ENGINEERING RESEARCH INSTITUTE
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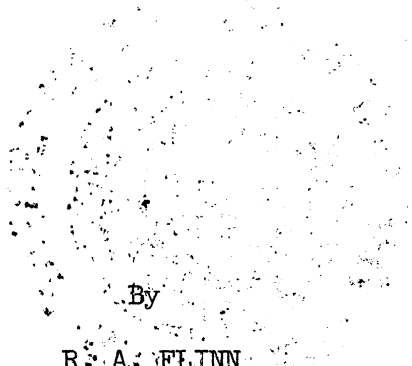
RISERING OF DUCTILE CAST IRON

PROGRESS REPORT NO. 2

RISER DIMENSIONS, FEEDING DISTANCE, AND OTHER DATA



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Project M862

THE INTERNATIONAL NICKEL COMPANY, INC.
NEW YORK, NEW YORK

May, 1954

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RISERING OF DUCTILE CAST IRON

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I. SUMMARY

To obtain a sound ductile-iron casting, two principal factors must be considered, riser size and riser placement.

Riser size can be calculated from Fig. 1, which provides both for sufficient feed metal in the riser and for a cooling rate enough slower than that of the casting.

Riser placement depends on the effective feeding distance of a riser in a particular casting. The following formulas indicate feeding distance in simple plates and bars; the data may be projected for more complex shapes:

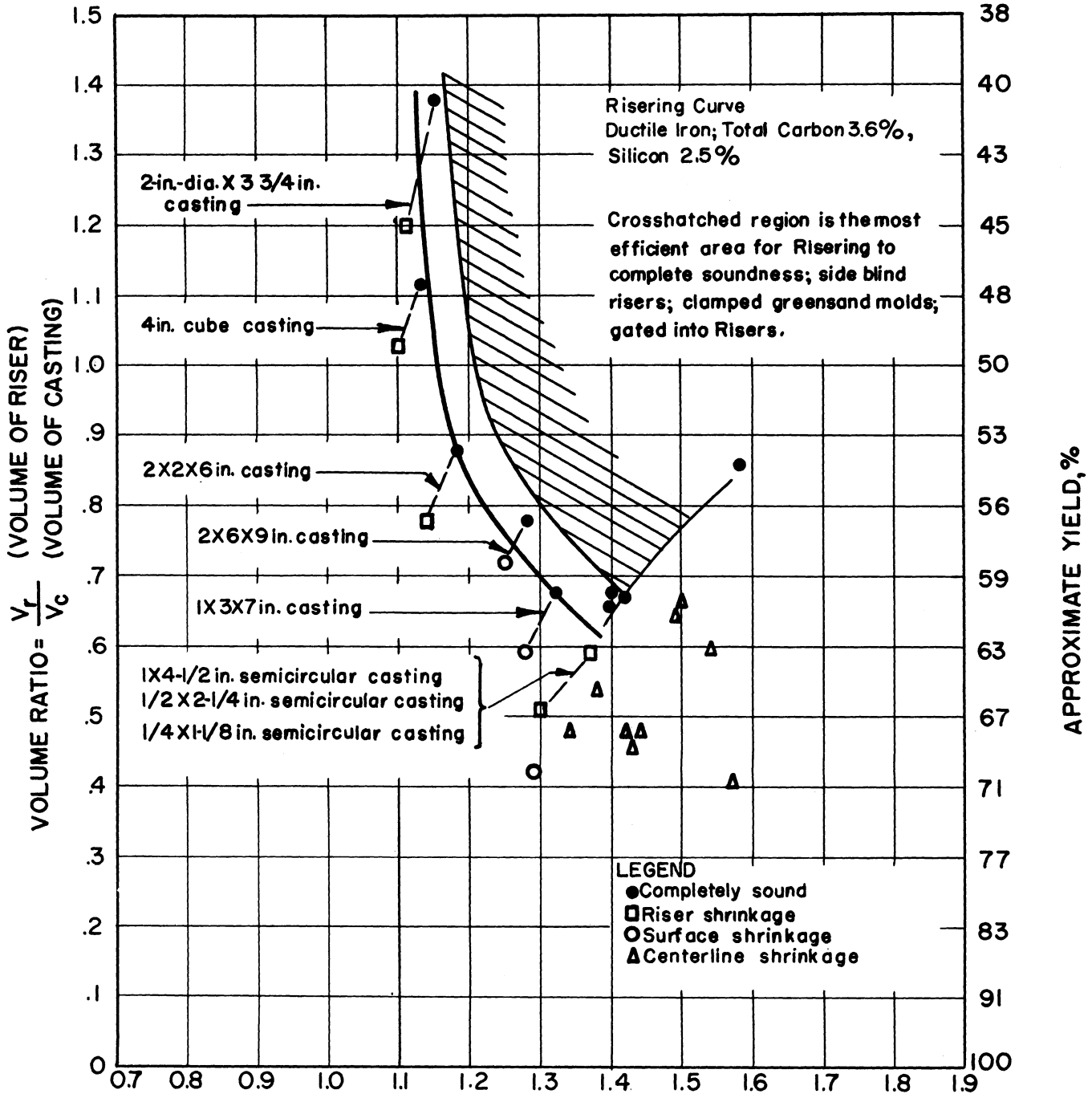
For plates: Effective feeding distance = 4.5t, where t is the thickness of the plate (applies to 1/4-to 2-inch sections).

For bars: Effective feeding distance = $6\sqrt{t}$, where t is the thickness of the bar (applies to 2-to 4-inch sections). A bar is considered as such when the width is less than 3t. These data corroborate those of Pellini for cast steel.

In the category of miscellaneous data, the eutectic for the ductile irons is shown to lie near 4.4 carbon equivalent and interesting supercooling phenomena are described.

II. INTRODUCTION

When a risering system is improperly designed, shrinkage may be encountered in the casting from one of the two distinct causes illustrated in



$$\text{FREEZING RATIO} = \frac{\frac{SA_c}{V_c}\ \text{(COOLING RATE OF CASTING)}}{\frac{SA_r}{V_r}\ \text{(COOLING RATE OF RISER)}}$$

FIG. 1

Fig. 2a and b:

(1) Riser-neck shrinkage (Fig. 2a) extending into the casting is caused by a riser that is too small. A riser of the proper (larger) size freezes much later than the casting and delivers an adequate supply of liquid iron to fill the shrinkage voids in the casting.

(2) Centerline shrinkage (Fig. 2b) away from the riser cannot, in general, be corrected by an increase in riser size. This type of shrinkage results from an inadequate thermal gradient across the casting. The shrinkage zone is walled off from the riser containing ample liquid metal by the rest of the casting. In the case illustrated, even a tenfold increase in riser size would not produce enough change in the thermal gradient across the entire casting to avoid the uniform solidification pattern which blocks liquid-metal flow from the riser.

It is very important to notice that the remedies for these two types of shrinkage are distinctly different. For riser-neck shrinkage a larger riser is needed, while for centerline shrinkage either an increased number of risers, chill inserts in the mold, or design changes are necessary. For completeness it should be noted that instead of these being shrinkage voids at these locations, the cope surface may be sucked in toward the hot spot by the vaccum at this point; in this case surface shrinkage partly or completely replaces the internal shrinkage. The causes and remedies are the same as those just discussed. This is illustrated in Fig. 2c.

The first progress report in risering of ductile iron was largely concerned with riser size and not with the feeding distance. During the past year the data on riser size have been enlarged to include a wider variety of test castings and to determine the conditions necessary for obtaining radiographically sound castings. In the first report only careful visual inspection of sectioned castings was employed following the work of Caine, but because of the demands of the aircraft industry and others for radiographic soundness this added requirement received study.

The principal effort of the year has been directed, however, toward evaluating the effective feeding distance of a riser in ductile iron.

Since all castings may be considered as combinations of the simple geometrical shapes, it is logical to determine the feeding distance of risers in bars, plates, and cubes as a guide to proper riser placement in castings. It is evident from inspection that feeding distance in a cube is not a problem, since a cube is merely a very short bar. We will be concerned, therefore, with obtaining a quantitative expression for feeding distance in bars and plates.

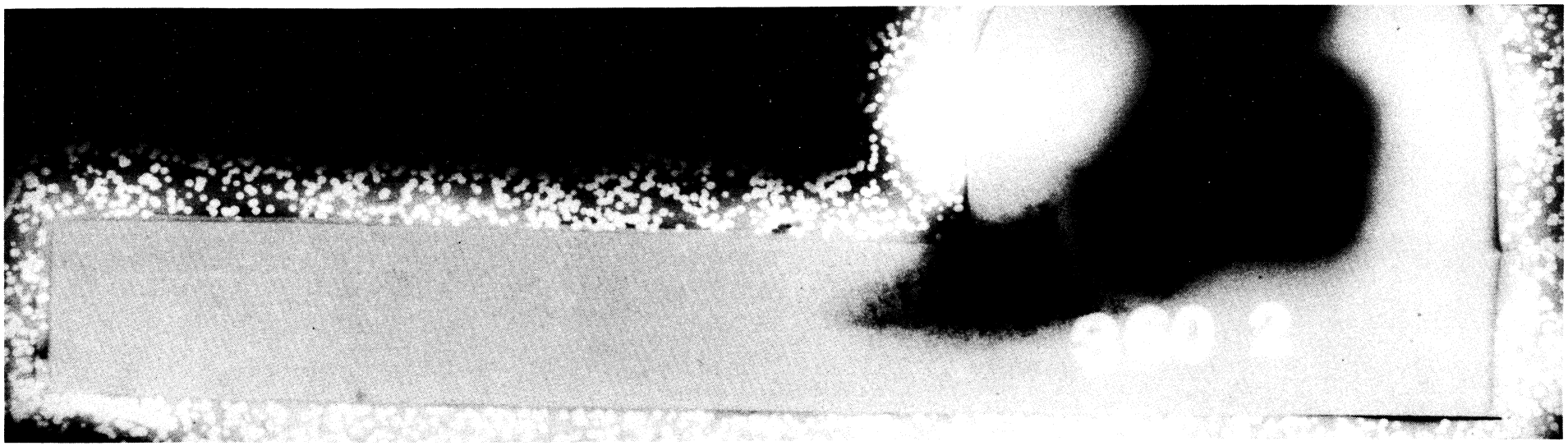


Fig. 2a. Radiograph showing riser neck shrinkage (inadequate riser size)

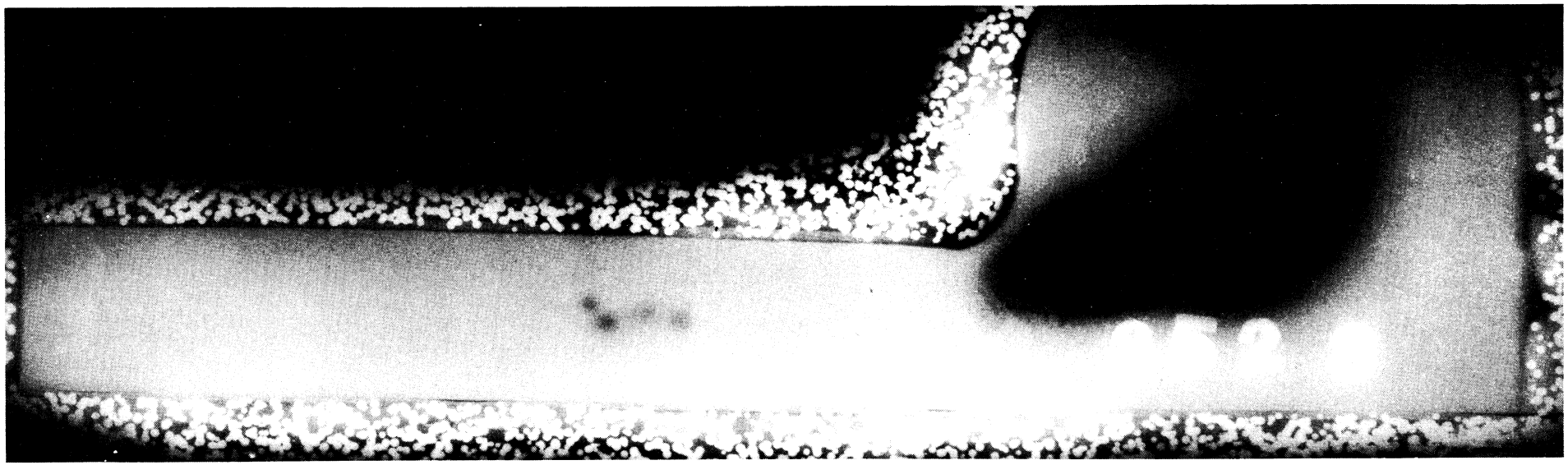


Fig. 2b. Radiograph showing centerline shrinkage (beyond effective feeding distance)

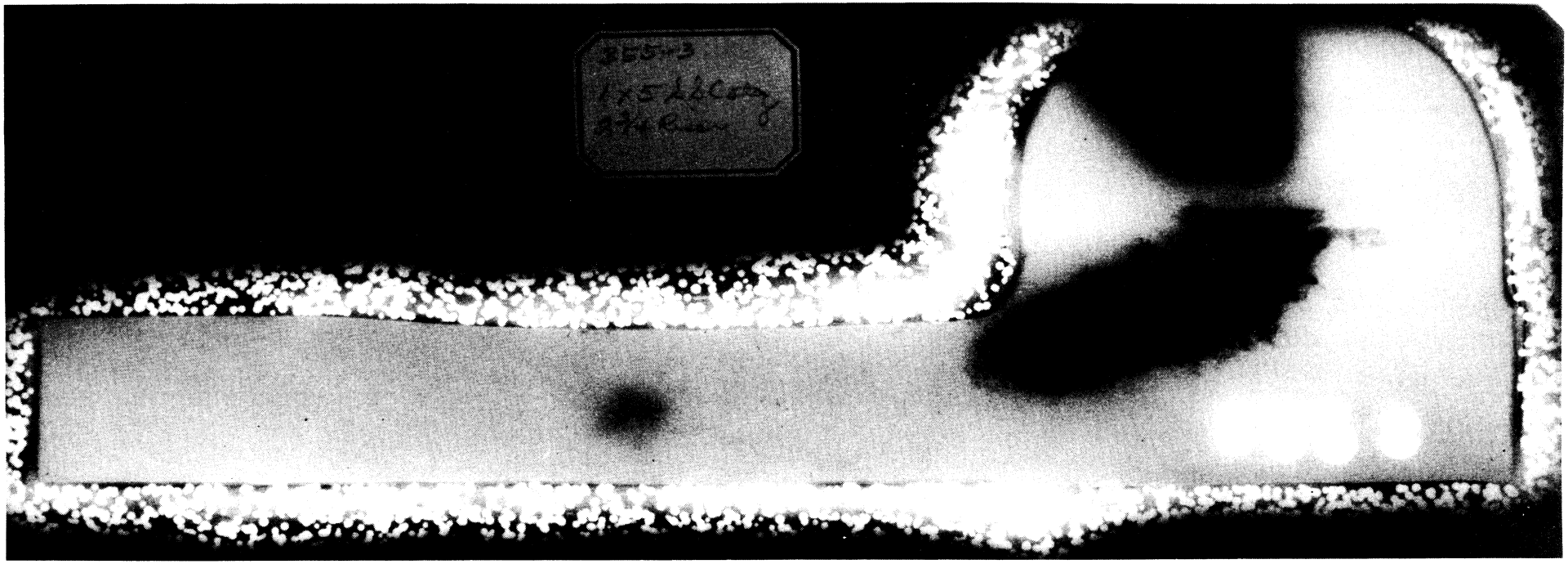


Fig. 2c. Radiograph showing surface shrinkage (can be caused by inadequate riser size, or exceeding effective feeding distance)

III. PROCEDURE

A. Melting Practice

The melting practice followed that described in the previous report with the exception that .015% cerium as mischmetal was added with the ferrosilicon addition. "Foundry-grade" Electromet 85% ferrosilicon (1.5%Al) was generally used as a post-inoculant. It was necessary to break the mischmetal into small pieces.

Melts were made in a 200-pound high-frequency induction furnace with a rammed magnosite lining, heated to 2770°F, inoculated with No. 1 nickel magnesium silicon, reladled for the ferrosilicon addition, and poured at 2500-2590°F.

B. Molding

1. Riser Size. The castings used for determination of the risering curve are illustrated in Fig. 3. The dimensions were selected to provide a wide range of cooling rates.

2. Feeding Distance. The various bar and plate castings with risers are illustrated in Figs. 4a and b, and described in the tables of data. Some of these castings also provided data for the risering curve. The greensand molding practice has been described in the previous report.

C. Inspection

In the previous report the principal criterion of soundness was the careful visual inspection of sections through critical regions. This was more conservative than the technique Caine used in developing risering curves for steel, since the occurence of flowed metal across shrinkage voids during cutting was minimized by sandblasting of the cut face. However, the increasing demand for radiographically sound castings prompted the use of radiographic inspection of all castings. Since the best sensitivity was obtainable with machined surfaces, the critical sections were cut out of each casting for radiographing as shown by the cross-hatched marks in Figs. 4a and b. The sensitivity is sufficient to disclose defects above 0.010 inch in size in any of the castings made.

In Fig. 5 the change in riser-neck shrinkage as riser size is increased is shown by radiographs

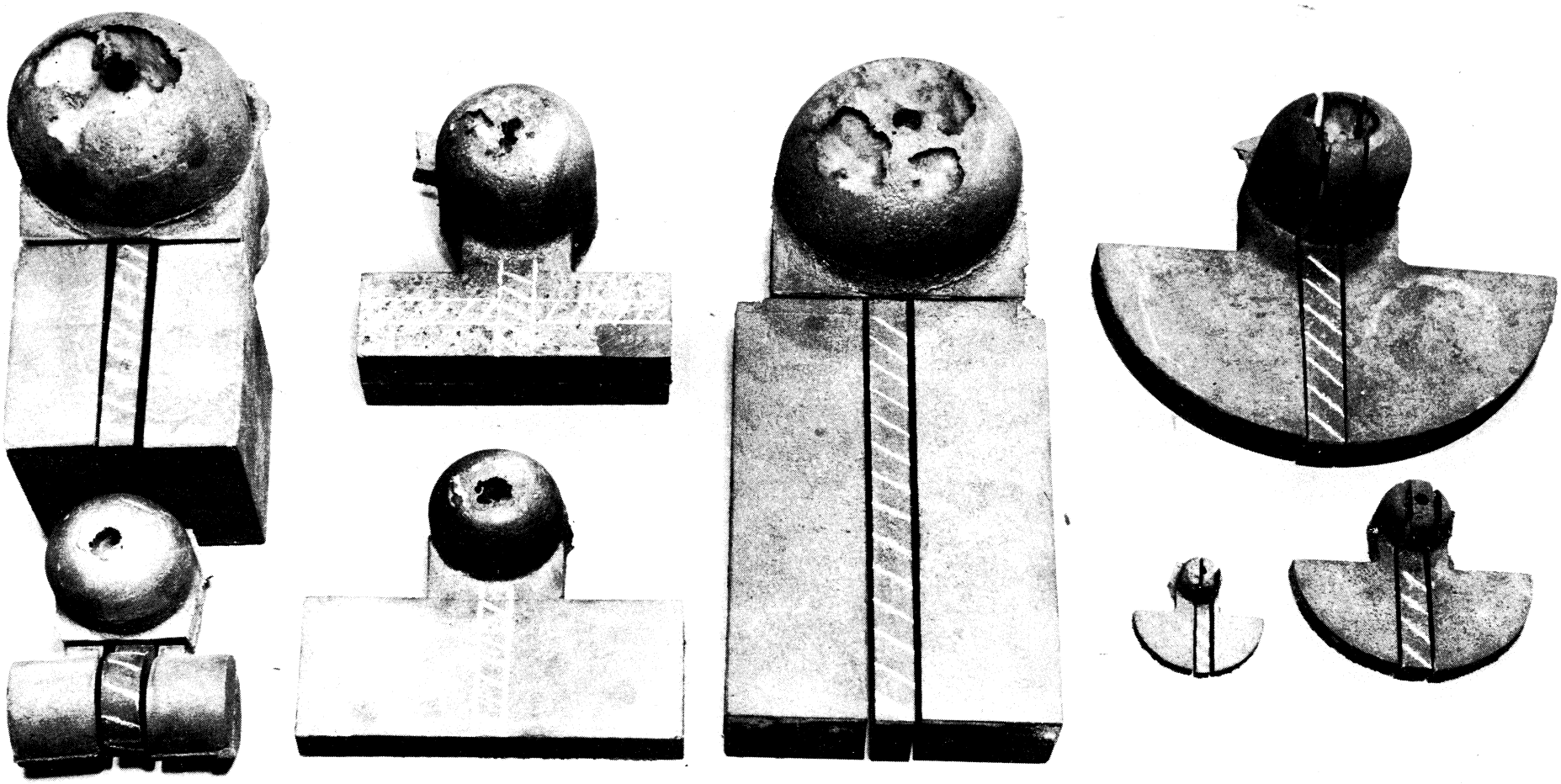


Fig. 3. Castings used for determining risering curve

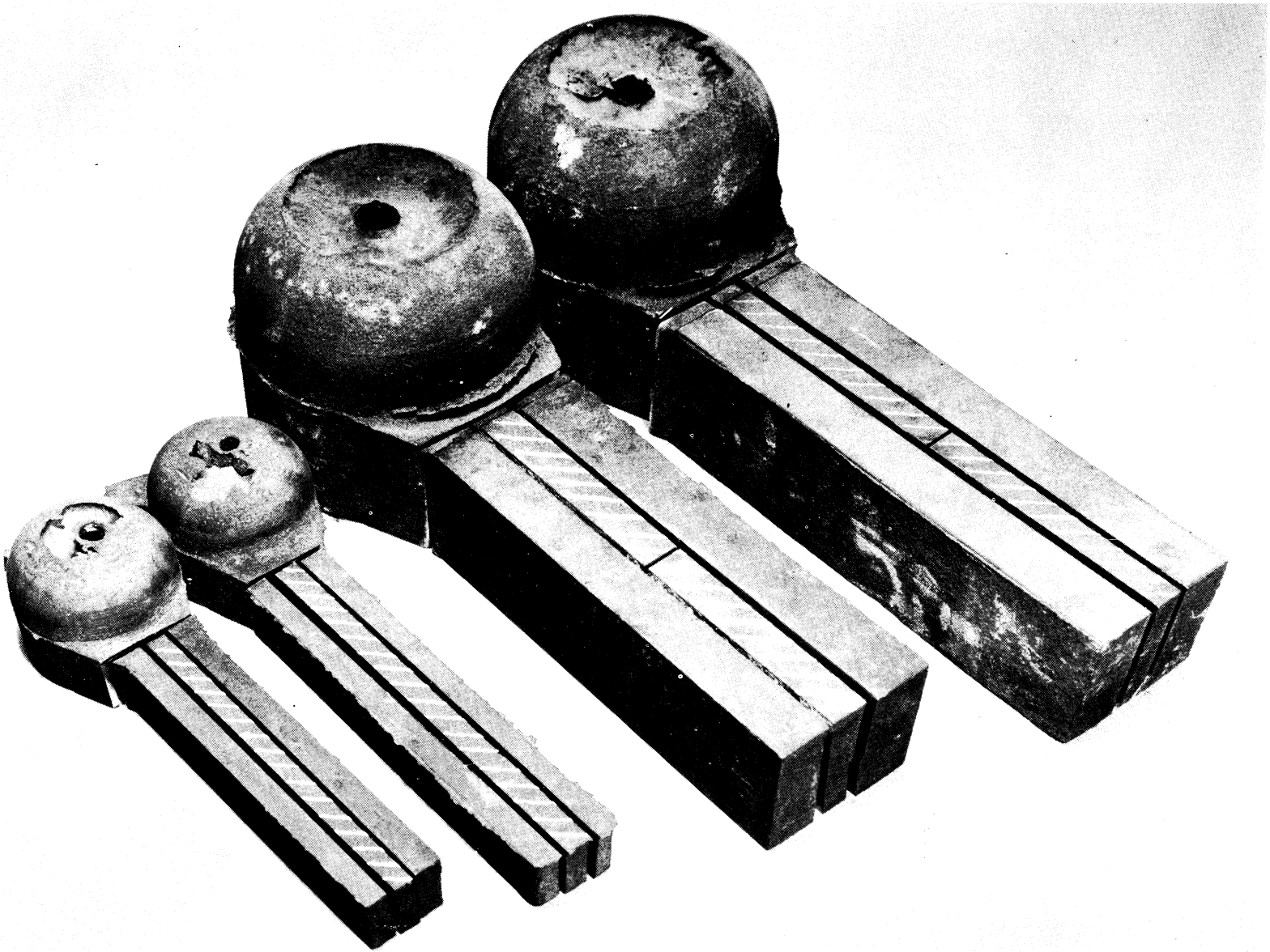


Fig. 4a. Bar castings for feeding distance

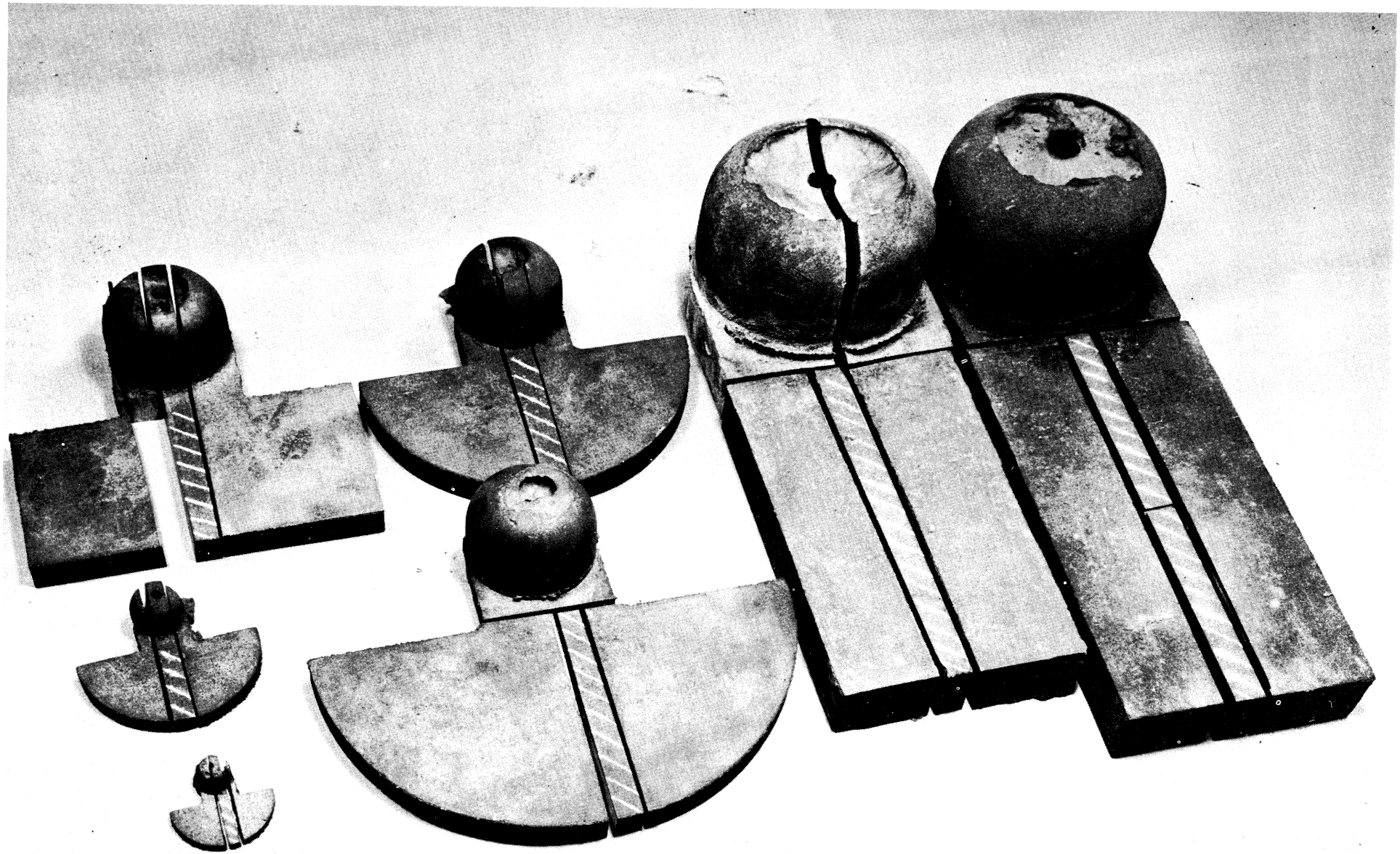


Fig. 4b. Plate castings for feeding distance

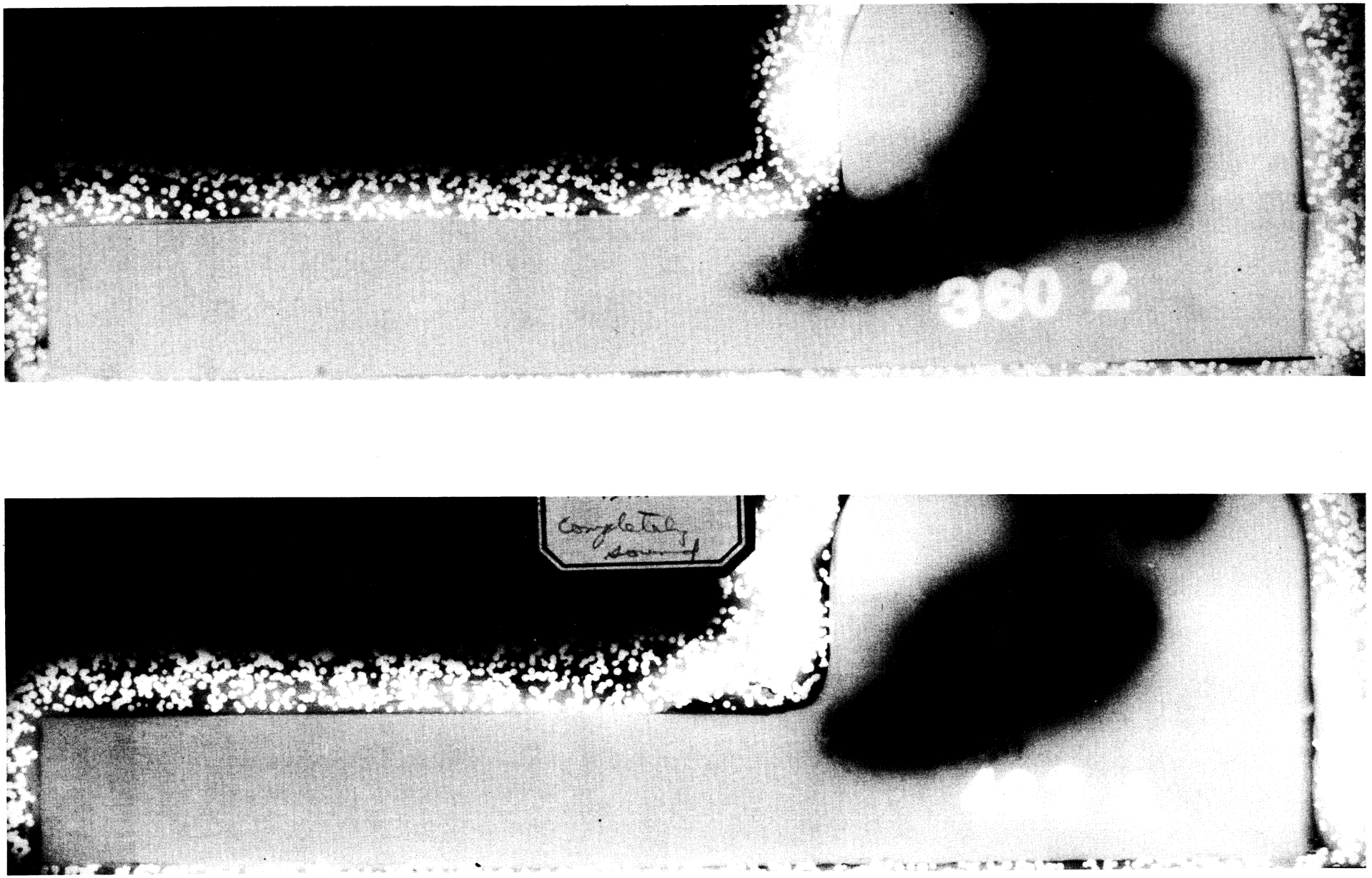


Fig. 5. Radiographs showing effect of riser size on riser neck shrinkage

In Fig. 6 a typical set of radiographs illustrates the appearance of centerline shrinkage as effective feeding distance is exceeded.

IV. DATA

The data may be divided into two principal groups for discussion:

A. Risering Curve Data affecting riser size, Table I and Figs. 1, 3, and 5.

B. Effective Feeding Distance Data affecting riser placement, Table II and Figs. 4 and 6.

C. Miscellaneous Data.

A. Risering Curve Data

The application of the risering curve data shown in Fig. 1 to the calculation of the proper riser size for a given casting has been rather thoroughly discussed in the previous report. In summary, to determine whether a given riser will avoid riser-neck shrinkage in a given casting (or portion of a casting if more than one riser is used):

(1) Calculate the freezing ratio of the casting to the riser. Since the cooling rate of either riser or casting is proportioned to the surface-area / volume ratio,

$$\text{Freezing ratio } \frac{\text{casting}}{\text{riser}} = \frac{\dfrac{\text{Surface area}}{\text{volume}} \text{ of casting}}{\dfrac{\text{Surface area}}{\text{volume}} \text{ of riser}}$$

This must be greater than one for all normal cases, since the cooling rate of the riser must be less than that of the casting in order to have liquid feed metal available.

(2) Calculate the volume ratio of riser to casting. In steel the volume of liquid metal in the riser must be at least 3 percent of the casting volume, since 3 percent liquid-to-solid shrinkage takes place.

These two values provide the x and y axes of the graph on which the date for a given riser-casting combination indicate a sound or unsound riser-neck. Conversely, the graph may be used to select the proper riser size;

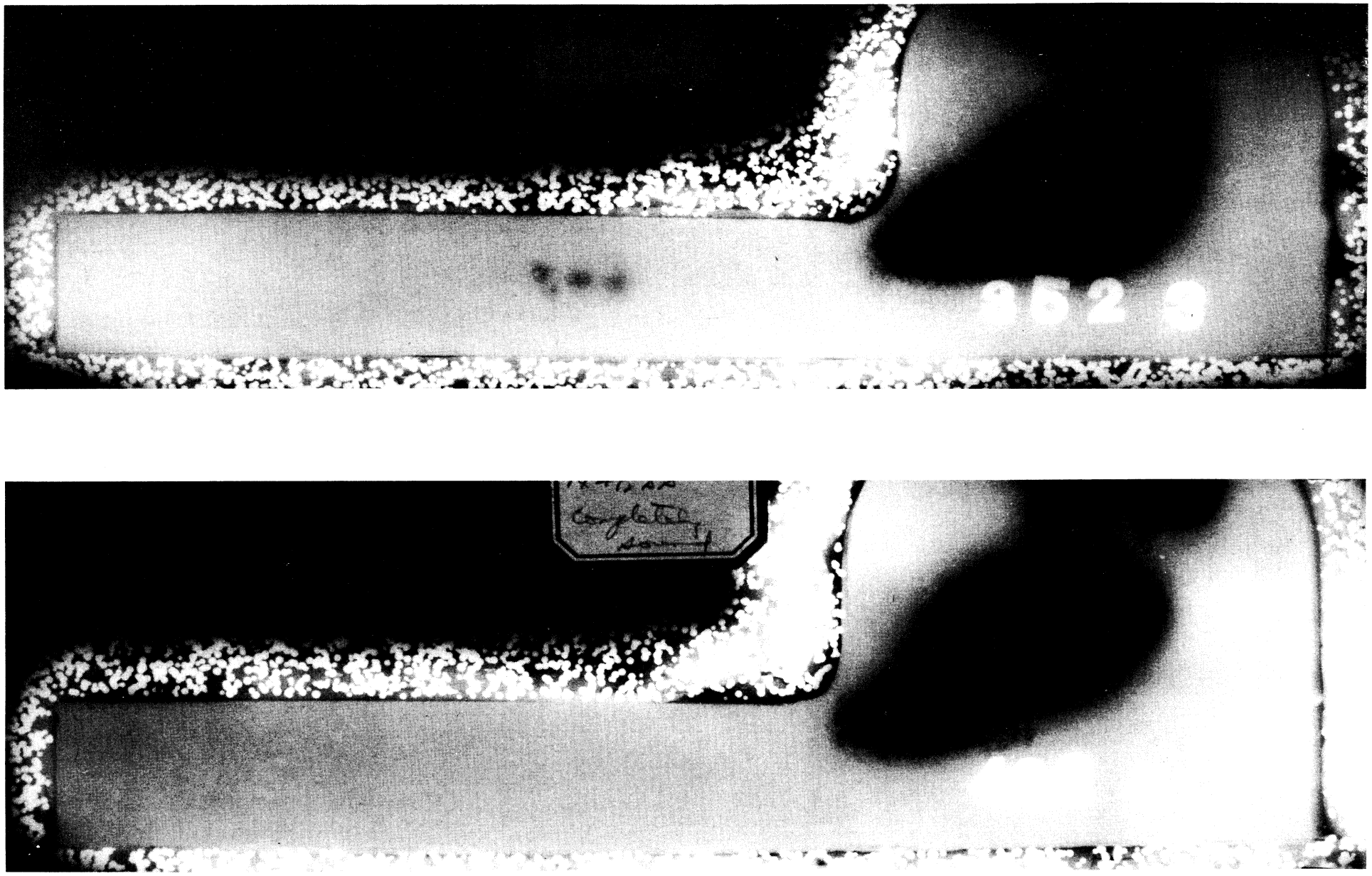


Fig. 6. Radiographs showing effect of feeding distance on centerline shrinkage

several trial-and-error calculations (usually two are sufficient) rapidly establish the necessary riser size for soundness.

This new graph has been established for radiographic soundness from the data of Table I, as mentioned in the procedure.

TABLE I

RISERING CURVE FOR 3.6%C, 2.5% Si DUCTILE IRON
(See Appendix Pages Noted Below For Other Confirmatory Data)

	Cstg. No.	F.R.	V.R.
a.) 2-in. Dia. x 3-3/4-in. long casting (see page 23)			
1.) 2-3/4-in. Riser - completely sound	352-2	1.15	1.38
2.) 2-5/8-in. Riser - riser shrinkage	355-2	1.11	1.20
b.) 4-in. Cube casting (see page 24)			
1.) 4-1/2-in. Riser - completely sound	345-4	1.13	1.12
2.) 4-3/8-in. Riser - riser shrink	348-5	1.10	1.03
c.) 2 x 2 x 6-in. Casting (see pages 24 and 25)			
1.) 3-in. Riser - completely sound	253-1	1.18	.88
2.) 2-7/8-in. Riser - riser shrink	254-6	1.14	.78
d.) 2 x 6 x 9-in. Casting (see page 35)			
1.) 4-3/4-in. Riser - completely sound	363-1	1.28	.78
2.) 4-5/8-in. Riser - surface shrink	364-5	1.25	.72
e.) 1 x 3 x 7-in. Casting (see pages 25 and 26)			
1.) 2-5/8-in. Riser - completely sound	256-4	1.32	.68
2.) 2-1/2-in. Riser - surface shrink	257-3	1.28	.59
f.) 1 x 4-1/2-in. Semicircular Casting (see page 27)			
1.) 3-in. Riser - completely sound	422-4	1.41	.67
2.) 2-7/8-in. Riser - riser shrink	360-2	1.30	.51
g.) 1/2-in. x 2-1.4-in. Semicircular Casting (see page 31)			
1.) 1-1.2-in. Riser - completely sound	363-2	1.42	.67
2.) 1-3/8-in. Riser - 3/16-in. riser shrink, no centerline shrink	364-2	1.30	.51
h.) 1/4-in. x 1-1/8-in. Semicircular Casting (see page 33)			
1.) 3/4-in. Riser - completely sound	364-1	1.41	.66
i.) 1-in. x 5-in. Semicircular Casting (see page 26)			
1.) 2-7/8-in. Riser - centerline shrink	352-3	1.34	.48
2.) 2-3/4-in. Riser - surface shrink	355-3	1.29	.42

TABLE I (CONCLUDED)

RISERING CURVE FOR 3.6%C, 2.5% Si DUCTILE IRON
(See Appendix Pages Noted Below For Other Confirmatory Data)

	Cstg. No.	F.R.	V.R.
j.) 1-in. x 6-in. Semicircular Casting (see page 27)			
1.) 3-1/4-in. Riser - centerline shrink	345-2	1.44	.48
k.) 1 x 5 x 10-in. Casting (see page 27)			
1.) 3-1/8-in. Riser - centerline shrinkage	357-6	1.42	.48
l.) 1-in. x 4-1/2-in. x 9-in. Casting (see page 28)			
1.) 3-1/4-in. Riser - centerline shrinkage	422-6	1.50	.67
m.) 1/2-in. x 2-1/4-in. x 4-1/2-in. Casting (see page 31)			
1.) 1-5/8-in. Riser - centerline shrinkage	364-3	1.49	.66
n.) 1/2-in. x 2-1/2-in. Semicircular casting (see page 31)			
1.) 1-1/2-in. Riser - centerline shrinkage	357-1	1.38	.54
o.) 1/2-in. x 3-in. Semicircular casting (see page 30)			
1.) 1-5/8-in. Riser - centerline shrinkage	348-1	1.43	.47
p.) 1/2-in. x 4-in. Semicircular casting (see page 30)			
1.) 1-7/8-in. Riser - centerline shrinkage	338-1	1.57	.41
q.) 1/4-in. x 1-1/2-in. Semicircular casting (see page 33)			
1.) 7/8-in. Riser - centerline shrinkage	363-4	1.54	.60

Proper riser-neck dimensions are needed as shown by the following comparison:

Effect of Neck Dimensions on Feeding Distances (3.6%C, 2.5% Si)

a.) 1 x 4-in. Semicircular Casting (see page 26)	Cstg. No.	F.R.	V.R.
1.) 15/16 x 1-7/8 x 15/32-in. neck, 2-3/4-in. Riser; 3/8-in. centerline shrinkage	295-5	1.33	.64
2.) 15/16 x 2-3/4 x 15/32-in. neck, 2-3/4-in. Riser; completely sound	325-1	1.34	.64

In general, necks of insufficient width have been employed in plate-like castings.

It should be reemphasized that the above data give only the side riser dimensions needed to avoid riser-neck shrinkage, and do not govern

isolated centerline shrinkage, which is determined by effective feeding distance. Centerline shrinkage is avoided by proper riser placement and will now be discussed.

B. Effective Feeding Distance Data (Riser Placement)

As mentioned in the introduction, this problem resolves into the question "In a given bar or plate, how far will a riser feed?" It is assumed that the riser is large enough to avoid riser-neck shrinkage as calculated in Section A. To answer this question, bars and plates of different lengths and cross sections were prepared (Figs. 4a and 4b, and Table II). In the following summary, Table II, comparison of these data with those obtained by Pellini for steel is indicated. In general the data are in remarkably good agreement, as predicted in the earlier report.

TABLE II

FEEDING DISTANCE FOR 3.6%C, 2.5% Si DUCTILE IRON
(See Appendix Pages Noted Below For Confirmatory Data)

	Cstg. No.	F.R.	V.R.
a.) 2 x 2-in. Bar (see pages 33 and 34)			
1.) With 4-in. riser, 10-in. length; sound	352-5	1.48	1.26
With 4-in. riser, 11-in. length; unsound	355-4		
2.) With 3-in. dia., 4-in. high riser, 9-in. length; unsound	355-5	1.25	.79
b.) 4 x 4-in. Bar (see page 35)			
1.) With 7-1/2 x 8-in. riser, 12-in. length; sound	353-1	1.46	1.84
With 7-1/2 x 8-in. riser, 14-in. length; unsound	349-1		
c.) 1/2-in. Thick Plate (see pages 32 and 33)			
1.) 1/4-in. x 1-1/8-in. Semicircular casting, sound	364-1	1.41	.66
2.) 1/4-in. x 1-1/2-in. Semicircular casting, unsound	363-4	1.54	.60
3.) 1/4-in. x 1-1/4-in. Semicircular casting, sound	422-1	1.58	.86
d.) 1/2-in. Thick Plate (see pages 29, 30 and 31)			
1.) 1/2 x 2-1/4-in. Semicircular casting; sound	363-2	1.42	.67
2.) 1/2 x 2-1/2-in. Semicircular casting; unsound	357-1	1.38	.54
3.) 1/2 x 2-1/4 x 4-1/2-in. casting; unsound	364-3	1.49	.66
4.) 1/2 x 4-in. Semicircular casting (3-in. Riser) sound	345-1	2.44	1.69
1/2 x 4-in. Semicircular casting (1-7/8-in. Riser) unsound	338-1	1.57	.41

TABLE II (CONCLUDED)

FEEDING DISTANCE FOR 3.6%C, 2.5% Si DUCTILE IRON
(See Appendix Pages Noted Below For Confirmatory Data)

	Cstg. No.	F.R.	V.R.
e.) 1-in. Thick Plate (see pages 25, 26, 27, and 28)			
1.) 1 x 4-1/2-in. Semicircular casting; sound	422-4	1.41	.67
2.) 1 x 5-in. Semicircular casting; unsound	338-2	1.39	.54
3.) 1 x 4-1/2 x 9-in. casting; unsound	422-6	1.50	.67
f.) 2-in. Thick Plate (see page 35)			
1.) 2 x 6 x 9-in. casting - sound (6-in. Riser)	360-1	1.56	1.58
2 x 6 x 9-in. casting - sound (4-3/4-in. Riser)	363-1	1.42	.78
2.) 2 x 6 x 10-in. casting - unsound (6-in. Riser)	359-1	1.54	1.42

With the availability of these data the risering of a given casting employing side blind risers may now be calculated quantitatively. Top risering should receive study in the future.

The chemical analyses of all heats are given in Appendix A, and a complete tabulation of all castings made appear in Appendix B.

C. Miscellaneous Data

During the course of the investigation it seemed advisable to determine the location of the eutectic to make certain that the analyses under study were not hypereutectic and hence subject to graphite flotation. Cooling curves were obtained using the technique illustrated in Fig. 7 for a number of heats. It is evident from Figs. 8a, b, and 9 and Table III that all the irons were hypoeutectic and that the analysis of the ferrosilicon can affect supercooling.

TABLE III

SUMMARY OF COOLING-CURVE DATA

Heat Number	Analysis, % T.C.	Si	C.E.	Temperature, °F Liquidus	Eutectic	Eutectoid
Heats inoculated with foundry-grade 85% ferrosilicon containing approximately 1.50% Al, 0.50% Ca						
247	3.53	1.92	4.17	2135	2110	1310
249	3.62	1.98	4.28	2130	2110	1320
253	3.50	2.48	4.33	2115	2110	1335
295	3.56	2.51	4.40	none	2120	1330

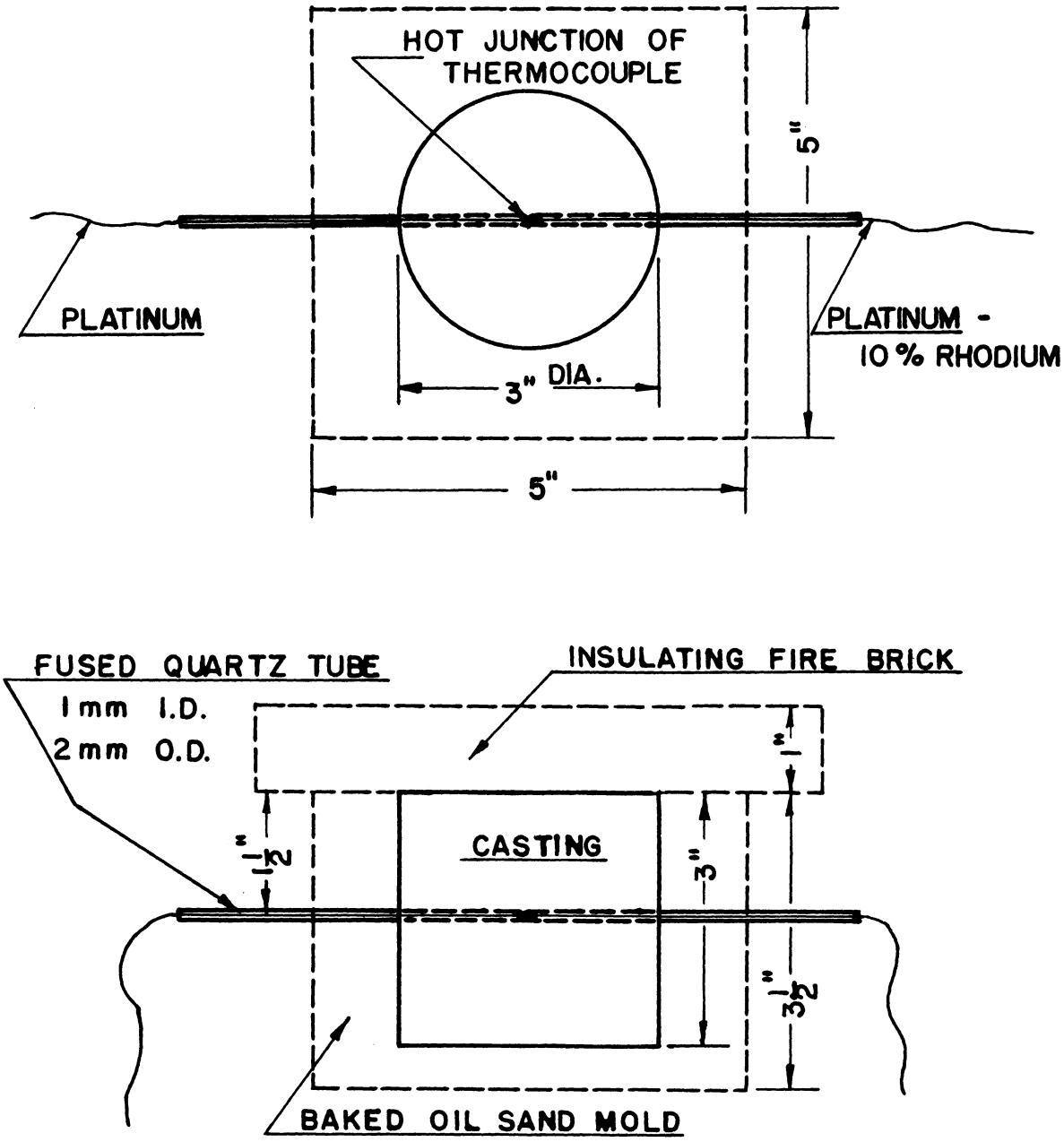


FIG. 7. SPECIMEN AND MOLD
FOR COOLING CURVE DETERMINATION

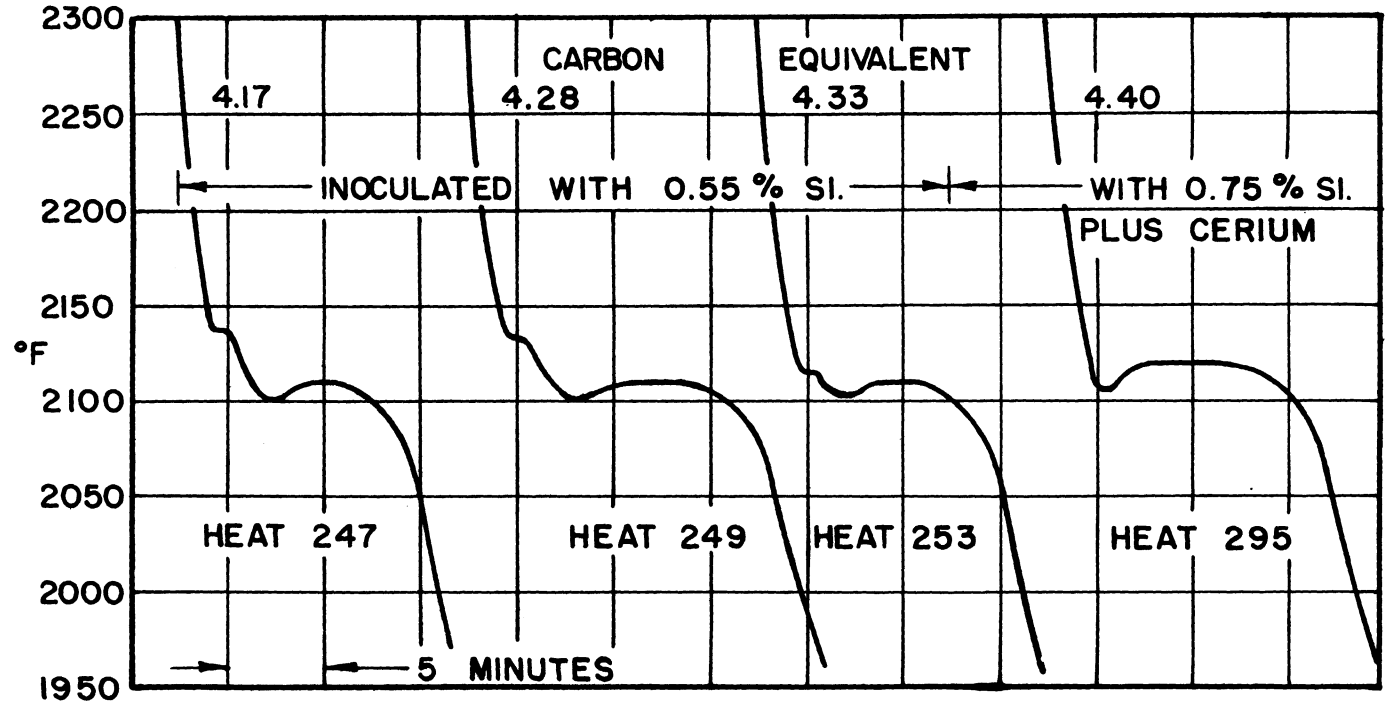


FIG. 8A. COOLING CURVES OF HEATS INOCULATED WITH FOUNDRY-GRADE FERROSILICON.

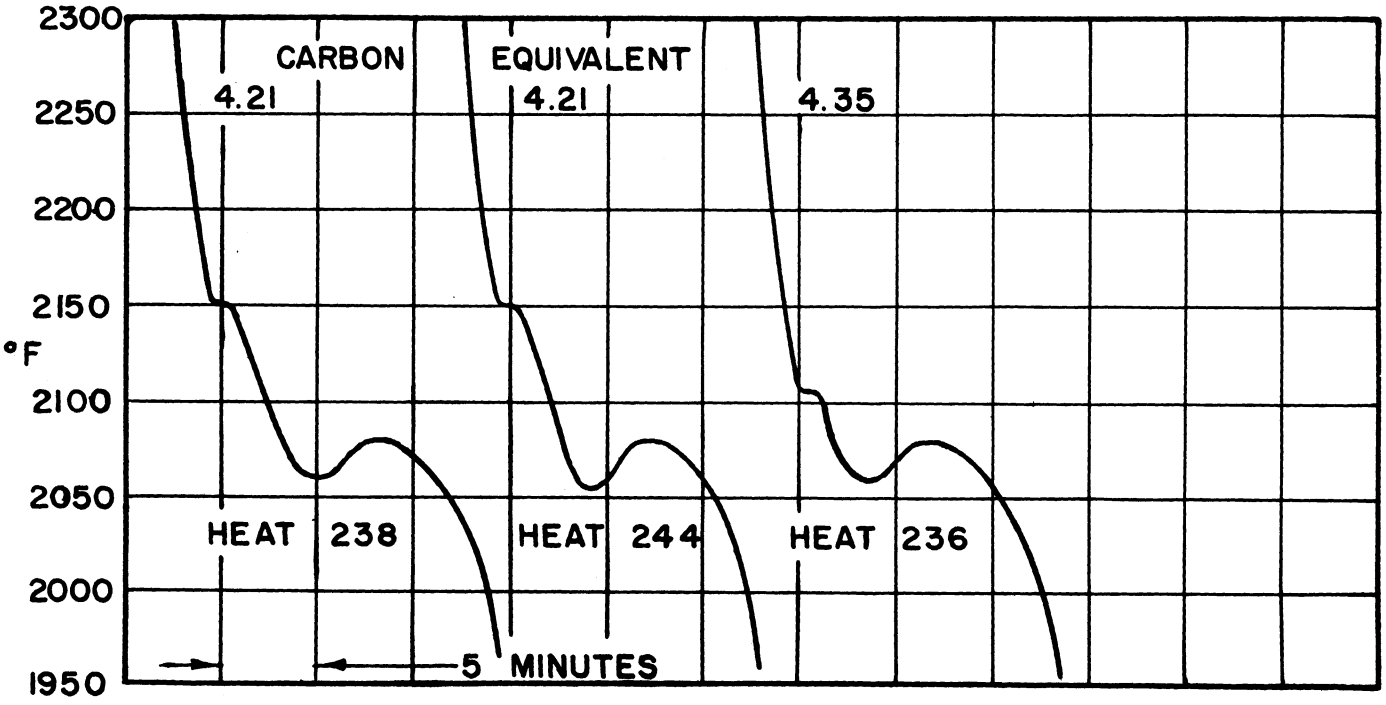


FIG. 8B. COOLING CURVES OF HEATS INOCULATED WITH LOW-AL FERROSILICON

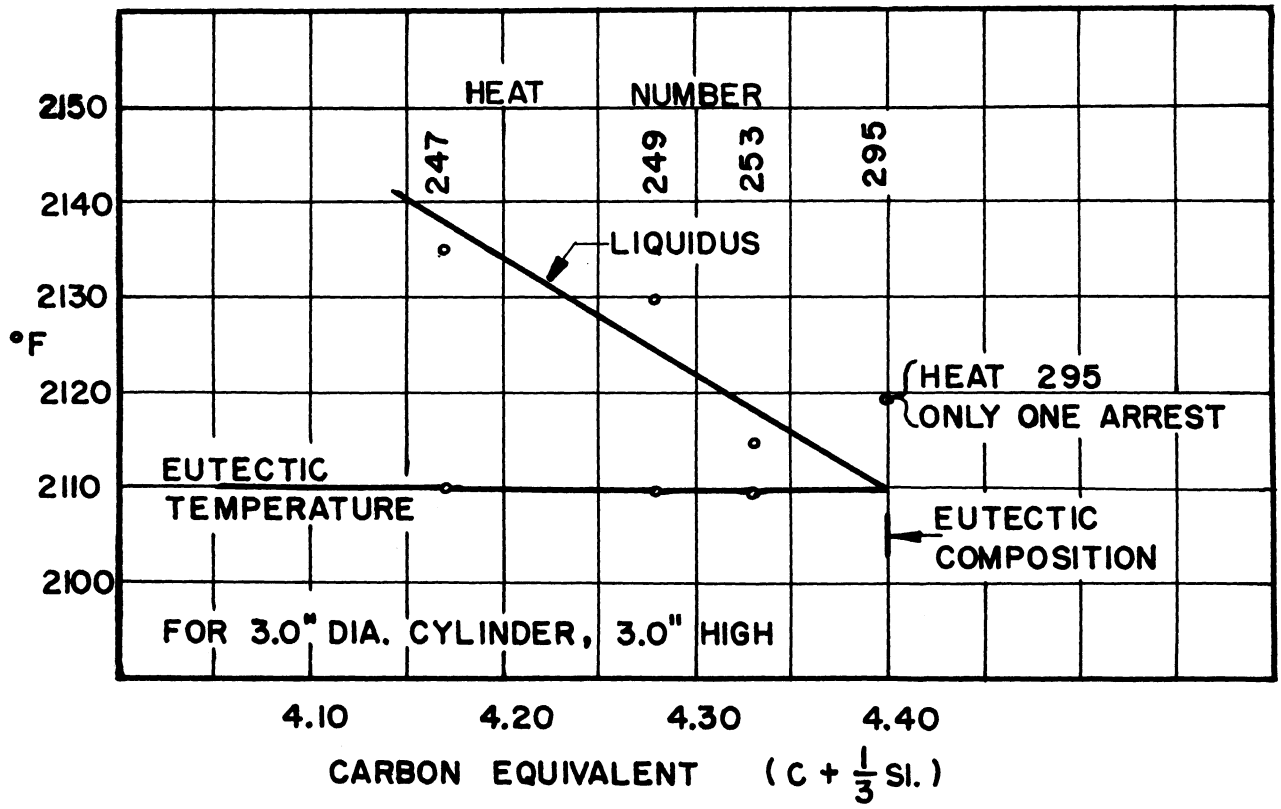


FIG. 9. COMPOSITE PLOT OF LIQUIDUS AND SOLIDUS TEMPERATURES TO LOCATE EUTECTIC COMPOSITION, AND EUTECTIC TEMPERATURE.

TABLE III (CONCLUDED)

SUMMARY OF COOLING-CURVE DATA

Heat Number	Analysis, % T.C.	Si	C.E.	Temperatures, °F Liquidus	Eutectic	Eutectoid
	Heats inoculated with low - aluminum ferrosilicon					
236	3.70	1.95	4.35	2105F	2080F	1320F
238	3.60	1.82	4.21	2150	2080	1310
244	3.65	1.68	4.21	2150	2080	1310

V. FUTURE WORK

For further understanding of ductile-iron risering and to insure maximum utility of the data already obtained, the following research seems indicated.

(1) Apply these risering data to test castings under laboratory conditions and evaluation of results.

(2) Establish risering curve for top risers, insulated and uninsulated.

(3) Determine whether any shift in risering curve or feeding distance is encountered when the ferrosiliconmagnesium-cerium alloy, now in common use, is employed. In general much lower chilling tendency has been noted with this inoculant, and the higher graphitization may decrease shrinkage.

(4) Examine risering conditions in very light (1/8-inch) sections such as are encountered in piston rings and other potential automotive uses.

APPENDICES

APPENDIX A

SUMMARY OF ANALYSES OF ALL HEATS

Heat No.	T.C.	Si	Mn	P	Mg	Date Cast
236	3.70	1.95	.28	.021		June 9, 1953
238	3.60	1.82	.25	.027		June 12, 1953
244	3.65	1.68	.24	.027		June 19, 1953
247	3.53	1.92	.27	.023		June 25, 1953
249	3.62	1.98	.31	.026		June 30, 1953
251	3.65	1.83	.30	.025		July 8, 1953
253	3.50	2.48	.22	.038		July 20, 1953
254	3.57	2.69	.31	.030		July 23, 1953
256	3.44	2.38	.24	.034		July 28, 1953
295	3.56	2.51	.32	.035	.067	Sept. 11, 1953
325	3.59	2.44	.23	.040	.080	Oct. 23, 1953
338	3.54	2.66	.34	.013	.075	Nov. 12, 1953
345	3.60	2.66	.31	.013	.082	Nov. 19, 1953
348	3.47	2.62	.30	.042	.080	Nov. 27, 1953
349	3.64	2.76	.26	.034	.090	Nov. 27, 1953
352	3.62	2.58	.19	.060	.080	Dec. 5, 1953
353	3.61	2.45	.18	.035	.070	Dec. 12, 1953
354	3.61	2.46	.19	.035	.080	Dec. 12, 1953
355	3.60	2.59	.18	.027	.090	Dec. 19, 1953
357	3.57	2.41	.17	.022	.070	Jan. 9, 1954
359	3.62	2.51	.22	.027	.110	Jan. 16, 1954
360	3.56	2.38	.29	.027	.070	Jan. 26, 1954
363	3.58	2.69	.23	.029	.090	Feb. 12, 1954
364	3.72	2.70	.22	.024	.080	Feb. 13, 1954
422	3.64	2.72	.20	.022	.084	Apr. 5, 1954

APPENDIX B

SUMMARY OF CASTINGS MADE SINCE FIRST PROGRESS REPORT

High - 3.9C, 2.5 Si
Int - 3.6C, 2.5 Si
Low - 3.6C, 1.8 Si

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
2-in.-Diameter x 3-3/4-in.-Long Casting					
2-3/8	1-5/16 half circle x 7/16.	Clamped	220-6	Low	Riser shrink 2-5/8-in. *
2-3/8	1-7/8 half circle x 7/16.	Clamped	236-6	Low	Riser shrink 2-5/8-in. *
2-1/2	1-7/8 half circle x 7/16.	Clamped	238-6	Low	Riser shrink 2-1/4-in. *
2-5/8	7/8 x 1-3/4 x 7/16 rounded and padded	Clamped	244-6	Low	Riser shrink 2-3/16-in. *
2-5/8	7/8 x 1-3/4 x 7/16	Clamped	249-6	Low	Uncertain; halves X-rayed
2-3/4	15/16 x 1-7/8 x 7/16	Clamped	251-6	Low	Uncertain; halves X-rayed
2-5/8	7/8 x 1-3/4 x 7/16 rounded and padded	Clamped	254-5	Int.	Centerline shrink 3/8-in.
2-1/2	7/8 x 1-3/4 x 7/16 rounded and padded	Clamped	256-6	Int.	Centerline shrink 1/4-in.
2-3/4	15/16 x 1-7/8 x 15/32	Clamped	295-6	Int.	Centerline shrink 3/16-in.
2-3/4	1 x 2 to 2-3/4 x 3/8 side blind	Clamped	252-2	Int.	Completely sound; X-ray
2-5/8	1 x 2 to 2-5/8 x 3/8 side blind	Clamped	355-2	Int.	3/16-in. riser shrink; X-ray

* Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
4-in.-Cube Casting					
4-3/8	1-7/16 x 2-7/8 x 11/16	Clamped	220-7	Low	Riser shrink 2-13/16-in. *
4-3/8	1-7/16 x 2-7/8 x 11/16	Clamped	236-7	Low	Riser shrink 1-1/4-in. *
4-1/2	1-1/2 x 3 x 3/4	Clamped	238-7	Low	Surface shrink at neck *
4-1/2	1-1/2 x 3 x 3/4	Clamped	244-7	Low	Surface shrink at neck *
4-1/2	1-1/2 x 3 x 3/4	Clamped	295-7	Int.	Surface shrink 1/8-in.
4-1/2	1-1/2 x 3 x 3/4	Clamped	325-4	Int.	Surface shrink
4-5/8	1-5/8 x 3-1/8 x 3/4	Clamped	338-4	Int.	Surface shrink
4-1/2	2 x 4 x 3/4	Clamped	345-4	Int.	Completely sound; X-ray
4-3/8	2 x 4 x 3/4	Clamped	348-5	Int.	Riser shrink 5/8-in.; X-ray
2 x 2 x 6-in. Casting					
3-1/8	1-1/16 x 2-1/8 x 17/32	Clamped	220-5	Low	Riser shrink 13/16-in. *
3-1/8	1-1/16 x 2-1/8 x 17/32	Clamped	236-5	Low	Riser shrink 1-3/16-in. *
3-1/4	1-1/16 x 2-1/8 x 17/32	Clamped	238-5	Low	Surface shrink 1/32-in. *
3-1/8	1-1/16 x 2-1/8 x 17/32	Clamped	249-5	Low	Uncertain

*Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
3	1 x 2 x 1/2	Clamped	253-1	Int.	Completely sound; X-ray
3-1/8	1-1/16 x 2-1/8 x 17/32	Clamped	253-2	Int.	Not inspected
2-7/8	1 x 2 x 1/2	Clamped	254-6	Int.	Riser shrink 3/8-in.
3	1 x 2 x 1/2 End Blind	Clamped	325-2	Int.	Centerline shrink 1.0 in.
1 x 3 x 7-in. Casting					
2-1/2	7/8 x 1-3/4 x 7/16	Clamped	220-4	High	Riser shrink 1-1/8-in. *
2-1/2	7/8 x 1-3/4 x 7/16	Clamped	236-4	High	Riser shrink 1-1/16-in. *
2-5/8	7/8 x 1-3/4 x 7/16	Clamped	238-4	Low	Riser shrink 1-1/16-in. *
2-3/4	15/16 x 1-7/8 x 15/32	Clamped	244-5	Low	Riser shrink 1.0-in. *
2-3/4	15/16 x 1-7/8 x 15/32	Clamped	251-5	Low	Completely sound; X-ray
2-5/8	7/8 x 1-3/4 x 7/16	Clamped	249-4	Low	Riser shrink 1-1/4-in.; X-ray
2-1/2	7/8 x 1-3/4 x 7/16	Clamped	247-4	Low	Riser shrink 1-3/4-in. X-ray
2-1/2	7/8 x 1-3/4 x 7/16	Clamped	254-4	Int.	Riser shrink 1-3/16-in.; X-ray

*Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
2-5/8	7/8 x 1-3/4 x 7/16	Clamped 9x9 Flask	256-4	Int.	Completely sound; X-ray
2-5/8	7/8 x 1-3/4 x 7/16	Clamped 13 x 13 Flask	256-5	Int.	Completely sound; X-ray
2-1/2	1 x 2-1/2 x 3/8	Clamped 9x9 Flask	257-3	Int.	1/16-in. surface shrink
1 x 4-in. Semicircular Casting					
2-3/4	15/16 x 1-7/8 x 15/32	Clamped	295-5	Int.	{Riser zone 1-1/4 in. Centerline shrink 3/8-in.} X-ray
2-3/4	15/16 x 2-3/4 x 15/32	Clamped	325-1	Int.	Completely sound; X-ray
1 x 5-in. Semicircular Casting					
3	1 x 3 x 1/2	Clamped	338-2	Int.	{Riser zone 5/8-in. Centerline 1-3/4 in.} X-ray
2-7/8	1 x 2-7/8 x 7/16	Clamped	352-3	Int.	{Riser zone 1-1/4 in. Centerline shrink 5/8-in.} X-ray
2-3/4	1 x 2-3/4 x 7/16	Clamped	355-3	Int.	Riser zone 1-1/2 in. Centerline 3/8-in. surface shrink 3/32-in.
2-7/8	1 x 2-7/8 x 3/8	Weighted	357-4	Int.	Surface shrink 3/32-in.
2-7/8	1 x 1 to 2-7/8 x 3/8 Knock-off	Clamped	357-5	Int.	Riser zone 1-1/4 in. Centerline shrink 5/8-in.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1 x 6-in. Semicircular Casting					
3-1/4	1 x 3-1/4 x 9/16	Clamped	345-2	Int.	{Riser zone 1-1/2-in. Centerline shrink 1-3/4-in.} X-ray
1 x 5 x 10-in. Casting					
3-1/8	1 x 3-1/8 x 3/8	Clamped	357-6	Int.	{Riser zone 1-1/4 in. Centerline shrink 1.0 in.} X-ray
1 x 4-1/2-in. Semicircular Casting					
2-7/8	1 x 2-7/8 x 3/8	Clamped	360-2	Int.	5/16-in. Riser shrink
3	1 x 3 x 3/8	Clamped	363-3	Int.	Surface shrink due to too thick gate, riser froze over, not X-rayed
3	1 x 3 x 3/8	Clamped	364-4	Int.	9/16-in. Riser zone 1/16-in. Centerline shrink Atmospheric pressure core failed.
3	1 x 3 x 3/8	Clamped	422-3	Int.	Surface shrink (Riser froze over)
3	1 x 3 x 3/8	Clamped	422-4	Int.	Completely sound
3	1 x 3 x 3/8	Weighted	422-5	Int.	Riser zone 5/8-in; Centerline 3/8-in.
3-1/8	1 x 3 x 3/8	Clamped	422-2	Int.	Not inspected

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1 x 4-1/2 x 9-in. Casting					
3-1/4	1 x 3-1/4 x 3/8	Clamped	422-6	Int.	Riser zone 1-in. Centerline 1/8-in.
3/4 x 4 x 7-in. Casting					
2-1/8	3/4 x 1-1/2 x 3/8	Clamped	220-3	High	Riser shrink 1-1/2-in. Surface shrink 3/32-in.*
2-1/8	3/4 x 1-1/2 x 3/8	Clamped	236-3	High	Riser shrink 1-3/4-in. Surface shrink 3/64-in.*
2-1/4	3/4 x 1-1/2 x 3/8	Clamped	238-3	Low	Riser shrink 1-7/8-in. *
2-3/8	13/16 x 1-5/8 x 13/32	Clamped	244-4	Low	Riser shrink 1-15/16-in. Surface shrink 3/64 in. *
2-1/4	3/4 x 1-1/2 x 3/8	Clamped	247-3	Low	Riser shrink 3/8-in.
2-3/8	13/16 x 1-5/8 x 13/32 padded	Clamped	249-3	Low	Centerline shrink; X-ray
2-1/2	7/8 x 1-3/4 x 7/16 padded	Clamped	251-3	Low	Completely sound; X-ray
2-1/2	3/4 x 1-3/4 x 7/16	Clamped	251-4	Low	Centerline shrink; X-ray
2-1/4	3/4 x 1-1/2 x 3/8	Clamped	254-3	Int.	Riser zone 1 in. Centerline shrink; X-ray

*Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
2-3/8	13/16 x 1-5/8 x 13/32 padded	Clamped	256-3	Int.	Riser zone 1-1/2 in.; X-ray Less centerline than 254-3
3/4 x 4-in. Semicircular Casting					
2-3/8	3/4 to 13/16 x 1-5/8 x 13/32	Clamped	295-4	Int.	Riser zone 9/16-in.; X-ray Centerline shrink 15/16-in.
2-3/8	3/4 x 2-3/8 x 5/16	Clamped	357-2	Int.	{Riser zone 2.0 in. Centerline 1/2-in.} X-ray.
1/2 x 4 x 7-in. Casting					
1-5/8	1/2 x 1-1/8 x 1/4	Clamped	220-2	High	Unsound *
1-5/8	1/2 x 1-1/8 x 1/4	Clamped	236-2	High	Centerline shrink *
1-3/4	1/2 x 1-1/8 x 1/4	Clamped	238-2	Low	Centerline shrink *
1-7/8	5/8 x 1-1/4 x 5/16	Clamped	244-2	Low	Centerline shrink *
1-5/8	9/16 x 1-1/8 x 9/32 padded	Clamped	247-2	Low	Riser shrink 1/2-in. into casting
1-3/4	9/16 x 1-1/8 x 9/32 padded	Clamped	249-2	Low	Riser zone 1-1/4-in. Centerline 13/16-in.
1-7/8	5/8 x 1-1/4 x 5/16 padded	Clamped	251-2	Low	Slight centerline shrink; X-ray

*Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1-3/4	5/8 x 1-1/4 x 5/16 padded	Clamped	254-2	Int.	Centerline shrink; X-ray
1-7/8	5/8 x 1-1/4 x 5/16 padded	Clamped	256-2	Int.	Centerline shrink; X-ray
1/2 x 4-in. Semicircular Casting					
1-7/8	1/2 to 5/8 x 1-1/4 x 5/16	Clamped	295-3	Int.	{Riser zone 1-5/8-in. Centerline 3/4-in.} X-ray
1-7/8	1/2 x 1-7/8 x 5/16	Clamped	338-1	Int.	{Riser zone 1-3/4-in. Centerline 3/4-in.} X-ray
3	1/2 x 3 x 5/16	Clamped	345-1	Int.	Completely sound; X-ray
1/2 x 3-in. Semicircular Casting					
1-5/8	1/2 x 1-5/8 x 7/32	Clamped	348-1	Int.	{Riser zone 1-in. Centerline 1/4-in.} X-ray
1-3/4	1/2 x 1-3/4 x 7/32	Clamped	352-1	Int.	{Riser zone 7/8-in. Centerline 3/8-in.} X-ray *
1-3/4	1/2 x 1-3/4 x 7/32	Clamped	355-1	Int.	{Riser zone 7/8-in. Centerline 1/2-in.} X-ray **

*Inoculated with 0.75% Si.

**Inoculated with 0.55% Si.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1/2 x 2-1/2-in. Semicircular Casting					
1-1/2	1/2 x 1-1/2 x 9/32	Clamped	357-1	Int.	Riser zone 9/16-in. Centerline shrink 7/16-in. X-ray
1/2 x 2-1/4-in. Semicircular Casting					
1-1/2	1/2 x 1-1/2 x 1/4	Clamped	363-2	Int.	Completely sound
1-3/8	1/2 x 1-3/8 x 1/4	Clamped	364-2	Int.	3/16-in. Riser shrink no centerline shrink
1/2 x 2-1/4 x 4-1/2-in. Casting					
1-5/8	1/2 x 1-5/8 x 1/4	Clamped	364-3	Int.	3/4-in. Riser zone; 3/16-in. centerline
3/8 x 4 x 7-in. Casting					
1-1/4	3/8 x 7/8 x 3/16	Clamped	220-1	High	Riser plus centerline shrink 1-5/8-in. into casting *
1-1/4	3/8 x 7/8 x 3/16	Clamped	236-1	High	Riser zone 1/2-in. Centerline 2-3/8-in. *
1-3/8	3/8 x 7/8 x 3/16	Clamped	238-1	Low	Sound riser zone with centerline shrinkage *
1-1/2	1/2 x 1 x 1/4 padded	Clamped	244-1	Low	Sound riser zone with centerline shrink *

*Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1-1/4	7/16 x 7/8 x 7/32 padded	Clamped	247-1	Low	Riser shrink 9/16-in. into casting
1-3/8	7/16 x 7/8 x 7/32	Clamped	249-1	Low	Sound riser zone with centerline shrink; X-ray
1-3/8	1/2 x 1 x 1/4 padded	Clamped	254-1	Int.	Sound riser and edge zones with centerline shrink; X-ray
1-1/2	1/2 x 1 x 1/4 padded	Clamped	256-1	Int.	Sound riser and edge zones with centerline shrink; X-ray
3/8 x 3 x 6-in. Casting					
1-1/2	1/2 x 1 x 1/4 padded	Clamped	244-3	Low	Sound riser and edge zones with centerline shrink *
3/8 x 4-in. Semicircular Casting					
1-5/8	3/8 to 9/16 x 1-1/8 x 9/32	Clamped	295-2	Int.	{Riser zone 1-3/8-in. Centerline 1-1/2-in.} X-ray
1/4 x 4 x 7-in. Casting					
1	3/8 x 3/4 x 3/16 padded	Clamped	251-1	Low	Riser zone 3/4-in. Centerline shrink 2-11/16-in. X-ray

*Heats inoculated with low-aluminum ferrosilicon.

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
1/4 x 4-in. Semicircular Casting					
1-1/4	1/4 to 7/16 x 7/8 x 7/32	Clamped	295-1	Int.	Riser zone 1-3/8-in. Centerline shrink 2-1/8-in. X-ray
1/4 x 1-1/2-in. Semicircular Casting					
7/8	1/4 x 7/8 x 3/16	Clamped	363-4	Int.	Riser zone 3/16-in. Centerline shrink 7/16-in.
1/4 x 1-1/8-in. Semicircular Casting					
3/4	1/4 x 3/4 x 3/16	Clamped	364-1	Int.	Completely sound
1/4 x 1-1/4-in. Semicircular Casting					
7/8	1/4 x 7/8 x 3/16	Clamped	422-1	Int.	Completely sound
2 x 2 x 8-in. Casting					
4	1-3/8 x 2-3/4 x 11/16 padded	Clamped	254-7	Int.	Completely sound; X-ray
4	2 x 2 to 2-3/4 x 11/16	Clamped	338-3	Int.	Atmospheric pressure core broke, riser froze over, surface shrink.
4	2 x 2 to 2-3/4 x 11/16	Clamped	345-3	Int.	Completely sound; X-ray
2 x 2 x 9-in. Casting					
3-in. Dia. 3-3/4-in. High (open)	2 x 2 x 0	Clamped	251-7	Low	Unsound

APPENDIX B (CONTINUED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
4	2 x 2 to tangent x 11/16 Mold tilted	Clamped	348-4	Int.	Completely sound; X-ray
4	2 x 2 to tangent x 11/16	Clamped	352-4	Int.	Completely sound; X-ray
3-in. Dia. 4-in. High (Blind)	2 x 2 to tangent x 9/16	Clamped	355-5	Int.	{Riser zone 4-1/8-in. Centerline 3/8-in.} X-ray
2 x 2 x 10-in. Casting					
4	1-3/8 x 2-3/4 x 11/16 padded	Clamped	256-7	Int.	Completely sound; X-ray
4	1-3/8 x 2 to 2-3/4 x 11/16	Clamped	325-3	Int.	{Riser zone 3-3/8-in. Centerline shrink 3-1/2-in} X-ray
4	2 x 2 to tangent x 11/16	Clamped	352-5	Int.	Completely sound; X-ray
2 x 2 x 11-in. Casting					
4	2 x 2 to tangent x 11/16	Clamped	355-4	Int.	{Riser zone 5-in. Centerline shrink 1/4-in.} X-ray
2 x 2 x 12-in. Casting					
4	1-3/8 x 2-3/4 x 11/16 padded	Clamped	253-4	Int.	{Riser zone 4-7/8-in. Centerline 3-5/8-in.} X-ray
2 x 2 x 14-in. Casting					
4	1-3/8 x 2-3/4 x 11/16 padded	Clamped	253-3	Int.	{Riser zone 5-1/2-in. Centerline 4-15/16-in} X-ray

APPENDIX B (CONCLUDED)

Riser Diameter and Height, in.	Neck Dimensions, in.	Restraint	Heat and Casting Number	Carbon Equivalent	Soundness
4 x 4 x 14-in. Casting					
7-1/2-in. Dia. 8-in. High	4 x 4 to tangent x 1	Clamped	349-1	Int.	{Riser zone 6-1/4-in. Centerline shrink 2-1/4-in.} X-ray
4 x 4 x 12-in. Casting					
7-1/2-in. Dia. 8-in. High	4 x 4 to tangent x 1	Clamped	353-1	Int.	Completely sound; X-ray of 3/4-in. thick center slice.
2 x 6 x 12-in. Casting					
6	2 x 6 x 5/8	Clamped	354-1	Int.	{Riser zone 3-3/4-in. Centerline 1-1/4-in.} X-ray
2 x 6 x 10-in. Casting					
6	2 x 6 x 5/8	Clamped	359-1	Int.	{Riser zone 0.0-in. Centerline shrink 7-3/4-in} X-ray
2 x 6 x 9-in. Casting					
6	2 x 6 x 5/8	Clamped	360-1	Int.	Completely sound; X-ray
4-3/4	2 x 4-3/4 x 5/8	Clamped	363-1	Int.	Completely sound
4-5/8	2 x 4-5/8 x 5/8	Clamped	364-5	Int.	Surface shrink