ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report

PRECISION-CAST ORDNANCE COMPONENTS

September 1 - October 31, 1957

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Project 2400

DEPARTMENT OF THE ARMY
DETROIT ORDNANCE DISTRICT
CONTRACT NO. DA-20-018-ORD-13832

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UMR 7005

ABSTRACT

Considerable progress has been made during the period September 1 to October 31, 1957. The most important results of the application of precision casting to ordnance components can be summarized as follows:

1. Superior service of the precision-cast AISI 4150 steel Drive Sprockets, No. 8671597, tested at General Motors Proving Ground, Milford, Michigan, is due to the uniform response to flame hardening, structural homogeneity, and high hardenability.

2. The poor service of fabricated AISI 1345 steel Drive Sprocket, No. 8671597, tested with the precision-cast sprockets is due to structural inhomogeneities caused by rolling, low hardenability, and nonuniform response to flame hardening.

3. Two precision castings of the Final Drive Gear, No. 7364141, by Griffin Wheel Company have resulted in changes in the graphite molds to eliminate shrinkage and gas defects.

4. The shell-cast ductile iron Follower castings, No. 7359510 and No. 7360356, tested at Port Erie, Ohio, were severely scored by the gun tube. The excessive amount of ferrite in the matrix resulted in soft castings.

Modified chemical analysis and heat treatment will be used to produce pearlitic ductile iron Follower castings for Ordnance evaluation.

OBJECTIVE

The purpose of this investigation is to apply the most advanced precision-casting methods to the production of large ordnance components to obtain substantial reduction in cost or critical materials as well as improvement in design.

INTRODUCTION

The progress of current work on the application of precision casting to ordnance components can best be considered under the following three subject headings:

I. Graphite Mold Pressure-Poured Drive Sprocket, No. 8671597
II. Graphite Mold Pressure-Poured Final Drive Gear, No. 7364141
III. Shell-Cast Ductile Iron Follower Castings, No. 7359510 and No. 7360356.

I. GRAPHITE MOLD PRESSURE-POURED DRIVE SPROCKET, NO. 8671597

The metallurgical examination of the sprocket castings tested at the General Motors Military Proving Ground in Milford, Michigan, is practically complete. The microstructures, hardness data, and macrostructures taken from the fabricated and cast test sprockets are as follows.

A. CURRENT PROGRESS

1. Chemistry and Macrostructure.—Table I summarizes the chemical analyses of both cast and fabricated sprockets.

TABLE I

Chemical Analyses of Cast and Fabricated Sprockets

Test Position	Sprocket	%C	%Mn	%P	%S	%Si	%Cr	%Mo
Right Inside	Fabricated "A"	.48	2.04	.013	.027	.32	-	-
Right Outside	Fabricated "B"	.41	1.75	.014	.032	.23	-	-
Left Outside	Cast 197	.51	.90	.013	.024	.34	1.07	.22
Left Inside	Cast 191	.53	.94	.013	.028	.39	1.08	.21
No Test	Cast 195	.53	.81	.010	.030	.33	1.08	.22

Figure 1 is a drawing made from the template of a cast sprocket prior to testing. The dashed line contour shows the wear resulting from 2416 miles of service without reversal. Figure 2 is a drawing made from the template of a fabricated sprocket. The dashed contour indicates the wear after 1177 miles. This wear contour is from the second set of fabricated sprockets which replaced the original set after 1239 miles of service.

The superior wear of the cast sprocket is quite obvious. The cast tooth contour shown in Fig. 1 is from the most severely worn tooth; the average wear is less than this.

Macroetched specimens of the cast sprocket exhibited a fine columnar zone approximately 3/4 in. deep with an equiaxed dendritic core. The fabricated sprocket contains a fine grain structure with pronounced orientation in the rolling direction which is both parallel and perpendicular to the wearing surface of the various teeth.

2. Mechanical Testing.—The results of Rockwell "C" hardness surveys on the cast and fabricated teeth are presented in Tables II - VII.

Tables II and III record the hardness pattern of two cast AISI 4150 steel teeth after 2416 miles of service. The drive sides of these teeth still have hardened zones of from 6/32 to 8/32 in.

Tables IV and V contain the hardness surveys of two cast AISI 4150 steel teeth after hardening but without service testing. The satisfactory hardness and hardenability are evident in Table IV. The results of Table V indicate poor flame-hardening treatment and are being investigated further.

Tables VI and VII contain the Rockwell "C" surveys of two fabricated AISI

1345 steel sprockets after 1177 miles of service. There is no hardened zone on the drive side and the hardness values on the back side are not satisfactory.

3. Metallographic Examination.— Figures 3 - 8 are photomicrographs of the structure of the fabricated AISI 1345 steel sprocket teeth. Figures 3 and 4 illustrate the fine martensitic case. Figures 5 and 6 are typical structures of the transition zone in the fabricated sprockets. Of particular importance is the presence of large elongated bands of martensite separated by areas of pearlite proeutectoid ferrite. Figures 7 and 8 reveal the unaffected hypoeutectoid core of pearlite proeutectoid ferrite.

Figures 9 - 14 are photomicrographs of the structure of the cast AISI 4150 steel sprockets. Figures 9 and 10 illustrate the coarse martensite case. Figures 11 and 12 are from the transition zone and show a fairly uniform distribution of martensite, pearlite, and bainite. Figures 13 and 14 clearly illustrate the pearlitic core of the cast 4150 steel.

B. DISCUSSION AND FUTURE WORK

Based solely on chemical composition, the superior properties exhibited by the precision-cast AISI 4150 steel might be attributed to superior hardenability. Using the Grossman method of calculation and assuming an austenitic grain size of 7, the Ideal Critical Diameter for the cast 4150 steel is 6.83 in. and for the 1345 (carbon to .50%) is 2.58 in. With comparable carbon contents the hardness of the martensite would vary little between the AISI 4150 and AISI 1345. The answer seems to be in the superior hardenability of the AISI 4150 steel. Metallographic examination of the microstructures and macrostructures yields other conclusions.

The consideration of these structures leads to the following observations:

1. The anticipated columnar and dendritic segregation in the cast sprockets caused little structural variation after the flame-hardening treatment.

2. The pronounced unidirectional banding produced by rolling the AISI 1345 steel resulted in gross structural variation before and after flame hardening.

3. The presence of high percentages of proeutectoid ferrite in a structure prior to a nonequilibrium hardening treatment, i.e., flame or induction hardening, promotes a shallow case and a soft transition zone in the finished steel.

4. The banding caused by rolling aggravates the problem of uniform response to hardening as outlined in paragraph 3.

While the amount of proeutectoid ferrite present in a fabricated sprocket

may be reduced by changing the chemical analysis, the problem of banding will be present as long as a rolled product is used. The geometry of the sprocket and plate stock result in transverse wear sections in some teeth while others have longitudinal wear surfaces. This results in considerable property variation from tooth to tooth in any one sprocket.

The cast sprockets have a uniform pearlitic matrix which promotes rapid solution of carbon and uniform response to hardening. The transition zone retains a high percentage of martensite, and exhibits no banding or proeutectoid ferrite.

These results indicate that hardenability is important, but it is only part of the cause for the superior service of the cast sprocket. It should be noted, however, that the fabricated sprockets used in this test were produced to an obsolete drawing.

The service tests now in progress at Aberdeen Proving Ground have substantiated after 1900 miles the relative wear previously reported at General Motors Proving Ground. All the data relative to the Graphite Mold Pressure-Poured Drive Sprocket will be compiled in the final report.

The service tests being conducted at Fort Stewart, Georgia, have progressed less than 300 miles as of October 31, 1957, and are inconclusive at this point.

II. GRAPHITE MOLD PRESSURE-POURED FINAL DRIVE GEAR, NO. 7364141

A. CURRENT PROGRESS

Two experimental castings have been produced by Griffin Wheel Company in accordance with drawings E-1402.14-2 and E-1402.15-1. This pilot work has led to improvement of the graphite mold assembly to eliminate shrinkage and surface defects caused by entrapped gas. Results of this investigation will be reported as they become available.

B. FUTURE WORK

In view of the results to date it is estimated that satisfactory castings should be produced by December 21, 1957. At that time, representatives from Ordnance Tank-Automotive Command and The University of Michigan will inspect the results prior to production of all test castings for heat treatment and ordnance evaluation.

III. SHELL-CAST DUCTILE IRON FOLLOWERS, NO. 7359510 AND NO. 7360356

A. CURRENT PROGRESS

The castings returned to The University of Michigan following proof testing are under study. Figures 15 - 18 are photomicrographs taken from the most severely scored area of the front and rear followers. The matrix contains 5-15% pearlite and 85-95% ferrite with spheroidal graphite. The irregular edges of these specimens are cross sections from the zones of maximum scoring. The effects of cold deformation of the matrix are visible on the edge surfaces as well as a noticeable deformation of the graphite spherulites beneath the surface.

B. DISCUSSION AND FUTURE WORK

The examination of the proof-tested castings confirmed preliminary estimates and are as follows:

1. Excessive ferrite in the matrix caused scoring of the Follower castings by the gun tube.

2. The scored areas exhibit considerable plastic deformation.

3. There was no pickup of metal from the gun tube. All scored surfaces on the Follower castings resulted from removal of soft ferritic ductile iron.

Three sets of additional Follower castings are being produced in ductile iron. The matrix will be modified by chemistry change and heat treatment to assure a pearlitic structure. In addition, one of these sets will be tin-plated and one will be Teflon-coated to minimize friction.

Firing tests will be conducted on these castings at Port Erie, Ohio.

Table VIII summarizes the financial status of the project for September and October, 1957.

TABLE VIII

Financial Status Report

Month	Current Month Commitments	Payments to Date	Balance Unpaid Commitments	Uncommitted Balance
9/1/57-10/1/57	$65,127.59	$233,703.39	$66,378.02	$7,918.59
10/1/57-11/1/57	$ 4,169.45	$239,762.21	$64,506.67	$3,731.12

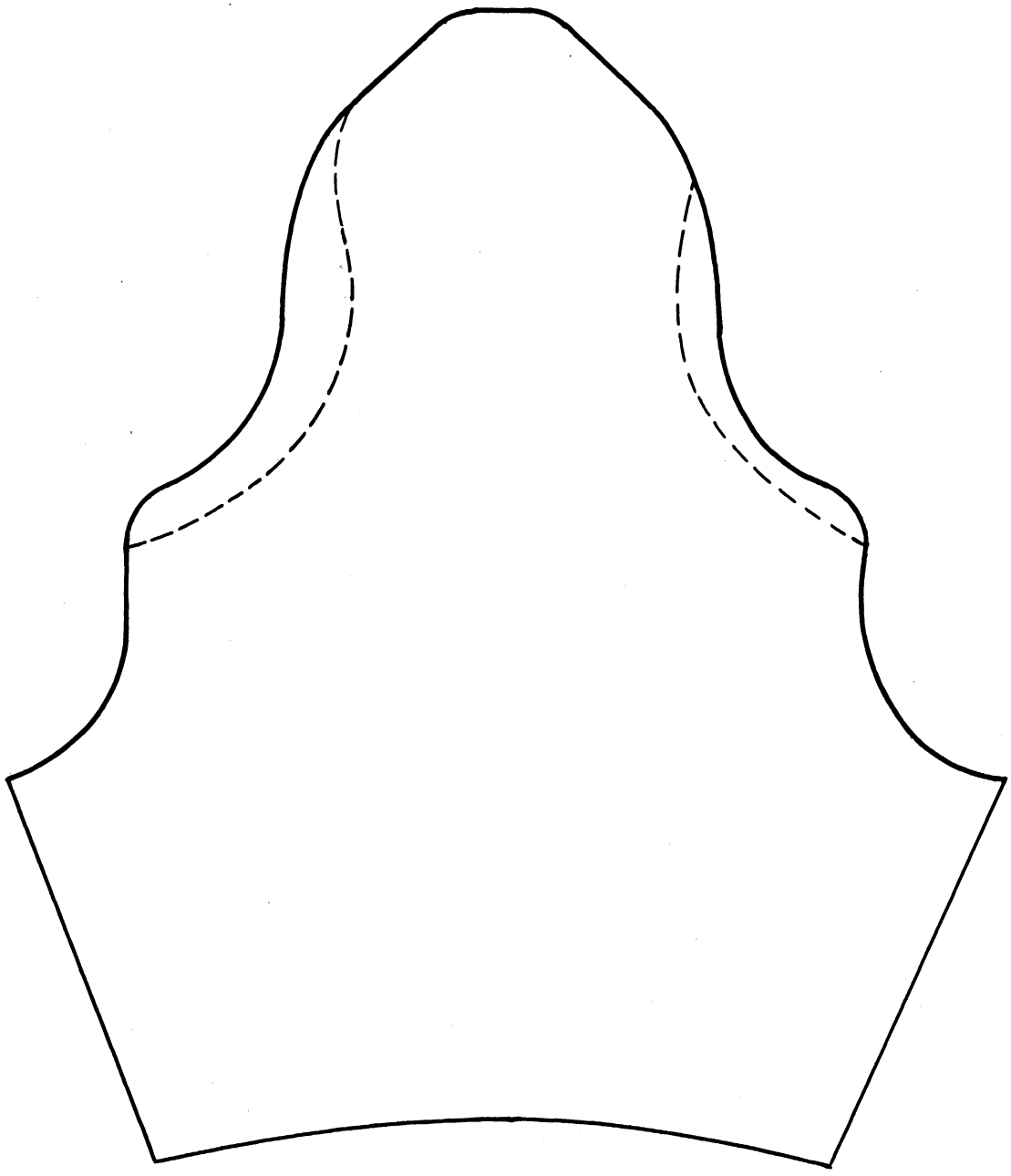


Fig. 1. Cast AISI 4150 sprocket No. 197. 2416 service miles.

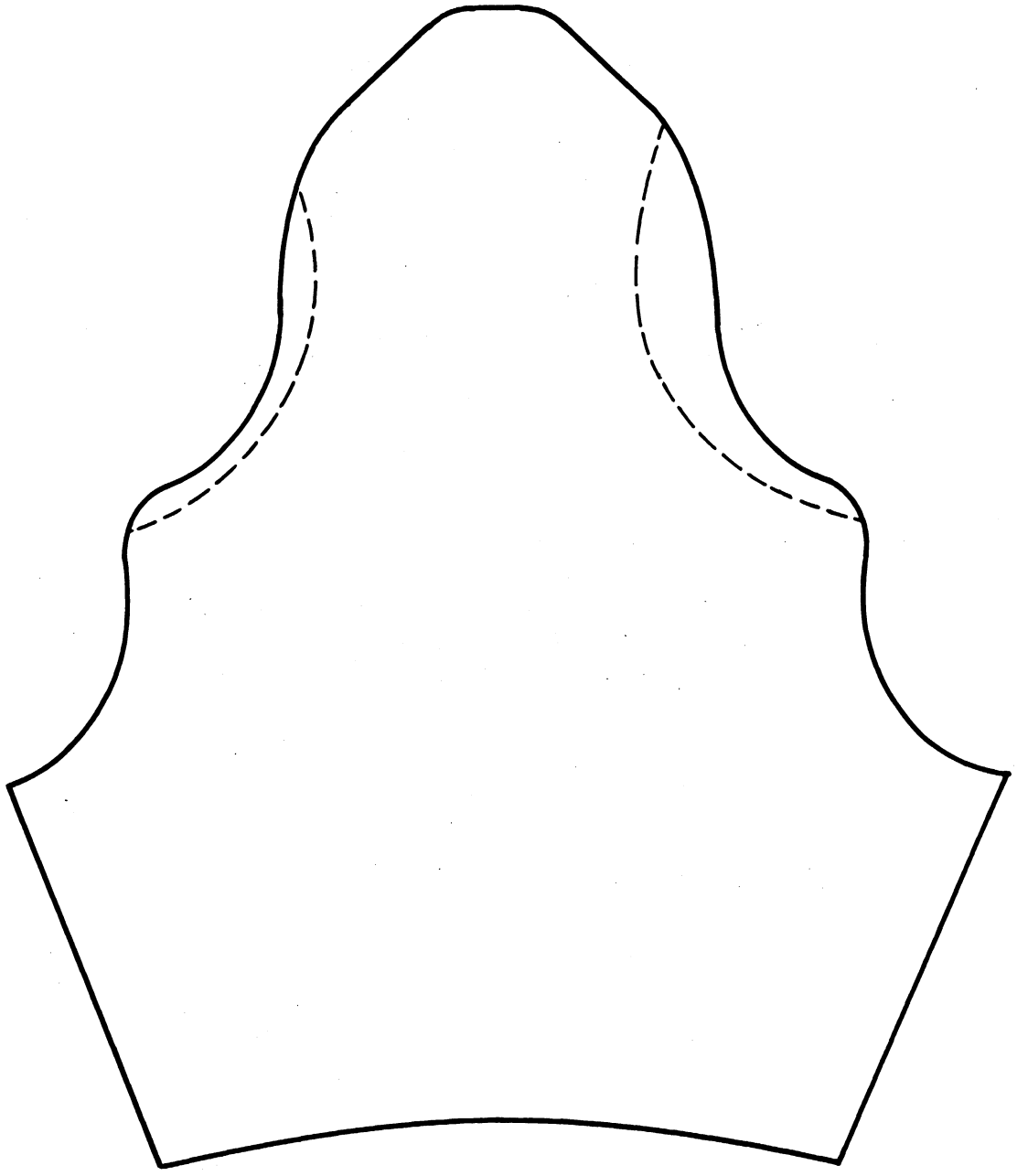


Fig. 2. Fabricated AISI 1345 sprocket No. A. 1177 service miles.

TABLE II

Rockwell "C" Hardness Traverse of Tooth
Left Inside Sprocket - Cast AISI 4150 - No. 191
2416 Miles of Service at G.M. Proving Ground

Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"
1	59.0	31	17.5
2	59.0	32	17.0
3	58.5	33	18.0
4	57.5	34	16.5
5	56.5	35	17.5
6	54.5	36	17.5
7	53.5	37	18.5
8	51.5	38	18.0
9	51.0	39	18.0
10	48.0	40	17.5
11	47.5	41	18.5
12	37.0	42	17.5
13	34.5	43	18.0
14	18.5	44	17.5
15	18.5	45	18.0
16	17.0	46	20.0
17	18.0	47	22.0
18	18.0	48	28.0
19	17.5	49	45.5
20	17.5	50	45.0
21	17.5	51	51.0
22	18.0	52	50.5
23	17.5	53	54.5
24	17.5	54	54.5
25	18.0	55	57.5
26	17.5	56	58.0
27	17.5	57	59.5
28	16.5	58	59.5
29	17.5		
30	17.0		

TABLE III

Rockwell "C" Hardness Traverse of Tooth
Left Outside Sprocket - Cast AISI 4150 - No. 197
2416 Miles of Service at G.M. Proving Ground

Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"
1	59.0	31	17.0
2	56.5	32	18.0
3	56.5	33	17.0
4	53.5	34	17.0
5	53.0	35	17.0
6	50.5	36	17.5
7	49.0	37	17.5
8	46.5	38	17.5
9	44.5	39	17.5
10	39.5	40	17.5
11	37.5	41	17.5
12	19.5	42	18.0
13	18.5	43	17.5
14	18.0	44	18.0
15	18.0	45	18.0
16	17.5	46	19.0
17	17.5	47	32.5
18	17.0	48	37.0
19	17.5	49	42.5
20	18.0	50	44.5
21	17.5	51	47.5
22	17.5	52	49.0
23	17.0	53	51.5
24	17.0	54	52.5
25	17.0	55	55.5
26	17.0	56	57.0
27	17.0	57	58.5
28	17.0	58	59.5
29	18.0	59	60.0
30	17.0	60	60.5

TABLE IV

Rockwell "C" Hardness Traverse of Tooth
Cast AISI 4150 - No. 195 As-Hardened

Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"
1	57.0	26	15.8	51	16.7
2	57.6	27	12.2	52	33.2
3	56.9	28	12.8	53	31.1
4	57.2	29	11.6	54	38.1
5	57.8	30	10.4	55	35.5
6	54.6	31	10.3	56	42.2
7	57.7	32	10.9	57	40.7
8	52.7	33	10.2	58	45.6
9	56.3	34	10.2	59	45.0
10	52.2	35	10.5	60	50.0
11	54.2	36	10.5	61	48.9
12	48.8	37	10.3	62	53.0
13	51.5	38	9.6	63	53.0
14	45.8	39	9.8	64	56.1
15	46.6	40	10.7	65	56.3
16	43.6	41	11.2	66	58.7
17	42.7	42	11.2	67	58.8
18	41.8	43	11.3	68	59.6
19	38.6	44	11.3	69	60.0
20	39.8	45	11.2	70	59.7
21	34.4	46	11.3	71	60.2
22	36.6	47	10.8	72	60.2
23	26.0	48	13.8	73	60.6
24	30.3	49	12.5		
25	15.3	50	23.2		

TABLE V

Rockwell "C" Hardness Traverse of Tooth
Cast AISI 4150 - No. 195 As-Hardened

Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"
1	59.0	26	15.0	51	14.5
2	60.0	27	11.5	52	18.5
3	60.0	28	12.0	53	19.5
4	60.0	29	10.5	54	24.0
5	59.5	30	10.5	55	25.5
6	60.0	31	10.0	56	31.0
7	59.5	32	11.0	57	33.0
8	59.5	33	11.0	58	34.5
9	58.0	34	10.5	59	35.5
10	58.0	35	10.5	60	38.5
11	56.0	36	12.0	61	40.5
12	55.0	37	11.0	62	42.0
13	51.5	38	----	63	42.5
14	52.0	39	----	64	46.0
15	48.0	40	----	65	45.5
16	46.5	41	----	66	49.5
17	42.5	42	----	67	47.0
18	41.5	43	----	68	47.5
19	37.5	44	11.0	69	48.5
20	36.5	45	11.5	70	50.0
21	34.0	46	10.0	71	48.5
22	32.5	47	10.5	72	49.0
23	26.0	48	11.5	73	48.5
24	26.5	49	12.0	74	48.5
25	17.0	50	13.5	75	47.0

TABLE VI

Rockwell "C" Hardness Traverse of Tooth
Right Outside Fabricated AISI 1345 - No. B
1177 Miles of Service at G.M. Proving Ground

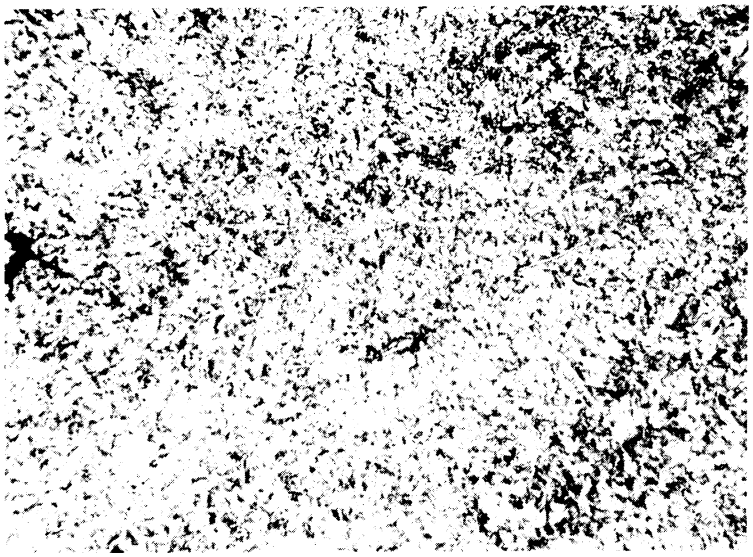
Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"
1	*	31	14.5
2	14.5	32	12.0
3	17.0	33	13.5
4	15.8	34	13.5
5	16.8	35	14.0
6	16.0	36	15.0
7	16.0	37	15.0
8	15.0	38	16.5
9	16.0	39	15.0
10	15.5	40	14.5
11	15.0	41	15.5
12	16.5	42	16.0
13	14.0	43	14.0
14	17.5	44	15.0
15	15.0	45	15.0
16	16.5	46	15.0
17	17.0	47	18.0
18	17.0	48	16.0
19	15.0	49	19.0
20	17.5	50	28.0
21	15.0	51	32.5
22	17.5	52	39.0
23	15.5	53	45.0
24	17.0	54	47.5
25	15.5	55	53.5
26	17.0	56	53.0
27	15.0	57	55.5
28	14.0		
29	15.0		
30	13.5		

*Soft, no reading.

TABLE VII

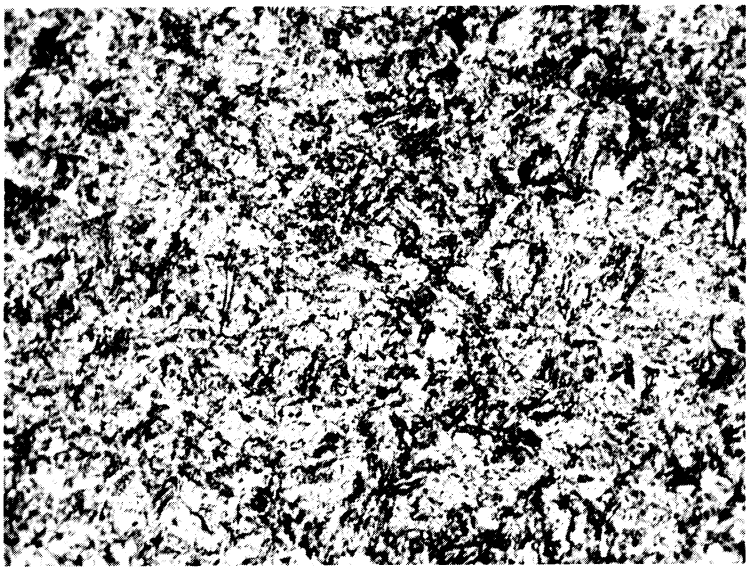
Rockwell "C" Hardness Traverse of Tooth
Right Inside Fabricated AISI 1345 - No. A
1177 Miles of Service at G.M. Proving Ground

Distance, 1/32 in.	R"C"	Distance, 1/32 in.	R"C"
1	9.0	31	12.5
2	11.0	32	11.5
3	10.0	33	11.5
4	11.0	34	12.0
5	10.0	35	12.5
6	11.0	36	12.5
7	10.5	37	12.0
8	11.5	38	12.0
9	10.5	39	12.5
10	11.5	40	12.0
11	11.0	41	12.5
12	11.5	42	13.0
13	12.5	43	22.0
14	11.5	44	29.0
15	12.0	45	32.5
16	12.0	46	38.0
17	11.5	47	41.0
18	11.5	48	42.0
19	12.0	49	45.5
20	12.0	50	47.0
21	12.0	51	50.0
22	12.0	52	52.0
23	12.5	53	53.0
24	12.0	54	54.0
25	12.5	55	55.0
26	12.0	56	56.0
27	12.5	57	56.0
28	12.5		
29	12.0		
30	12.0		



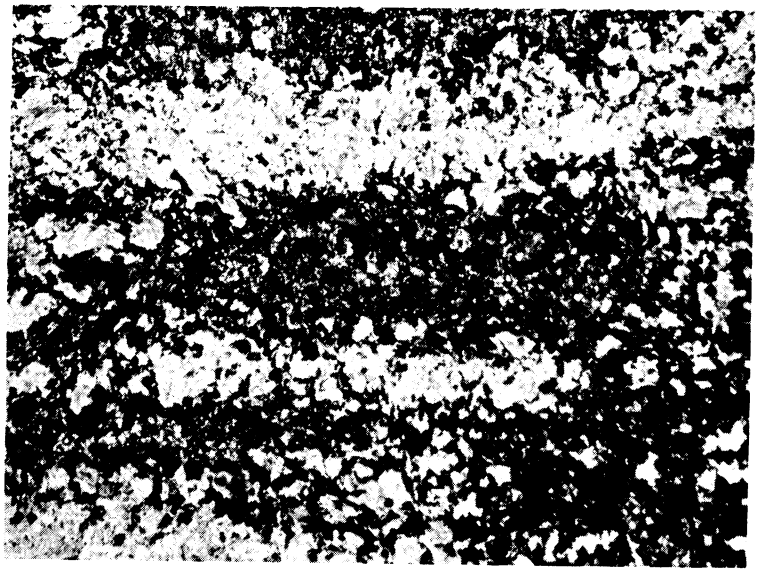
Flame-Hardened Case 250x 2% Nital

Fig. 3. Fabricated AISI 1345 sprocket No. A.



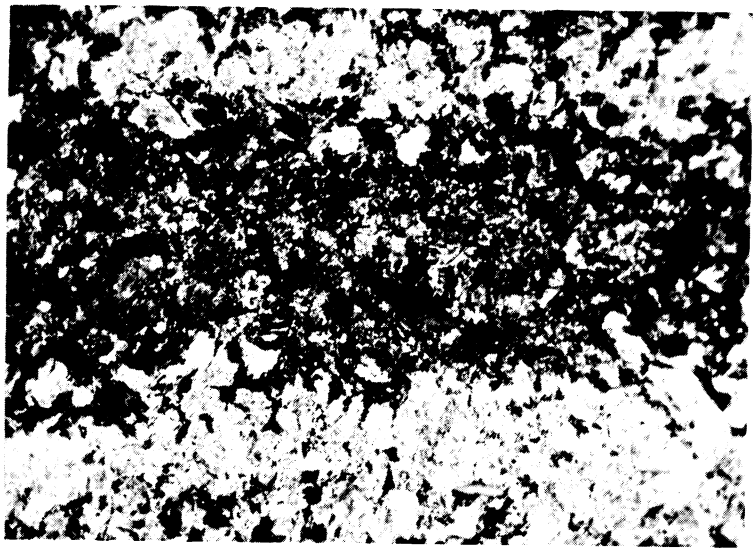
Flame-Hardened Case 500x 2% Nital

Fig. 4. Fabricated AISI 1345 sprocket No. A.



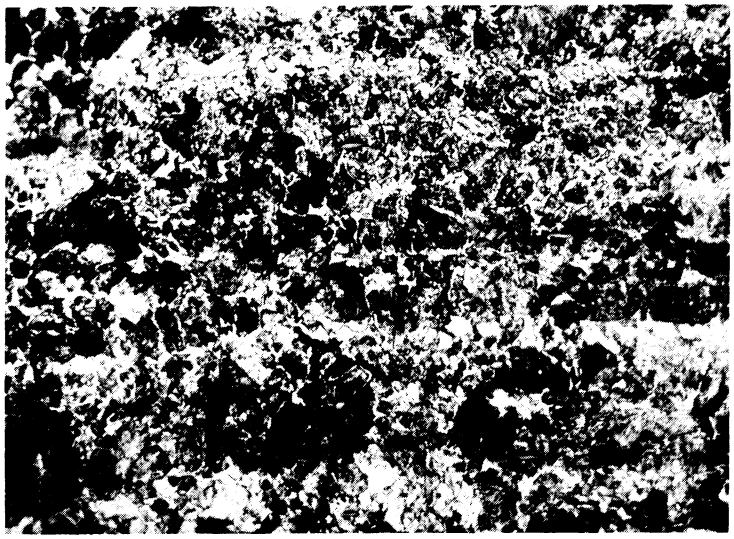
Transition Zone 250x 2% Nital

Fig. 5. Fabricated AISI 1345 sprocket No. A.



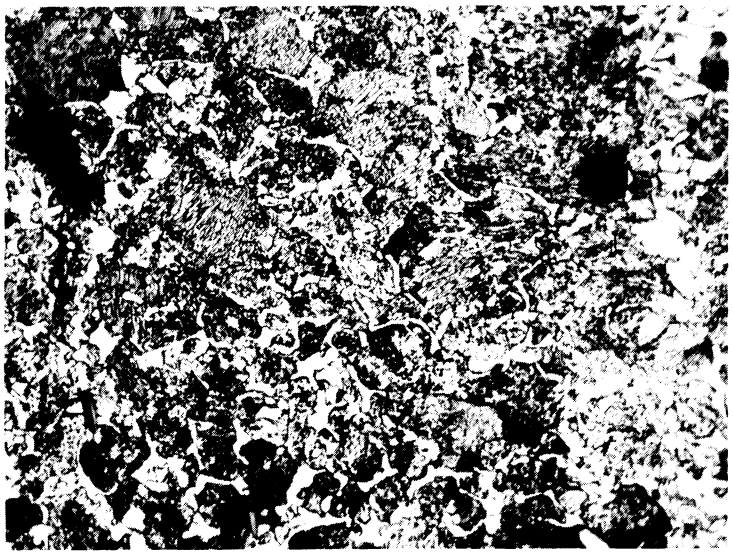
Transition Zone 500x 2% Nital

Fig. 6. Fabricated AISI 1345 sprocket No. A.



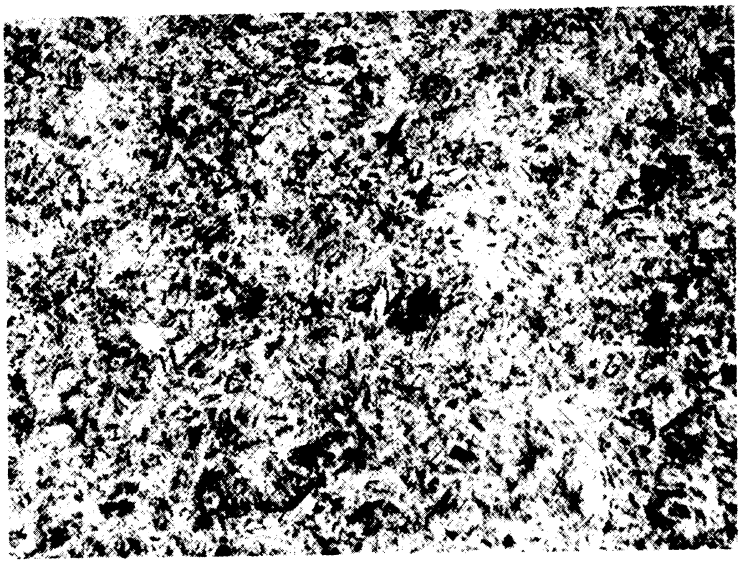
Hypoeutectoid Core 250x 2% Nital

Fig. 7. Fabricated AISI 1345 sprocket No. A.



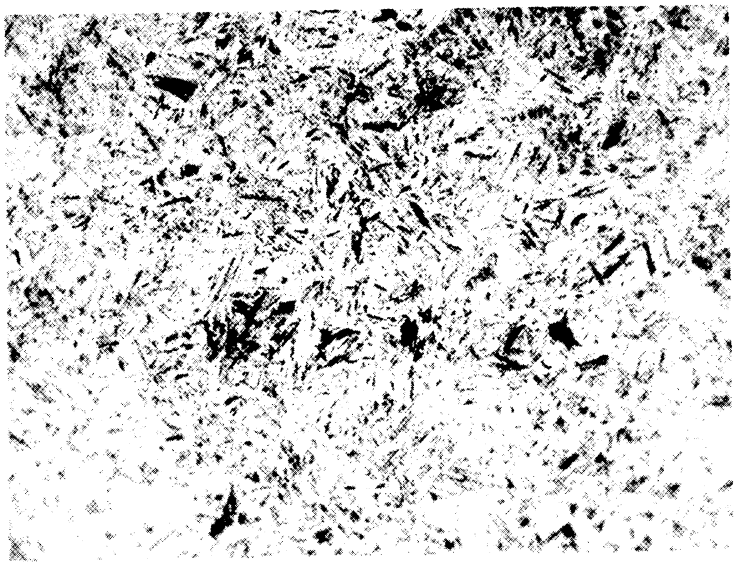
Hypoeutectoid Core 500x 2% Nital

Fig. 8. Fabricated AISI 1345 sprocket No. A.



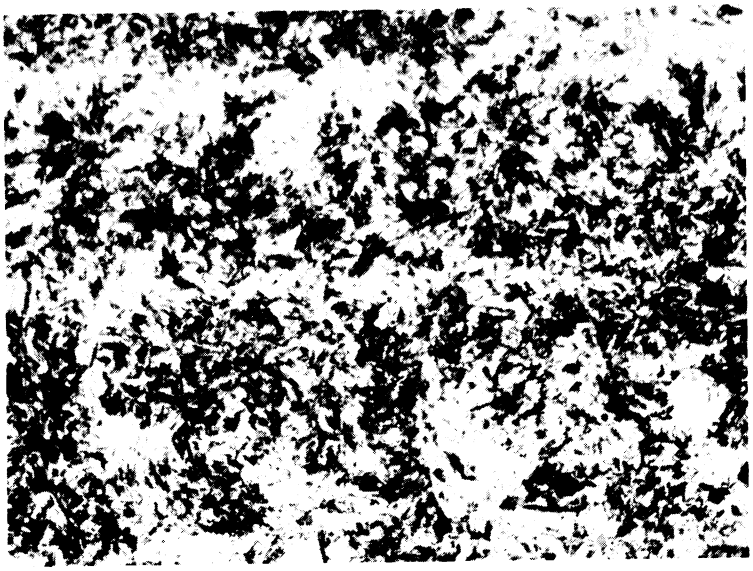
Flame-Hardened Case 250x 2% Nital

Fig. 9. Cast AISI 4150 sprocket No. 197.



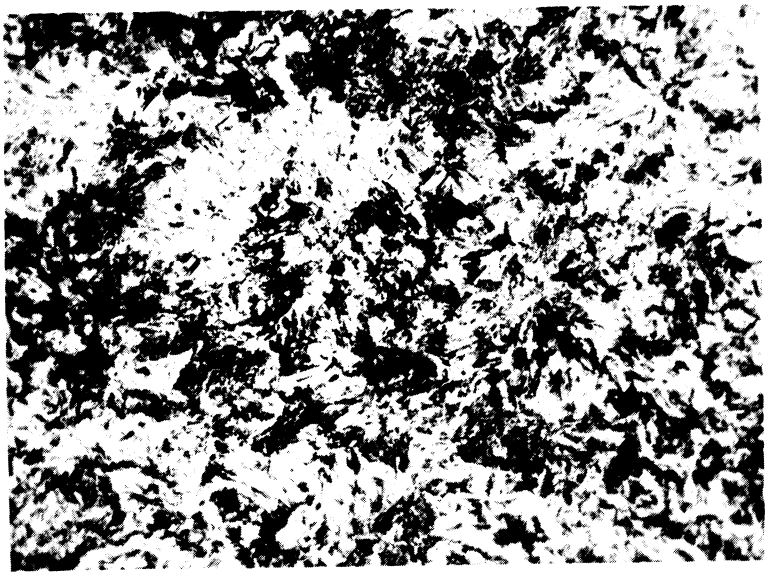
Flame-Hardened Case 500x 2% Nital

Fig. 10. Cast AISI 4150 sprocket No. 197.



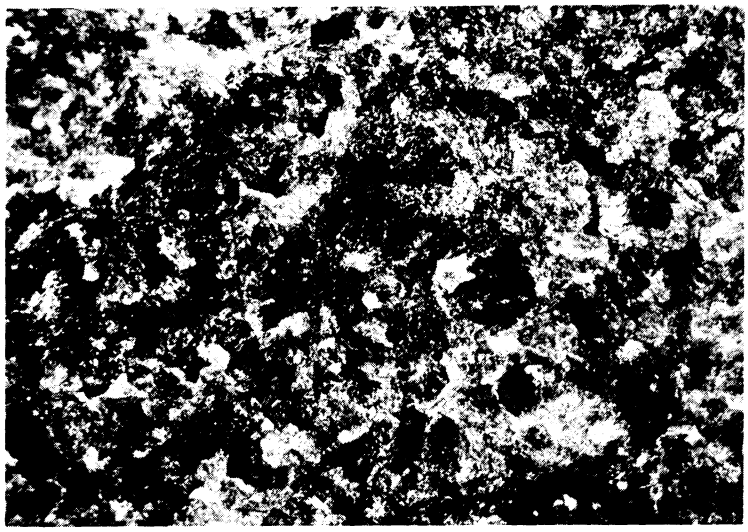
Transition Zone 250x 2% Nital

Fig. 11. Cast AISI 4150 sprocket No. 197.



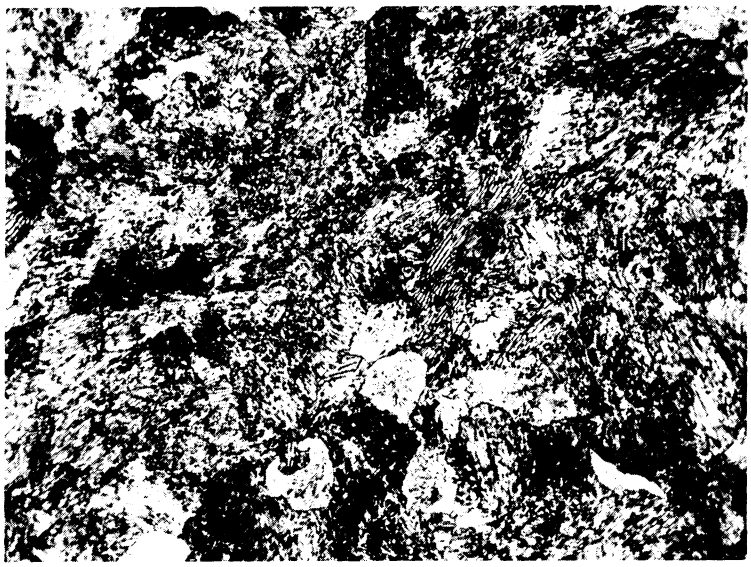
Transition Zone 500x 2% Nital

Fig. 12. Cast AISI 4150 sprocket No. 197.



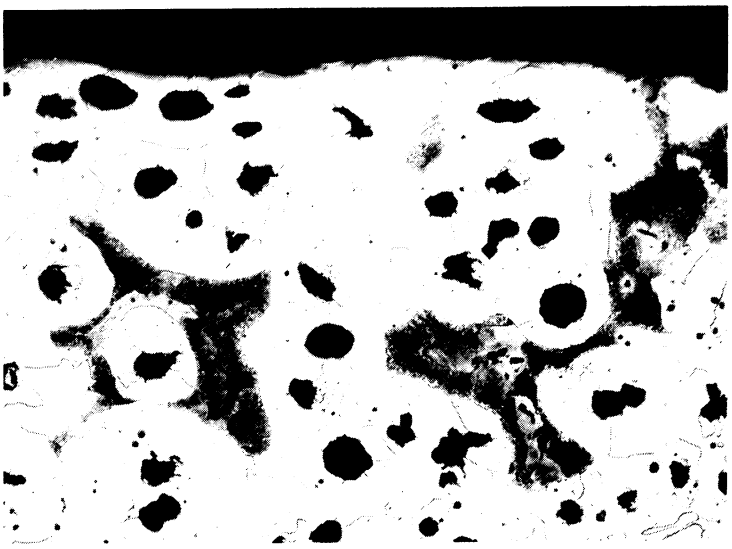
Eutectoid Core 250x 2% Nital

Fig. 13. Cast AISI 4150 sprocket No. 197.



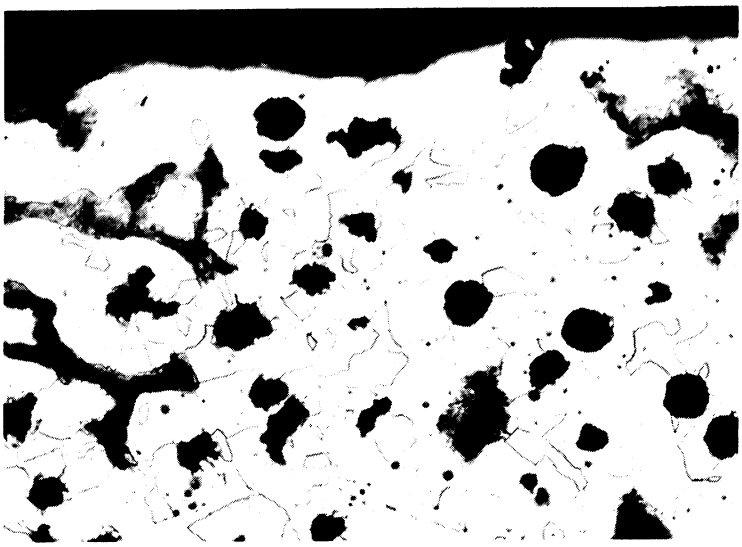
Eutectoid Core 500x 2% Nital

Fig. 14. Cast AISI 4150 sprocket No. 197.



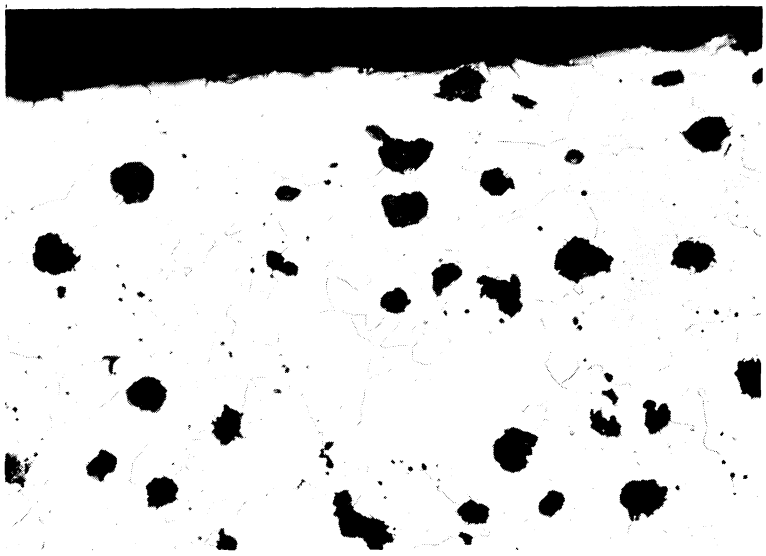
Scored Edge 100x 2% Nital

Fig. 15. Ductile cast iron rear Follower.



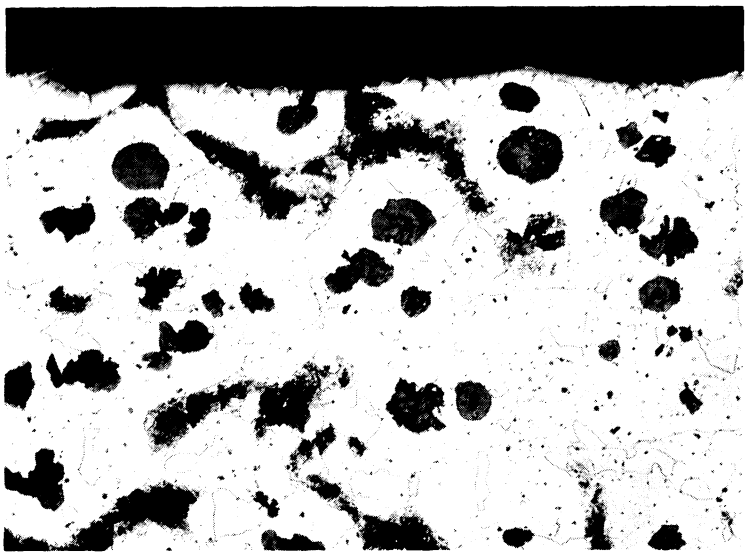
Scored Edge 100x 2% Nital

Fig. 16. Ductile cast iron rear Follower.



Scored Edge 100x 2% Nital

Fig. 17. Ductile cast iron front Follower.



Scored Edge 100x 2% Nital

Fig. 18. Ductile cast iron front Follower.