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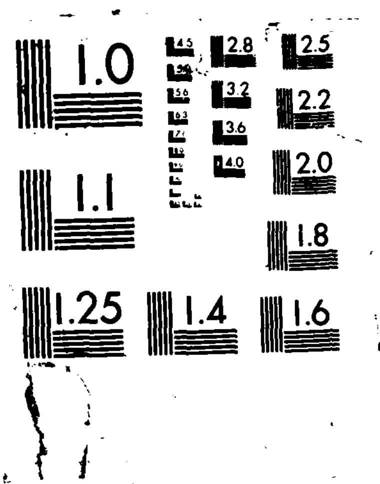
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EVALUATION OF THIXOCAST CARTRIDGE STOP PAWLS

PERRY R. SMOOT
PROCESSING TECHNOLOGY DIVISION

September 1987

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LABORATORY COMMAND
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Foundries	Die casting
Billets (materials)	Microstructure

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ABSTRACT

The objective of this work was to evaluate thixocast cartridge stop pawls for the M85 machine gun in accordance with applicable specifications. A "lot" composed of eight pawls was evaluated and found satisfactory with respect to chemical analysis. However, radiography revealed sponge and centerline shrink. Magnetic particle and visual inspection revealed severe surface cracking. Metallography showed hot tears, gas porosity, cold shots, inclusions, and gross chemical segregation, resulting in microstructural variation from ferrite to martensite, and hardness variation from 26 to 59 HRC. This segregation persisted through heat treatment. The surface hardness, roughness, and dimension did not conform to specifications, and the castings did not fulfill the specifications. The above defect problems must be resolved before the process can be utilized.

BACKGROUND

Massachusetts Institute of Technology Work

MTL awarded a contract to the Massachusetts Institute of Technology to investigate the "thixocasting" process. Thixocasting is a casting process in which a previously "rheocast" metal billet is used as the starting material. Rheocasting is a process in which material is cast in a mold while in a semi-liquid state, i.e., midway between its liquidus and solidus temperatures where it is partially liquid and partially solid. While at this temperature, the material is continuously stirred to keep all solid phases in suspension in the liquid. The process is capable of producing composites of materials that cannot otherwise be mixed together while one is in the liquid state. In this instance, the technique is being investigated for its potential as a low temperature, ferrous die casting process. The thixocasting process has potential application for a variety of vehicle and weapon components. A weapons component, a steel cartridge stop pawl (Figure 1), was selected as being the one most suitable for the investigation. The pawl is normally produced as a steel investment casting.

Figure 1 includes the specifications to which the pawls were supposed to conform under the contract. It also indicates some additional specifications to which the pawl would have to conform in production. The purpose of the investigation was to evaluate process feasibility, optimize variables, and evaluate process economics. The details of the results of the MIT investigation are given in a thesis by Boylan,[1] which was supervised by Professor Merton C. Flemings.

MTL Work

The objective of the MTL investigation was to make an independent Government evaluation of the castings with respect to the contract specifications and other specifications applicable to the part in production. The results provide valuable technical background for any future development of the process.

MATERIALS AND PROCEDURES

A lot consisting of eight pawls produced under the MIT study was selected for investigation. In addition, some castings made under slightly different conditions were taken outside this lot for chemical analysis and surface roughness measurement. These slight variations in thixocasting conditions would not affect the test results.

The thixocast steel was evaluated in the as-cast condition, with respect to the specifications, by visual and magnetic particle inspection, radiography, metallography, and chemical analysis. The pawls were then normalized at 1625°F for one hour in vacuum; austenitized at 1150°F for 30 minutes in air; oil quenched; and tempered at 850°F for one hour. Further evaluation was made by surface roughness test, dimensional measurement, hardness, and metallography.

1. BOYLAN, J.F. *Machine Casting of a Low Alloy Steel Via the Thixocasting Processing.* Master of Science Thesis, Massachusetts Institute of Technology, June 1978.

RESULTS AND DISCUSSION

As-Cast

Visual, Magnetic Particle, and Radiographic Examination

On visual examination, unacceptable cracks were seen. Magnetic particle inspection revealed unacceptable indications of severe cracking. Radiography showed unacceptable sponge and centerline shrink. The test results are summarized below.

Test	Result	Acceptability	Applicable Specification
Visual (Figure 2)	Cracks present	No	MIL-W-13855
Magnetic Particle (Figure 3)	Indications of severe cracking	No	MIL-I-6868
Radiography (Figure 4)	Sponge and centerline shrink	No	MIL-C-6021H

Chemical Analysis

Chemical analysis of the steel was as follows:

Element (Wt.%)	Analyzed	Specification MIL-S-22141B
C	0.36-0.44	0.36-0.44
Mn	0.68-0.78	0.60-0.90
Si	0.25-0.29	0.20-0.80
Cr	0.76-0.81	0.70-0.90
Ni	1.70-1.74	1.65-2.00
Mo	0.23-0.25	0.20-0.30
P	0.008-0.009	0.025 max
S	0.014-0.023	0.025 max
Al	0.04-0.06	N/A
N (ppm)	130-200	300 typ.*
H (ppm)	3.1-5.6	10-20 typ.*
O (ppm)	480-1060	50 typ.*

*Typical values obtained from Dr. Gordon A. Bruggeman, MTL, Watertown, MA

The analysis conformed to the specification. The aluminum analysis did not indicate that any great amount of the aluminum-bearing insulation used in thixocasting had become entrained. The nitrogen and hydrogen analyses appeared satisfactory. However, the oxygen analysis seemed rather high, possibly due to the entrainment of surface oxides.

Metallographic Examination

Metallographic examination revealed the presence of shrinkage, hot tears, and gas porosity (Figures 5-9). The hot tearing occurred through the liquid, between the primary solid particles. The gas porosity may have resulted from air entrained during rheocasting or thixocasting. The cracks observed visually and by magnetic particle inspection were found to be surface cracks due to cooling, initiating at the surface and propagating through the prior liquid and around the primary solid particles (Figure 10). Cold shots and three phase inclusions were also present (Figure 11). These inclusions may consist of insulation from the lining of the die casting machine and/or entrained oxide. The prior liquid was grossly segregated from the primary solid (Figure 12).

The primary solid was mostly ferrite, and its microhardness converted to HRC 26. Areas to which carbon had segregated were mostly pearlite, and their converted hardness was HRC 44. Areas of even greater carbon segregation, composed primarily of martensite, had a converted hardness of HRC 59. The primary solid was ferrite and pearlite, and the prior liquid was pearlite and martensite, showing the segregation of martensite-stabilizing elements to the liquid (Figure 13). A particularly highly segregated area of the prior liquid was martensite, bainite and pearlite (Figure 14).

Dimensions

The dimensions (see Figure 1) were as follows:

Dimension (in.)	Specified	Measured	Remarks
A	0.373-0.003	0.375-0.388	Unacceptable
B	0.343-0.013	0.343	Acceptable

Dimension "A" was in an area of shrinkage and gas porosity, which may have resulted in its unacceptably large measurement. Dimension "B" was in a relatively sound area, which resulted in an extraordinarily accurate measurement. If the problem of lack of soundness could be solved, the ability to cast accurate dimensions might be very valuable.

Heat Treated

Hardness

The hardness as heat treated ranged from below the HRC scale, in an area of porosity, up to 42.5 HRC. This was acceptable with respect to the 43-48 HRC specified.

Surface Roughness

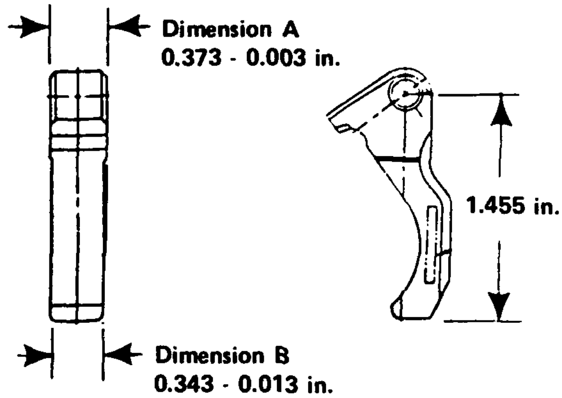
The surface roughness was 70-180 micro in. RMS. If the usual specification of 125 micro in. RMS had applied, this surface roughness would have been unacceptable.

Microstructure

In the microstructure, both low and high alloy tempered martensite were present after heat treatment, showing that the segregation produced by thixocasting persisted through thermal processing (Figure 15). Due to these defects and those noted above, before heat treatment, the structure was unacceptable on the basis of MIL-C-6021H.

CONCLUSIONS

The thixocastings were unacceptable with respect to the specifications for Class 2 castings. The problems of shrinkage, hot tearing, gas porosity, cooling cracking, gross segregation, cold shots, inclusions, surface roughness, and dimensional control must be solved before the process can be considered for production.



Notes:

1. Steel, composition IC 4340, MIL-S-22141B.

2. Classification and inspection shall be in accordance with Class 2, MIL-C-6021H.

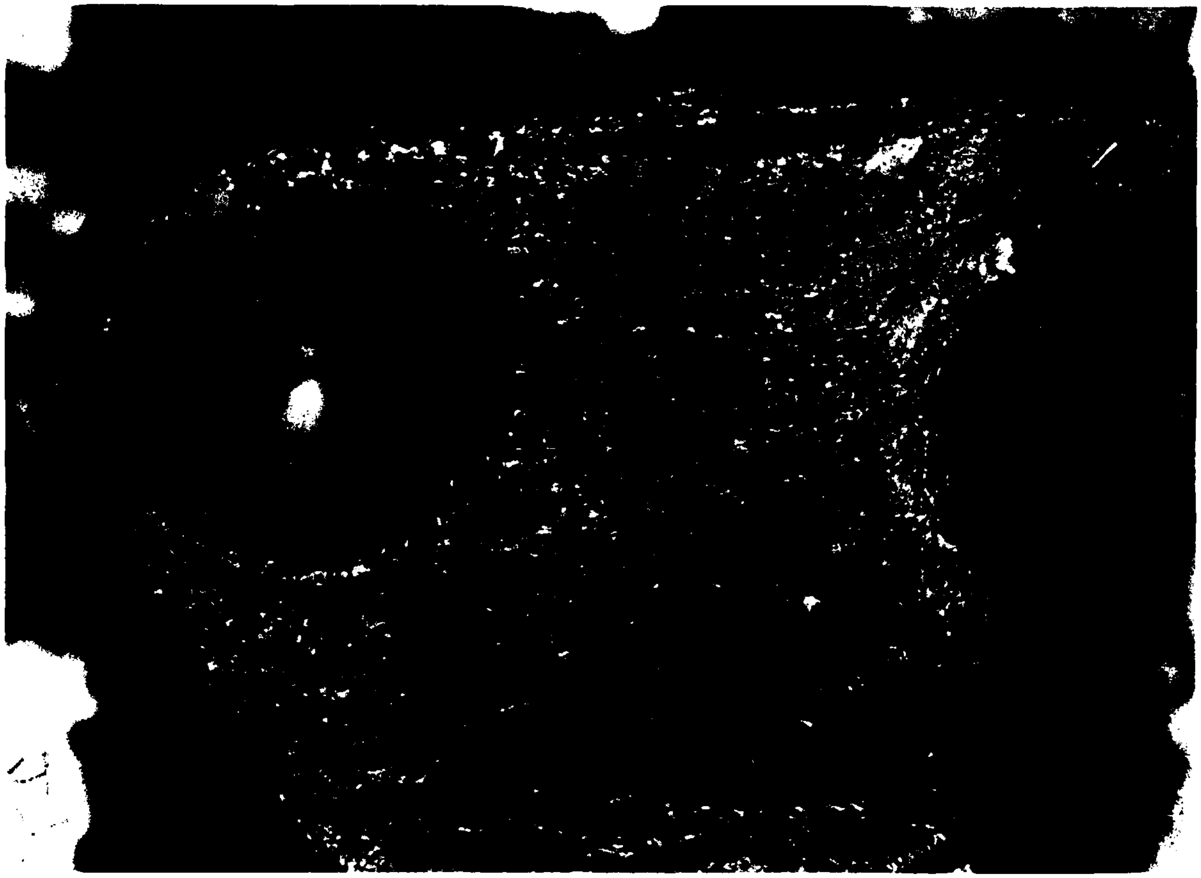
3. Heat treat per Spec. MIL-H-6875, quenched and tempered to 43 to 48 HRC.

4. The following notes would ordinarily apply, but not under the present contract:

   a. Finish 125 micro in. RMS except as noted.
   b. Inspect per MIL-I-6868.
   c. MIL-W-13855 applies.

5. All dimensions in inches.

Figure 1. Pawl, cartridge stop.



0.1 in.

Figure 2. Cracks observed by visual examination.

Figure 3. Magnetic particle indications of severe surface cracking.

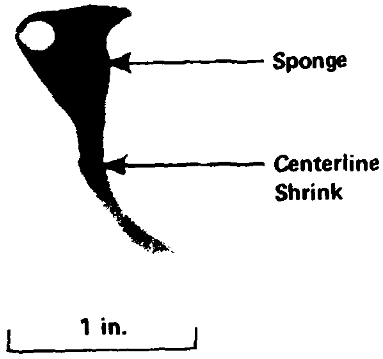
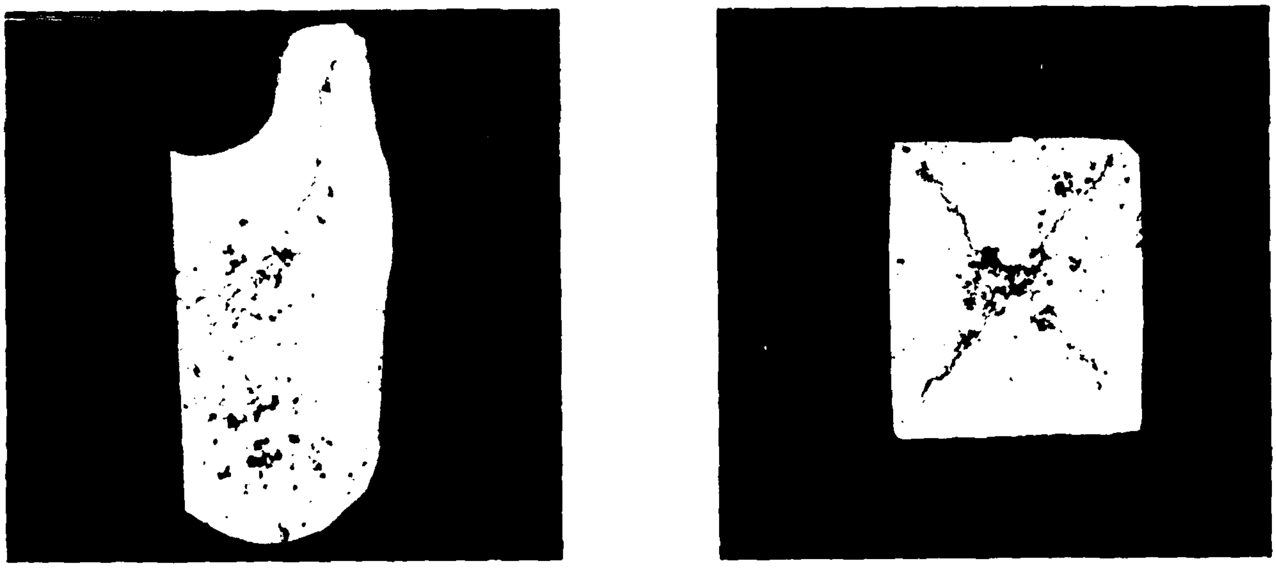


Figure 4. Radiograph of casting No. 64. Unacceptable sponge and centerline shrink.



Spec. 64 -1

Spec 39-2

0.5 in.

Figure 5. Shrinkage, hot tears and gas porosity (both specimens).

Spec. 39-1

0.1 in.

Figure 6. Shrinkage cavity.

Spec. 64-2

0.1 in.

Figure 7. Hot tear.

Spec. 39-1

0.01 in.

Figure 8. Gas porosity.

Spec. 64-2

0.001 in.

Figure 9. Hot tear through liquid and around primary solid.

Spec. 64-1

0.1 in.

Figure 10. Surface cooling crack through prior liquid and around primary solid.

Spec. 64-2

0.01 in.

Figure 11a. Cold shot.

Spec. 64-2

0.001 in.

Figure 11b. Three phase inclusion.

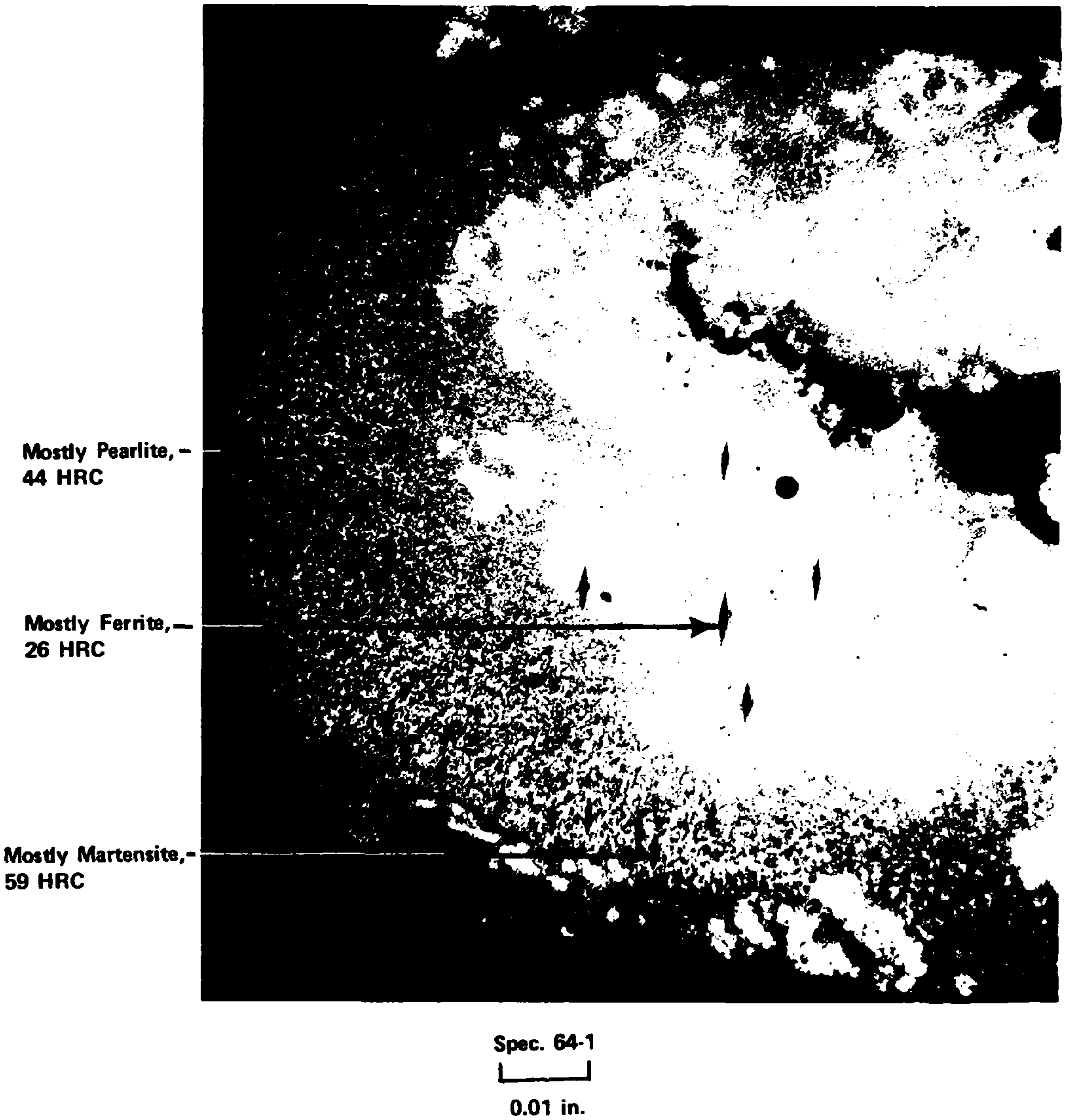
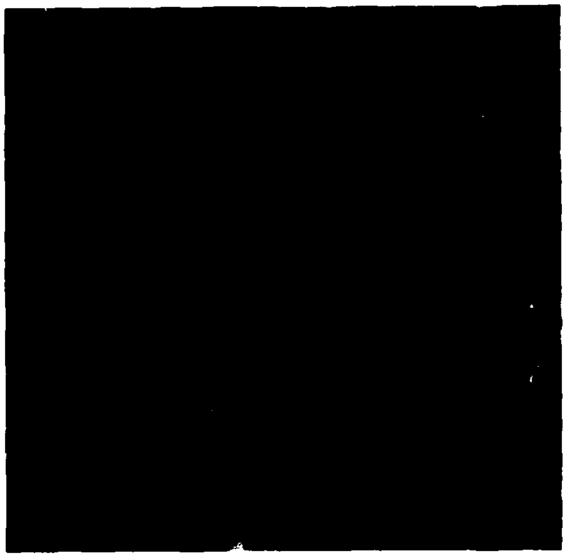


Figure 12. Prior liquid segregated from primary solid.



Spec. 64-1

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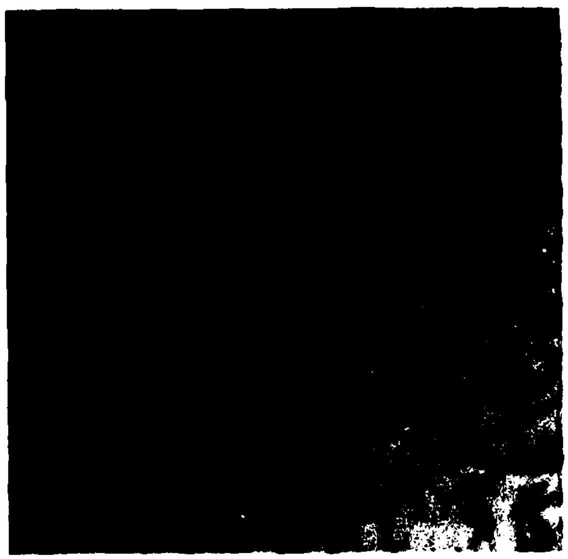
Figure 13a. Primary solid: ferrite and pearlite.



Spec. 64-1

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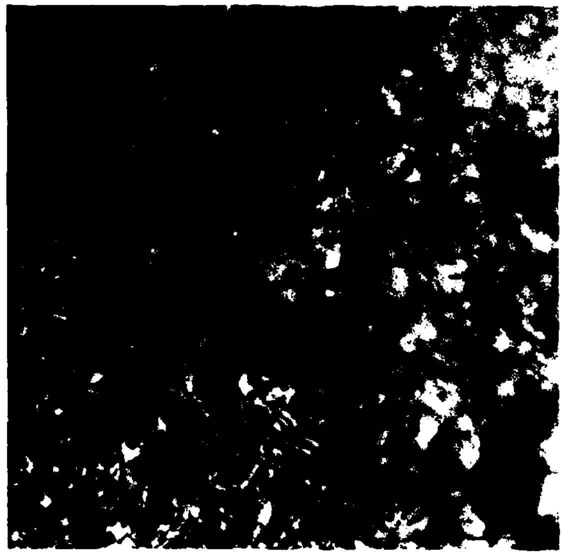
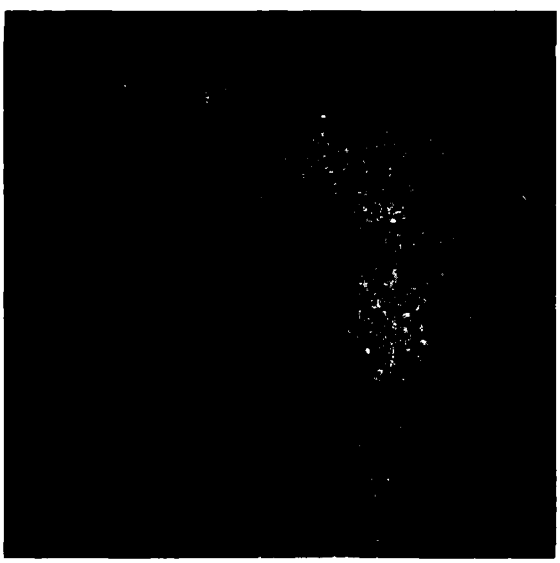
Figure 13b. Prior liquid: pearlite and martensite.



Spec. 64-1

0.001 in.

Figure 14. Particularly highly segregated prior liquid area: martensite, bainite, and pearlite.



Spec. 47-1

0.1 in.

Spec. 47-1

0.001 in.

Figure 15. Low and high alloy martensite. Segregation persisting after heat treatment.

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Die casting
Microstructure

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