Casting Emission Reduction Program

Prepared by:
TECHNIKON LLC
5301 Price Avenue ▼ McClellan, CA, 95652 ▼ (916) 929-8001
www.technikonllc.com

US Army Contract DAAE 30-02-C-1095
FY 2002 Tasks

Quality Improvement: Mechanically Assisted Greensand Molding

Technikon #1409-611 FH

Originally Published
30 September 2003
This document revised for public distribution.

United States Environmental Protection Agency

CISA

AMERICAN FOUNDRY SOCIETY, INC.

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

DaimlerChrysler Ford Motor Company General Motors

THIS PAGE INTENTIONALLY LEFT BLANK

Quality Improvement: Mechanically Assisted Greensand Molding

1409-611-FH

This report has been reviewed for completeness and accuracy and approved for release by the following:

Process Engineering Manager:	*// Original Signed //* Steven Knight	Date
VP Measurement Technologies:	*// Original Signed //* Clifford Glowacki, CIH	Date
VP Operations:	*// Original Signed //* George Crandell	Date
President:	*// Original Signed //* William Walden	Date

The data contained in this report was developed to assess the relative consistency of greensand molds and the surface appearance of castings made from them. The molds and castings were produced in the Technikon casting facility. You may not obtain the same results in your facility. Data was not collected to assess casting cost or environmental impact.

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

List of Figures

List of Tables

Appendices

Executive Summary

This report contains the casting results from greensand molds made by use of a pneumatic semi-automatic Osborne WhisperRam Model 716 molding machine. By contrast, prior experiments at Technikon used molds made by hand ramming wherein a pneumatic rammer was directed over the mold sand surface at the will of an operator.

Molding, or the densification of granular molding media about a fixed-geometry pattern, is subject to many variables in the mold sand, the pattern geometry, and the operator's skill. The grossest measure of manufacturing consistency is the variation of the mold weight.

The surface texture, in the absence of defects, is a direct consequence of the void size between sand grains. The metal's surface tension must bridge these voids to make a smooth cast surface. The metal is naturally extruded into the sand voids hydraulically by the liquid metal pressure head (metal penetration aka burned in sand). Small improvements in compaction efficiency have a significant impact upon the resulting average void size between sand particles. In the absence of chemical reactions that cause chemical bonding (fusion aka burned-on sand) and wetting of the mold media surface by the metal, the smaller sand voids result in a smoother casting. The compacted bulk sand density is a broad measure of the sand void size for a given type of sand mixture. Higher sand density is a demonstration of smaller voids between the sand grains.

The table below compares these two parameters for hand rammed six-on stars and machine-rammed four on stars made with the same type of sand controlled to the same parameters.

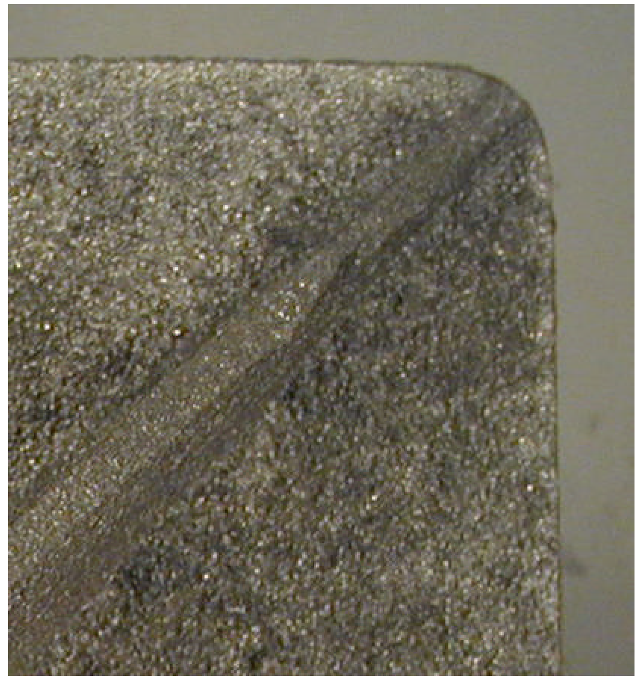
	Mold size L x W x D Inches	**Mold weight Pounds**	**Mold weight 2-sigma variance % of mold weight**	**Sand bulk density Lb/ft^3**
6-on hand rammed	36 x 24 x 28	1307	4.1	93.8
4-on machine rammed	24 x 24 x 20	640	1.6	96.1

The increase in density and better consistency are demonstrated benefits of the ability of a machine to apply higher compaction pressures more uniformly.

Metal penetration was chosen as the criterion for visual comparison of molding-method-related surface finish with the star pattern. All other defects were ignored. Five persons made relative visual judgments of the surface quality by mold sequence and mold cavity on each pattern to rank-order the castings. Various tables in the report show this ranking. Pictures of all of the ranked castings and some hand molded castings are presented in the Appendices D and E.

Osborn made castings had a superior surface finish as compared to previous hand-rammed molds.

Metal penetration aka burned in sand on flat surface of gray cast iron



Fusion penetration on surface of gray cast iron near hot spot

1.0 Introduction

1.1 Background

Technikon LLC is a privately held contract research organization located in McClellan, California, a suburb of Sacramento. Technikon offers emissions research services to industrial and government clients specializing in the metal casting and mobile emissions areas. Technikon operates the Casting Emission Reduction Program (CERP). CERP is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). Its purpose is to evaluate alternative casting materials and processes that are designed to reduce air emissions and/or produce more efficient casting processes. Other technical partners directly supporting the project include: the American Foundry Society (AFS); the Casting Industry Suppliers Association (CISA); the US Environmental Protection Agency (US EPA); and the California Air Resources Board (CARB).

1.2 Technikon Objectives

The primary objective of Technikon is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was designed to evaluate alternate materials and production processes designed to achieve significant air emission reductions, especially for the 1990 Clean Air Act Amendment. The facility has two principal testing arenas: a Pre-Production Foundry designed to measure airborne emissions from individually poured molds, and a Production Foundry designed to measure air emissions in a continuous full scale production process. Each of these testing arenas has been specially designed to facilitate the collection and evaluation of airborne emissions and associated process data.

The Production Foundry provides simultaneous detailed individual emission measurements using methods based on US EPA protocols for the melting, pouring, sand preparation, mold making, and core making processes. The core making area of the Production foundry contains three core blowers, a Georg Fischer for the preparation of automotive block cores, a Redford that is used for the production of step cores, and a second smaller Redford to produce dogbone tensile test specimens.

1.3 Report Organization

This report has been designed to document the methodology and results of a specific test plan that was used to evaluate the greensand mold hardness and casting surface finish. Section 2 of this report includes a summary of the methodologies used for data collection and analysis and data management. Specific data collected during this test are summarized in Section 3 of this report. Appendix B of this report includes the details of sand mixing, mold hardness surveys, & melting logs.

1.4 Specific Test Plan and Objectives

The Test Plan to make the molds and castings is included in Appendix A. The objective of this testing was to demonstrate the casting surface finish that can be achieved with mechanically assisted molding operating under the process parameter conditions previous use by Technikon to produce castings from hand rammed molds.

Table 1-1 provides a summary of the test plan for the greensand mold making. The details of the approved test plans are included in Appendix A.

Table 1-1 Test Plan Summary

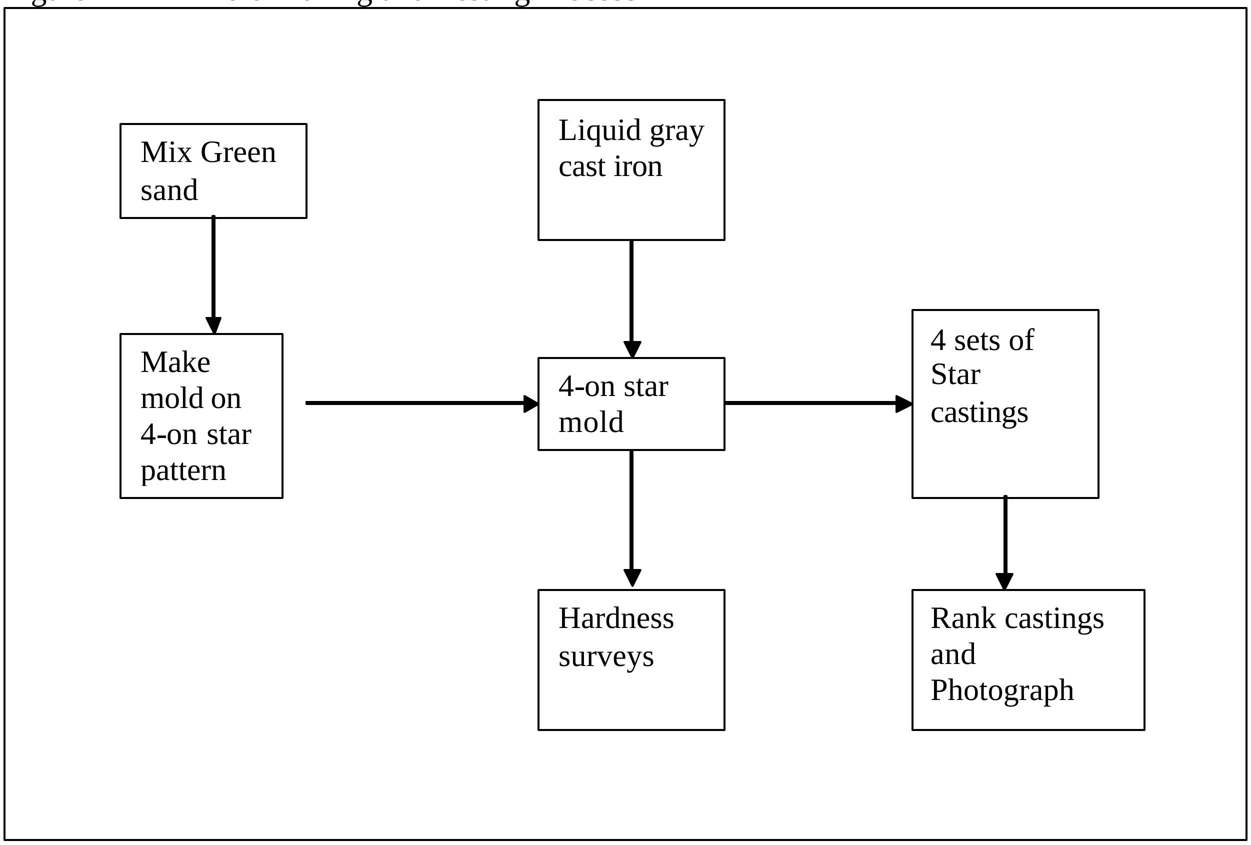
	Test Plan
Type of Process tested	Quality Improvement: Mechanically Assisted Coreless Greensand Molding
Test Plan Number	FH
Core Binder System	None
Metal Poured	Iron
Casting Type	4-on Star
Number of molds poured	11
Test Dates	6/30/03>7/08/03
Emissions Measured	None
Process Parameters Measured	Total Casting, Mold, and Binder Weights; Metallurgical data, % LOI, Sand Temperature, Mold hardness surveys, Casting photos

2.0 Test Methodology

2.1 Description of Process and Testing Equipment

Figure 2-1 is a diagram of the greensand mold making process and testing equipment.

Figure 2-1 Mold Making and Testing Process



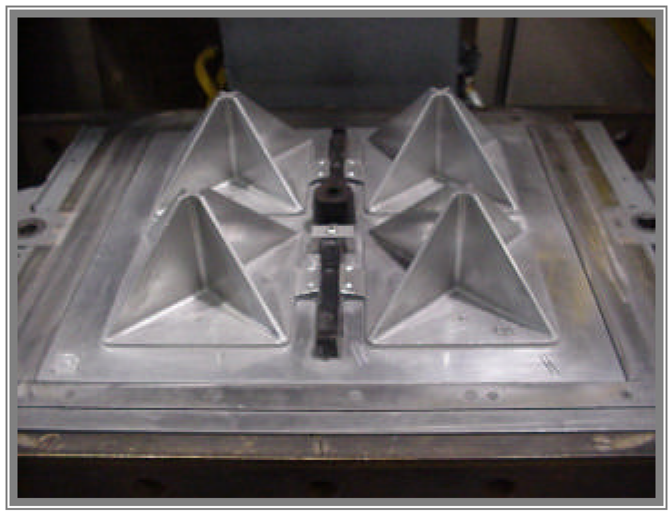
2.2 Description of Testing Program

The specific steps used in this sampling program are summarized below:

1. **Test Plan Review and Approval:** The proposed test plan was reviewed by the Technikon staff and the CERP Steering Committee, and approved.

2. **<u>Sand Preparation</u>:** Green molding sand is prepared to a standard composition in a vertical wheeled muller. Virgin materials are used with out preconditioning to assess how many cycles are required before the mold hardness and casting surface finish stabilize. Wexford 450 Lakesand is combined with 7% western (sodium rich) and southern (Calcium rich) bentonite clays in a 5:2 ratio. Seacoal (Bituminous aka soft coal) is added to yield a 5 % Loss on Ignition (LOI) value when burned for two hours at 1800^{o}F.

3. **<u>Pattern:</u>** A four-on star pattern was built to be used in this test. The stars have 5.3 millimeter thick fins cope and drag measured along the free edge.



4. **<u>Mold Preparation</u>:** Greensand cope and drag mold halves were produced on a single Osborne model 716 WhisperRam semi-automatic molding machine in a 24x24x10 inch mold flask utilizing a 4-on star pattern.

5. **<u>Process Parameter Measurements:</u>** Table 2-1 lists the process parameters that are monitored during each test. The analytical equipment and methods used are also listed.

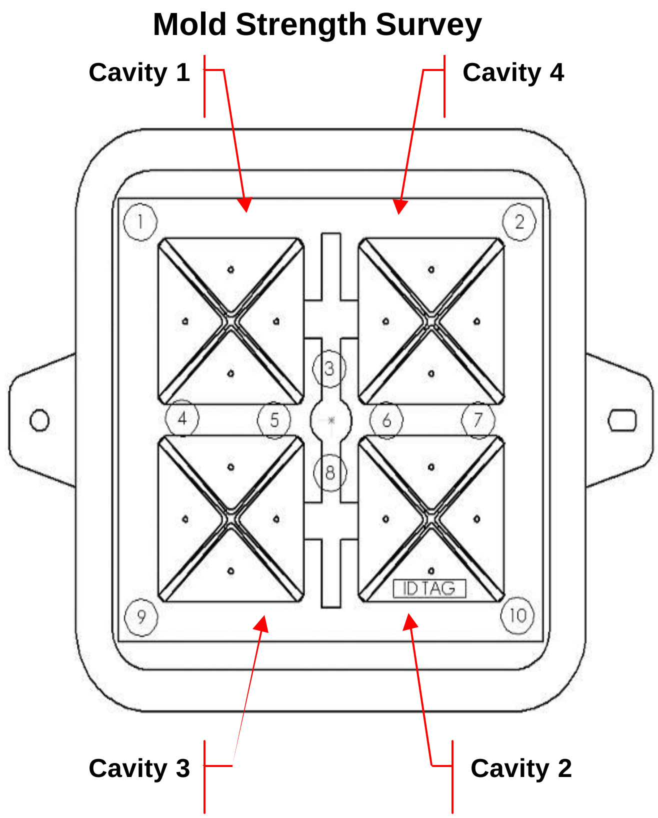
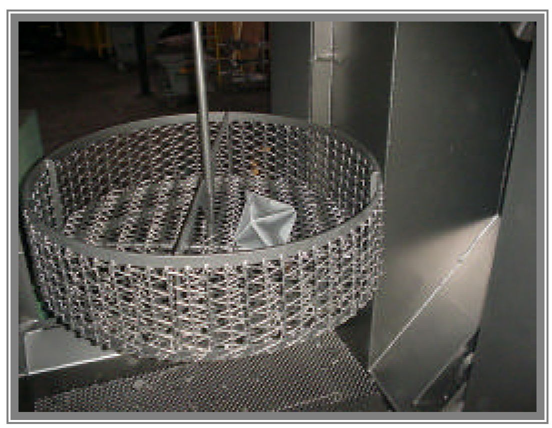


Table 2-1 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Binder Weight (mixing)	Mettler PJ8000 Digital Scale (Gravimetric)
Sand Weight (mixing)	OHAUS 110# digital platform scale
Sand Temperature (mixing)	Stem type dial thermometer
Cycle Time	Digital elapsed time clocks
Mold Weight	Cardinal 748 Digital Platform Scale
Cooling curve	Thermocouple and multi-channel recorder
Mold hardness	Deitert 454B mold strength tester
Casting Weight	OHAUS 110# digital platform scale
Metal Alloy Weight	OHAUS 110# digital platform scale

6. **Metal Melting:** Iron is melted in a 1000 lb. Ajax induction furnace. The amount of metal melted is determined from the poured weight of the casting and the number of molds to be poured. The metal composition is prescribed by a metal composition work-sheet. The weight of metal poured into each mold is recorded on the process data summary sheet.

7. **Casting Process**: Mold is poured with gray cast iron at 2680^{o}F.



8. **Casting Cleaning:** The castings were shot blast to a standard 8 minute cycle. Castings were separated by mold and pattern numbers.

9. **Report Preparation and Review:** The Preliminary Draft Report is reviewed by the Manager, Process Engineering, and the Emissions Team to ensure its completeness, consistency with the test plan, and adherence to the prescribed QA/QC procedures. Appropriate observations, conclusions and recommendations are added to the report to produce a Draft Report. The Draft Report is reviewed by the Vice President-Measurement Technologies, the Vice President-Operations. Comments are incorporated into a Final Report prior to final signature approval and distribution.

3.0 Test Results

Eleven (11) molds were poured utilizing mold sand recycled from the previous mold, the first being in the virgin state. The initial content was 8.6% clay as determined by AFS standard method 2210-00-S Methylene Blue determination of foundry clays and 5.6 % Loss on Ignition (LOI) as determined by AFS method 5100S, (Loss on Ignition in greensand). A fixed addition rate of new clays and Bituminous coal was planned to be made to maintain the clay and LOI values, however the burn out rate was sufficiently low that no further additions were required until it was judged that the surface finish was no longer improving.

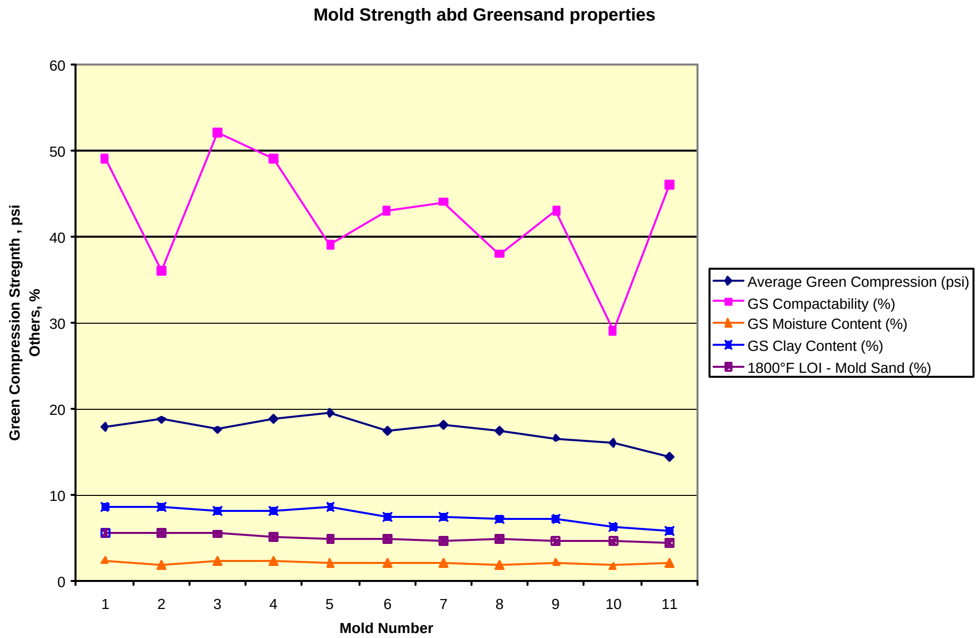
The molds were poured with class 30 gray cast iron at 2680 +/- 10°F and allowed to cool for 45 minutes then shaken out.

Table 3-1 demonstrates the average greensand properties, cast weights, and metal properties during pouring that were maintained during the recycling test.

Table 3-1 Average Greensand and Metal Properties during Pouring

Greensand PCS	Average	St Dev	RSD
GS Mold Sand Weight, (lbs.)	640.0	10.1	0.016
Cast Weight- all metal inside mold (lbs.)	95.7	3.9	0.041
Pouring Time (sec.)	24	5.1	0.210
Pouring Temp (°F)	2683	5.4	0.002
Carbon Equivalent, %C	4.01	0.1	0.020
Carbon Content, %	3.28	0.1	0.018
Silicon Content., %	2.20	0.1	0.049
Average Green Compression (psi)	17.55	1.4	0.081
GS Compactability (%)	43	6.7	0.157
GS Moisture Content (%)	2.17	0.2	0.096
GS Clay Content (%)	7.64	0.9	0.123
1800°F LOI - Mold Sand (%)	5.02	0.4	0.080
900°F Volatiles (%)	1.00	0.3	0.258
Pour hood average process air temp, F	81	4.3	0.052

Figure 3-1 Selected Mold Sand Properties



Each mold yielded four (4) castings identified by casting cavity number according to Fig 3-2. The position on the mold machine is as if the reader is standing below Fig. 3-1 and looking upward. The numbers indicate the location of the mold strength measurements

Figure 3-2 Mold layout

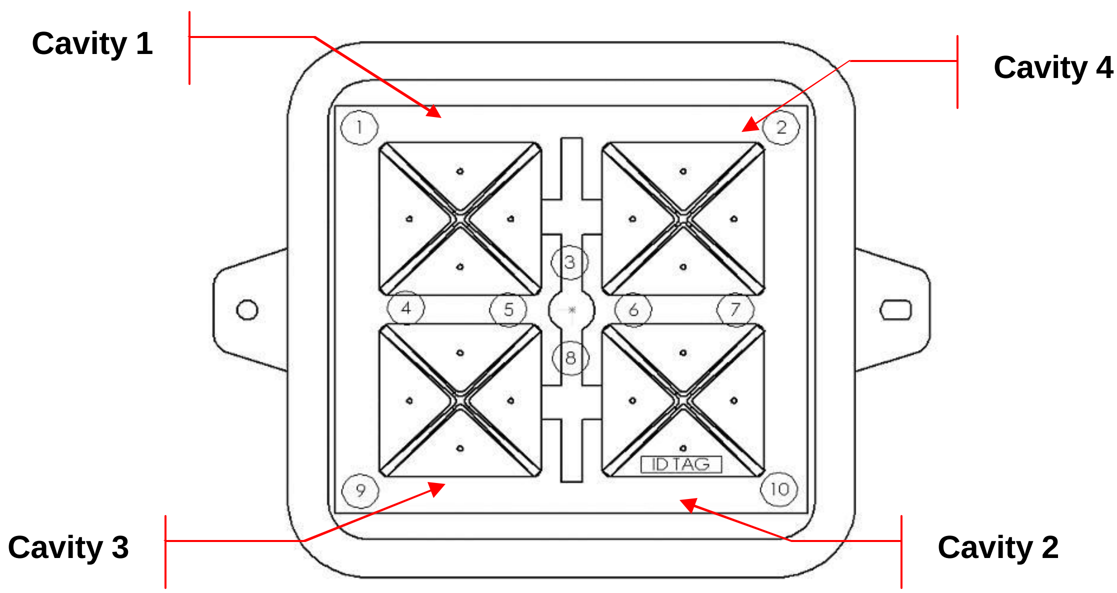


Table 3-2 Cope and Drag Mold Strength (psi) by Mold and Position in Mold

Mold	C/D	Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Pos10
FH001	Cope	3	3	18	10	13	13	10	14	5	3
	Drag	4	4	17	10	12	14	10	16	3	3
FH002	Cope	7	7	22	17	19	19	14	23	7	7
	Drag	6	7	21	16	20	17	13	22	9	7
FH003	Cope	6	6	19	12	15	15	14	21	6	6
	Drag	7	6	22	15	17	18	14	21	6	3
FH004	Cope	7	7	20	13	16	16	13	20	6	6
	Drag	7	7	22	13	18	17	14	21	7	7
FH005	Cope	7	7	23	17	18	18	17	22	8	8
	Drag	6	6	18	13			12	18	6	5
FH006	Cope	7	7	21	15	16	16	15	20	7	7
	Drag	7	6	22	15	15	15	14	20	7	7
FH007	Cope	6	6	19	12	13	13	13	19	6	6
	Drag	6	6	19	13	14	14	13	19	6	6
FH008	Cope	6	7	20	14	16	16	14	20	7	7
	Drag	7	7	20	14	16	16	14	20	7	7
FH009	Cope	6	7	20	12	14	15	14	20	7	6
	Drag	6	6	19	13	14	14	13	19	6	6
FH010	Cope	6	7	20	13	14	14	13	20	6	6
	Drag	6	6	19	13	15	15	13	19	6	6
FH011	Cope	6	7	21	12	16	15	14	19	7	7
	Drag	6	7	20	11	12	14	13	20	6	6
Average		6.14	6.32	20.09	13.32	15.38	15.43	13.36	19.68	6.41	6.00
St.Dev.		0.99	1.04	1.54	1.94	2.18	1.66	1.47	1.94	1.14	1.38
RSD		0.16	0.16	0.08	0.15	0.14	0.11	0.11	0.10	0.18	0.23

Figure 3-3 Indenter Mold Strength at Measured Position vs. Mold Cycle X 2

Data from Table 3-2

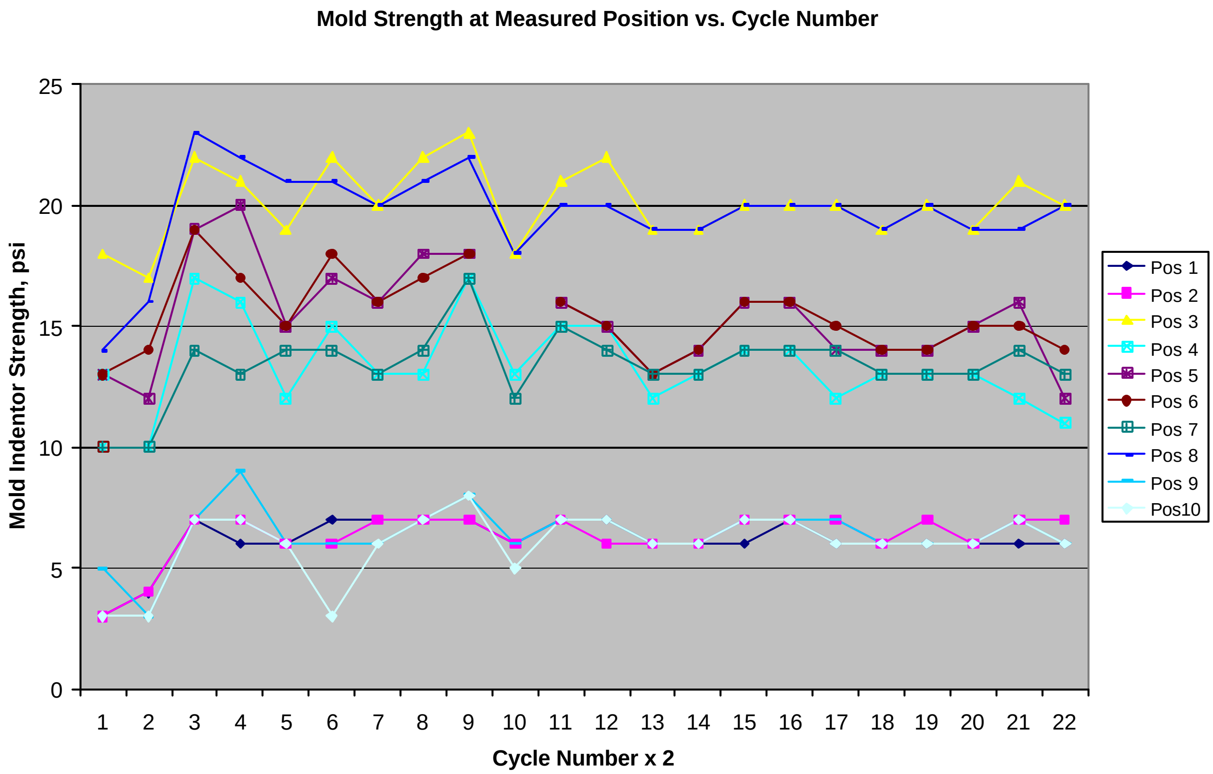


Table 3-3 is the casting surface finish ranking. The Rank-Order procedure requires that each cavity initially be laid out in order of production. (See Appendix D) Five (5) experienced foundry personnel then rate the surface finish of each casting relative to its nearest neighbors within each cavity according to a fixed set of criteria. The criteria in this test required that we ignore all surface defects except metal penetration and fusion (see Glossary). These two defects, of those present, best relate to molding parameters. The rated casting is moved either up or down the quality line as the relative rating dictates. After several iterations each cavity lineup will be ranked according to relative surface quality. The best casting at each quality level is in *italics*.

Table 3-3 Rank–Order of Four (4) Cavities of Star Castings from Eleven Molds

FH CASTING RANK-ORDER

CAVITY #	WORST					MED					BEST
1	FH003	FH001	FH004	FH005	FH007	FH009	FH010	FH011	FH006	FH002	FH008
2	FH003	FH001	FH005	FH004	FH008	*FH007*	FH009	FH010	FH011	FH002	*FH006*
3	FH003	*FH001*	*FH004*	*FH005*	*FH002*	FH010	*FH006*	*FH007*	*FH008*	*FH009*	FH011
4	*FH002*	FH001	FH004	FH007	FH003	FH009	FH006	FH008	FH010	FH011	FH005
RANK	11	10	9	8	7	6	5	4	3	2	1
	Photos					Photos					Photos

Figure 3-4, 3-5, and 3-6 are photos of Best, Median, and Worst cope surface castings as ranked in Table 3-3.

Figure 3-4 **Best Surface** **Figure 3-5** **Median Surface** **Figure 3-6** **Worst Surface**

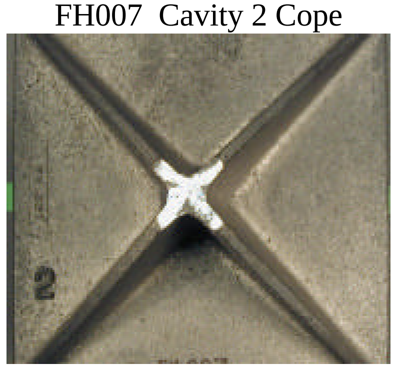
FH003 Cavity 1 Cope

FH009 Cavity 1 Cope

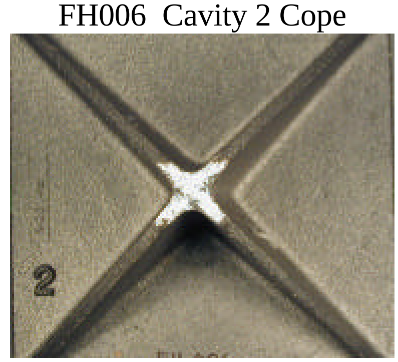
FH008 Cavity 1 Cope

FH003 Cavity 2 Cope

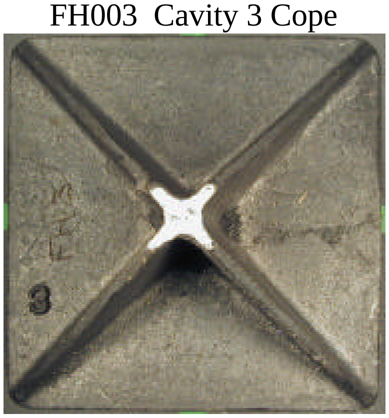
FH007 Cavity 2 Cope



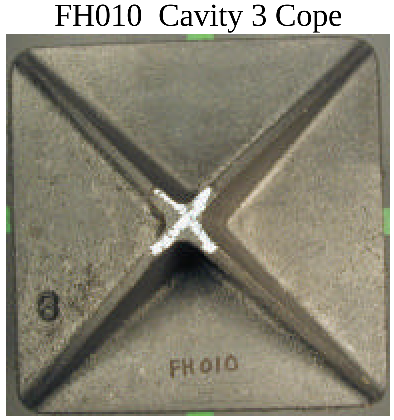
FH006 Cavity 2 Cope



FH003 Cavity 3 Cope



FH010 Cavity 3 Cope



FH011 Cavity 3 Cope

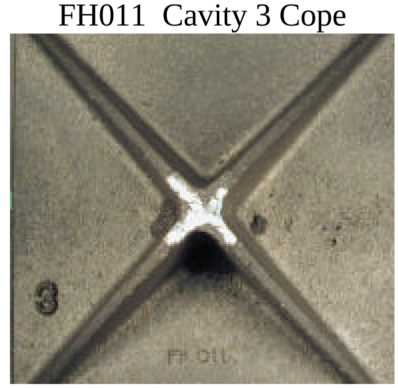


Figure 3-4 Best Surface

FH002 Cavity 4 Cope

Figure 3-5 Median Surface

FH009 Cavity 4 Cope

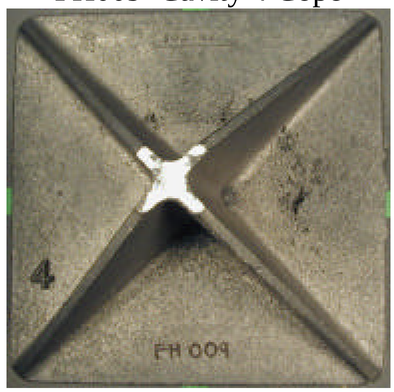


Figure 3-6 Worst Surface

FH005 Cavity 4 Cope

Table 3-4 Cavities Ranked during Each Run

FH RANKED ORDER BY CAVITY FOR EACH RUN

Run	FH001	FH002	FH003	FH004	FH005	FH006	FH007	FH008	FH009	FH010	FH011
Cavity Rank 1	**3-10**	1-2	4-7	2-8	4-1	1-2	**3-4**	1-1	**3-2**	4-3	3-1
Cavity Rank 2	1-10	2-2	1-11	1-9	**3-8**	**2-2**	**2-6**	**3-3**	2-5	2-5	4-2
Cavity Rank 3	2-10	**3-7**	2-11	**3-9**	1-8	**3-7**	1-7	4-4	4-6	3-6	2-3
Cavity Rank 4	4-10	**4-11**	3-11	4-9	2-9	4-11	4-8	2-7	1-6	1-5	1-4

Body values are cavity number & rank order

Table 3-5 Frequency of Cavity Ranking during Each Run

FREQUENCY OF RANKING BY CAVITY

	Cavity 1	Cavity 2	Cavity 3	Cavity 4
Rank 1	3	1	4	3
Rank 2	3	5	2	1
Rank 3	2	3	4	2
Rank 4	3	2	1	5

4.0 Discussion of Results

This report contains the results of making greensand molds by use of a pneumatic semi—automatic Osborne WhisperRam Model 716 molding machine. By contrast prior experiments used molds made by hand ramming wherein a pneumatic rammer was directed over the mold sand surface at the will of an operator.

Molding, or the densification of granular molding media about a fixed-geometry pattern, is subject to many variables in the mold sand, the pattern geometry, and the operator's skill or inclination.

The grossest measure of manufacturing consistency is the variation of the mold weight. Additionally bulk sand density is a broad measure of the sand void size for a given type of sand mixture. Historically, the hand rammed six (6)-on star pattern exhibited a (2 sigma) weight variance of 54 pounds about a 1307 pound average weight after an initial three (3)-cycle conditioning. (See Appendix B test EM). The observed weight variance therefore was 4.1 % and the mean bulk density, corrected for the casting cavity void, was 93.8 pounds/ ft^3. With the exception of the first virgin sand mold, the mechanically assisted four (4) on star molds exhibited a (2 sigma) weight variance of 10.2 pounds, about a 640 pound average mold weight, or 1.6%. The casting-cavity-void-corrected mean bulk density was 96.1 pounds/ ft^3 with the same type of sand (See Appendix B, Test FH). The increase in density and better consistency are demonstrated benefits of the uniformly applied higher compaction pressures.

The average casting surface roughness reflects, among other things, the size of the sand grain voids in the compacted mold sand. The metal's surface tension must bridge these voids. In the absence of chemical reactions, the metal is naturally extruded into the sand voids hydraulically by the liquid metal pressure head (metal penetration aka burned in sand). Small improvements in compaction efficiency have a significant impact upon the resulting average sand grain void size. Again, in the absence of chemical reactions that cause chemical bonding (fusion aka burned-on sand) and wetting of the mold media surface by the metal, the smaller the sand voids the smoother the casting. The higher sand density is demonstration of smaller voids between the sand grains.

In the real world chemical reactions are not totally inhibited and explosions from vapor formation can send acoustic pressure waves through the metal adding to the total pressure. Metal penetration was therefore chosen as the criterion for comparison of surface finish with the star pattern. Figures 4.1 and 4.2 illustrate metal penetration on gray iron surfaces

Figure 4-1 Metal Penetration aka Burned-In Sand on Flat Surface of Gray Cast Iron

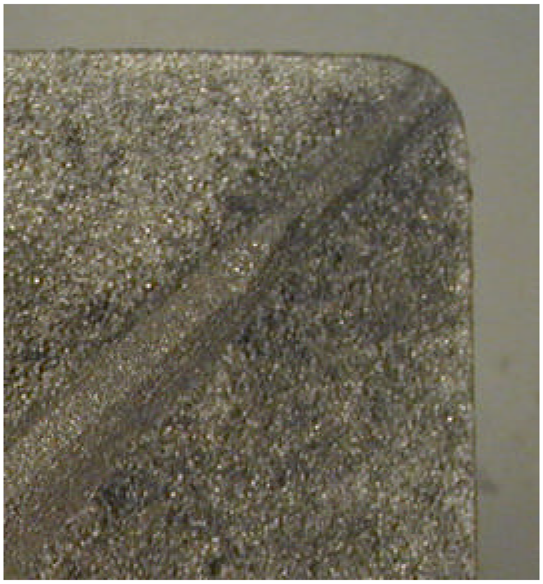


Figure 4-2 Fusion Penetration on Surface of Gray Cast Iron Near Hot Spot

Other surface defects arising from, weak sand, broken molds and slag entrainment were ignored. The defects are illustrated in Figures, 4.3, 4.4, and 4.5 without comment. The causes of these defects are several. They are not independent but they are somewhat less dependent on mold compaction than is metal penetration.

Figure 4-3 Weak Sand Grains Torn Out of the Mold at Mold Stripping (Positive Relief) and Loose Sand aka Dirt (Negative Relief)

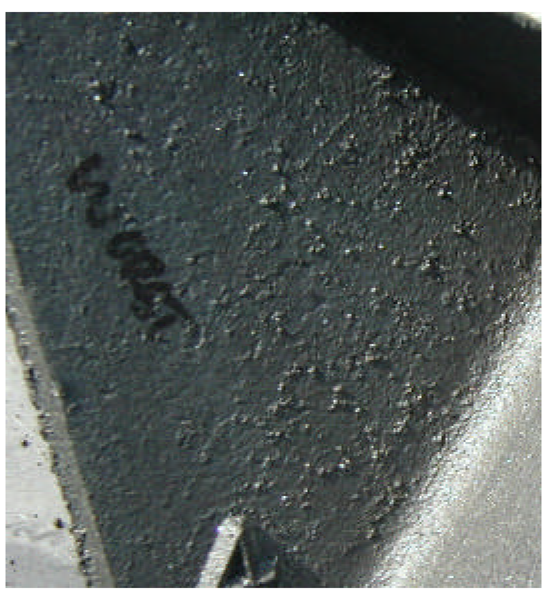
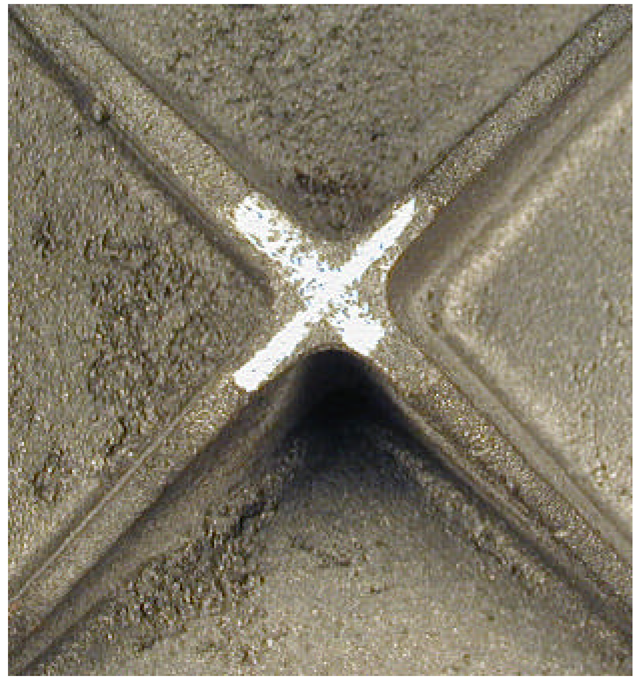


Figure 4-4 Broken Mold Created at Mold Stripping

Figure 4-5 Slag Entrainment



During the casting cycle organic components are volatilized, decomposed, recombined, and condensed bringing about a redistribution of materials and a fundamental change in the mold sand's physical character. The maturation process can be seen in Figure 3-3 (page 14) where the indenter mold strength for 10 positions in the cope and drag molds is plotted against the cycle count. The actual count is only half of that shown because both cope and drag halves, of the same mold, are documented. Noteworthy is the reduction in variation for each location after 6 cycles.

Table 3-4 (page 16) shows the rank-order analysis and demonstrates the general trend for the first castings poured to be of inferior surface finish and the surface finish improving with the sand conditioning and stabilization associated with continued recycling of the sand.

Table 3-5 (page 16) illustrates the random occurrence that any one cavity is better or worse than any other cavity during a given run. There is some aberration in cavities 2 and 4, but the sample size is too small to resolve it. In view of the lack of a preferred cavity for quality during each run it, the high occurrence frequency that cavity 3 stands out as the best cavity at 8 out of 11 quality levels is unexpected.

A comparison of representative photographs of star castings made by the Osborn machine and those made by hand-ramming (see Appendix E) illustrates the superior visual finish obtained by the Osborn machine. This visual superiority is confirmed by the tactile sense of the castings. The machine molded castings feel smoother.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A APPROVED TEST PLAN AND SAMPLE PLAN FOR TEST FH

THIS PAGE INTENTIONALLY LEFT BLANK

TECHNIKON TEST PLAN

- > **CONTRACT NUMBER:** 1409 **TASK NUMBER:** 6.1.1 **Series:** FH
- > **WORK ORDER NUMBER:** 1182
- > **SAMPLE EVENTS: Estimated 20**
- > **SITE**: X **PRE-PRODUCTION** ___ **FOUNDRY**
- > **TEST TYPE:** Quality improvement: greensand mechanically assisted molding
- > **METAL TYPE:** Class 30 gray iron
- > **MOLD TYPE:** 4-on coreless star greensand with seacoal
- > **NUMBER OF MOLDS:** 20+.
- > **CORE TYPE:** None
- > **TEST DATE:** **START:** 26 May 2003
  FINISHED: 10 June 2003

TEST OBJECTIVES:

Determine the relative casting surface quality and consistency that can be achieved using mechanically assisted versus hand rammed molding.

VARIABLES:

The pattern will be the 4-on star. The mold will be made with Wexford W450 sand, 7 % western and southern bentonite in a 5:2 ratio, seacoal to yield a 5 +/-0.5% LOI, tempered to 40-45% compactability, mechanically compacted. A rank order comparison will be made to previously made hand molded star castings. The molds will be maintained at 80-90^{o}F prior to pouring. The sand heap will be maintained at 1550-1600 pounds. Molds will be poured with iron at 2680 +/- 10^{o}F. Mold cooling will be 45minutes follow by 15 minutes of shakeout, or until no more material remains to be shaken out.

BRIEF OVERVIEW:

Hand rammed molds are inherently inconsistent. At different locations in the mold conditions will exist that are inconsistent with good casting requirements while in other locations valid conditions will lead to good casting quality. Mechanically assisted molding, because it is consistent and can have greater mechanical force that can be provided manually, provides the opportunity to determine a good casting environment and then cause it to exist throughout most of the mold leading to a higher percentage of high quality molds.

SPECIAL CONDITIONS:

The process will include rigorous maintenance of the size of sand heap and maintenance of the material and testing environmental temperatures to reduce seasonal and daily temperature dependent influence on the emissions

Process Engineering Manager (Technikon)	Date
V.P. Measurement Technology (Technikon)	Date
V.P. Operations (Technikon)	Date
Test Design Committee Representative	Date
Emission Committee Representative	Date

Series FH

Quality Improvement Mechanized Greensand Molding

Process Instructions

A. Experiment: A study to determine how many cycles of a virgin molding material compacted with mechanical molding equipment are necessary to achieve a constant commercial quality coreless casting. The molds shall be started with all virgin Wexford W450 sand, bonded with 7% Western & Southern Bentonite in the ratio of 5:2 and H&G bituminous coal measuring 5.0 % LOI. The molds shall be tempered with potable water to 40-45% compactability, poured at constant weight, temperature, surface area, & shape factor. This test will recycle the same mold material, replacing burned clay and coal with new materials after each casting cycle. The test will be considered complete when the casting surface appearance of six (6) consecutively cast castings are indistinguishable by the rank-order procedure.

1. No emission testing is associated with this test.

B. Materials:

1. Mold sand: Virgin mix of Wexford W450 lake sand, western and southern bentonites in ratio of 5:2, H&G seacoal, and potable water per recipe.
2. Core: None
3. Metal: Class 30-35 gray cast iron poured at 2680^{o}F.

Caution: Observe all safety precautions attendant to these operations as delineated in the Pre-production operating and safety instruction manual.

4. The following test shall be conducted:

   a. Sand batch: Single sand batch to be used for all FH molds.
   b. The sand heap shall be maintained at 775-800 pounds
   c. FH001: Virgin mix as described above, vented mold.
   d. FH002-FH0XX: Re-mulled, reconstituted greensand, potable water, vented mold.

C. Sand preparation

1. Start up batch: make 1, FH001.
   a. Thoroughly clean the pre-production muller.

b. Weigh and add 700 +/- 10 pounds of new Wexford W450 Lakesand, per the recipe, to the running pre-production muller.

c. Add 5 pounds of potable to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.

d. Add the clays slowly to the muller to allow them to be distributed throughout the sand mass in proportion to the sand weight per the recipe for this test.

e. Dry mull for about 3 minutes to allow distribution and some grinding of the clays to occur.

f. Temper the sand-clay mixture slowly, with potable water, to allow for distribution.

g. After about 2 gallons of water have been added allow 30 seconds of mixing then start taking compactability test samples.

h. Based on each test add water incrementally to adjust the temper. Allow 1 minute of mixing. Retest. Repeat until the compactability is in the range 40-45%.

i. Discharge the sand into the mold station elevator.

j. Grab sufficient sample after the final compactability test to fill a quart zip-lock bag. Label bag with the test series and sequence number, date, and time of day and deliver it immediately to the sand lab for analysis

k. Record the total sand mixed in the batch, the total of each type of clay added to the batch, the amount of water added, the total mix time, the final compactability and sand temperature at charge and discharge.

l. The sand will be immediately characterized for Methylene Blue Clay, Moisture content, Compactability, Green Compression strength, 1800°F loss on ignition (LOI), and 900°F volatiles. Each volatile and LOI test requires a separate 50 gram sample from the collected sand.

m. Empty the residual greensand from the mold hopper into a clean empty dump hopper whose tare weight is known.

2. Re-mulling: FH002-FH0XX

a. Add all the sand from the previous mold to the sand retained from the mold hopper and weigh the sand. Record the sand weight.

b. Add sufficient new Wexford W450 sand and proportional new clay and coal to the hopper to get back to the original sand mass.

c. Return the sand to the muller and dry blend for about one minute.

d. Add clays and coal to replace the burned out components per the sand lab results.

e. Add 5 pounds of water to the muller to suppress dust distributing it across the sand. Allow to mix for 1 minute.

f. Add the clays and coals per the re-bond recipe slowly to the muller to allow them to be distributed throughout the sand mass. Follow the above procedure beginning at C.1.f.

D. Molding: 4- on star pattern.

1. Pattern preparation:

- **a.** Inspect and tighten all loose pattern and gating pieces.
- **b.** Repair any damaged pattern or gating parts.

2. Mount the drag 4-on star pattern with gating into the mold machine bolster and bolt it down, tightly.

   - **a.** Lightly rub parting oil from a damp oil rag on the pattern particularly in the corners and recesses.

Caution: Do not pour gross amounts of parting oil on the pattern to be blown of with air. This practice will leave sufficient oil at the parting line to be adsorbed by the sand weakening it and the burning oil will be detected by the emission samplers.

3. Mount a cope follower board containing a pour cup pattern to the underside of the squeeze head plate.
4. Check the alignment of the pour cup using the flask.
5. Making the green sand mold on the Osborn manually raising the table using the squeeze bypass valve at the bottom rear of the machine until the sprue pierces the pour cup pattern. Move the pour cup pattern as necessary.
6. Remove the sprue if making a mold drag half. Leave it attached if making a cope half.
7. Use the overhead crane to place the pre-weighed drag/cope flask on the mold machine table, parting line surface down.
8. Locate a 24 x 24 x 8 inch deep wood upset on top Whisper Ram Jolt-Squeeze mold machine

WARNING: Only properly trained personnel may operate this machine. Proper personal protective equipment must be worn at all times while operating this equipment, including safety glasses with side shields and a properly fitting hard hat. Industrial type boots are highly recommended.

WARNING: Stand clear of the mold machine table and swinging head during the following operation or serious injury or death could result.

- **a.** Open the air supply to the mold machine.

WARNING: The squeeze head may suddenly swing to the outboard side or forward. Do not stand in the outer corners of the molding enclosure.

- **b.** On the operator's panel turn the POWER switch to ON.
- **c.** Turn the RAM-JOLT-SQUEEZE switch to ON.
- **d.** Turn the DRAW UP switch to AUTO
- **e.** Set the PRE-JOLT timer to 4-5 seconds.
- **f.** Set the squeeze timer to 8 seconds.
- **g.** Manually riddle a half to one inch or so of sand on the pattern using a ¼ inch mesh riddle. Source the sand from the overhead mold sand hopper by actuating the CHATTER GATE valve located under the operators panel.

h. Fill the 24 x 24 x 10 inch flask and the upset with greensand from the overhead molding hopper.

i. Manually level sand in the upset. By experience manually adjust the sand depth so that the resulting compacted mold is fractionally above the flask only height.

WARNING; Failure to stand clear of the molding table and flasks in the following operations could result in serious injury as this equipment is about to move up and down with great force.

j. Initiate the settling of the sand in the flask by pressing the PRE-JOLT push button. Allow this cycle to stop before proceeding.

WARNING: Stand clear of the entire mold machine during the following operations. Several of the machine parts will be moving. Failure to stand clear could result in severe injury even death.

k. Using both hands initiate the automatic machine sequence by simultaneously pressing and releasing the green push buttons on either side of the operators panel. The machine will squeeze and jolt the sand in the flask and then move the squeeze head to the side.

WARNING: Do no re-approach the machine until the squeeze head has stopped at the side of the machine.

l. Remove the upset and set it aside.

m. Screed the bottom of the mold flat if required.

n. Press and release the LOWER DRAW/STOP push button to separate the flask and mold from the pattern.

o. Use the overhead crane to lift the mold half and remove it from the machine.

p. Finally, press and release the draw down pushbutton to cause the draw frame to return to the start position.

9. If the mold half is a drag, roll it parting line side up, set it on the floor, blow it out, and cover it to keep it clean. If it is a cope mold drill ¼ inch vents into the top of each cavity, from the outside, about 1 inch off center and about 6 inches deep. Use a template.
10. Close the cope over the drag being careful not to crush anything.
11. Clamp the flask halves together.
12. Weigh and record the weight of the closed un-poured mold, the pre-weighed flask, and the sand weight by difference
13. Deliver the mold to the previously cleaned shakeout to be poured. Do not cover the mold with the emission hood.

E. Shakeout.

1. After the cooling time prescribed in the test plan turn on the shakeout unit and run it for until the greensand has passed into the hopper below.
2. Turn off the shakeout, remove the flask with casting, and recover the sand from the hopper and surrounding floor.

3. Weigh and record the metal poured and the total sand weight recovered and rejoined with the left over mold sand from the molding hopper.

F. Melting:

1. Initial charge:

a. Charge the furnace according to the heat recipe.
b. Place part of the steel scrap on the bottom, followed by carbon alloys, and the balance of the steel.
c. Place a pig on top on top.
d. Bring the furnace contents to the point of beginning to melt over a period of 1 hour at reduced power.
e. Add the balance of the metallic under full power until all is melted and the temperature has reached 2600 to 2700^{o}F.
f. Slag the furnace and add the balance of the alloys.
g. Raise the temperature of the melt to 2700^{o}F and take a DataCast 2000 sample. The temperature of the primary liquidus (TPL) must be in the range of 2200-2350^{o}F.
h. Hold the furnace at 2500-2550^{o}F until near ready to tap.
i. When ready to tap raise the temperature to 2700^{o}F and slag the furnace.
j. Record all metallic and alloy additions to the furnace, tap temperature, and pour temperature. Record all furnace activities with an associated time.

2. Back charging.

a. Back charge the furnace according to the heat recipe,
b. Charge a few pieces of steel first to make a splash barrier, followed by the carbon alloys.
c. Follow the above steps beginning with F.1.e.

3. Emptying the furnace.

a. Pig the extra metal only after the last emission measurement is complete to avoid contaminating the air sample.
b. Cover the empty furnace with ceramic blanket to cool.

G. Pouring:

1. Preheat the ladle.

a. Tap 400 pounds more or less of 2700^{o}F metal into the cold ladle.
b. Casually pour the metal back to the furnace.
c. Cover the ladle.
d. Reheat the metal to 2780 +/- 20^{o}F.

- **e.** Tap 450 pounds of iron into the ladle while pouring inoculating alloys onto the metal stream near its base.
- **f.** Cover the ladle to conserve heat.
- **g.** Move the ladle to the pour position, and wait until the metal temperature reaches 2680 +/- 10^{o}F.
- **h.** Commence pouring keeping the sprue full.
- **i.** Upon completion return the extra metal to the furnace, and cover the ladle.

H. Casting cleaning

1. Spin blast set up.

- **a.** Load the spin blast shot storage bin with 460 steel shot.
- **b.** Turn on the spin blast bag house.
- **c.** Turn on the spin blast machine.
- **d.** Increase the magnetic feeder so that the motor amperage just turns to 12 amps from 11 amps.
- **e.** Record the shot flow and the motor amperage for each wheel

2. Cleaning castings.

- **a.** Place the four (4) castings from a single mold on one (1) casting basket.
- **b.** Process each rotating basket for eight (8) minutes.
- **c.** Remove and remark casting ID on each casting.

I. Rank order evaluation.

1. The supervisor shall select a group of five persons to make a collective subjective judgment of the casting relative surface appearance.
2. Review the general appearance of the castings and select specific casting features to compare.
3. Separate castings by cavity number.
4. For each cavity:

- **a.** Place each casting initially in sequential mold number order.
- **b.** Beginnings with a casting from mold FH001 compare it to castings from mold FH002.
- **c.** Place the better appearing casting in the first position and the lesser appearing casting in the second position.
- **d.** Repeat this procedure with FH001 to its nearest neighbors until all castings closer to the beginning of the line are better appearing than FH001 and the next casting farther down the line is inferior.
- **e.** Repeat this comparison to next neighbors for each casting number.
- **f.** When all casting numbers have been compared go to the beginning of the line and begin again comparing each casting to its nearest neighbor. Move the castings so

that each casting is inferior to the next one closer to the beginning of the line and superior to the one next toward the tail of the line.

g. Repeat this comparison until all concur with the ranking order.

5. Record mold number by rank-order series for each cavity.

Steven Knight
Mgr. Process Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B MOLD SAND PROPERTY DETAILS

THIS PAGE INTENTIONALLY LEFT BLANK

Green Sand PCS Test FH

Molding Date	6/30/03	7/01/03	7/01/03	7/01/03	7/02/03	7/02/03	7/02/03	7/03/03	7/03/03	7/03/03	7/08/03	Ave.	St. Dev	RSD
Production Sample #	FH 001	FH 002	FH 003	FH 004	FH 005	FH 006	FH 007	FH 008	FH 009	FH 010	FH 011			
Emissions Sample #	FH 001	FH 002	FH 003	FH 004	FH 005	FH 006	FH 007	FH 008	FH 009	FH 010	FH 011			
GS Mold Sand Weight, (lbs.)	610	650	640	640	640	640	640	630	640	640	640	**640**	**10.1**	**0.016**
Cast Weight all metal inside mold (lbs.)	98.5	96.0	97.0	102.5	92.5	89.0	95.5	90.5	98.0	94.5	99.0	**95.7**	**3.9**	**0.041**
Pouring Time (sec.)	18	28	31	26	25	29	21	30	20	20	17	**24**	**5.1**	**0.210**
Pouring Temp (°F)	2677	2685	2685	2689	2680	2687	2685	2689	2683	2673	2676	**2683**	**5.4**	**0.002**
Carbon Equivalent, %C	3.94	4.17	4.07	3.97	4.03	4.09	3.93	4.01	3.90	4.06	3.99	**4.01**	**0.1**	**0.020**
Carbon Content, %	3.24	3.39	3.31	3.23	3.36	3.33	3.23	3.28	3.20	3.27	3.26	**3.28**	**0.1**	**0.018**
Silicon Content., %	2.10	2.35	2.27	2.22	2.02	2.26	2.13	2.20	2.10	2.36	2.20	**2.20**	**0.1**	**0.049**
Average Green Compression (psi)	17.94	18.77	17.62	18.90	19.51	17.44	18.18	17.49	16.65	16.15	14.41	**17.55**	**1.4**	**0.081**
GS Compactability (%)	49	36	52	49	39	43	44	38	43	29	46	**43**	**6.7**	**0.157**
GS Moisture Content (%)	2.51	1.97	2.38	2.34	2.22	2.18	2.16	1.92	2.25	1.81	2.10	**2.17**	**0.2**	**0.096**
GS Clay Content (%)	8.59	8.72	8.21	8.21	8.59	7.44	7.56	7.18	7.31	6.28	5.90	**7.64**	**0.9**	**0.123**
1800°F LOI - Mold Sand (%)	5.60	5.62	5.53	5.20	4.92	4.95	4.78	4.87	4.63	4.62	4.54	**5.02**	**0.4**	**0.080**
900°F Volatiles (%)	1.34	1.32	1.24	1.24	1.10	0.92	0.82	0.84	0.76	0.74	0.64	**1.00**	**0.3**	**0.258**
Pour hood process air temp at start of pour, F	73	79	82	85	75	83	86	81	85	85	82	**81**	**4.3**	**0.052**

Production Data from Hand-Rammed Greensand Test Series EM (For Comparison)

Description	Conditioning			Test series EM													
	EM001	EM002	EM003	EM004	EM005	EM006	EM007	EM008	EM009	EM010	EM011	EM012	Ave. All	**Report Ave**	StDev Rpt	2s lo lim	2s hi lim
Date	7/03/02	7/08/02	7/09/02	7/09/02	7/10/02	7/10/02	7/11/02	7/16/02	7/16/02	7/17/02	7/18/02	7/19/02					
Casting Metal Weight, lbs.	177	213	219	223	201	208	195	203	215	213	209	195	206	**207**	9.40	188	226
Total Mold Weight, lbs.	1383	1376	1334	1361	1279	1317	1292	1317	1268	1318	1301	1310	1321	**1307**	27.02	1253	1361
Total Core Weight, lbs.	62.1	59.0	60.8	59.3	60.0	60.0	60.5	58.4	58.7	58.7	57.3	57.6	59.4	**58.9**	1.10	57	61
Compact-ability, %	53	48	52	54	53	52	54	---	50	---	51	52	52	**52**	1.50	49	55
Sand Temperature °F	82	81	110	104	104	100	100	106	100	115	100	95	100	**103**	5.63	91	114
Total Binder Weight, lbs: Note 1,2	1.513	1.439	1.483	1.446	1.463	1.463	1.474	1.424	1.430	1.432	1.398	1.404	1.448	**1.437**	0.03	1.384	1.491
No. Cavities Poured	6	8	8	8	8	8	8	8	8	8	8	8	8	**8**	0.00	8	8
LOI, % (at mold)	4.85	5.16	4.72	4.71	5.38	5.30	5.04	4.84	5.01	5.00	4.97	5.36	5.03	**5.07**	0.23	4.60	5.53
LOI, % (at shakeout)	4.75	5.21	4.62	4.10	5.08	4.89	4.94	5.01	5.36	4.85	4.63	5.36	4.90	**4.91**	0.38	4.14	5.68
Clays, % (at mold) Note 5	7.50	7.90	7.25	7.12	7.90	8.03	7.00	7.38	7.00	7.25	7.12	6.74	7.35	**7.28**	0.43	6.43	8.14
Clays, % (at shakeout) Note 5	7.50	7.51	6.62	5.73	6.60	7.12	6.62	6.87	6.62	7.12	6.48	6.08	6.74	**6.58**	0.45	5.67	7.49
Volatiles, % (at mold) avg.	1.42	1.16	1.18	1.06	1.24	1.28	0.98	1.12	1.14	1.04	0.92	1.08	1.13	**1.10**	0.12	0.86	1.33
Volatiles, % (at shakeout) avg.	1.28	1.04	1.18	0.94	1.00	1.08	1.12	0.94	0.96	1.02	0.80	1.14	1.04	**1.00**	0.11	0.79	1.21
Pouring time, sec.	31	22	23	22	17	27	16	21	13	15	14	16	20	**18**	4.54	9	27
Pouring Temperature, °F	2626	2641	2645	2628	2645	2649	2638	2636	2642	2646	2645	2636	2640	**2641**	6.60	2627	2654
Ambient Temperature, °F	Not Measured	Not Measured	75	82	74	88	74	64	77	68	68	66	74	**73**	7.92	58	89

APPENDIX C MOLD STRENGTH SURVEYS

THIS PAGE INTENTIONALLY LEFT BLANK

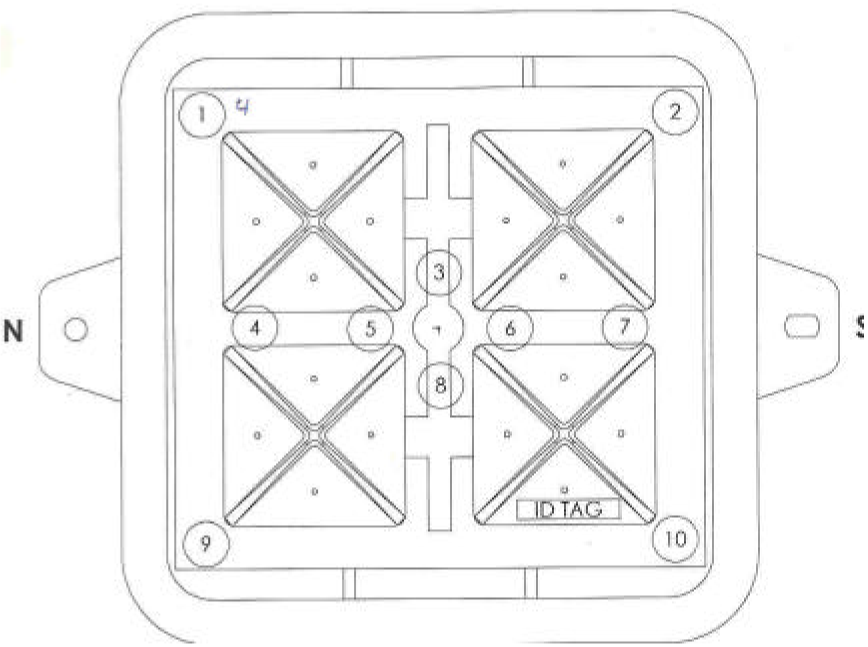
FH001 Mold Survey

MOLD HARDNESS MAP- STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH 001
DATE: 6/30/03
TIME: 12:00

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	3	3	18	10	13	13	10	14	5	3
DRAG:	4	4	17	10	12	14	10	16	3	3



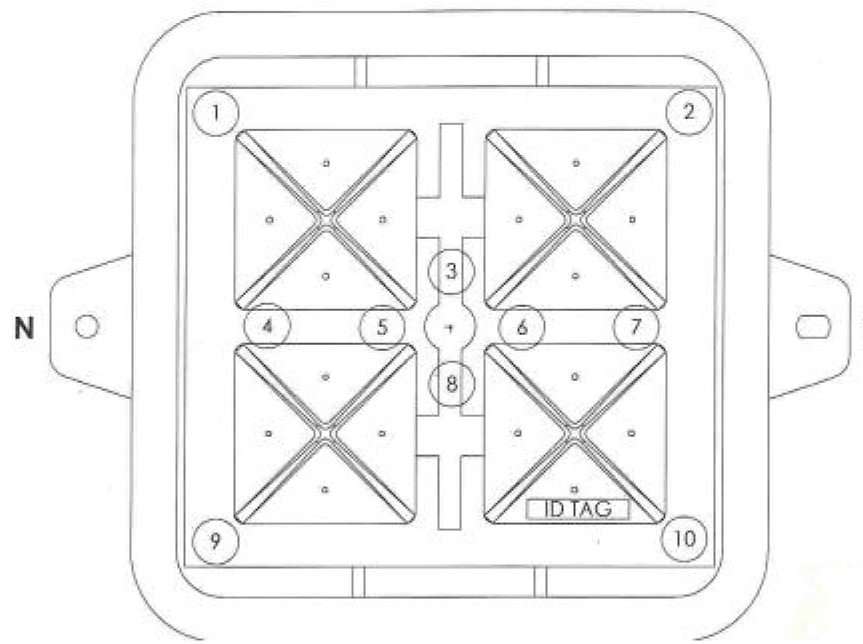
FH002 Mold Survey

MOLD HARDNESS MAP- STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH002
DATE: JULY 1, 2003
TIME: 7:25

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	7	7	22	17	19	19	14	23	7	7
DRAG:	6	7	24	16	20	17	13	22	9	7



FH003 Mold Survey

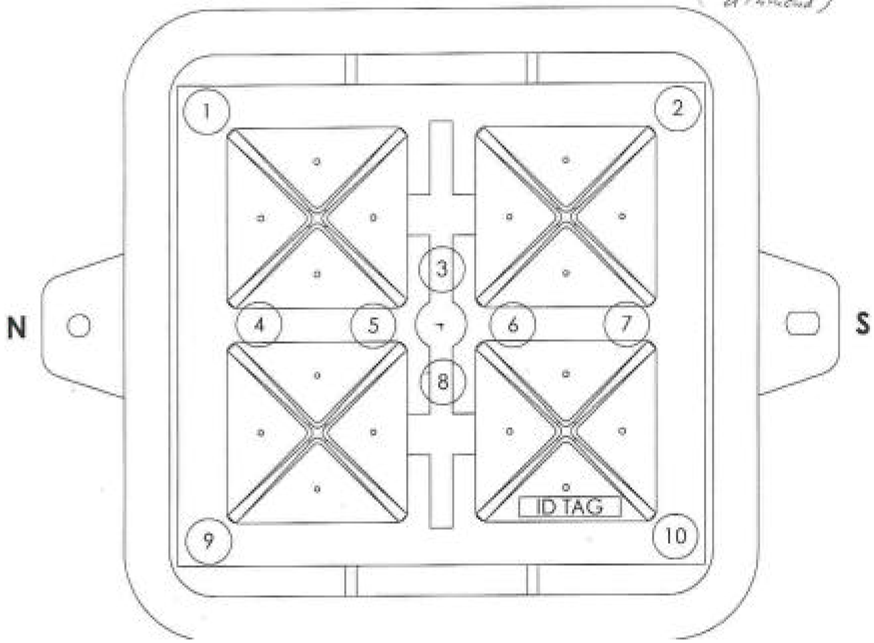
MOLD HARDNESS MAP- STAR PLATE

ANALYST: Kevin Lay C
MOLD ID: FH 003
DATE: 1 Jul 03
TIME: 12:00

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	6	6	19	12	15	15	14	21	6	6
DRAG:	7	6	22	15	17	18	14	21	6	3

note: this pattern had excessive parting oil on it (black diamond)



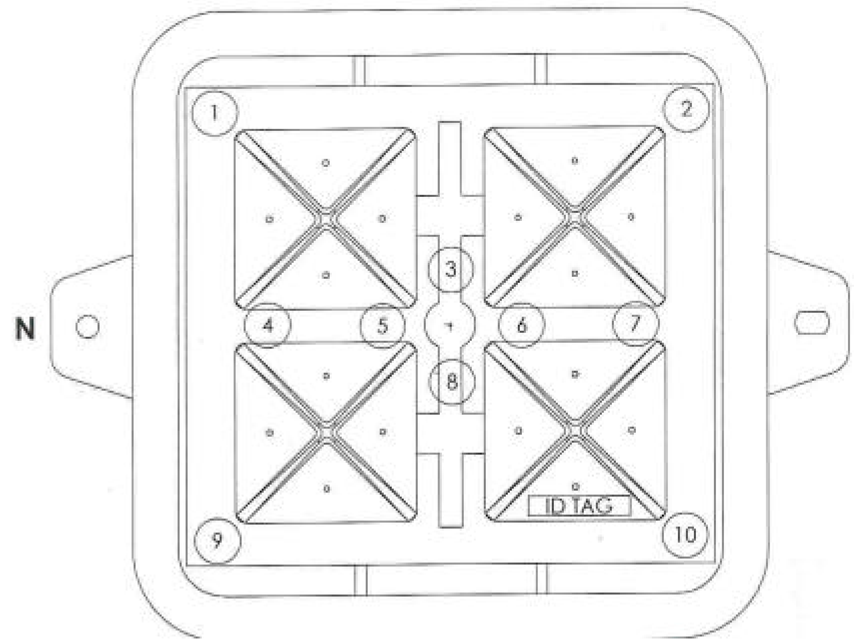
FH004 Mold Survey

MOLD HARDNESS MAP- STAR PLATE

ANALYST: K. Lancel
MOLD ID: FH 004
DATE: 1 Jul 03
TIME: 2:45

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	7	7	20	13	16	16	13	20	6	6
DRAG:	7	7	22	13	18	17	14	21	7	7



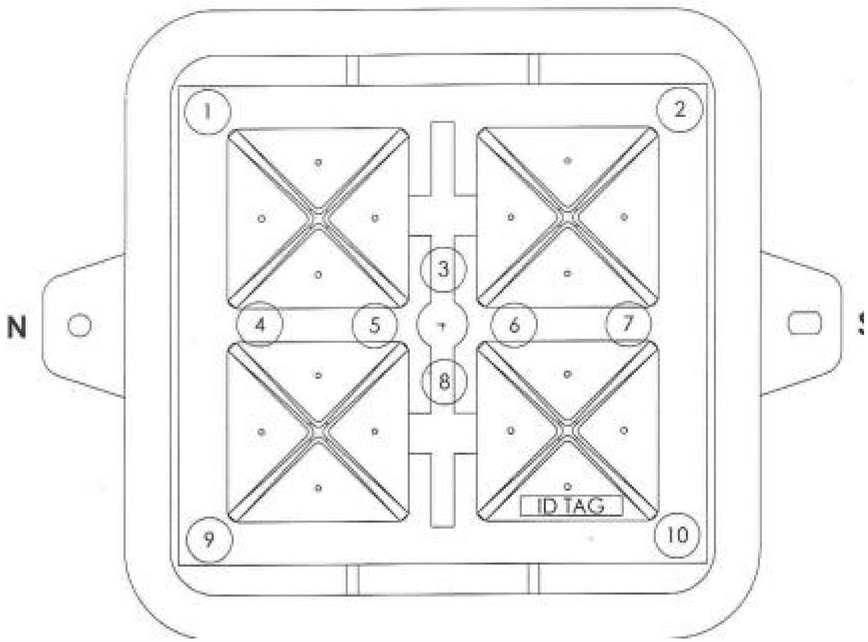
FH005 Mold Survey

MOLD HARDNESS MAP- STAR PLATE

ANALYST: KEVIN LANGER
MOLD ID: FH005
DATE: 7/2/03
TIME: 8:30

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	7	7	23	17	18	18	17	22	8	8
DRAG:	6	6	18	13	4	4	12	16	6	5



FH006 Mold Survey

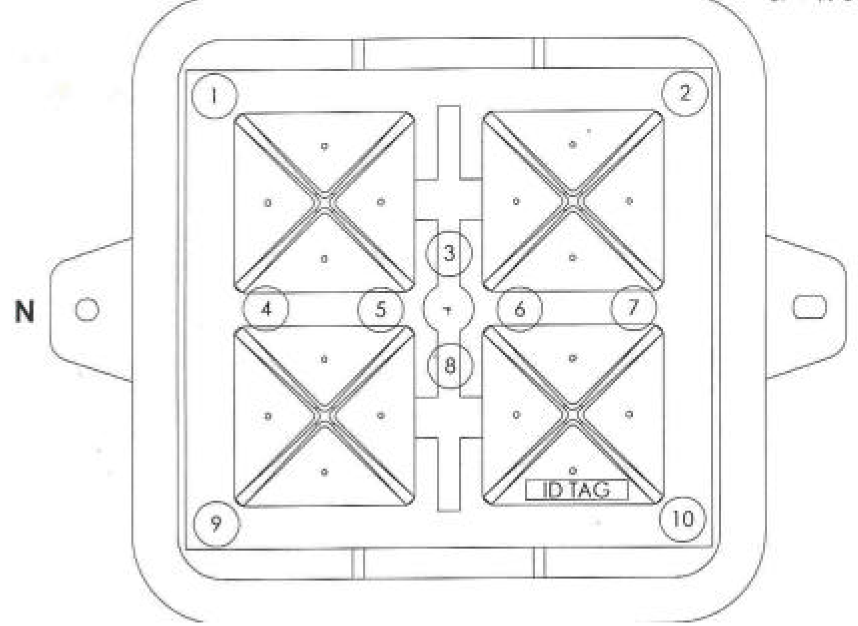
MOLD HARDNESS MAP- STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH006
DATE: 7/2/03
TIME: 11:05

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	7	7	21	15	16	16	15	21	7	7
DRAG:	7	6	22	15	15	15	14	20	7	7

Note: 70 lbs of stuck on casting sand returned to mu
for this b



FH007 Mold Survey

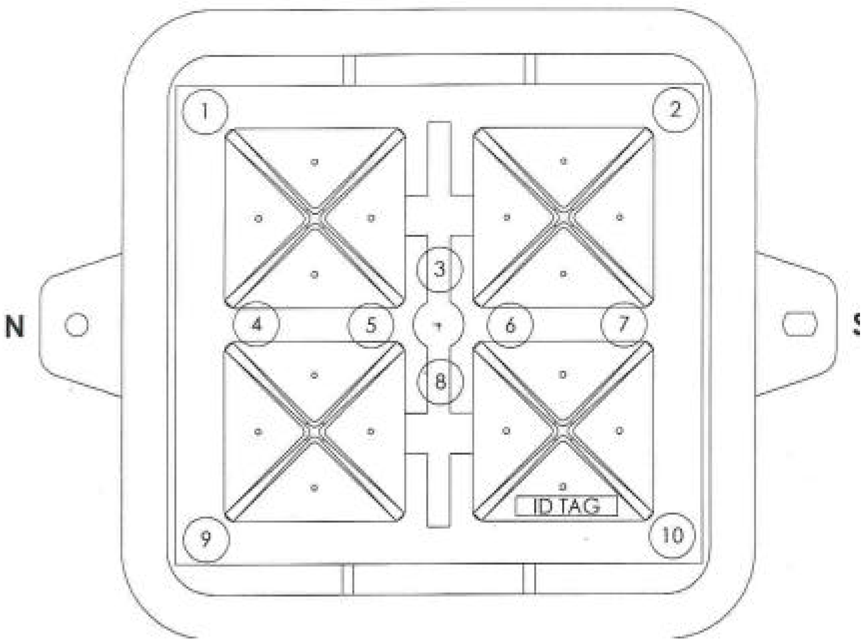
MOLD HARDNESS MAP- STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH007
DATE: 7/2/03
TIME: 13:33

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	6	6	19	12	13	13	13	19	6	6
DRAG:	6	6	19	13	14	14	13	19	6	6

NOTE: USE 75 ML TOTAL OF PARTING SPRAY FOR BOTH COPE/DRAG. (H&G 5-Y 2T



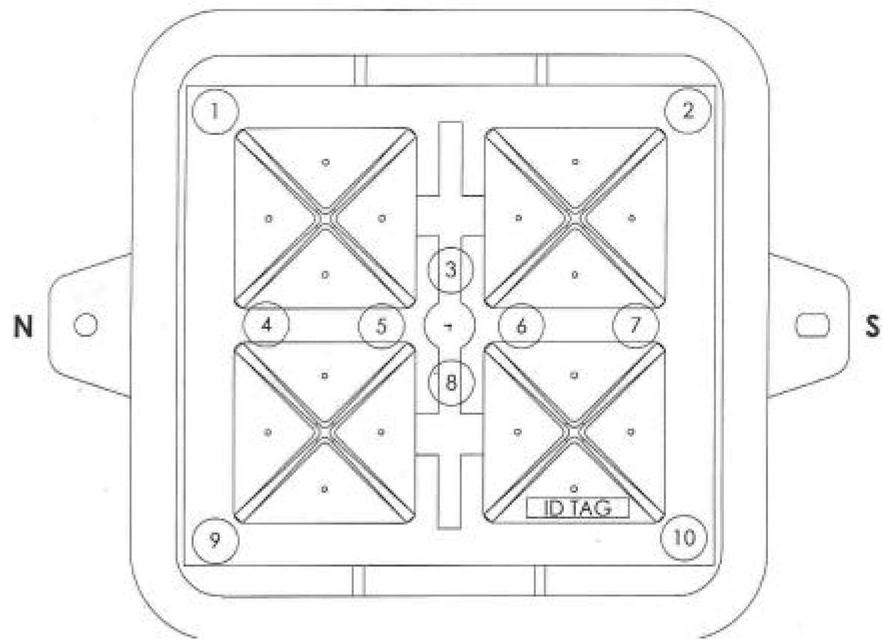
FH008 Mold Survey

MOLD HARDNESS MAP- STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH008
DATE: 7/3/03
TIME: 8:00

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	6	7	20	14	16	16	14	20	7	7
DRAG:	7	7	20	14	16	16	14	20	7	7



FH009 Mold Survey

MOLD HARDNESS MAP- STAR PLATE

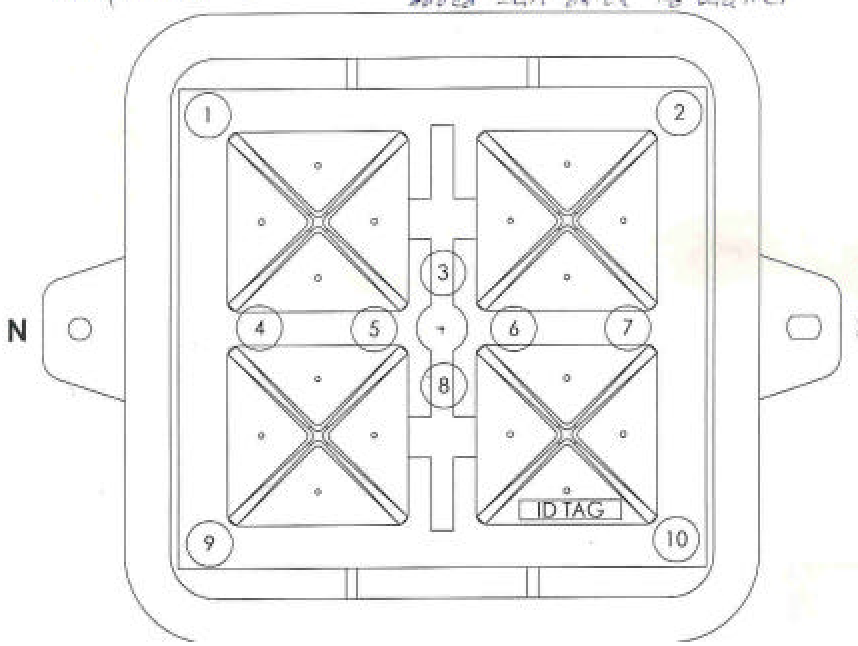
ANALYST: JOSE CHAVEZ
MOLD ID: FH009
DATE: 7/3/2003
TIME: 10:50

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	6	7	20	12	14	15	14	20	7	6
DRAG:	6	6	19	13	14	14	13	19	6	6

NOTE: 75ML TOTAL OF PARTING SPRAY

55 lbs of reclaimed sand added this batch to muller



FH010 Mold Survey

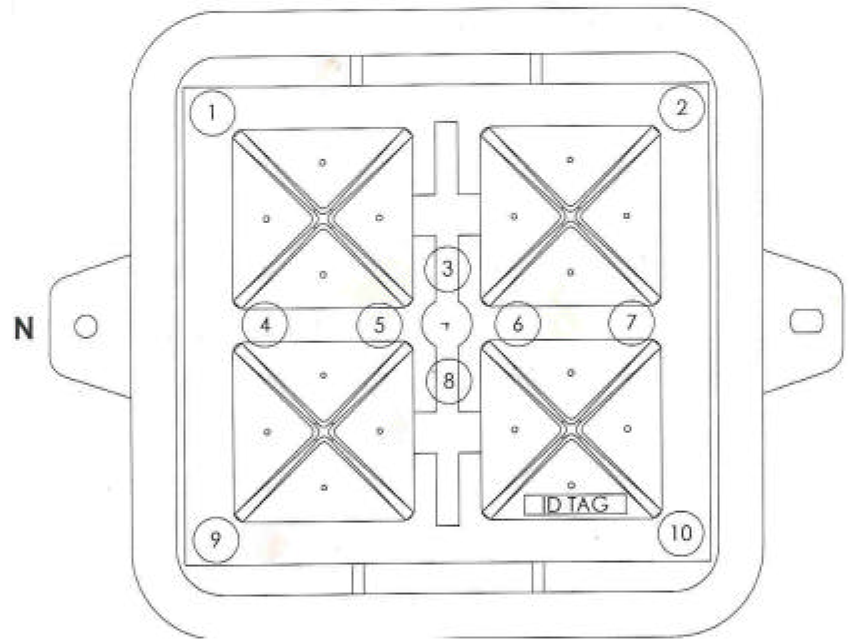
MOLD HARDNESS MAP- STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH010
DATE: 7/3/2003
TIME: 13:33

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	6	7	20	13	14	14	13	20	6	6
DRAG:	6	6	19	13	15	15	13	19	6	6

NOTE: USED 100ML TOTAL OF PARTING SPRAY



FH011 Mold Survey

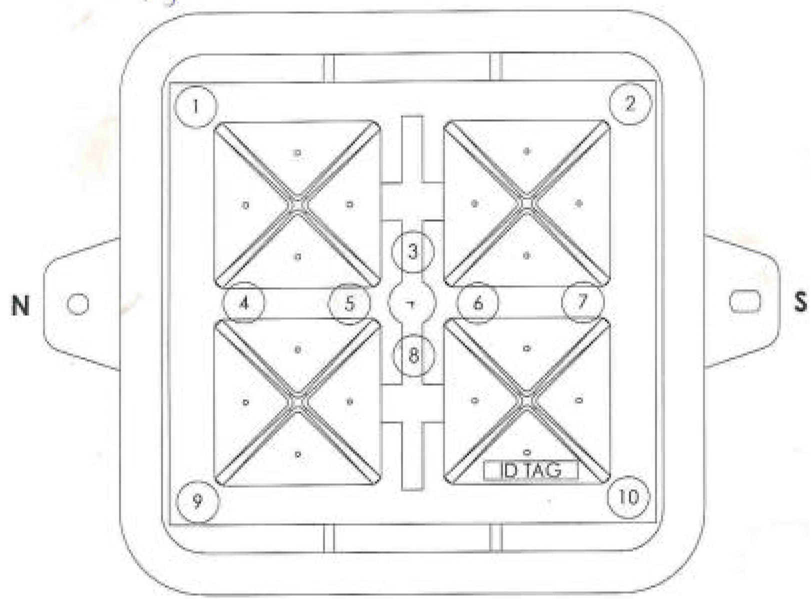
MOLD HARDNESS MAP - STAR PLATE

ANALYST: JOSE CHAVEZ
MOLD ID: FH011
DATE: JULY 8, 2003
TIME: 10:50

INDICATE MOLD HARDNESS (psi)

POSITION:	1	2	3	4	5	6	7	8	9	10
COPE:	6	7	21	12	16	15	14	19	7	7
DRAG:	6	7	20	11	12	14	13	20	6	6

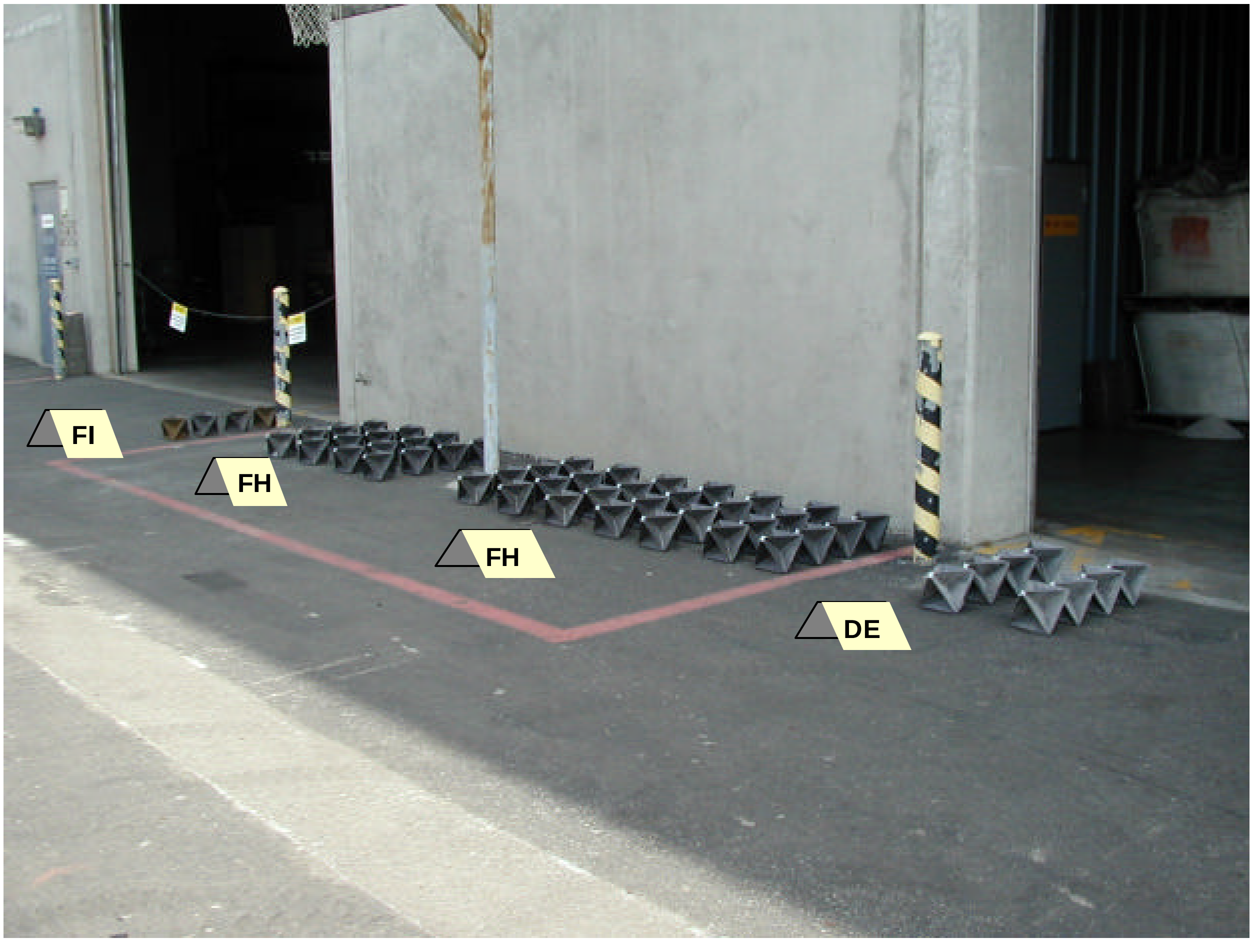
NOTE: USED ~~2g~~ 19g PARTING SPRAY ON DRAG



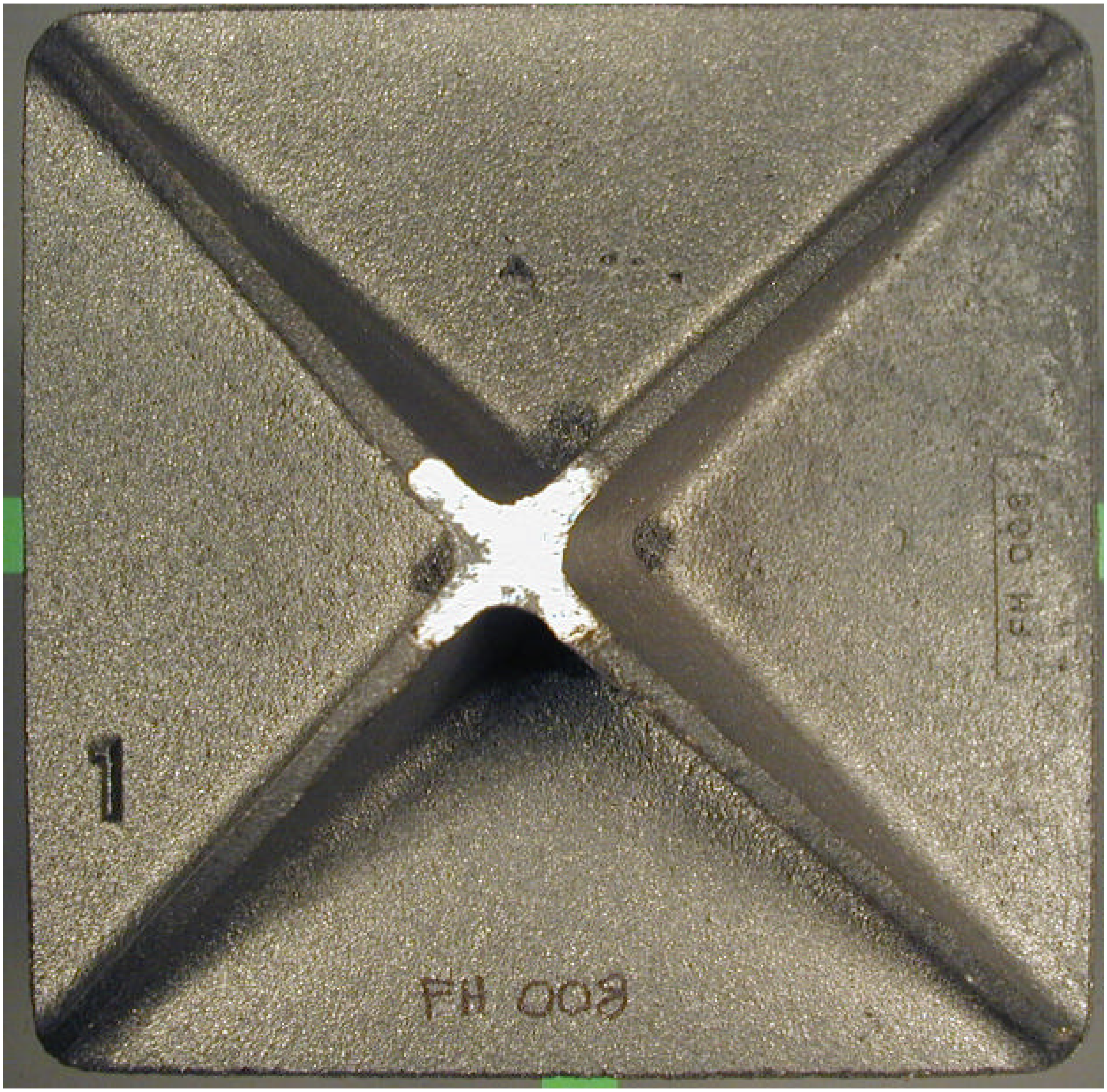
APPENDIX D FH CASTING COPE AND DRAG PHOTOGRAPHS

THIS PAGE INTENTIONALLY LEFT BLANK

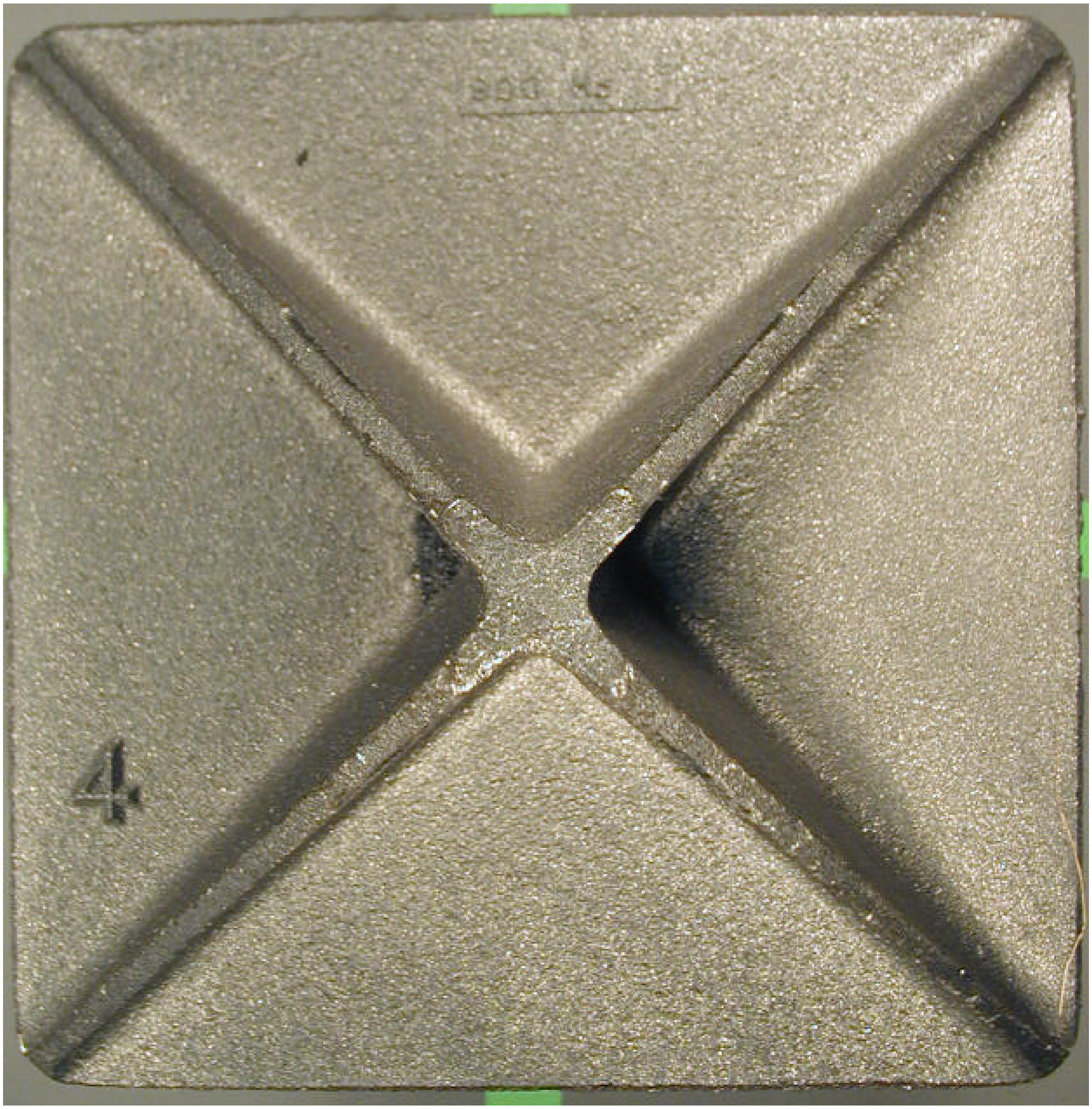
Mold Line Up for Tests FI, FH and DE



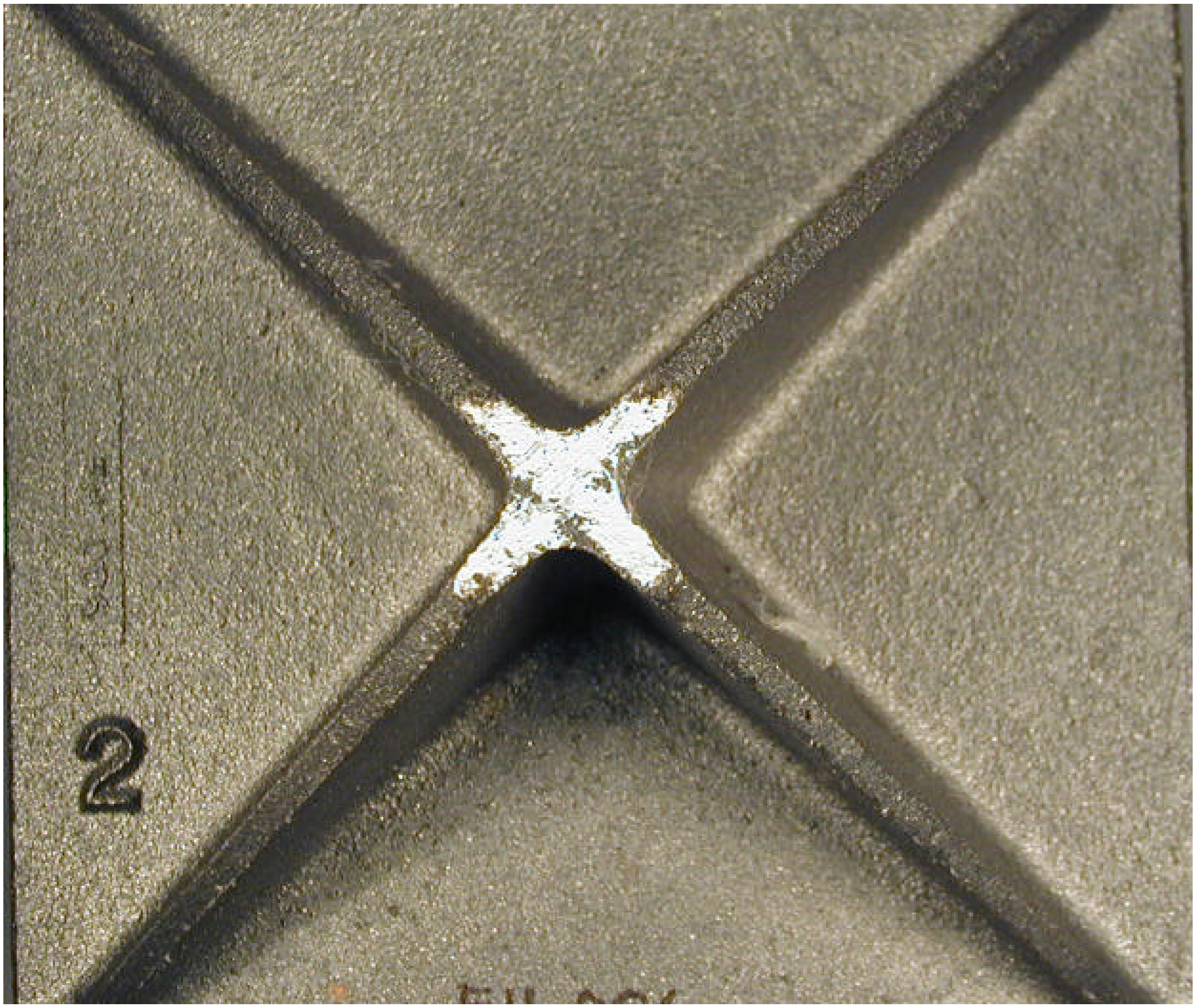
Mold FH008 Best Cope Cavity 1



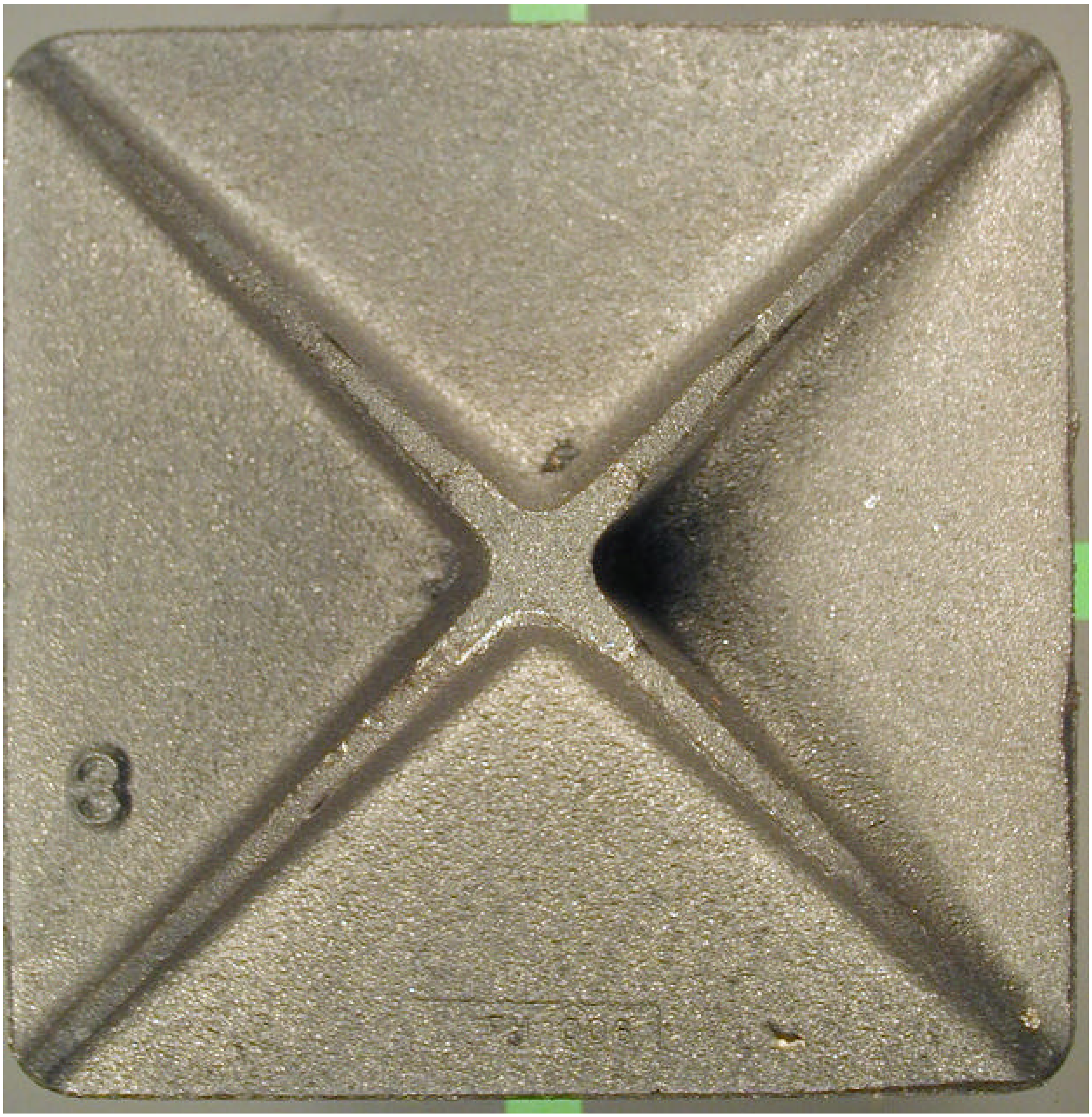
Mold FH008 Best Drag Cavity 1



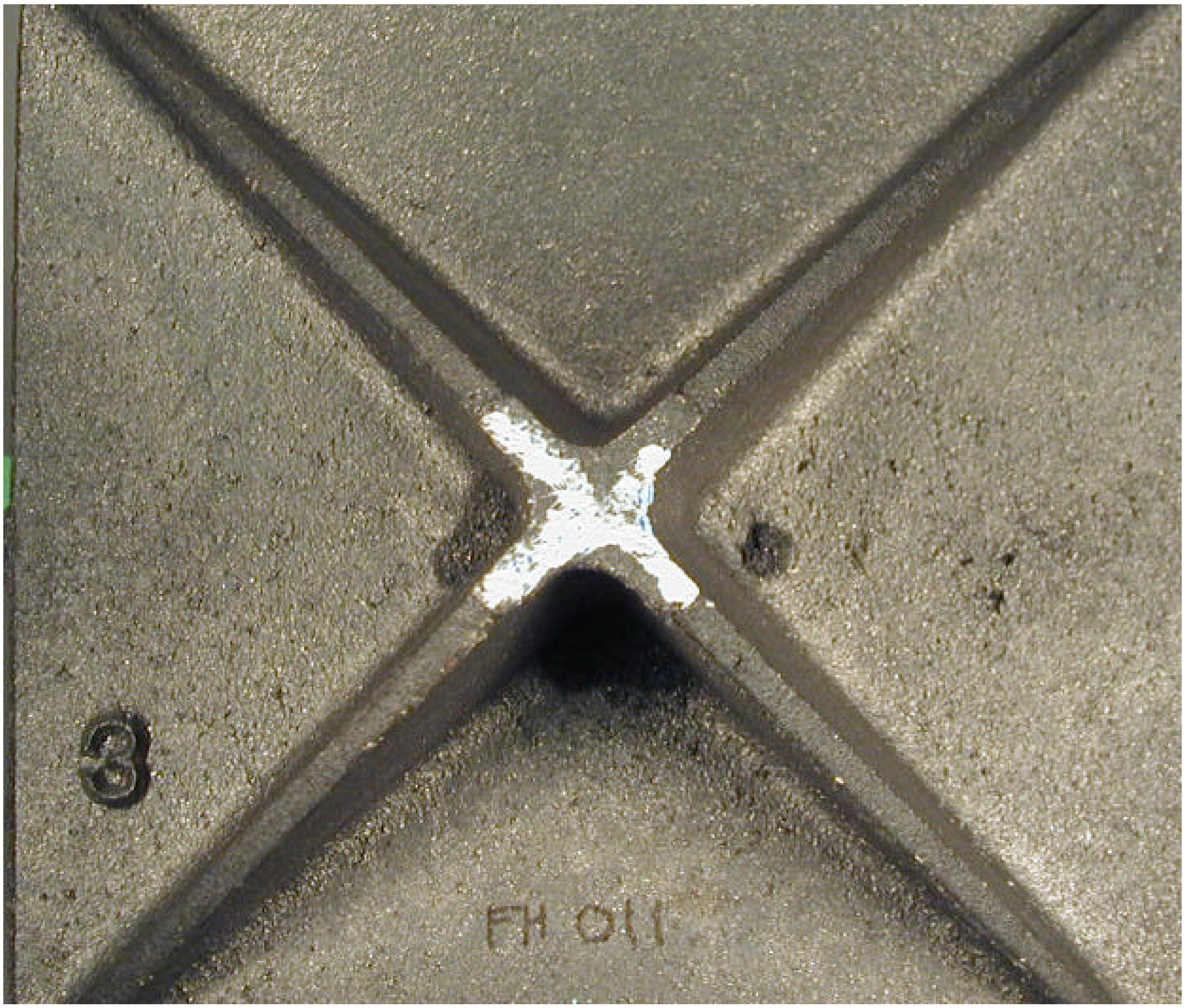
Mold FH006 Best Cope Cavity 2



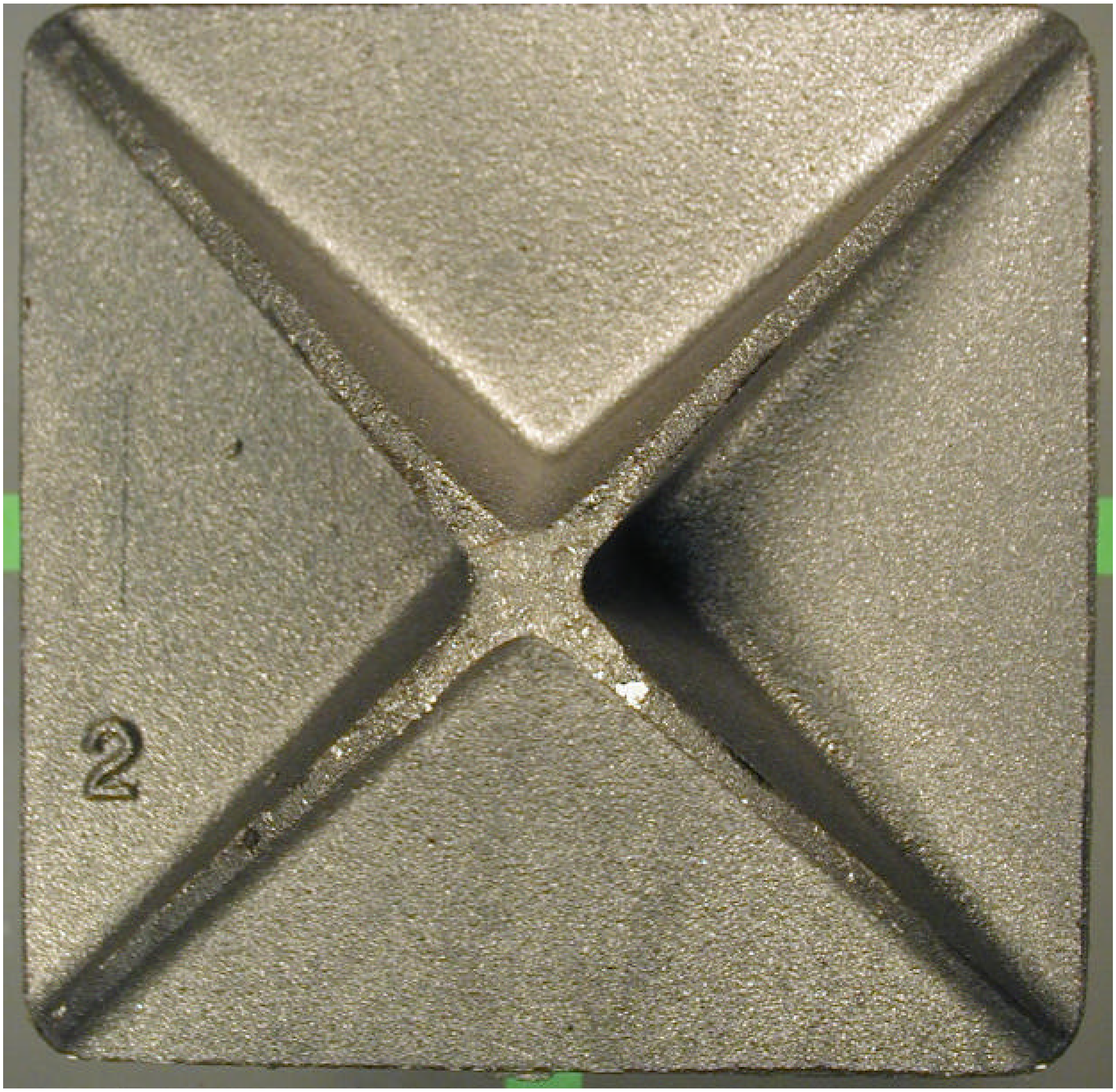
Mold FH006 Best Drag Cavity 2



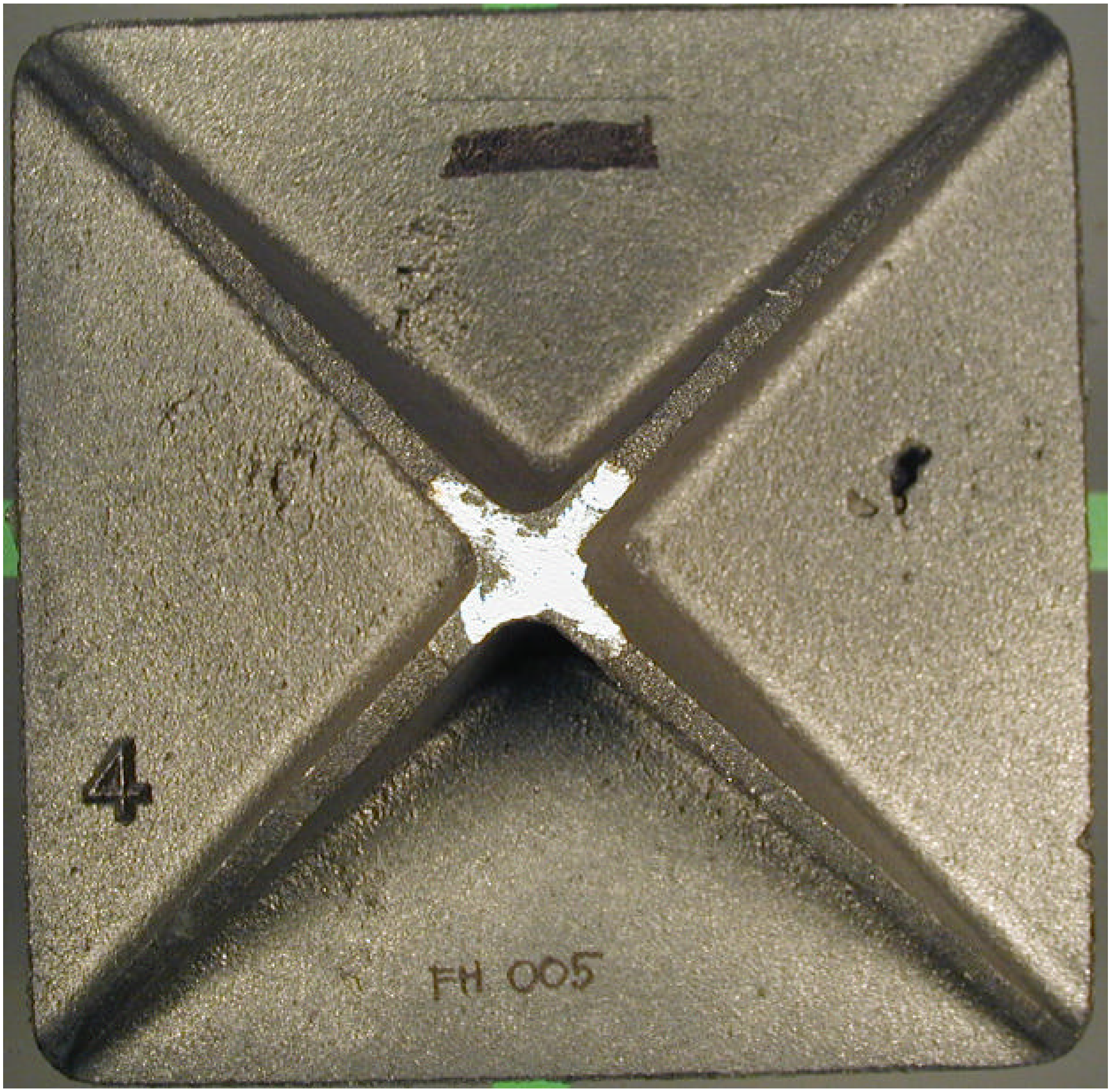
Mold FH011 Best Cope Cavity 3



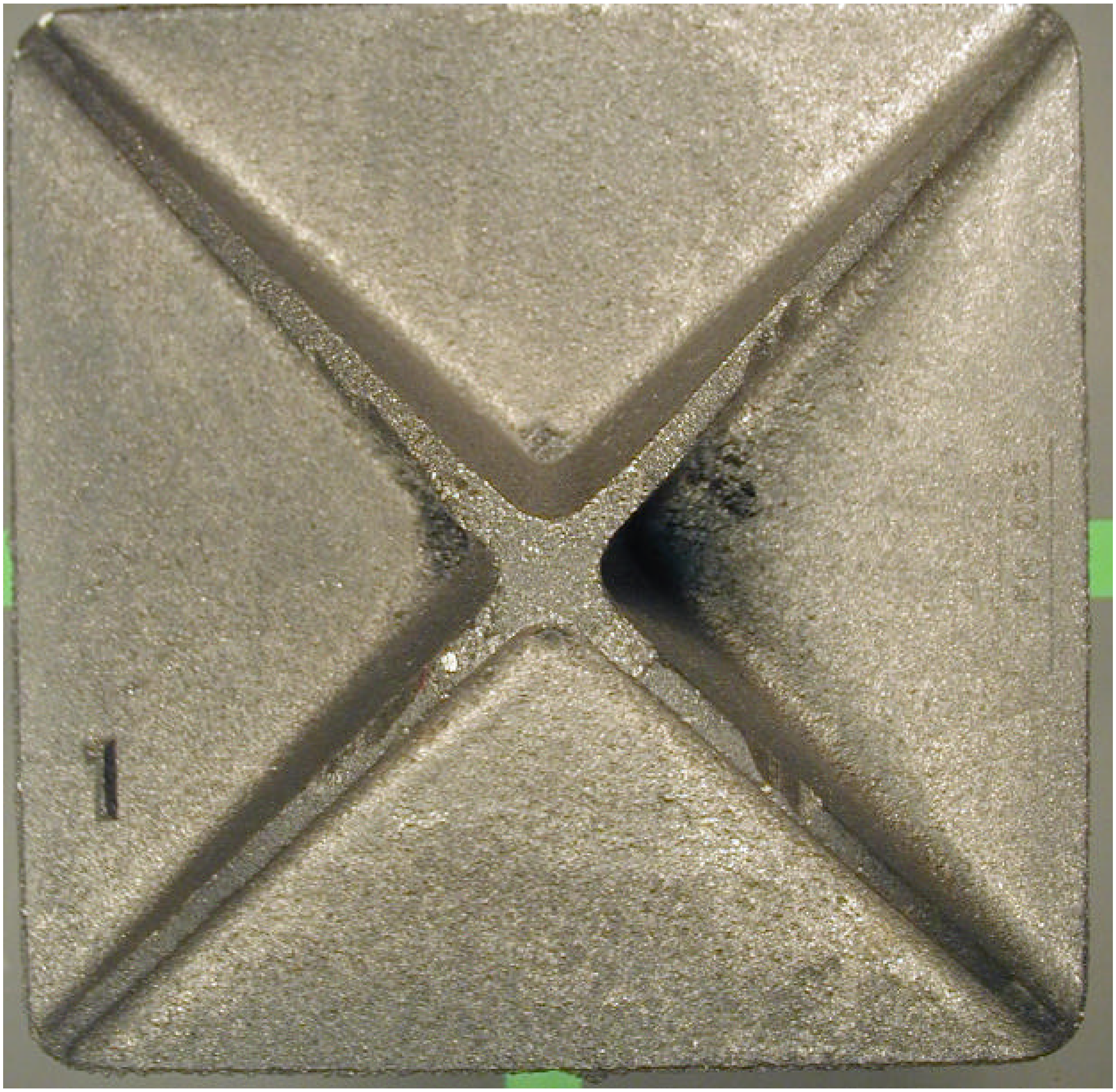
Mold FH011 Best Drag Cavity 3



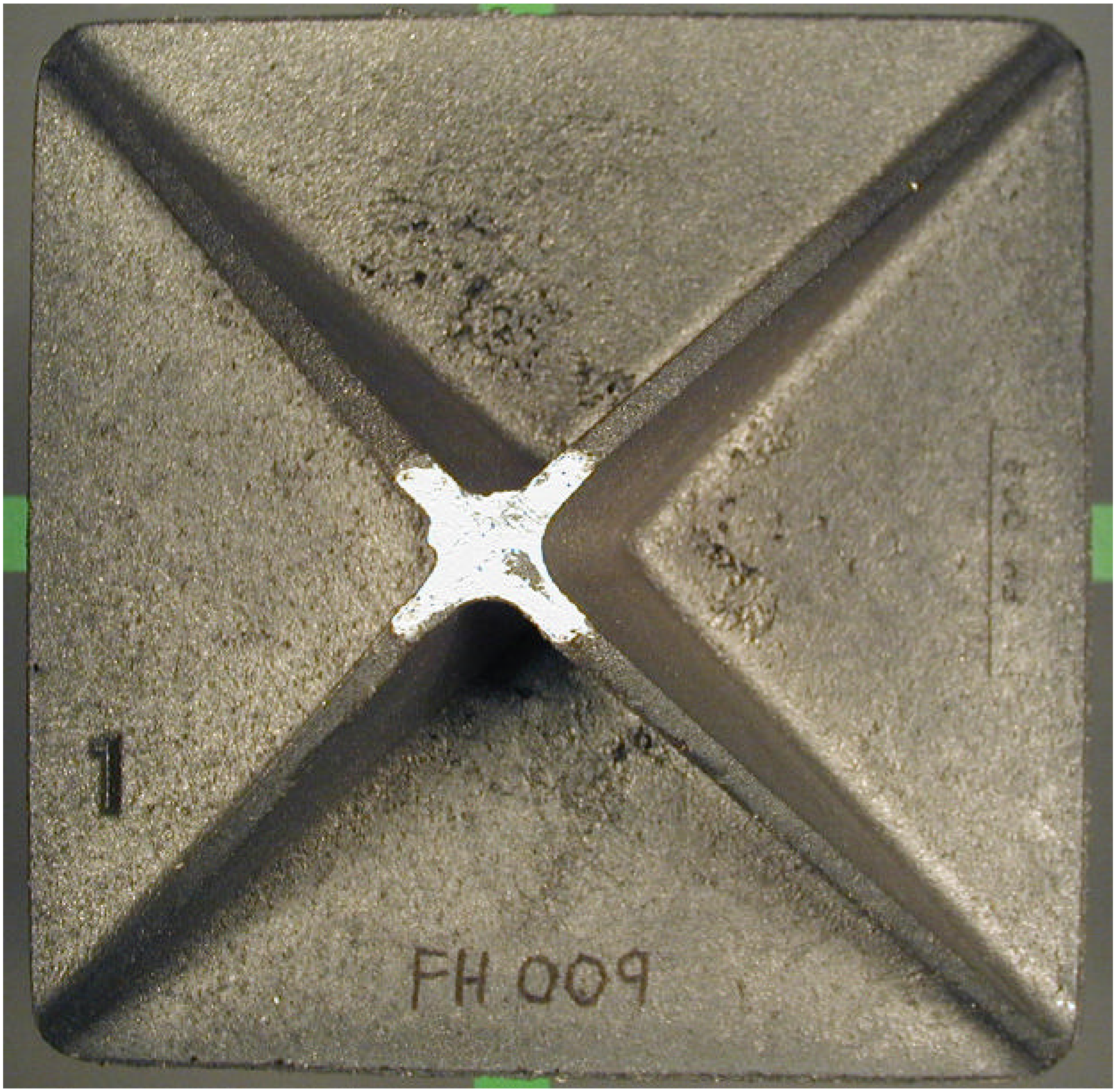
Mold FH005 Best Cope Cavity 4



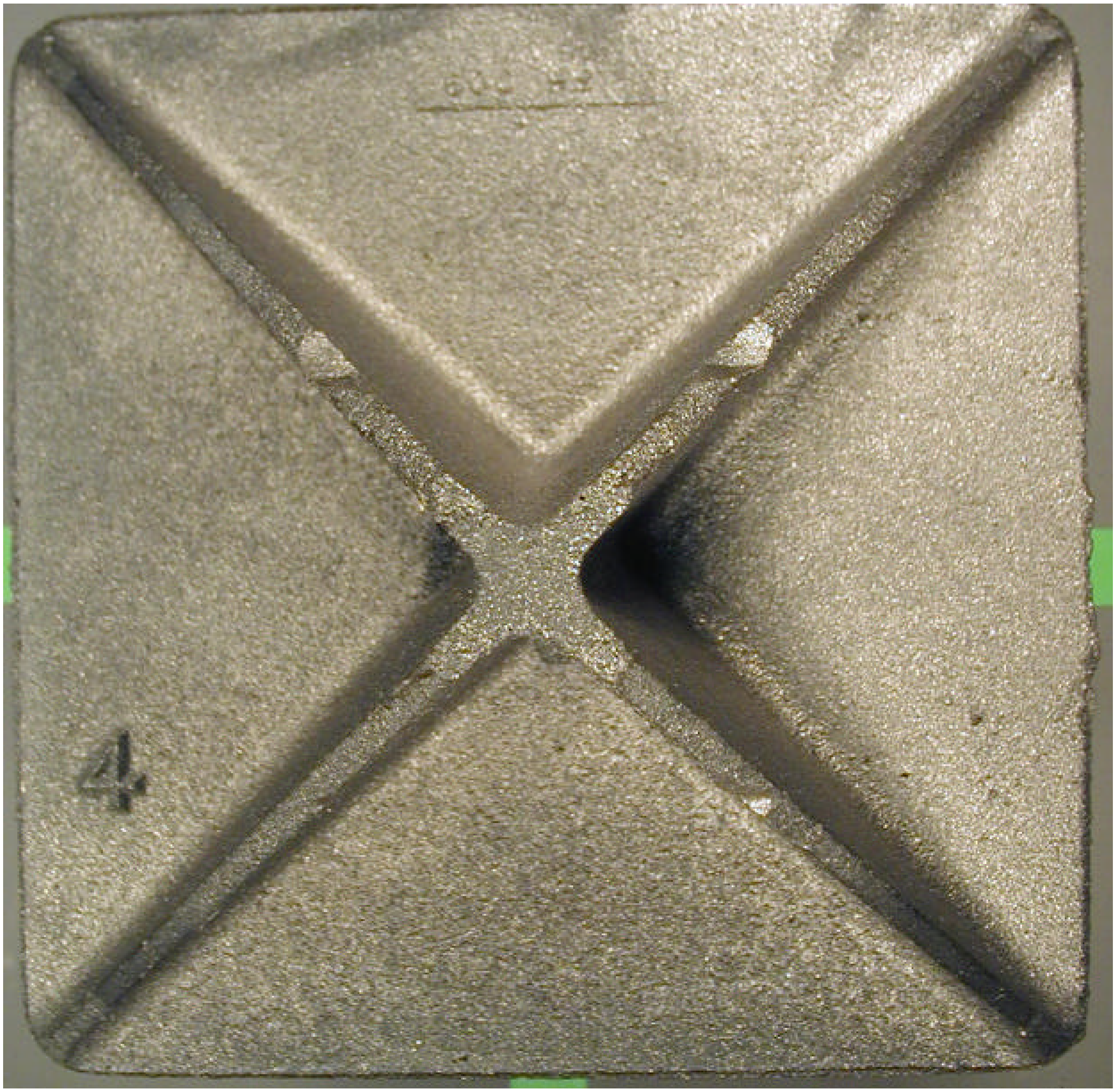
Mold FH005 Best Drag Cavity 4



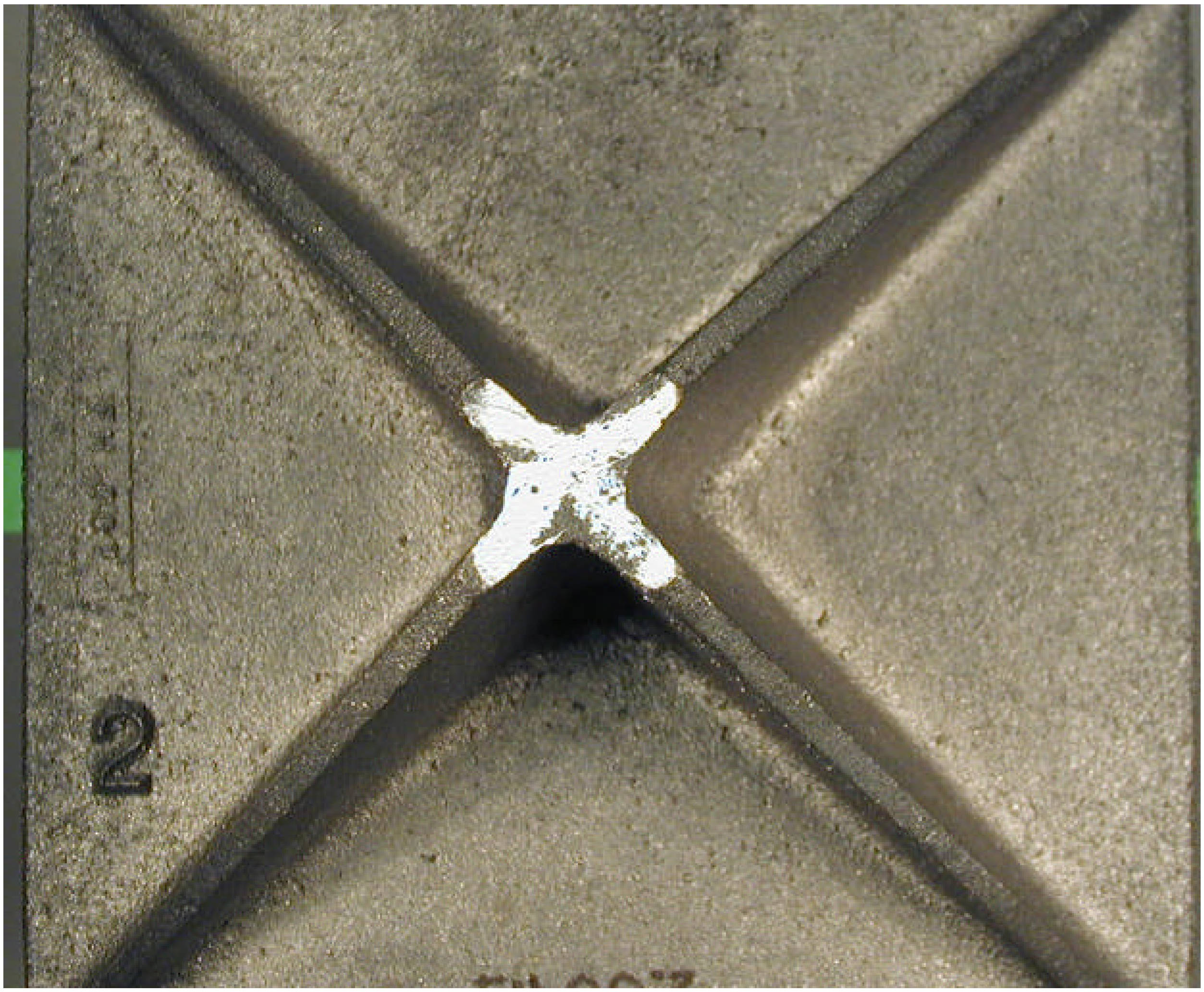
Mold FH009 Median Cope Cavity 1



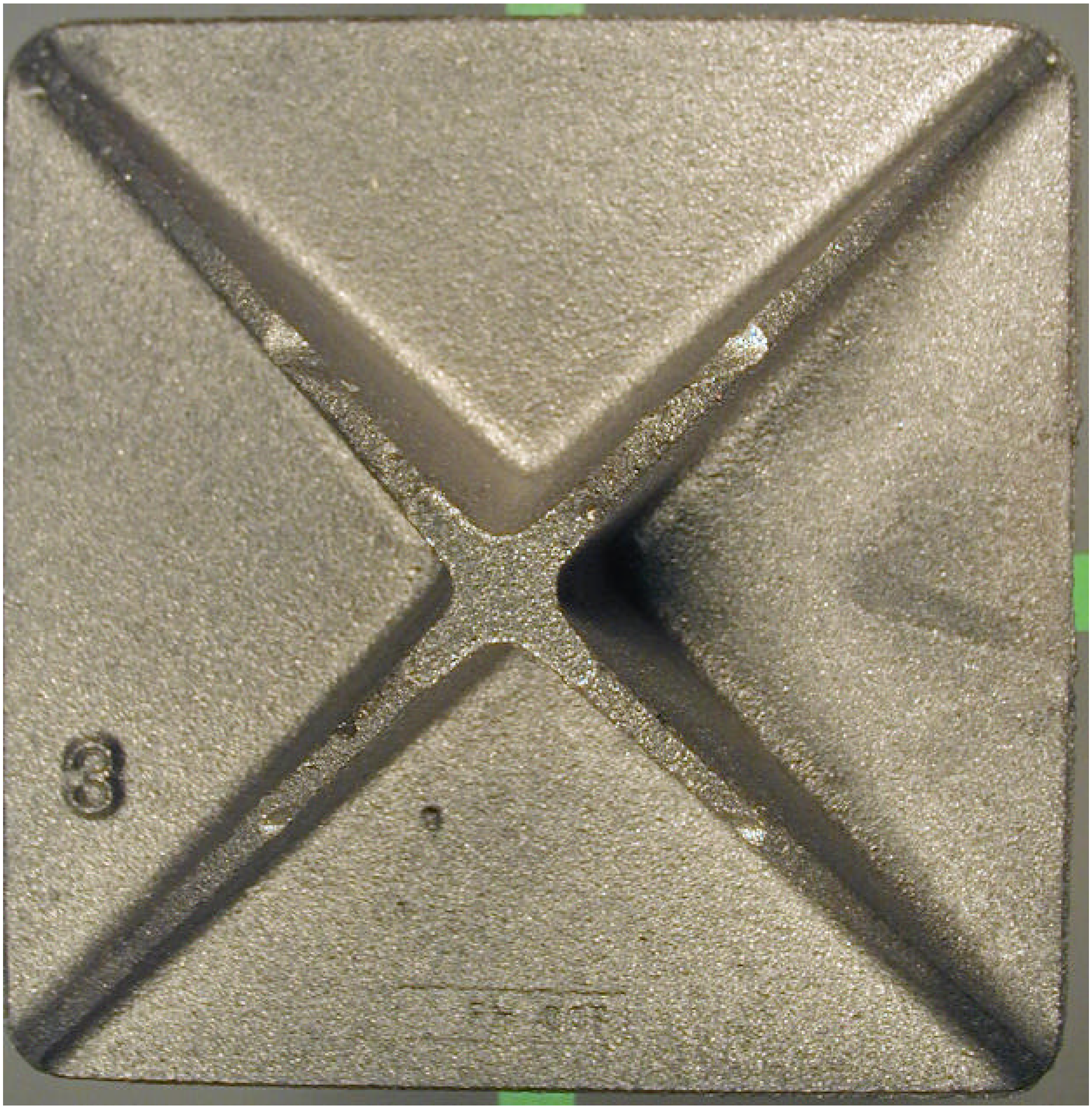
Mold FH009 Median Drag Cavity 1



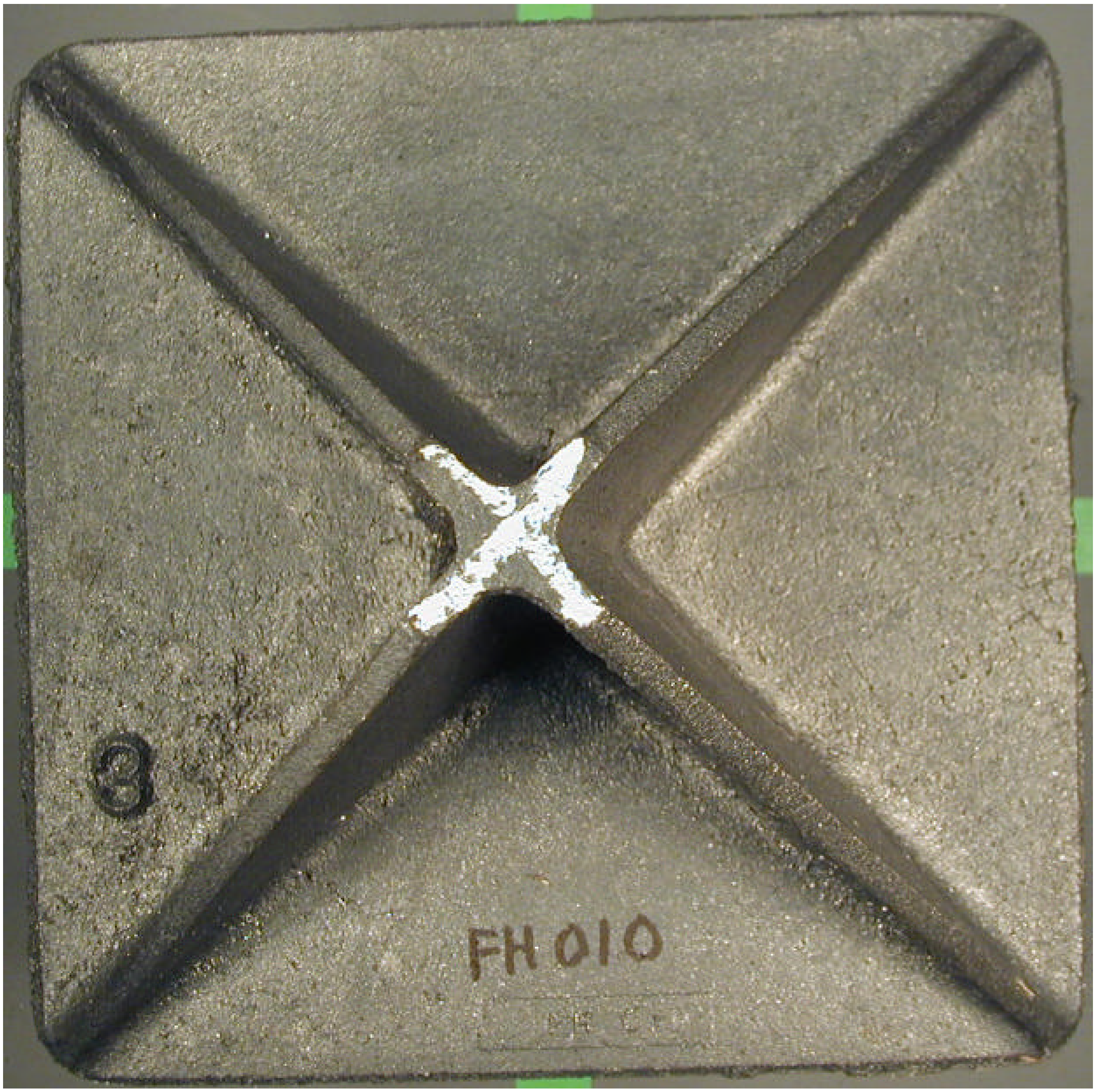
Mold FH007 Median Cope Cavity 2



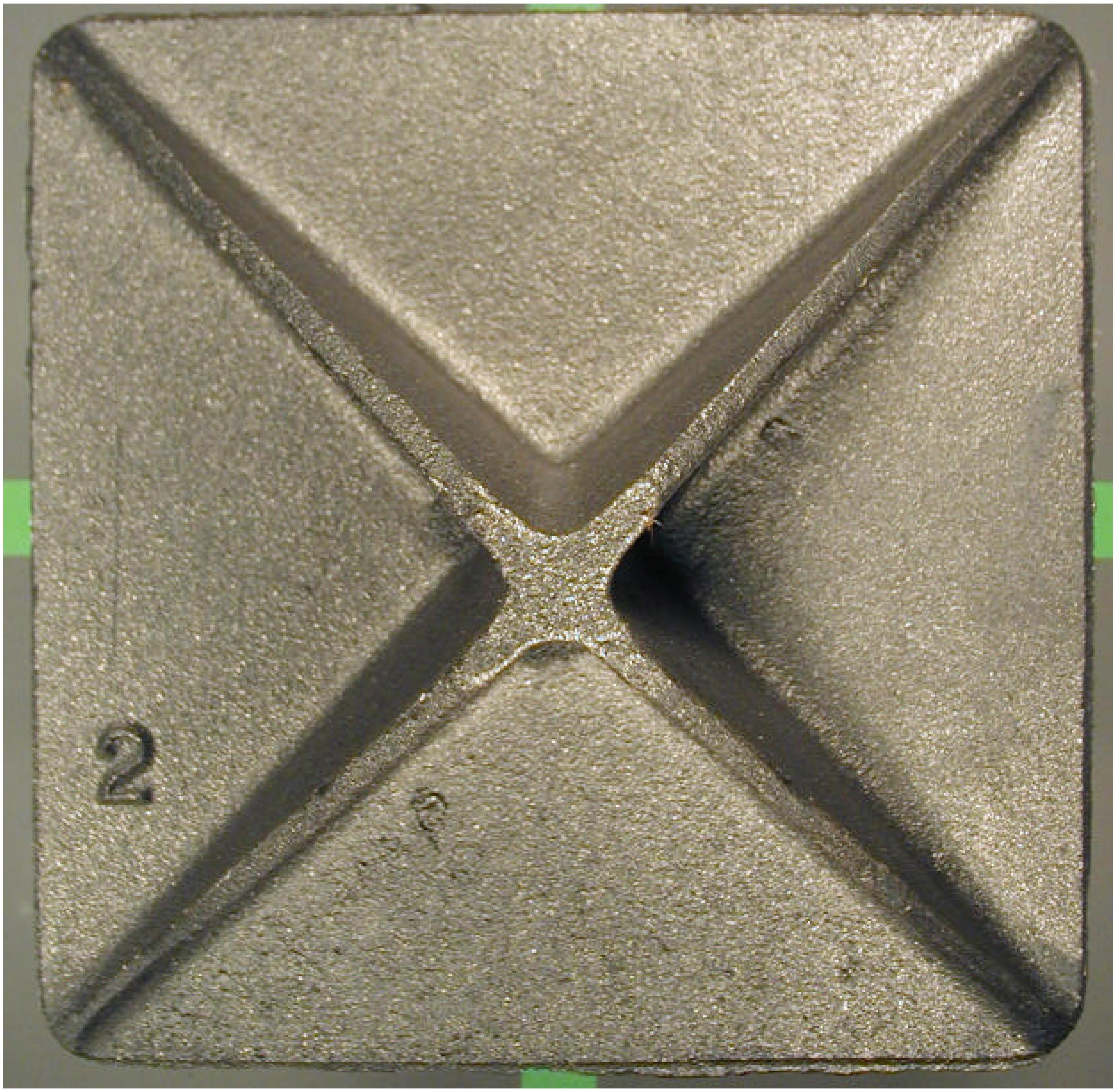
Mold FH007 Median Drag Cavity 2



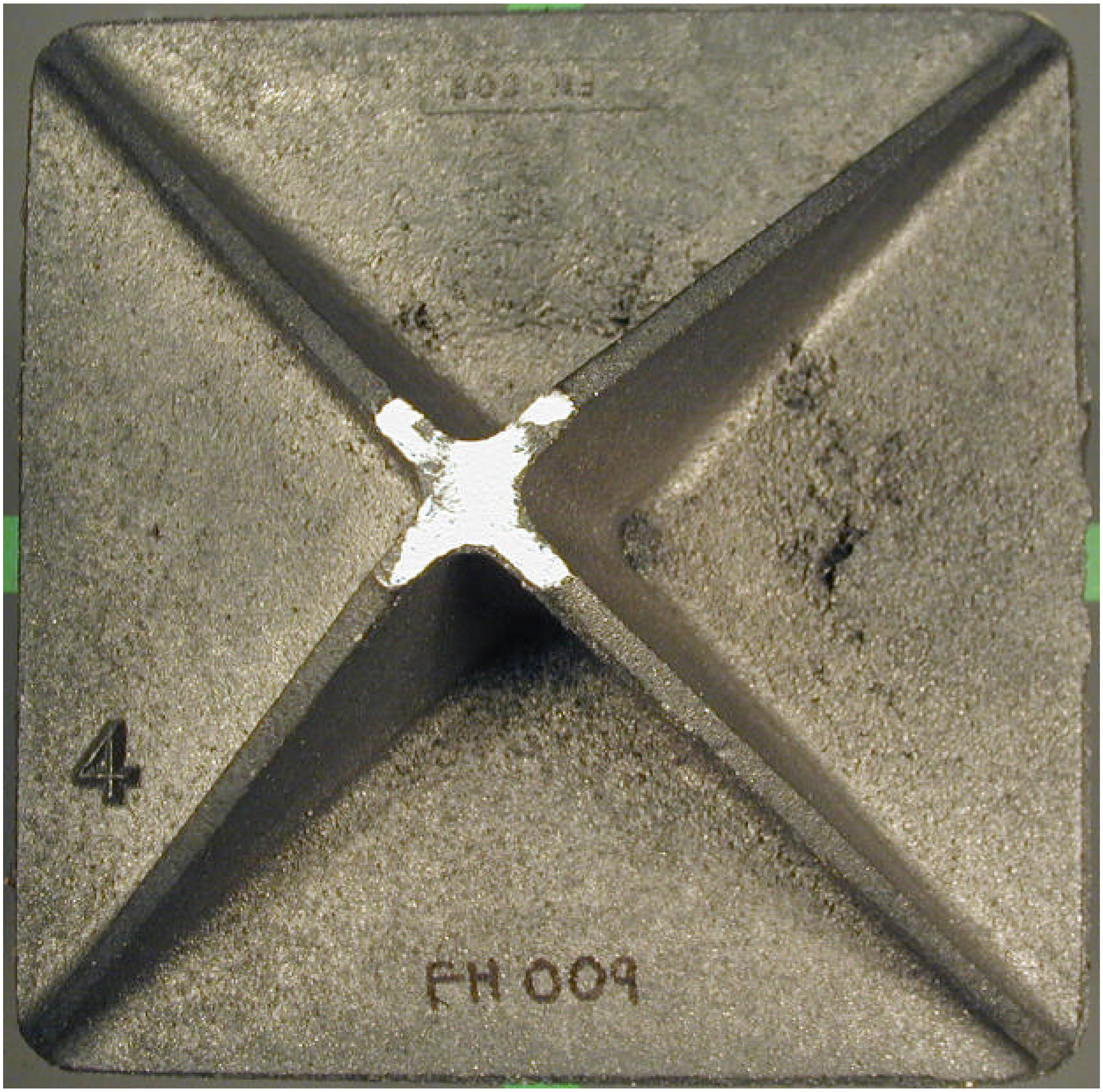
Mold FH010 Median Cope Cavity 3



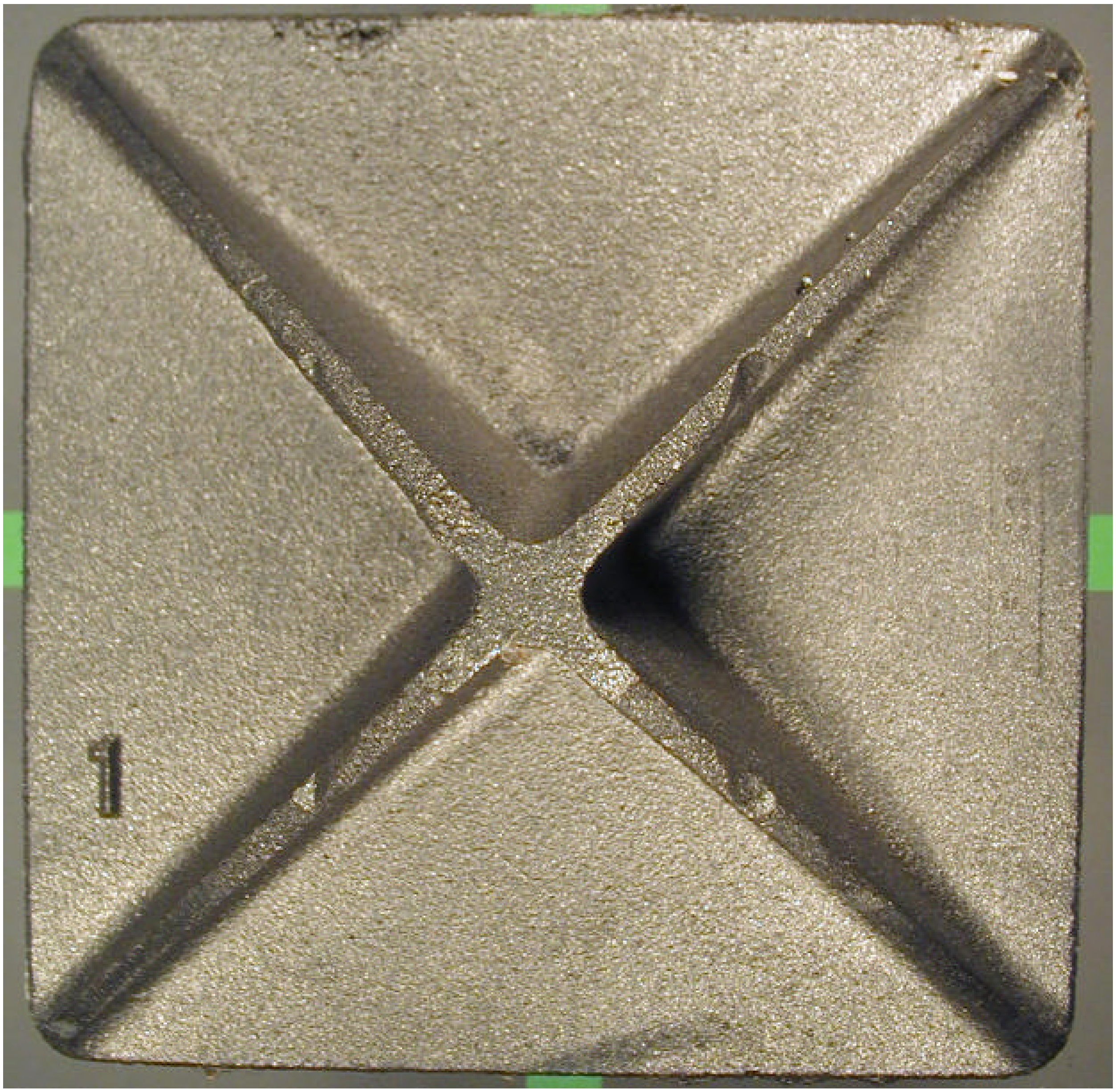
Mold FH010 Median Drag Cavity 3



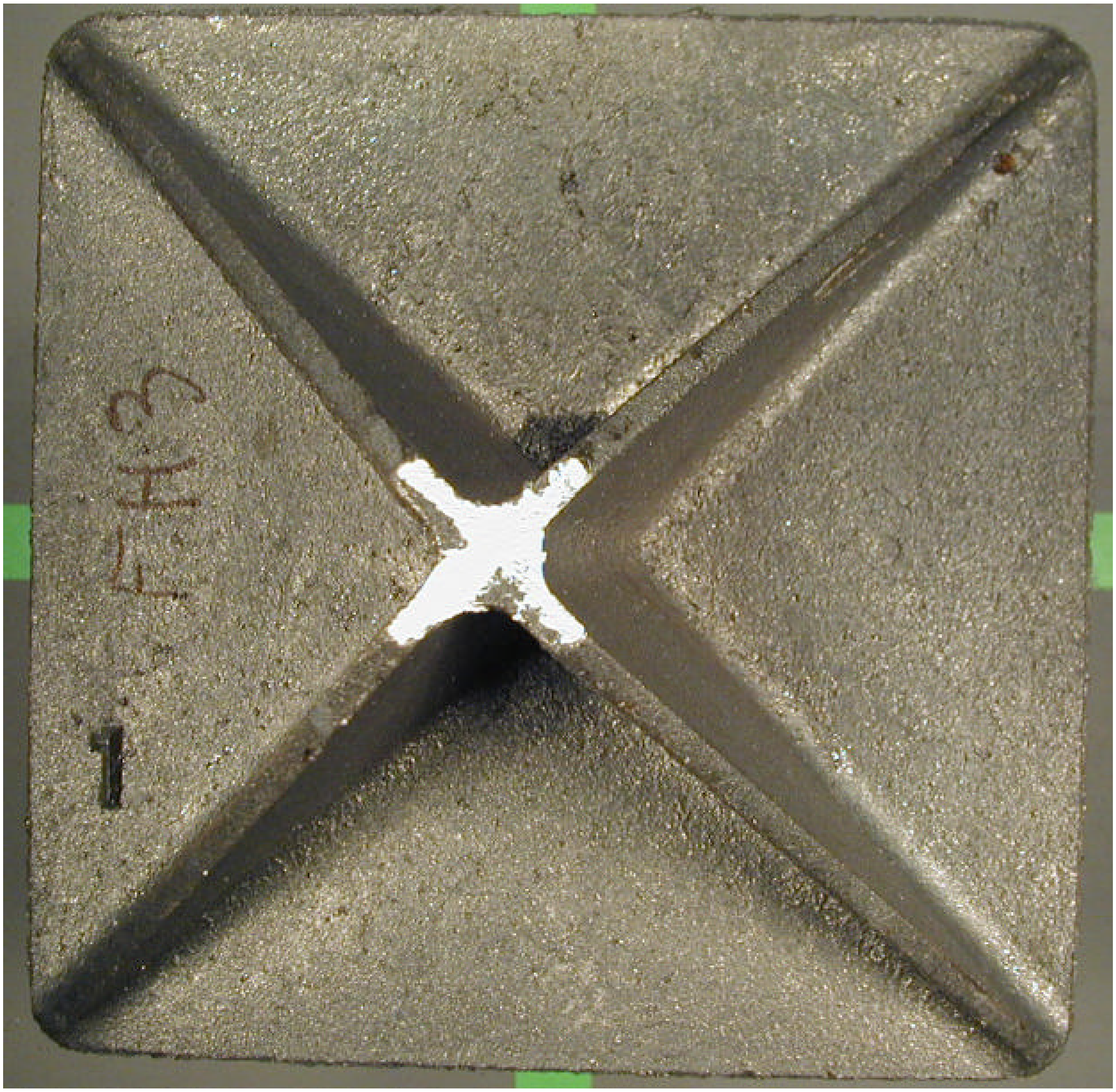
Mold FH009 Median Cope Cavity 4



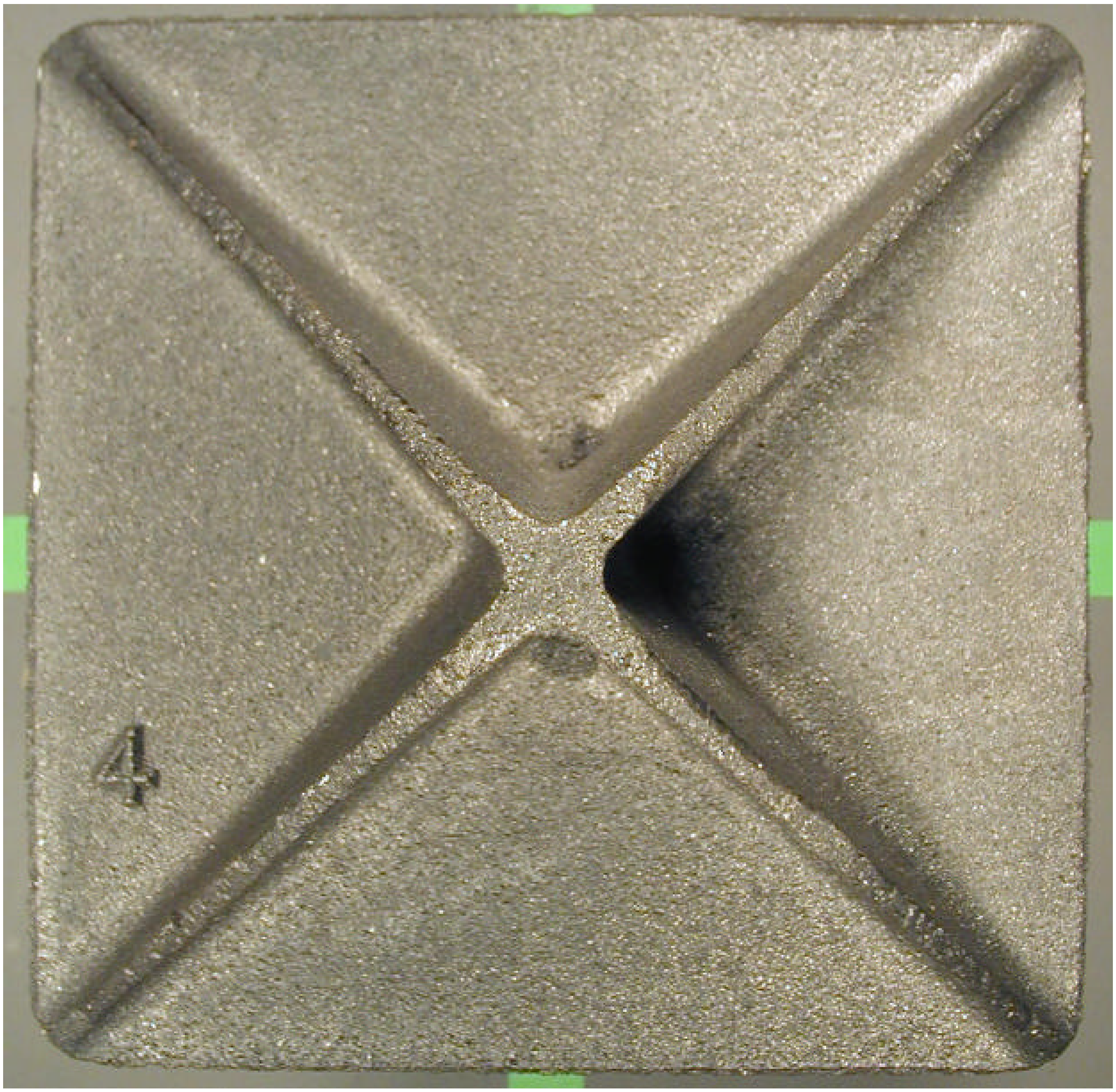
Mold FH009 Median Drag Cavity 4



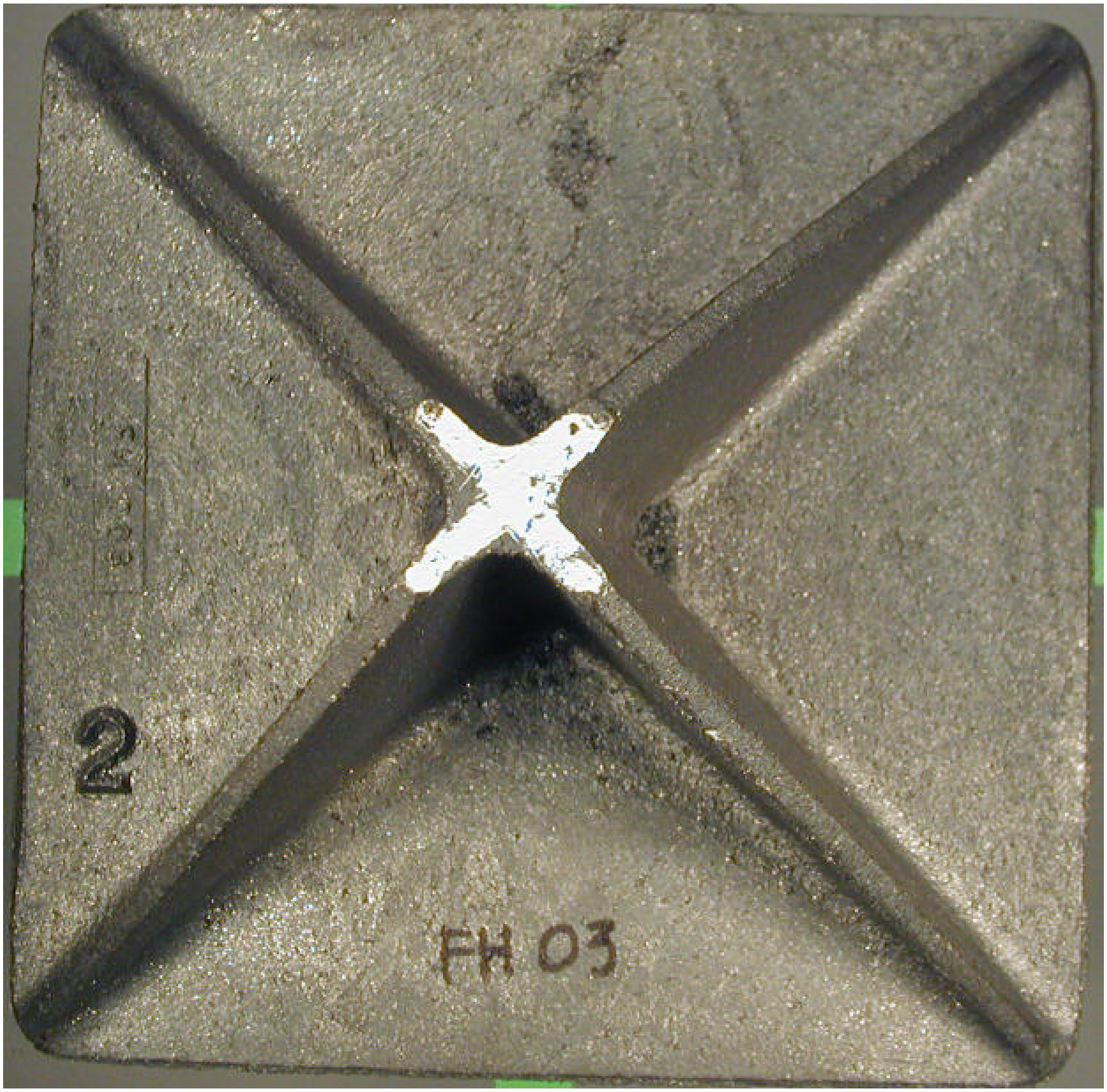
Mold FH003 Worst Cope Cavity 1



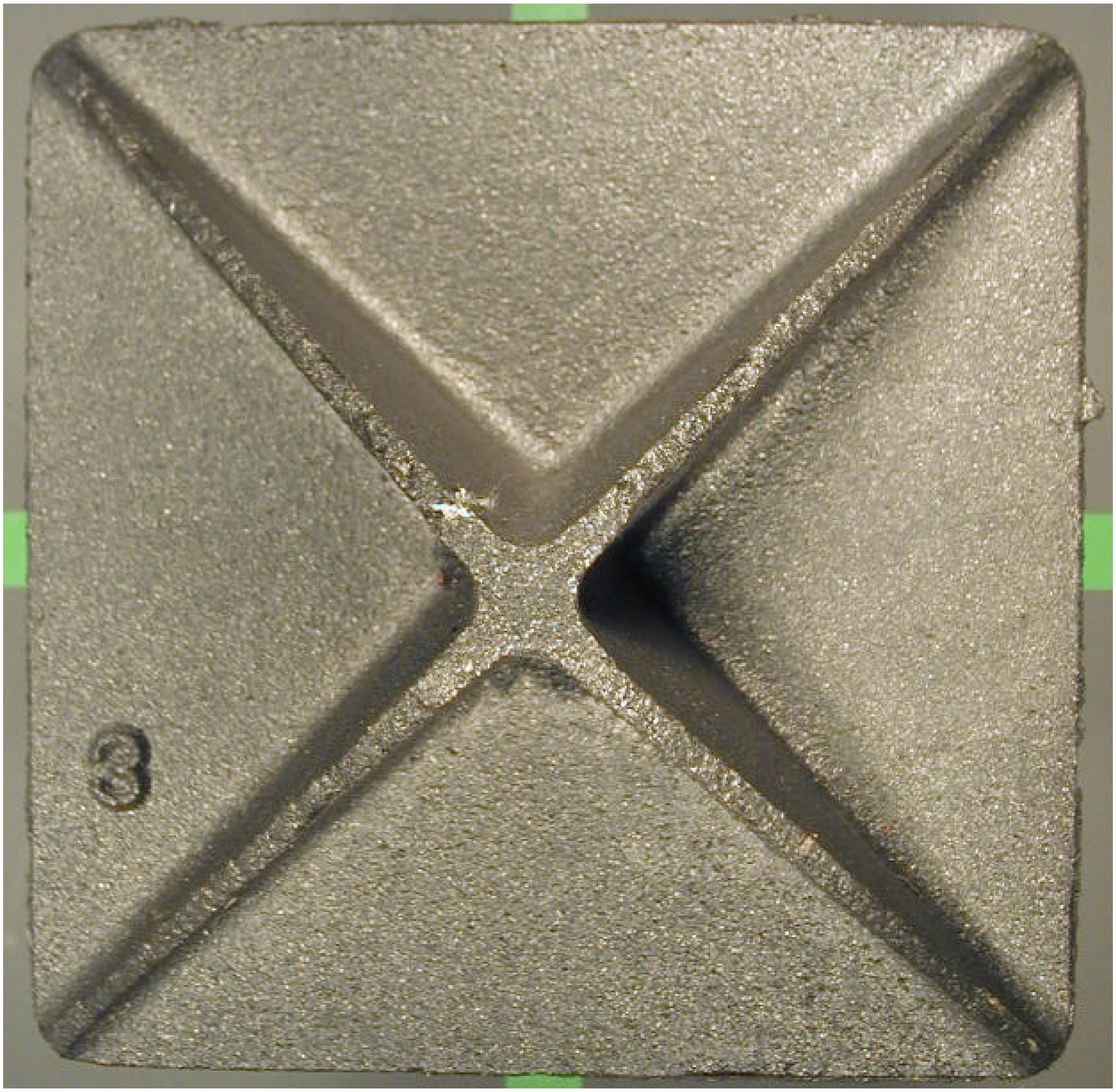
Mold FH003 Worst Drag Cavity 1



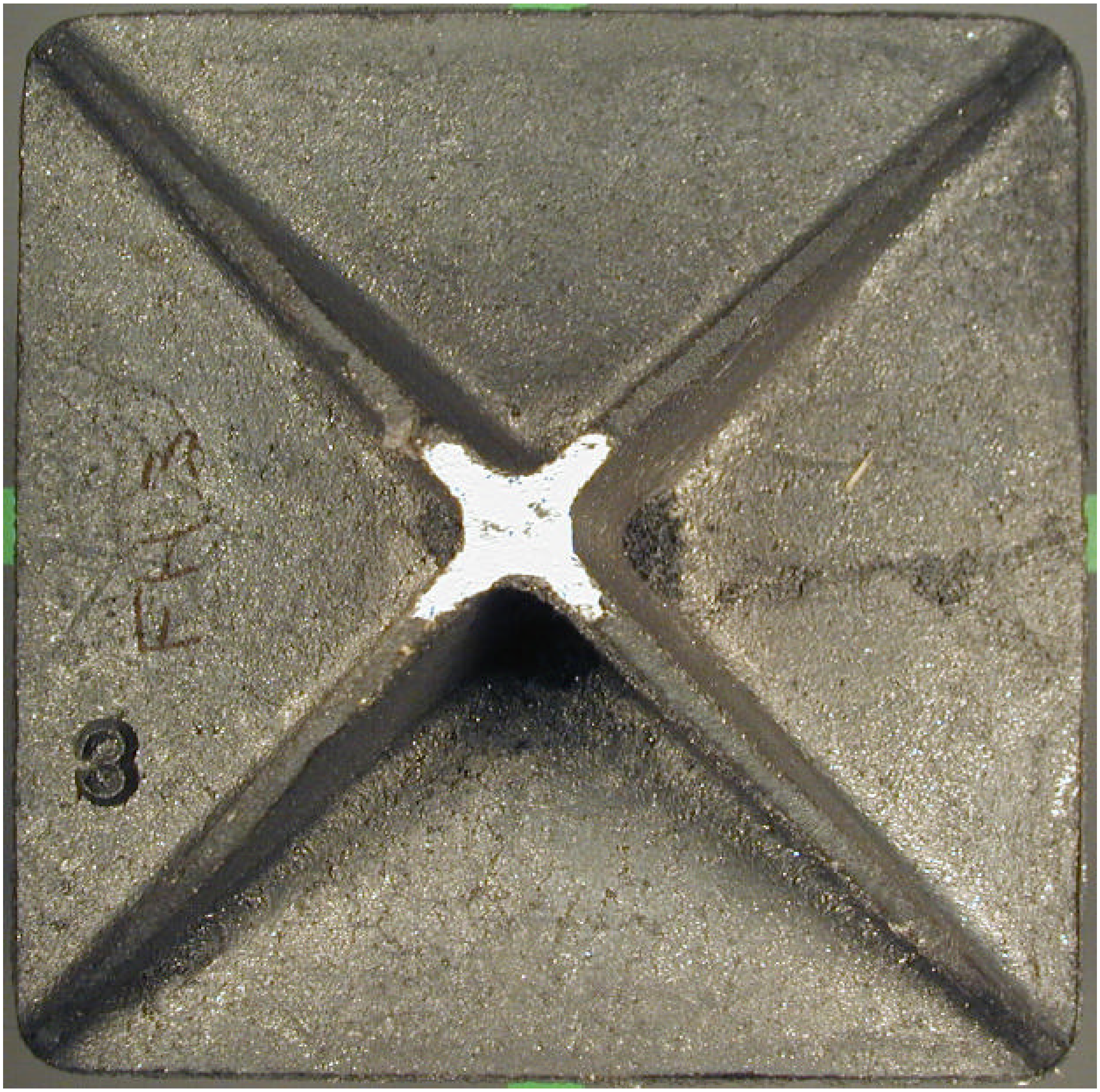
Mold FH003 Worst Cope Cavity 2



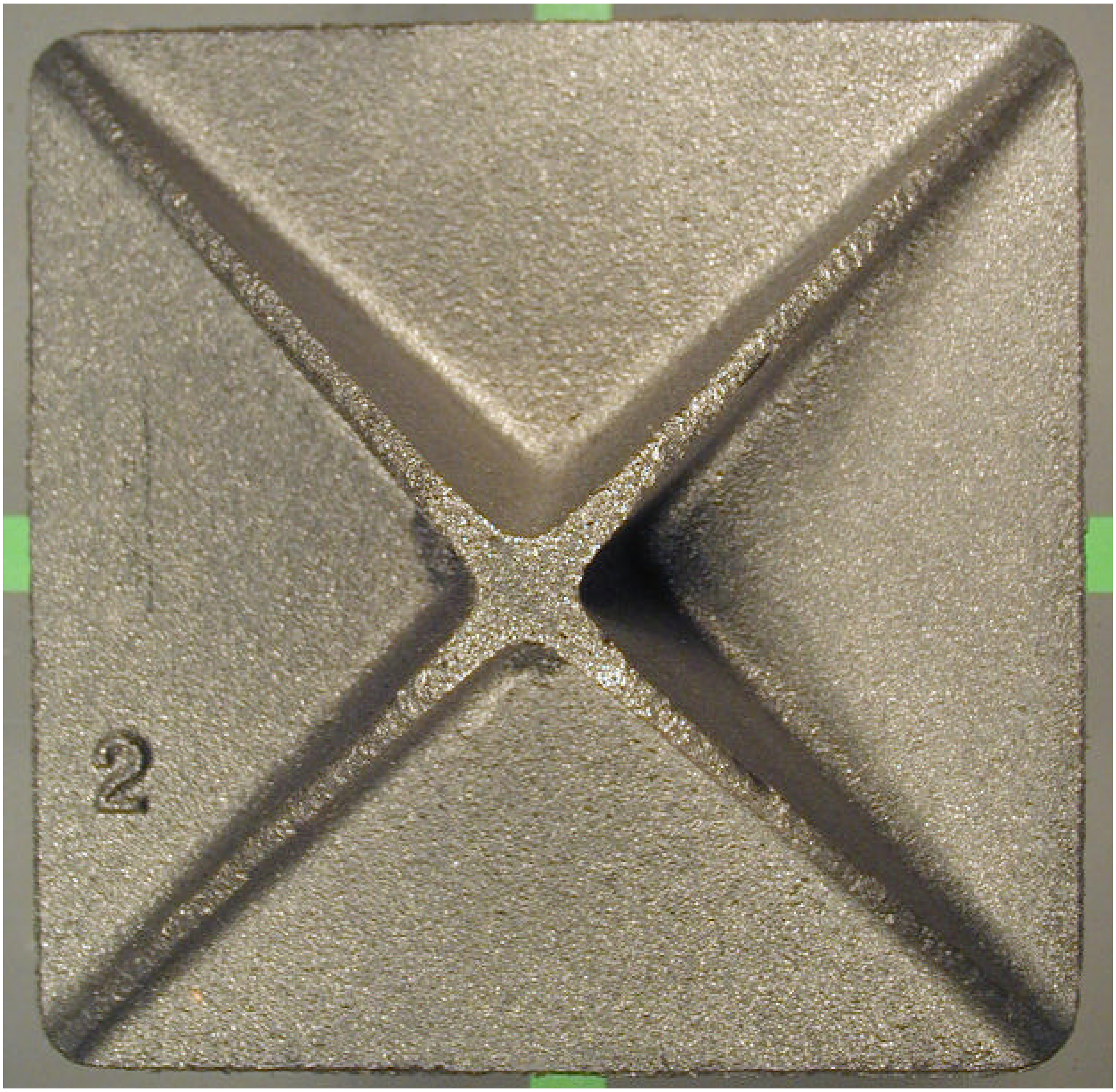
Mold FH003 Worst Drag Cavity 2



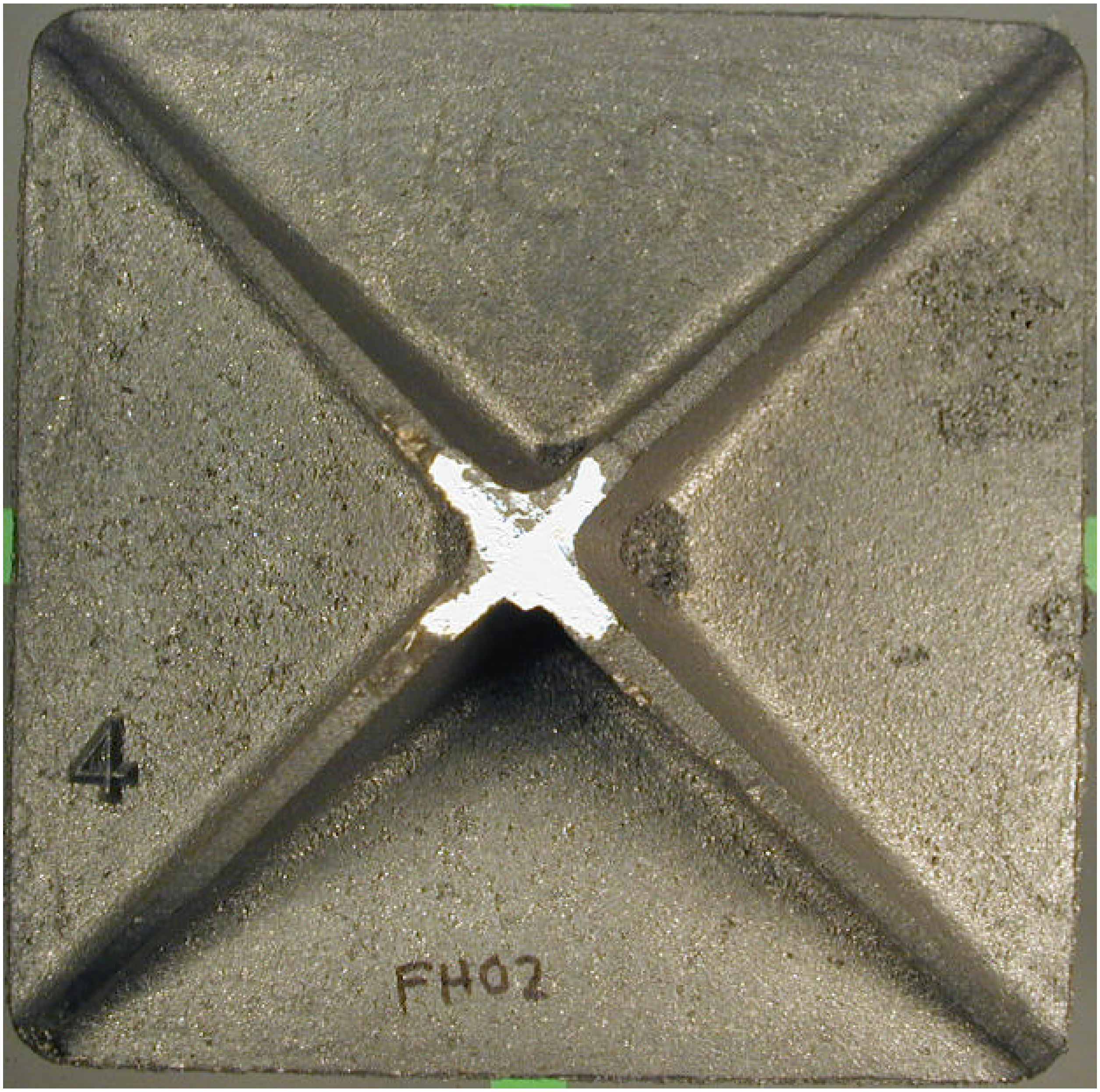
Mold FH003 Worst Cope Cavity 3



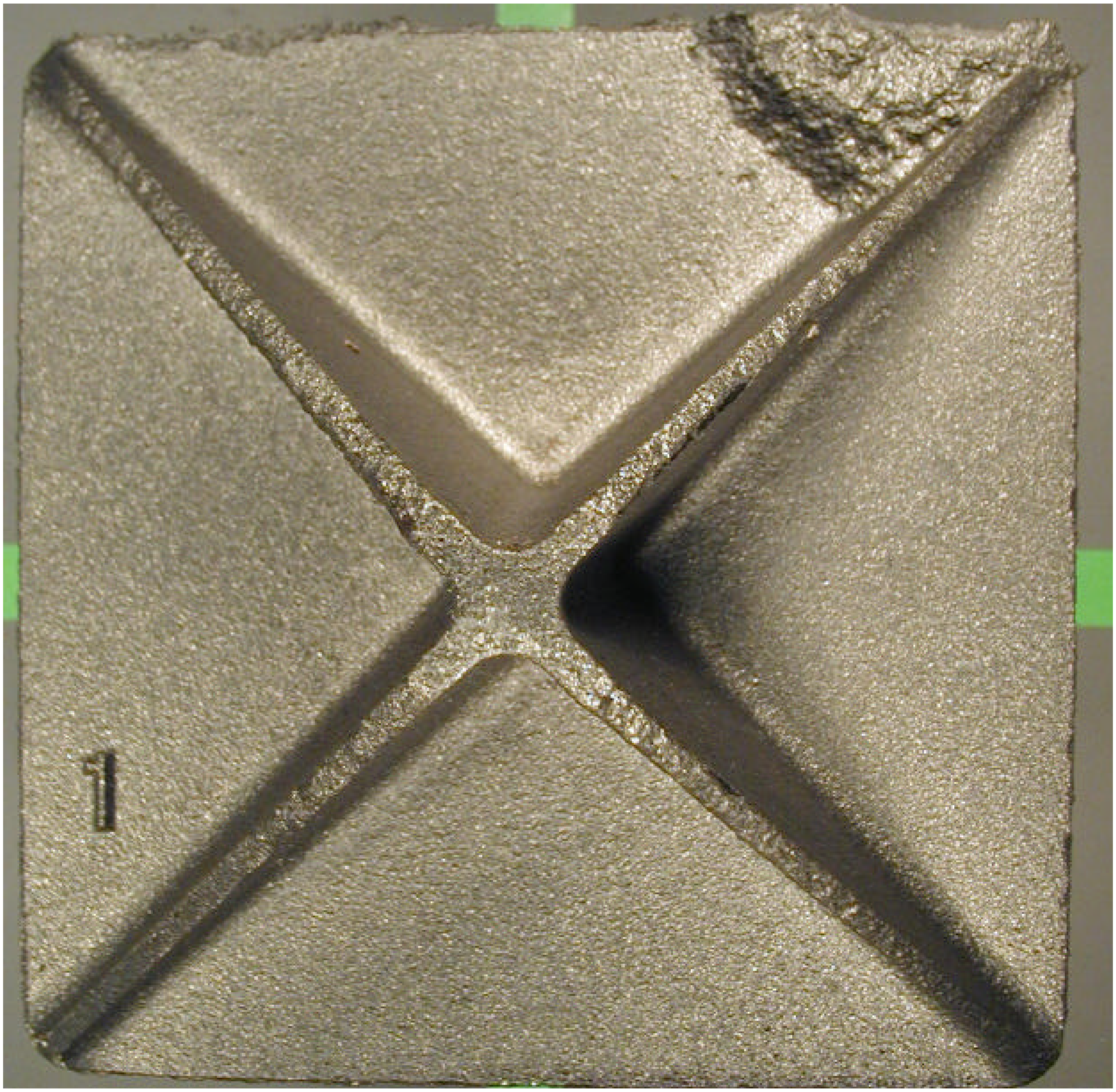
Mold FH003 Worst Drag Cavity 3



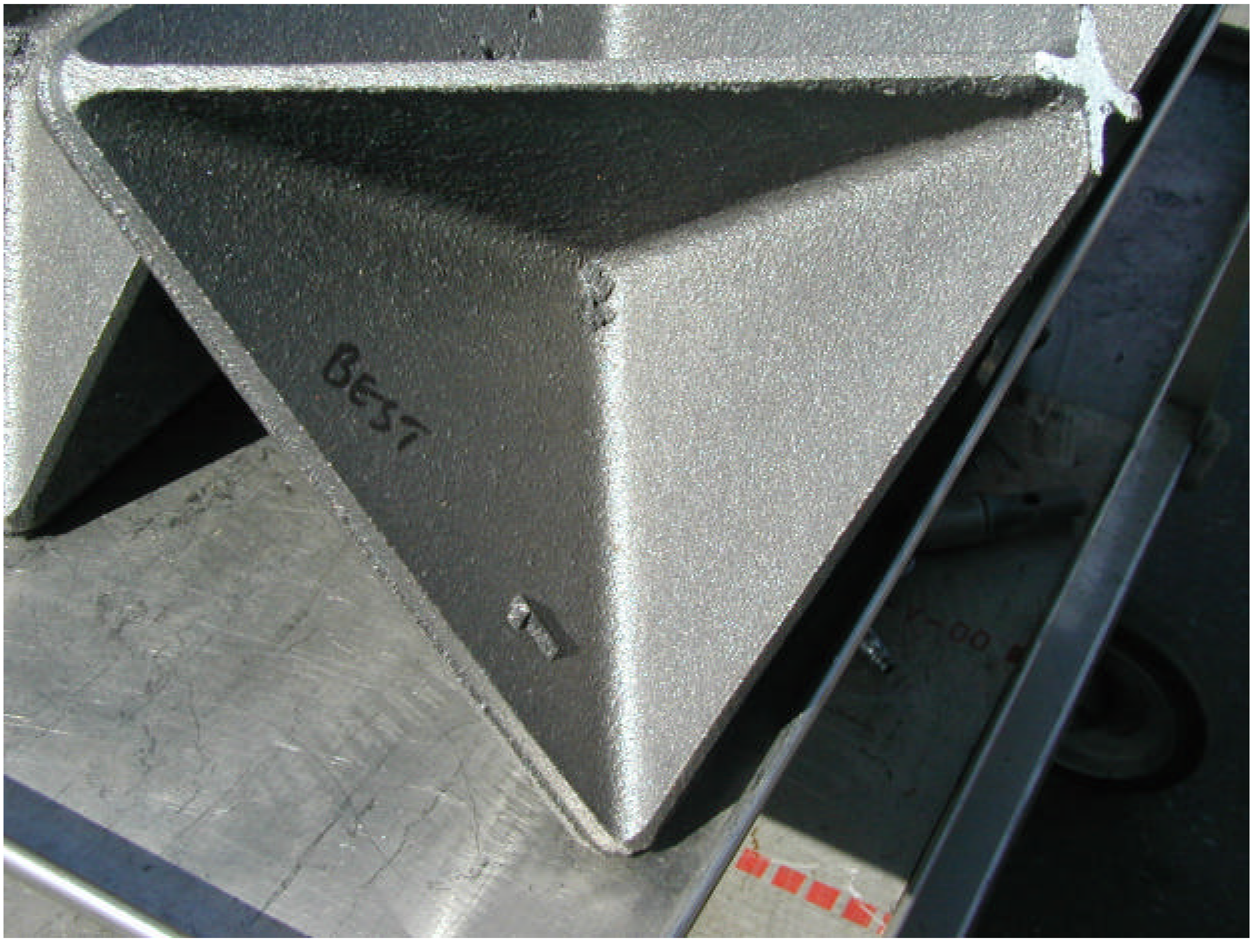
Mold FH002 Worst Cope Cavity 4



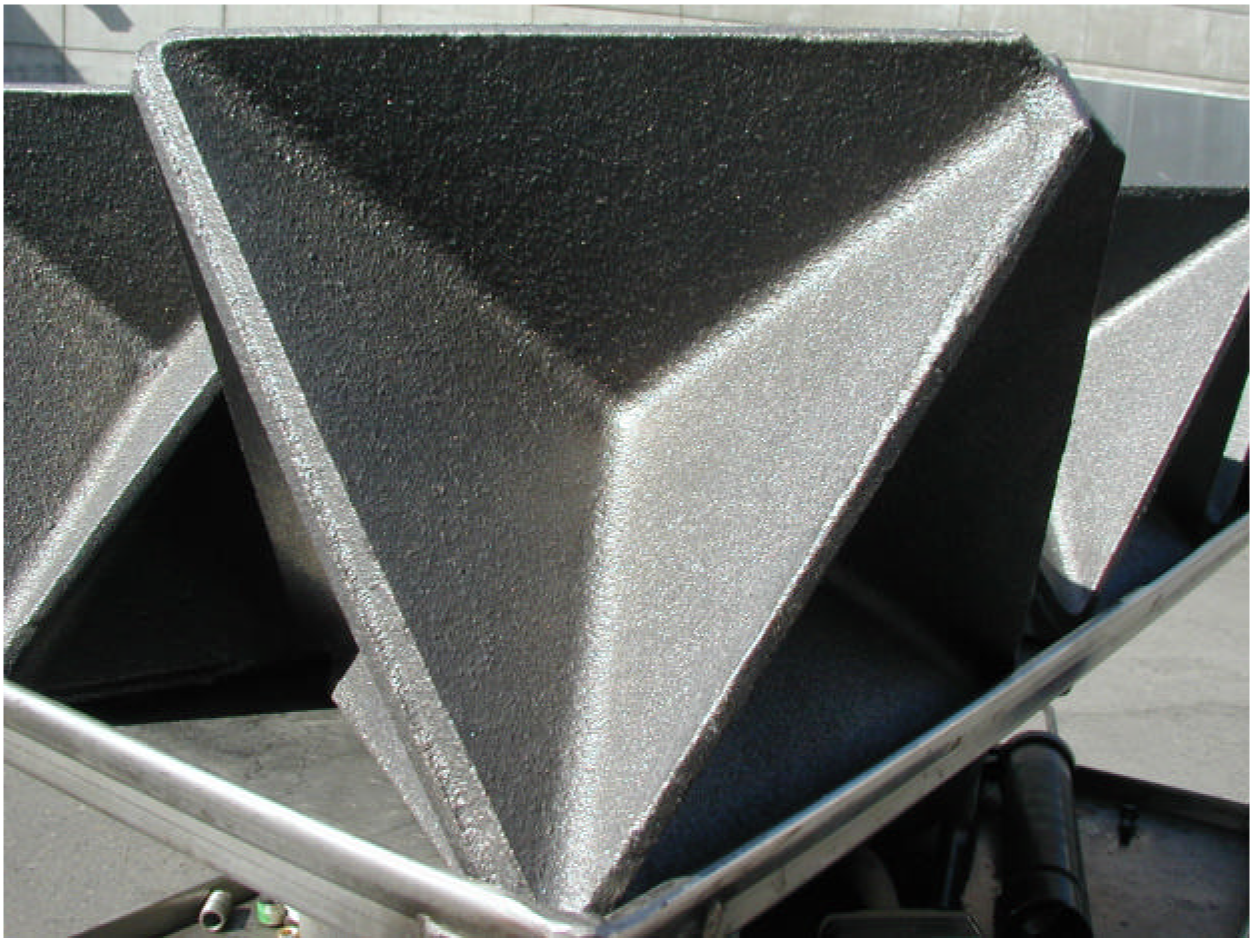
Mold FH002 Worst Drag Cavity 4



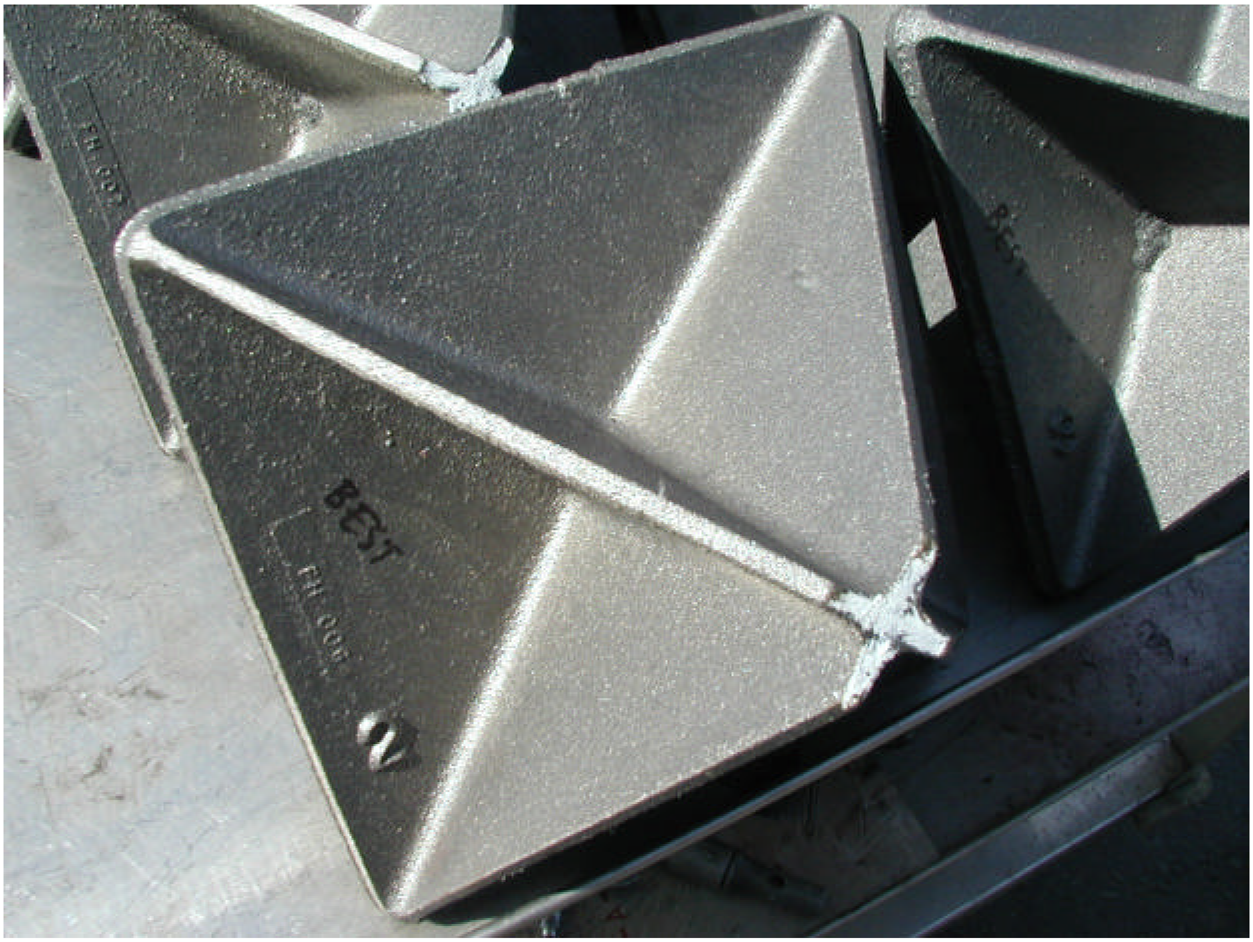
Mold FH008 Best Cope Cavity



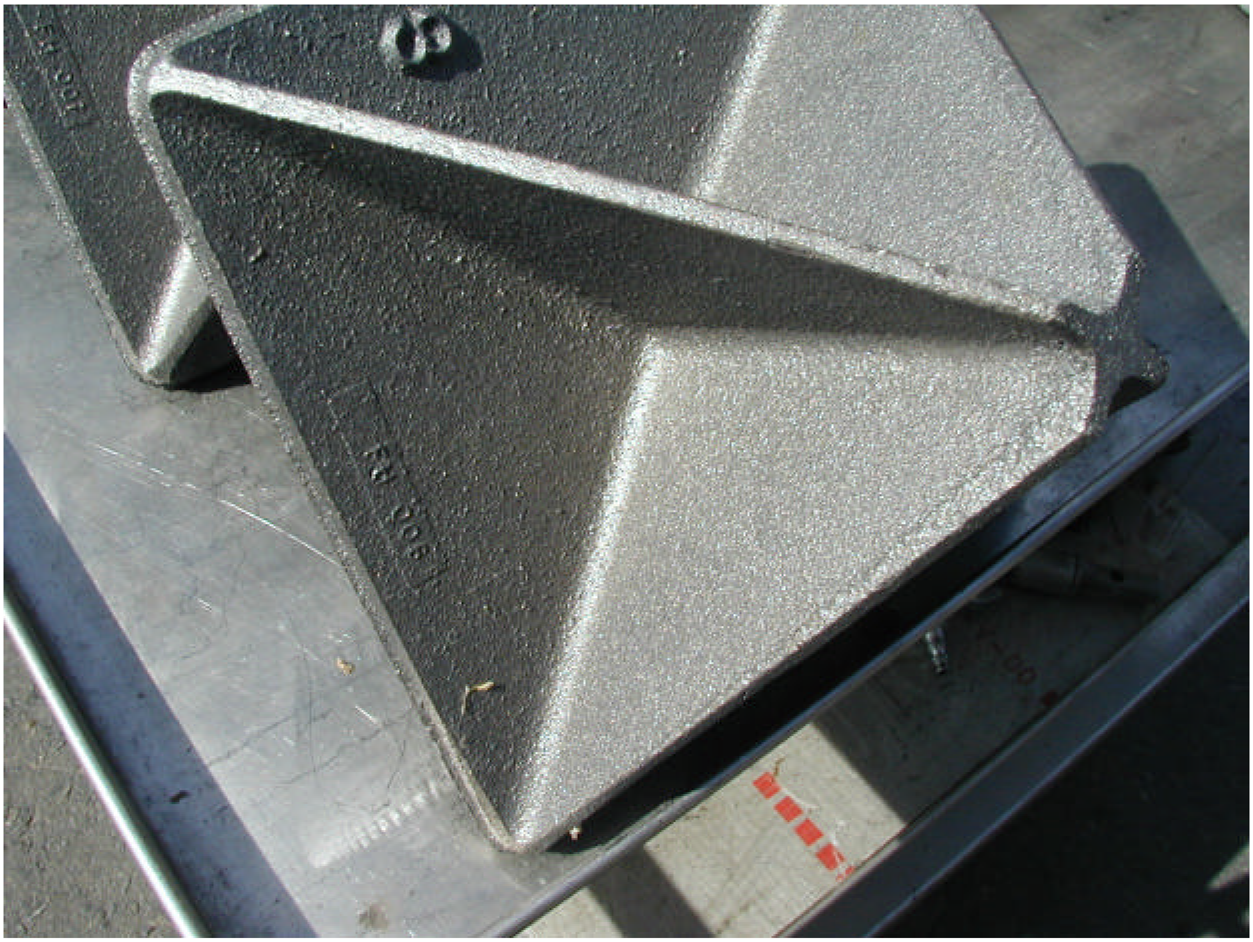
Mold FH008 Best Drag Cavity 1



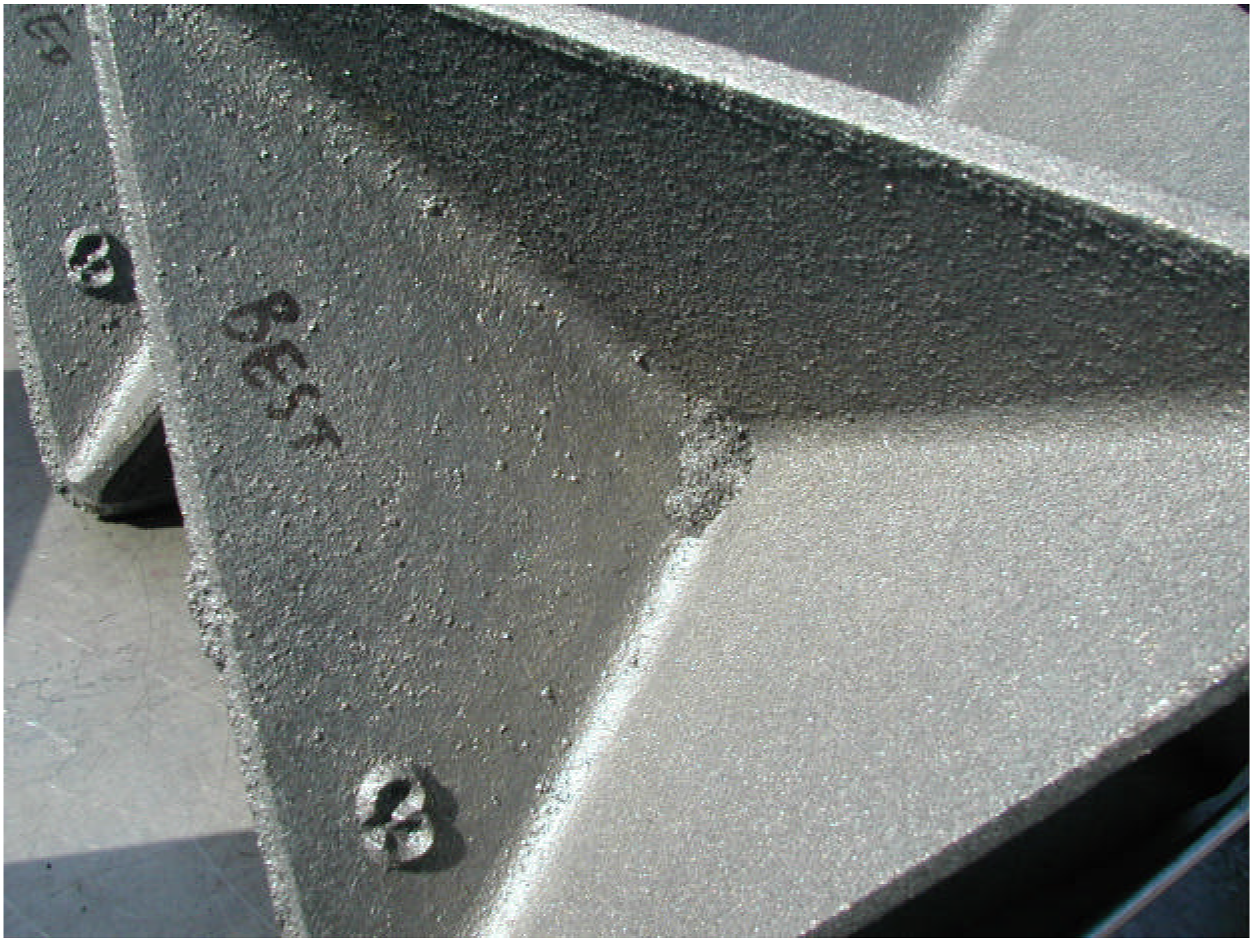
Mold FH011 Best Cope Cavity 2



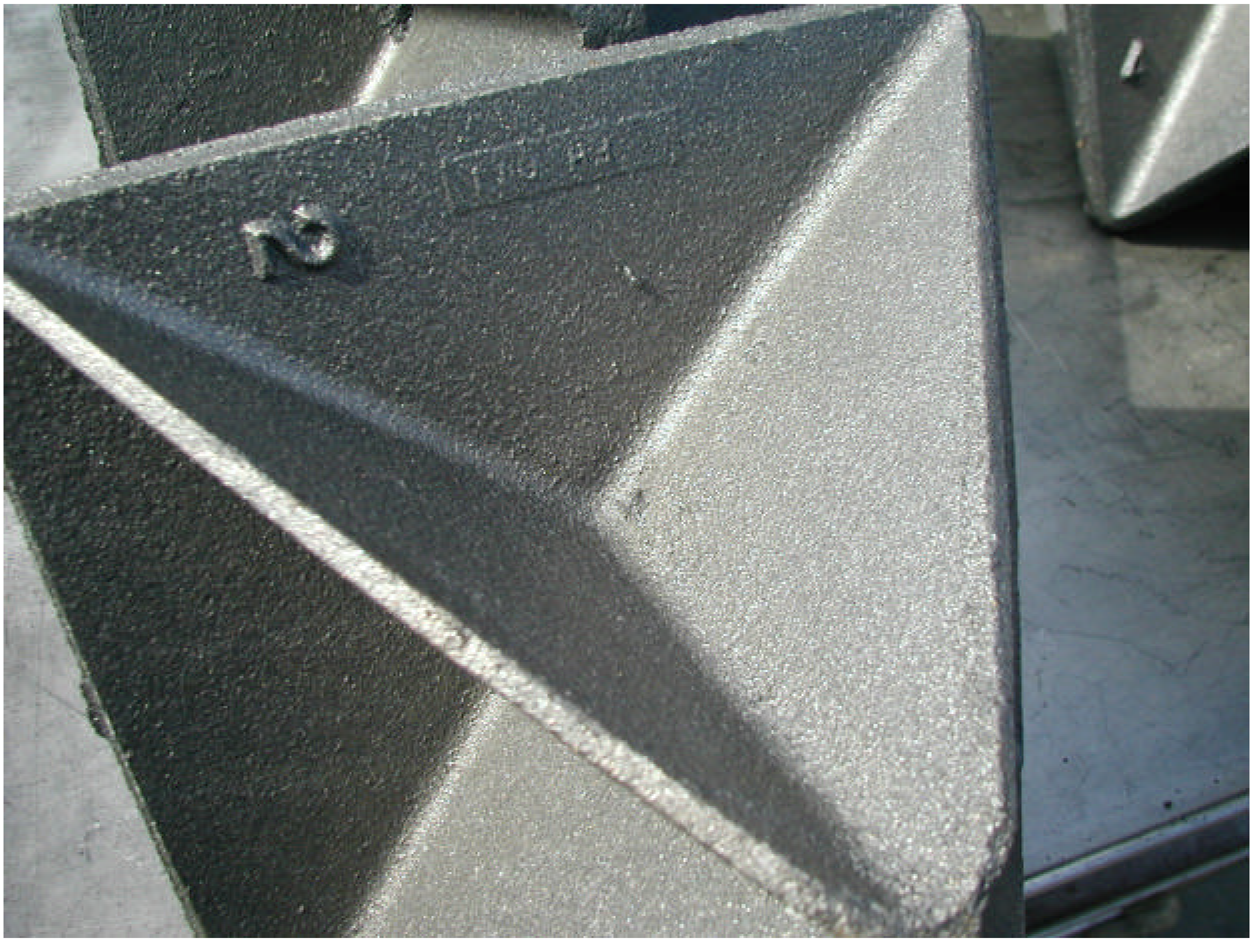
Mold FH006 Best Drag Cavity 2



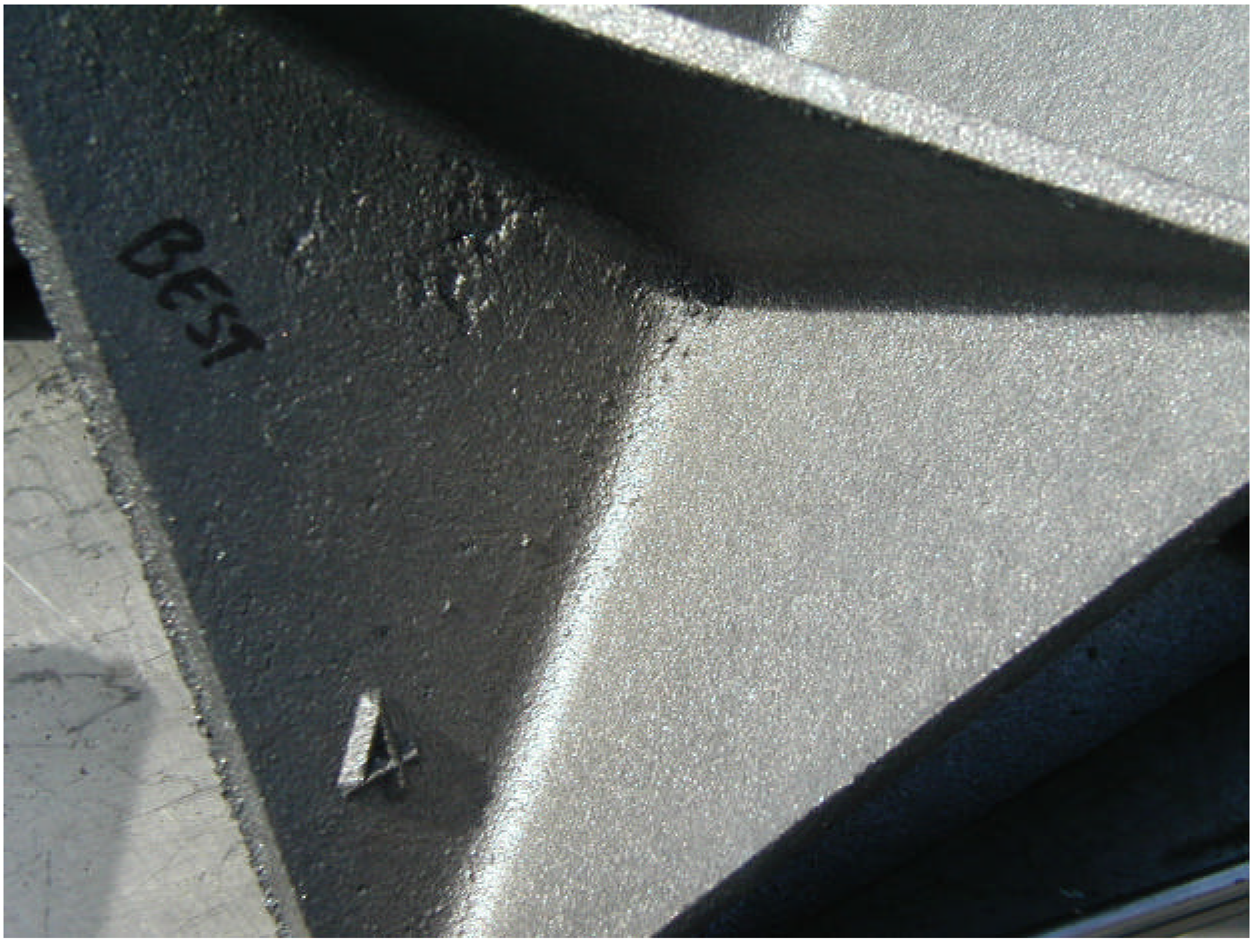
Mold FH011 Best Cope Cavity 3



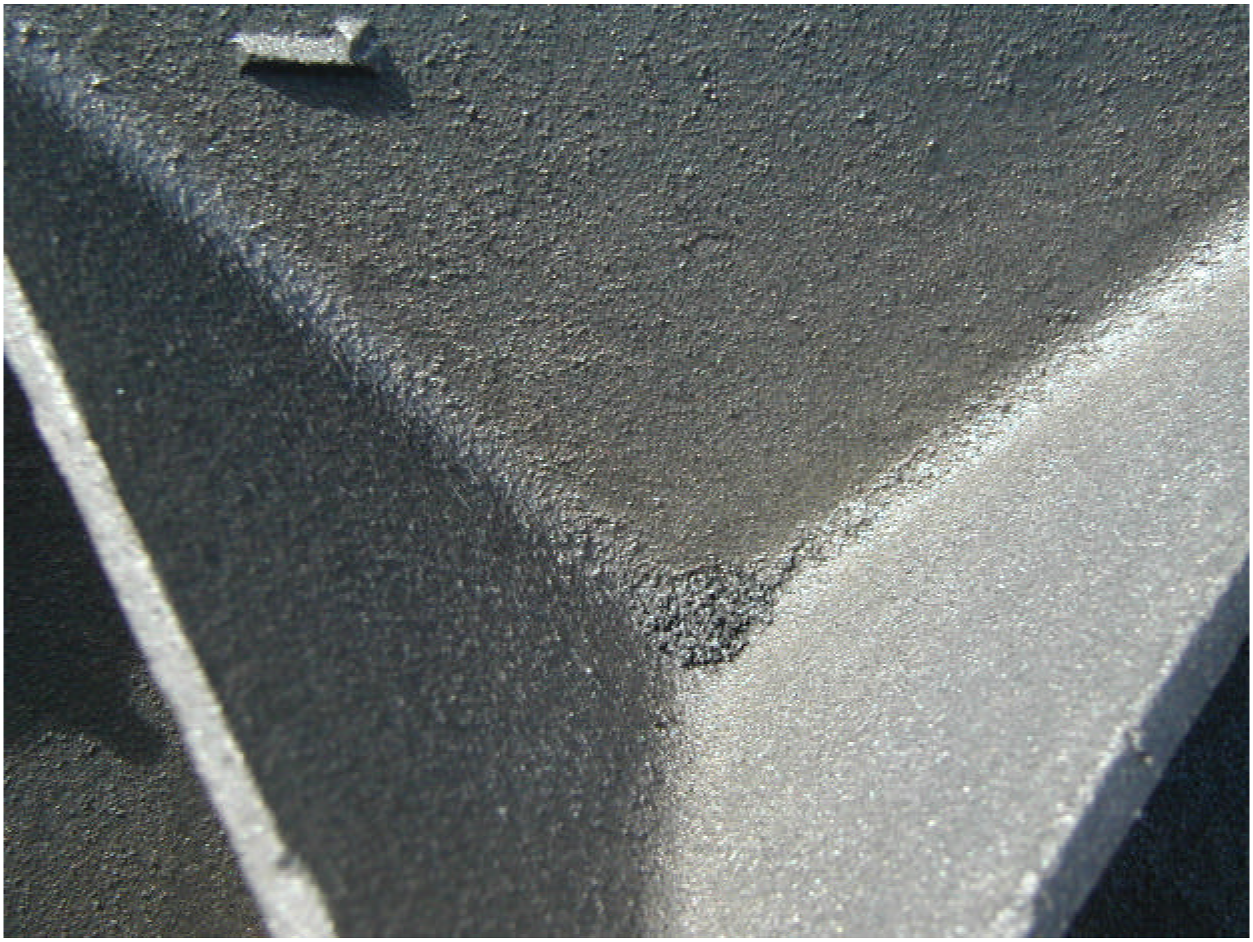
Mold FH011 Best Drag Cavity 3



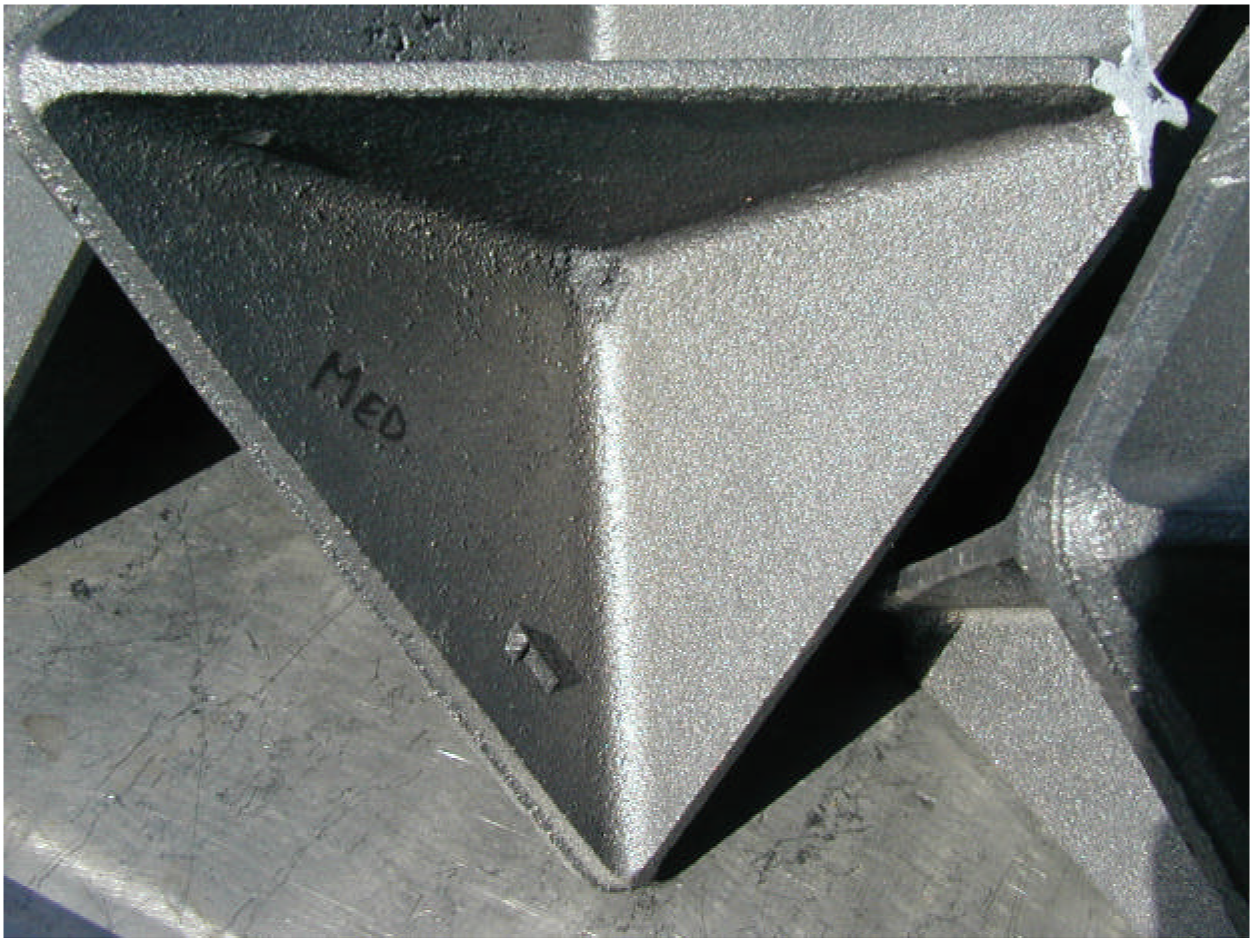
Mold FH005 Best Cope Cavity 4



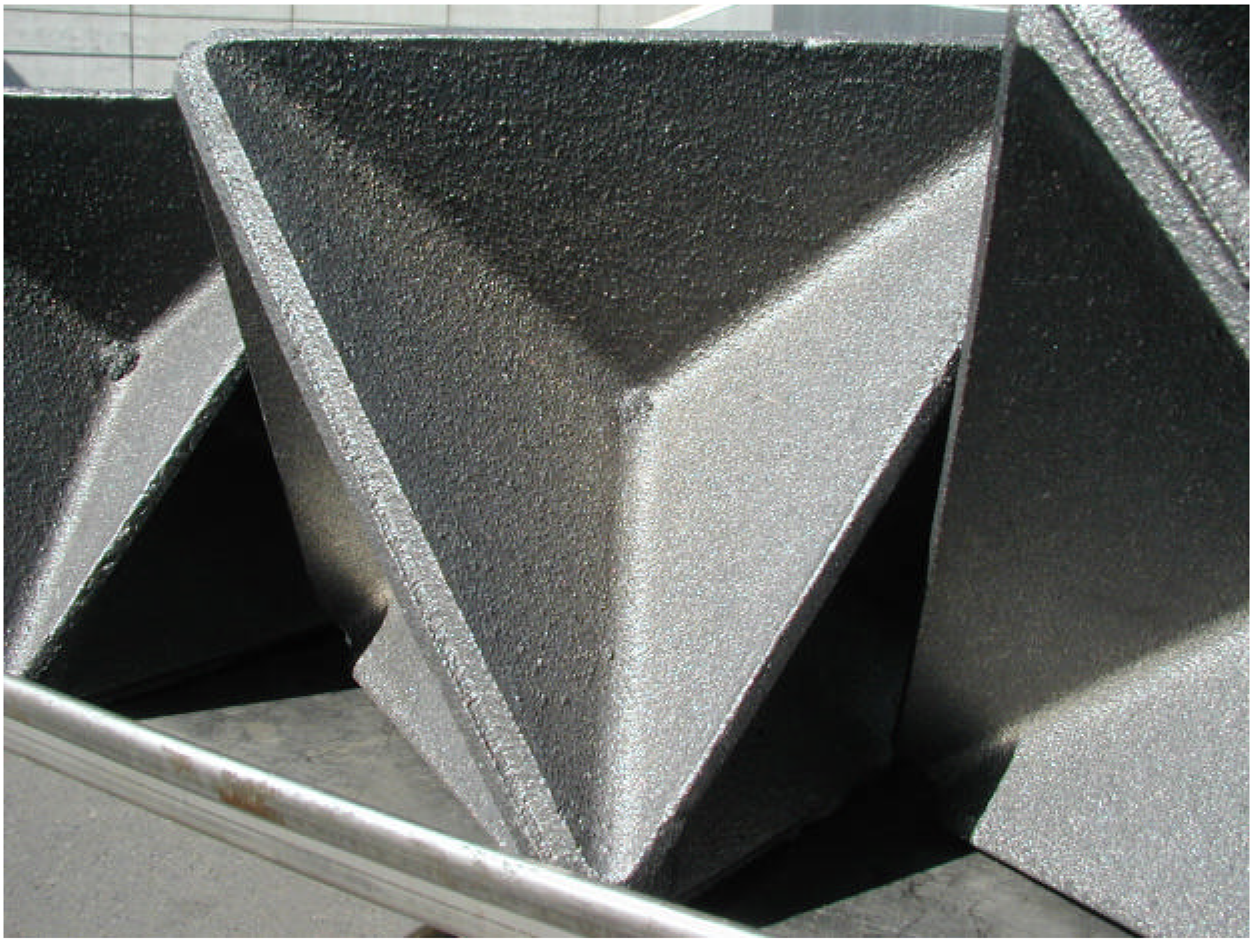
Mold FH005 Best Drag Cavity 4



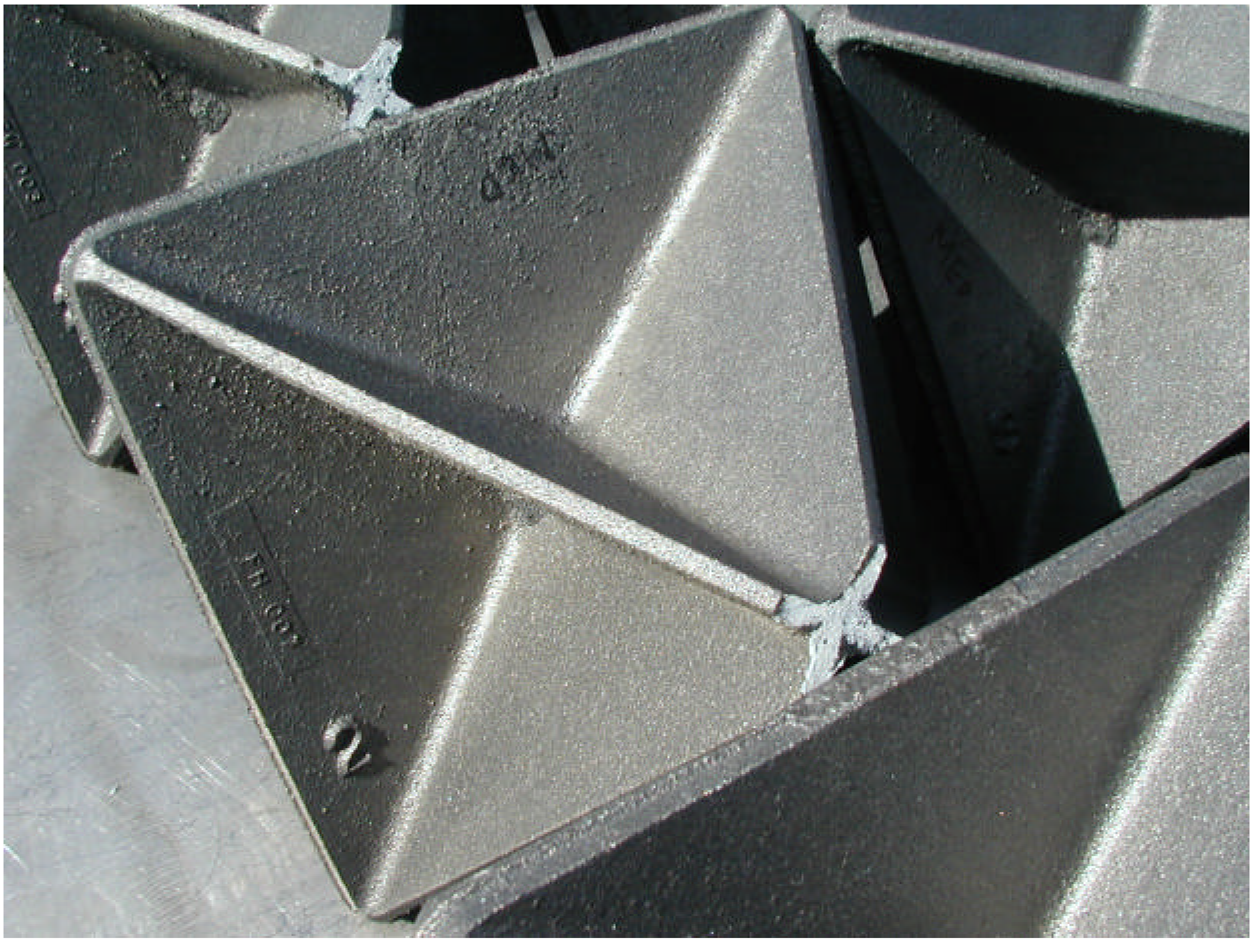
Mold FH009 Median Cope Cavity 1



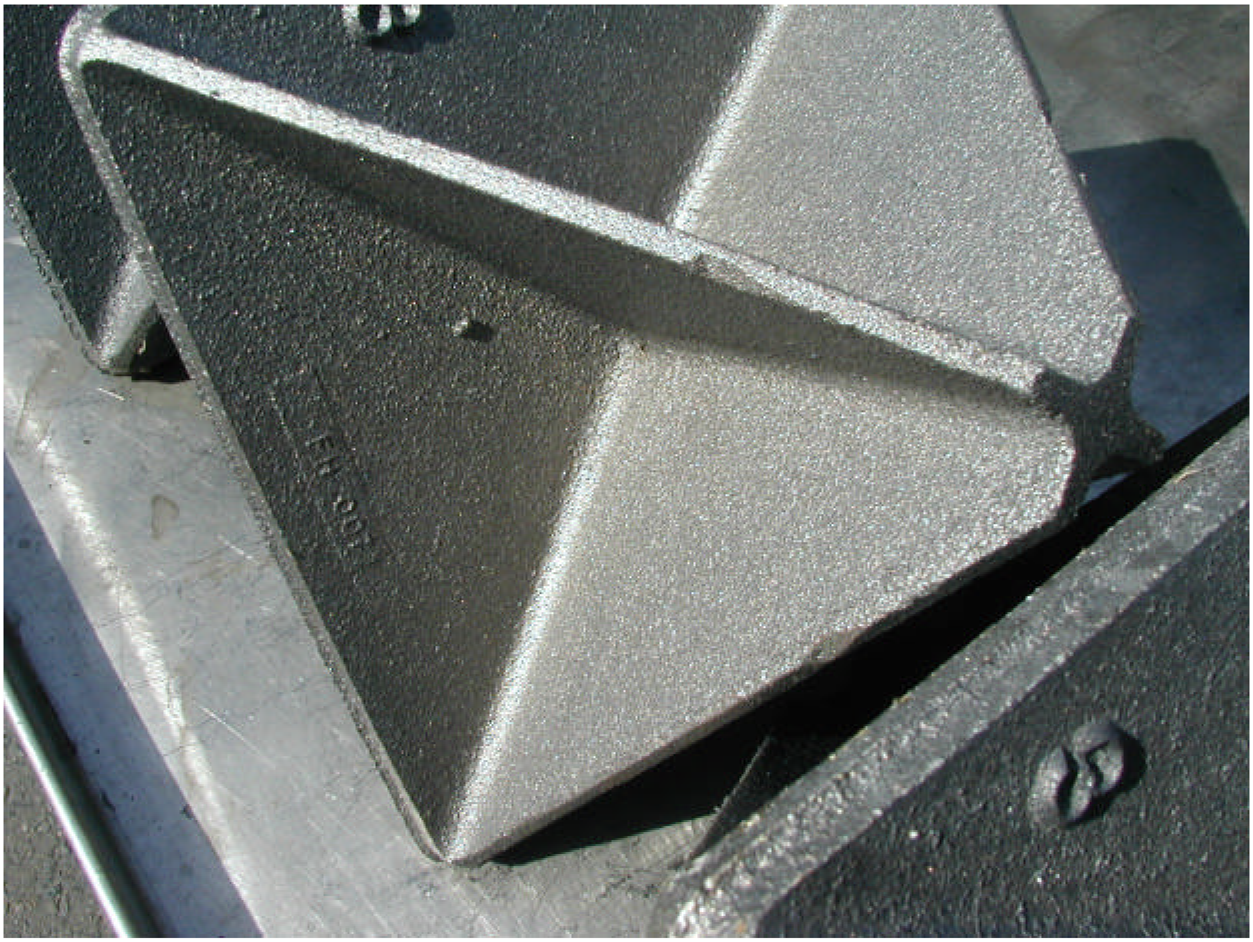
Mold FH009 Median Drag Cavity 1



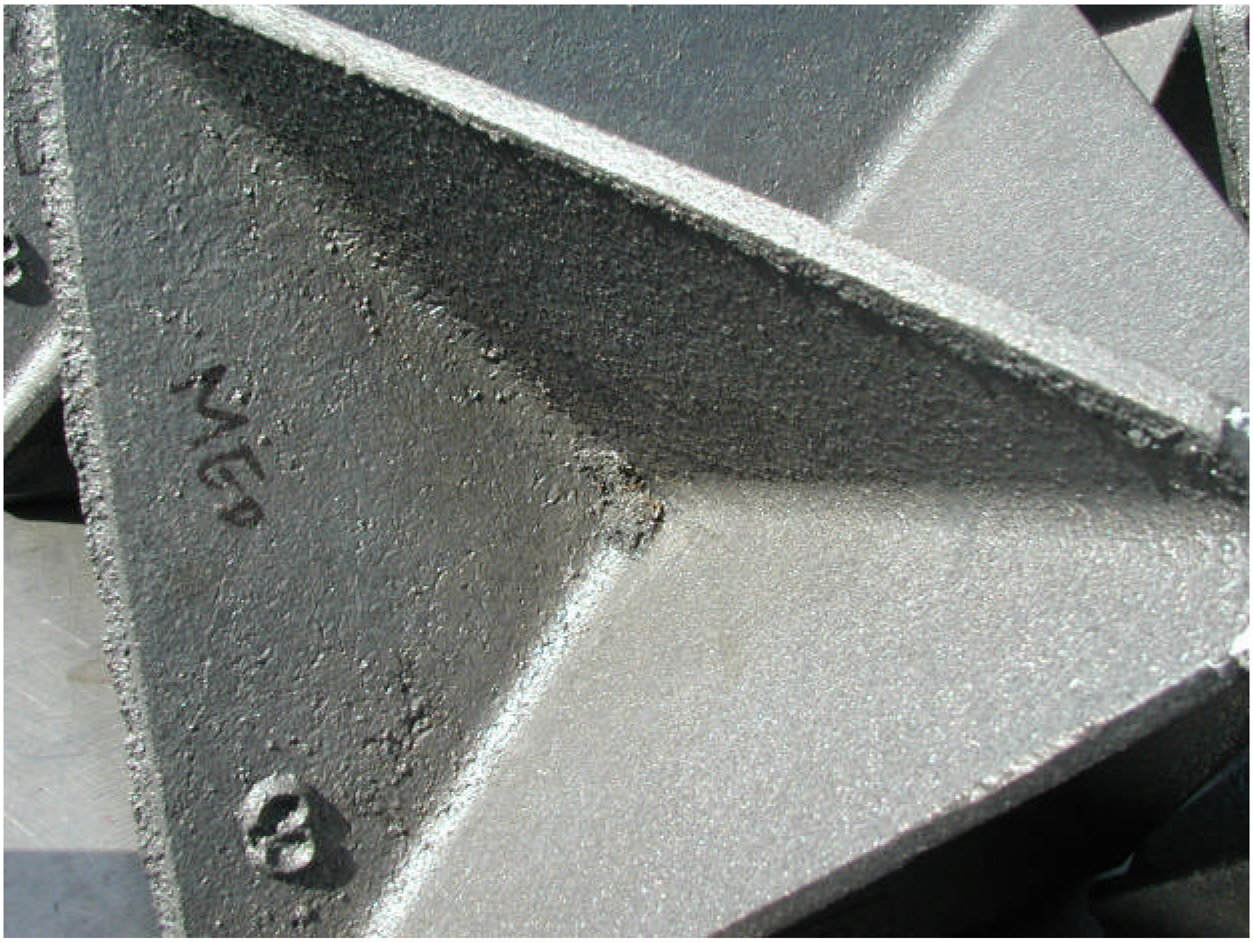
Mold FH007 Median Cope Cavity 2



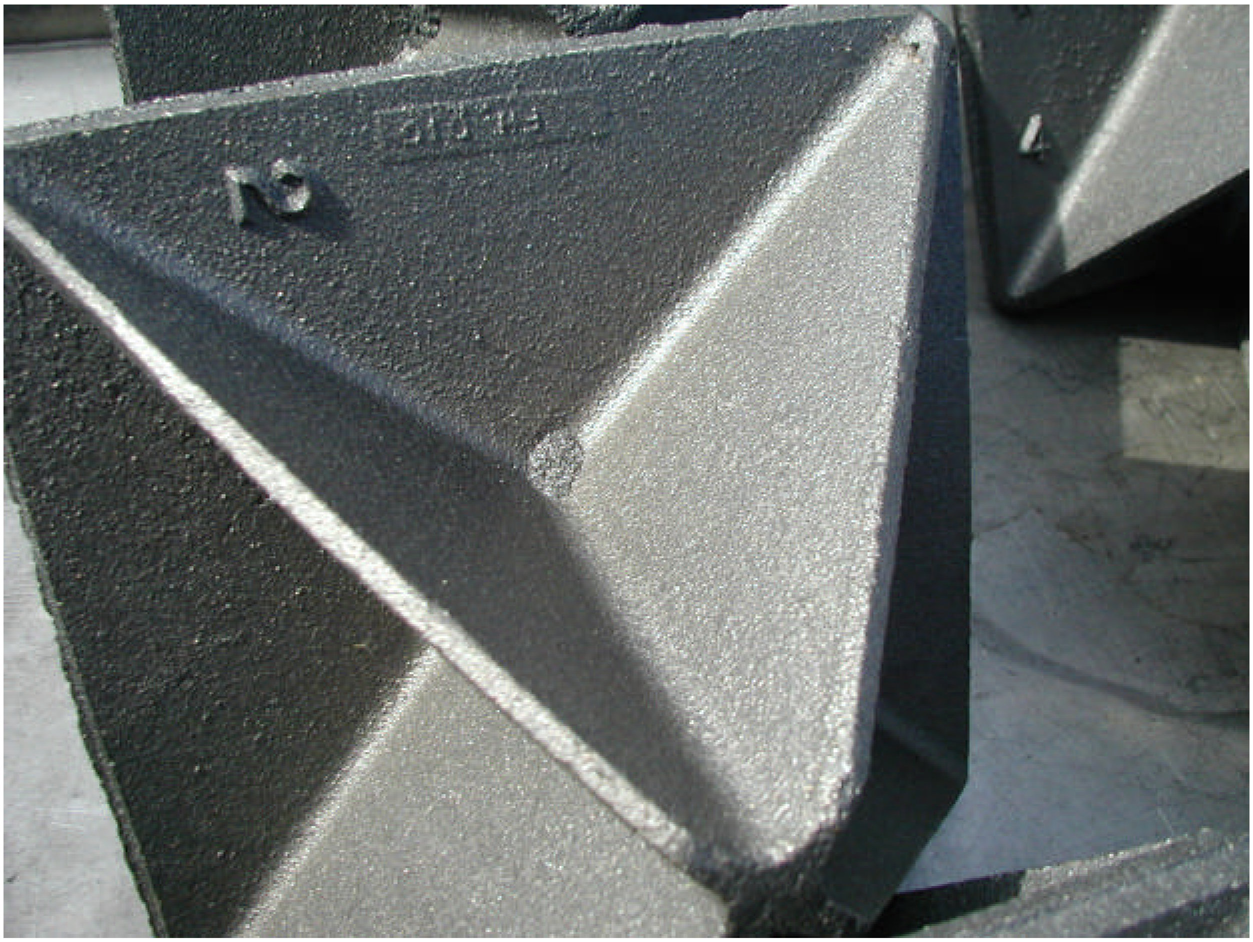
Mold FH007 Median Drag Cavity 2



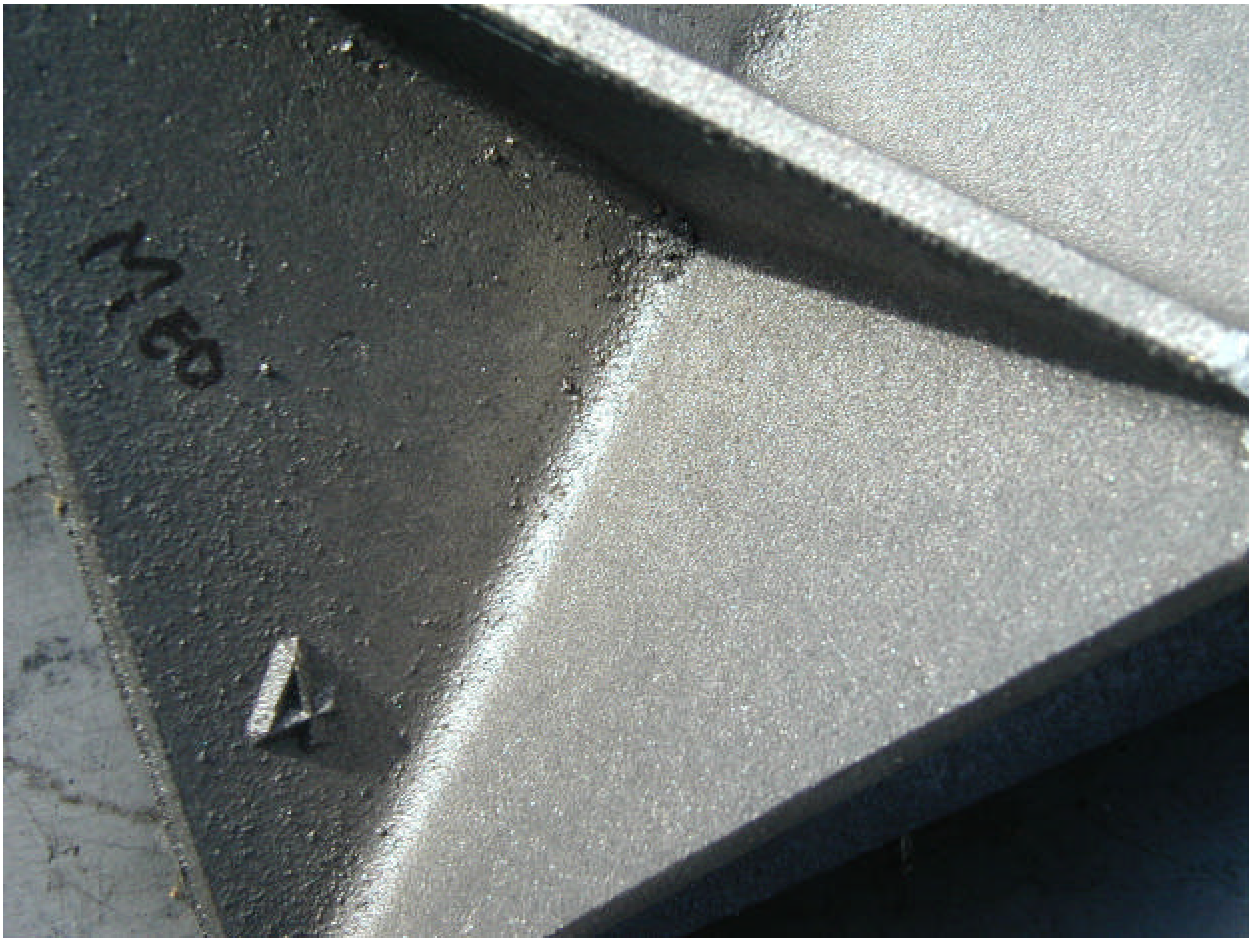
Mold FH010 Median Cope Cavity 3



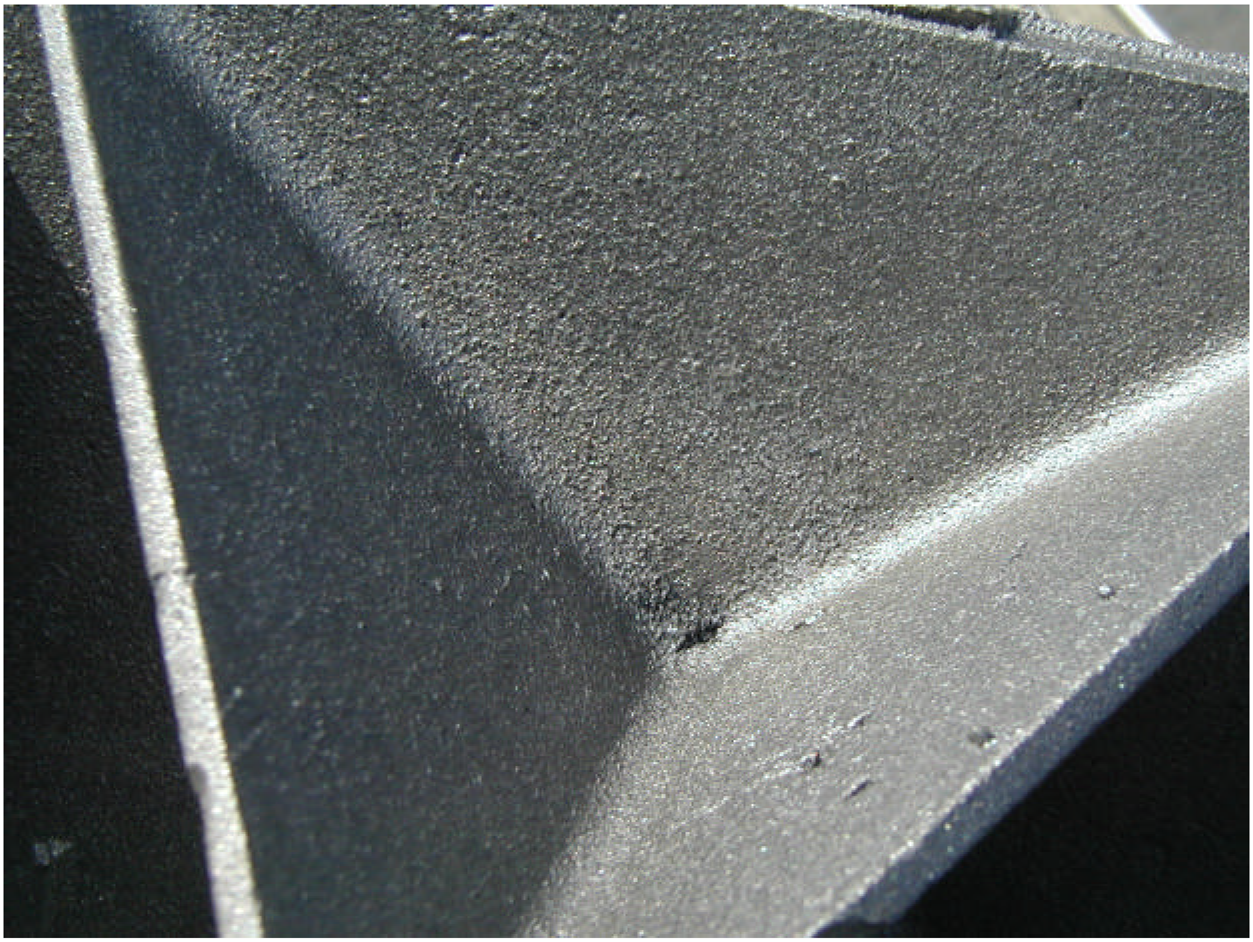
Mold FH010 Median Drag Cavity 3



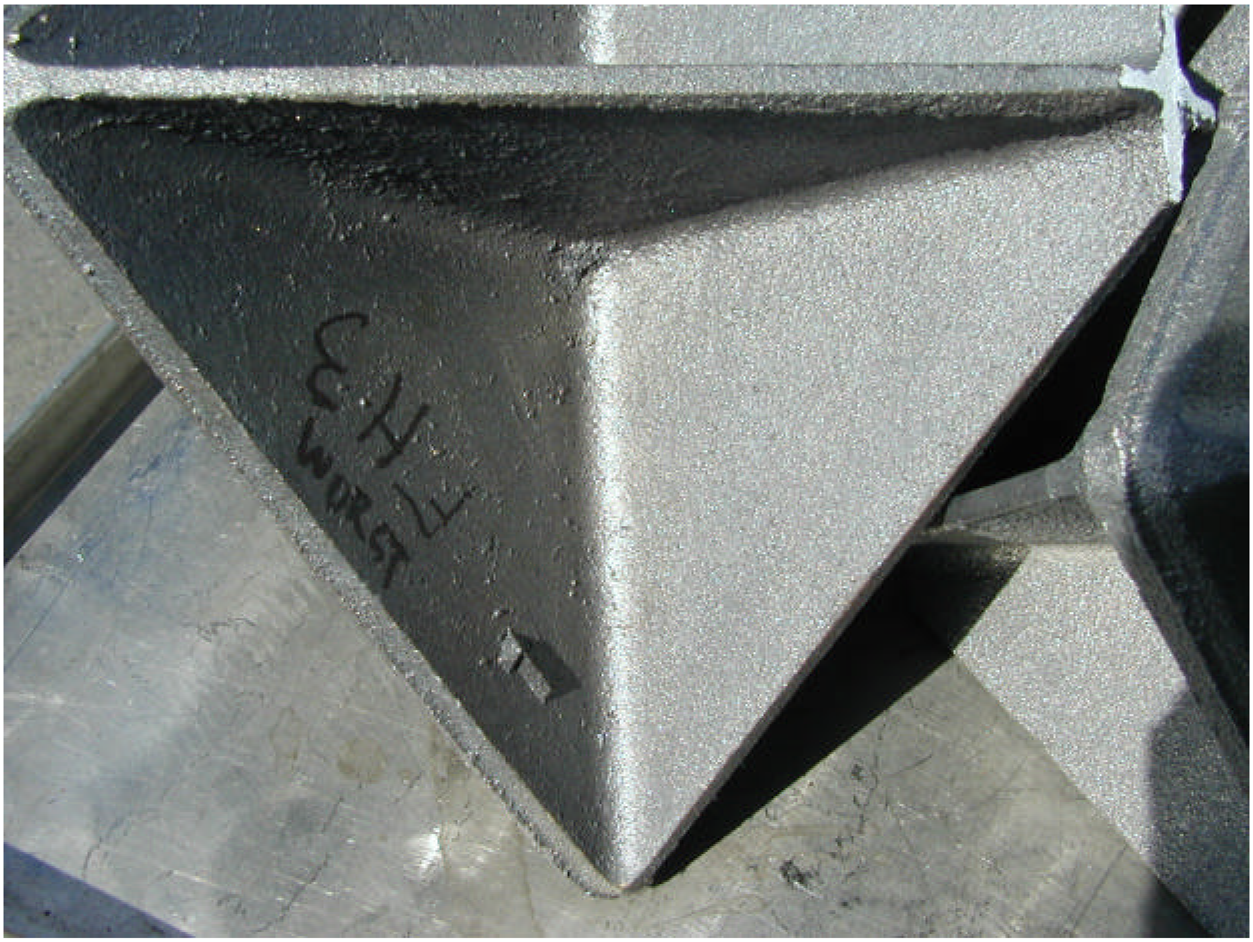
Mold FH009 Median Cope Cavity 4



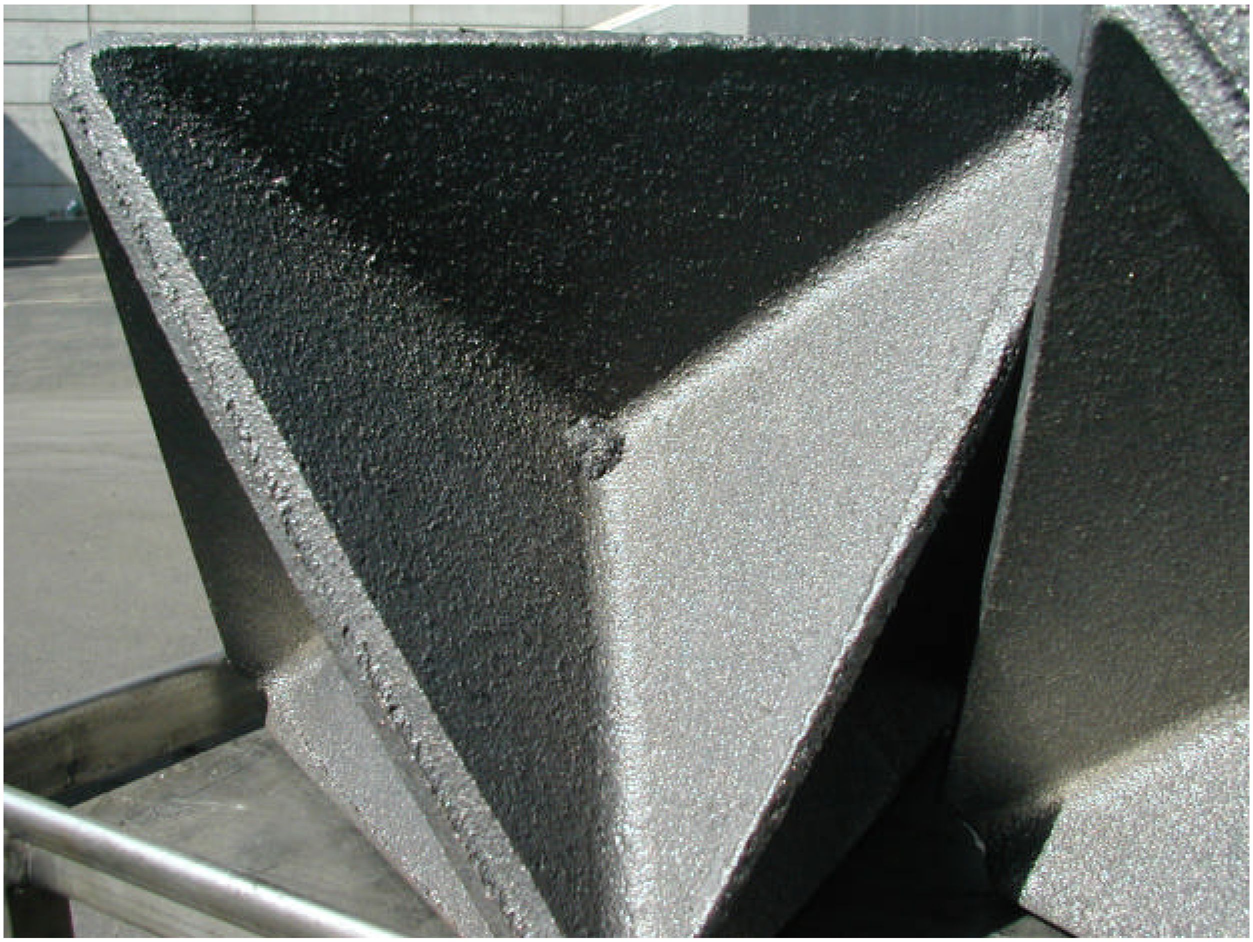
Mold FH009 Median Drag Cavity 4



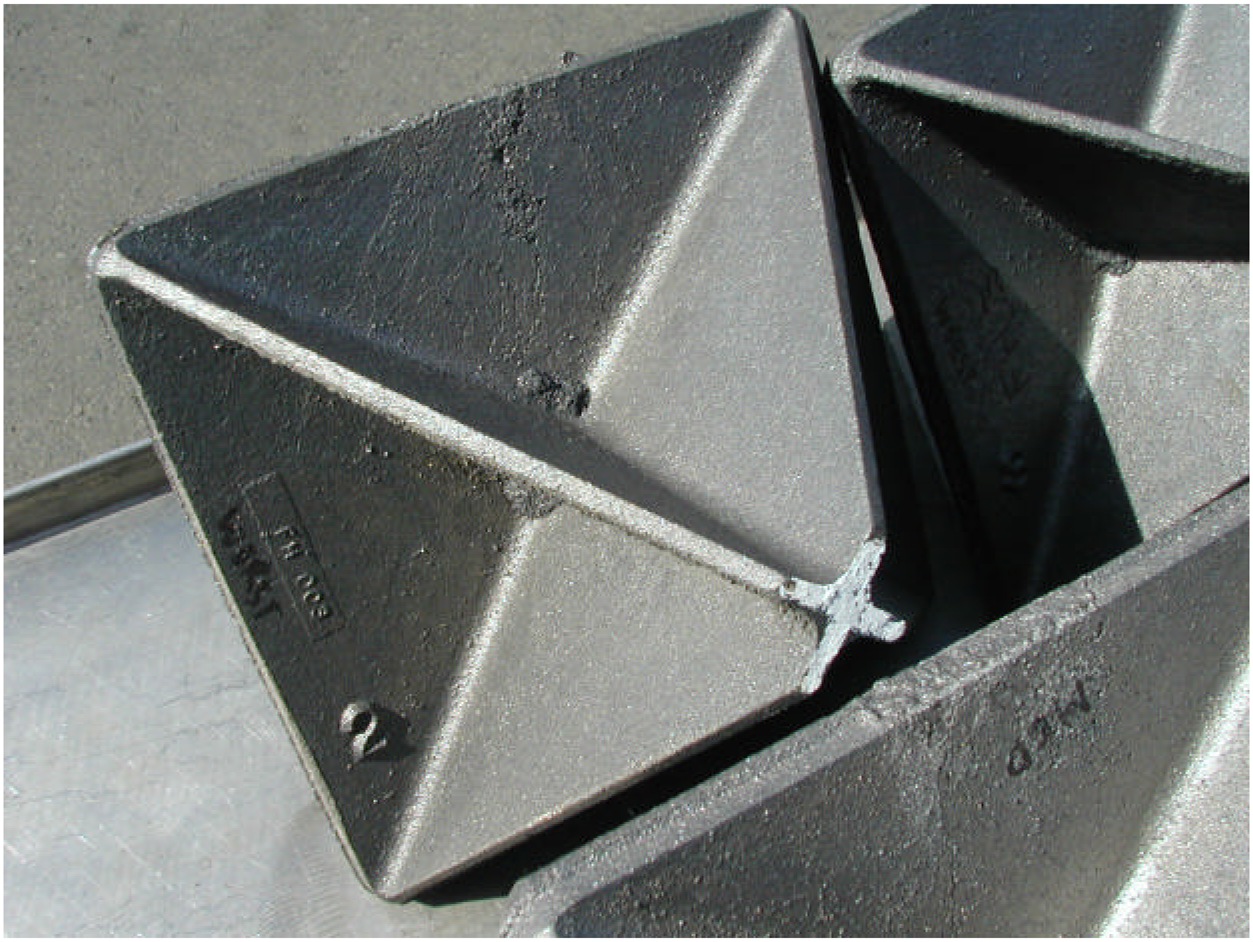
Mold FH003 Worst Cope Cavity 1



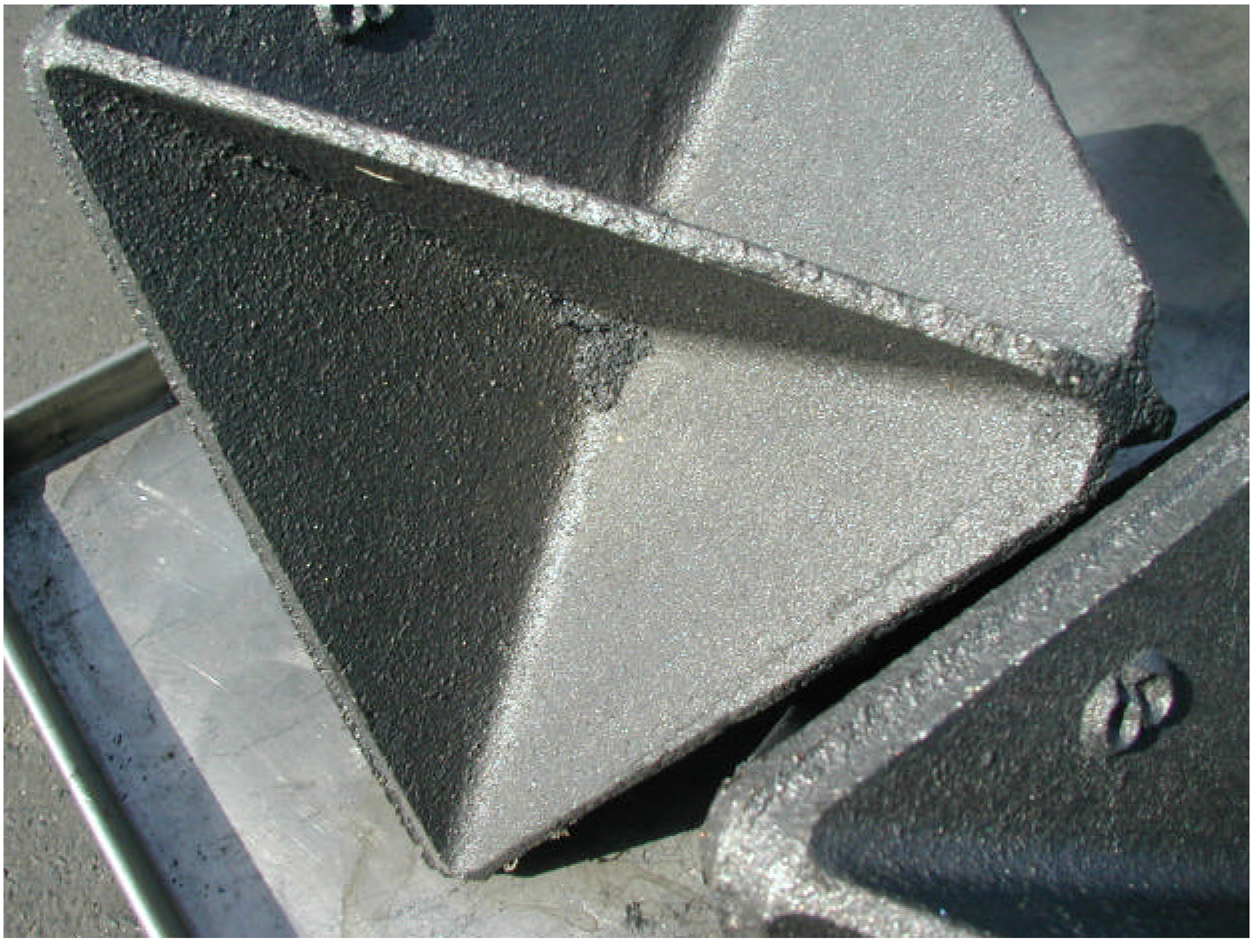
Mold FH003 Worst Drag Cavity 1



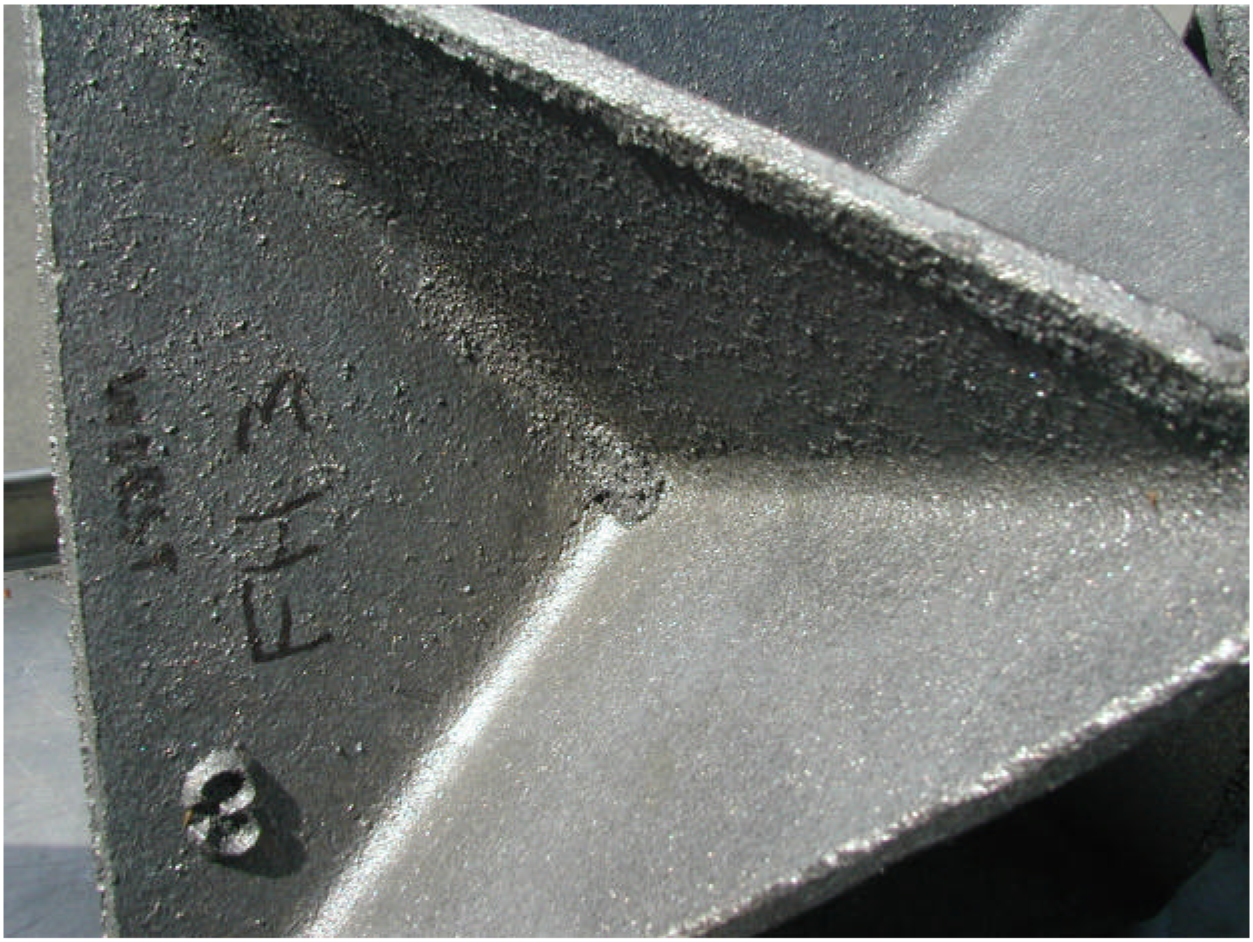
Mold FH003 Worst Cope Cavity 2



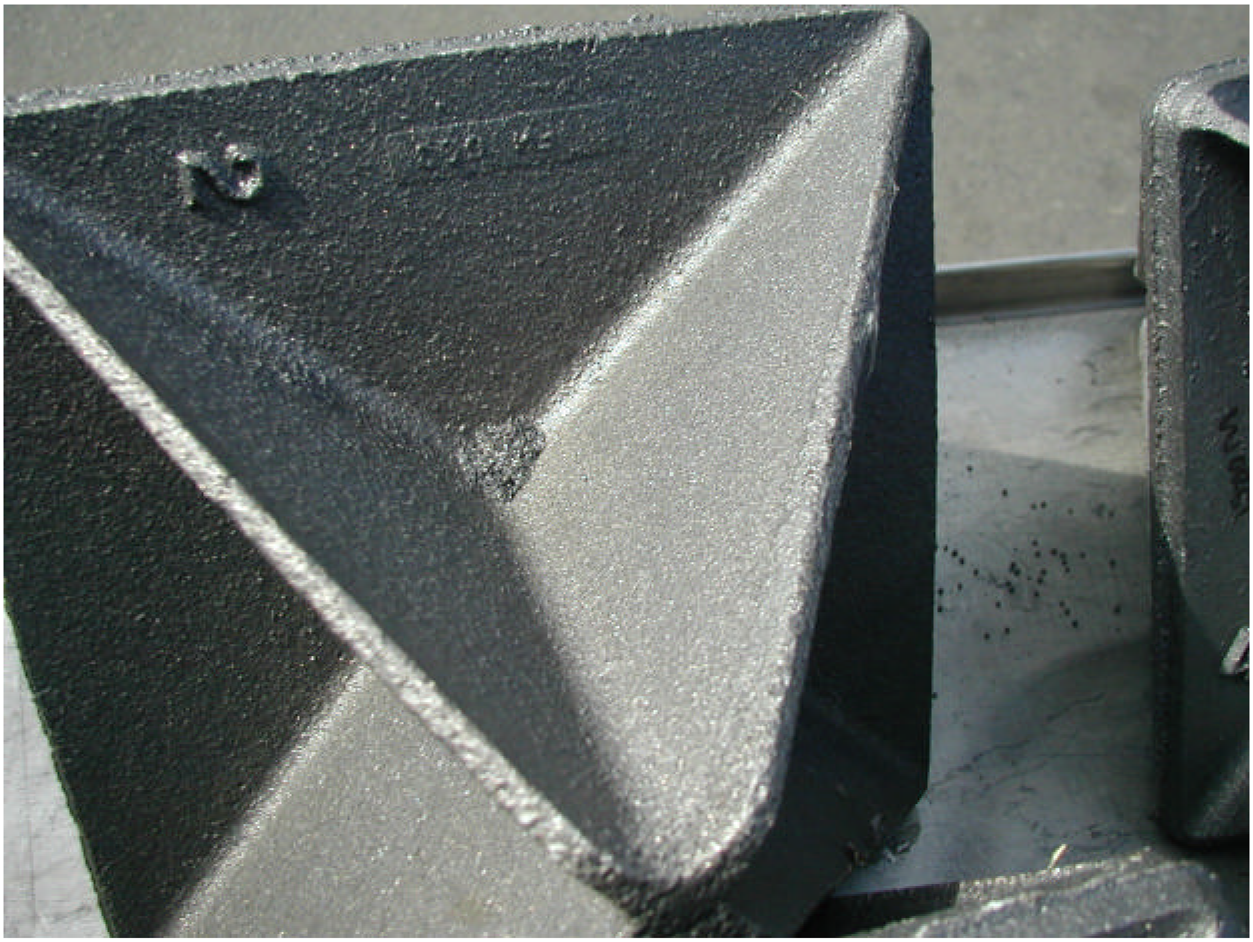
Mold FH003 Worst Drag Cavity 2



Mold FH003 Worst Cope Cavity 3

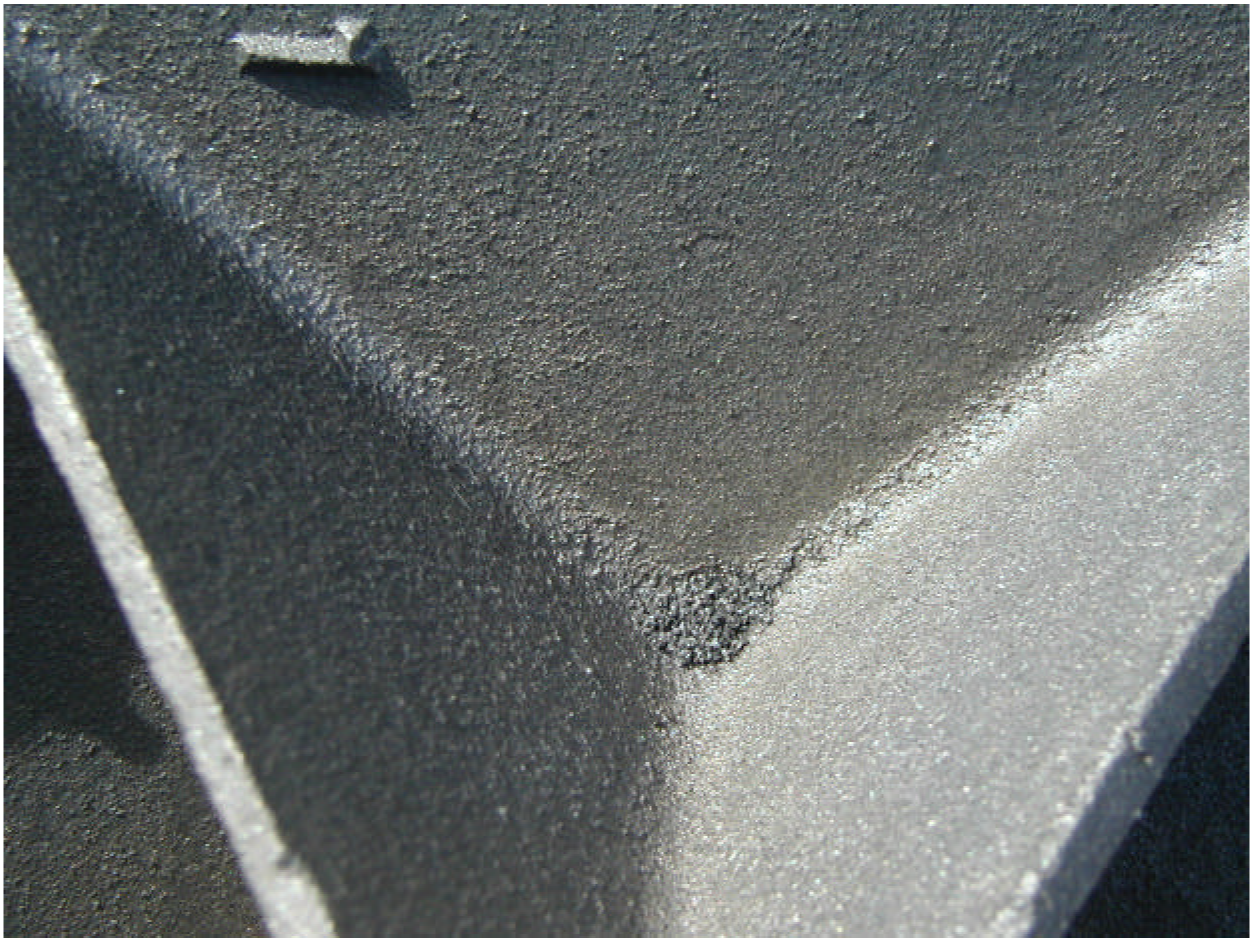


Mold FH003 Worst Drag Cavity 3



Mold FH002 Worst Cope Cavity 4

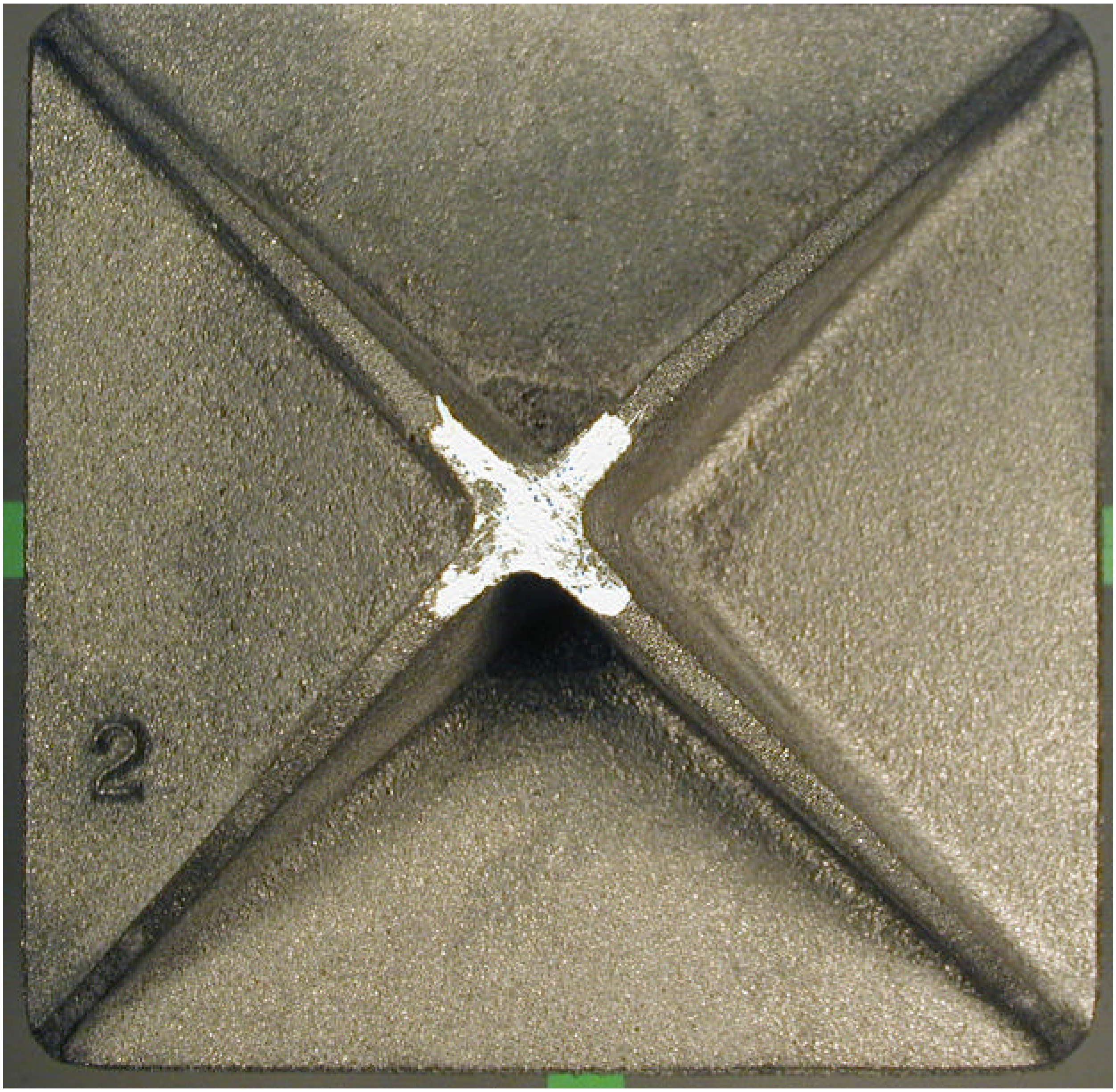
Mold FH002 Worst Drag Cavity 4



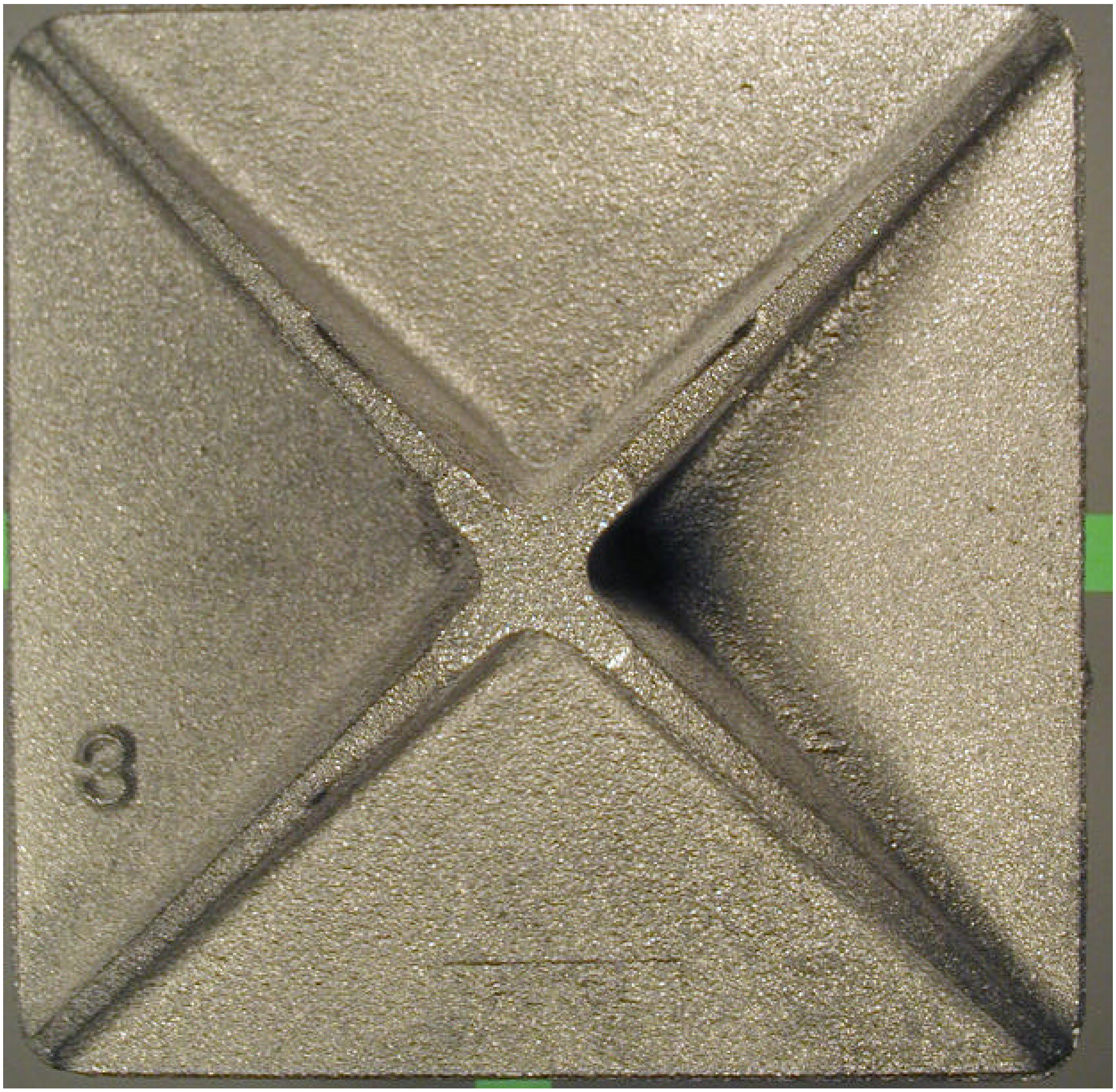
THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX E FJ HAND-RAMMED AND DE IMPACT MOLDED CASTING

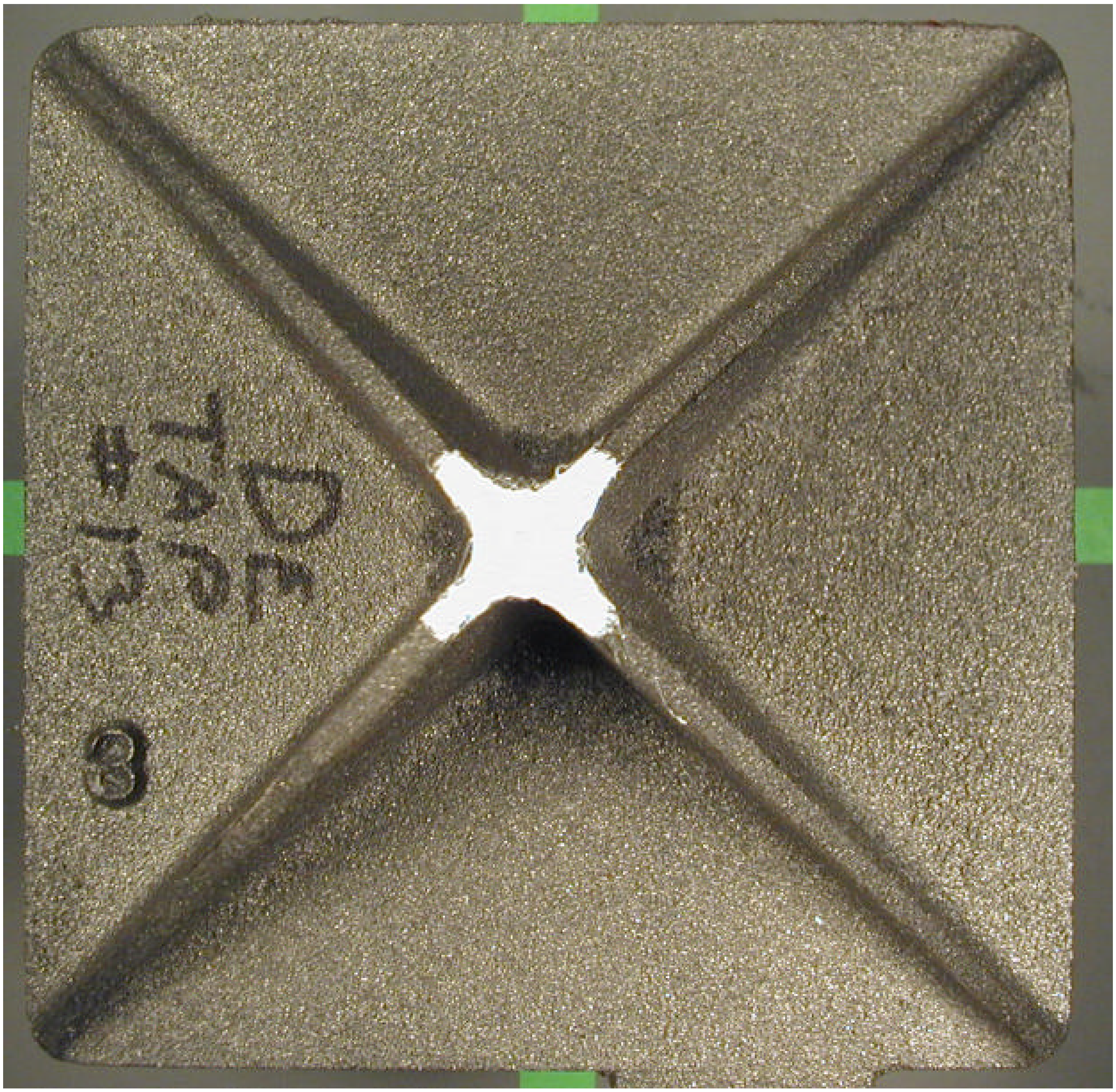
FJ009 Cope Cavity 2



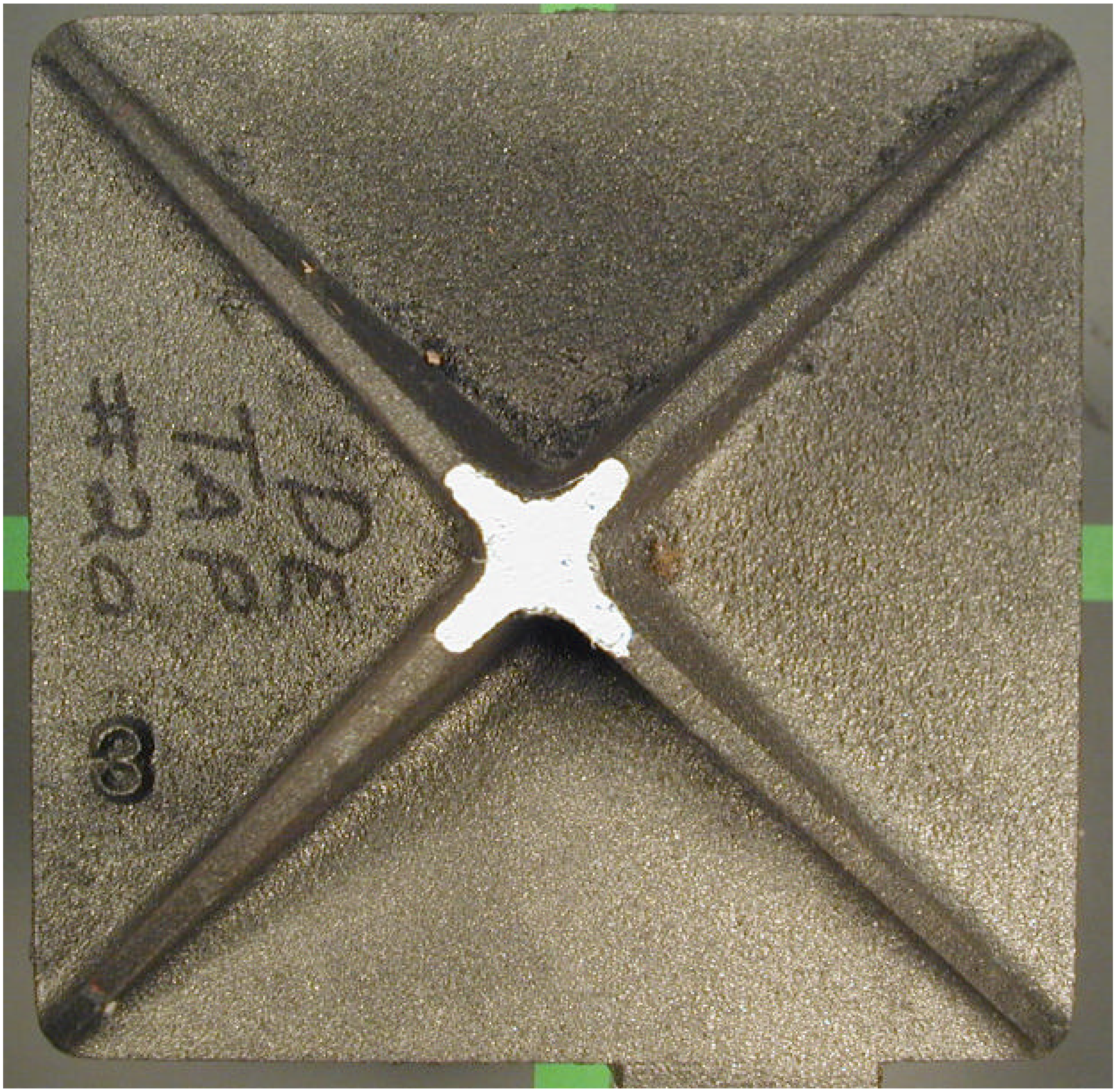
FJ009 Drag Cavity 2



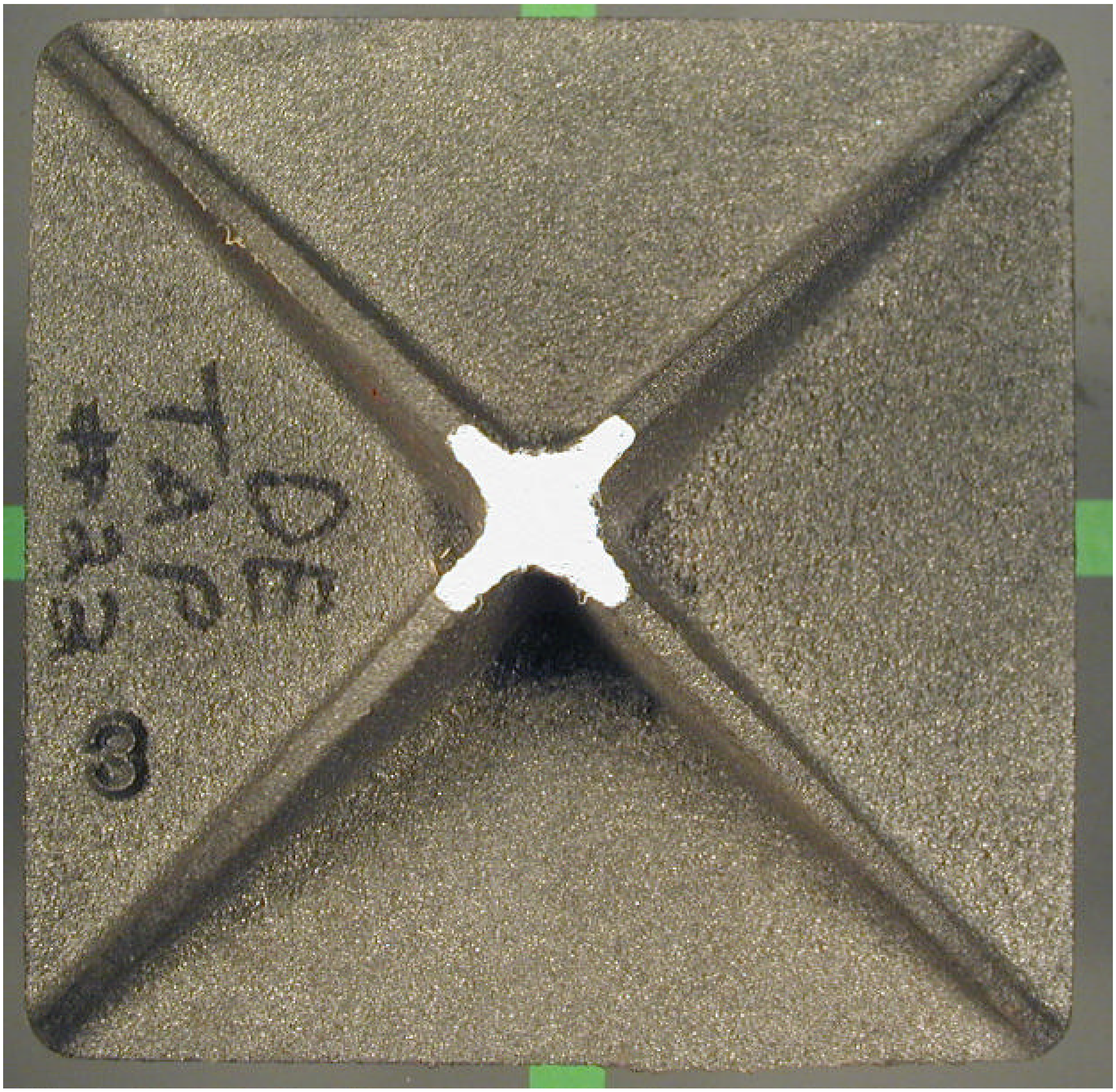
Test DE (tap water) Mold 13 Cope Cavity 3



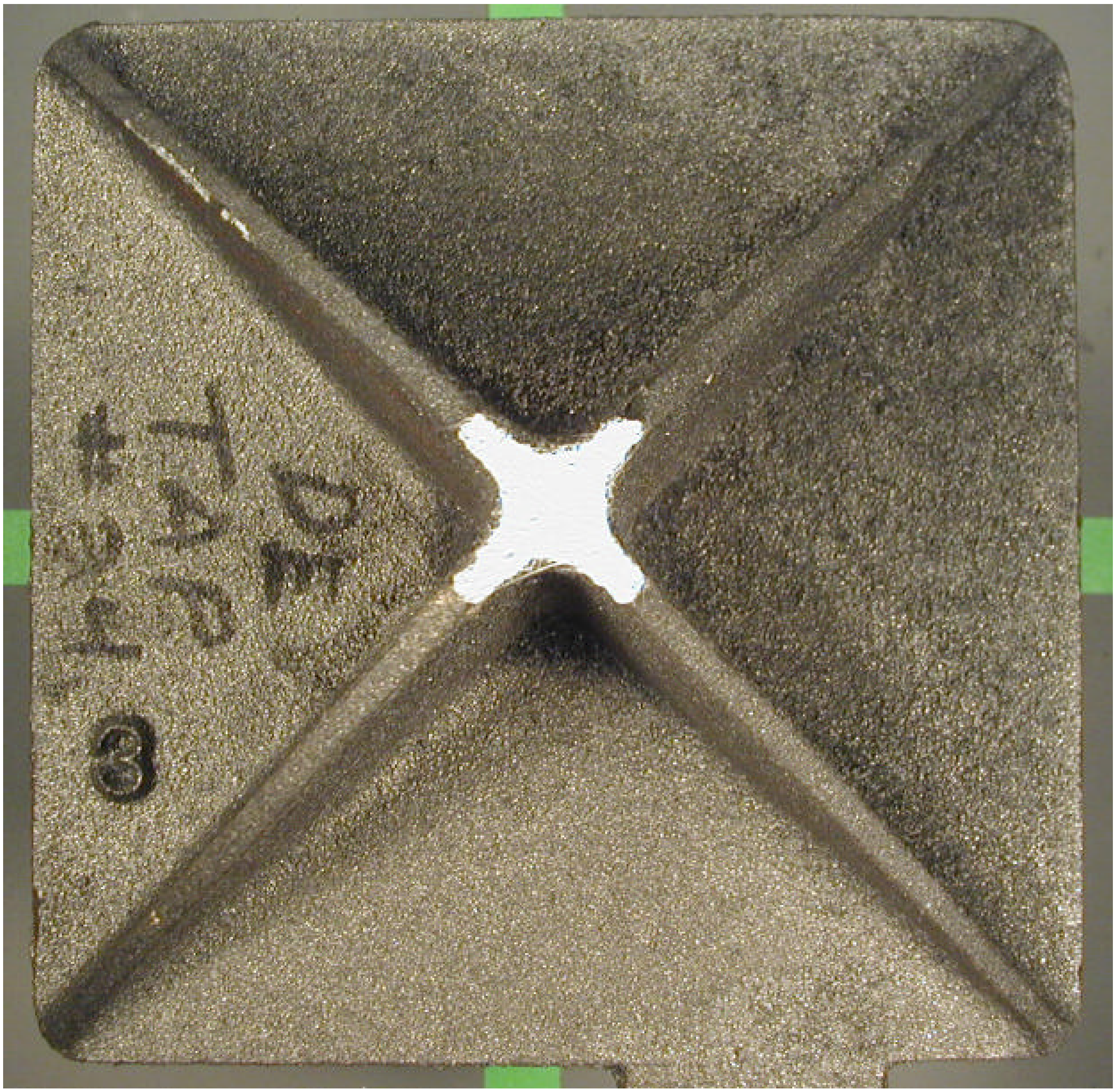
Test DE (tap water) Mold 20 Cope Cavity 3



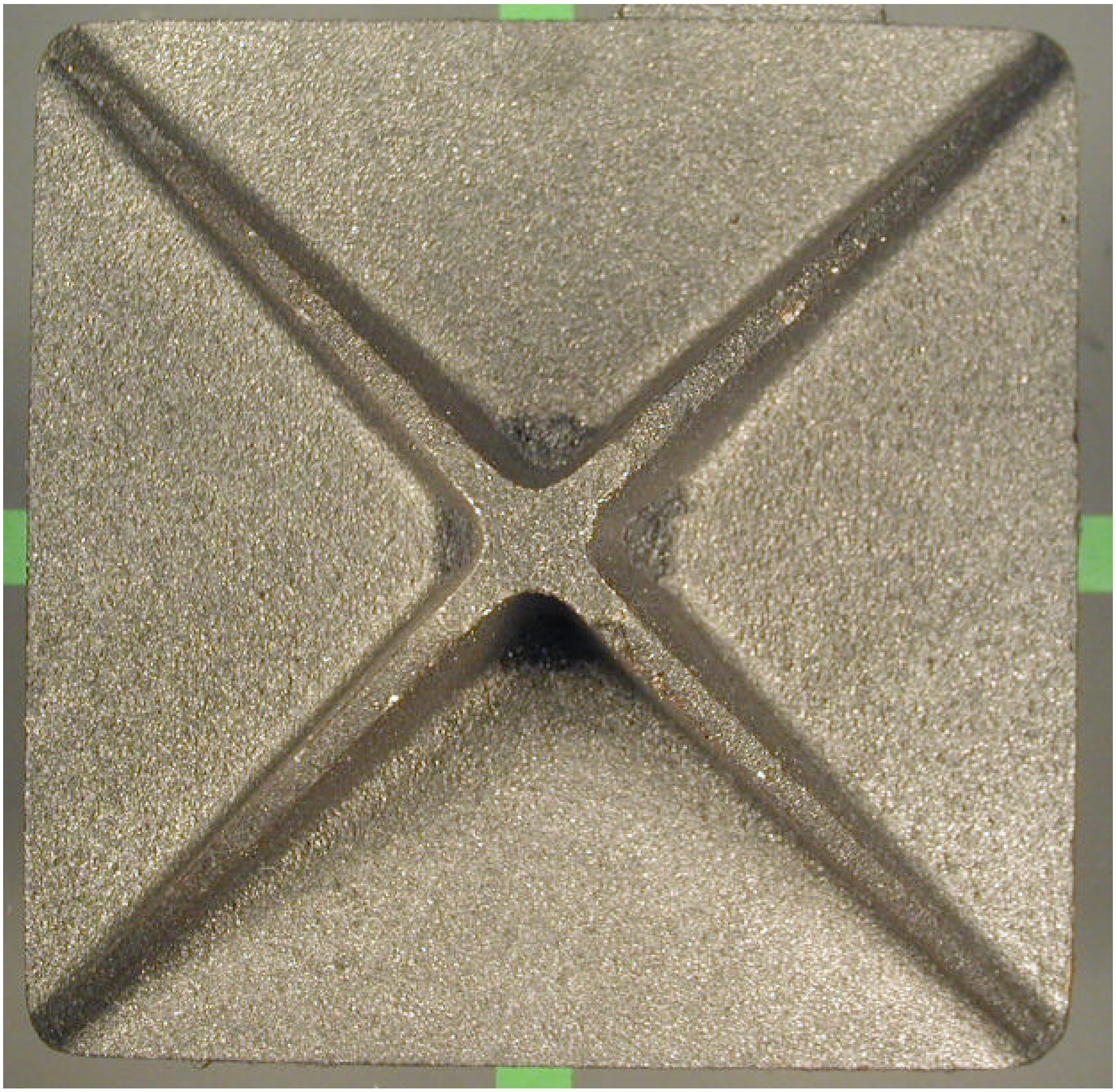
Test DE (tap water) Mold 22 Cope Cavity 3



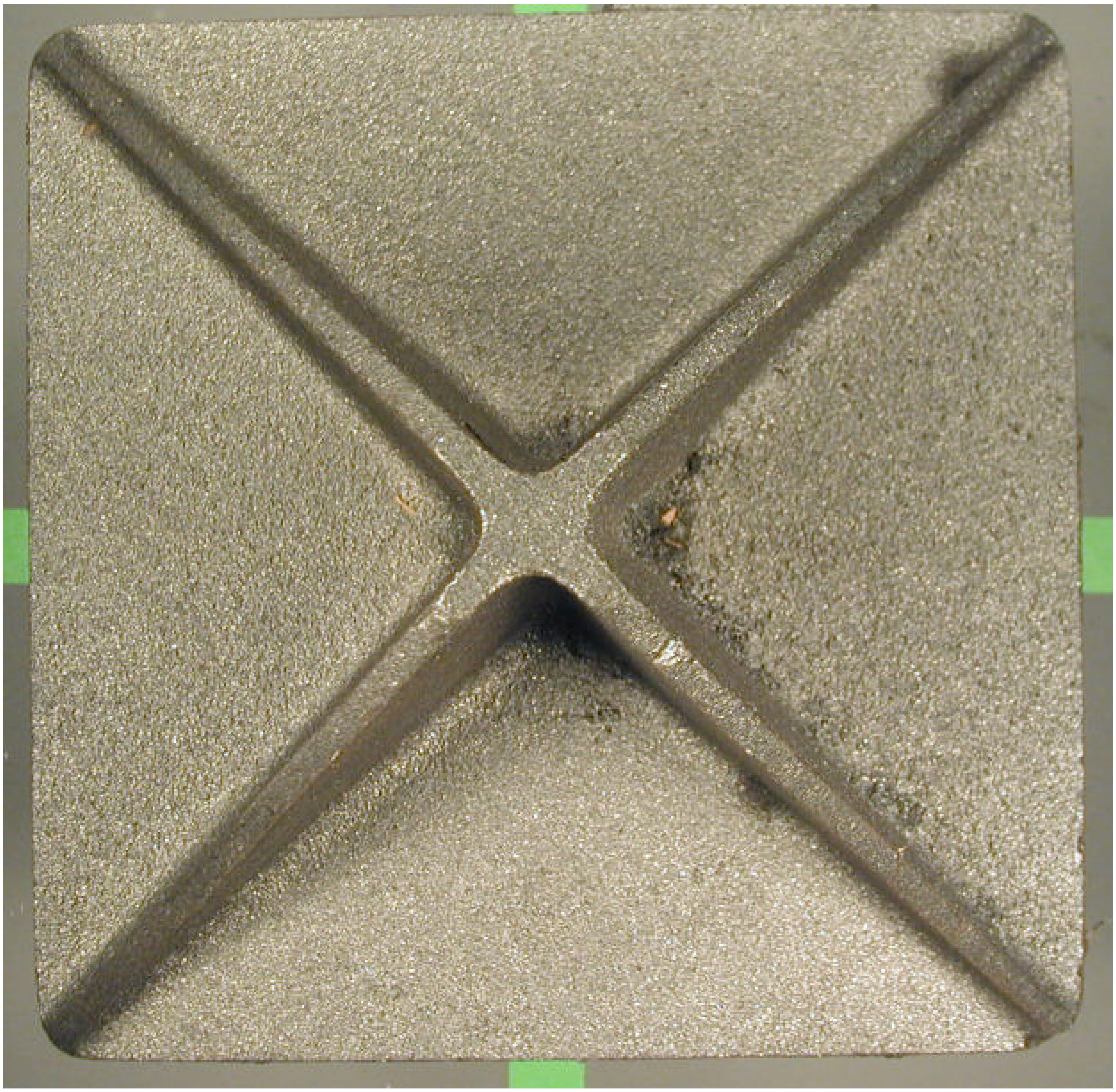
Test DE (tap water) Mold 24 Cope Cavity 3



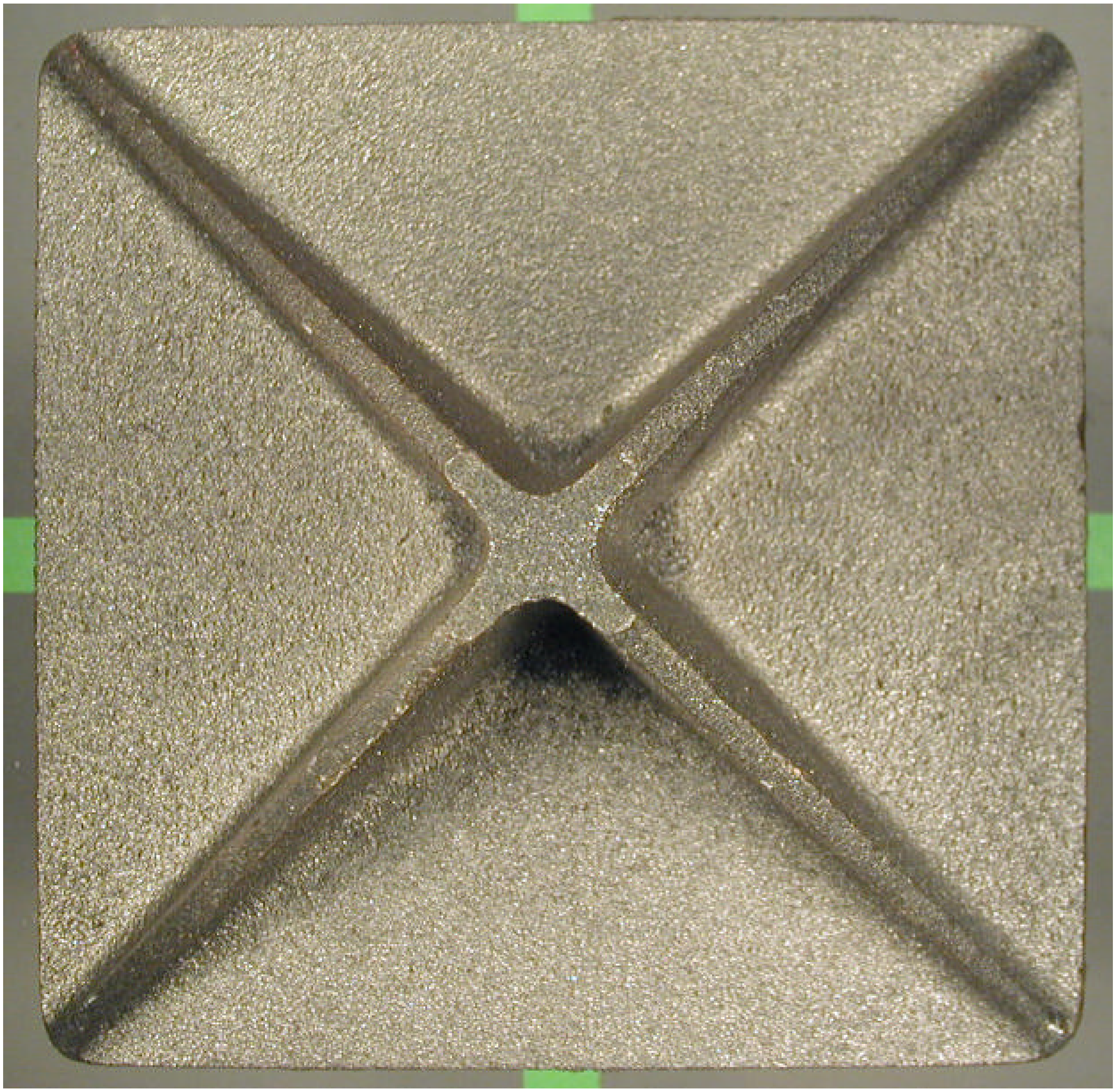
Test DE (tap water) Mold 13 Drag Cavity 3



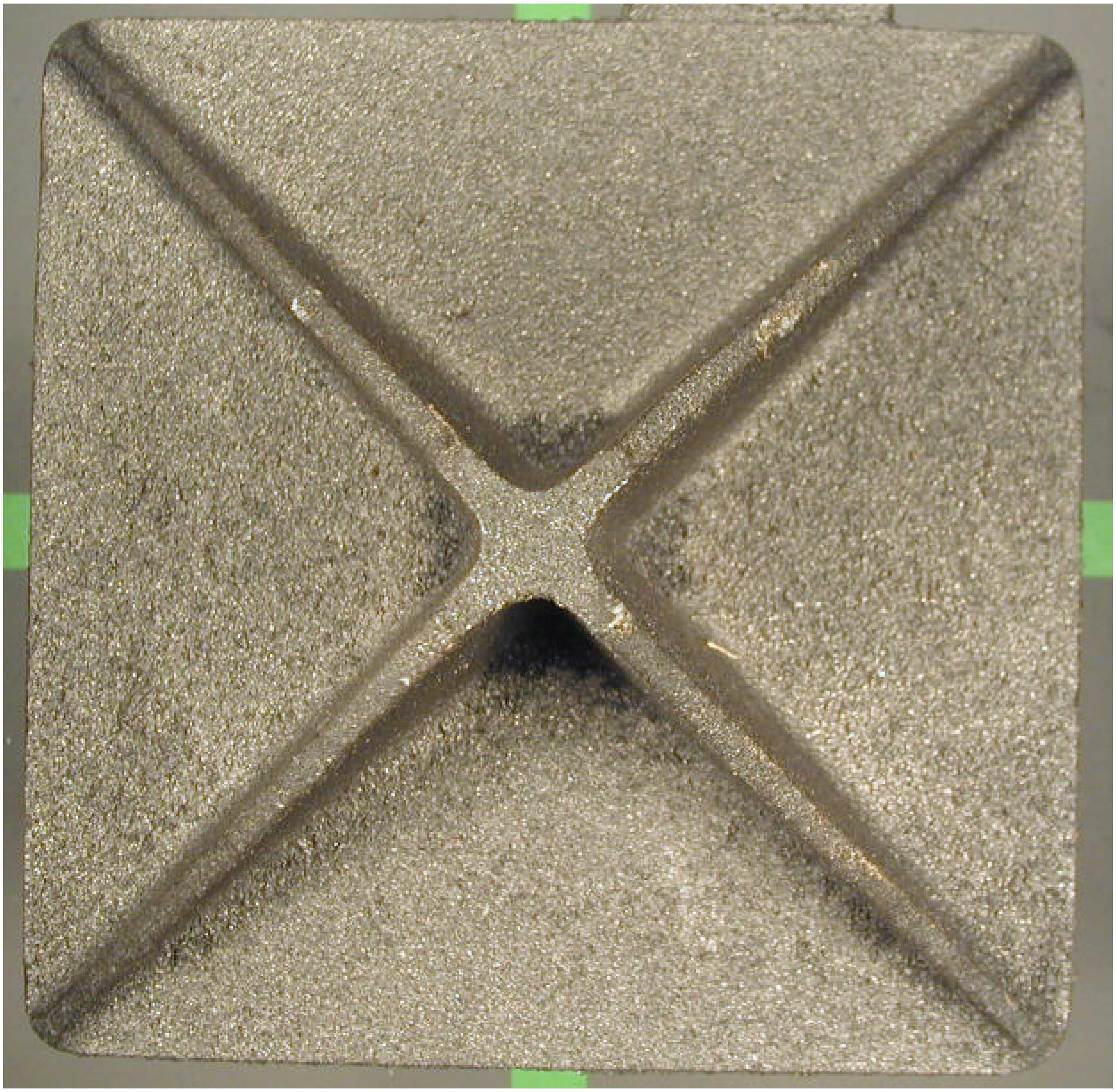
Test DE (tap water) Mold 20 Drag Cavity 3



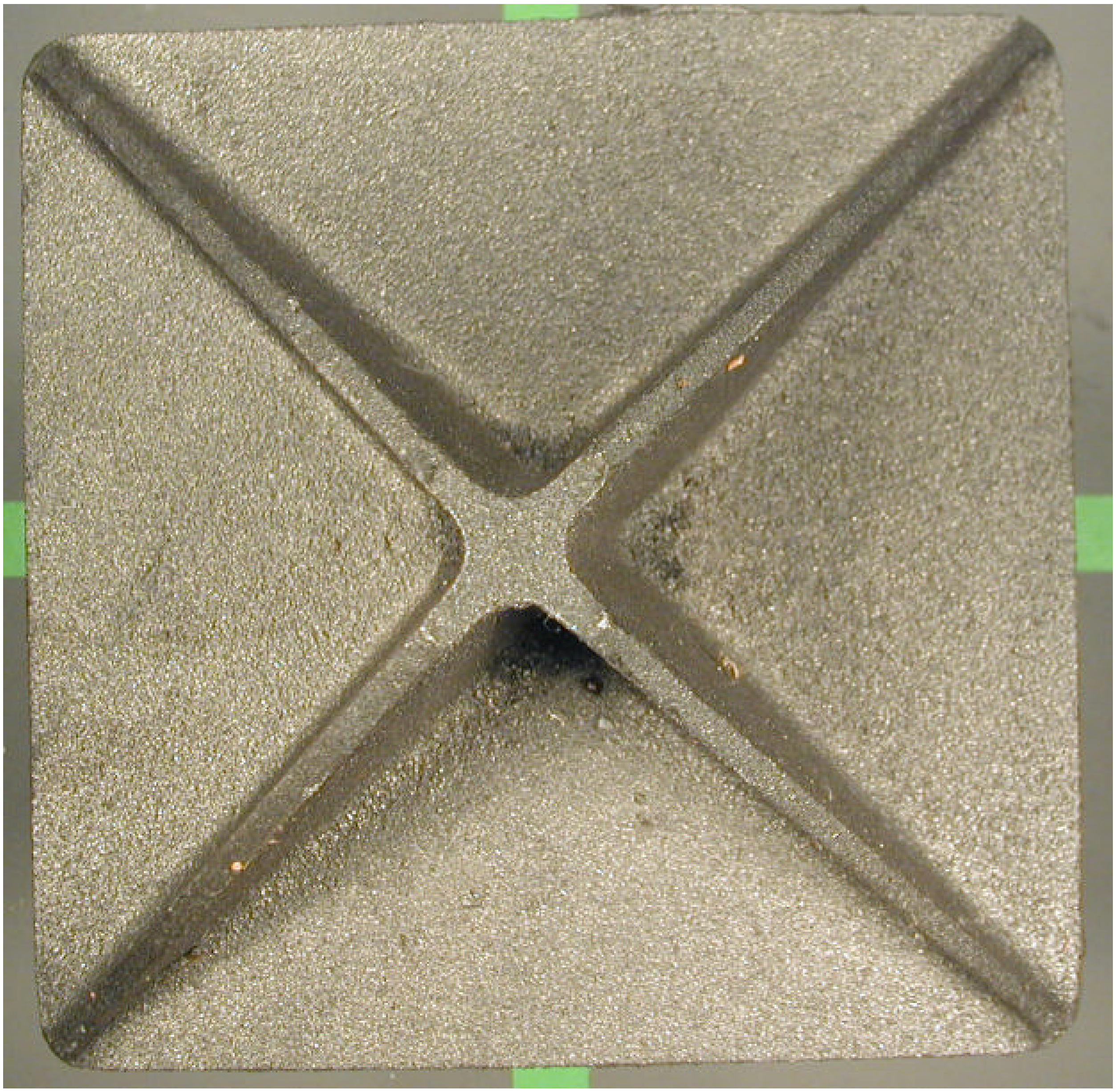
Test DE (tap water) Mold 22 Drag Cavity 3



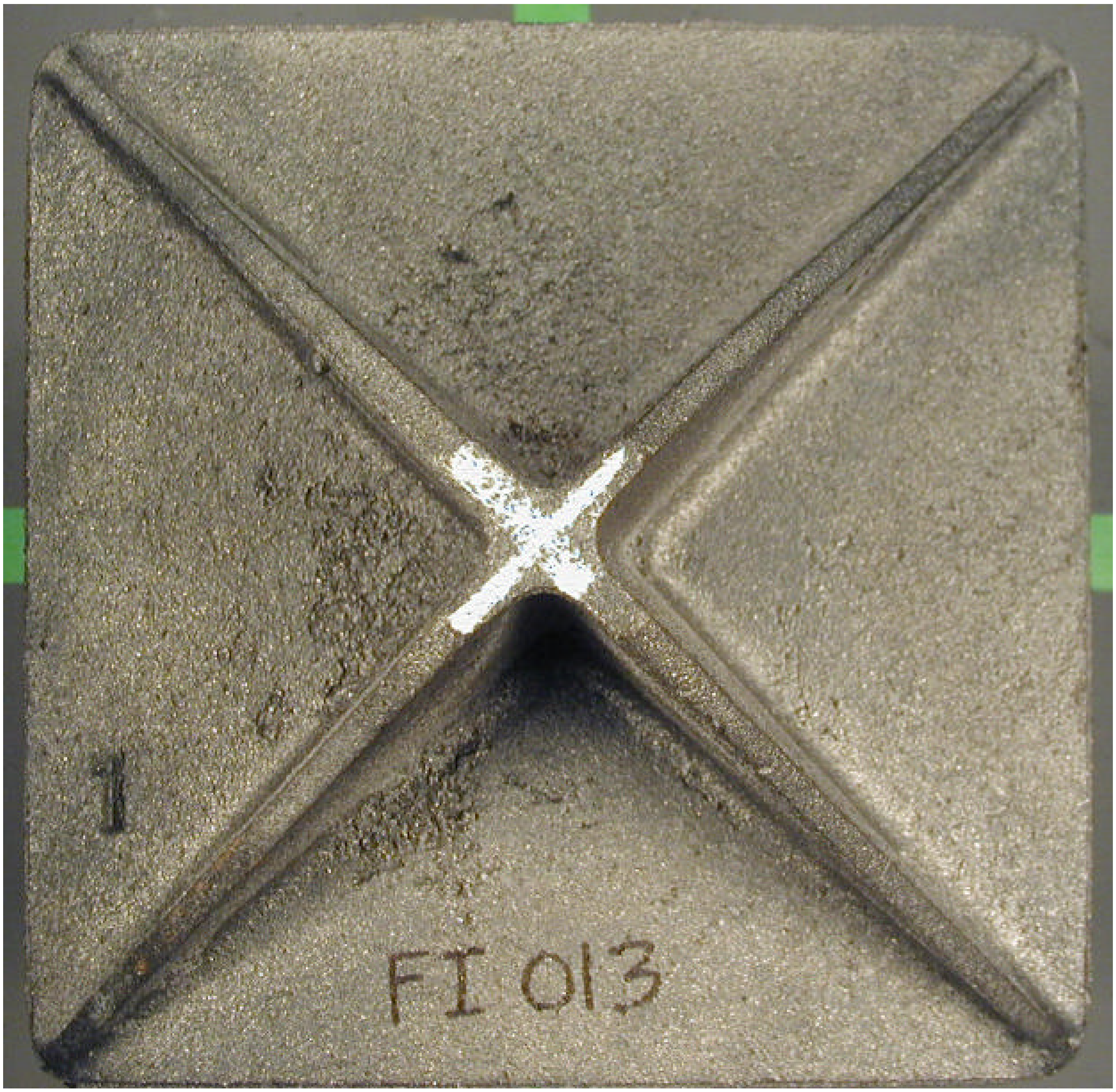
Test DE (tap water) Mold 24 Drag Cavity 3



Test FI Mold 13 Drag Cavity 3



Test FI Mold 13 Cope Cavity 3



THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX F GLOSSARY

THIS PAGE INTENTIONALLY LEFT BLANK

Glossary

Metal Penetration aka Burned-in Sand
A rough surface casting defect resulting from the mechanical intrusion of the metal into the voids between the sand grains without displacing the sand grains. With this defect the metal appears to encapsulate the sand. Visually similar to burned-on sand

Fusion aka Burned-on Sand
A rough surface casting defect resulting from the chemical reaction of the metal or its surface oxides with the mold media. With this defect the metal appears to be bonded to the sand. Even encapsulated sand will be chemically bonded to the metal. Visually similar to burned-in sand.