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CAST IRON FOR LOCOMOTIVE-CYLINDER PARTS

BY

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By C. H. Strand

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PART 1

INVESTIGATION—METHODS AND RESULTS

I. INTRODUCTION

Frequent renewal of cylinder parts of locomotives results in greatly increased cost of maintenance to the railroads, and consequently the quality of the cast iron entering into their construction is a matter of paramount importance, particularly from the standpoint of wear. These parts include piston-valve bushings, piston-valve packing rings, piston-valve bull rings, cylinder bushings, piston packing rings, and piston-head or bull rings.

It was found that ordinary high-silicon cast iron gave unsatisfactory wear, particularly in modern superheater locomotives, and the tendency has been toward a harder and stronger iron.

At the request of the former U. S. Railroad Administration the Bureau of Standards has investigated the mechanical, chemical, and microscopical properties of a number of packing rings furnished with service-mileage records, as well as arbitration-test bars, chill-test specimens, and miscellaneous samples from different manufacturers. All of this material was cast iron such as used for the various cylinder parts. It was desired at the same time to review the previous work and specifications on this subject, to ascertain as far as possible the practices of the different foundries and to suggest such revision of existing specifications as would be warranted by the results of the present and of earlier investigations.

The samples, 131 in number, were furnished to the Bureau of Standards by the U. S. Railroad Administration. The first samples were received April 2, 1919, and the last September 26, 1919; they were numbered 1 to 131, inclusive, in order of receipt, and their identification marks and history are to be found in Table 1. In accordance with the policy of the Bureau of Standards, the names of the manufacturers are withheld. In the course of this paper the nine foundries are designated by the letters A to I, inclusive.

TABLE 1.—Identification and History of Material Received for Examination

No.	Manufacturer	Service record	Description
		Miles	
1-26, inclusive	B	93 000	26 pieces constituting a packing ring removed for purpose of this investigation after giving remarkably long service.
27	C	Never in service	A small piece of packing ring of iron claimed to give excellent results.
28	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Sept. 4, 1918.
29	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Sept. 10, 1918.
30	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Oct. 16, 1918.

TABLE 1—Continued

No.	Manufacturer	Service record	Description
		Miles	
31	A	Never in service	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Jan. 17, 1919.
32	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Feb. 4, 1919.
33	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Feb. 15, 1919.
34	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Feb. 20, 1919.
35	A	do	Broken arbitration-test bar representing packing ring and cylinder iron furnished for U. S. Railroad Administration engines. Tests were made in presence of U. S. Railroad Administration inspector, Mar. 10, 1919.
36	A	do	Piece of cylinder packing ring, stamped contract B 1492, for use on U. S. Railroad Administration engines.
37	A	do	Piece of cylinder bushing blank, stamped contract B 1500, for use on U. S. Railroad Administration engines.
38	A	do	Piece of cylinder bushing blank, order 201, for use on U. S. Railroad Administration engines.
39	A	do	Piece of valve-chamber bushing blank, order 201, for use on U. S. Railroad Administration engines.
40	A	do	Piece of packing ring, order 201, for use on U. S. Railroad Administration engines.
41	A	do	Do.
42–43, inclusive	D	17 504	Two entire packing rings in service from May 22, 1918, to Dec. 15, 1918, on a Mikado or 2–8–2 superheated steam locomotive.
44–46, inclusive	C	Never in service	Three new packing rings intended for a superheated engine.
47	C	Apparently in service but no record furnished.	Small piece of packing ring which had apparently been in service.
48–49, inclusive	A	28 988	Two entire packing rings which made "fair" service on engine 5107, Pacific type, superheated.
50–55, inclusive	E	1516	Pieces of packing ring giving poor service on Pacific type engine 5116, superheated.

TABLE 1—Continued

No.	Manufacturer	Service record	Description
		Miles	
56	B	11 251, 20 670, 30 793 Average 20 905	Piece of packing ring, stamped 19, from engine using saturated steam.
57	F	5349, 4324, 6085 Average 5253	Piece of packing ring, stamped No. 39, from engine using superheated steam. Scotch iron.
58	F	10 183, 10 798, 8824 Average 9935	Piece of packing ring, stamped No. 47, from engine using superheated steam. Common iron.
59	F	22 905, 14 938 Average 18 921	Piece of packing ring, stamped No. 16, from engine using saturated steam. Common iron.
60	G	11 012, 30 427 Average 20 719	Piece of packing ring, stamped No. 25, from engine using saturated steam. Common iron.
61	G	16 918, 21 610, 11 251 Average 16 593	Piece of packing ring, stamped No. 27, from engine using saturated steam. Common iron.
62	G	7386, 6050 Average 6718	Piece of packing ring, stamped No. 55, from engine using superheated steam.
63	A	15 576, 15 943, 6832 Average 12 484	Piece of packing ring, stamped No. 33, from engine using superheated steam.
64–69, inclusive	D	Never in service	Six untested arbitration bars of packing-ring iron.
70–75, inclusive	D	do	Six chill-test blocks of packing-ring iron.
76–81, inclusive	C	do	Six untested arbitration bars of packing-ring iron.
82–87, inclusive	A	do	Do.
88–93, inclusive	A	do	Six chill-test blocks of packing-ring iron.
94–99, inclusive	B	do	Six untested arbitration bars of packing-ring iron. Rough castings.
100–103, inclusive	B	do	Four chill-test blocks of packing-ring iron.
104–109, inclusive	H	do	Six untested arbitration bars of packing-ring iron.
110–113, inclusive	H	do	Four chill-test blocks of packing-ring iron.
114–117, inclusive	I	10 000	Four pieces from packing ring from engine 2503.
118–121, inclusive	I	12 000	Four pieces from packing-ring iron, engine 2918, passenger service, using superheated steam.
122–127, inclusive	I	32 000	Six pieces of packing-ring iron, engine 2943, passenger service, using superheated steam.
128–131, inclusive	I	Never in service	Four untested arbitration test bars of packing-ring iron.

II. PREVIOUS WORK

This Bureau thought it desirable to study the previous work upon this subject, and to that end made a survey of the literature. The U. S. Railroad Administration furnished the Bureau with the results of mechanical tests and chemical analyses of a number of melts of air-furnace iron (foundry A) and also with considerable interesting information on the foundry practice of several of the makers whose products were tested in this investigation and on the service-mileage records of packing rings.

1. REVIEW OF LITERATURE

The most noteworthy contributions to this subject are in the Proceedings of the American Railway Master Mechanics' Association, now the mechanical section of the American Railroad Association. Their original specification, adopted in 1906, required the chemical composition to be within the following limits: Graphitic carbon, 2.75 to 3.25 per cent; combined carbon, 0.50 to 0.70 per cent; silicon, 1.25 to 1.60 per cent; sulphur, 0.06 to 0.10 per cent; phosphorus, 0.50 to 0.80 per cent; manganese, 0.30 to 0.60 per cent. The mechanical requirements of the same specification were a minimum tensile strength of 25 000 pounds per square inch, a minimum transverse breaking load of 3000 pounds, and a minimum deflection of 0.10 inch on the standard 1¼-inch arbitration bar of the American Society for Testing Materials.

The above specifications have undergone several revisions, until their present mechanical and chemical requirements are as indicated in Table 2. In the more recent specifications the composition of the iron is for the most part left to the foundryman, as greater dependence is placed upon the results of the transverse test. A stronger iron is required than in the earlier days.

TABLE 2.—Chemical and Mechanical Characteristics of Cast Iron for Cylinder Parts

[1918 Specifications, American Railway Master Mechanics' Association]

Chemical requirements:		
Phosphorus, maximum	per cent	0.70
Sulphur, maximum	do	.12
Transverse tests, 1¼-inch round bar, 12-inch supports:		
Strength (castings ⅝ inch or less thick), minimum	pounds	3200
Strength (castings over ⅝ inch thick), minimum	do	3500
Deflection (both cases), minimum	inch	.09
Chill in 1¾ by 2 inch block:		
For castings ⅝ inch or less thick, minimum	do	1/16
For castings over ⅝ inch thick	do	⅛

In 1916 a committee of the American Railway Master Mechanics' Association [1] appointed to investigate cast iron for cylinder parts reported in part as follows:

> That gun iron (air-furnace iron) is generally considered to be efficient, economical, and for these reasons desirable, can not be doubted, considering the fact that 80 per cent of the roads reporting are using this product in their superheater locomotives for some of the parts mentioned; therefore, the committee does not hesitate to recommend its use for piston-valve bushings, piston-valve packing rings, and pistons or piston bull rings.

[1] Proc. Am. Railway Master Mechanics Assoc., 49, p. 234; 1916.

Moldenke [2] offers the following explanation of the origin of the term "gun iron":

This is essentially an air-furnace iron, and, having been put into cast-iron guns from the earliest times, has retained that appellation. At present this grade of metal is used for the most important classes of work, and, being expensive to produce, only the best of pig irons enter into it as a rule.

With regard to cast iron for locomotive cylinders, Moldenke [3] remarks:

For the latest type of compound engines operated with superheated steam at very high temperatures only the very best of irons should be used, and preferably melted in the air furnace. The metal must be strong and sound, as otherwise leaks develop, which cause loss of power to a serious extent. Moreover, the iron is under very high temperatures and, unless low in graphite, will give serious trouble from "growing."

Hurst [4] has published an interesting paper, which, however, deals mostly with cast iron for cylinders and pistons for internal combustion engines, where the temperatures are considerably higher than in superheated steam locomotive cylinders.

2. DATA FURNISHED BY U. S. RAILROAD ADMINISTRATION

(*a*) Foundry Practice.—The U. S. Railroad Administration advised this Bureau that of the nine foundries supplying material for this investigation, A is the only maker which used the air furnace; all others use the cupola process, as far as could be ascertained.

The cupola is a vertical-shaft furnace lined with refractory material; an opening is provided in the side of the furnace near the top for charging fuel and iron. An air blast is introduced near the bottom, where the molten metal is tapped. In this process of manufacture the iron is in intimate contact with the fuel and absorbs from it such objectionable impurities as sulphur. The air furnace, on the other hand, is of the reverberatory type, and the fire is at one end and the chimney at the other end of the hearth. The flame sweeps across the furnace and furnishes the heat necessary to melt the metal. It is obvious that the iron and fuel are not in as close contact as in the cupola. Other methods of melting in use by the gray-iron foundry are the crucible, the open-hearth, and the electric furnace. As no very considerable percentage of gray-iron castings are made by any of these processes, they are not described in this paper. The electric furnace, however, is rapidly coming to the foreground in the iron foundry.

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[2] Richard Moldenke, Principles of Iron Founding, p. 191; 1917. McGraw Hill Book Co.

[3] Principles of Iron Founding, p. 193; 1917.

[4] J. E. Hurst, Growth of Cast Iron by Repeated Heating, Proc. Staffordshire Iron and Steel Inst., **33**, pp. 26–54; 1918. Also, Foundry, **46**, pp. 227–229; 1918.

Manufacturer A, who, as previously stated, uses the air furnace, claims that no steel or ferroalloys are added for the purpose of furnishing strength and that no difficulty is experienced in obtaining a transverse strength of arbitration bar of 4000 pounds, or a tensile strength of 32 000 pounds per square inch; also that the sulphur content seldom exceeds 0.06 per cent. Foundry C states that his practice is to add 2 per cent of an 80 per cent ferrosilicon to approximately 4000 pounds of metal, also claiming that great care should be exercised in skimming and gating when pouring packing rings and bushings. Manufacturer D, who states that he uses 15 per cent of steel scrap in the cupola, furnishes the following additional information:

Cylinder and valve rings are made in the form of pot castings in green-sand molds. Piston-valve bushings are also cast in green-sand molds, and the steam ports are cored with the admission and the exhaust ports both on one core, and the mold is poured at the center. The cylinder bushings are cast on end with dry-sand molds, and the pouring of metal is done as rapidly as possible; the bushings are cast without steam ports.

(*b*) Tests Made by U. S. Railroad Administration.—One of the railroad inspectors tested samples from 23 casts of air-furnace iron made between July 15, 1918, and March 10, 1919, with the results shown in Table 3.

TABLE 3.—Results of Air-Furnace Iron Tests by U. S. Railroad Administration

Items determined	Average	Maximum	Minimum
Transverse strength of 1½-inch arbitration bar in pounds, using 12-inch supports	4300	4939	3583
Transverse modulus of rupture of arbitration bar, pounds per square inch	67 300	77 200	56 000
Deflection, inch	.117	.144	.089
Tensile strength, pounds per square inch	33 400	38 000	27 000
Total carbon, per cent	3.23	3.50	2.84
Graphitic carbon, per cent	2.38	2.73	1.94
Combined carbon, per cent	.84	1.02	.59
Silicon, per cent	1.26	1.57	.95
Sulphur, per cent	.052	.100	.036
Phosphorus, per cent	.39	.49	.30
Manganese, per cent	.40	.52	26

In these heats the strength of arbitration bar was below 4000 pounds in only two instances (3583 and 3720 pounds), and the sulphur content only twice exceeded 0.06 per cent (0.062 and 0.100 per cent).

Several of the railroads made service tests of packing rings, and these records, together with the samples, were kindly furnished

to the Bureau through the U. S. Railroad Administration. At this point it would, perhaps, be desirable to emphasize the fact that many other factors besides the quality of the iron have considerable bearing upon the results of these tests; such factors are design, lubrication, method of handling locomotive, level or hilly country, good and bad water districts, etc. As a consequence, these facts are to be borne in mind in endeavoring to establish a correlation between laboratory and service tests.

III. INVESTIGATION AT BUREAU OF STANDARDS

1. MECHANICAL TESTS

The mechanical tests made at the Bureau of Standards consisted of transverse, tension, hardness, and fracture of chill-test specimens furnished by the U. S. Railroad Administration.

(*a*) TRANSVERSE TESTS.—*Arbitration Bars.*—Thirty-four arbitration bars, ordered made in accordance with the American Society for Testing Materials standards, from six different manufacturers, were tested (Tables 4 and 5). The foundries were A, H, B, C, I, and D, the preceding order indicating the quality, the first-named being the highest in transverse strength in terms of the modulus of rupture in pounds per square inch. The bars from H showed a higher transverse breaking load in pounds than those from A, but, when the variation in diameter of bar is taken into consideration, the latter is found to be the stronger material. The bars from foundries C and D were unfortunately machined before testing, and, as a consequence, the average strength of the bar is decreased because of the absence of skin hardness. The iron from both sources, however, was of low strength, which fact was amply demonstrated by subsequent tests. The iron from foundry I was irregular in quality, while that from D and H was spongy.

TABLE 4.—Transverse Tests of Unmachined Arbitration Bars

[Span 12-inch, centrally applied load]

No.	Manufacturer	Diameter	Breaking load	Modulus of rupture	Maximum deflection
		Inches	Pounds	Lbs./in.^{2}	Inch
82	A	1.23	3836	63 000	0.117
83	A	1.22	3900	65 600	.110
84	A	1.23	4080	67 000	.122
85	A	1.22	4220	71 000	.136
86	A	1.22	4414	74 200	.132
87	A	1.23	4116	68 000	.132
Average		1.23	4094	68 100	.125

TABLE 4—Continued

No.	Manufacturer	Diameter	Breaking load	Modulus of rupture	Maximum deflection
		Inches	Pounds	Lbs./in.²	Inch
94	B	1.25	3600	56 300	0.101
95	B	1.27	4280	63 900	.138
96	B	1.25	4210	65 800	.137
97	B	1.25	3986	62 300	.119
98	B	1.27	4160	62 000	.124
99	B	1.25	3480	54 400	.095
Average		1.26	3953	60 800	.119
104	H	1.28	4320	63 000	.099
105	H	1.29	4320	61 500	.104
106	H	1.27	4260	63 600	.111
107	H	1.26	4250	64 900	.118
108	H	1.27	4360	65 100	.115
109	H	1.31	4430	60 200	.102
Average		1.28	4323	63 100	.108
128	I	1.25	4140	64 800	.125
129	I	1.27	2500	37 300	.075
130	I	1.26	3600	55 000	.104
131	I	1.27	3160	47 100	.097
Average		1.26	3325	51 100	.100

TABLE 5.—Transverse Tests of Machined Arbitration Bars

[Span 12-inch, centrally applied load]

No.	Manufacturer	Cross section		Breaking load	Modulus of rupture
		Width	Height		
		Inch	Inch	Pounds	Lbs./in.²
64	D	0.865	0.860	1604	45 100
65	D	.875	.873	1714	46 200
66	D	.856	.865	1580	44 400
67	D	.857	.858	1590	44 700
68	D	.864	.860	1794	50 800
69	D	.854	.859	1630	46 600
Average		.862	.862	1652	46 300
76	C	.854	.851	1850	53 800
77	C	.852	.853	1565	45 500
78	C	.854	.854	1864	53 800
79	C	.853	.852	1820	52 900
80	C	.852	.852	1830	53 200
81	C	.863	.850	1650	47 600
Average		.855	.852	1763	51 100

Packing Rings.—When the packing rings were sufficiently large in size, specimens for small transverse tests were machined from them, as indicated in Fig. 1. The reader is referred to Table 6 for the results of the tests, together with the service records.

It is not to be expected that these results will be similar to those on unmachined arbitration bars, because of the absence of skin or surface hardness. The rings from manufacturer A, which gave fairly good service, had a transverse strength of 48 900 pounds per square inch; B, 47 400 pounds per square inch; C, 46 800

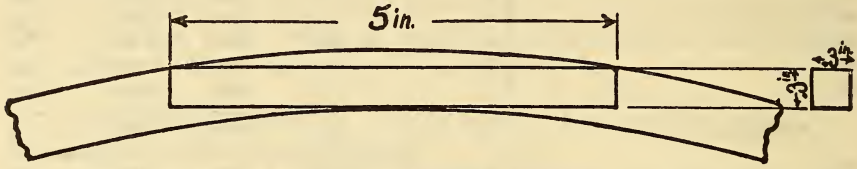

FIG. 1.—*Method of cutting small transverse test pieces from packing ring*

pounds per square inch; and D, 40 600 pounds per square inch. It is apparent from these tests that the transverse strength of the ring from foundry B, which gave the excellent service record of 93 000 miles, was not exceptional.

TABLE 6.—Transverse Tests of Packing Rings

[Span 4 inches, centrally applied load]

No.	Manufacturer	Cross section		Modulus of rupture	Maximum deflection	Service record
		Width	Height			
		Inch	Inch	Lbs./in.²	Inch	Miles
42	D	0.311	0.309	41 200	0.070	17 504
43	D	.308	.309	40 000	.073	17 504
Average				40 600		
44	C	.304	.307	45 300	.085	
44	C	.313	.307	44 400	.073	
45	C	.304	.305	53 500	.072	
45	C	.306	.306	44 600	.071	
46	C	.313	.312	45 300	.074	
46	C	.314	.313	42 900	.071	
47	C	.313	.308	51 800	.068	
Average				46 800		
48	A	.297	.312	50 000	.092	28 988
48	A	.312	.306	50 300	.074	28 988
49	A	.313	.308	46 500	.077	28 988
Average				48 900		
2	B	.298	.302	46 200	.071	93 000
24	B	.287	.292	47 100	.073	93 000
56	B	.276	.312	48 900	.070	20 905
Average				47 400		

(*b*) TENSION TESTS.—*Arbitration Bars.*—After breaking the arbitration bars in the transverse tests the broken pieces were used to determine the tensile strength of the material. The results of the tests of the products of six of the foundries are summarized

in Table 7. The iron from A, as in practically all of the tests, showed some slight superiority, with an average tensile strength of 34 600 pounds per square inch. The others in order of decreasing strength were B, 33 500 pounds per square inch; I, 32 050 pounds per square inch; H, 30 700 pounds per square inch; D, 25 750 pounds per square inch; and C, 25 050 pounds per square inch.

TABLE 7.—Tension Tests of Arbitration Bars

No.	Manufacturer	Diameter	Tensile strength	No.	Manufacturer	Diameter	Tensile strength
		Inch	Lbs./in.²			Inch	Lbs./in.²
82	A	0.505	33 300	94	B	0.505	32 900
84	A	.503	35 900	97	B	.502	34 100
Average		.505	34 600	Average		.503	33 500
64	D	.501	24 300	106	H	.503	30 600
69	D	.505	27 200	108	H	.503	30 800
Average		.503	25 750	Average		.503	30 700
77	C	.505	26 200	128	I	.503	34 600
79	C	.505	23 900	129	I	.505	30 600
				130	I	.505	32 100
Average		.505	25 050	131	I	.503	30 900
				Average		.504	32 050

Packing Rings.—Tension tests were made from packing rings furnished by foundries A, B, F, and G, and the results, together with service records, are to be found in Table 8. The ring from foundry B, which gave excellent service, also had the highest tensile strength; namely, 25 450 pounds per square inch. The other rings, all of which gave poor results in the service tests, were likewise inferior in tensile strength. From these tests, at least, there appears to be some more or less definite relation between laboratory and service tests.

TABLE 8.—Tension Tests of Packing Rings

No.	Manufacturer	Diameter	Tensile strength	Service record
		Inch	Lbs./in.²	Miles
5	B	0.293	27 500	93 000
7	B	.300	23 400	93 000
13	B	.299	25 500	93 000
Average			25 450	
57	F	.505	18 500	5253
58	F	.505	18 500	9935
Average			18 500	
62	G	.505	21 900	6718
63	A	.501	16 700	12 484

(*c*) BRINELL HARDNESS TESTS.—*Arbitration bars.*—Brinell hardness tests, using a 10 mm ball with a pressure of 3000 kg, sustained for 30 seconds, were made on flat, longitudinal sections of the arbitration bars. Approximately one-fourth of an inch of material was removed by the shaper to obtain a surface for the Brinell tests. In Table 9 it will be seen that the iron from A was hardest, with a Brinell hardness numeral of 213, H and I next, each with a hardness of 211, and that C was softest, with a Brinell hardness numeral of 203. As there is a variation of only 10 points from the maximum to minimum hardness, it is concluded that, in view of the widely varying quality of the irons as indicated by other tests, the Brinell test does not satisfactorily measure the quality of iron for cylinder parts.

TABLE 9.—Brinell Hardness of Arbitration Bars

[3000 kg pressure for 30 seconds, 10 mm ball]

No.	Manufacturer	Brinell hardness numerals [a]	No.	Manufacturer	Brinell hardness numerals [a]
64	D	206	94	B	207
65	D	192	95	B	211
66	D	207	96	B	207
67	D	204	97	B	206
68	D	207	98	B	226
69	D	216	99	B	197
Average		205	Average		209
76	C	206	104	H	214
77	C	192	105	H	212
78	C	206	106	H	213
79	C	206	108	H	205
80	C	205	108	H	211
81	C	204	109	H	212
Average		203	Average		211
82	A	204	128	I	210
83	A	216	129	I	207
84	A	213	130	I	219
85	A	212	131	I	210
86	A	209			
87	A	226	Average		212
Average		213			

[a] Average of 3 determinations.

TABLE 10.—Brinell Hardness of Packing Rings, Bushings, Etc.

[3000 kg pressure for 30 seconds, 10 mm ball]

No.	Manufacturer	Brinell hardness numeral	Service record
			Miles
1	B	175	93 000
5	B	163	93 000
7	B	165	93 000
13	B	166	93 000
56	B	167	20 905
Average		167	
27	C	186	
44	C	159	
45	C	160	
46	C	163	
47	C	187	
Average		180	
36	A	175	
37	A	153	
38	A	155	
39	A	180	
40	A	170	
41	A	179	
48	A	161	28 988
49	A	170	28 988
Average		168	
42	D	133	17 504
43	D	160	17 504
Average		147	
51	E	146	1516
57	F	141	5253
58	F	159	9935
59	F	166	18 921
Average		155	
60	G	171	20 719
61	G	183	16 593
62	G	177	6718
Average		177	
114–117, inclusive	I	172	10 000
118–121, inclusive	I	158	12 000
122–127, inclusive	I	174	32 000
Average		168	

Packing Rings, Bushings, and Similar Parts.—The Brinell hardness tests of packing rings, bushings, etc. (Table 10), indicate that the castings themselves are considerably softer than the arbitration bars. This is undoubtedly due to the fact that the slower rate of cooling of the former results in a higher graphitic carbon content. This is particularly true of some of the samples from foundry A, which were cylinder bushings, having a considerably larger cross-sectional area than packing rings.

(*d*) Chill Tests.—Chill-test specimens were received from four foundries. Foundries A and H used the standard chill-test specimen of the American Society for Testing Materials, while B and D used specimens not standard in size. Details are shown in the drawings in Fig. 2. The specimens were broken at the Bureau of Standards, four to six samples of the product of each foundry having been submitted. The iron from makers A and D showed an average depth of chill of one-half an inch, and that from B and H had a chill of approximately one-fourth of an inch.

2. CHEMICAL COMPOSITION

(*a*) Arbitration Bars.—Chemical analyses were made of one of each of the arbitration bars (Table 11) from each of six foundries, except in the case of I, where two bars were analyzed because of

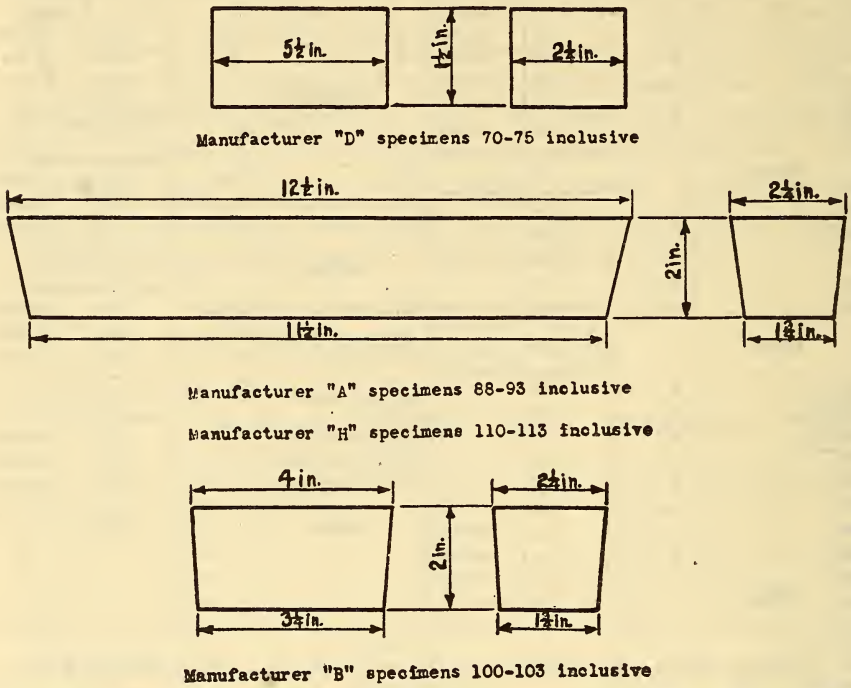

Fig. 2.—*Dimensions of three types of chill-test specimens from various manufacturers*

the widely varying mechanical properties, as shown in Table 4. The poor quality of the iron in specimen No. 129 (foundry I) is attributable to its high silicon content.

TABLE 11.—Chemical Composition of Arbitration Bars

No.	Manufacturer	Carbon			Silicon	Sulphur	Phosphorus	Manganese
		Total	Graph.	Combined				
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
64	D	3.36	2.55	0.81	1.42	0.093	0.48	0.61
77	C	3.36	2.40	.96	1.33	.167	.56	.39
84	A	3.30	2.39	.91	1.13	.051	.51	.36
94	B	3.30	2.50	.80	1.36	.124	.37	.90
106	H	3.32	2.42	.90	1.03	.137	.52	.54
128	I	3.26	2.37	.89	1.00	.161	.38	.63
129	I	3.31	2.66	.65	1.47	.132	.50	.53

The various bars were quite uniform in total, graphitic, and combined carbon content. The silicon and sulphur contents, however, varied within rather wide limits, the former from 1 per cent to 1.47 per cent (both samples from I) and the latter from 0.051 per cent (A) to 0.167 per cent (C). The iron from manufacturer B was the lowest in phosphorus content, with 0.37 per cent, and that from C was highest, with 0.56 per cent. Manganese varied from 0.36 per cent in the product from A to 0.90 per cent in the material from foundry B.

It is generally recognized that there should be at least three times the percentage of manganese as sulphur present; otherwise, sulphur will combine with iron instead of manganese, and brittle material will result. It will be observed that in the iron from C there is approximately only twice as much manganese as sulphur present. This condition, together with the high combined carbon content, accounts, in all probability, for the poor showing of this iron in the mechanical tests (Tables 5 and 7).

(*b*) Packing Rings, Bushings, and Similar Parts.—In general (Table 12), the silicon, and naturally the graphitic carbon, is higher in the packing rings, bushings, and similar castings than in the arbitration bars. The ring from B, which gave 93 000 miles in service, showed no unusual characteristics in chemical composition. The rings from foundry C were high in phosphorus and sulphur, as in the case of the arbitration bars. The castings from B were low in sulphur, and the ring which had a service record of 28 988 miles was rather low in combined carbon content. D's rings were high in sulphur and graphitic carbon. The latter condition (high graphitic carbon), of course makes too soft a ring for prolonged wear. The locomotive packing ring from foundry E, which gave a service of only 1516 miles, was very high in silicon (2.84 per cent), and consequently low in combined carbon (0.33 per cent). The rings from I (32 000 miles of service) were fairly low in graphitic carbon content.

TABLE 12.—Chemical Composition of Packing Rings, Bushings, Etc.

No.	Manufacturer	Carbon			Silicon	Sulphur	Phosphorus	Manganese	Service record
		Total	Graph.	Combined					
		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Miles
1	B	3.46	2.79	0.67	1.68	0.120	0.260	0.56	93 000
5	B	3.39	2.80	.59	1.67	.140	.260	.57	93 000
7	B	3.53	2.91	.62	1.67	.150	.250	.57	93 000
13	B	3.43	2.69	.74	1.69	.130	.250	.58	93 000
56	B	3.08	2.67	.41	1.70	.124	.825	.43	20 905
27	C	3.36	2.42	.94	1.47	.190	.310	.42	.....
44	C	3.57	2.88	.69	1.51	.130	.601	.51	.....
45	C	3.45	2.84	.61	1.95	.130	.582	.51	.....
47	C	3.44	2.87	.57	1.46	.136	.639	.56	.....
29	A	3.33	2.42	.91	1.21	.060	.250	.38	.....
36	A	3.24	2.40	.84	1.06	.071	.220	.24	.....
37	A	3.37	2.75	.62	1.24	.068	.260	.28	.....
38	A	3.31	2.90	.41	1.50	.068	.230	.54	.....
39	A	3.24	2.65	.59	1.21	.150	.220	.45	.....
40	A	3.31	2.56	.75	.85	.055	.220	.40	.....
41	A	3.28	2.55	.73	.87	.062	.210	.61	.....
48	A	3.46	2.91	.55	1.52	.062	.502	.45	28 988
63	A	3.51	2.84	.67	1.40	.102	.440	.38	12 484
42	D	3.47	3.12	.35	1.83	.151	.668	.56	17 504
43	D	3.50	3.10	.40	1.94	.165	.704	.55	17 504
50	E	3.34	3.01	.33	2.84	.068	.675	.55	1516
57	F	3.40	2.74	.66	1.58	.117	.410	.35	5253
58	F	3.24	2.73	.51	2.14	.119	.855	.32	9935
62	G	3.47	2.68	.79	1.33	.106	.380	.42	6718
116	I	3.22	2.53	.69	1.83	.112	.670	.34	10 000
117	I	3.11	2.54	.57	1.78	.116	.670	.34	10 000
118	I	3.16	2.54	.62	1.22	.140	.360	.52	12 000
121	I	3.29	2.53	.76	1.25	.140	.370	.52	12 000
122	I	3.35	2.57	.78	1.96	.087	.740	.44	32 000
125	I	3.38	2.76	.62	1.95	.091	.760	.43	32 000

3. METALLOGRAPHIC EXAMINATION

Specimens from packing rings made by B (No. 5, 93 000 miles), A (No. 48, 28 988 miles; No. 63, 12 484 miles), D (No. 42, 17 504 miles), G (No. 62, 6718 miles), and E (No. 50, 1516 miles) were examined microscopically.

The samples were polished and examined microscopically both before and after etching. Heat tinting was found to be very suitable for revealing the irregularly shaped masses of phosphide eutectic and at the same time allowing the black flakes of graphite to stand out clearly. Micrographs were taken only of typical

FIG. 3.—*Specimen No. 5*

Manufacturer "B" (93 000 miles service). Etched with 2 per cent nitric acid. ×100

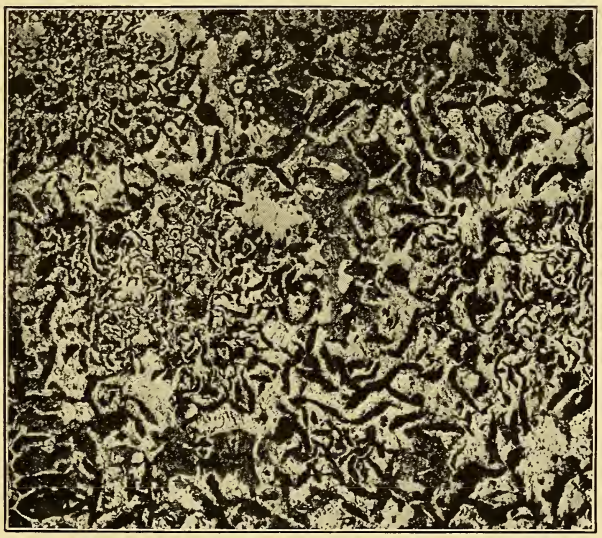

FIG. 4.—*Specimen No. 50*

Manufacturer "E" (1516 miles service). Etched with 2 per cent nitric acid. ×100

FIG. 5.—*Specimen No. 42*

Manufacturer "D" (17 504 miles service). Heat tinted. ×50

FIG. 6.—*Specimen No. 42*

Manufacturer "D" (17 504 miles service). Etched with 2 per cent nitric acid. ×100

samples selected for purposes of illustration. Fifty diameters magnification was used to show the size, distribution, and amount of graphite flakes, and 100 diameters to show the constitution of the matrix.

Some attempt was made to correlate the microstructure with the endurance in service, but, due to the many variable factors, it was realized that any very close comparisons were apt to be misleading. The inhomogeneity of cast iron made it somewhat doubtful that the small sample used for metallographic examination was representative of the whole. In some instances, however, with the aid of the principles governing the constitution of gray cast iron, the samples could be approximately classified, and the service records bore out fairly well the predictions that could be made of mechanical qualities from a study of the microstructure.

In Figs. 3 and 4 are shown samples Nos. 5 and 50 after etching with 2 per cent nitric acid. Fig. 3 is the microstructure of the ring which gave 93 000 miles of service, while Fig. 4 shows the ring which gave only 1516 miles' service. The difference between them is striking. In Fig. 3 the gray areas are pearlite, the pure white is ferrite, the irregular speckled masses are phosphide, and the large, black flakes are graphite. In Fig. 4 the white constituent, rather large in amount, is ferrite, the gray areas forming the easily visible network are pearlite, the irregular lighter-colored masses are phosphide, and the small, black flakes are graphite. As might be inferred from the chemical composition (No. 5, 0.59 per cent combined carbon; No. 50, 0.33 per cent combined carbon) the matrix of the former is largely pearlitic, with very little ferrite, while the reverse is true in the latter. The rate of cooling in the latter sample (No. 50) was the more rapid, and thus the finely divided condition of the graphite is to be explained. The very high silicon content of 2.48 per cent accounts for the high graphitic carbon content. This resulted in a soft iron, which, together with the physical unsoundness of the material as revealed by microscopical examination, accounted for the poor service record of 1516 miles. B's ring, on the other hand, while higher in combined carbon (pearlite) and lower in graphite or free carbon, under the microscope shows no explanation for the extraordinarily long service obtained.

The microstructure of the ring from D (No. 42, 17 504 miles) is shown in Figs. 5 and 6. While the combined carbon content is low the distribution of the various constituents is much more uniform than in Fig. 4. The ring, however, was too soft to give

good wearing qualities. In Fig. 7 is shown the structure of A's ring, sample No. 48, which gave 28 988 miles of service. It does not materially differ in microstructure from the other rings giving fair service; it is, in fact, as indicated by Brinell hardness test and chemical composition, somewhat too low in combined carbon for maximum wear. Fig. 8 shows the microstructure of a ring made by G (6718 miles). The distribution of the graphite is quite uniform, and from a metallographic point of view it is impossible to account for the poor results reported in service.

The microscope is most useful in determining the size, amount, and distribution of graphite flakes, amount of combined carbon, and to some extent the physical soundness of the castings.

IV. COMPARISON OF PROPERTIES OF AIR-FURNACE AND CUPOLA CAST IRON

From a study of the data given in the various tables of tests, it will be observed that the air-furnace iron is somewhat more uniform in character and of generally better quality than cupola iron. A comparison of the two kinds of iron, bearing out this conclusion, and which was computed from all tests of arbitration bars mentioned in this paper, is given in Table 13.

TABLE 13.—Properties of Air-Furnace Iron and of Cupola Cast Iron

Process of manufacture	Transverse test, modulus of rupture			Tensile strength		
	Average	Maximum	Minimum	Average	Maximum	Minimum
	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²	Lbs./in.²
Air furnace	67 500	77 200	56 000	33 500	37 500	27 000
Cupola	54 700	65 800	37 300	29 700	34 600	23 900

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions are drawn and recommendations made as follows:

1. On the basis of tests made by inspectors of the U. S. Railroad Administration and this Bureau, which were substantially in agreement, it is concluded that air furnace or so-called "gun iron" is more uniform in character and on the average of somewhat better mechanical properties than cupola iron. The latter, however, often equals or even excels in mechanical properties the specimens of air-furnace iron tested in this investigation. The sulphur content of the air-furnace irons examined seldom exceeded 0.06 per cent, while the cupola irons varied in sulphur content from 0.10 to 0.17 per cent.

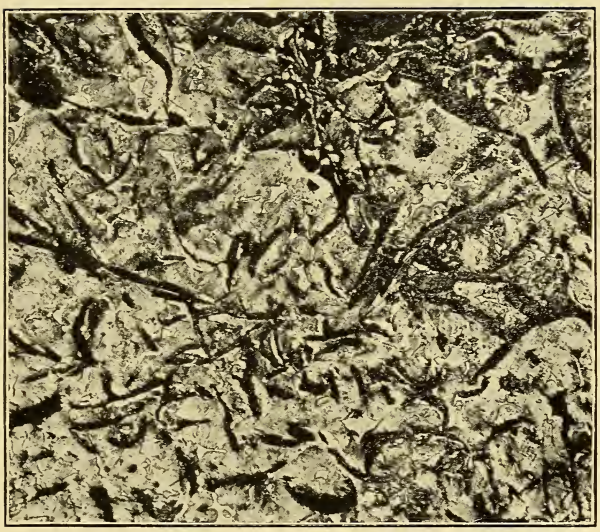

FIG. 7.—*Specimen No. 48*

Manufacturer "A" (28 988 miles service). Heat tinted. ×50

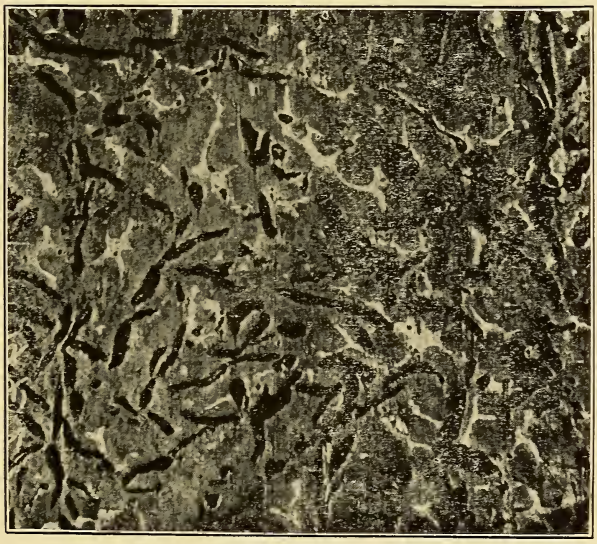

FIG. 8.—*Specimen No. 62*

Manufacturer "G" (6718 miles service). Heat tinted. ×50

2. The findings of the American Railway Master Mechanics' Association with respect to correlation of laboratory and service tests are confirmed in the present investigation. It was impossible, except in a very general way to find any correlation between the quality of the iron as developed by laboratory tests and the mileage obtained in service. This is explained by the fact that many other factors besides the quality of the iron enter into consideration in the service results; namely, design, lubrication, method of handling the locomotive, topography of the country, character of water used in locomotive, etc. The ring from foundry B, which gave the exceptionally good service of 93 000 miles, showed no unusual properties in laboratory tests. It is for the reasons cited above that the conclusions and recommendations of this paper are based essentially upon the results of laboratory tests.

3. The present specifications of the American Railway Master Mechanics' Association are somewhat lax in the requirements for mechanical properties. It is recommended that the transverse-strength requirements of 1¼-inch arbitration bar be increased from 3200 to 3500 pounds for castings one-half of an inch or less in thickness, and from 3500 to 3800 pounds for castings over one-half of an inch in thickness. It is further recommended that the minimum deflection requirements for both cases be increased from 0.09 to 0.11 inch. The division line of the casting thickness is changed from five-eighths of an inch of the American Railway Master Mechanics' Association, to one-half of an inch in order to conform to the recognized standards of the American Society for Testing Materials.

4. It is preferable to leave the chemical composition and the melting process used to the manufacturer, depending for the most part on the mechanical tests, and of these primarily upon the transverse test. The existing specifications allow a maximum of 0.70 per cent phosphorus and 0.12 per cent sulphur; there are no developments in this investigation which would warrant a revision of the maximum permissible amounts of these elements.

Acknowledgment is due to Capt. S. N. Petrenko and T. W. Greene for the mechanical tests and also to S. Epstein for the metallographic work. The cooperation of the chemistry division of the Bureau of Standards in making the chemical analyses is likewise acknowledged.

PART 2

PROPOSED SPECIFICATION[5] FOR CAST-IRON CYLINDER PARTS FOR LOCOMOTIVES

I. SCOPE

These specifications cover cast iron for piston-valve bushings, piston-valve packing rings, piston-valve bull rings, cylinder bushings, piston packing rings, and piston-head or bull rings.

II. MANUFACTURE

1. PROCESS

The castings shall be made from good quality close-grained iron.

III. CHEMICAL PROPERTIES AND TESTS

1. CHEMICAL COMPOSITION

Drillings taken from the fractured ends of the transverse-test bars shall conform to the following limits in chemical composition:

	Per cent
Phosphorus, not over	0.70
Sulphur, not over	.12

IV. PHYSICAL PROPERTIES AND TESTS

1. TRANSVERSE TEST

When placed horizontally upon supports 12 inches apart and tested under a centrally applied load, the arbitration-test bars specified in Section IV–3*a* shall show an average transverse strength of not less than 3500 pounds for castings one-half inch or less in thickness, and an average transverse strength of not less than 3800 pounds for castings over one-half inch in thickness; and the deflection for either thickness of material shall not be less than 0.11 inch. The rate of application of the load shall be from 20 to 40 seconds for a deflection of 0.10 inch.

2. CHILL TEST

Before pouring, a sample of the iron shall be taken and chilled in a cast-iron mold, as specified in Section IV–3*b*. The sample shall be allowed to cool in the mold until it is dark red or almost

[5] Prepared at the request of the U. S. Railroad Administration to embody the results of this and other investigations.

black, when it may be knocked out and quenched in water. The sample, on being broken, must show a close-grained gray iron, with a well-defined border of white iron at the bottom of the fracture. The depth of the white iron must not be less than one-sixteenth of an inch as measured at the center line, for castings one-half inch or less in thickness, nor less than one-eighth of an inch for castings over one-half inch in thickness.

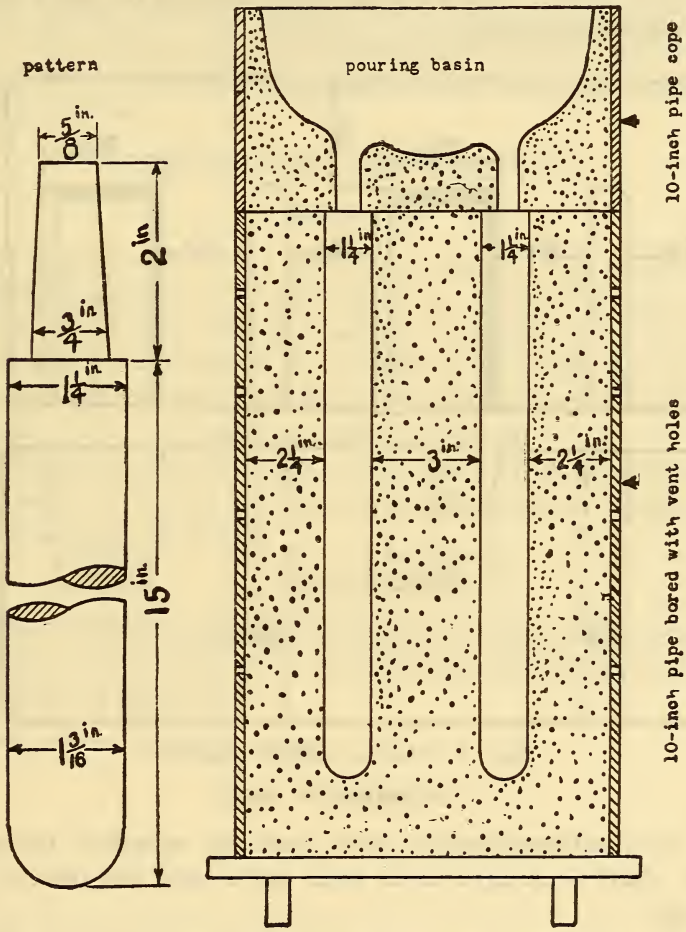

FIG. 9.—*Mold for arbitration test bar*

3. MOLDS FOR TEST SPECIMENS

(*a*) ARBITRATION BAR.—The mold for the bars is as shown in Fig. 9. The bottom of the bar is one-sixteenth of an inch smaller in diameter than the top to allow for draft and strain of pouring. The diameter of the test bar shall not vary more than 0.02 inch above or below the specified size. The flask is to be rammed up

with green molding sand, a little damper than usual, well mixed and put through a No. 8 sieve, with a mixture of 1 to 12 bituminous facing. The mold shall be rammed evenly and fairly hard, thoroughly dried, and not cast until it is cold. The test bar shall not be removed from the mold until it is cold enough to be handled. It shall not be rumbled or otherwise treated, being simply brushed off before testing.

(*b*) CHILL TEST.—The form and dimensions of the mold shall be in accordance with Fig. 10.

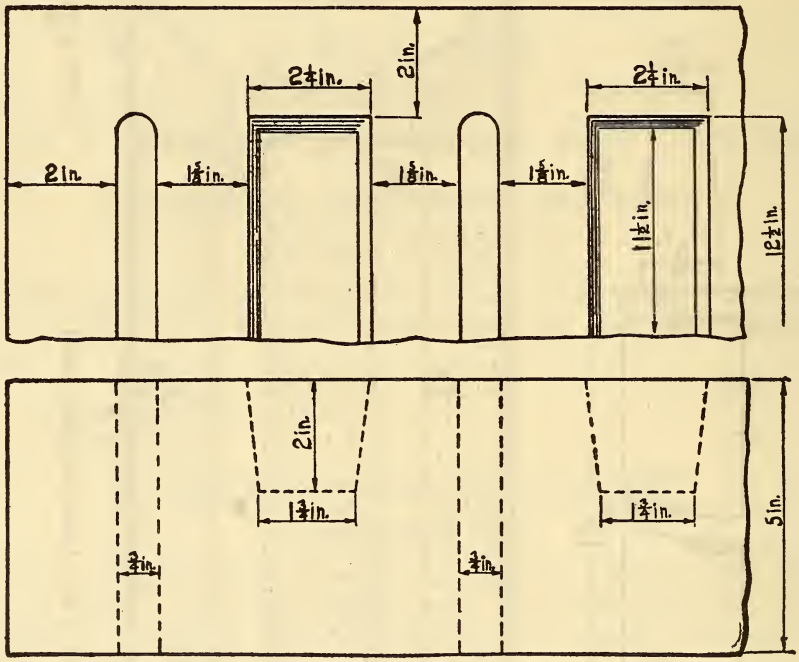

FIG. 10.—*Mold for chill-test specimen*

4. NUMBER OF TESTS

(*a*) Two arbitration-test bars, cast as specified in section IV–3*a*, shall be poured from each ladle used for one or more castings.

(*b*) One chill test, cast as specified in Section IV–3*b*, shall be poured from each ladle of metal used for one or more castings. The chill-test specimens may be cast in adjacent molds, but in such cases a space must be provided between the molds. (See Fig. 10.)

V. WORKMANSHIP AND FINISH

1. CHARACTER OF CASTINGS

Castings shall be smooth, well cleaned, free from shrinkage cracks and from other defects sufficiently extensive to impair their value, and must finish to blue-print size.

2. MARKING

Each casting when so specified shall have cast on it, in raised letters and figures, marks designating the maker, the date of casting, the serial and pattern numbers, and other marks specified by the purchaser.

VI. INSPECTION AND REJECTION

1. INSPECTION

(*a*) The purchaser, or his inspector, shall be given a reasonable opportunity to witness the pouring of the castings and test specimens, as well as to be present when the mechanical tests are made.

(*b*) In case the inspector is not present to witness the pouring of the castings and test specimens, the manufacturer will hold the latter for test by the inspector upon his arrival.

(*c*) Inspection shall be made at the place of manufacture, and the manufacturer shall also furnish the facilities for making the mechanical tests, if desired.

2. REJECTION

Unless otherwise specified, any rejection based on tests made in accordance with Section IV–1 shall be reported within five days from receipt of samples.

WASHINGTON, April 30, 1920.