y	**14.888**	**7.444**	
Along Z	**11.645**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 835 072**
Size cell	**0.081 in**	**Casting cells**	**358 224**

Boundary conditions	Low	High
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**14.58 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**92.592**		

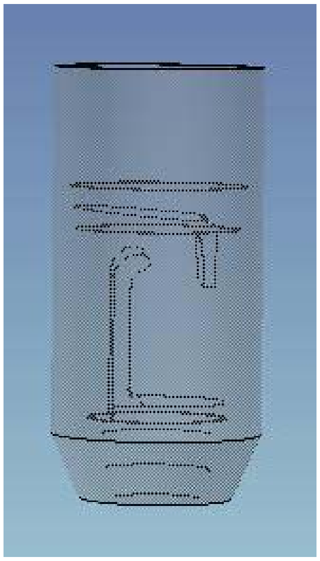
File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.02**	**6 sensors temp, vel, press, flow**

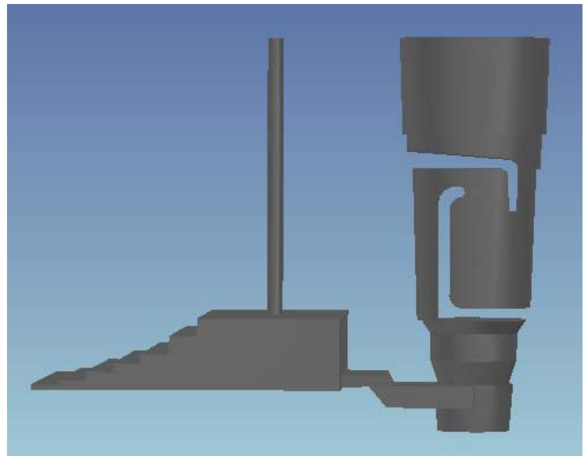
Results

Filling time	**5.389**
Sustained flow, lb/s	**6.58**
Max flow, lb/s	**118.55**

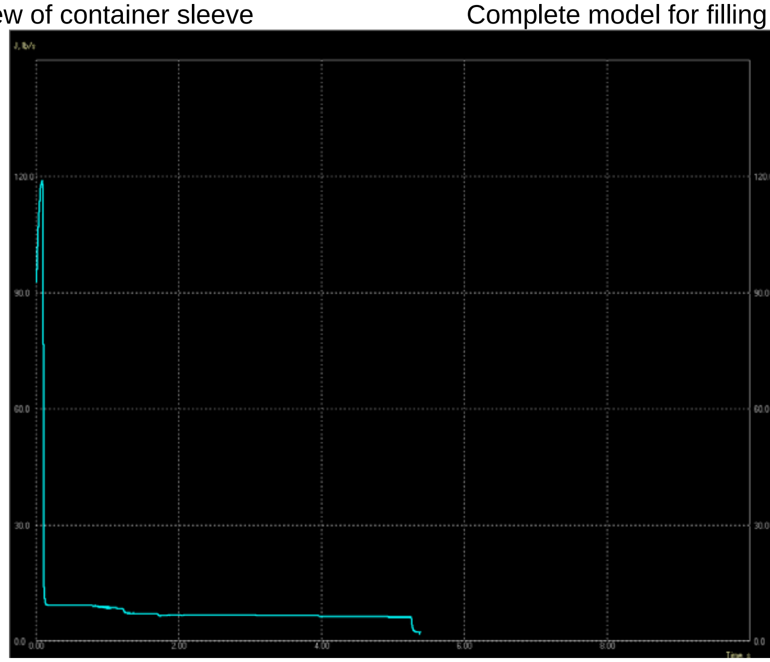
Results



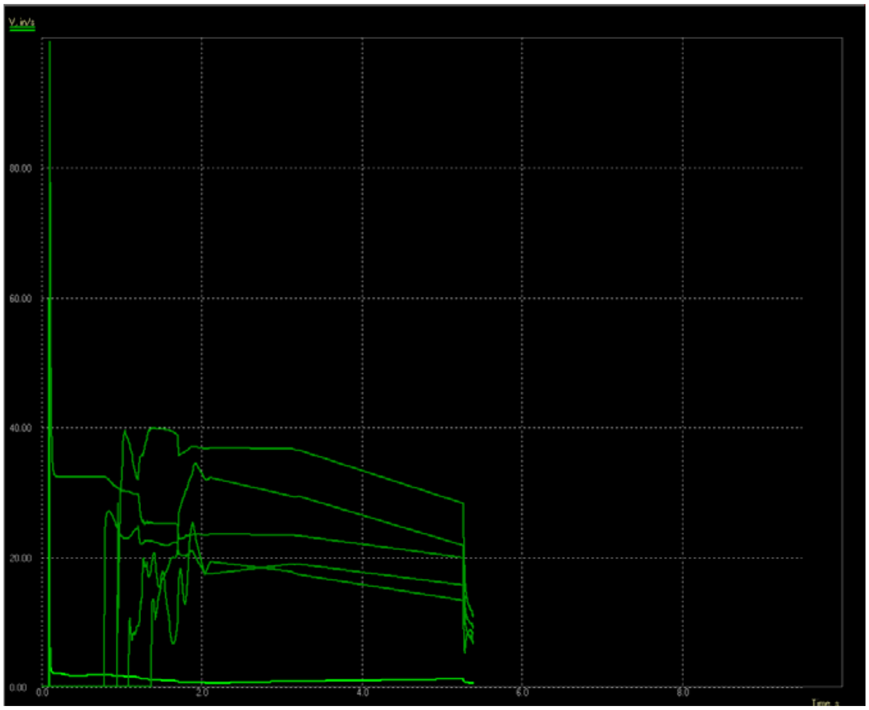
Inside view of container sleeve



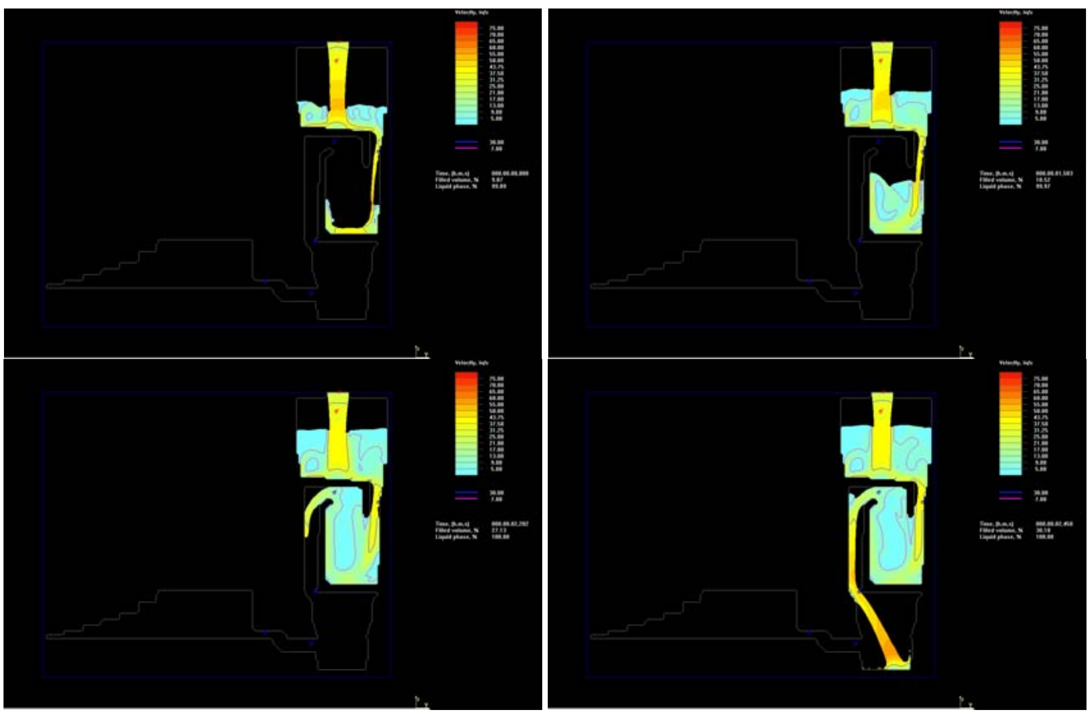
Complete model for filling simulation

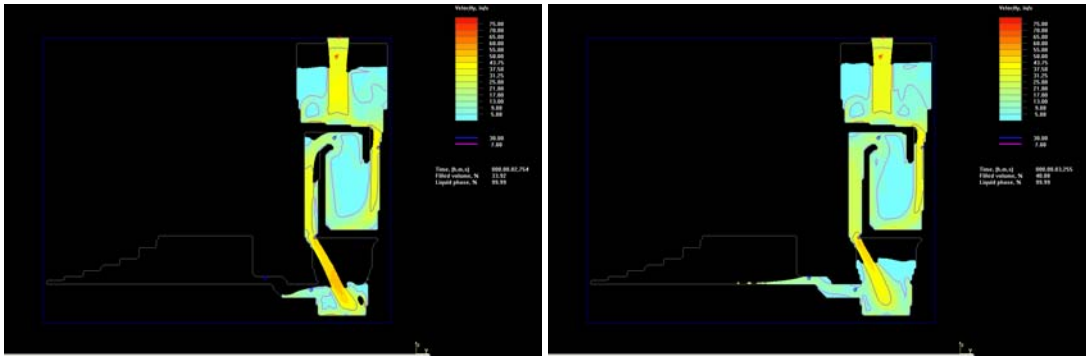


Graph of metal flow in [lb/s].



Virtual sensor data of velocity in [in/s].





Screen shots of the filling progress.

050625 DPInew rev4_1

Full scale simulation, no symmetry shortcut, rev4 design,

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.888**	**7.444**	
Along Z	**11.645**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 835 072**
Size cell	**0.081 in**	**Casting cells**	**358 224**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**14.58 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**4, F:1.0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**92.592**		

File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05**	**6 sensors temp, vel, press, flow**

Results

Filling time	**5.375**
Sustained flow, lb/s	**6.6**
Max flow, lb/s	**118.55**

050627 DPInew rev4_1no lip30

Full scale simulation, no symmetry shortcut, rev4 design, modified by removal of lip and baffle height adjustment to 3.0 in
050627_DPI rev4 NoLip30.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.888**	**7.444**	
Along Z	**11.645**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 835 072**
Size cell	**0.081 in**	**Casting cells**	**359 734**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**14.58 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**92.592**		

File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05**	**6 sensors temp, vel, press, flow**

Results

Filling time	**5.349**
Sustained flow, lb/s	**6.6**
Max flow, lb/s	**118.55**

050627 DPInew rev4_1no lip35

Full scale simulation, no symmetry shortcut, rev4 design, modified by removal of lip and baffle height adjustment to 3.5 in
050627_DPI rev4 NoLip30.sim

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**8.670 in**	**4.335**	
Along Y	**14.888**	**7.444**	
Along Z	**11.645**	**6.120**	
Min. mold thickness	**0.160 in**	**Total cells**	**2 835 072**
Size cell	**0.081 in**	**Casting cells**	**359 734**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**14.58 in^2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**1**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**92.592**		

File information

Autostop	**100% filled**	**Velocity**
Autosave	**0.05**	**6 sensors temp, vel, press, flow**

Results

Filling time	**5.173**
Sustained flow, lb/s	**6.9**
Max flow, lb/s	**118.01**

Results

050711_DPI2 complete2

Full scale simulation, no symmetry shortcut, rev4 design, including new casting design and two vents of 1 cm diameter, Flow & Solidification

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**396.089 mm**	**198.045 mm**	
Along Y	**186.000 mm**	**93.0 mm**	
Along Z	**311.400 mm**	**165.0 mm**	
Min. mold thickness	**3 mm**	**Total cells**	**22 907 016**
Size cell	**1 mm**	**Casting cells**	**3 326 866**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**9405.15 mm2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**40 mm**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**52.685 kg/s**		

File information

Autostop	**100% solid**	**Velocity, liq phase**
Autosave	**0.1**	**4 sensors temp, vel, press, flow**

Results

Filling time	
Sustained flow, lb/s	
Max flow, lb/s	

Results
Simulation did not finish, got aborted

050713_DPI2 complete

Full scale simulation, no symmetry shortcut, rev4 design, including new casting design and two vents of 1 cm diameter, Flow & Solidification

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**20C, 68F**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**396.089 mm**	**198.045 mm**	
Along Y	**186.000 mm**	**93.0 mm**	
Along Z	**311.400 mm**	**165.0 mm**	
Min. mold thickness	**6 mm**	**Total cells**	**2 855 720**
Size cell	**2 mm**	**Casting cells**	**384 989**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**9405.15 mm2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**0**
Pressure height, in	**40 mm**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**52.685 kg/s**		

File information

Autostop	**100% solid**	**Velocity, liq phase**
Autosave	**0.05**	

Results

Filling time	**5.355**
Sustained flow, lb/s	
Max flow, lb/s	

050720_DPI2 complete

Full scale simulation, no symmetry shortcut, rev4 design, including new casting design and two vents of 1 cm diameter, Bottom insert with spacers, exactherm sleeve

Material data

Alloy	**Grey iron**	**Pouring temp**	**1400C, 2552F**
Mold materials	**Twig sand**	**Initial temp**	**20C, 68F**
	Exatherm	**Initial temp**	**20**

MESH

	Box dimensions	**Casting position**	**Number of cells**
Along X	**401.311 mm**	**200.655 mm**	
Along Y	**185.080 mm**	**92.540mm**	
Along Z	**304.465 mm**	**154.772mm**	
Min. mold thickness	**2.54**	**Total cells**	**8 986 880**
Size cell	**1.359**	**Casting cells**	**1 279 651**

Boundary conditions	**Low**	**High**
YZ plane	**Normal conditions**	**Normal conditions**
XZ	**Normal conditions**	**Normal conditions**
XY	**Normal conditions**	**Heat radiation**

Gatings

# of gating points	**1**	**Section**	**9224.45 mm2**
Boundary conditions at gating point		**Normal conditions**	
Pouring type	**Gravity casting**	**Filters**	**3 F:1.0**
Pressure height, in	**50 mm**		
Friction factor	**0.90**	**Normal values range from 0.8 to 0.9**	
Flow, lbs/s	**55.956 kg/s**		

File information

Autostop	**100% solid**	**9 sensors**
Autosave	**0.075**	

Results

Filling time	**6.170 s** **17min 11 sec for complete solid**	**Liq, vel**

Sustained flow, lb/s	**2.59 kg/s**
Max flow, lb/s	**63.06**

Appendix –Technical drawings

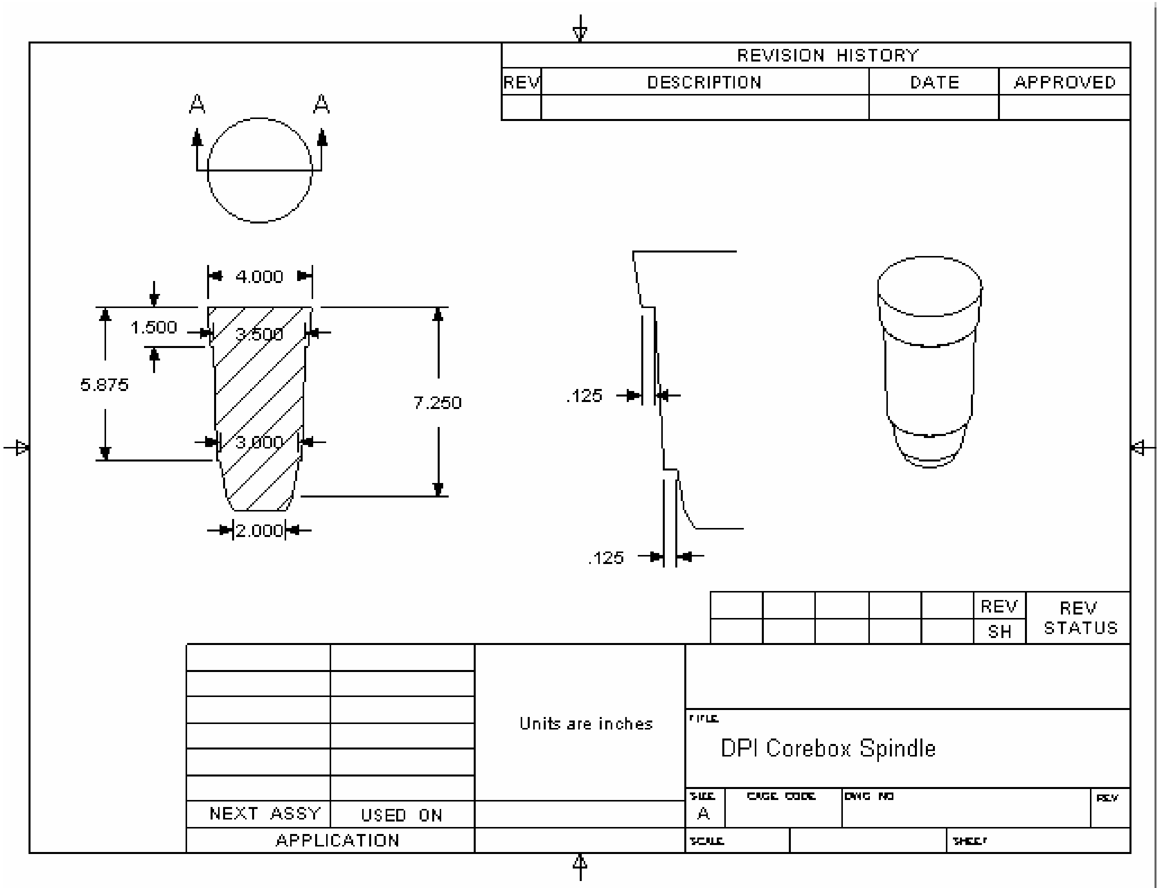


Fig. 1 Technical drawing of sleeve core box insert

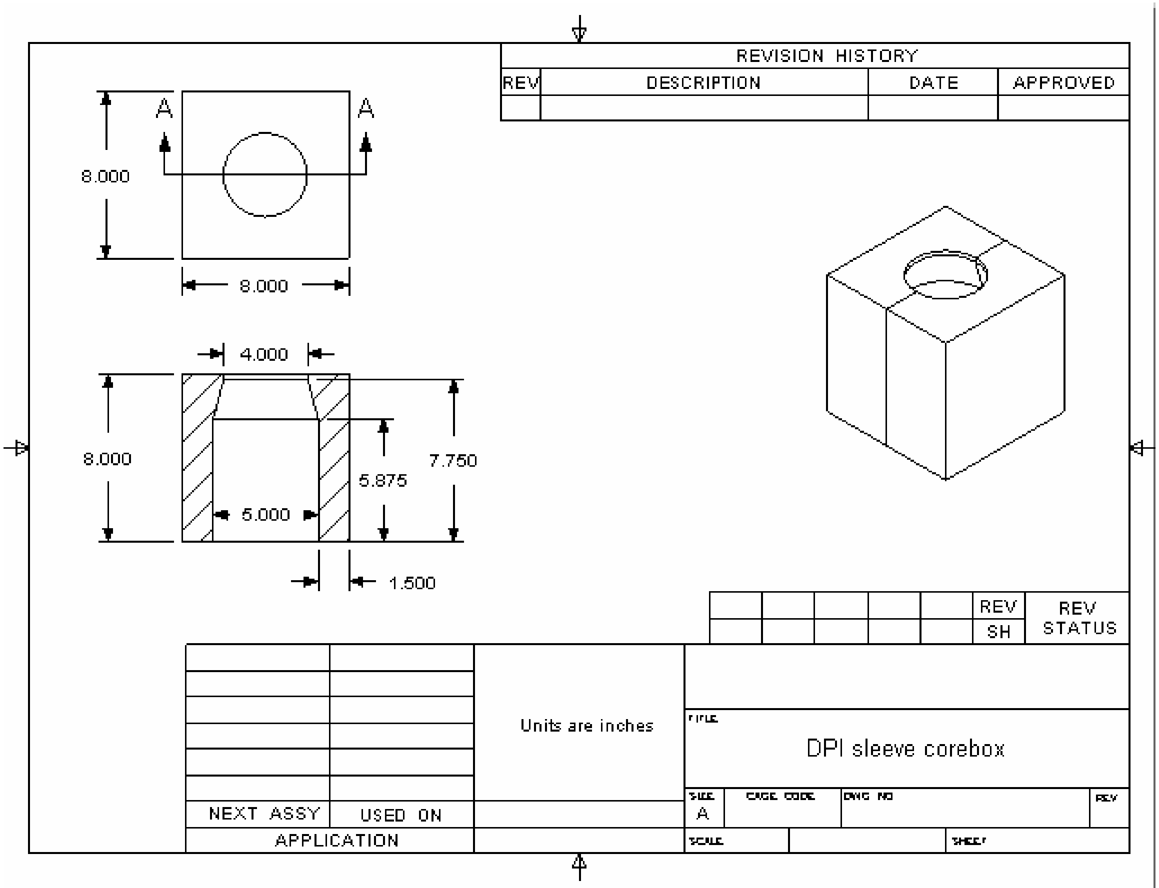


Fig. 2 Technical drawing of sleeve core box

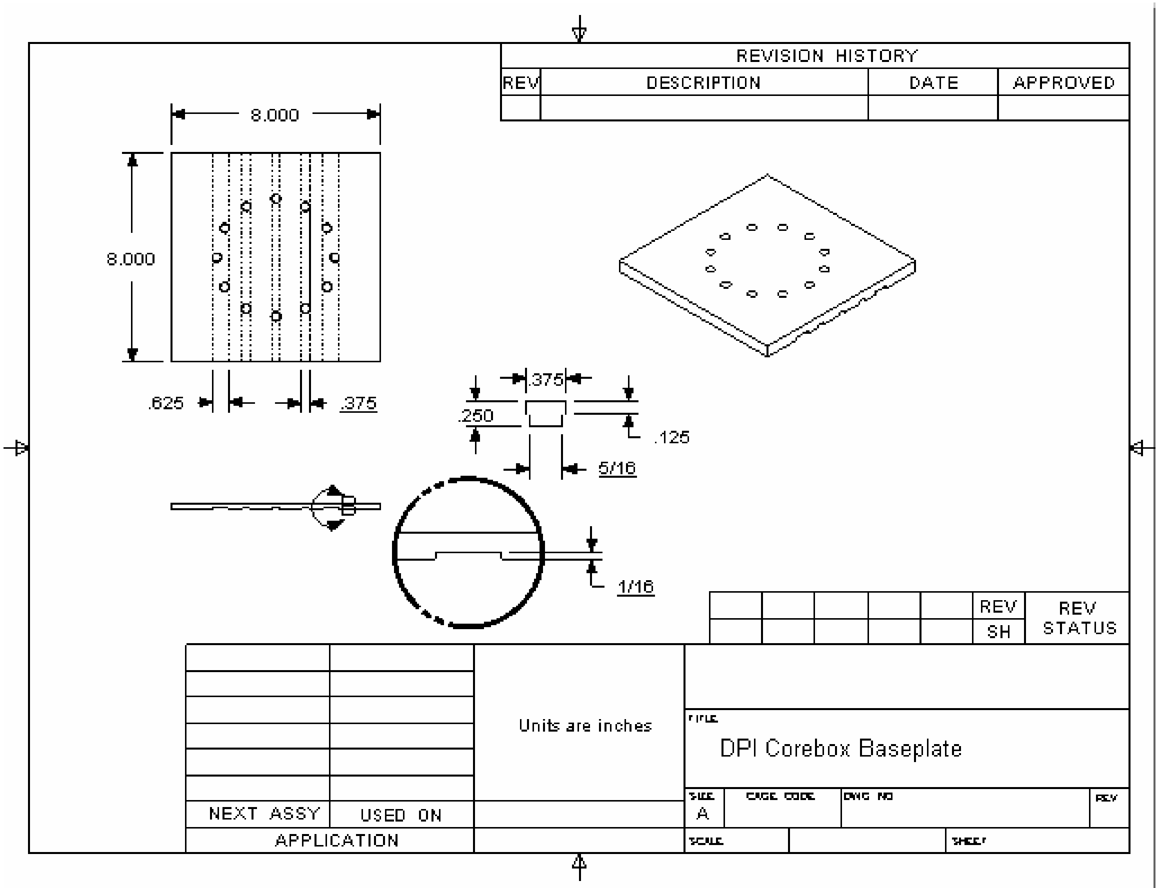


Fig. 3 Technical drawing of sleeve core box base plate

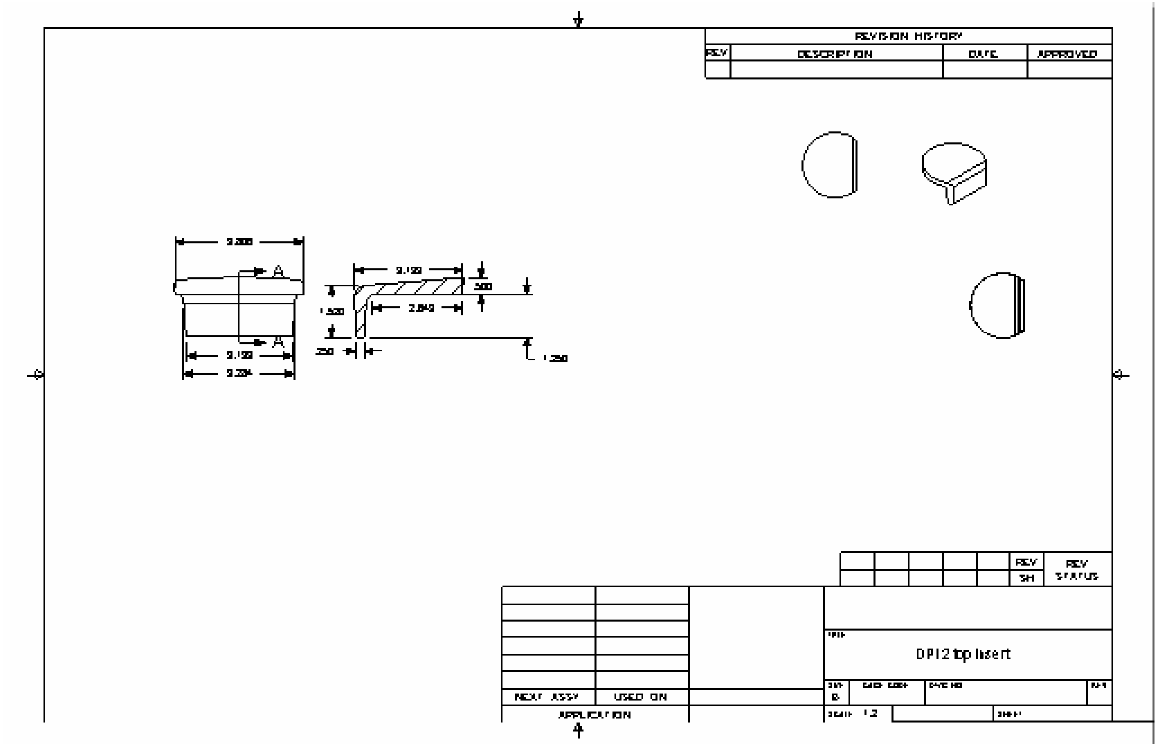


Fig. 4 Technical drawing of top insert

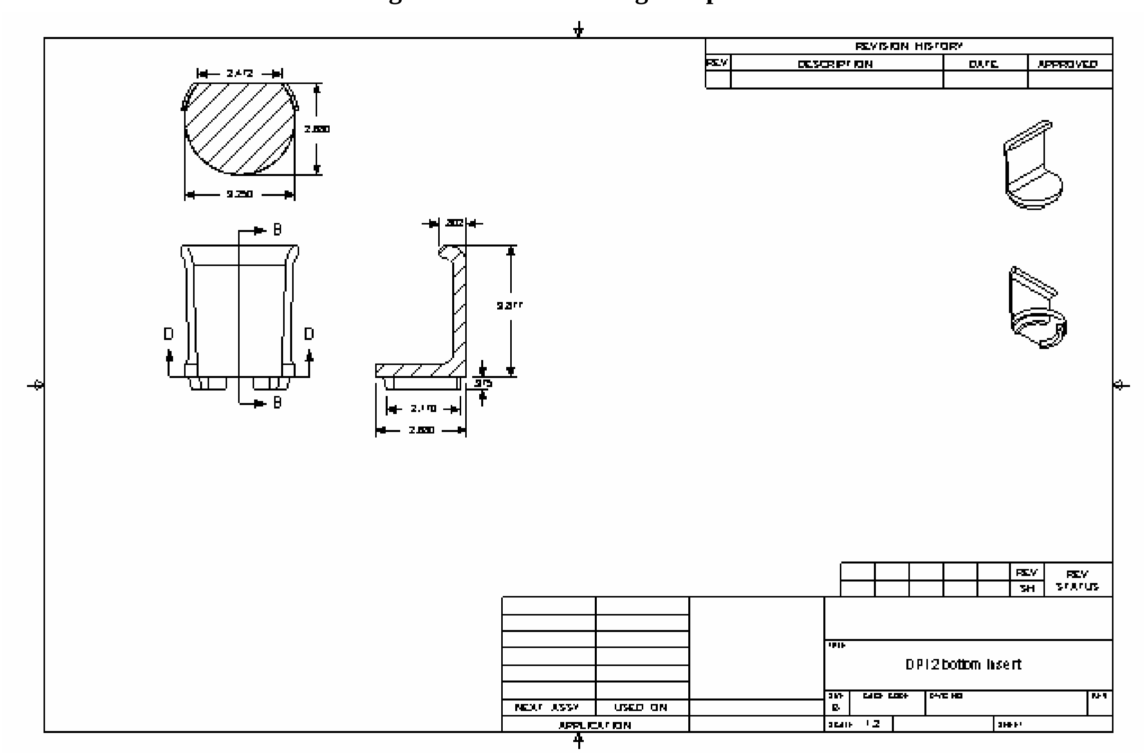


Fig. 5 Technical drawing of bottom insert

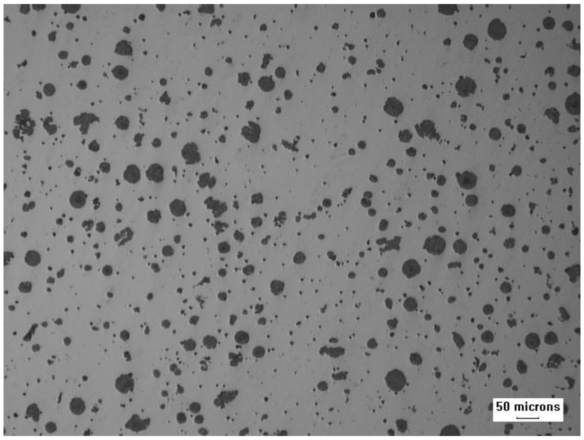
Appendix - Alloy calculation

1st heat

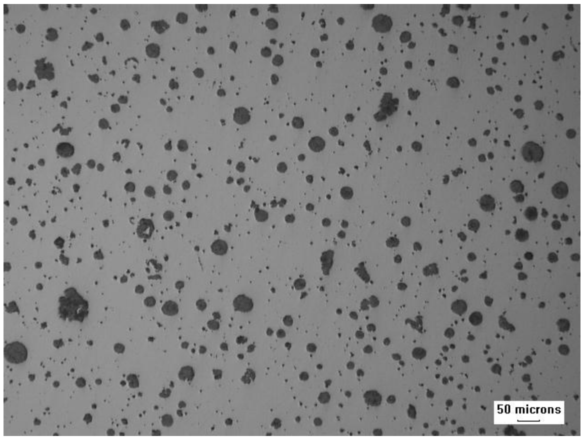
DPI alloy addition calculation

Desired Mg level		0.04 residual				
Solution factor from graph (based on 5% Mg)		0.855				
for 6%Mg line shifts to left						
initial trial assume 5% and 10% reduction		0.8122	**5%**			
in solution factor		0.7695	**10%**			
Percent alloy additon		1%				
Weight of casting [lbs] (based on IronCad analysis)		40		18.182 kg		
Pouring time [s]	from simulation	6.17	sim	1%=	0.182	kg
Pouring rate, sustained [lbs/s]	from simulation	5.698			181.818	g
					6.413	oz
calculated pouring rate (weight/time) [lbs/s]		6.4830		1.2%=	0.218	g
Cross sectional area [in^2]		5.9425				
Height [in]		2.751				
from Inmold manual						
cross sectional area	:=pouring rate/solution factor	7.0155	**5%**			
		7.4048	**10%**			
weight of nodularizer (table 2) for 40 lbs casting						
with 1% alloy addition		6.4	ozs			
volume of alloy addition		5.35	in^3			
depth of chamber (=alloy vol/area of chamber)		0.9003	in			
added reaction space (0.75in)		1.6503	in			

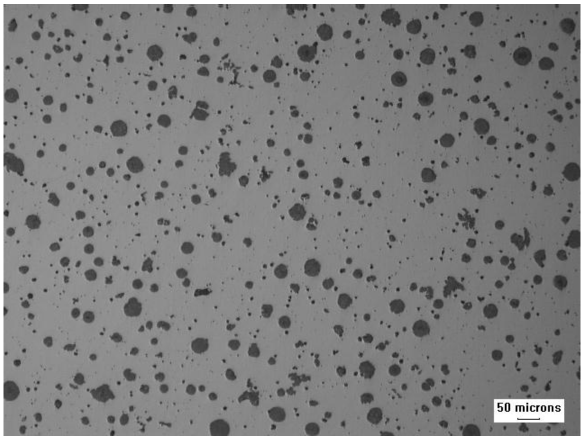
Appendix - DPI2-A CGI casting microstructures-end section



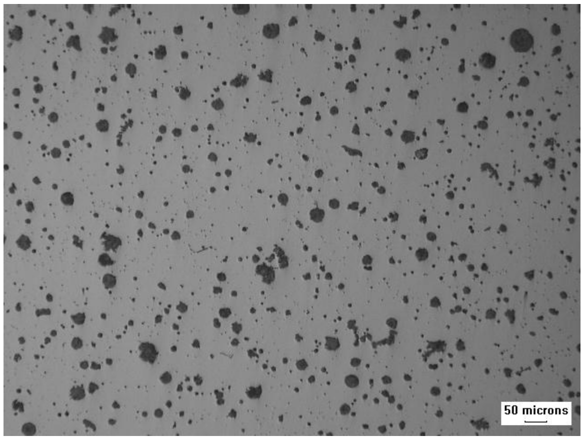
1



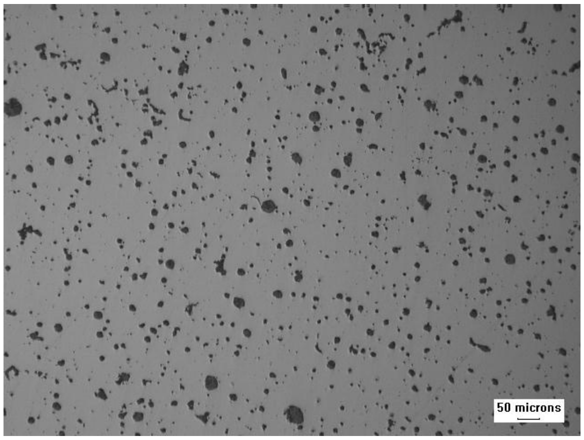
2



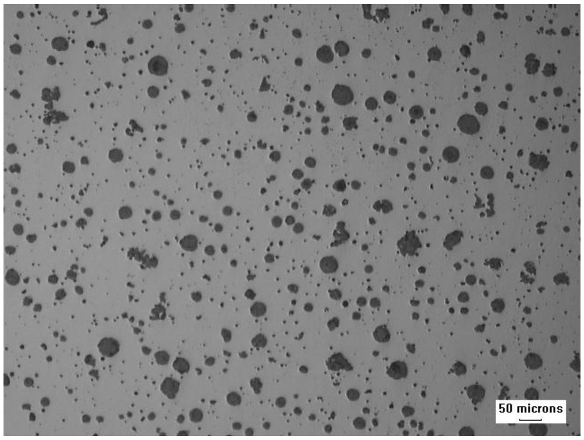
3



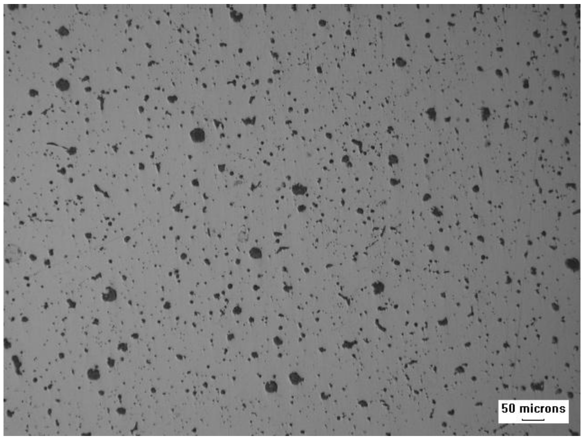
4



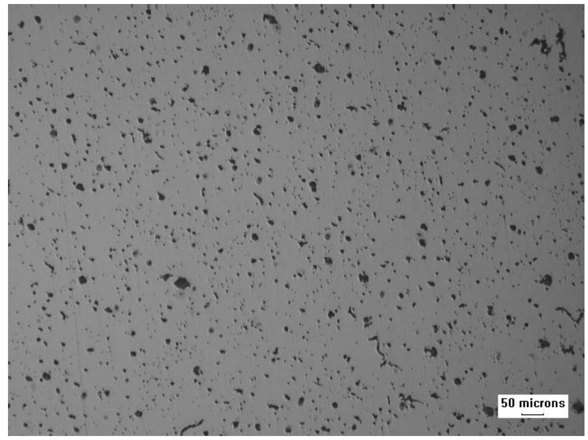
5



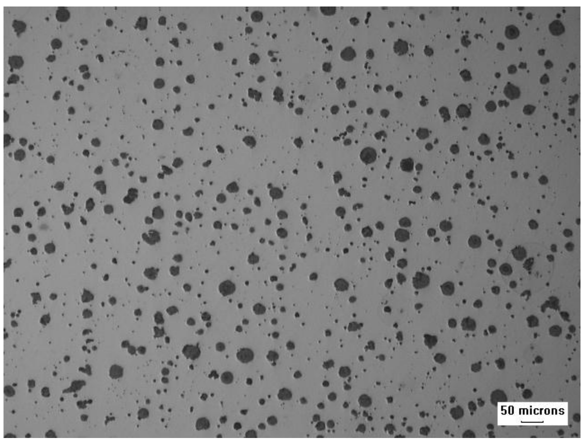
6


50 microns

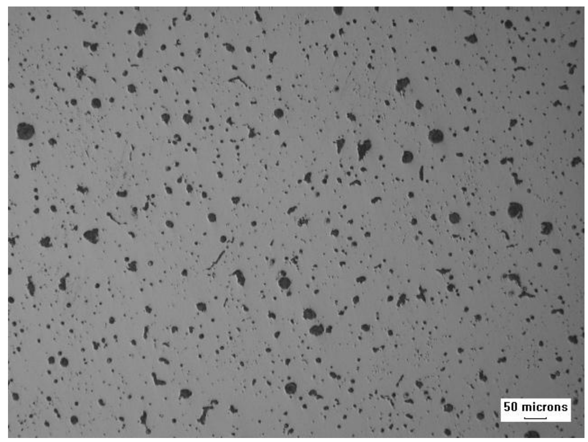
7


50 microns

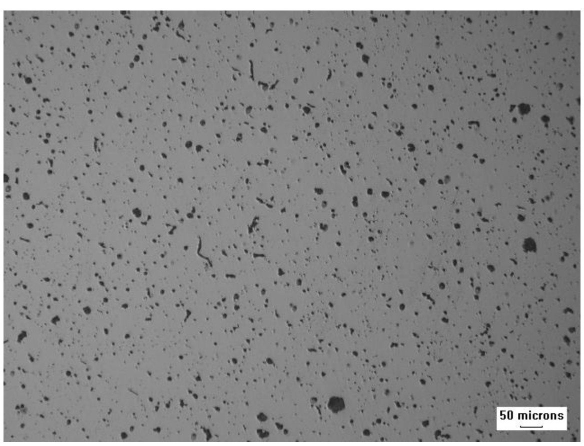
8


50 microns

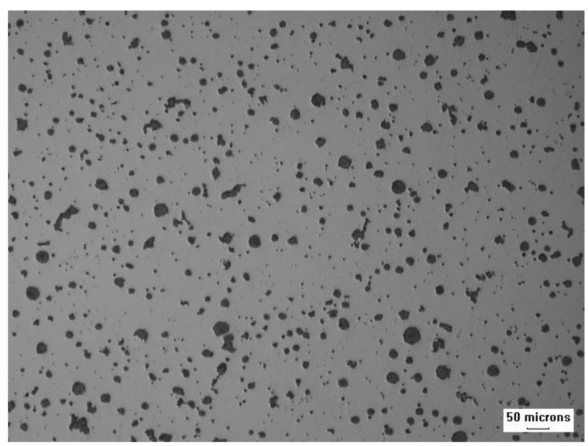
9


50 microns

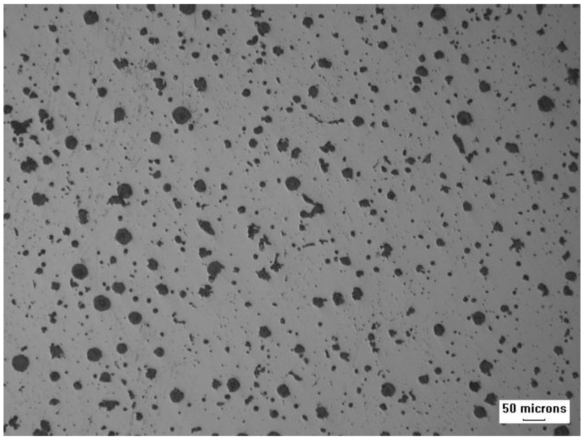
10


50 microns

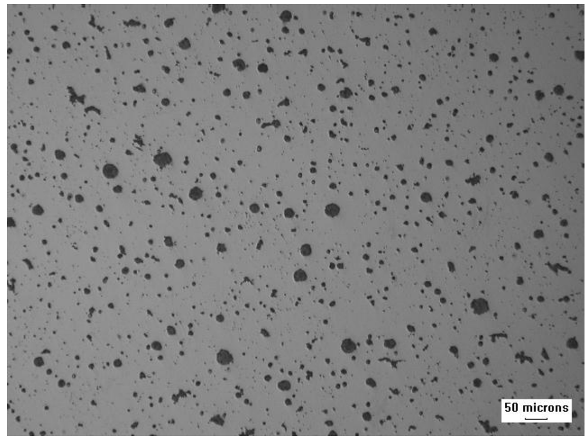
11


50 microns

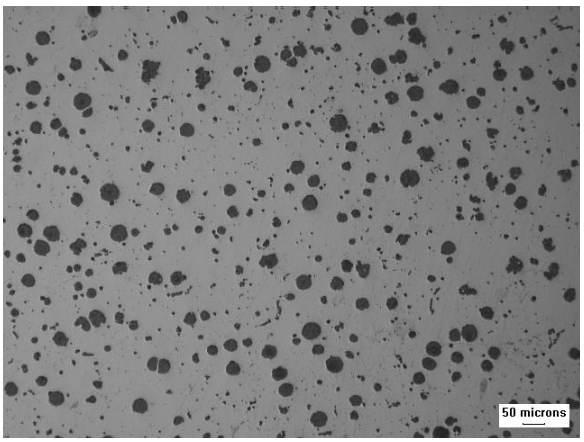
12



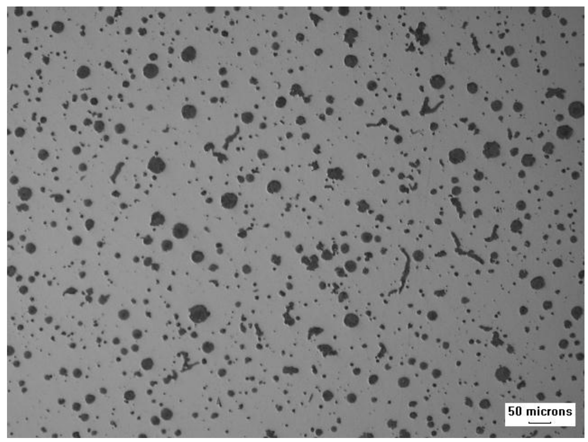
13



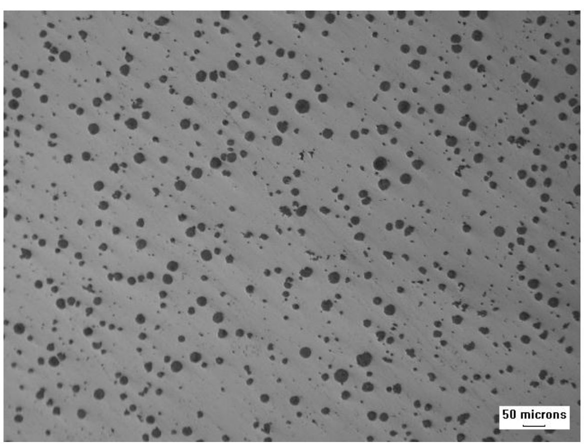
14



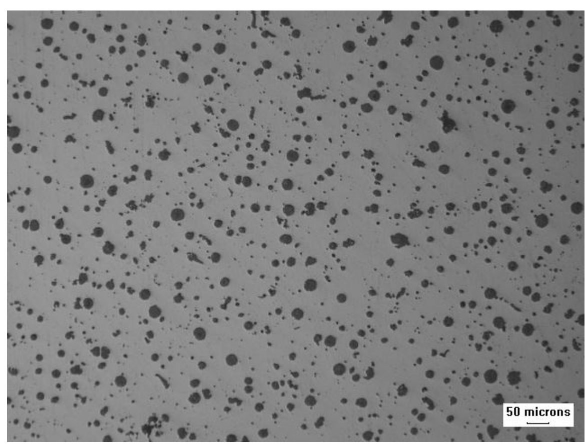
15



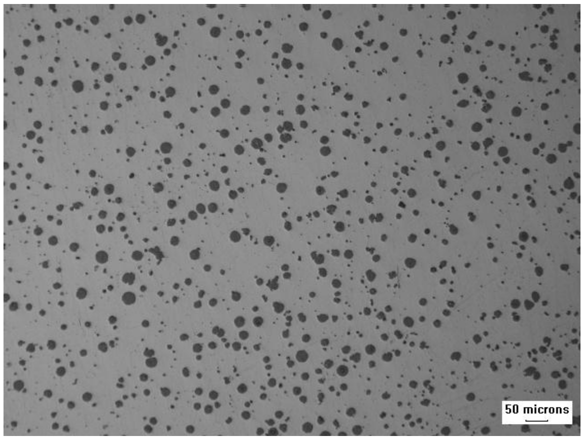
16



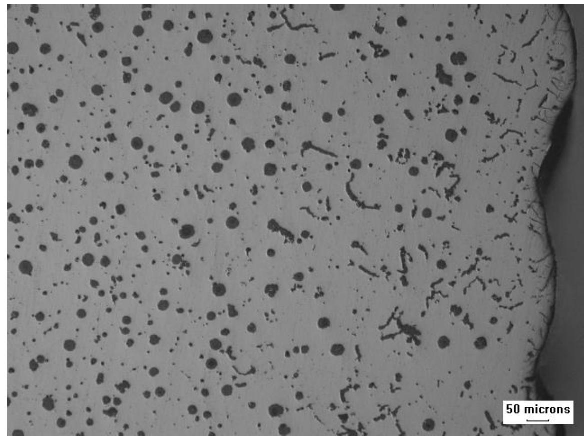
17



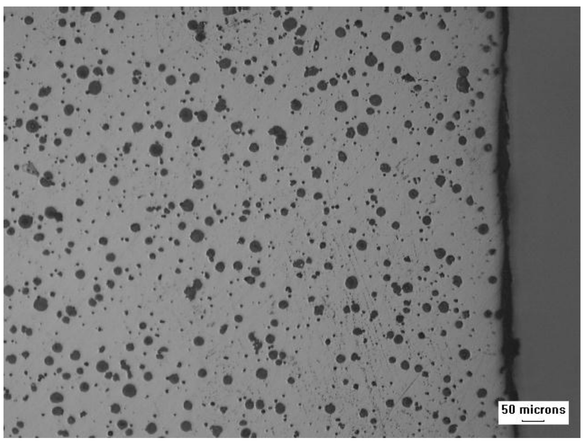
18



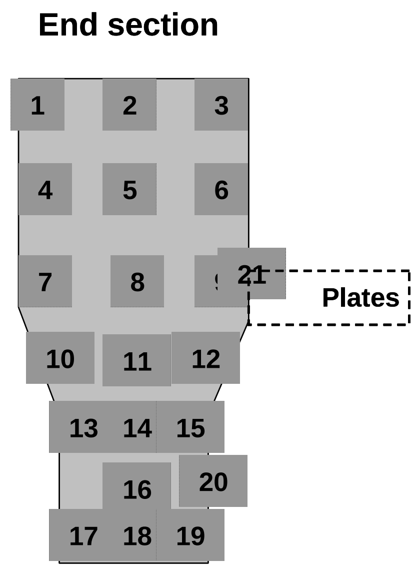
19



20

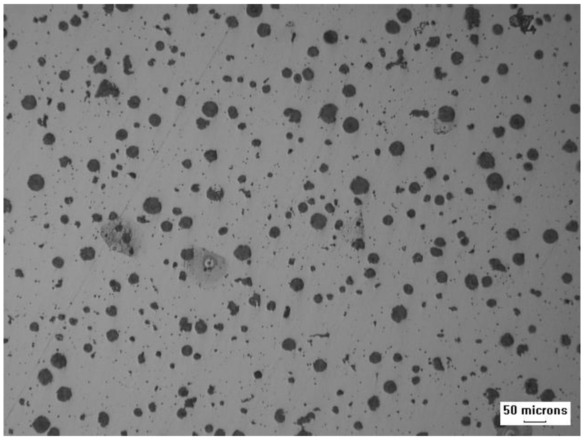


21

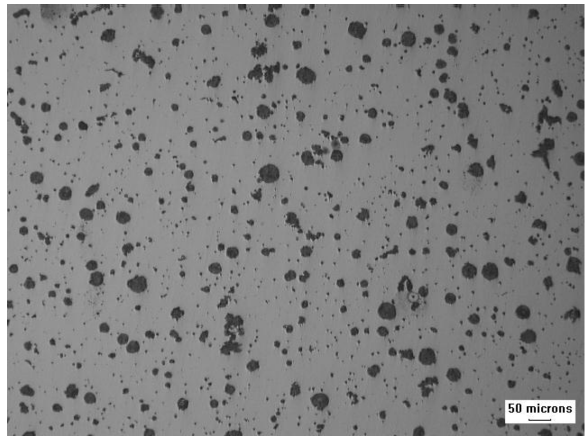


Locator

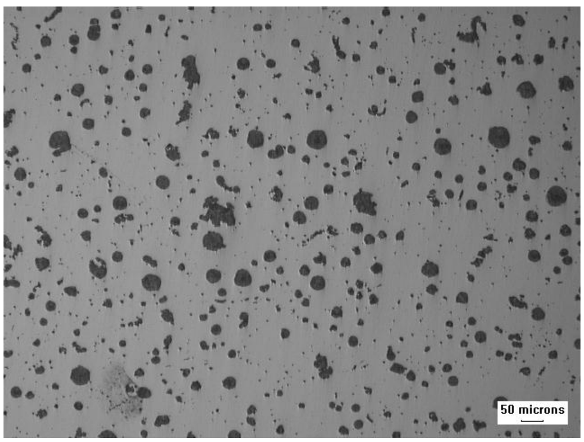
Appendix - DPI2-A CGI casting microstructures-ingate section



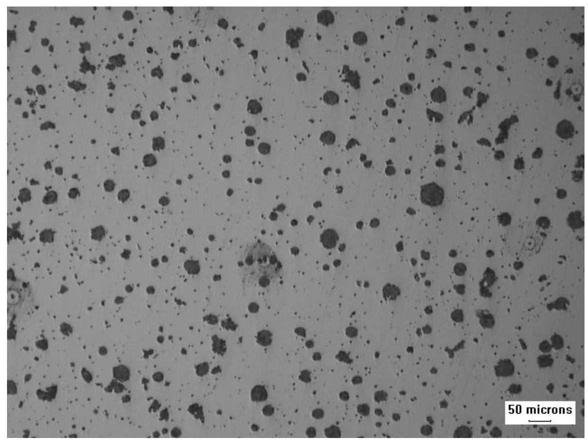
1



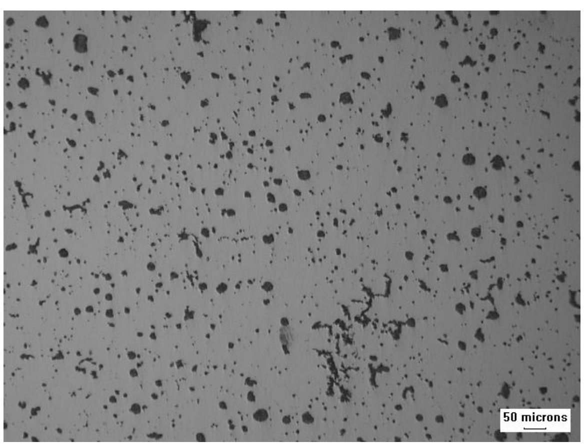
2



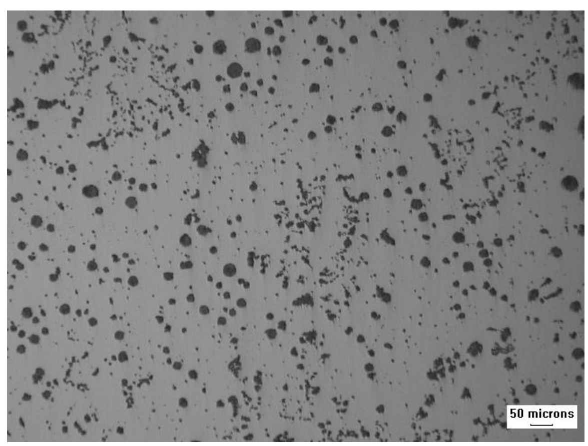
3



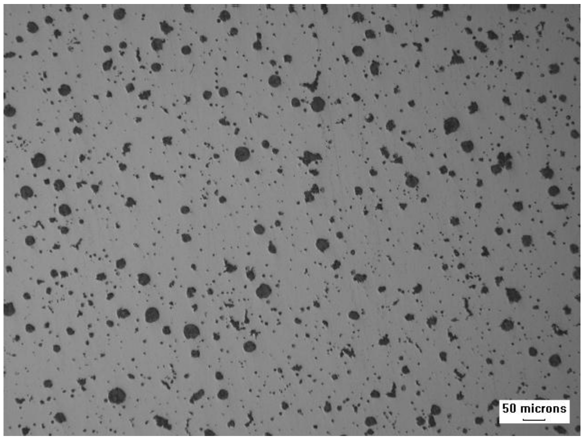
4



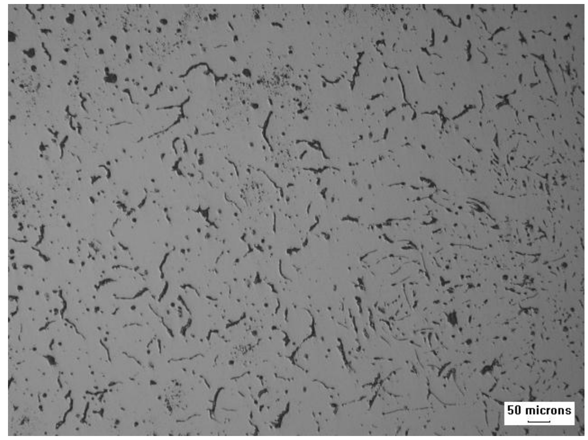
5



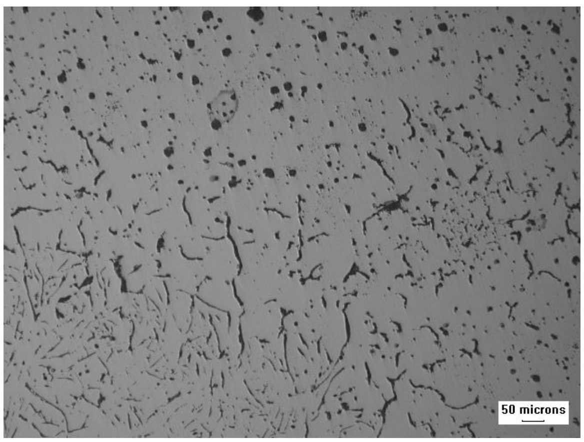
6


50 microns

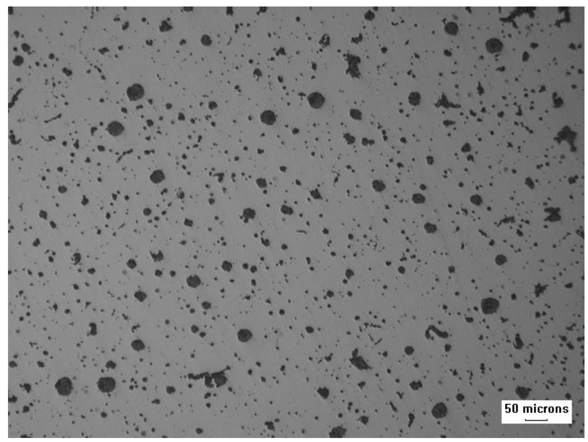
7


50 microns

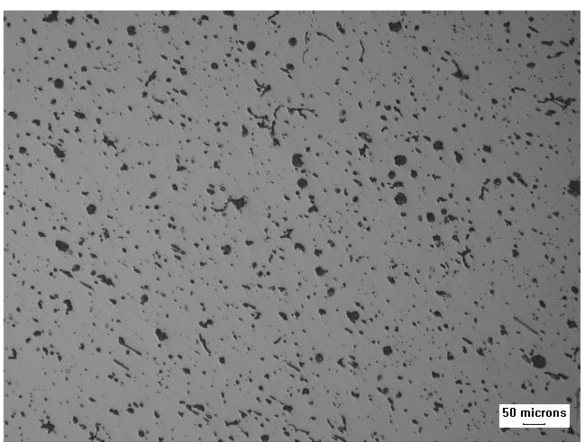
8


50 microns

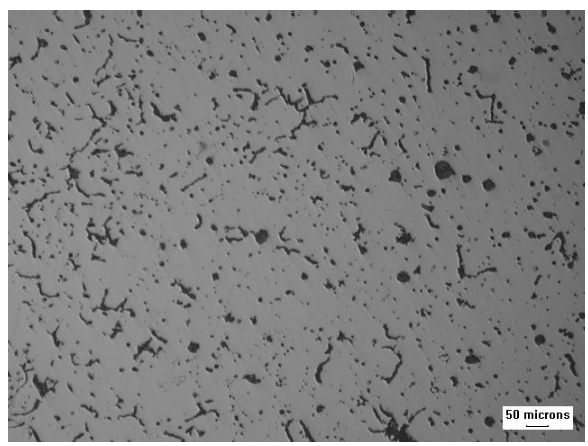
9


50 microns

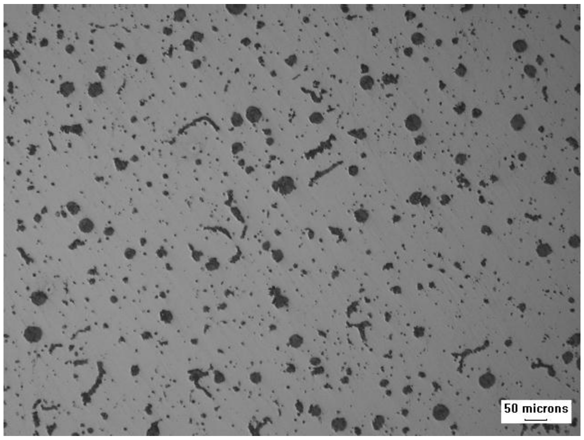
10


50 microns

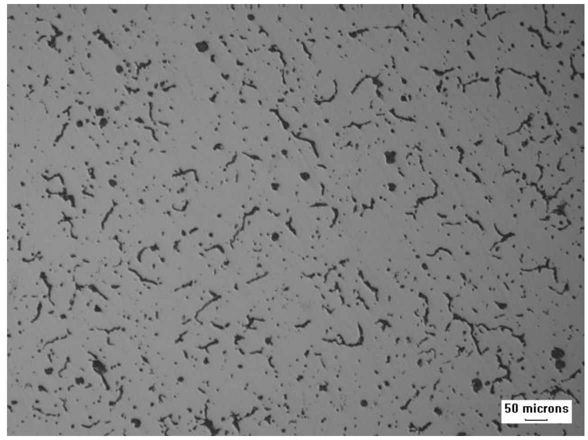
11


50 microns

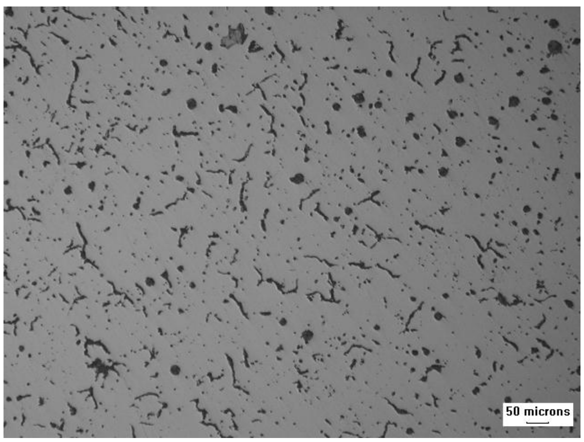
12



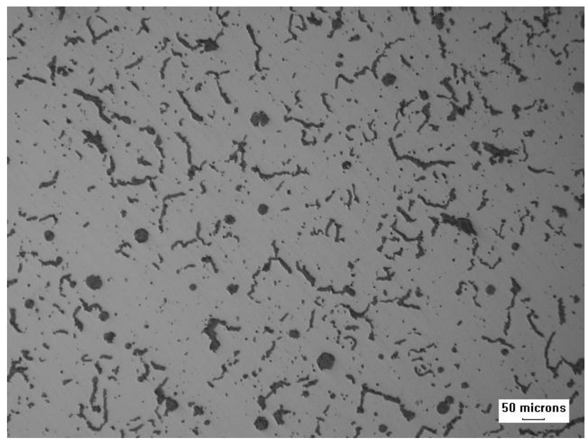
13



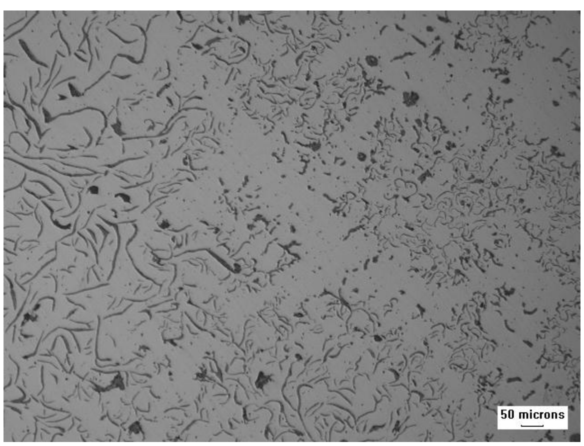
14



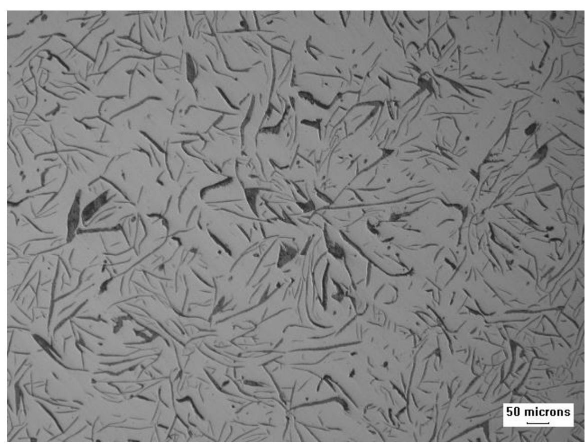
15



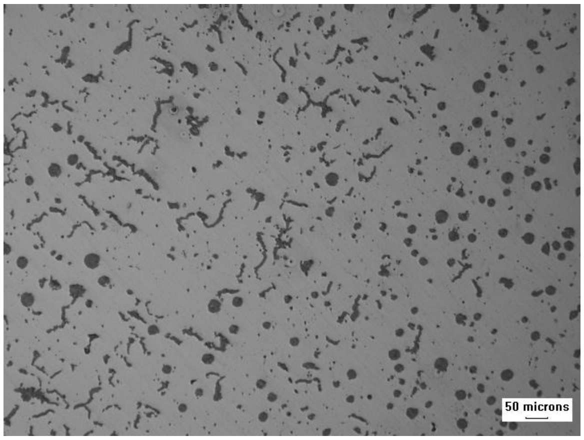
16



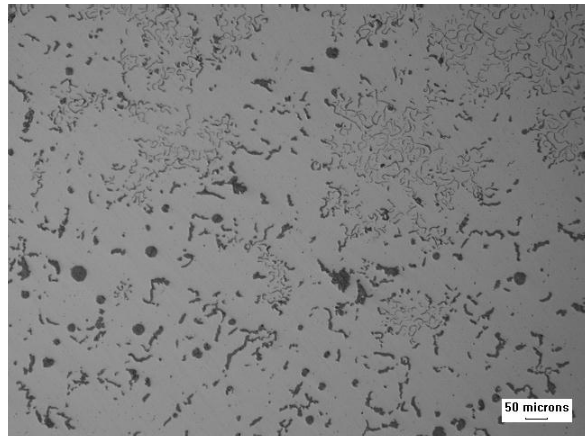
17



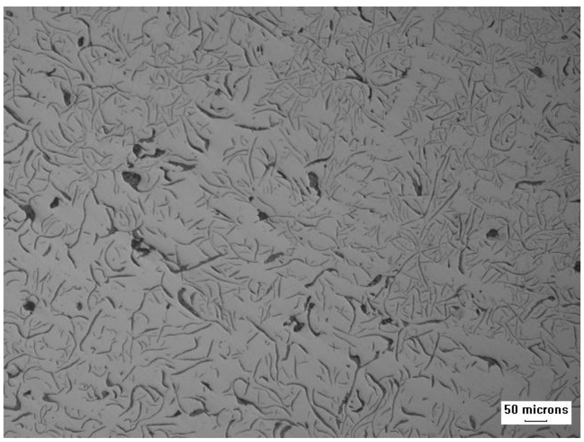
18



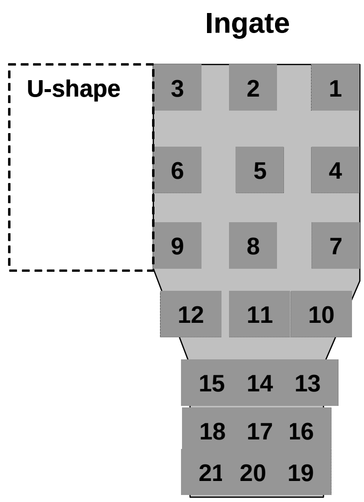
19



20

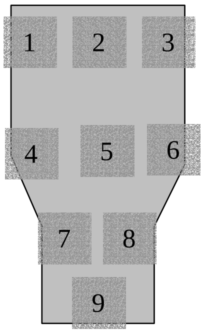


21

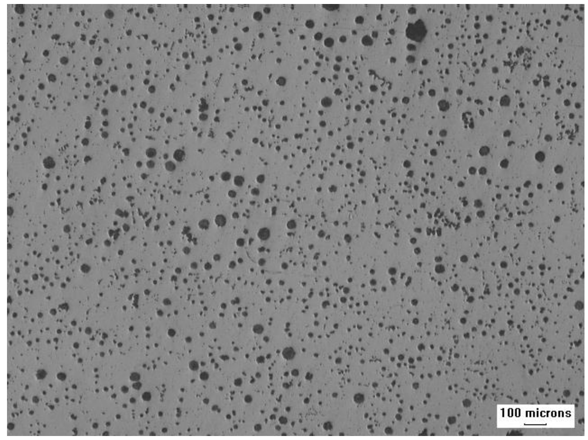


Locator

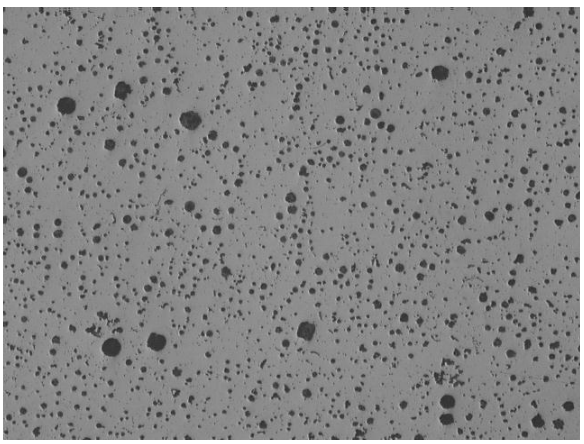
Appendix - DPI2-B CGI casting microstructures-ingate section



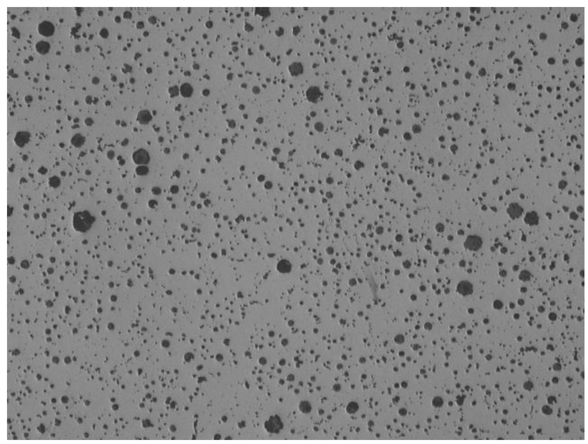
locator



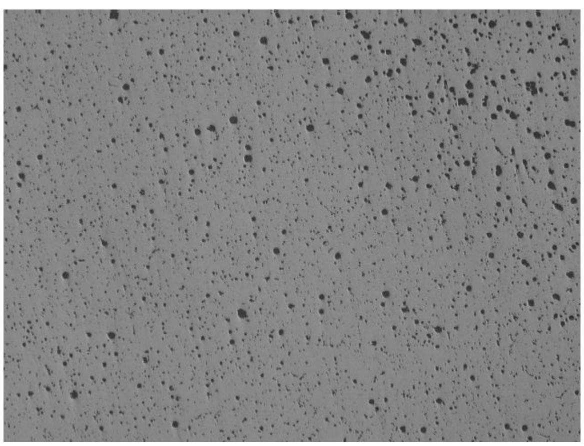
1



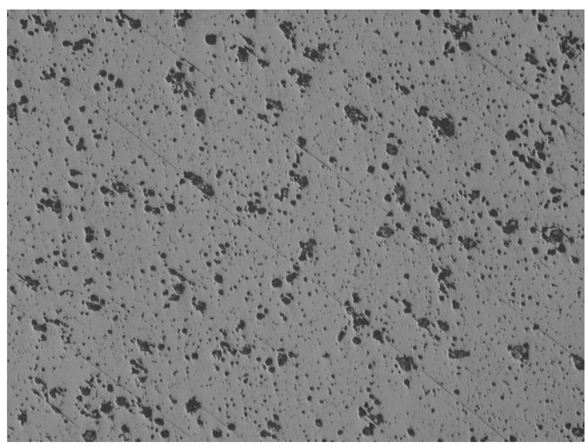
2



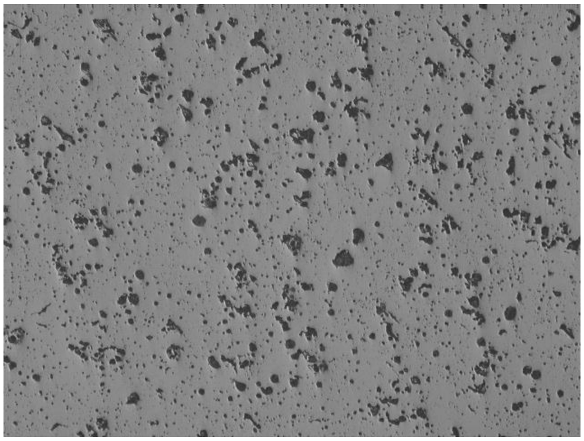
3



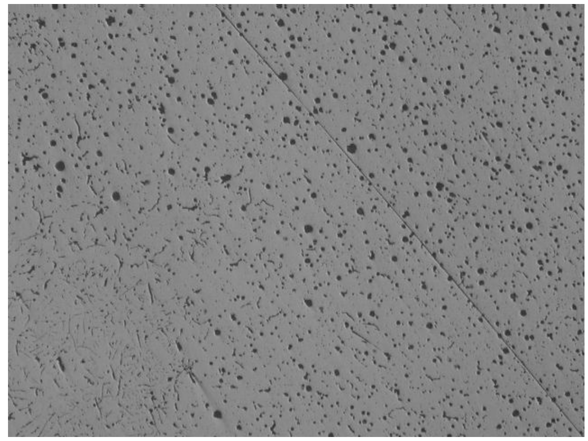
4



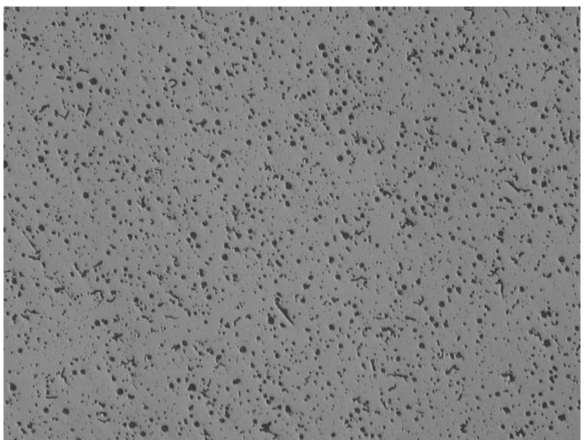
5



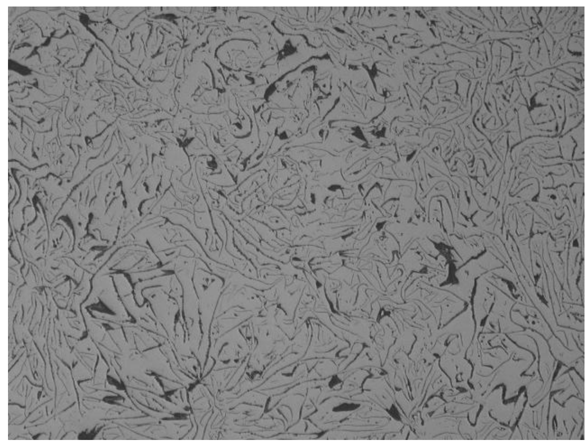
6



7

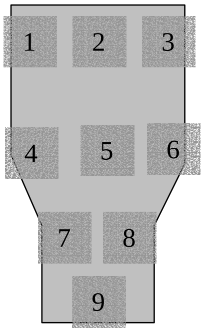


8

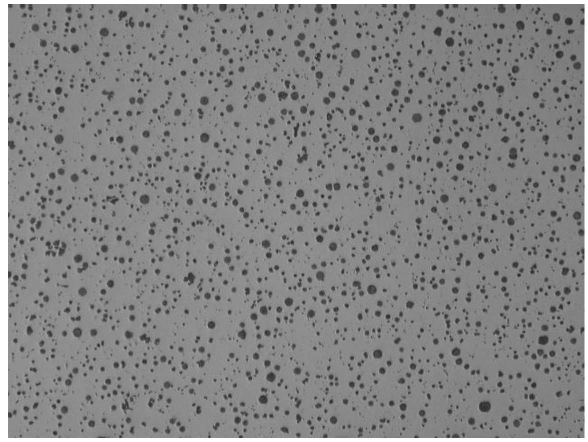


9

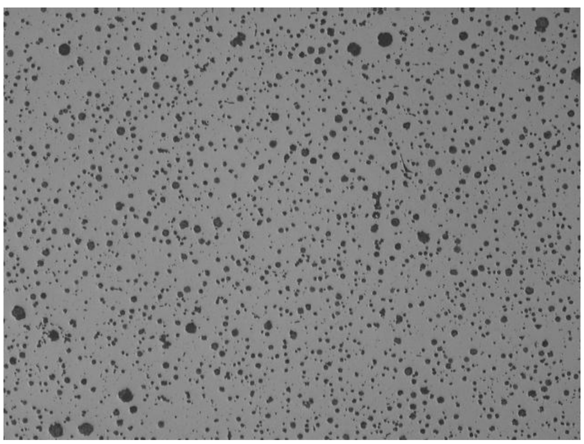
Appendix - DPI2-B CGI casting microstructures-end section



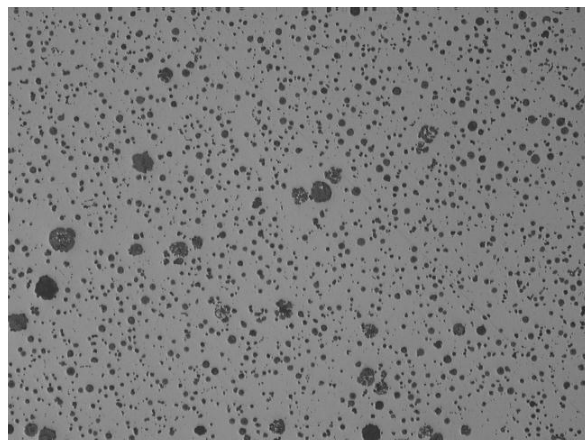
locator



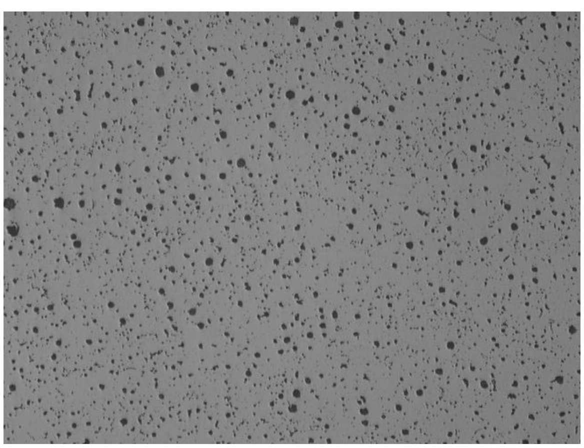
1



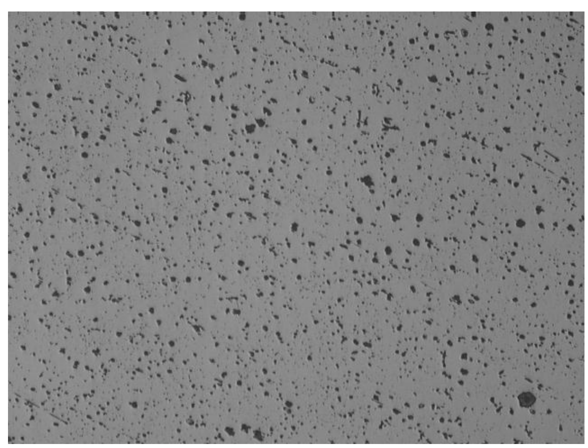
2



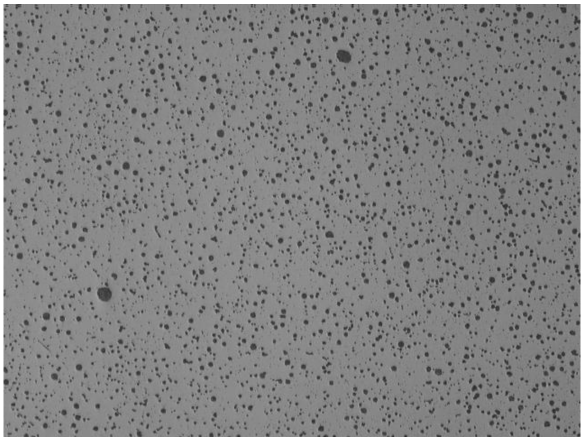
3



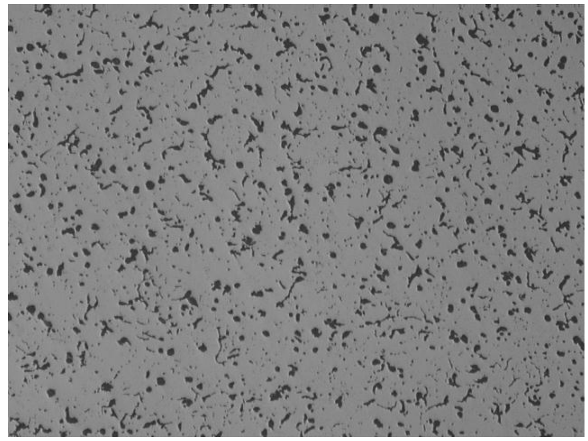
4



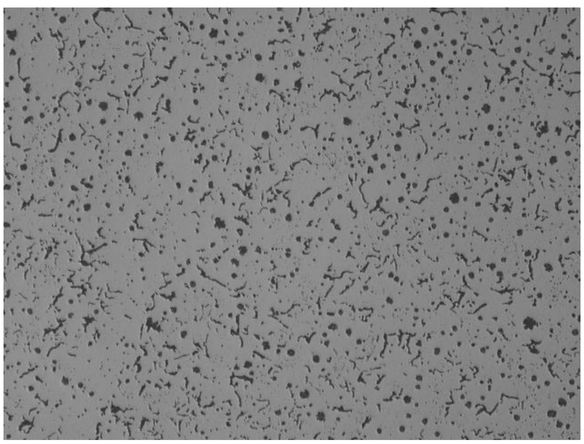
5



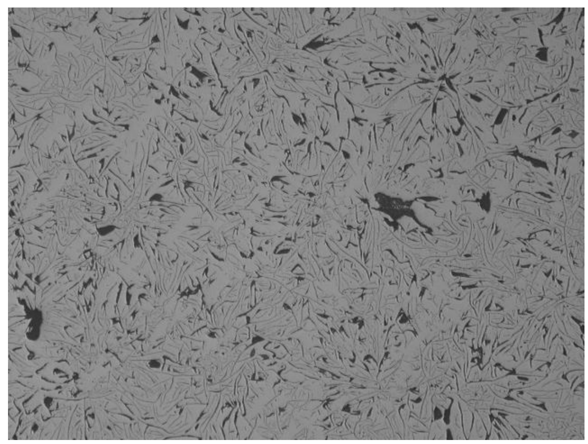
6



7

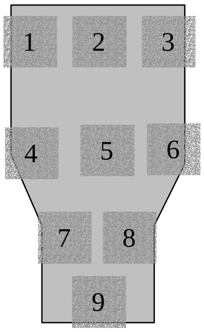


8

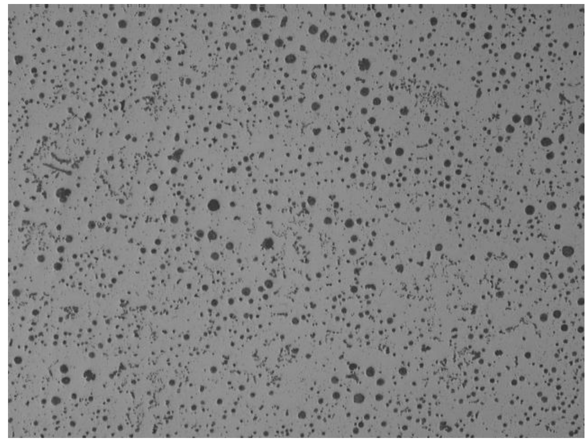


9

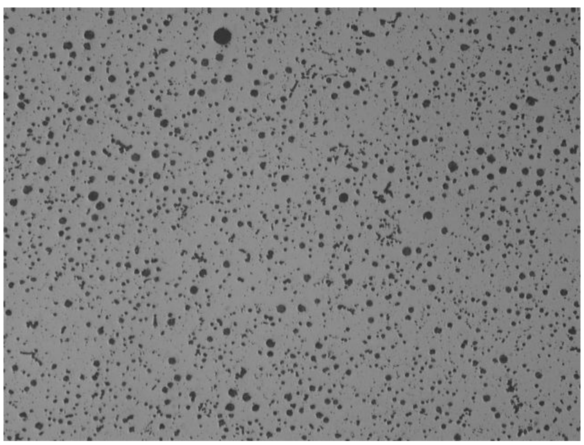
Appendix - DPI2-C CGI casting microstructures-ingate section



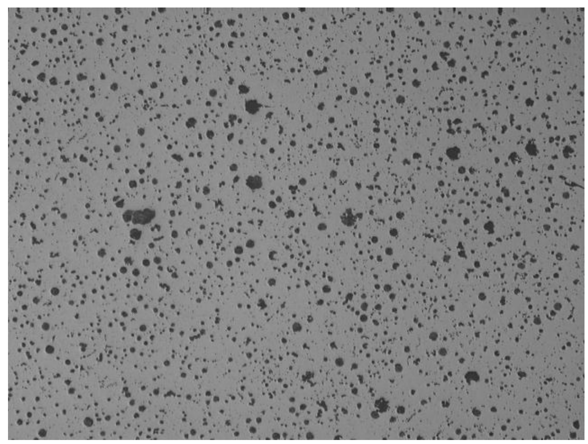
locator



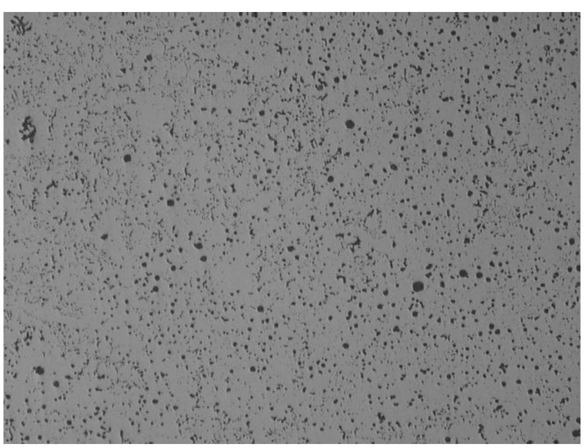
1



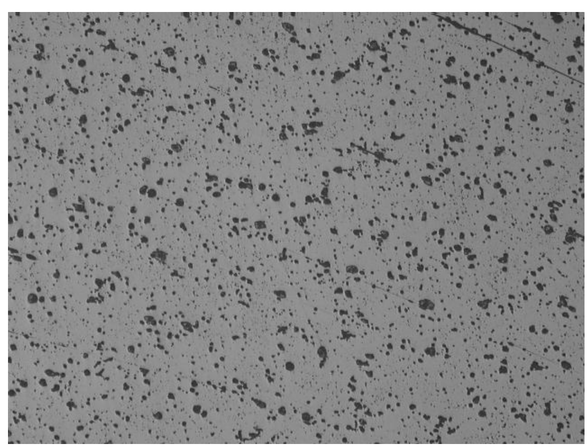
2



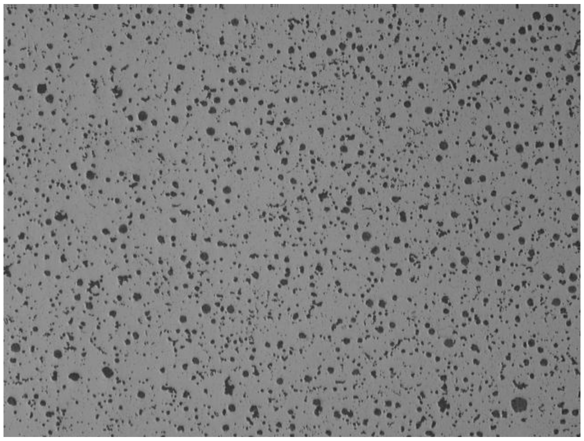
3



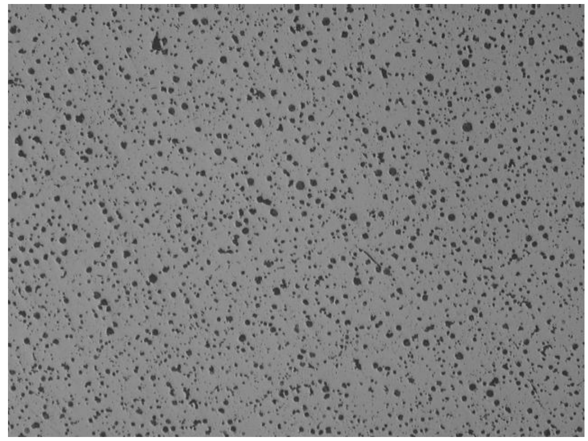
4



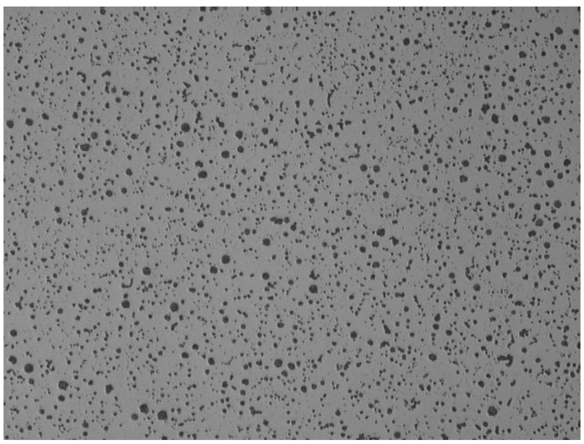
5



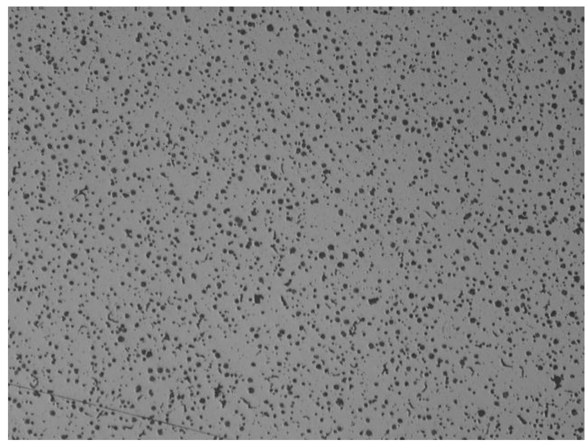
6



7

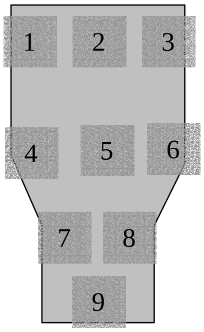


8

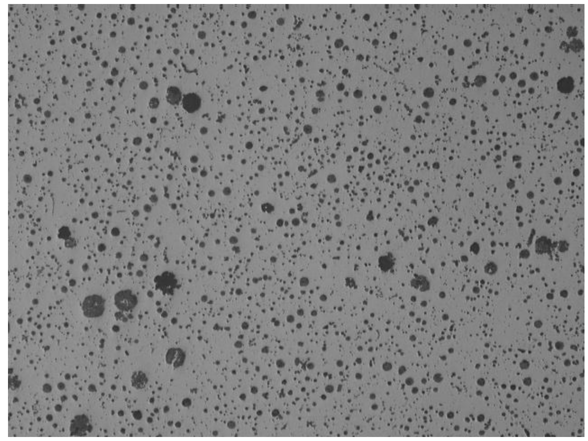


9

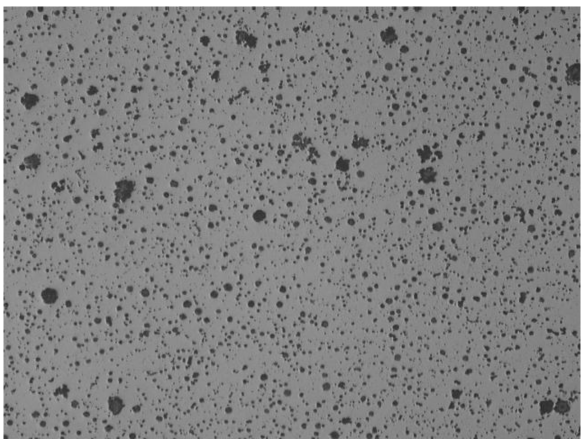
Appendix - DPI2-C CGI casting microstructures-end section



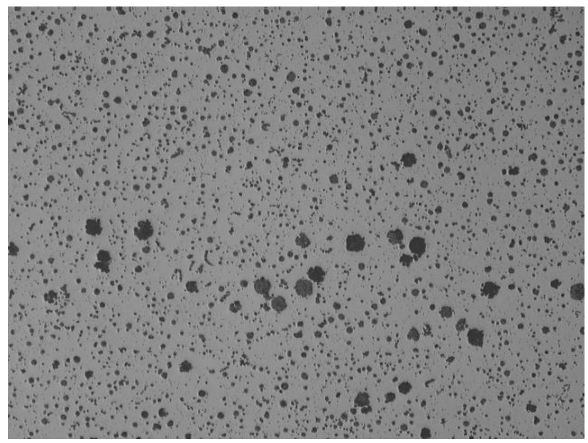
locator



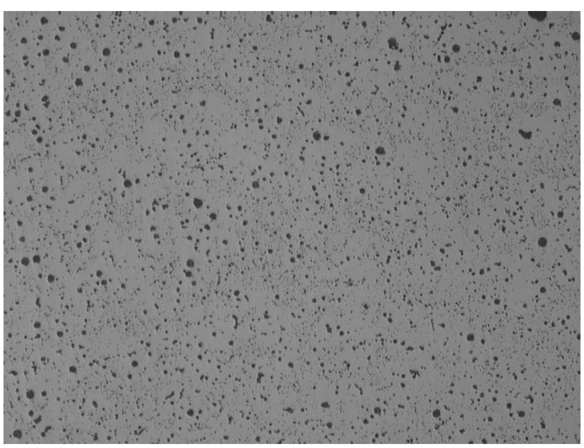
1



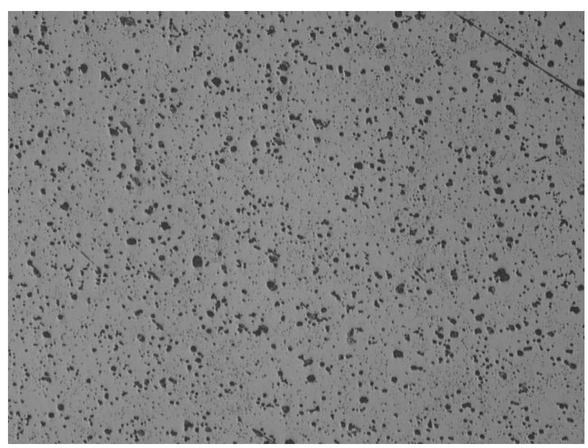
2



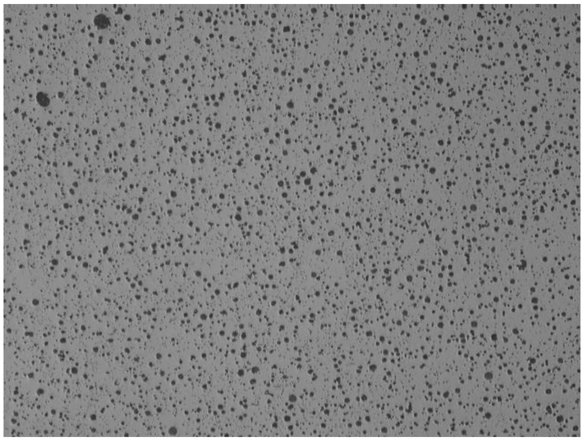
3



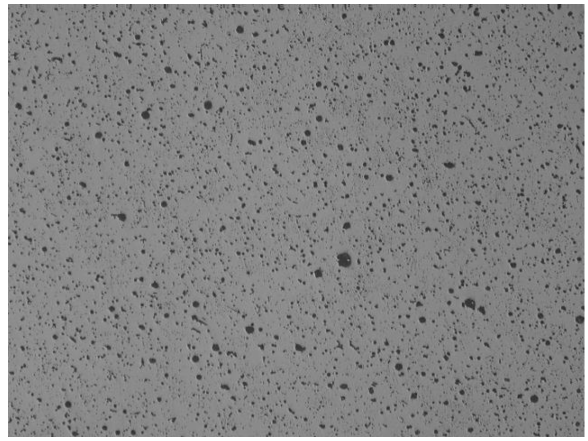
4



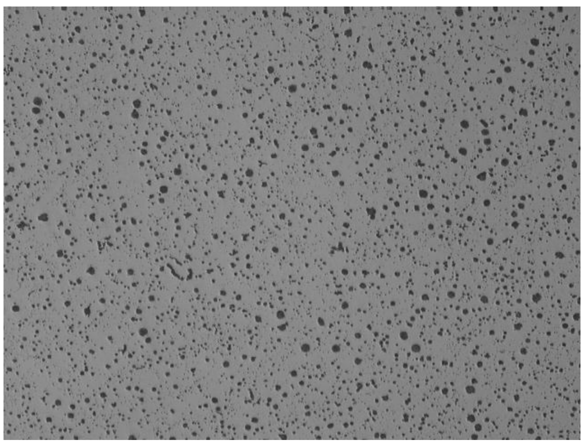
5



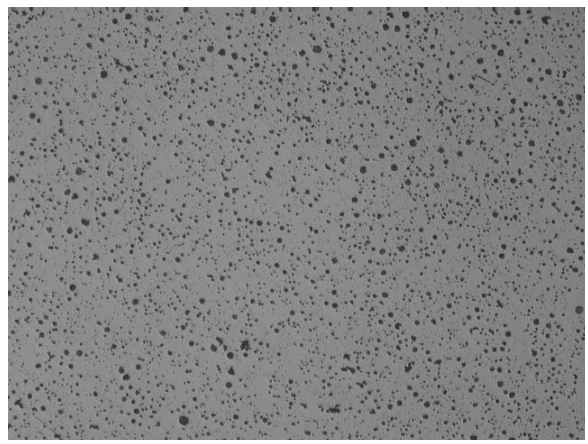
6



7

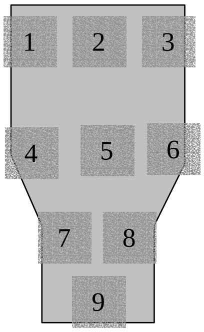


8

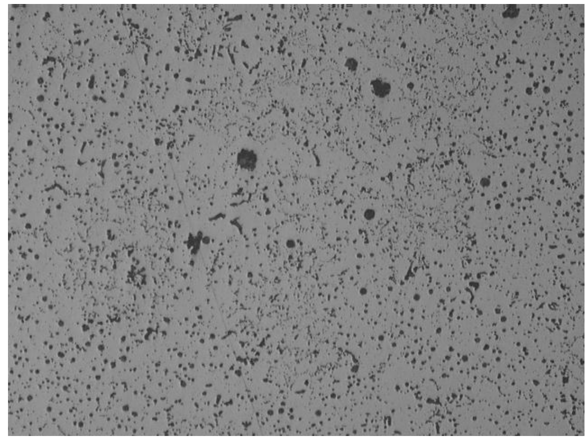


9

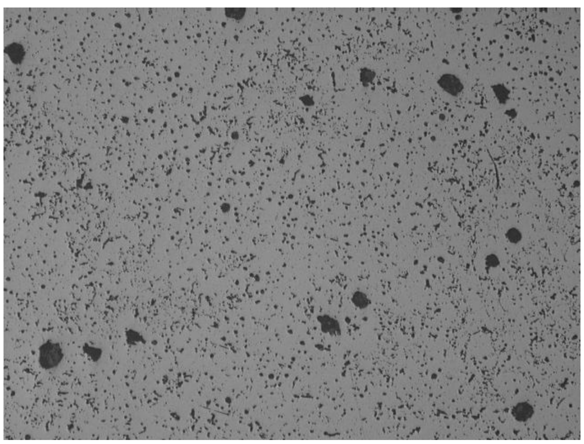
Appendix - DPI2-D CGI casting microstructures-ingate section



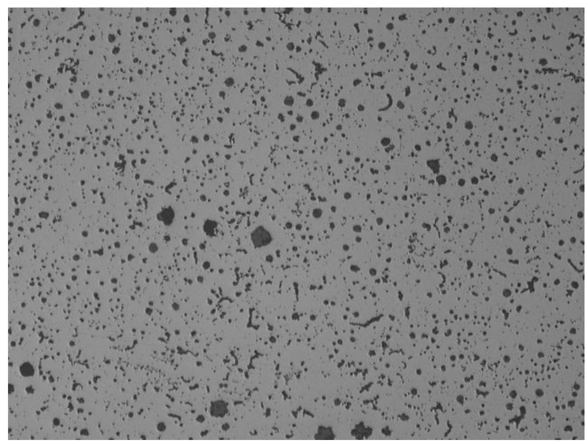
locator



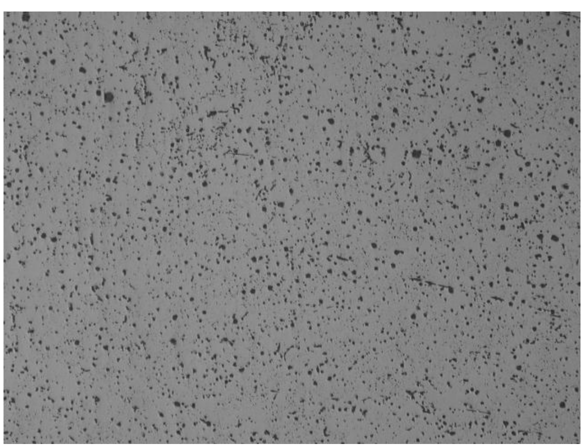
1



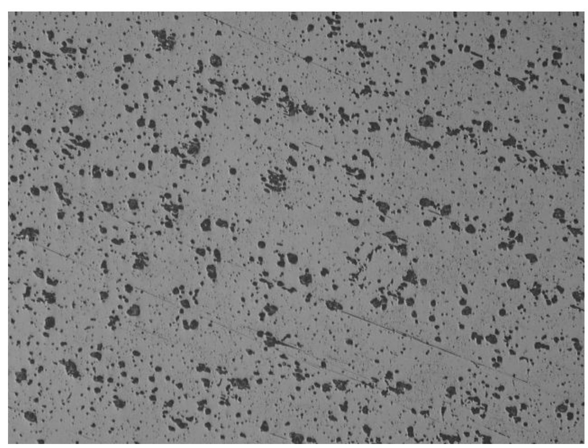
2



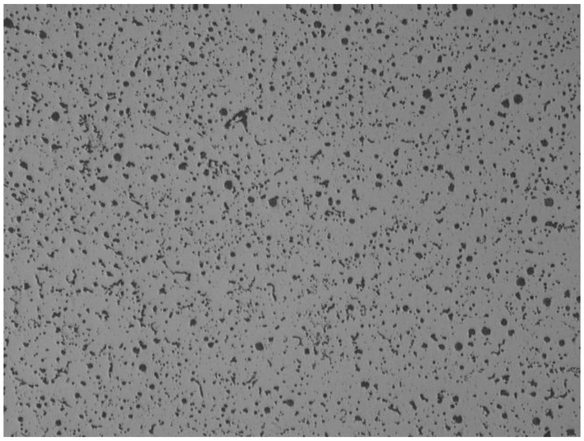
3



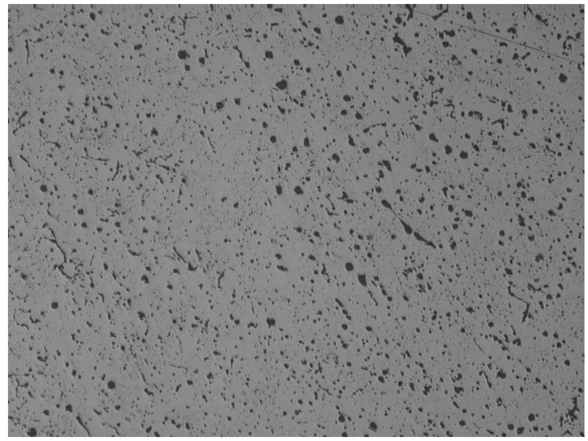
4



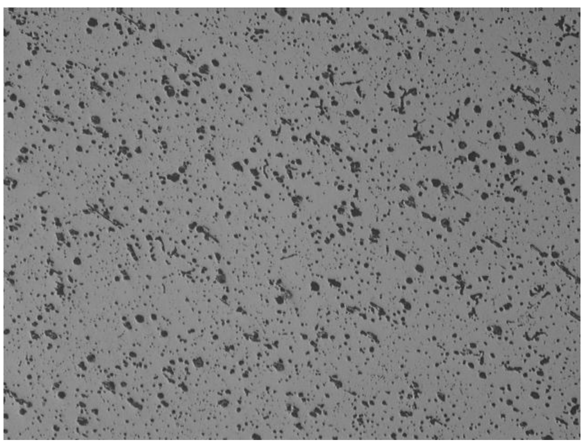
5



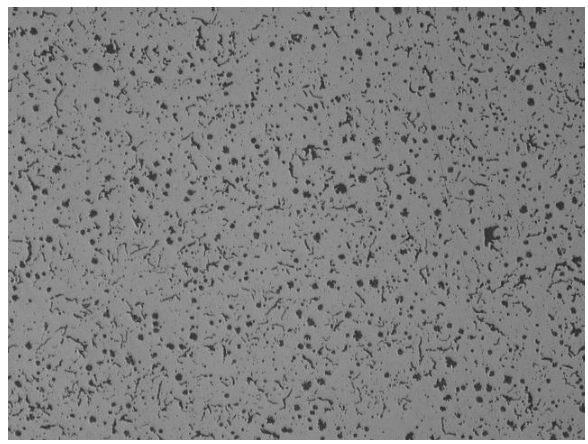
6



7

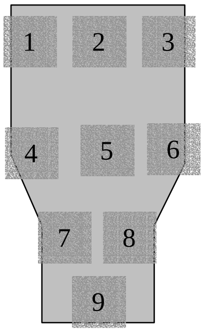


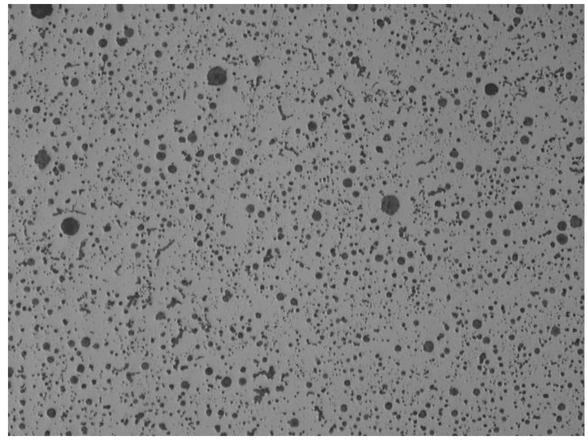
8



9

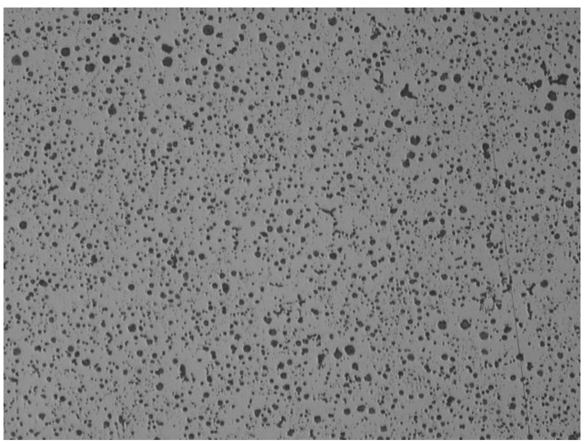
Appendix - DPI2-D CGI casting microstructures-end section

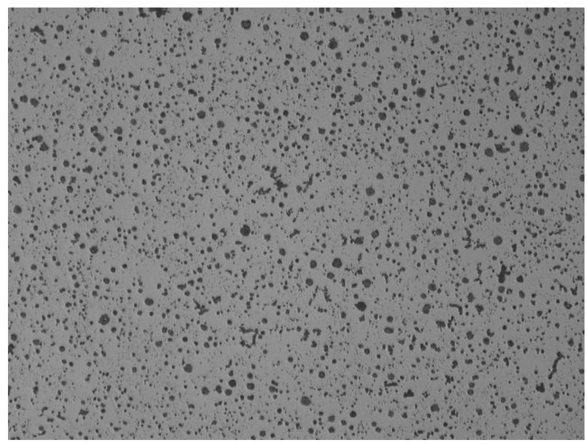




locator

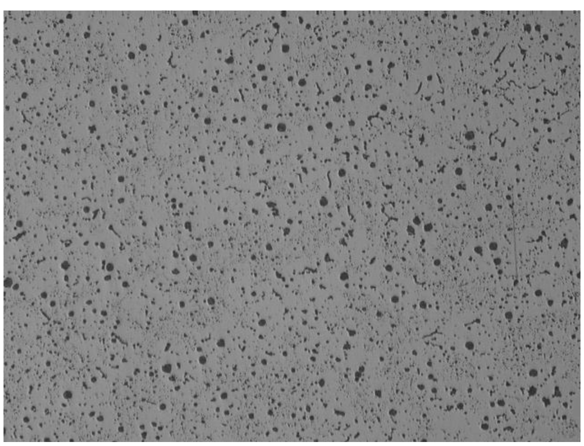
1

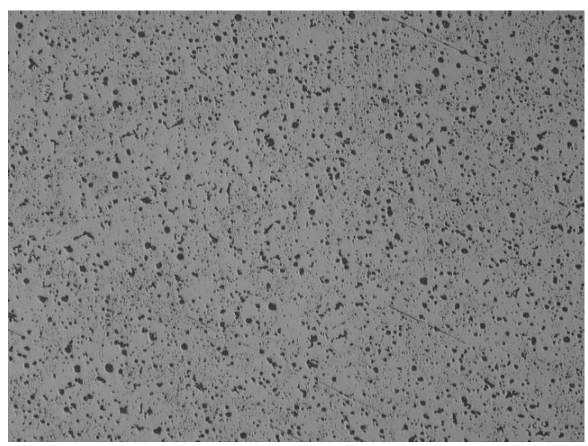




2

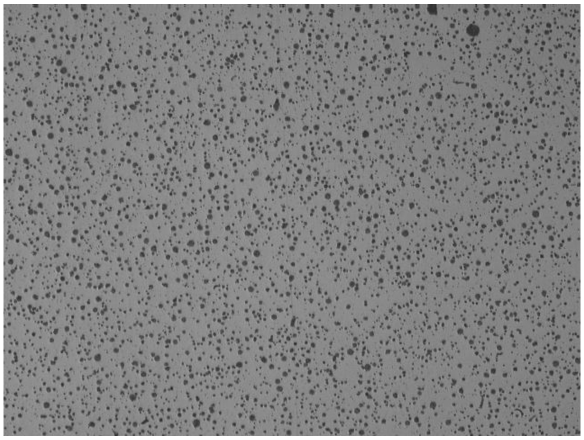
3



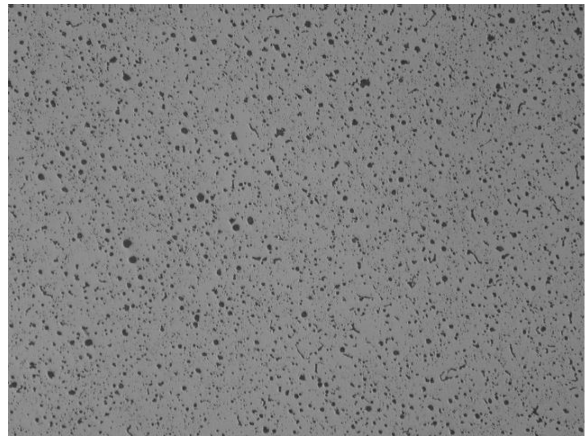


4

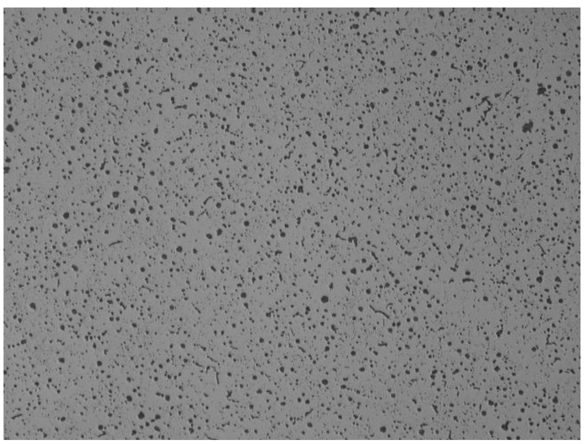
5



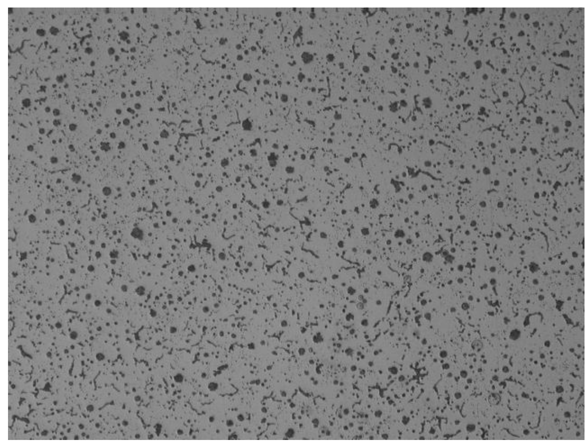
6



7



8



9

Appendix - Ingate microstructures for CGI trials

The microstructures were obtained from the thicker section close to the DPI container. For each ingate five microstructures were obtained at various locations across the width of the ingate. Fig. 6 shows a schematic of the location. Note that the figure shows the ingate on its head, that is the thicker section is normally on the bottom and the thinner one on top.

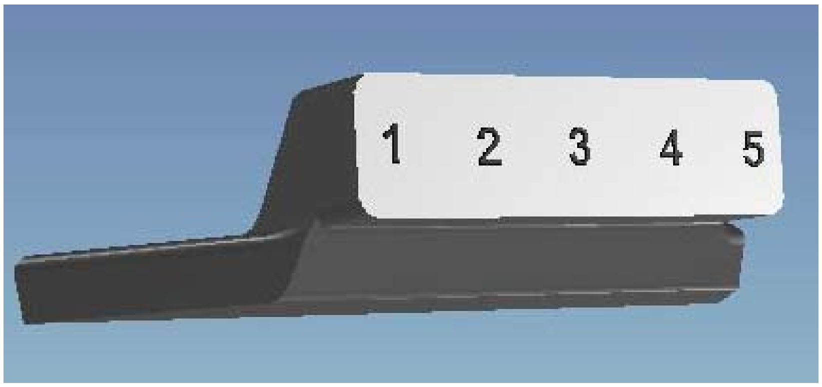
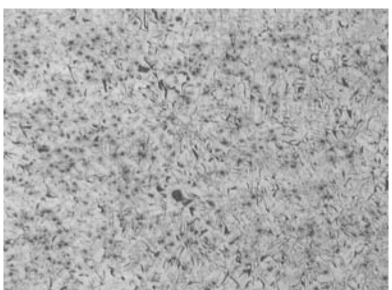
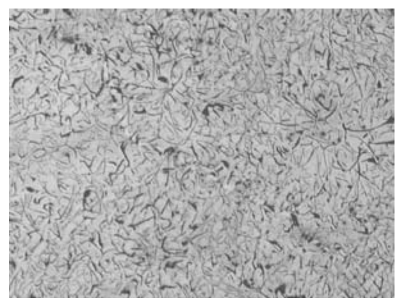
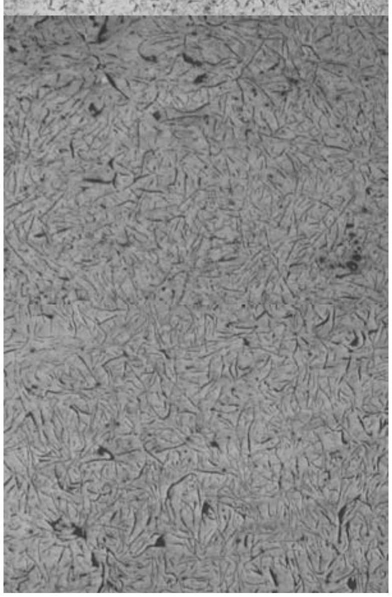
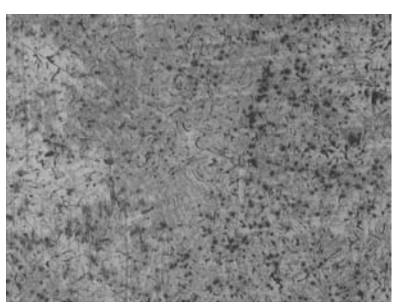


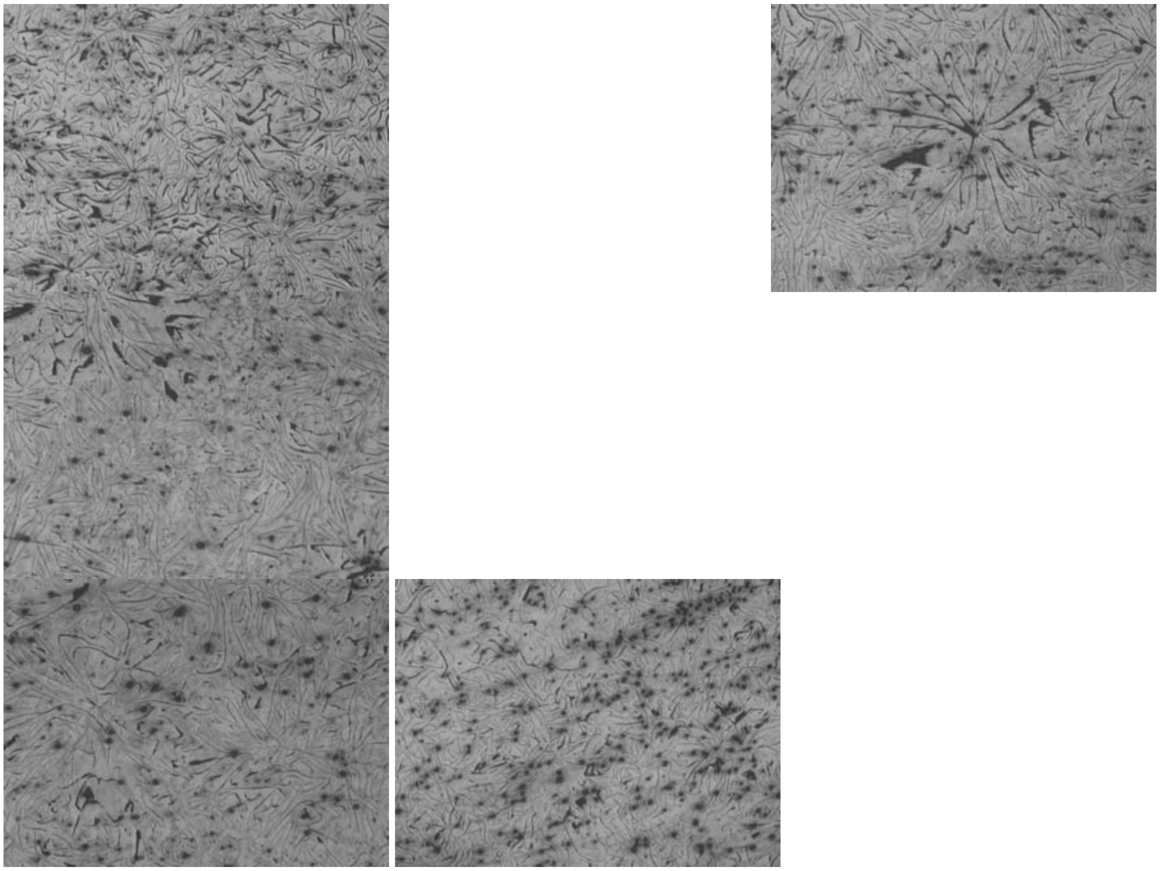
Fig. 6 Locator for the microstructures of the DPI2 CGI heats.

All micrographs were taken with a magnification of 50X. The initial image size was 6.3" but was reduced to 2" width. Since this investigation is predominantly qualitative, the reduction is size is deemed acceptable.

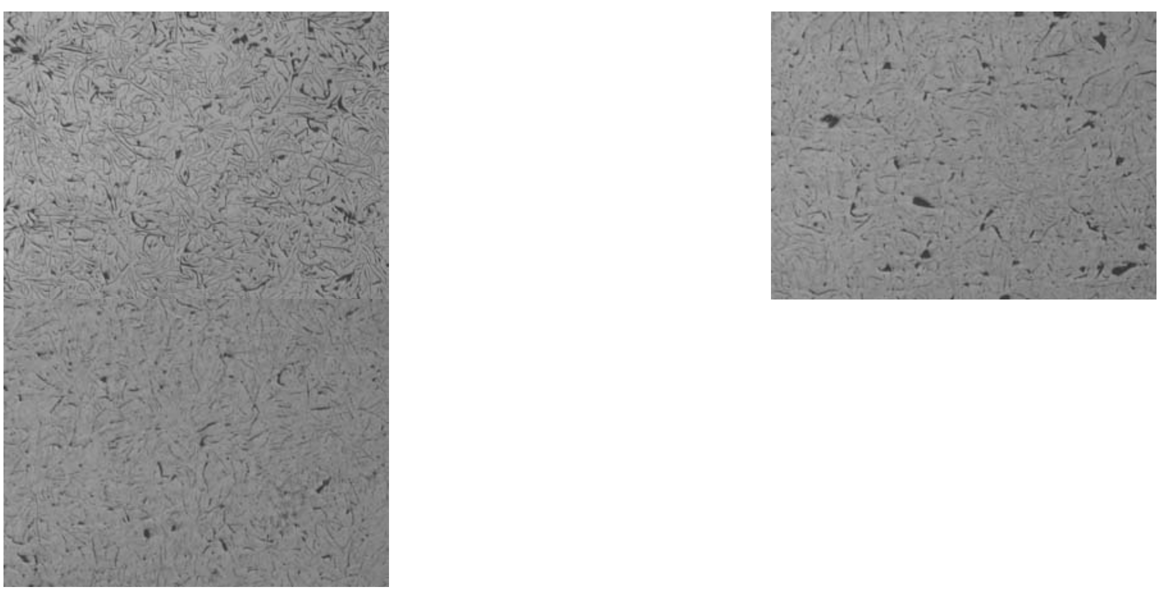
DPI2-A

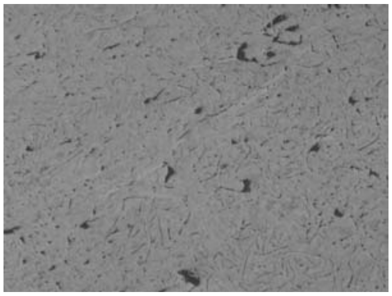





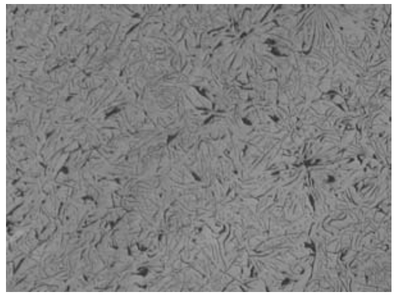
DPI2-B



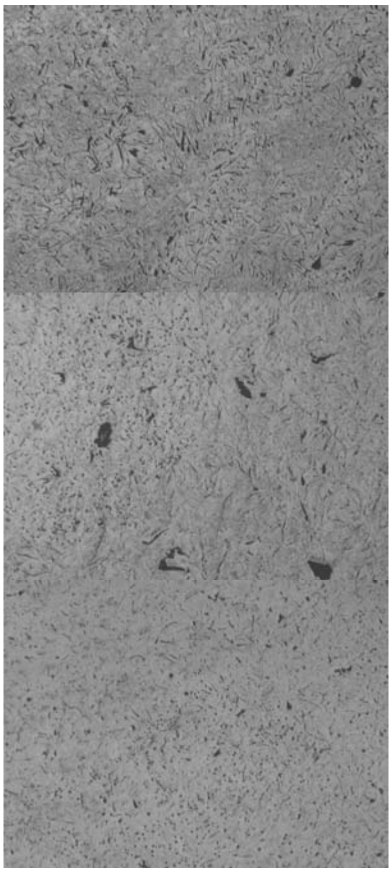
DPI2-C

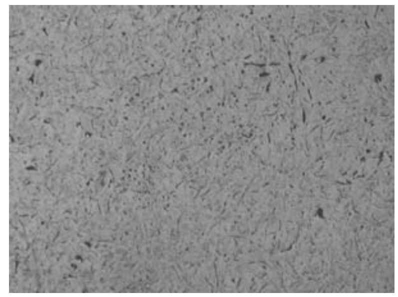


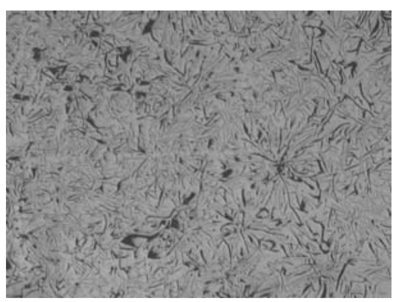




DPI2-D



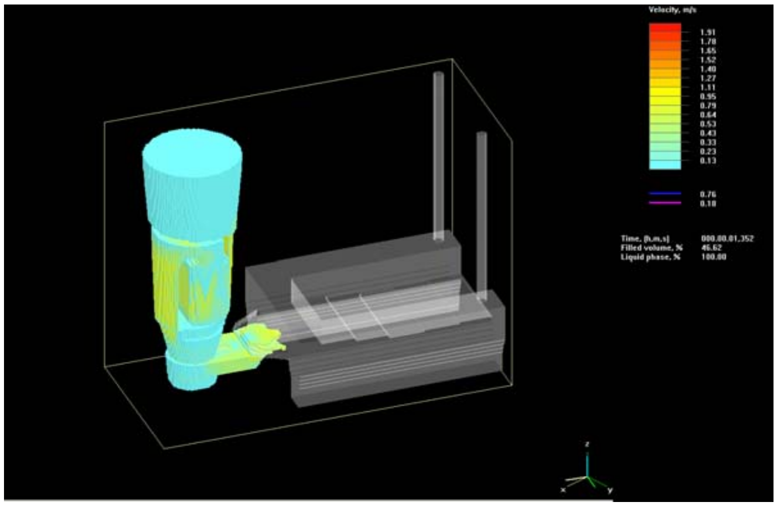


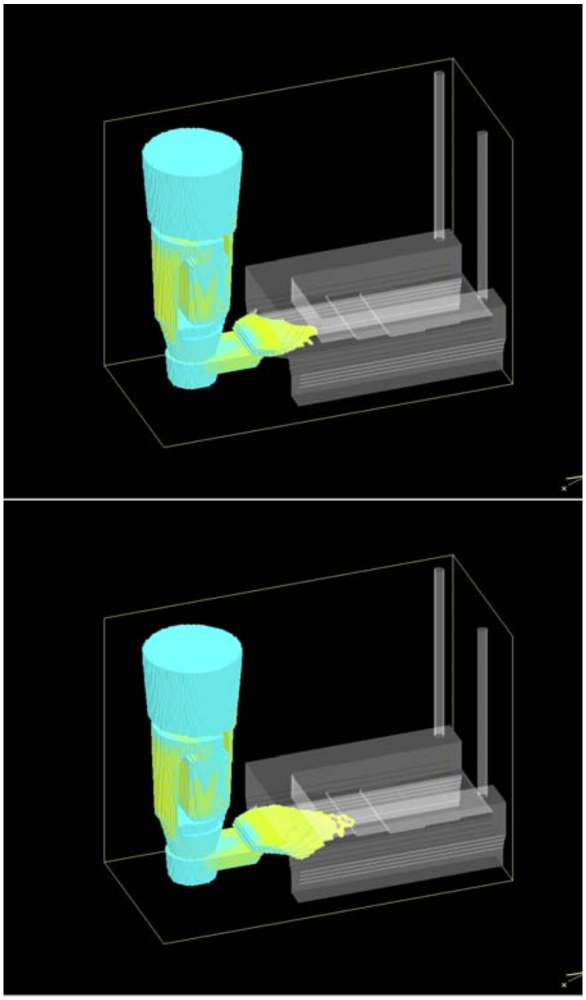


Appendix - Filling sequence of simulation 050720

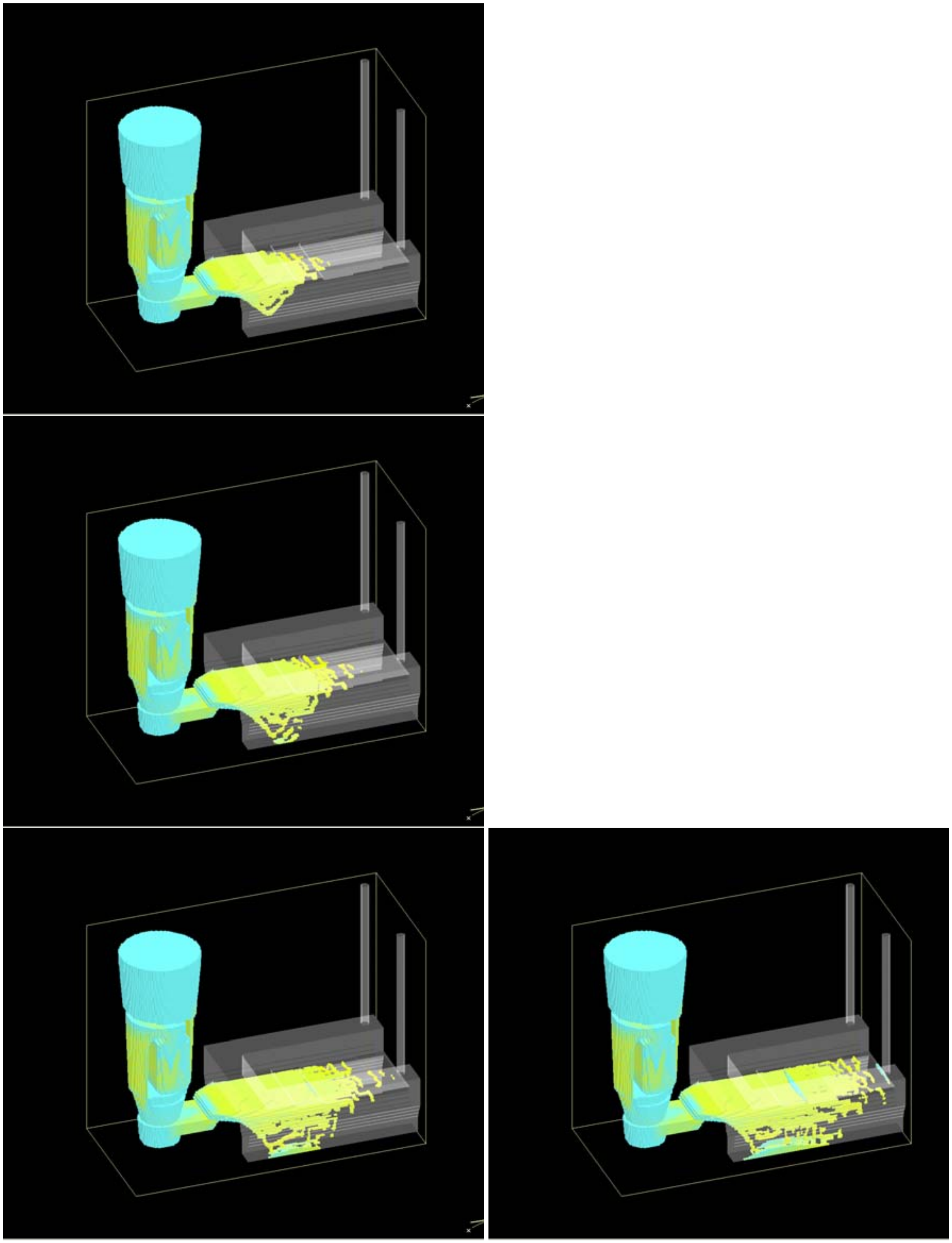
Time step 0.5 seconds

From the time the first liquid enters the casting.
The simulation was run for the velocity profile, thus the unit in the scale is [in/s]. Areas in yellow show a higher velocity than those in light blue.

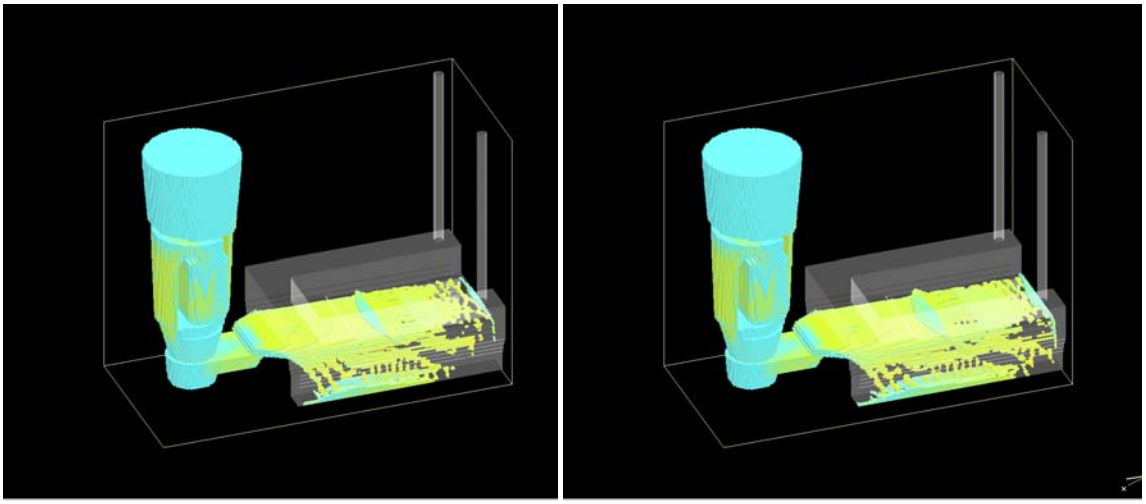




Unobstructed flow of liquid over the flat portion of the casting, liquid about to flow into the Y-block section.



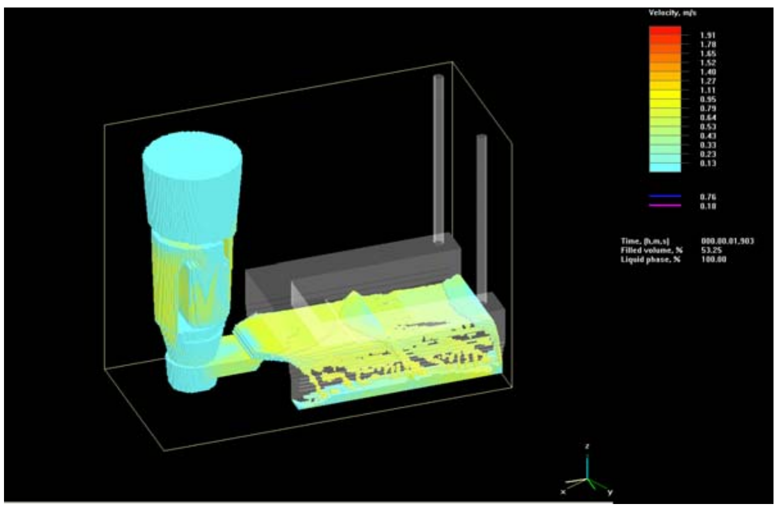
Onset of the liquid getting stopped by the 2mm plate in the middle.

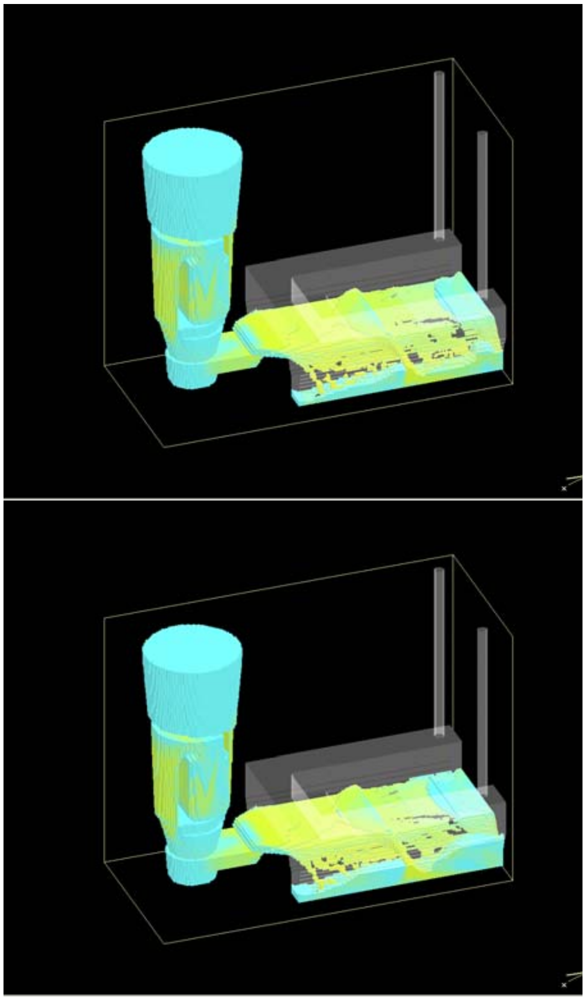


Liquid is cascading down the side into the Y-block.

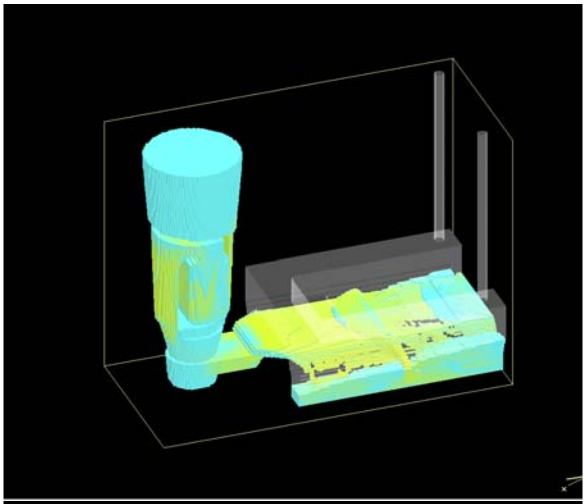
Time step 2 seconds

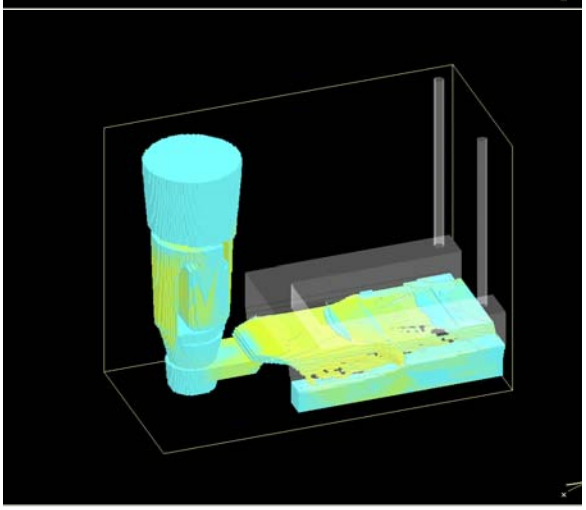
Continuation of the preview sequence with a 2 seconds time step



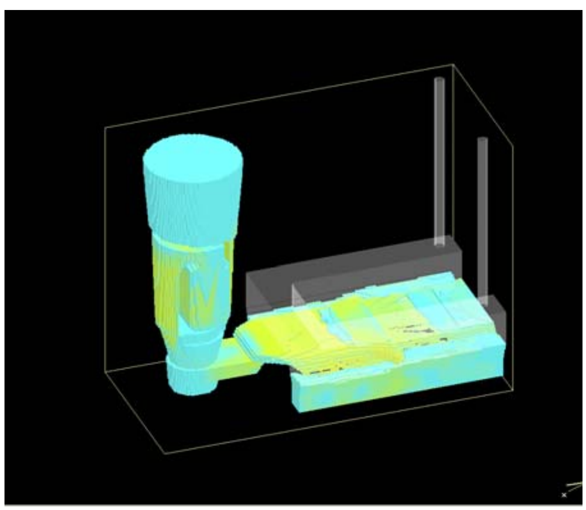


Filling of the backside of the casting.





Liquid flow is obstructed by the 10mm plate, filling of the Y-block continues.



6mm and 4mm plate is filled.