U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

RESEARCH PAPER RP880

Part of Journal of Research of the National Bureau of Standards, Volume 16, April 1936

AN IMPROVED METHOD FOR PREPARING CAST-IRON TRANSVERSE TEST BARS

By A. I. Krynitsky and C. M. Saeger, Jr.

ABSTRACT

The importance of preparing cast-iron transverse-strength test bars free from "burnt-on" sand and surface defects is discussed. A molding material and casting technique which will produce such test bars in green-sand molds has been developed.

Test bars 0.75, 1.2, 1.5, and 2.2 inches in diameter and 23 inches in length were cast in top-poured and bottom-poured vertical molds, horizontal molds, and horizontally inclined molds. The effect of maximum heating temperature on the transverse breaking strength, hardness, primary structure, and microstructure of test bars made by these methods was investigated. Test bars cast in bottom-poured vertical molds yielded the most consistent results.

The transverse breaking strength of the irons investigated increased with an increase of the maximum heating temperature, regardless of the casting method employed. A finer primary structure and finer graphite and pearlite constituents were found to be associated with higher transverse strength.

CONTENTS

I. INTRODUCTION

In an investigation of the effect of maximum heating temperatures on the physical properties of different types of cast irons [1] [1] a method was developed at the National Bureau of Standards for making trans-

[1] Figures in brackets here and throughout the text indicate literature references given at the end of this paper.

verse-strength test bars in dry-sand molds. The Committees on Cast Iron of both the American Society for Testing Materials and the American Foundrymen's Association have expressed their interest in this subject and pointed out the desirability of extending the investigation to include a study of transverse-strength test bars made in green-sand molds.

It is well known that bars used for the determination of transverse strengths hould not only be free from "burnt-on" sand but should also have a smooth surface, since the breaking strength of a test piece may be seriously affected by the character of its surface. The removal of burnt-on sand by sand blasting or tumbling may leave the surface pitted or roughened, which condition may cause the bars to break under a relatively low load by the so-called "notch effect".

Many investigators are of the opinion that the surface layer on test bars should be removed by machining before the bars are tested. This point was strongly emphasized in the discussion of the paper entitled Relationship in Cast Iron Test Results [2]. It is believed by many investigators that the surface layer or so-called "surface skin" is the strongest part of the bar and, therefore, one should expect its removal to lower the transverse strength. It has been found [1] experimentally that the removal of the surface layer lowers the strength under transverse loading, although the results of some other investigators are not in agreement with this. However, surface defects, such as those mentioned earlier, might account for these results, which indicate the transverse strength of a bar with the surface skin removed to be stronger than a similar bar without the skin removed.

In this investigation an attempt was made to prepare test bars in green-sand molds having smooth surfaces free from burnt-on sand. Factors such as the horizontal or vertical position of the mold, the location and size of the gates and risers, the molding and facing materials, the permeability, strength and degree of ramming of the mold, and the temperature of the metal and rate at which it is poured into the molds, are important and should be considered in producing satisfactory test bars.

The investigation is naturally divided into two parts, the first, to develop a molding procedure which will yield satisfactory test bars when green-sand molds are used, and the second, to compare the results obtained on test bars produced by pouring (1) by the method developed at this Bureau and (2) by the three tentative methods specified by the American Society for Testing Materials [3].

II. MOLDING AND CASTING TECHNIQUE

A molding material to be suitable for this purpose must be such that it is possible to make satisfactory bars of various diameters with irons of various chemical compositions. It was felt that the molding material would be satisfactory if it yielded satisfactory test bars free from burnt-on sand and surface defects, when the following types of irons, and the following melting and casting procedure is used to produce bars of the following sizes.

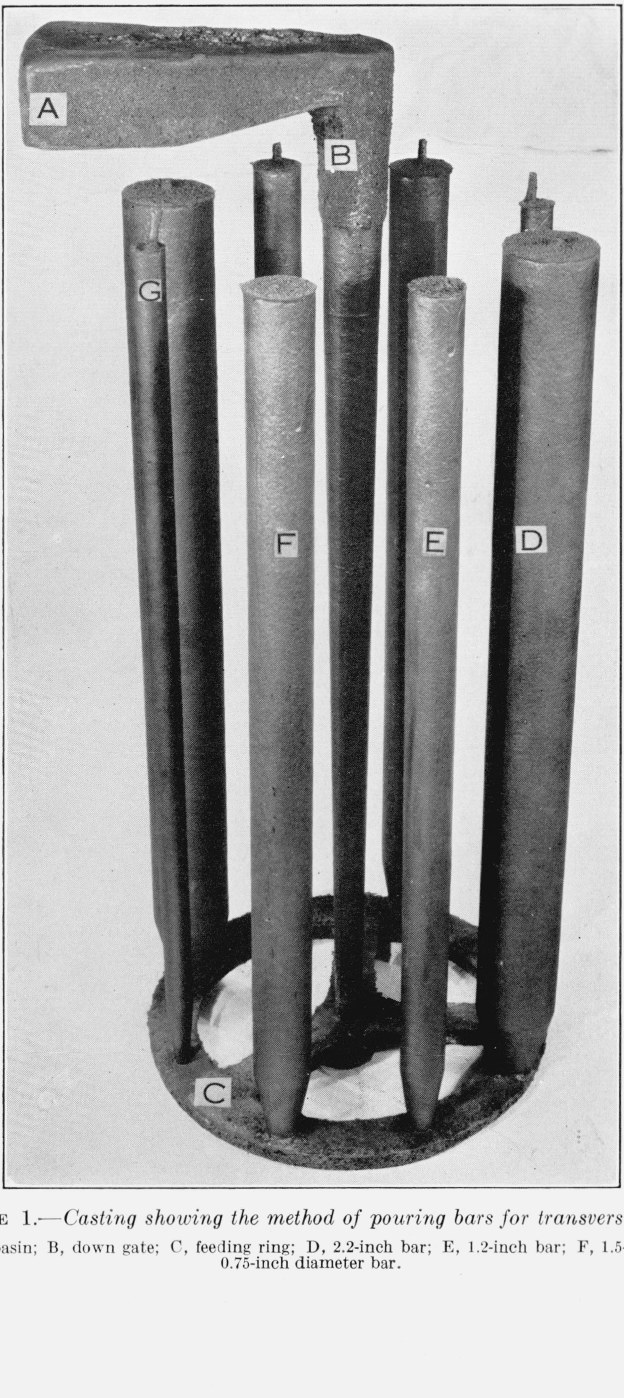

FIGURE 1.—*Casting showing the method of pouring bars for transverse tests.*

A, Pouring basin; B, down gate; C, feeding ring; D, 2.2-inch bar; E, 1.2-inch bar; F, 1.5-inch bar; G, 0.75-inch diameter bar.

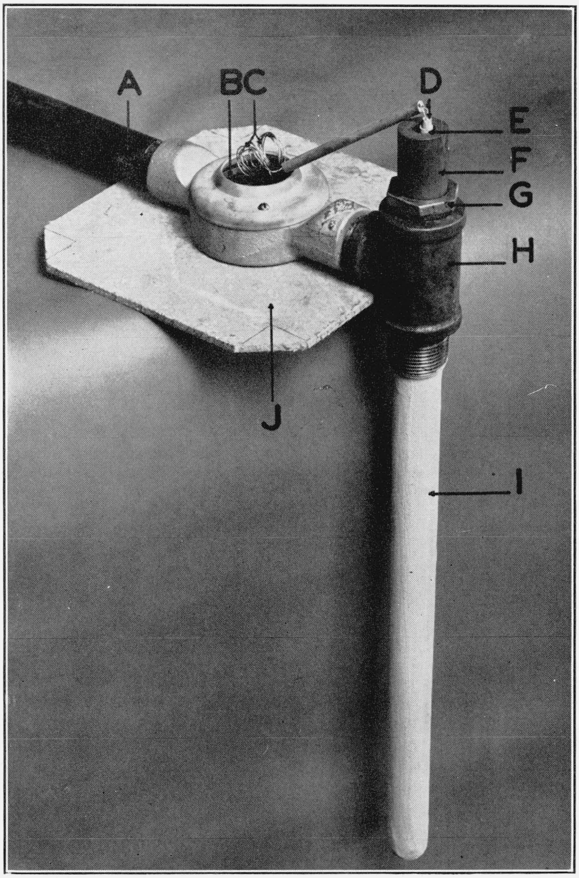

FIGURE 3.—*Thermocouple assembly used in measuring temperatures of molten cast iron.*

A, Thermocouple-handle enclosing extension leads; B, thermocouple junction with extension leads; C, platinum-platinum rhodium thermocouple wires; D, 2-hole porcelain insulating tube; E, porcelain tube; F, graphite tube; G, split lock nut; H, pipe tee; I, refractory coating applied to graphite tube; J. heat insulating plate.

1. TYPES OF TEST BARS

The test bars prepared and studied in this investigation were 23 inches in length and 0.75, 1.2, and 2.2 inches in diameter, respectively. Similar bars, 1.5 inches in diameter, were also used to a limited extent.

2. TEST-BAR MOLDS

The bottom-poured vertical mold, which was developed for casting test bars in dry sand [1], was used in this phase of the investigation. In this method a set of cylindrical test bars, consisting of four pairs molded in a three-part cylindrical flask, with the cheek extending the full length of the bar, were made in green sand (fig. 1). The diameters of the various bars were 0.75, 1.2, 1.5, and 2.2 inches, respectively. The bars were arranged so as to minimize the heating effect of the large bars on the small ones during cooling after casting.

3. STOCK IRON

The types of irons used are shown in table 1.

TABLE 1.—*Results of chemical analyses of stock irons used*

Iron	Total carbon	Silicon	Manganese	Phosphorus	Sulphur	Copper	Nickel	Chromium
	%	%	%	%	%	%	%	%
A	3.99	1.70	0.70	0.59	0.045	0.51		
B	3.41	1.63	.49	.44	.073		0.10	0.13
C	3.79	1.32	.73	.12	.06			
D	2.86	2.06	.18	.65	.028			
E	3.55	2.73	.24	.82	.021			
F [1]	2.13	1.64	.14	.49	.013			

[1] Chemical analysis calculated.

Irons A, C, and E were sand-cast pig irons. Iron B was a specially selected scrap iron; D, a mixture of E and 20 percent of commercial open-hearth ingot iron; and F, a mixture of E and 40 percent of commercial open-hearth ingot iron.

4. MELTING AND CASTING PROCEDURE

The irons were melted in a crucible of commercial magnesia in a high-frequency induction furnace of the tilting type. Charges of 200 pounds of metal were heated to maximum heating temperatures of 1,400° C (2,550° F); 1,500° C (2,730° F); 1,600° C (2,910° F); and 1,700° C (3,090° F), respectively, and held at the maximum heating temperature for approximately 1 minute before being allowed to cool to the desired pouring temperature.

The metal was allowed to cool from the maximum heating temperature to approximately 150° C (270° F) above the liquidus temperature of the stock pig iron or mixture used in that particular charge. It was then poured directly from the furnace into the test-bar molds, and the bars allowed to remain in the mold for a period of not less than 18 hours. The liquidus temperature was obtained from the diagram in figure 2, which shows the relation [4] between the liquidus temperature of cast iron and the total impurities.

5. TEMPERATURE MEASUREMENT OF MOLTEN IRON

Temperatures up to 1,550° C (2,820° F) were measured by a platinum-to-platinum 10-percent rhodium thermocouple. The thermocouple wires were separated by means of a two-hole porcelain insulator and protected by a closed-end, glazed, porcelain tube inserted into a closed-end graphite tube. The portion of the graphite tube, which came in contact with the molten iron, was coated with a layer of aluminum oxide over which a layer of a mixture of 95 percent of zircon (zirconium silicate) and 5 percent of bentonite was applied. The thermocouple assembly is shown in figure 3. An optical pyrometer was used for measuring temperatures above 1,550° C (2,820°

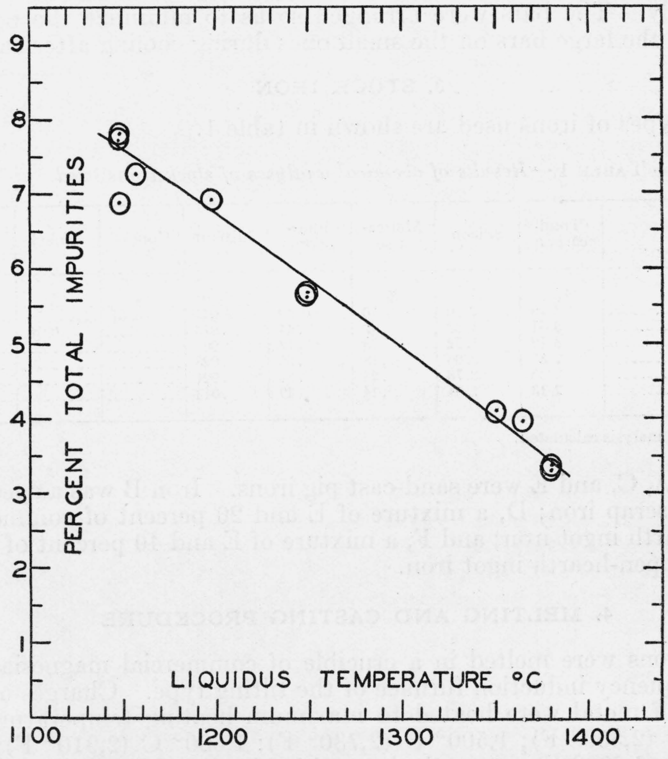

FIGURE 2.—*Relation of liquidus temperature to total impurities in cast iron.*

F). In order to determine the corrections to be applied to the readings of the optical pyrometer under these particular conditions, observations were taken simultaneously with both the thermocouple and the optical pyrometer in the temperature range 1,400 to 1,550° C (2,550 to 2,820° F). These corrections were then plotted as a function of the temperature, and the curve extended up to 1,700° C (3,090° F).

6. MOLDING MATERIAL

Considerable preliminary work was necessary with green-sand molds to develop a suitable molding material which would yield test bars free from surface defects or "burnt-on" sand. A number of bars were cast in green-sand molds of various moisture contents made from an iron molding sand commercially known as Lumberton molding sand (American Foundrymen's Association grade 3–C). An excessive amount of burnt-on sand in each case was noted.

Further tests were made with molds of the same molding material in which the cavities were coated with a facing material such as ceylon graphite, as well as a nongraphitic carbonaceous material.[2] Mixtures of the nongraphitic carbonaceous material with bentonite, silica flour, aluminum-oxide cement, or portland cement were also tried as facing material. These were applied by dusting, by brushing with a camel hair brush, and by swabbing with a hemp swab. In each case the facing material was applied in dry form. None of the bars made in molds so treated was satisfactory on account of burnt-on sand.

Mixtures of sand and sea-coal were tried with some degree of success. A mixture of 8 parts of molding sand to 1 part of sea-coal, tempered to approximately 7 percent of moisture, was used in making molds. However, the test bars made in these molds were not entirely satisfactory because of the roughened surface and, to some extent, burnt-on sand. By facing the mold cavities with a fine ceylon graphite, bars were obtained that were free from burnt-on sand, although the surfaces of the bars were still very rough. However, by swabbing the mold surfaces with a nongraphitic carbonaceous material, bars which were free from burnt-on sand and which possessed a very smooth surface were obtained.

This molding mixture composed of 8 parts of molding sand to 1 part of sea-coal, tempered to approximately 7 percent of moisture, with the mold cavities faced with a nongraphitic carbonaceous facing material, was used in the remainder of the experiments and will be referred to as the "selected molding material."

Two experiments were conducted to determine the temperature of the sand between different sizes of test bars immediately after casting. The purpose of these experiments was to determine if the molding sand reached a temperature high enough to produce appreciable annealing effects in the bars. This is particularly of interest in those cases where a small diameter bar is cast in the same mold with larger bars. In both experiments a casting similar to that shown in figure 1 was made. In the first mold, two thermocouples were inserted, one midway between the 0.75- and 2.2-inch bars, and another, between the 0.75- and 1.50-inch bars. The metal was poured into the mold at 1,400° C (2,550° F), and the temperatures at these two points were recorded as the mold cooled to room temperature. At the end of 50 minutes the temperature between the 0.75, and 2.2-inch bars was 300° C (570° F), the maximum observed, while the maximum temperature observed between the 0.75- and 1.5-inch bars was 170° C (340° F). The metal was poured into the second mold at 1,380° C (2,515° F) a thermocouple being placed midway between the 1.5- and 0.75-inch bars and one between the 1.2- and 2.2-inch bars. The maximum temperature observed between the 1.5- and the 0.75-inch bars was 165° C (330° F) and between the 1.2- and the 2.2- inch bars, 400° C (750° F), at the end of 40 minutes.

[2] Approximate analysis:

Volatile matter	4.0%
Fixed carbon	74.0%
Ash	22.0%

On the basis of these results, it is doubtful whether the molding material reached a temperature sufficiently high to have a marked influence on the physical properties of the test bars.

7. UNIFORMITY IN DIMENSIONS OF TEST BARS

Measurements were made to determine the variation in diameter of the bars of different sizes using the selected molding material described earlier. The diameter of each bar was measured at the midsection in four radial directions. The difference between the maximum and minimum diameters is expressed (table 2) in percentage of the average diameter. The 2.2-, 1.2,- and 0.75-inch bars were tested under transverse loading in an Amsler universal testing machine of 50,000-pound capacity, the load being applied to give approximately 0.02-inch deflection in 10 seconds. The span used for the 1.2- and 2.2-inch bars was 18 inches, and for the 0.75-inch bars, 15 inches. The breaking load for each bar was calculated to the nominal diameter and the difference between the breaking loads of the two bars of the same size was calculated as the percentage of the highest breaking load for the pair (table 2). It will be noted from table 2 that the maximum variation in all the bars tested was 0.77 percent in the diameter and 6.2 percent in the breaking load. Complete data on the results of the transverse tests of these bars will be considered later in this paper.

TABLE 2.—*Variations in diameters of cylindrical test bars cast in bottom-poured vertical green-sand molds and in transverse breaking strength of companion bars*

IRON A

Temperature				Average diameter	Difference between maximum and minimum diameter	Difference in breaking load
Maximum heating		Pouring				
°C	°F	°C	°F	*Inches*	*Percent*	*Percent*
1,400	2,550	1,300	2,370	2.26	0.18	3.8
1,400	2,550	1,300	2,370	2.24	.36	
1,400	2,550	1,300	2,370	1.55	.45	(1)
1,400	2,550	1,300	2,370	1.55	.32	
1,400	2,550	1,300	2,370	1.24	.50	2.2
1,400	2,550	1,300	2,370	1.24	.31	
1,400	2,550	1,300	2,370	.79	.63	1.4
1,400	2,550	1,300	2,370	.79	.39	

IRON B

°C	°F	°C	°F	Inches	Percent	Percent
1,400	2,550	1,380	2,515	2.24	0.13	0.6
1,400	2,550	1,380	2,515	2.24	.18	
1,400	2,550	1,380	2,515	1.54	.32	(1)
1,400	2,550	1,380	2,515	1.55	.18	
1,400	2,550	1,380	2,515	1.24	.32	.4
1,400	2,550	1,380	2,515	1.24	.33	
1,400	2,550	1,380	2,515	.80	.37	2.2
1,400	2,550	1,380	2,515	.80	.41	
1,600	2,910	1,380	2,515	2.23	.18	.9
1,600	2,910	1,380	2,515	2.23	.27	
1,600	2,910	1,380	2,515	1.54	.40	(1)
1,600	2,910	1,380	2,515	1.54	.39	
1,600	2,910	1,380	2,515	1.23	.40	4.4
1,600	2,910	1,380	2,515	1.23	.32	

1 Bars cast for machining to 1.2-in. diameter, not tested for transverse strength.

TABLE 2.—*Variations in diameters of cylindrical test bars cast in bottom-poured vertical green-sand molds and in transverse breaking strength of companion bars*—Continued

IRON C

Temperature				Average diameter	Difference between maximum and minimum diameter	Difference in breaking load
Maximum heating		Pouring				
°C	°F	°C	°F	*Inches*	*Percent*	*Percent*
1,400	2,550	1,300	2,370	2.24	0.40	3.2
1,400	2,550	1,300	2,370	2.25	.40	
1,400	2,550	1,300	2,370	1.54	.70	(1)
1,400	2,550	1,300	2,370	1.54	.26	
1,400	2,550	1,300	2,370	.78	.77	3.2
1,400	2,550	1,300	2,370	.78	.63	
1,500	2,730	1,380	2,515	2.25	.40	3.5
1,500	2,730	1,380	2,515	2.25	.35	
1,500	2,730	1,380	2,515	1.55	.45	(1)
1,500	2,730	1,380	2,515	1.54	.71	
1,500	2,730	1,380	2,515	1.23	.50	2.3
1,500	2,730	1,380	2,515	1.23	.32	
1,500	2,730	1,380	2,515	.80	.38	6.2
1,500	2,730	1,380	2,515	.80	.50	
1,600	2,910	1,380	2,515	2.24	.27	4.2
1,600	2,910	1,380	2,515	2.24	.27	
1,600	2,910	1,380	2,515	1.54	.19	(1)
1,600	2,910	1,380	2,515	1.54	.32	
1,600	2,910	1,380	2,515	1.23	.33	3.1
1,600	2,910	1,380	2,515	1.23	.24	
1,600	2,910	1,380	2,515	.79	.51	.5
1,600	2,910	1,380	2,515	.78	.37	
1,700	3,090	1,380	2,515	2.24	.50	.2
1,700	3,090	1,380	2,515	2.25	.31	
1,700	3,090	1,380	2,515	1.55	.32	(1)
1,700	3,090	1,380	2,515	1.55	.38	
1,700	3,090	1,380	2,515	1.23	.48	3.2
1,700	3,090	1,380	2,515	1.23	.40	

[1] Bars cast for machining to 1.2-in. diameter, not tested for transverse strength.

III. COMPARISON OF TEST BARS PRODUCED BY FOUR METHODS

1. FOUR METHODS OF PREPARING TEST BARS

In the second phase of this investigation, a comparison was made of the physical properties of transverse-strength test bars made by the method developed at this Bureau and by the methods tentatively adopted by the American Society for Testing Materials. These methods differ only in the position in which the bar is cast and the method of pouring. In the method developed at this Bureau, the bars are cast in a vertical position and poured from the bottom. Bars produced in this manner are referred to as bottom-poured vertical mold. The American Society for Testing Materials has tentatively adopted three methods of casting transverse-strength test bars. In one method, the bars are cast in a vertical position and poured from the top (top-poured vertical mold). In another, the bars are cast in a horizontal position (horizontal mold) and in the third, they are cast in a position inclined about 8 degrees with the horizontal (horizontally inclined mold). In the latter case, the bars are poured from the lower end. Test bars 0.75, 1.2, and 2.2 inches in diameter were produced by each of the above-mentioned methods.

In view of the satisfactory results obtained in the earlier work with the mixture of 8 parts of molding sand to 1 part of sea-coal, tempered to approximately 7 percent of moisture and faced with a nongraphitic carbonaceous refractory material, these materials were used to make the molds for casting transverse-strength test bars by each of four methods.

(a) TOP- AND BOTTOM-POURED VERTICAL MOLD

The mold used, in making these bars shown in figure 4, was a modification of the one used for making the bars shown in figure 1. Bars of the same diameter were cast in pairs simultaneously in a vertical mold, 2 bars being bottom-poured, and 2 bars being top-poured. The molds were made in a three-part cylindrical flask, with the cheek extending the full length of the bars, and the mold cavities were spaced 7 inches between centers.

(b) HORIZONTAL MOLD

Two bars of the same diameter were cast simultaneously through filter cores, with the ends of the bars provided with risers (fig. 5). The distance between the center line of the 2 bars was 6 inches. The patterns used in making these bars were removed by withdrawing them from one end of the flask, thereby eliminating parting-line defects in the mold cavities such as may be encountered when the cope is removed from the drag and the pattern is lifted out from the mold.

(c) HORIZONTALLY INCLINED MOLD

The mold used in making the bars shown in figure 6 was similar to the horizontal mold, with the exception that the risers were connected to an overflow basin, which served as a reservoir to retain the excess of metal poured through the test bar mold during casting. The mold was inclined at an angle of 8 degrees while it was being poured.

2. SURFACE CONDITION AND DIMENSIONAL UNIFORMITY OF TEST BARS

The surfaces of all bars were smooth and free from burnt-on sand, this being true even when a pouring temperature of 1,470° C (2,680° F) was employed. The diameter of each test bar was measured at midsection of the bar in four radial directions, and the differences between the maximum and minimum diameters expressed as the percentage of the average diameter. The results (summarized in table 3) on 64 bars cast by the four methods show that the vertically cast bars, particularly those which were bottom-poured, were much more uniform in their diameter than the bars cast in the horizontal or the horizontally inclined molds.

3. PHYSICAL PROPERTIES OF TEST BARS

(a) TRANSVERSE BREAKING TEST

The results of the transverse breaking tests are shown in tables 4 and 5, and the chemical analyses of the different bars in table 6. The results determined on bars cast as shown in figure 1 in the bottom-

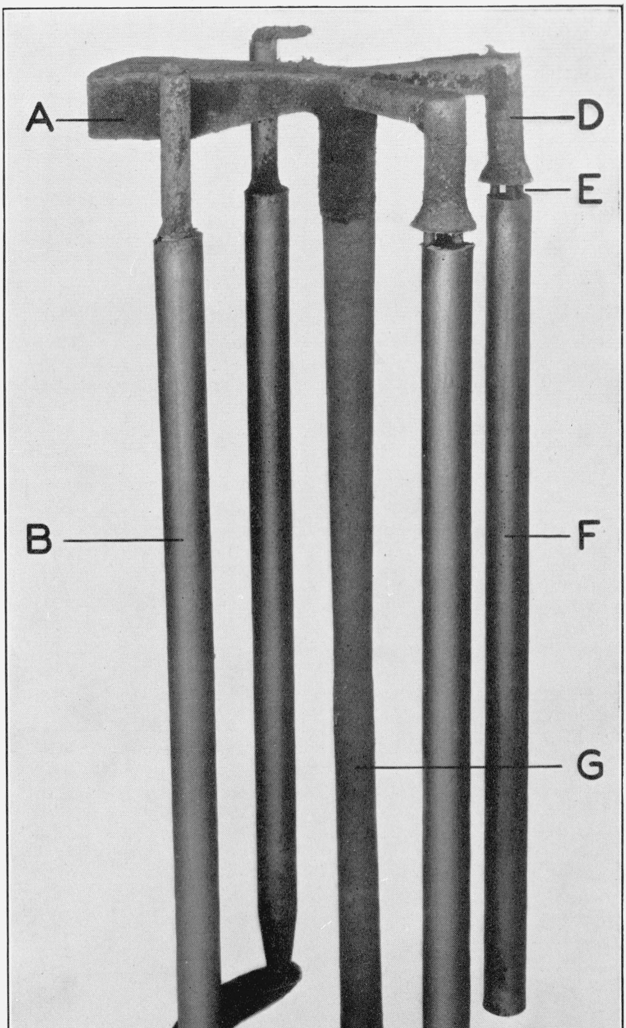

FIGURE 4.—*Transverse-strength test bars cast in a vertical mold by top-pouring and bottom-pouring.*

A, Pouring basin; B, vertically cast bars, bottom-poured; C, feeding semi-ring for bottom-pouring; D, top-pouring gates; E, pencil gates of 0.25-inch diameter made in oil-sand cores; 5 pencil gates for 2.2-inch diameter bars; 3 pencil gates for 1.2-inch diameter bars; 1 pencil gate for 0.75-inch diameter bars; F, vertically cast bars, top-poured; G, down gate.

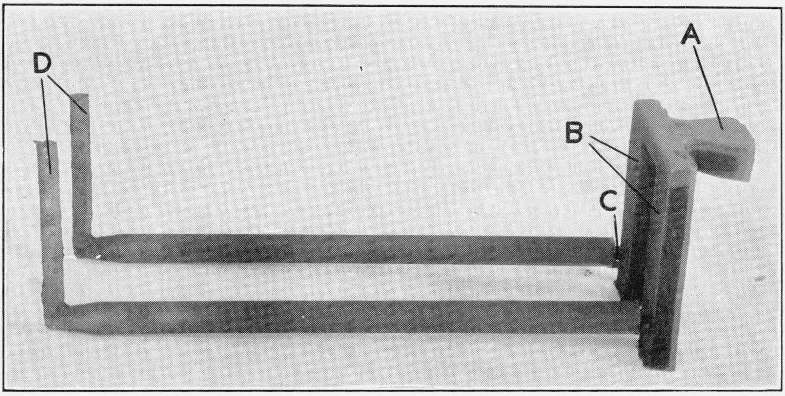

FIGURE 5.—*Transverse test bars cast horizontally.*

A, Pouring gate; B, down gates 1×2.25×10 inches; C, pencil gates of 0.25-inch diameter, 5 gates for 2.2-inch diameter bars, 3 gates for 1.2-inch diameter bars, 1 gate for 0.75-inch diameter bars; D, risers.

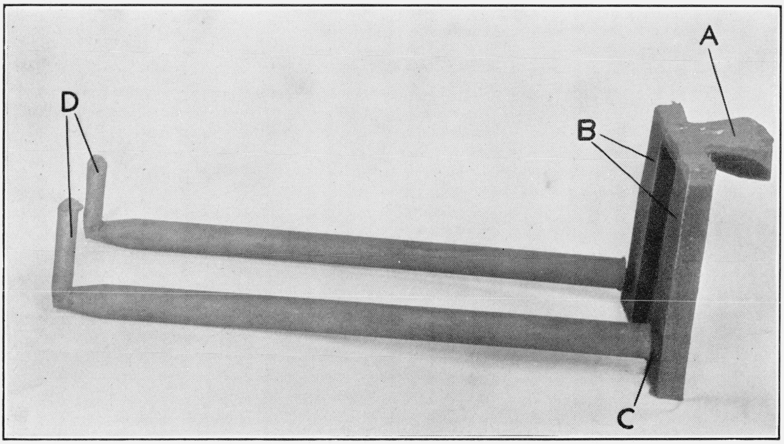

FIGURE 6.—*Transverse test bars cast in a horizontally inclined mold.*

A, Pouring gate; B, down gate 1×2.25×10 inches; C, feeding gate; gates of 1-inch diameter for 2.2-inch diameter bars, gates of 0.75-inch diameter for 1.2-inch diameter bars, gates of 0.5-inch diameter for 0.75-inch diameter bars; D, risers to overflow basin.

poured vertical mold are also included. In view of the fact that higher breaking strengths have been reported for transverse-strength test bars cast in horizontal position when tested with the "cope side" up [5, 6], the test bars cast in the horizontal and the horizontally inclined molds were placed on the testing machine so that their position corresponded to their position in the mold.

TABLE 3.—*Variations in diameter* [1] *of test bars cast by four methods*

Iron	Temperature				Vertical mold				Horizontally inclined mold		Horizontal mold	
	Maximum heating		Pouring		Top poured		Bottom poured		Average	Maximum variation	Average diameter	Maximum variation
					Average diameter	Maximum variation	Average diameter	Maximum variation				
	°C	°F	°C	°F	in.	%	in.	%	in.	%	in.	%
A	1,500	2,730	1,300	2,370	1.25	0.64	1.24	0.48	1.24	2.02	1.25	2.16
	1,500	2,730	1,300	2,370	1.25	.48	1.24	.24	1.24	1.21	1.25	2.00
A	1,600	2,910	1,300	2,370	.80	.62	.80	.50	.82	7.80	.80	2.12
	1,600	2,910	1,300	2,370	.80	1.62	.80	.75	.81	4.57	.80	1.12
A	1,600	2,910	1,300	2,370	1.25	.48	1.24	.08	1.24	.81	1.24	.81
	1,600	2,910	1,300	2,370	1.25	.32	1.24	.40	1.24	.73	1.25	1.36
A	1,600	2,910	1,300	2,370	2.25	.27	2.24	.31	2.26	1.37	2.27	1.10
	1,600	2,910	1,300	2,370	2.25	.62	2.25	.44	2.25	1.51	2.27	1.23
A	1,700	3,090	1,300	2,370	1.25	.88	1.24	.56	1.25	2.72	1.26	1.50
	1,700	3,090	1,300	2,370	1.25	.64	1.24	.32	1.25	1.60	1.25	1.36
C	1,400	2,550	1,380	2,515	1.26	.08	1.24	.32	1.25	2.16	1.26	2.14
	1,400	2,550	1,380	2,515	1.26	.71	1.24	.80	1.25	.64	1.26	2.00
D	1,700	3,090	1,380	2,515	1.25	.64	1.24	.56	1.25	2.24	1.25	1.84
	1,700	3,090	1,380	2,515	1.25	.56	1.24	.56	1.25	1.52	1.25	2.32
F	1,700	3,090	1,470	2,680	1.23	.57	1.22	.08	1.23	.89	1.23	.73
	1,700	3,090	1,470	2,680	1.23	.24	1.22	.24	1.23	.65	1.23	.80

[1] Diameters measured at midsection of test bars, in four radial directions.

TABLE 4.—*Physical properties of test bars cast in bottom-poured vertical molds*

[Brinell-hardness values determined with 3,000-kg load, using 10-mm ball]

Diameter	Maximum heating temperature		IRON A.—POURING TEMPERATURE 1,300° C (2,370° F)					IRON B.—POURING TEMPERATURE 1,380° C (2,515° F)					IRON C.—POURING TEMPERATURE 1,380° C (2,515° F)					IRON C.—POURING TEMPERATURE 1,300° C (2,370° F)				
			Breaking load	Difference	Modulus of rupture, avg	Deflection	Brinell number, avg	Breaking load	Difference	Modulus of rupture, avg	Deflection	Brinell number, avg	Breaking load	Difference	Modulus of rupture, avg	Deflection	Brinell number, avg	Breaking load	Difference	Modulus of rupture, avg	Deflection	Brinell number, avg
in	° C	° F	lb	%	lb/in²	in		lb	%	lb/in²	in		lb	%	lb/in²	in		lb	%	lb/in²	in²	
2.2	1,400	2,550	8,487	3.8	37,200	0.16	------	13,825	0.6	59,700	0.18	------	------	------	------	------	------	10,037	3.2	44,000	0.20	------
2.2	1,400	2,550	8,807					13,920										10,373				
1.2	1,400	2,550	1,632 1,596	2.2	42,700	.24	166	2,312 2,321	.4	61,300	.25	210	1,854 1,850	0.2	49,000	0.25	172	------ 2,103	------ ------	------ 55,700	------ .25	173
.75	1,400	2,550	608	1.4	56,000	.23	------	701	2.2	64,400	.23	------	------	------	------	------	------	524	3.2	47,100	.13	------
------	1,400	2,550	599					717										507				
2.2	1,500	2,730	------	------	------	------	------	------	------	------	------	------	10,654	3.5	45,100	.22	------	------	------	------	------	------
2.2	1,500	2,730	------	------	------	------	------	------	------	------	------	------	10,280									
1.2	1,500	2,730	1,827	4.7	47,200	.17	183						1,913	2.3	51,400	.28	173	------	------	------	------	------
1.2	1,500	2,730	1,741					------	------	------	------	------	1,959									
.75	1,500	2,730	------										791	6.2	69,700	.28	------	------	------	------	------	------
.75	1,500	2,730		------	------	------	------	------	------	------	------	------	742									
2.2	1,600	2,910	10,985	6.0	48,800	.14	------	15,226	.9	65,100	.18	------	10,700	4.2	47,100	.22	------	------	------	------	------	------
2.2	1,600	2,910	11,682					15,082					11,174									
1.2	1,600	2,910	1,931	1.8	51,600	.21	189	2,721	4.4	70,600	.26	214	2,117	3.1	55,300	.27	190	------	------	------	------	------
1.2	1,600	2,910	1,961					2,600					2,052									
.75	1,600	2,910	585	4.1	54,300	.19	------	765	------	69,900	.19	------	796	.5	72,800	.23	------	------	------	------	------	------
.75	1,600	2,910	610										800									
2.2	1,700	3,090	------										12,027	.2	51,900	.21	------	IRON D.—POURING TEMPERATURE, 1,380° C (2,515 ° F)				
2.2	1,700	3,090	------	------	------	------	------	------	------	------	------	------	12,056									
1.2	1,700	3,090	1,976	5.2	53,800	.18	201	------	------	------	------	------	2,284	3.2	59,600	.25	187	2,475	4.8	64,000	0.19	244
1.2	1,700	3,090	2,085										2,210					2,357				
.75	1,700	3,090	------										805	------	73,300	.18	------	------	------	------	------	------
.75	1.700	3,090	------	------	------	------	------	------	------	------	------	------										

Table 5.—*Physical properties of test bars cast by different methods*

[Brinell hardness values determined with a 3,000-kg load, using 10-mm ball]

IRON A

Diameter	Temperature				Horizontal mold					Horizontally inclined mold					Vertical mold, top-poured					Vertical mold, bottom-poured				
	Maximum heating		Pouring		Breaking load	Difference	Modulus of rupture avg.	Deflection	Brinell number avg.	Breaking load	Difference	Modulus of rupture avg.	Deflection	Brinell number avg.	Breaking load	Difference	Modulus of rupture avg.	Deflection	Brinell number avg.	Breaking load	Difference	Modulus of rupture avg.	Deflection	Brinell number avg.
in	°C	°F	°C	°F	lb	%	lb/in²	in		lb.	%	lb/in²	in		lb	%	lb/in²	in		lb	%	lb/in²	in	
1.2	1,500	2,730	1,300	2,370	1,619	1.6	43,400	0.18	176	1,949	0.5	51,700	0.21	182	1,850	17.7	44,800	0.19	184	1,827	4.7	47,200	0.17	183
1.2	1,500	2,730	1,300	2,370	1,646					1,958					1,522					1,741				
2.2	1,600	2,910	1,300	2,370	10,738	6.3	47,800	.15	------	11,070	2.9	48,400	.15	------	11,400	4.1	48,600	.14	------	10,985	6.0	48,800	.14	------
2.2	1,600	2,910	1,300	2,370	11,465					11,400					10,934					11,682				
1.2	1,600	2,910	1,300	2,370	1,931	3.3	50,400	.22	178	1,894	3.7	51,100	.22	178	1,664	12.5	47,400	.19	187	1,931	1.8	51,600	.21	189
1.2	1,600	2,910	1,300	2,370	1,867					1,967					1,903					1,967				
.75	1,600	2,910	1,300	2,370	644	4.6	59,900	.23	------	597	10.8	51,300	.22	------	486	4.9	45,300	.16	------	585	4.1	54,300	.19	------
.75	1,600	2,910	1,300	2,370	676					533					511					610				
1.2	1,700	3,090	1,300	2,370	2,072	1.8	54,600	.20	187	1,902	11.2	53,700	.19	187	2,132	13.3	52,900	.18	202	1,976	5.2	53,800	.18	201
1.2	1,700	3,090	1,300	2,370	2,035					2,141					1,849					2,085				

IRON C

1.2	1,400	2,550	1,380	2,515	1,641	0.5	43,400	0.25	165	1,805	0.5	48,000	0.23	176	1,770	0.2	46,900	0.22	173	1,854	0.2	49,000	0.25	172
1.2	1,400	2,550	1,380	2,515	1,632					1,814					1,766					1,850				

IRON D

1.2	1,700	3,090	1,380	2,515	2,274	6.2	62,400	0.17	236	2,061	4.1	56,000	0.15	239	2,469	3.2	64,600	0.18	242	2,475	4.8	64,000	0.19	244
1.2	1,700	3,090	1,380	2,515	2,424					2,150					2,389					2,357				

TABLE 6.—*Chemical composition of test bars*

Diameter	Temperature				Chemical composition [1] (percent)									
	Maximum heating		Pouring		Total carbon	Graphitic carbon	Combined carbon	Si	P	Mn	S	Cu	Ni	Cr
in.	°C	°F	°C	°F										
IRON A														
2.2	1,400	2,550	1,300	2,370	3.86	3.10	0.76	1.43	0.45	0.52	0.027	0.33	------	------
1.2	1,400	2,550	1,300	2,370	3.91	3.05	.86	1.43	.45	.52	.027	.33	------	------
.75	1,400	2,550	1,300	2,370	3.91	3.03	.88	1.43	.45	.52	.027	.33	------	------
1.2	1,500	2,730	1,300	2,370	3.84	3.11	.73	1.50	.62	.52	.033	.40	------	------
2.2	1,600	2,910	1,300	2,370	3.74	3.14	.60	1.55	.53	.56	.046	.48	------	------
1.2	1,600	2,910	1,300	2,370	3.83	3.28	.56	1.78	.58	.60	.030	.41	------	------
.75	1,600	2,910	1,300	2,370	3.77	3.08	.69	1.60	.55	.59	.045	.48	------	------
1.2	1,700	3,090	1,300	2,370	3.82	3.19	.63	1.58	.57	.63	.043	.51	------	------
IRON B														
2.2	1,400	2,550	1,380	2,515	3.24	2.45	0.79	1.46	0.45	0.35	0.068	------	0.07	0.12
1.2	1,400	2,550	1,380	2,515	3.30	2.45	.85	1.46	.45	.35	.068	------	.07	.12
.75	1,400	2,550	1,380	2,515	3.30	2.35	.95	1.46	.45	.35	.068	------	.07	.12
2.2	1,600	2,910	1,380	2,515	3.16	2.37	.79	1.40	.44	.35	.076	------	.07	.12
1.2	1,600	2,910	1,380	2,515	3.25	2.41	1.04	1.40	.44	.35	.076	------	.07	.12
.75	1,600	2,910	1,380	2,515	3.27	2.14	1.13	1.40	.44	.35	.076	------	.07	.12
IRON C														
2.2	1,400	2,550	1,300	2,370	3.82	3.02	0.80	1.16	0.10	0.51	0.053	------	------	------
1.2	1,400	2,550	1,300	2,370	3.81	3.01	.80	1.16	.10	.51	.053	------	------	------
.75	1,400	2,550	1,300	2,370	3.83	2.61	1.22	1.16	.10	.51	.053	------	------	------
1.2	1,400	2,550	1,380	2,515	3.73	2.95	.78	1.12	.09	.54	.055	------	------	------
2.2	1,500	2,730	1,380	2,515	3.66	2.90	.76	1.10	.11	.51	.052	------	------	------
1.2	1,500	2,730	1,380	2,515	3.74	2.93	.81	1.10	.11	.51	.052	------	------	------
.75	1,500	2,730	1,380	2,515	3.76	2.56	1.20	1.10	.11	.51	.052	------	------	------
2.2	1,600	2,910	1,380	2,515	3.61	2.77	.84	1.12	.10	.56	.054	------	------	------
1.2	1,600	2,910	1,380	2,515	3.71	2.76	.95	1.12	.10	.56	.054	------	------	------
.75	1,600	2,910	1,380	2,515	3.69	2.14	1.55	1.12	.10	.56	.054	------	------	------
2.2	1,700	3,090	1,380	2,515	3.58	2.85	.73	1.08	.10	.51	.053	------	------	------
1.2	1,700	3,090	1,380	2,515	3.60	2.70	.90	1.08	.10	.51	.053	------	------	------
.75	1,700	3,090	1,380	2,515	3.63	.95	2.68	1.08	.10	.51	.053	------	------	------
IRON D														
1.2	1,700	3,090	1,380	2,515	2.86	2.06	0.83	2.06	0.65	0.18	0.028	------	------	------
IRON F														
1.2	1,700	3,090	1,470	2,680	2.13	------	------	1.64	0.49	0.14	0.013	------	------	------

[1] Analyses made by R. H. Elder and Roy Deas, American Cast Iron Pipe Co., Birmingham, Ala.

It is noteworthy that the difference in breaking loads for the two bars of a pair is, in general, smaller for bars cast either horizontally or in bottom-poured vertical molds than for the bars cast in the horizontally inclined mold or in the top-poured vertical mold.

In comparing the effect of maximum heating temperature on the strength of the 1.2-inch bars made by different methods it will be noticed (fig. 7) that in general the strength increases with an increase of maximum heating temperature, in the range 1,500 to 1,700° C (2,730 to 3,090° F).

The 1.2-inch bars made of iron A by different methods, with maximum heating temperature of 1,700° C (3,090° F), differed only slightly in their transverse breaking loads.

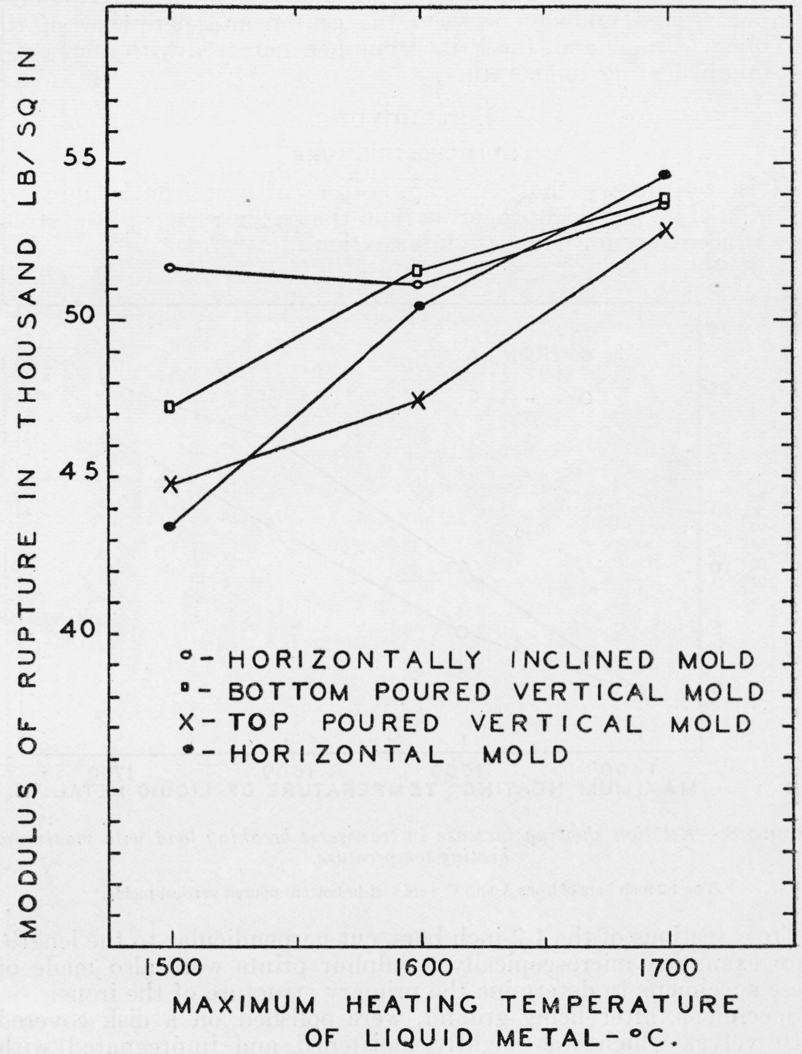

FIGURE 7.—*Relation between modulus of rupture and maximum heating temperature.*

Transverse-strength test bars, 1.2-inch in diameter, of iron A, were cast by four different methods.

On the basis of the breaking strength shown in tables 4 and 5, it appears that iron A was more affected by superheating than iron C (fig. 8), and that the modulus of rupture depended upon the cross-sectional area of the test bars and the amount of superheating (fig. 9).

(b) BRINELL NUMBERS

Brinell determinations were made on disks 0.5 inch in thickness, cut from broken sections of the 1.2-inch bars adjacent to the fracture. Impressions with a 10-mm ball, under 3,000-kg load, were made in the center and midway between the center and periphery of the specimen. In general, the Brinell number increased with increase of maximum heating temperature.

4. STRUCTURE

(a) MICROSTRUCTURE

It is well known that the composition of cast iron is only one criterion of its physical properties, and that a knowledge of the structure is necessary for adequate information.

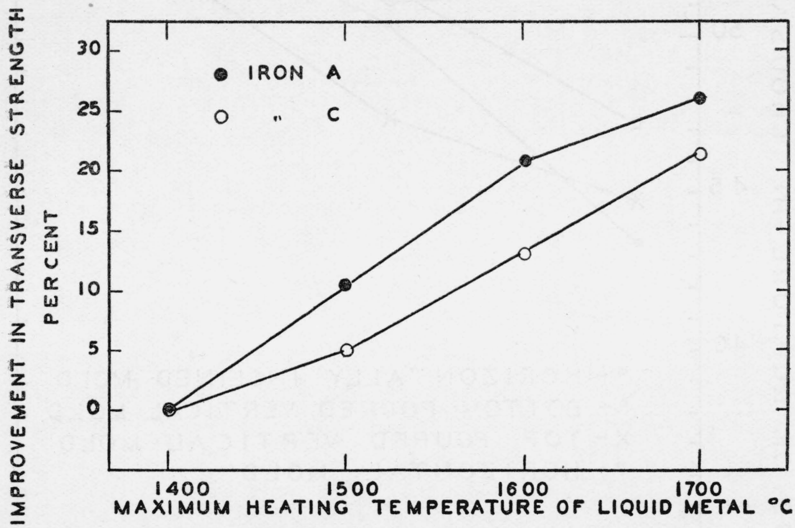

FIGURE 8.—*Relation showing increase in transverse breaking load with maximum heating temperature.*

The 1.2-inch bars of irons A and C were cast in bottom-poured vertical molds.

Cross sections of the 1.2-inch bars, cut perpendicular to the length. were examined microscopically. Sulphur prints were also made of these specimens to determine the primary structure of the irons.

Specimens, after being ground, were polished on a disk covered with velvet which was slightly moistened and impregnated with rouge. Micrographs of the specimens, as polished and after being etched with a 1-percent solution of nitric acid in ethyl alcohol, were made at 100 and 500 diameters near the center and the periphery of the specimen.

No significant difference in microstructure was found in the test bars of the same iron made by different methods. As is to be expected, those irons with the higher strength had finer graphite particles and finer pearlite. Some illustrations of the structure observed are shown in figures 10 to 12, inclusive.

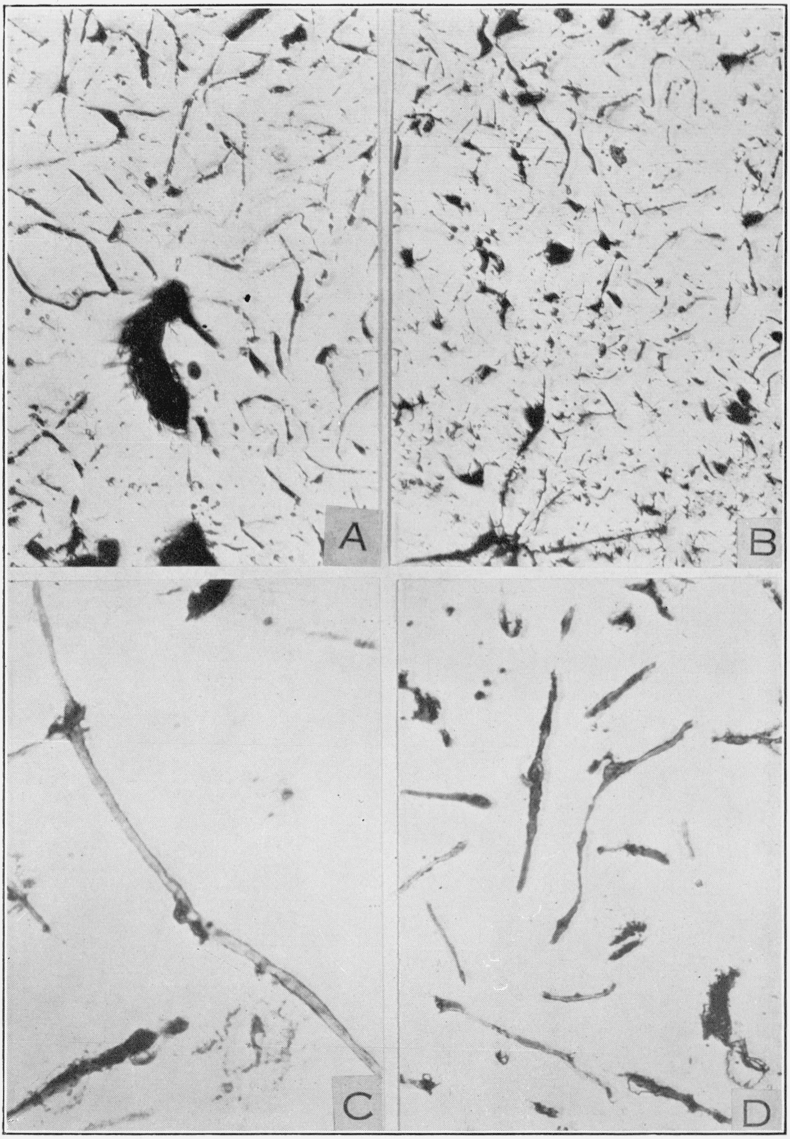

FIGURE 10.—*Microstructure of polished transverse section of 1.2-inch test bar of iron A cast in bottom-poured vertical mold.*

Maximum heating temperature 1,400° C (2,550° F); pouring temperature 1,300° C (2,370° F). Modulus of rupture 43,200 lb/in². A, center, × 100; B, periphery, × 100; C, center, × 500; D, periphery, × 500.

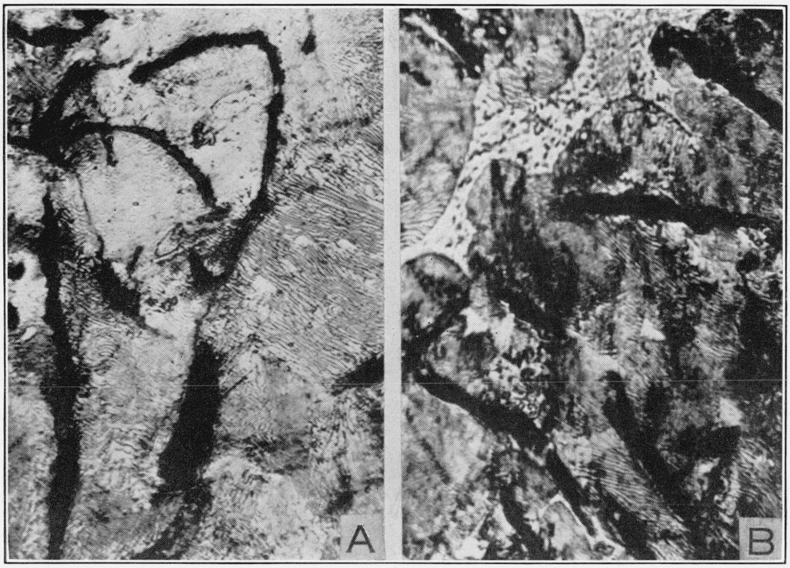

FIGURE 11.—*Microstructure of material of figure 10 after etching.*

Etched with 1-percent solution of nitric acid in ethyl alcohol. A, center × 500; B, periphery × 500.

Figures 10 and 11 represent the structure of the 1.2-inch bars cast in a bottom-poured vertical mold and show the presence of coarse graphite and pearlite, to which the low strength of these test bars may be attributed. Figure 12 shows the structure of similar bars made of

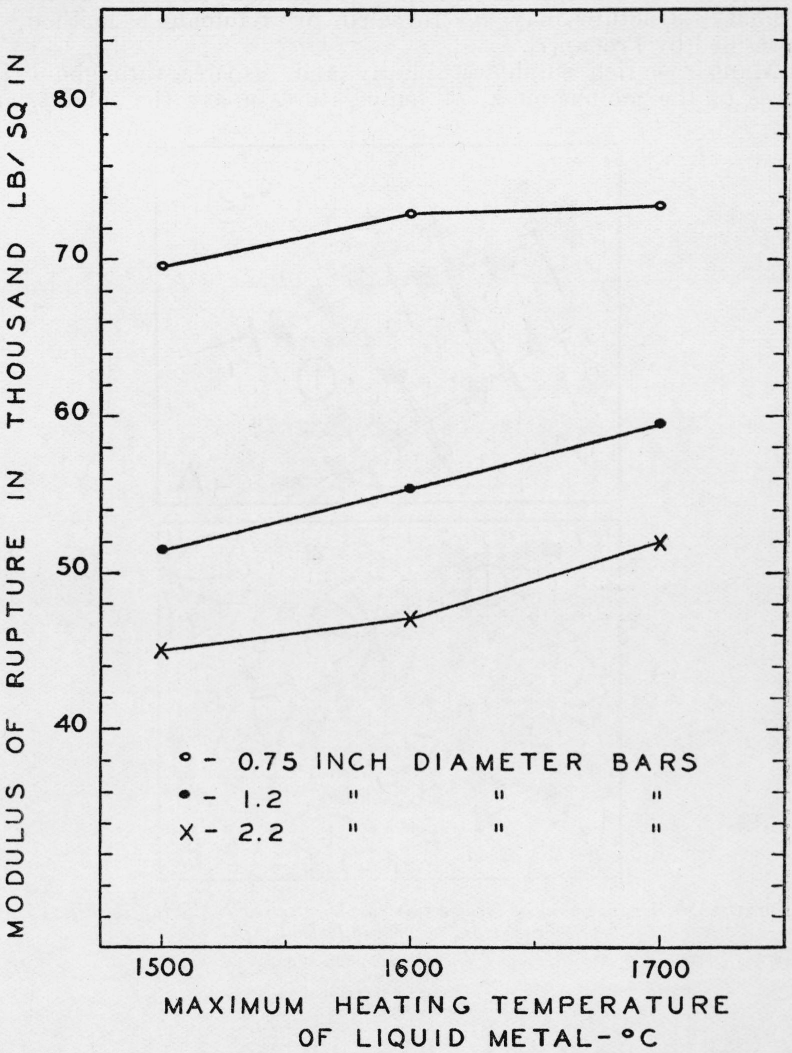

Figure 9.—*Relation between modulus of rupture of transverse-strength test bars and maximum heating temperature.*

Iron C was cast in bottom-poured vertical molds.

the same iron but heated to a higher temperature 1,700° C (3,090° F). The decrease in the size of the graphite particles and pearlite, as compared with figures 10 and 11, is believed to be significant.

(b) PRIMARY STRUCTURE

Another factor, which may have an important effect on the physical properties of cast iron, is the primary structure. By the term "primary structure" is meant that structure which is formed during solidification and not the structure revealed by the fracture. The primary structure may be revealed by Baumann's method, as described by Preuss [7].

Manganese-rich sulphides solidify and disperse throughout the mass of the molten metal at temperatures above the solidus, and

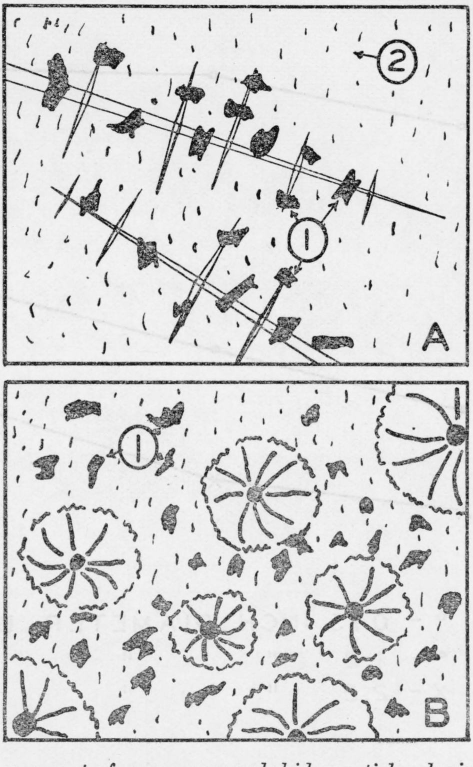

FIGURE 13.—*Arrangement of manganese sulphide particles during solidification of cast iron, according to Roll* [8].

A.—Dendritic solidification.
B.—Globular solidification.
1.—Manganese-rich sulphides.
2.—Mother liquor.

upon solidification of the iron, the particles arrange themselves along the axes and branches of the dendrites or along the grain boundaries, as is illustrated in figure 13.

Sulphur prints were made of the cross sections of all 1.2- and 2.2-inch transverse strength test bars used (fig. 14) and the differences observed in the primary structure of bars cast by different methods were very slight. Sulphur prints of bars of the same iron heated to the maximum temperatures of 1,400° C (2,550° F) and 1,700° C (3,090° F) suggest that the higher strength of the bars is associated with a finer primary structure.

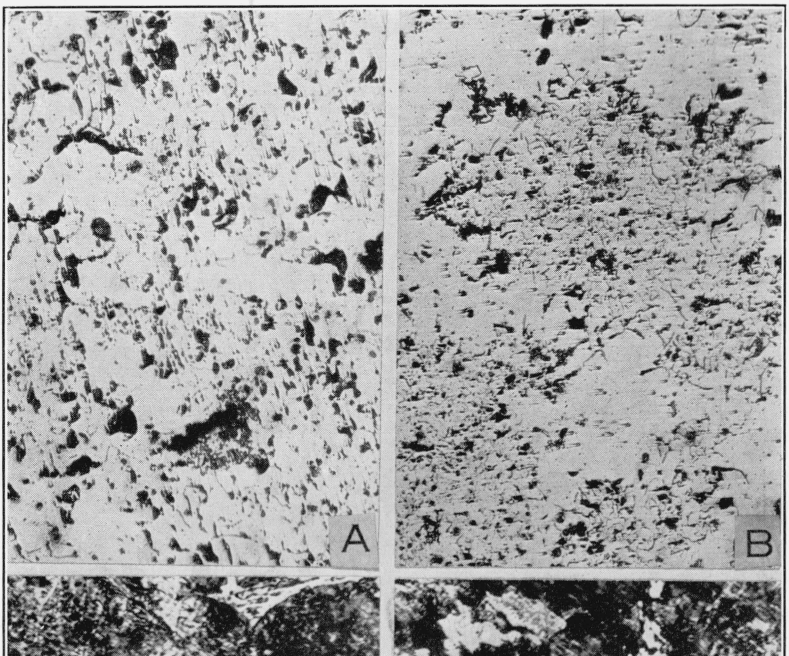

FIGURE 12.—*Microstructure of material of figure 10 after a maximum heating temperature of 1,700° C (3,090° F); other conditions as for figure 10.*

Modulus of rupture 55,200 lb/in². A, center × 100; B, periphery × 100, both polished; C, center × 500; D, periphery × 500, both etched with 1-percent solution of nitric acid in ethyl alcohol.

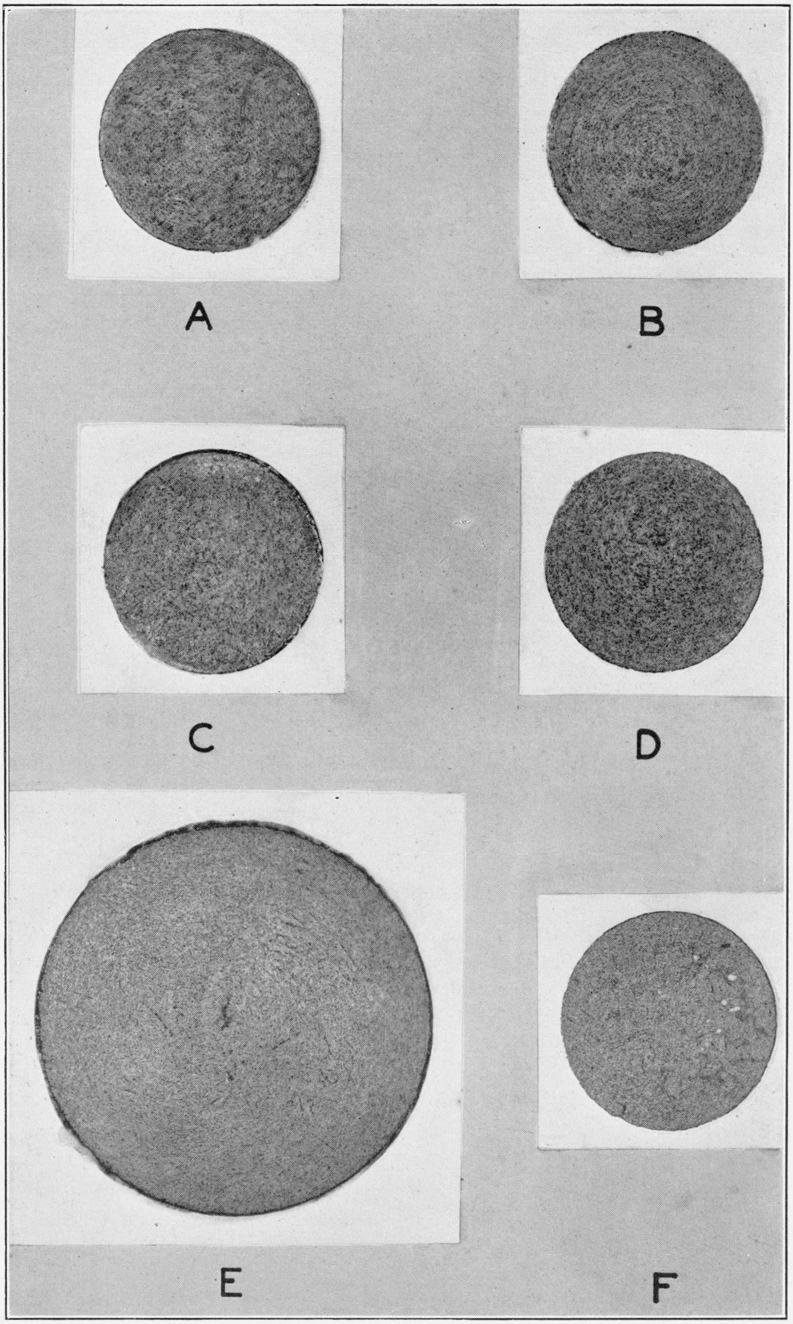

FIGURE 14.—*Sulphur prints of cross section of transverse-strength test bars of iron* C, *poured at 1,380°* C *(2,515°* F*).*

A.—Horizontal mold
B.—Horizontal inclined mold
C.—Top-poured vertical mold
D.—Bottom-poured vertical mold
} 1.2-inch bars. Maximum heating temperature 1,400° C (2,550° F).

E.—2.2-inch bars
F.—1.2-inch bars
} Maximum heating temperature 1,700° C (3,090° F). Bottom-poured vertical mold.

IV. SUMMARY

In preparing transverse-strength test bars of cast iron, freedom from burnt-on sand and other surface defects is very important.

A method of casting transverse-strength test bars in green-sand molds, consisting of a mixture of 8 parts of iron molding sand to 1 part of sea-coal, tempered to approximately 7 percent of moisture, with the surface of the mold cavities swabbed with a carbonaceous nongraphitic material, has been found satisfactory in preparing test bars having superior surface characteristics.

Five types of cast irons heated to maximum heating temperatures of 1,400° C (2,550° F); 1,500° C (2,730° F); 1,600° C (2,910° F); and 1,700° C (3,090° F), respectively, and then cooled to a temperature of 150° C (270° F) above the liquidus temperature were poured directly from the high-frequency induction furnace into transverse-strength test-bar molds.

Four methods of molding test bars of various diameters were employed; bottom-poured vertical mold, top-poured vertical mold, horizontal mold, and horizontally inclined mold.

The temperatures of the molds after casting test bars were measured. The data obtained do not indicate that the temperature attained by the molding material between the different diameter test bars was sufficiently high to influence the physical properties of the bars to any appreciable extent as the maximum temperatures of the mold were well below the critical temperature of the iron.

Vertically cast bars, particularly those which were bottom-poured, were much more uniform in diameter than bars cast in horizontal or horizontally inclined molds. The bars of iron A made by different methods, with a maximum heating temperature of 1,700° C (3,090° F), differed only slightly in the transverse breaking loads.

The effect of maximum heating temperature on the strength and hardness of the transverse-strength test bars made by four methods was studied. In general, the strength and hardness of all the bars investigated increased with increase of maximum heating temperature.

No essential differences in the primary structure or in the microstructure of test bars of the same composition and size, but cast by different methods, were revealed.

A finer primary structure, and finer graphite and pearlite constituents, were found to be associated with higher transverse strength.

The authors express their appreciation and thanks to L. D. Jones, senior molder, for the assistance rendered by him in this investigation.

V. REFERENCES

[1] C. M. Saeger, Jr. and E. J. Ash, *Properties of gray cast iron as affected by casting conditions*, Trans. Am. Foundrymen's Assn. **41**, 449 (1933); NBS J. Research **13**, 573 (1935) RP726.

[2] G. L. Harbach, *Relationship in cast iron test results.* Foundry Trade J. (London) **53**, 61–63 and 72 (1935); *Present position of the cast iron test bars*, discussion on Harbach's paper, Foundry Trade J. (London) **53**, 146–147 (1935).

[3] Tentative specifications for gray iron castings, Proc. ASTM, **32**, I, 630 (1932).

[4] E. J. Ash and C. M. Saeger, Jr., *Shop method for determining volume changes in cast iron during casting*, Trans. Am. Foundrymen's Assn. **40,** 188–200 (1932).

[5] R. Moldenke, The Principles of Iron Founding, second edition, p. 197 (McGraw-Hill Book Co., New York, 1930).

[6] S. Southcott, *Test bars from the foundrymen's point of view*, Foundry Trade J. (London) **51,** 73–75 (1934).

[7] R. Baumann's method as described in Die praktische Nutzanwendung der Prüfung des Eisens durch Ätzverfahren und mit Hilfe des Mikroskopes, by E. Preuss-Berndt-v. Schwarz, p. 6 (Julius Springer, Berlin, Germany, 1927).

[8] Franz Roll, Das Primärgefüge des grauen Gusseisens, Arch. Eisenhuttenw. **8,** no. 3, 129–130 (Sept. 1934).

WASHINGTON, February 28, 1936.

O