DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

George K. Burgess, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 252

[Part of Vol. 18]

THE NICK-BEND TEST FOR WROUGHT IRON

BY

HENRY S. RAWDON, Physicist

SAMUEL EPSTEIN, Associate Physicist

Bureau of Standards

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By Henry S. Rawdon and Samuel Epstein.

ABSTRACT.

The "nick-bend" test is included in nearly all specifications for wrought iron, the character of the fracture of a nicked bar being the criterion by which the material is judged. A coarsely crystalline fracture is generally considered as indicative of inferior material. Most American specifications are very indefinite regarding the manner by which the specimen is to be broken and permit any method between slowly applied pressure and a single-blow impact stress. This investigation was carried out upon eight different grades of wrought iron and one of open-hearth iron which were fractured under different conditions and the character of the fracture studied. The "crystallinity" of the fracture depends upon the size and distribution of the slag threads in the wrought iron and is a maximum in open-hearth iron, which contains no such slag inclusions. The rate at which the specimen is fractured also affects the character of the break, and when broken by severe impact crystallinity usually results. The same material broken by bending, which is permitted by most specifications, usually shows a fibrous fracture. The results show that the test can not be depended upon to show the presence of "steel" in wrought iron nor to give results by which the phosphorous content may be judged. In short, in many specifications the "nick-bend clause" is meaningless and should either be eliminated or redefined.

CONTENTS.

I. INTRODUCTION.

In practically all specifications for wrought iron in the form of rods and bars, and very often plates, the material is required to pass satisfactorily a "nick-bend" test. The clause from the standard specifications of the American Society for Testing Materials [1] for stay bolt, engine bolts, and extra refined wrought-iron bars may be quoted as typical of this requirement:

The test specimen when nicked 25 per cent around with a tool having a 60° cutting edge, to a depth of not less than 8 nor more than 16 per cent of the diameter of the specimen and broken, shall show a wholly fibrous fracture. Bend tests may be made by pressure or by blows.

In some grades of wrought iron a certain percentage of crystalline area is permitted in the fracture of a test specimen broken as described above. For example, the standard specifications of the A. S. T. M. for wrought-iron plates (specification A 42–18) permit 10 per cent crystalline area in a fractured nick-bend specimen of wrought-iron plate. According to the Navy specifications [2] few crystalline spots will be tolerated in the fracture of a nick-bend specimen of wrought-iron bars for the manufacture of chain, provided they do not exceed 10 per cent of the total area of the face of the fractured specimen.

The requirements of British specifications for wrought iron may be illustrated by the following clause from specification 51 of the British Engineering Standards Association:

Test pieces * * * shall be lightly and evenly nicked on one side with a sharp cutting tool and bent back at this point through an angle of 180° by pressure in a press or by a succession of light blows, when they shall show a fibrous fracture free from slag or dirt. The same test pieces when nicked all around and broken off short shall show a fine uniform crystalline fracture.

The following clause [3] may be taken as representative of the French method of carrying out this test:

The bars, notched by machine or by a chisel, are broken suddenly by a hand sledge or by a power hammer while firmly held at one end. The iron ought never to show in its texture large brilliant, or laminated crystalline areas; the grain should be semi-fine, with slight tears; the fiber should be white, elongated, and without traces of slag.

It is quite evident from the preceding that the nick-bend test for wrought iron is a common requirement; also that there are pronounced differences to be noted in the manner in which this test may be carried out. In none of the specifications for wrought iron examined by the authors was there any definite suggestion

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[1] 1921 Book of A. S. T. M. Standards, p. 317, specification A 84–21.

[2] U. S. Navy specifications No. 47–I–1a.

[3] Specifications techniques et cahiers des charges unifies; Chemins de fer Français. Ch. Beranger, publisher, Paris.

offered as to the real significance of the crystalline areas in the fractures of the nick-bend specimens.

It is generally admitted by testing engineers that considerable experience is necessary in conducting this test and in interpreting the results. This is evidenced by the requests which have been received by this bureau for help in the interpretation of the results obtained in this test. Figure 1 shows an assembled group of tested specimens of wrought iron submitted and illustrates the general type of results which may be expected in practice in carrying out the test. It was principally for the purpose of obtaining reliable information for replying to such inquiries that the investigation discussed below was undertaken.

II. SCOPE OF INVESTIGATION.

In brief, the investigation consisted of the fracturing, under known conditions, of nicked bars of a number of grades of wrought iron, the composition, mechanical properties, and structure of which had been carefully determined. The material, which was contributed by various manufacturers for the purpose, in most cases had been manufactured to meet certain A. S. T. M. specifications. Nicked bars, representative of the different materials furnished, were broken under different conditions varying from a simple transverse bending of a specimen supported at the ends to a severe single-blow impact test (drop test). The appearance and nature of the fracture produced under these different methods of fracturing was, of course, the feature which received most attention.

The test is somewhat of the same general nature as the standardized notch-bar impact test, so that it might be expected, *a priori*, that any generalizations concerning the latter, such as the effect of the character of the notch, ought to apply, to some degree at least, in the discussion of this test.

III. MATERIALS USED.

The general nature and character of the different irons used in the investigation are summarized in Table 1, the source from which each material was obtained being referred to by a letter. The order in which the materials have been arranged has no significance other than that it represents the sequence in which they were received at the Bureau of Standards from the manufacturers. Most of the irons were in the form of 1-inch diameter rods of 12-foot lengths. These were cut up into specimens 6 inches in

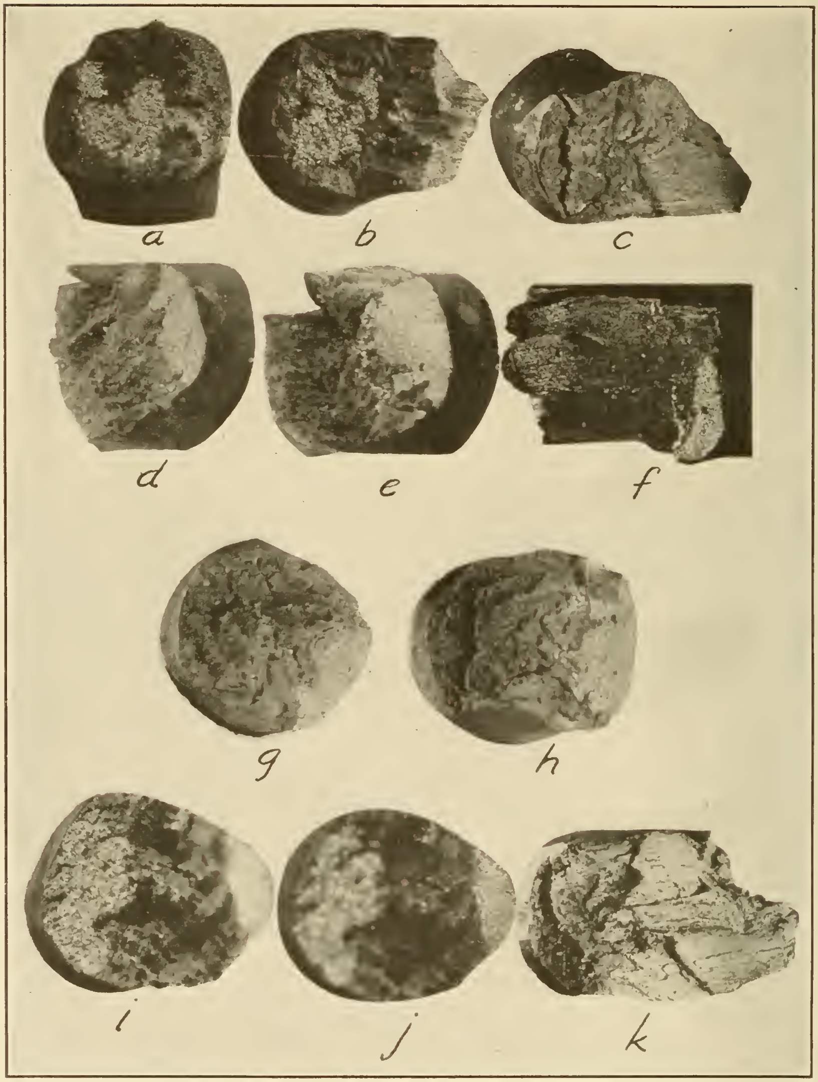

FIG. 1.—*Typical fracture of wrought iron broken by the nick-bend test, submitted by a commercial laboratory (slightly less than* $\times 1$*). The notch in each case is at the left.*

(*a*) 1-inch bar nicked and broken by sledge blows.
(*b*) Specimen similar to (*a*) broken by transverse bending, the specimen (notch downward) being supported at the ends and loaded above the notch. Note the "tension" and the "compression" crystalline areas in both (*a*) and (*b*).
(*c*) Specimen similar to (*a*) fractured by lengthwise compression by means of *light* blows from a steam hammer. The fracture was largely fibrous.
(*d*) Fracture of a nicked bar produced by lengthwise compression in a testing machine.
(*e*) Specimen similar to (*d*) broken by sledge blows. Note the absence of crystallinity on the tension side and the very prominent crystalline area on the compression side of (*d*) and (*e*).
(*f*) Side view of a nicked specimen broken by lengthwise compression in the testing machine. Note the "compression" crystalline area.
(*g*) Specimen broken by lengthwise compression in the testing machine.
(*h*) Specimen broken by light sledge blows. Note the conspicuous "compression" crystalline area in each case and the complete absence of crystallinity on the tension side of the bar.
(*i*), (*j*) Two views, at different focus, of a nicked specimen broken as by sledge blows. Note both "tension" and "compression" crystalline areas.
(*k*) Same specimen as (*i*), broken by lengthwise compression. Note the fibrous character of the fracture.

length, each one being marked so as to record its location in the bar. In the following tests duplicate specimens were used for the most part, care always being taken that for such duplicates two specimens adjacent to each other along the length of the bar were chosen, so as to eliminate possible variations in properties along the length of the bar.

TABLE 1.—Materials Used in Investigation.

Source.	Designation of materials.	Nature of materials.
A	A1	1-inch diameter engine-bolt iron, grade A, A. S. T. M. specifications A 84–21.
	A2	1-inch diameter engine-bolt iron, grade C, A. S. T. M. specifications A 84–21.
	A3	1-inch diameter all-puddle bar, A. S. T. M. specifications A 41–18.
B	B1	1-inch diameter stay-bolt iron, grade A, A. S. T. M. specifications A 84–21.
	B2	1-inch diameter extra refined, grade C, A. S. T. M. specifications A 84–21.
	B3	1-inch diameter refined iron, A. S. T. M. specifications A 41–18.
C	C	1-inch diameter special grade, double-refined iron.
D	D	1-inch diameter stay-bolt iron, grade A, A. S. T. M. specifications A 84–21.
E	E	⅝-inch bar, from first rough rolling of puddled bloom, squeezed from puddled ball (intermediate product).
F	F	1-inch diameter high-phosphorus wrought iron.
G	G	2-inch diameter engine-bolt iron, grade B, A. S. T. M. specifications A 84–21.
H	H	"Open-hearth" iron.

For comparison with the regular commercial grades of wrought iron several special irons were also included. Material E was used to represent an intermediate stage in the manufacture of wrought iron and should not be considered as representative of the finished product of any manufacturer. It was included in the series for the purpose of showing in some measure the extent to which the properties of the finished product are influenced by the amount of "refining" received by the material.

Material F was a wrought iron of exceptionally high phosphorus content. G, although a regular commercial product, was of a much larger size than the other bars tested and was included for the purpose of showing to what extent the crystallinity in a fracture is dependent upon the size of the bar used. Material H designated as "open-hearth iron" is a commercial product which has a structure very similar to wrought iron, except that the slag threads which give the latter its "fibrous" appearance are entirely lacking. In using this material it was hoped that the results would show to what extent the absence of slag threads affect the crystalline appearance of the fracture.

1. CHEMICAL COMPOSITION.

It is quite generally recognized that, for a material which lacks homogeneity to the extent that wrought iron does, the chemical composition is usually of relatively slight significance. How-

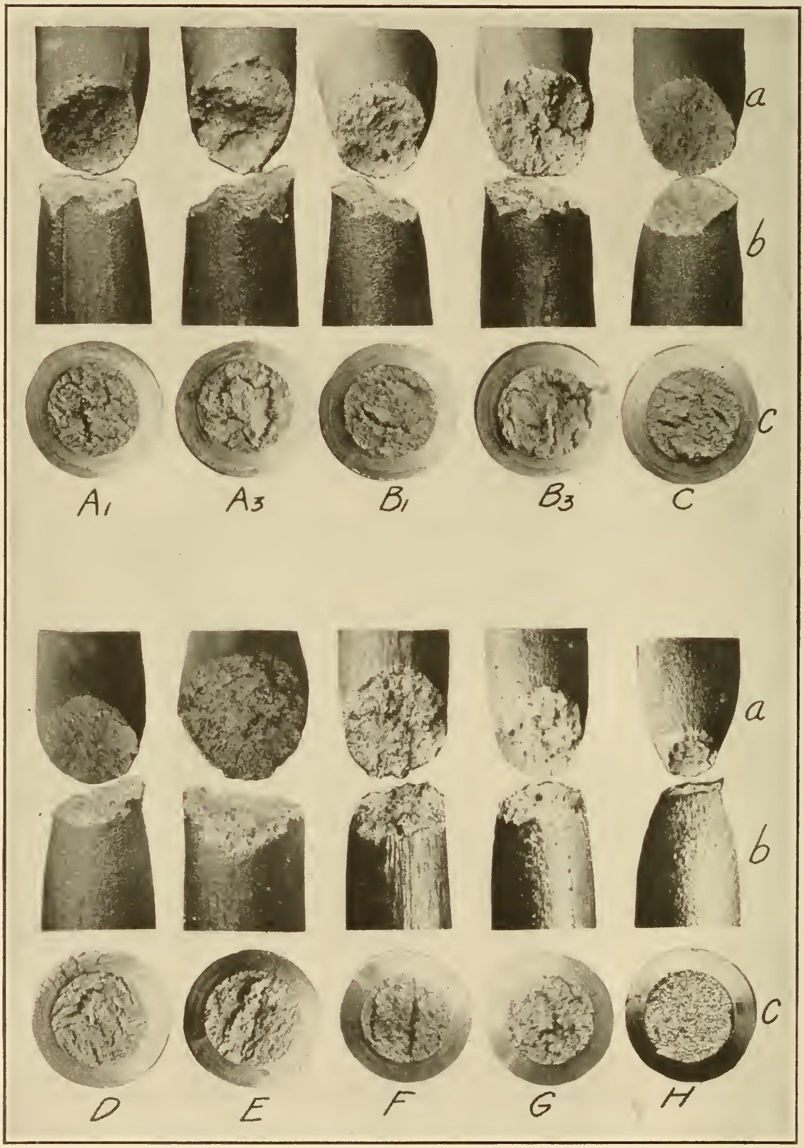

Fig. 2.—*Typical fractures of the various grades of iron broken in tension.*

(*a*) Oblique (45°) view of the end of the broken tension specimen.
(*b*) Side view of the specimens shown in (*a*)
(*c*) End view of fractured notched-tension specimens.
No crystallinity is to be observed in the fractures of any of the specimens of wrought iron (A to G, inclusive).

ever, for purpose of reference and comparison, there are given in Table 2 the results of the chemical analyses of the materials used.

TABLE 2.—Composition of Materials Used.[1]

Specimen.	Elements determined.				
	Carbon.	Man-ganese.	Phos-phorus.	Sulphur.	Silicon.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
A1	0.04	0.046	0.136	0.025	0.265
A2	.03	.051	.139	.022	.25
A3	.04	.114	.132	.027	.09
B1	.03	.031	.083	.015	.13
B2	.01	.030	.126	.016	.16
B3	.02	.080	.129	.017	.10
C	.03	.028	.114	.023	.17
D	.07	.025	.082	.015	.10
E	.04	.031	.103	.023	.22
F	.02	.02	.345	.026	.22
G	.03	.07	.150	.012	.19
H	.02	.02	.004	.020	.003

[1] Analysis by H. A. Bright, associate chemist, Bureau of Standards.

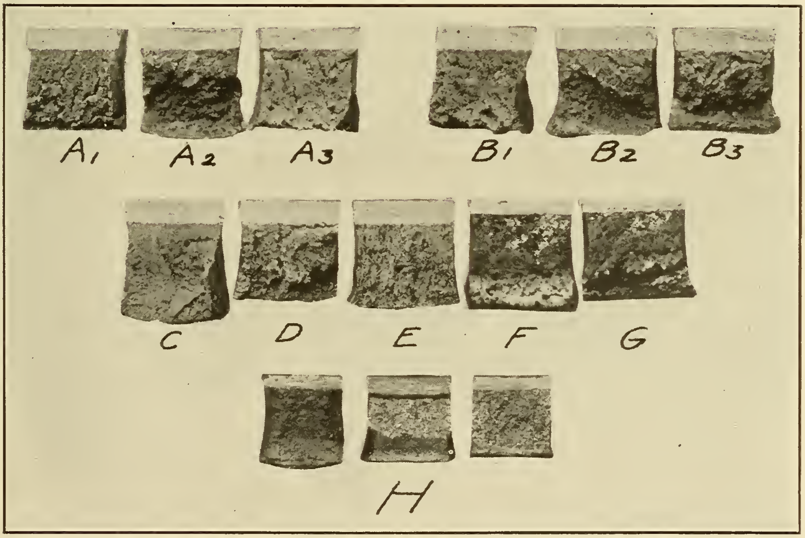

FIG. 3.—*Typical fractures of wrought iron broken by the notched-bar impact (Izod) test.*

Only a few of the specimens show any evidence of crystalline areas in the fracture. Note the high phosphorus wrought iron, F, and the open hearth iron, H.

2. MECHANICAL PROPERTIES.

In Table 3 are summarized the results of the mechanical tests upon the various materials. In addition to the usual tensile properties, the behavior of the material under several other methods of stress application was determined, the tests chosen being those which, it was felt, might possibly throw some light upon the reason for the character of the fracture resulting from the nick-bend method of testing. The resistance to shock was determined by the single-blow notched-bar impact test, the Izod machine being used for most of the determinations, since this permits of several tests being made upon a single specimen; the Eden-Foster method was employed for determining the behavior under repeated impact. The special tension test given in Table 3 was carried out upon specimens in which the reduction of the

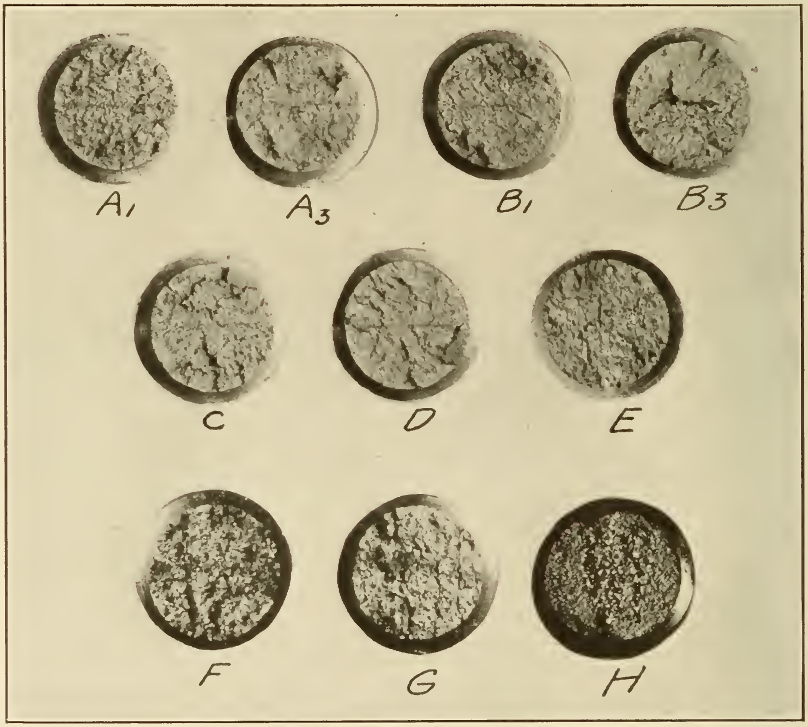

Fig. 4.—*Typical fractures of iron broken by repeated impact (Eden-Foster test).*

Note the traces of crystallinity in *E*, *F*, *G*, and *H*.

bar to a diameter of 0.505 inch was made at only one point along the length by means of a 60° notch. The general character of the results obtained in such a test are well known; there is no appreciable elongation or reduction of area, and the ultimate tensile strength is approximately that obtained in an ordinary tension test if allowance is made for the reduced cross-sectional area in calculating. The nature of the fracture resulting under the conditions of stress employed is of most importance so far as the present investigation is concerned.

TABLE 3.—Mechanical Properties of Materials Used.

Material.	Tensile properties.				Notched-bar tension test.		Impact resistance (Izod), energy absorbed.[2] [3]	Repeated impact test, number of blows, 5-pound hammer.[4]
	Yield point.[1]	Ultimate tensile strength.	Elongation in 2 inches.	Reduction of area.	Yield point.[1]	Ultimate tensile strength.		
	Lbs./in.²	Lbs./in.²	Per cent.	Per cent.	Lbs./in.²	Lbs./in.²	Ft.-lb.	
A1	36,500	51,750	30.5	41.0	....	57,000	35.5, 51.3, 38.5	[5] 21,912 3,422
A2	31,750	50,350	32.0	37.0	....	....	48, 41, 46.5	....
A3	36,500	51,750	30.5	32.5	....	59,000	37.5, 47.5, 42.5	3,022 1,630
B1	33,600	49,350	36.0	50.0	50,500	58,500	46, 49.5, 47	7,070 10,340
B2	37,000	50,100	35.0	51.0	....	....	44.5, 43.5, 45	....
B3	34,500	48,000	19.5	26.5	50,000	56,000	45.5, 45.5, 62	702 700
C	37,900	51,250	38.5	55.0	55,500	60,500	55, 61, 45.5	1,980
D	33,750	48,500	40.5	57.0	54,500	65,000	56.5, 63, 44.5	1,468 660
E	28,500	46,750	11.0	15.0	35,500	40,500	40, 30, 34.5	306 532
					36,000	42,000	31.5, 25.5, 35.5	1,468 726
F	34,250	53,350	29	29.5	47,000	56,000	24, 26, 35 25, 29, 24	1,952
G	32,000	50,500	36	39.5	46,000	58,500	37, 58, 42 49, 47, 37	3,190 2,590
H	27,000	43,250	51.5	76.5	47,500	81,500	[6] 66, 24, 6	2,486

[1] From stress graph: Amsler testing machine was used with the usual 0.505-inch tension test specimens.
[2] Triple-notched specimens (1 cm² (0.394 by 0.394 inch) cross section, 45° V notch 0.079 inch deep) were used, the notches being arranged on three sides of the specimen. Hence, the relationship of notch to orientation of slag threads varied in each specimen. The capacity of the Izod pendulum machine was 120 foot-pounds.
[3] None of the specimens of wrought iron fractured completely upon impact. The results in each horizontal line (F, G, H) were obtained with specimens from the same bar.
[4] Eden-Foster machine was used, the specimens being 6½ inches long, ½ inch in diameter, with a round filleted notch 0.05 inch deep.
[5] 2½-inch drop; 4-inch drop was used for all the others.
[6] See also Table 4.

Some of the variations in the impact-resistance properties to be noted for the same specimens of wrought iron in Table 3 are undoubtedly to be attributed to variations in the location of the notch on the specimen with respect to the arrangement of the slag threads within. The variations in the impact resistance of the open-hearth iron are discussed later at greater length.

3. STRUCTURE.

Macrographs showing the gross structure of the different grades of iron are given in Figures 5 to 16, inclusive. In all cases the finely ground section was etched with an aqueous solution of ammonium persulphate. Concentrated hydrochloric acid was also used, but, on the whole, its use was not so convenient nor successful as the ammonium persulphate. This reagent may be considered as a weak acid, the action of which is intensified by oxygen.[4] The method of "piling" is plainly shown in the trans-

[4] Use of ammonium persulphate for revealing the macrostructure of iron and steel. H. S. Rawdon, B. S. Sci. Papers No. 402; 1920.

verse sections. The conspicuous white streaks may be considered in most cases as the steel-bearing portions of the iron. The posi-

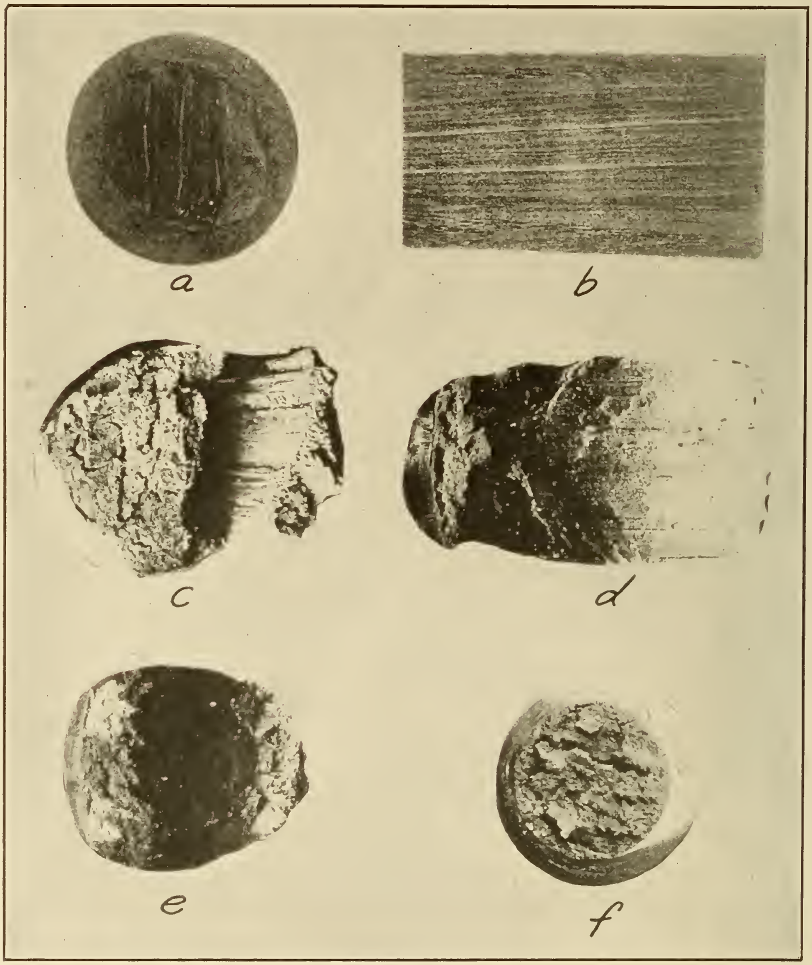

Fig. 5.—*Typical results obtained by the nick-bend test upon wrought iron, specimen A 1 (× 1).*

(*a*) Transverse section, etched with ammonium persulphate to reveal the macrostructure.
(*b*) Longitudinal section, etched with ammonium persulphate.
(*c*) Fracture produced in the nicked bar by transverse bending, the load being applied opposite the notch and the specimen supported 2 inches each side of the notch.
(*d*) Fracture of a nicked bar broken by blows from a 10-pound sledge.
(*e*) Fracture of a bar nicked on one side and broken by the drop test (50-pound, 9 feet).
(*f*) Fracture of a specimen with a circumferential notch broken as in (*e*).
The notched side of the bar is toward the left, in (*f*) the blow was received from the left.

tion of the notch with respect to the macrostructure can be easily determined, since the notch is in the same relative position in all the specimens as is shown in the different figures.

IV. TESTING PROCEDURE.

The necessity for uniformity in the notching of the specimens was recognized at the outset. The extensive investigations which have been carried out on the interpretation of the notched-bar

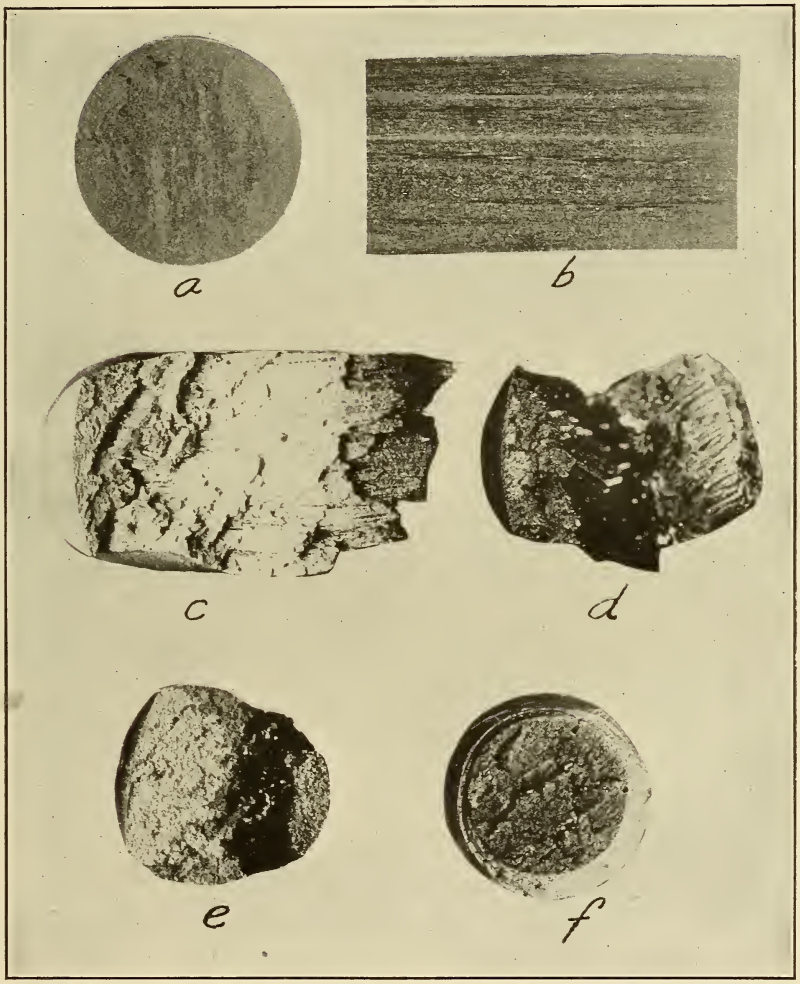

Fig. 6.—*Typical results obtained by the nick-bend test upon wrought iron, specimen A 2 (× 1).*

See legend of Figure 5.

impact test have demonstrated beyond question the fact that the results to be obtained are dependent upon the character of the notch. Thus, of two bars of the same material notched to the same depth, one with a sharp V notch the other having a notch semicircular in section, the impact resistance of the first will, in general, be much less than the second.

1. METHOD OF NOTCHING.

For nicking the bars before fracturing a special tool was employed. This was a chisel, ground so as to produce a 60° cut and having a curved edge, the curve being somewhat greater than that of the circumference of the rod which was to be nicked.

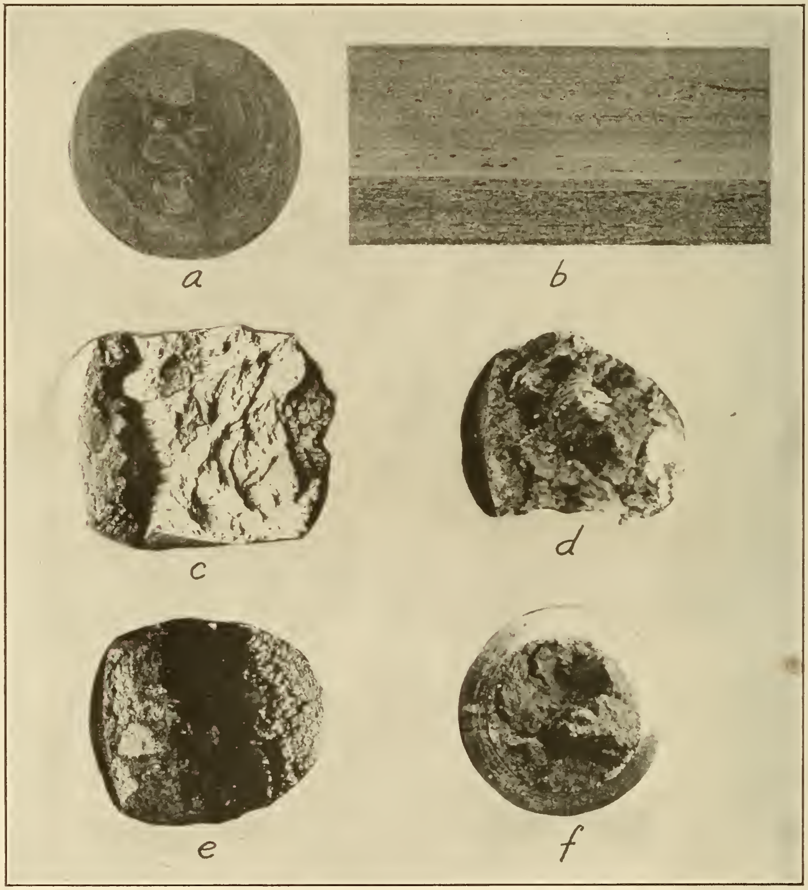

FIG. 7.—*Typical results obtained by the nick-bend test upon wrought iron, specimen A 3 (× 1).*

See legend of Figure 5.
Note the "compression" crystalline area in (*d*) and (*e*).

In order to secure uniformity, the nicks were all made by compression in the testing machine, a load of 20,000 pounds being applied upon the head of the chisel for two minutes. The depth of the notch produced varied slightly with the different grades of iron, from 0.129 to 0.153 inch, the average depth being 0.14 inch. Precautions were also taken to notch all the specimens from each of the bars of wrought iron on the same side, so that the location of the notch with respect to the arrangement of slag threads within would be approximately the same throughout the series.

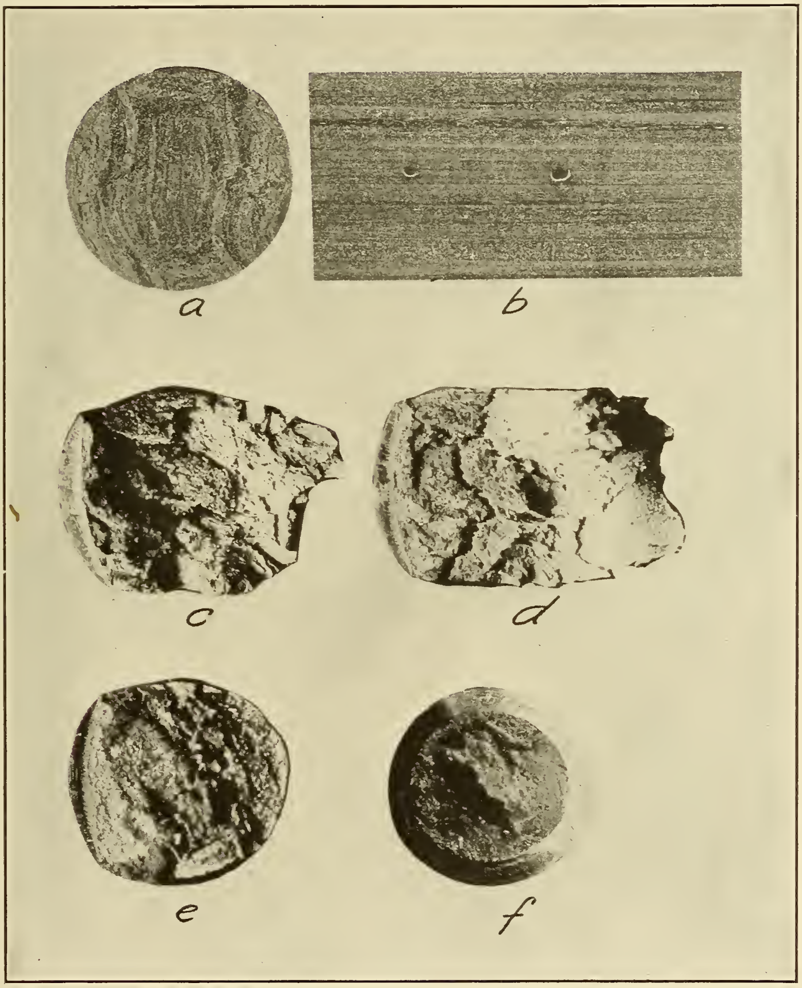

FIG. 8.—*Typical results obtained by the nick-bend test upon wrought iron, specimen B 1* (× *1*).

See legend of Figure 5.

2. METHODS OF FRACTURING.

The following methods were used for fracturing the bars after notching, as described above:

(*a*) TRANSVERSE BEND.—The 6-inch specimen, symmetrically supported on a 4-inch span, was fractured in the Amsler testing machine by having a cylindrical-nosed "pin" approximately 0.8

inch (2 cm) thick forced into it until fracture occurred or the bent specimen could be forced completely through the space between the supports (4 inches).

(*b*) Upright Bend.—The notched 6-inch specimen after having been given a slight preliminary bend was supported on end between

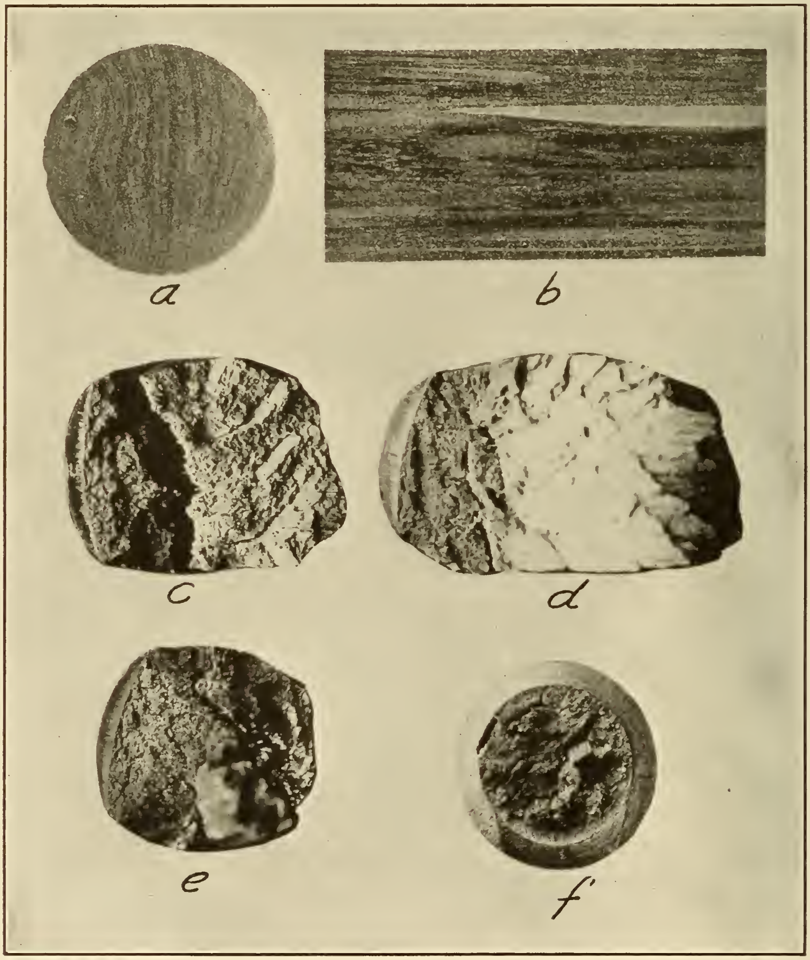

Fig. 9.—*Typical results obtained by the nick-bend test upon wrought iron, specimen B 2* (× *1*).

See legend of Figure 5.

the jaws of the Amsler testing machine and slowly compressed lengthwise until fracture occurred, approximately three minutes being required in the operation. A few of the specimens were also given the preliminary bend before being notched. However, no significant differences in the fractures resulting upon lengthwise compression could be detected in such specimens as compared with those which were notched before being given the preliminary bend.

(*c*) Upright Bend, Second Method.—The test was carried out as above, except that the forging press was used for applying

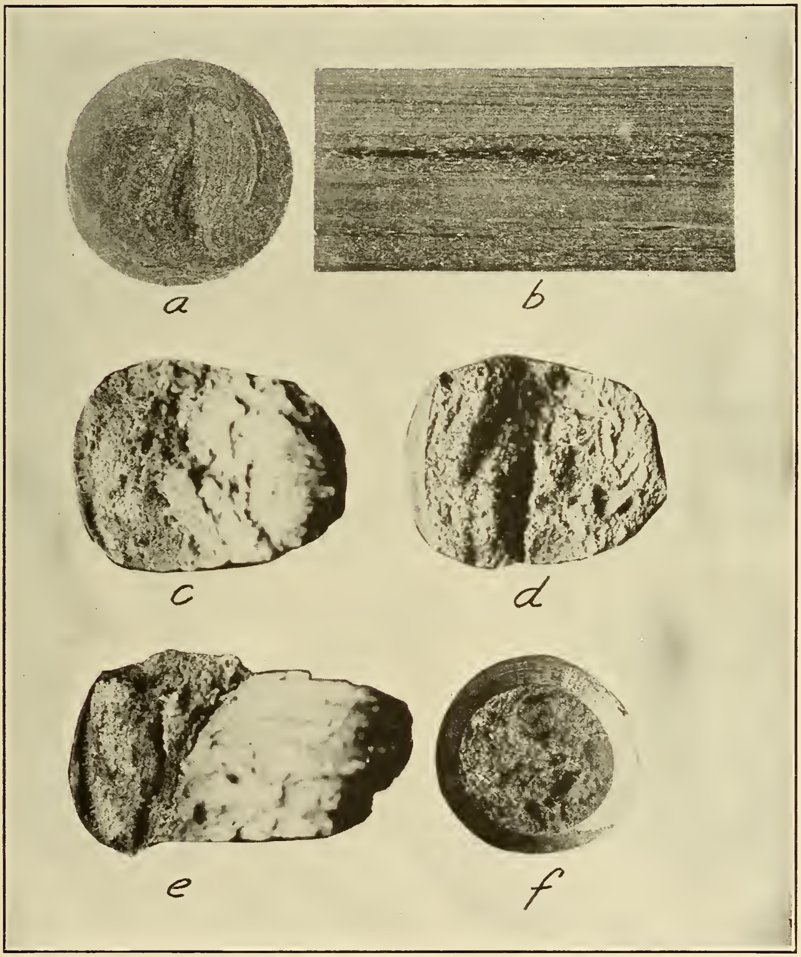

Fig. 10.—*Typical results obtained by the nick-bend test upon wrought iron, specimen B 3* (× *1*).

See legend of Figure 5.

the load, two applications of the load being necessary. The slightly bent specimen was adjusted between the jaws of the press and then suddenly compressed, less than one second being required for the compression. It was necessary to readjust the partially fractured specimen for the second compression.

(*d*) Impact, Hammer Blows.—The 6-inch specimen was inserted up to the notch in a hole only very slightly larger in diameter than the specimen in a heavy anvil and broken by means of blows from a 10-pound sledge hammer applied on the projecting end on the side containing the notch. The number of blows

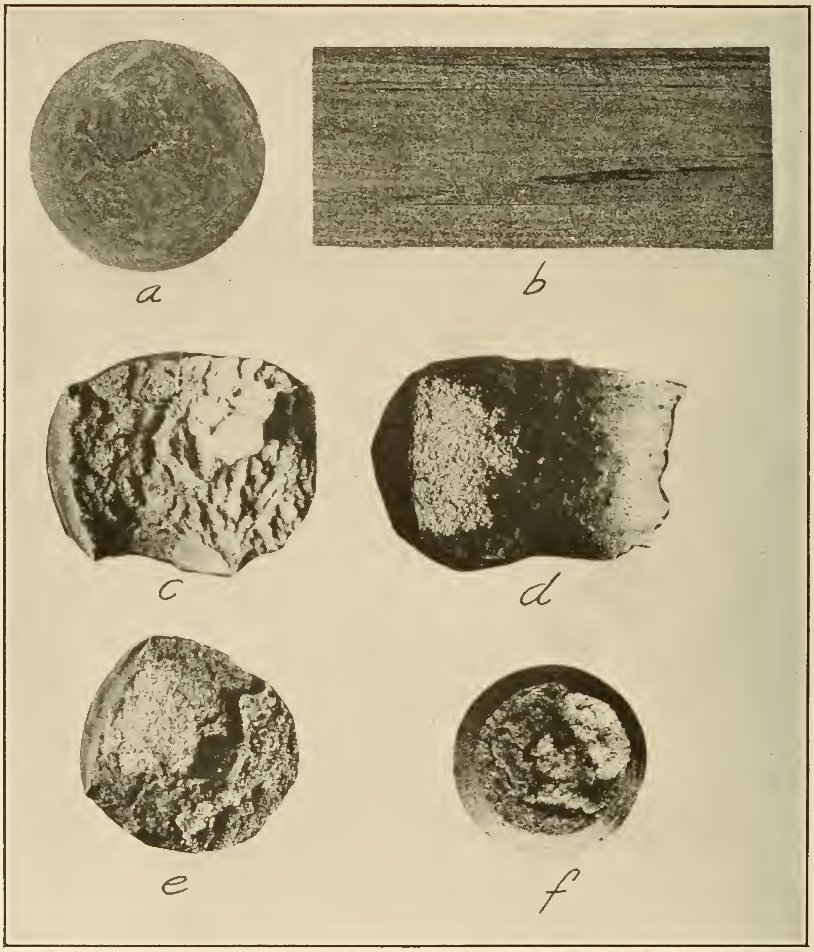

Fig. 11.—*Typical results obtained by the nick-bend test upon wrought iron, specimen C* (× *1*).

See legend of Figure 5.

necessary to produce fracture varied from one to seven with the different specimens. In case crystallinity resulted, the first blow was usually sufficient to reveal it, the others being only supplementary to complete the break.

(*e*) Impact, Single Blow.—The specimen, with the notched side upward, was inserted up to the notch in a hole in a heavy anvil and a 50-pound iron block allowed to fall from a height of 9 feet upon the projecting end. This height was chosen after a few preliminary drops had been made with the same weight from various lesser heights. In addition to the specimens which had been notched in the usual manner, as previously described, duplicate specimens of all the grades, which had been given in the lathe

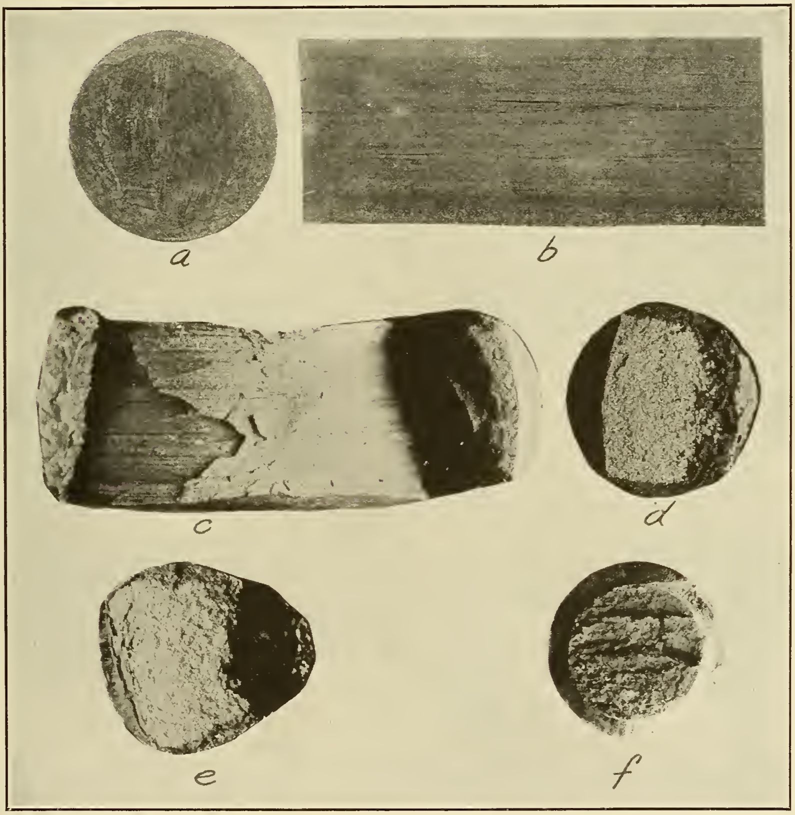

FIG. 12.—*Typical results obtained by the nick-bend test upon wrought iron, specimen D (slightly less than* $\times$ *1).*

See legend of Figure 5.
Note the compression crystalline area in (*d*) and (*e*).

a complete circumferential notch of the same average depth as in the other method of notching, were subjected to the drop test.

3. SPECIAL TESTS.

(*a*) EFFECT OF SIZE OF SPECIMEN.—The nick-bend test as ordinarily carried out in practice is made upon the finished bar regardless of its size. In order to illustrate the possible effect of variations in the size of specimens used, a series of tests was carried out upon a wrought-iron bar 2 inches in diameter. The bar was cut into sections of a length convenient for testing, approximately 9 inches. The series was divided into two groups, alternate specimens—that is, relative to their position in the initial bar—being placed in the same group. The bars constituting one group were tested in the full size after notching;[5] the others were reduced in cross section to 1 inch diameter (fig. 15) and then tested in the same manner. Care was taken so that for each particular method of fracturing the specimens used were taken from adjacent portions of the bar.

(*b*) Preliminary Cold Working.—The suggestion was made by one of the manufacturers supplying material that the results of a test may be influenced to a very marked degree by any cold working the bar may receive prior to test. In order to try this out, specimens 18 inches long cut from bars A^1, A^3, C, and D were permanently stretched in the testing machine in amounts varying from 8 to 25 per cent, as measured on the central 2-inch length of the stretch bar. Six-inch specimens were then cut from the central portion of the bars and after nicking were fractured by transverse bending and by the single-blow drop test.

(*c*) Impact Tests of Open-Hearth Iron.—It was evident from the outset that the nick-bend test partakes more or less of the nature of an impact test, according to the manner in which it is carried out. In order to show the extent to which the results of impact tests, particularly the character of the fracture, are dependent upon the structural condition of the material tested, a series of standard notched-bar impact tests was carried out in addition to those reported in Table 3. For these open-hearth iron was the material used, since this material closely resembles in structure the ferrite or metallic matrix of wrought iron. The results already obtained in the impact tests of wrought iron indicated, in a measure, the important rôle of the slag threads of wrought iron in influencing the type of fracture obtained and suggested the desirability of a material free from such features as this for this test. The preliminary heat treatment given the material to produce variations in grain structure, together with the results obtained, are summarized in Table 4. Microscopic examinations of the fractured specimen were made, special attention being given to the relation of the "path" of the fracture and the crystalline structure of the bar. Examinations were also made of crystalline

[5] See footnote 1, p. 116.

fractures obtained by other methods of fracturing, such as the notched-bar tension test and repeated impact, and the results compared with those obtained by simple impact.

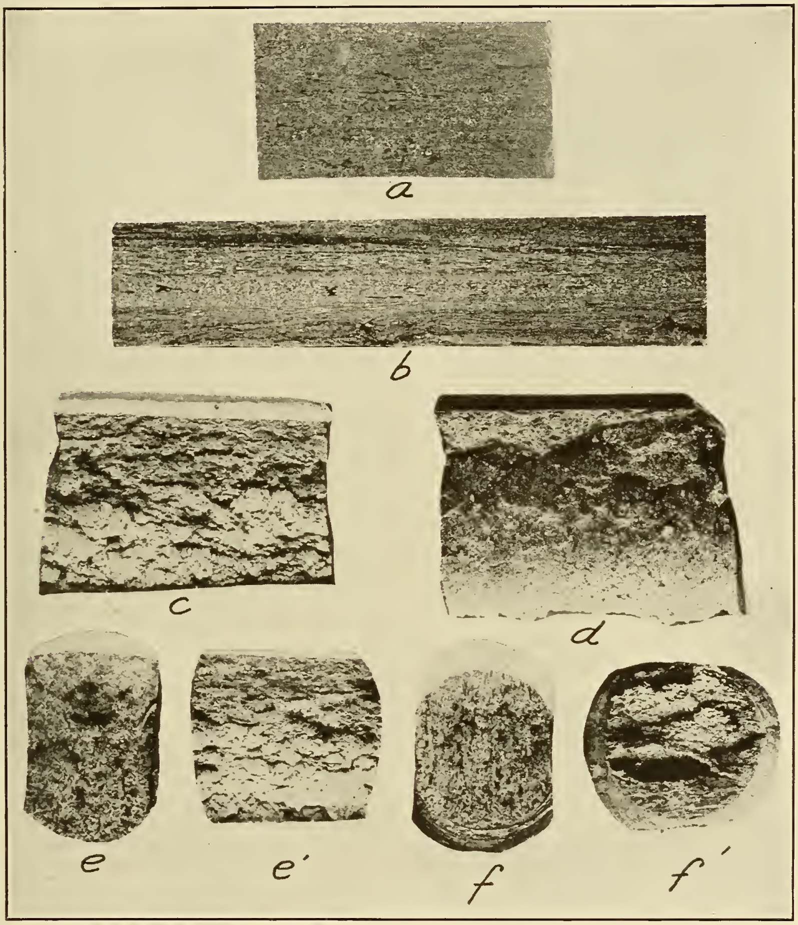

Fig. 13.—*Typical results obtained by the nick-bend test upon wrought iron, specimen E* (× *1*).

(*a*) Cross section of a bar etched with ammonium persulphate to reveal the macrostructure.
(*b*) Longitudinal section of a bar etched as in (*a*).
(*c*) Fracture produced by a transverse bend of a notched bar, the load being applied opposite the notch and the specimen supported 2 inches each side of the notch.
(*d*) Fracture of a nicked bar produced by a 10-pound sledge hammer. Note the small isolated crystalline spots.
(*e*) Fracture produced by the drop test (50-pound, 9 feet) on a specimen nicked on the "edge" of the plate. Note the crystalline area on the tension side.
(*e′*) Fracture of a bar similar to (*e*) which was notched on the flat side of the plate. Note the almost complete absence of crystallinity.
(*f*) Fracture of a bar similar to (*c*), notched completely around. Note the absence of crystalline areas.
(*f′*) Fracture of a bar similar to (*f*), the blow was so as to bend the specimen as in (*e′*).

V. RESULTS.

One of the principal difficulties in an investigation of the kind discussed here lies in the effective presentation of the results, since most of these can not be expressed numerically. A simple statement with reference to the presence or absence of crystalline areas in the fracture of the tested specimen would fall far short of fulfilling the purpose of the investigation. To reproduce photographs of all the bars tested is also undesirable.

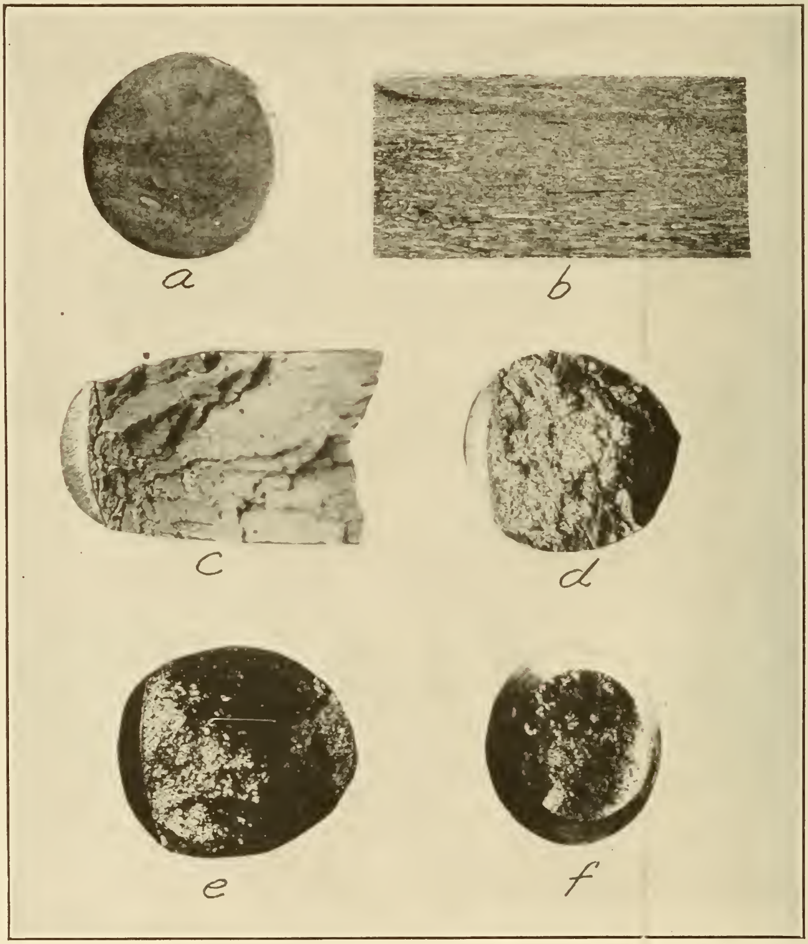

FIG. 14.—*Typical results obtained by the nick-bend test upon wrought iron of high-phosphorus content, specimen F* (× *1*).

See legend of Figure 5.

The characteristic features of the fractures produced by breaking nicked specimens of the various grades of iron under different conditions have been summarized by means of representative photographs in Figures 5 to 15, inclusive. For purposes of comparison Figures 2, 3, and 4, showing the fracture of the different materials when subjected to the various mechanical tests; tension, impact, and repeated impact, have been included. In none of the ordinary tension or the notched-bar tension specimens (fig. 2) was there any indication of a crystalline structure revealed in the fracture of the wrought irons. In the notched-bar impact (Izod) fracture only slight indications of crystallinity were shown by a few of the specimens (fig. 3). Of those fractured by repeated impact (Eden-Foster test) only one gave any indication of crystalline spots in the fracture. It may be concluded, then, that the nick-bend test, as employed for the testing of wrought iron, is evidently intended to reveal certain characteristics of the material which the usual mechanical tests indicate only very slightly, if at all.

It will be seen from Figures 2, 3, and 4 that the behavior of open-hearth iron (specimen H) when tested was quite different from that of the wrought irons. Although very ductile, as was evidenced by the usual tension test, this material showed a very pronounced crystalline fracture when broken by the notched-bar tension tests. Likewise, the notched-bar impact specimens showed much more evidence of a crystalline fracture than did the similar specimens of wrought iron. This feature is discussed below at greater length.

The fractures produced in nicked bars by lengthwise compression in the testing machine and in the forging press were found for most of the materials not to differ in any marked respects from those resulting from simple transverse bending. Hence, in order to conserve space in reproduction, photographs respresentative of this method of fracturing have not been included in the sets given.

The photographs were taken so as to show all the specimens at natural size. In many cases, however, it was necessary to tilt the sample so as to reveal clearly the characteristic features; hence some distortion appears in some of the photographs. It will be evident even from a cursory examination of the fractures that simple transverse bending of a nicked bar of each of the nine grades of iron used was not sufficient to reveal in the fracture any significant features, such as the nick-bend test is intended to show. The fact that impact is necessary in the production of the large conspicuous crystalline areas is evident in nearly all the figures in the fractures resulting from the use of the sledge or from the single-blow impact test. In many of the fractured specimens, and particularly in the open-hearth iron, two crystalline areas may be noted, one immediately beneath the notch and the other on the opposite side of the bar. This feature is illustrated in Figures 1,

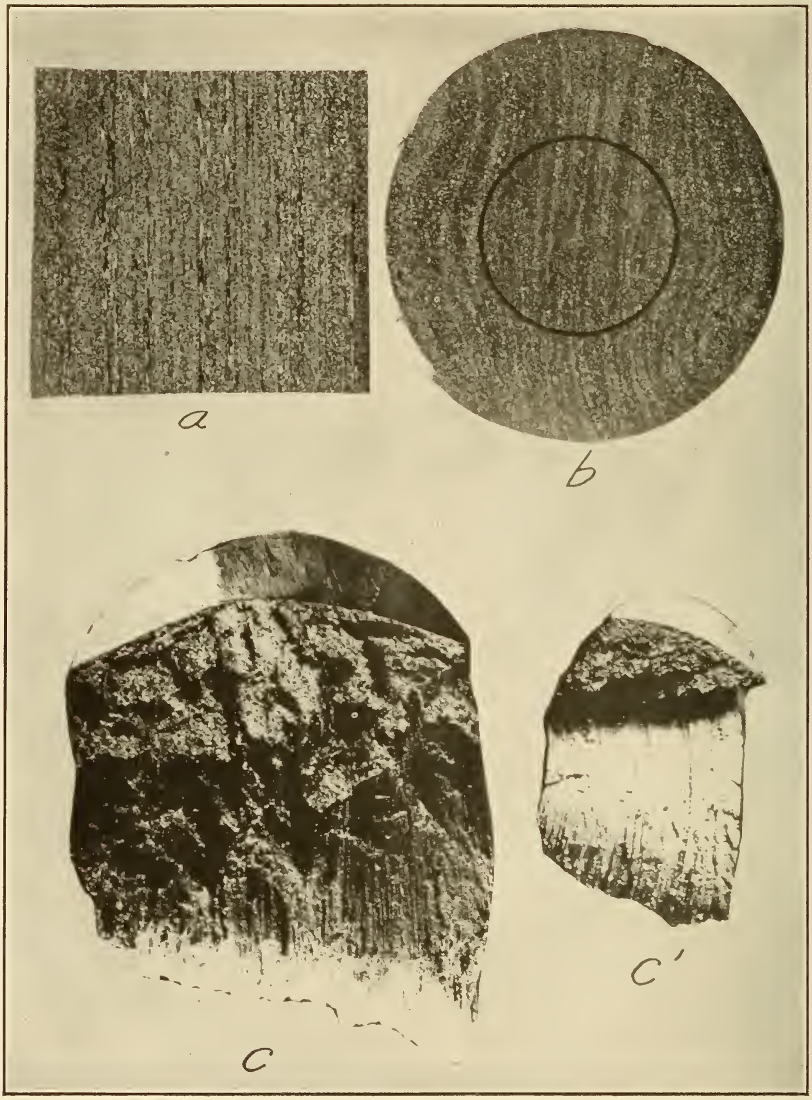

FIG. 15.—*Typical results obtained by the nick-bend test upon wrought iron, specimen G (× 1).*

The small bars were obtained by machining the 2-inch bars to 1 inch diameter as indicated in (*b*).
(*a*) Longitudinal section, etched with amonium persulphate to reveal the macrostructure.
(*b*) Transverse section etched in a similar manner.
(*c*) Fracture produced in the nicked 2-inch bar by transverse bending, the load being applied centrally on a 6-inch span, opposite the notch.
(*c*') Fracture produced in the nicked 1-inch bar stressed as in (*c*), 4-inch span.

6, 7, 12, 14, and 16, and the real significance of these two crystalline areas will be considered later.

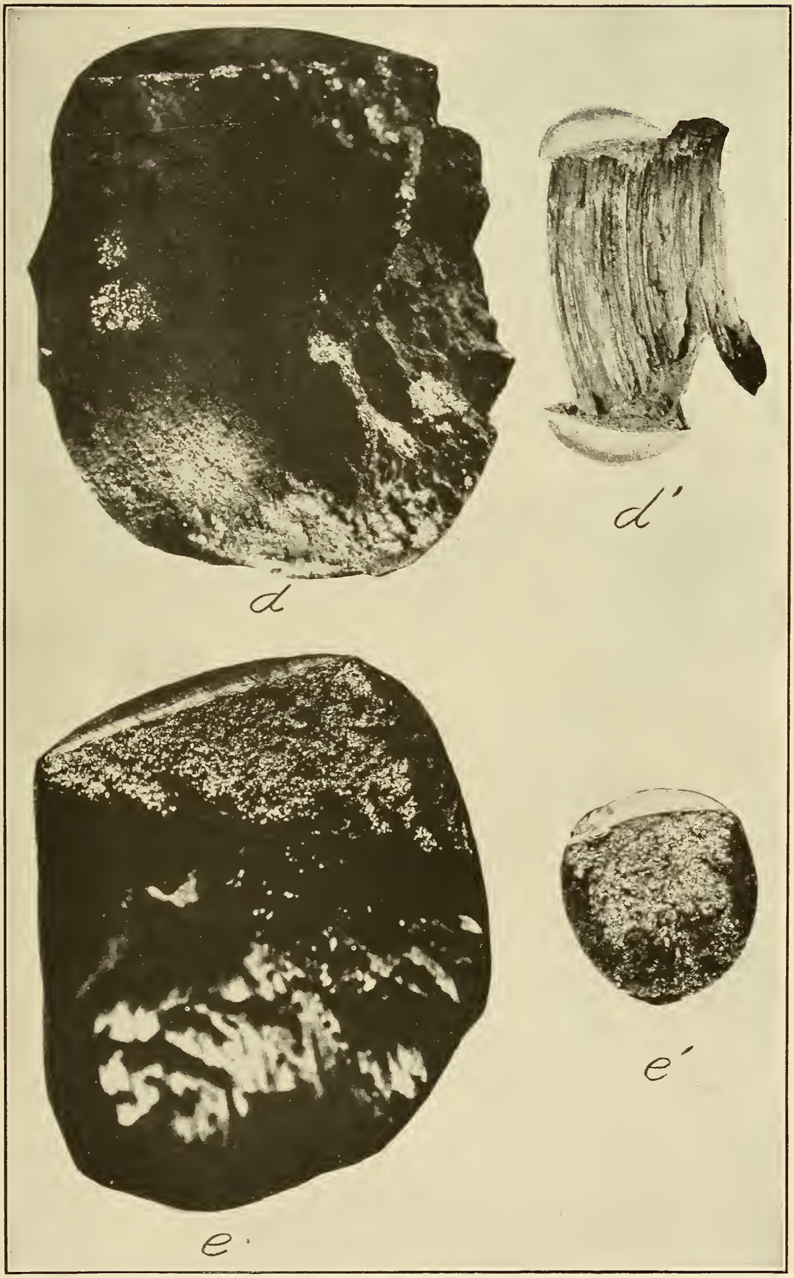

FIG. 15 (Continued).—*Typical results obtained by the nick-bend test upon wrought iron, specimen G* (× *1*).

(*d*) Fracture produced in the nicked 2-inch bar by upright bend in the forging press.
(*d'*) Fracture produced in the nicked 1-inch bar, stressed as in (*d*.)
(*e*) Fracture produced in the nicked 2-inch bar by blows from a 10-pound sledge.
(*e'*) Fracture produced in the nicked 1-inch bar, stressed as in (*e*).

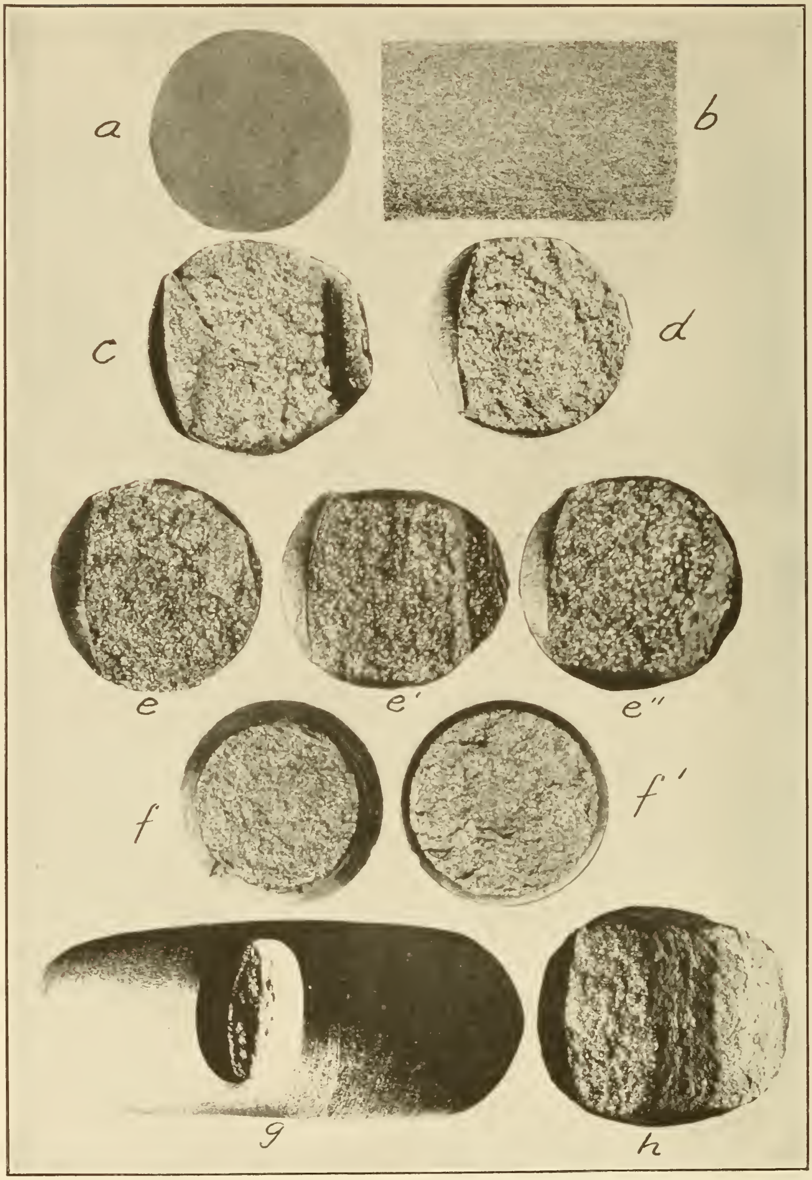

FIG. 16.—*Typical results obtained by the nick-bend test upon open-hearth iron, specimen H. Notch is toward the left.* (× 1).

(*a*) Transverse section etched with ammonium persulphate.
(*b*) Longitudinal section similarly etched.
(*c*) Fracture of a nicked broken by transverse bending, the load being applied centrally opposite the nick, 4-inch span.
(*d*) Fracture resulting from blows with a 10-pound sledge.
(*e*), (*e'*), and (*e''*), fracture resulting from the drop test, 50-pound tup, 6, 4, and 3 feet, respectively.
(*f*) and (*f'*), fracture resulting from the drop test (50-pound, 9 feet) on circumferentially notched specimens, notch one-eighth and one-sixteenth inch, respectively.
(*g*) Results of an "upright bend" as carried out in the testing machine.
(*h*) Fracture resulting from an "upright bend" in the forging press. Note the two types of crystalline areas.

It will also be seen in the bars fractured by the single-blow impact test that the extent of the notch around the specimen had a pronounced effect upon the character of the fracture. In none of the specimens of wrought iron having the circumferential notch was there any pronounced crystallinity in the fracture when

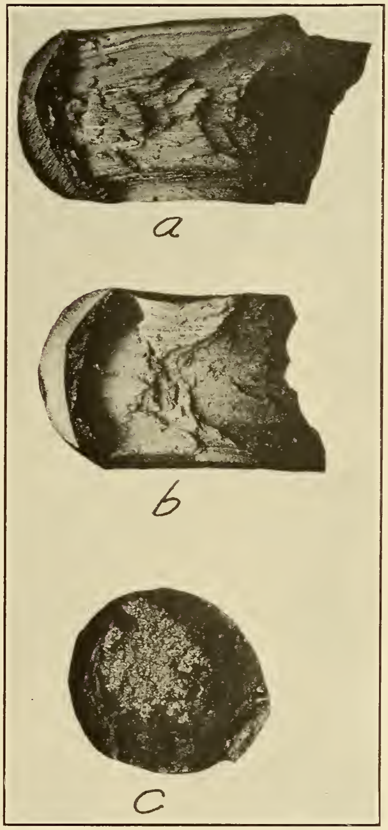

FIG. 17.—*Fractures resulting from the nick-bend test of wrought iron (grade C), previously deformed by stretching* (× *1*).

(*a*) The nicked specimen was broken by transverse bending.
(*b*) Similar specimen broken by the drop test (50-pound, 9 feet).
(*c*) Similar specimen broken by the drop test (50-pound, 13 feet).
Compare with Figure 10.

broken by the drop test. Figure 15 shows the fractures which were obtained with specimens of different cross-sectional area cut from the same bar. It will be noted that areas which were crystalline in the smaller bars were not so in the fractures of the larger ones.

The appearance of the fracture of the bars subjected to cold working by stretching prior to carrying out the nick-bend test showed no differences which might be considered as characteristic of irons which had received such a treatment. The results shown in Figure 17 for material C are typical of the fractures obtained for all those tested. The cold working which the bar received in the preliminary stretching increased the tensile strength to a very marked extent, so that a much severer blow was necessary in order to fracture the bar. For specimen C a fall of 13 feet for the 50-pound weight was necessary in order to fracture the specimen, whereas for the unstretched specimen a blow from the same weight from 9 feet was sufficient. Aside from this no other differences were noted and the characteristic features of the fracture were not essentially changed.[6]

TABLE 4.—Results of Notched-Bar Impact Tests of Open-Hearth Iron After Annealing.

Specimen number.	Treatment, degrees Centigrade, furnace cooled.	Test used.	Impact resistance, energy absorbed.	Remarks.
			Ft.-lb.	
H1	As received	Izod [1]	[1] 66, 24, 6	See Figure 3 for fractures.
H2	do	do	29, 49, 69	
H3	do	do	65, 66, 71	
H13	1,100°, ½ hour	do	41, 46, 75	
H14	1,000°, ½ hour	do	72, 75, 77	
H17	900°, ½ hour	do	73, 78, 76	
Ha, b, c	1,150°, 1 hour	Charpy	194, 194, 195	Figure 22, micrograph Hc.
Hd, e, f	1,000°, 1 hour	do	23, 189, 199	Figure 21, micrographs of Hd and He.
H9, 10	900°, ½ hour	do	199, 204	
H21–24	1,150°, 1 hour	Charpy, square	15, 180	Figure 19 for fractures of H21–32.
		Charpy, round [2]	34, 34	
H25–28	1,000°, 1 hour	Charpy, square	10, 14	Figure 22, micrograph H21.
		Charpy, round	27, 24	
H29–32	900°, ½ hour	Charpy, square	181, 171	Figure 19, micrographs of H30.
		Charpy, round	177, 173	

[1] Triple-notch bars in all Izod tests.
[2] Specimen 0.45 inch diameter, 45° V notch, 0.13 inch deep.

Wrought iron of relatively high phosphorus content fractures more readily under impact (Table 3), as would be predicted. The fractures resulting from the nick-bend test (fig. 14), however, show no features which can be considered as characteristic of this type of wrought iron alone.

The results of the notched-bar impact tests carried out upon open-hearth iron for the purpose of showing how the structural features may affect the impact resistance and the character of the fracture under impact are given in Table 4. The characteristic differences in structure are shown in the micrographs in Figures 20, 21, and 22 and are discussed in the next section.

[6] The results obtained are apparently not in accordance with those published by Jones and Greaves, Proceedings, Inst. Civ. Engrs. (British) 211 (1920–21), who report that the general effect of overstrain is to reduce the impact figure

VI. DISCUSSION.

It is evident from the results summarized above that the rate at which the load is applied in fracturing the notched bars of wrought iron is of very great importance and appears to be one of the predominating factors which determine the character of the fracture. Each of the nine grades of wrought iron, when stressed slowly or at a moderate rate in compliance with A. S. T. M. specifications for such materials, broke without showing any marked tendency toward crystallinity; whereas when fractured by impact, either by sledge blows or by the drop test, the appearance of the fracture was very materially changed. All of the specimens showed crystalline areas the size of which varied with the different grades of iron.

Another factor which appears to bear a close relationship to the size of the crystalline areas developed under impact is the relative size and distribution of the slag threads. Irons C and D (figs. 11 and 12) may be used to illustrate this point. The appearance of these two materials when etched showed a very uniform distribution of the slag threads, as compared with some of the other specimens, and also indicated the absence of any exceptionally large slag threads. The iron matrix was very uniform in appearance and lacked the conspicuous contrasting streaks which were so prominent in some of the other irons. Material D showed the most uniform structure by far of the nine grades of iron tested and also developed the most conspicuous crystalline fractures in the nick-bend test. Material C, which was somewhat less uniform in appearance, showed somewhat smaller crystalline areas when fractured.

When the continuity of the metallic matrix is broken by large slag threads, the probability of a fibrous fracture being produced is increased proportionally. In case there are very prominent slag plates favorably oriented with respect to the direction of the applied stress, longitudinal separation of the metal following the fracturing of a small portion of the metal may result as illustrated by several of the specimens tested. This is much more apt to occur when the specimen is slowly stressed than when subjected to shock.

The behavior of material E, which was wrought iron which had intentionally not received complete refining, confirms what has just been said concerning the influence of prominent slag threads on the production of crystalline fractures under the nick-bend test. This material represented an intermediate stage in the manufacture of wrought-iron plate and contained rather conspicuous plates of slag alternating with layers of iron, the whole being arranged like the leaves in a book. When nicked and fractured on the edge of the "leaves," conspicuous crystalline areas resulted; whereas when broken under the same conditions, except that the nick was made at right angles to the first—that is, on the flat side of the leaves—no crystallinity resulted. It should be noted, however, that the "depth" of the cross section of the specimen was not the same in both cases, a fact which may have had some effect upon the behavior of the sample.

The pronounced crystallinity of the fracture of the open-hearth iron (material H) when broken by the nick-bend test is very striking. As is shown in Figure 16, this material even when slowly stressed by transverse bending gave a fracture as crystalline in appearance as that resulting from impact in the drop test. The absence of slag threads from this material by which the continuity of the metallic matrix would be broken, without question will account in large measure for this characteristic behavior. Any separation once started would be propagated relatively easily across the specimen instead of being forced to start anew repeatedly, as would be the case with wrought iron where the continuity of the metallic matrix is interrupted by numerous included slag threads.

By many, in practice, the nick-bend test is thought to reveal the presence of steel in wrought iron. That this is not so was readily shown by an examination of the microstructure of the specimen in the portions showing the crystalline fracture. The fact that prominent "steel" streaks, as revealed by the deep etching of the specimens, were not found in all of the irons, whereas all of them readily developed "crystallinity" when the nicked specimen was broken in the proper manner, should constitute sufficient evidence in deciding upon this point. However, one of the specimens, A 3 (fig. 7), gave results which suggest that the presence of prominent steel streaks within wrought iron do affect to some extent the character of the break. The three prominent areas (fig. 7) seen in the cross section of specimen A3 were found to have the characteristic microstructure of low-carbon steel. In nearly all the fractures of this bar three areas corresponding to these streaks were noted, and in the fractures resulting from impact stresses these areas were largely crystalline in appearance. Likewise, it may be noted in B 1 (fig. 8) that the location and shape of the crystalline areas resulting from impact, particularly by the sledge, appear to have been determined to a noticeable extent by the white (steel bearing) streaks to be seen in the cross section

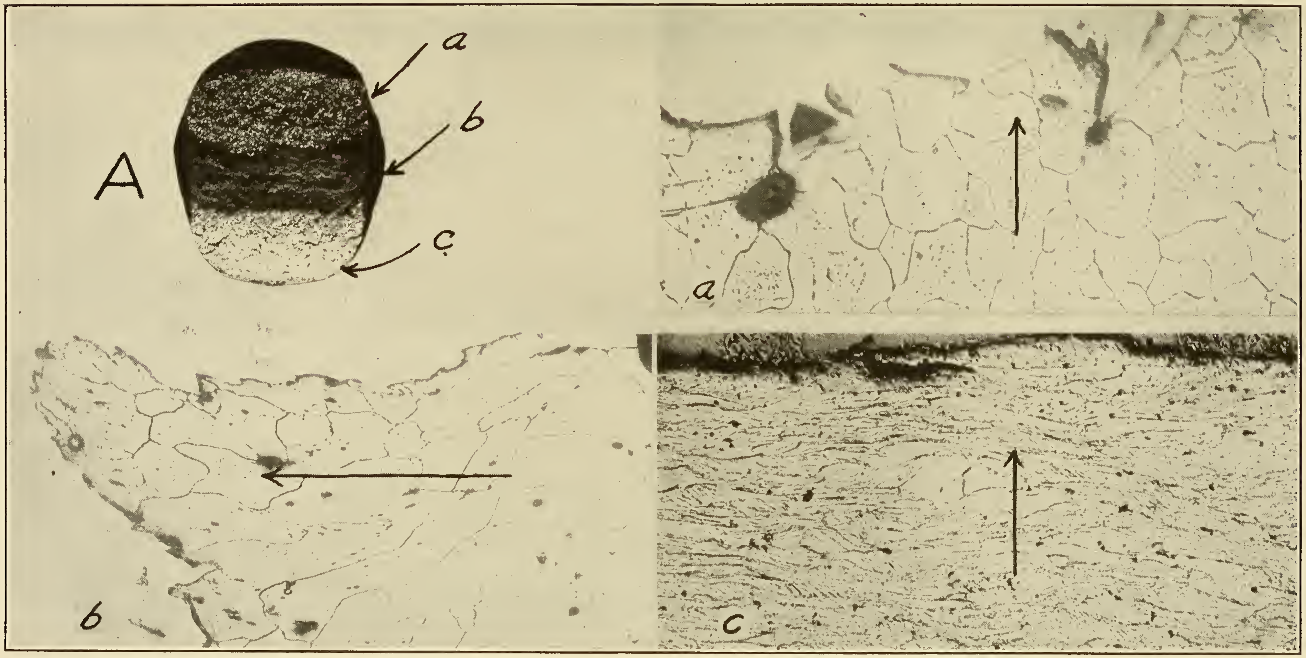

FIG. 18.—*Relation of the fracture in the nick-bend test of ferrite to the crystalline structure.*

A, Fracture, open-hearth iron nicked and broken by upright compression. × 1. (Compare fig. 16.)
(*a*) Microstructure of the "tension" crystalline area. Note the transcrystalline fracture with no deformation of the grains.
(*b*) Microstructure of the central fibrous portion. Note how crystals at the surface were drawn out to points.
(*c*) Microstructure of the "compression" crystalline area. Note the pronounced flattening of the grains perpendicular to the length of the bar.
Etching reagent, 5 per cent alcoholic picric acid; magnification, × 100. The arrows are perpendicular to the face of the fracture.

of this bar. This factor, as contributory to the character of the fracture, is of only minor importance, however, as compared to the character and distribution of the stress causing rupture.

In short, it may be concluded that the crystalline areas in the fractures of wrought-iron bars broken by the nick-bend test are not to be interpreted, necessarily, as indicative of the presence of steel. On the other hand, steel streaks do appear to render wrought iron somewhat more prone to develop crystalline fractures than similar irons free from such streaks.

Mention has already been made of the presence of two crystalline areas of different types in many of the nick-bend fractures, one on the tension side of the stressed specimen and the other near the compression side. Although the two types may appear very similar in a photograph, to the eye there are very distinct and characteristic differences to be noted. The "compression" areas, although crystalline in appearance, lack the rough, sharp contour, and hence much of the sparkling appearance of the "tension" areas. The softer sheen of the compression areas, taken in connection with the fact that they are best seen when viewed at certain definite angles, suggested an appearance characteristic of a surface covered with flattened scales.

The fact that the location of the notch along the circumference of the bar, which thus fixes the direction from which the stress will be applied, determines the position of these two areas is very significant. It would appear that since the relative position of the two areas can be varied at will, they do not depend upon nor indicate different characteristic properties of the material.

The real difference between these two types of crystalline areas is best shown by an examination of the microstructure as illustrated in Figure 18, which represents longitudinal sections of a specimen of open-hearth iron perpendicular to the face of the fracture. It will be noted that in the tension crystalline areas the fracture occurred as a transcrystalline break; that is, along cleavage planes, without any deformation of the individual crystals. The direction of the cleavage of several adjacent crystals was found to coincide frequently, thus giving rise to larger "facets." The contour of the surface resulting from this type of rupture presents a rough, jagged outline along any right section taken through it. These features in the fracture of a ductile metal as determined by ordinary tests are generally considered characteristic of a break occurring very suddenly, usually, though not always, by impact. In the fibrous portion of the fracture, for example between the two crystalline areas, the crystals of iron were severely deformed by tension, each being drawn out to a fine point at the place of rupture. Evidently the stress causing rupture in this part of the bar acted at a much slower rate than in the portion which gave the crystalline break just described. The appearance of the metal in the compression crystalline areas shows that the grains were subjected to very severe compression previous to the final tensile break. Many of the grains were flattened perpendicularly to the length of the bar, and others not so severely distorted in shape

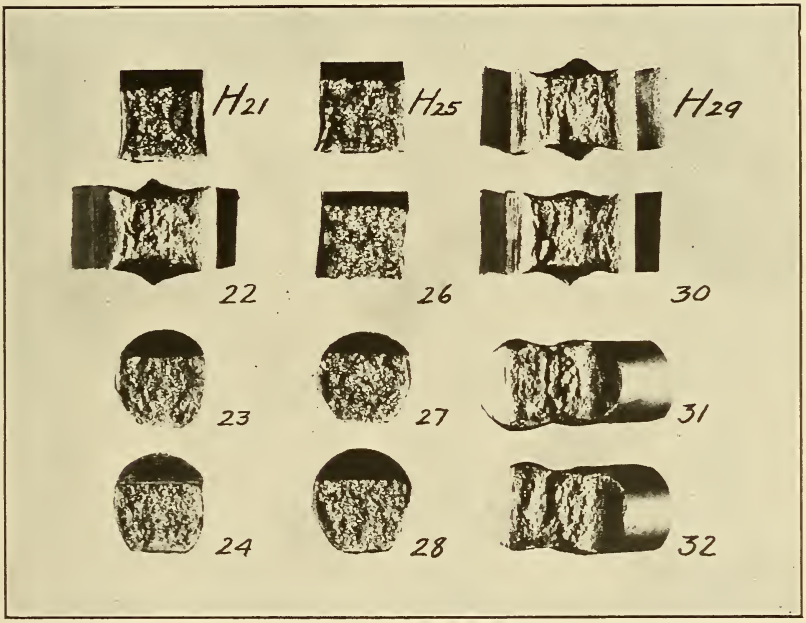

Fig. 19.—*Fractures of impact specimens of ferrite after different annealings, Charpy test.* Compare Table 4, specimens H 21 to 32.

showed numerous prominent slip bands resulting from compressive stress. In most cases the bar subjected to the drop test did not fracture completely. It was necessary to complete the break, usually by hammer and vise, whereupon the compressive crystalline area was revealed. The characteristic scaly appearance of these areas appears to be the direct result of the severe compression the crystals were subjected to during the period of impact rather than to any characteristic property of the metal as it exists in the unstressed bar. The fact that the location of the notch along the circumference of the bar determines the location of the two types of crystalline areas is also very significant. It is evident, then, that the two types of crystalline areas originate in an entirely different manner and should not be regarded as indicative of the same characteristic of the metal. The results shown in Figure 18 for open-hearth iron are representative also for the wrought irons.

The fact that crystalline fractures developed much more readily in the open-hearth iron, which was free from slag threads, than in the various grades of wrought iron used is shown by a comparison of Figures 5 to 16 of the specimens broken by the drop test after being notched circumferentially, instead of on only one side. The specimens of wrought iron having circumferential notches showed no crystallinity whatever, although the same material notched on one side and broken in a similar manner in all cases showed some crystalline patches and in many very pronounced ones. On the other hand, the open-hearth iron developed pronounced crystalline fractures by both methods, as it did also in the notched-bar tension test. Although there is a pronounced difference in stress distribution across the section of specimens notched in the two different manners when tested by impact, the decided difference in the behavior of the two materials indicates that the presence of the slag threads in the one case must be the real cause of the difference. Just why this is so is not evident from the results of this investigation.

The results obtained in the series of impact tests carried out upon the open-hearth iron (Table 4) after various annealing treatments throw some light upon the general subject of the production of crystalline fractures in ferrite. These results indicated that, in general, the impact resistance of ferrite decreases with increase of crystal size resulting from the annealing at a high temperature. This rule is not invariable, however, and several very pronounced and significant exceptions will be noted in Table 4.

The comparison of the microstructure of impact specimens showing wide variations in their impact resistance after identical treatments proved very suggestive. The micrographs of Figures 20, 21, and 22 illustrate the structural differences noted in such specimens. It will be seen that if, as a result of annealing at or beyond the critical temperature, the specimen consisted of enlarged polyhedral grains of fairly uniform shape and size a crystalline fracture and low impact resistance may be expected. On the other hand, if the grains, although perhaps as large or larger than in the first case, are more irregular in shape and present an "interlocked" appearance because of numerous reentrant angles, a crystalline fracture does not result nor is the impact resistance so low. Crystalline breaks depend upon the fracturing of the individual grains along their cleavage planes without appreciable

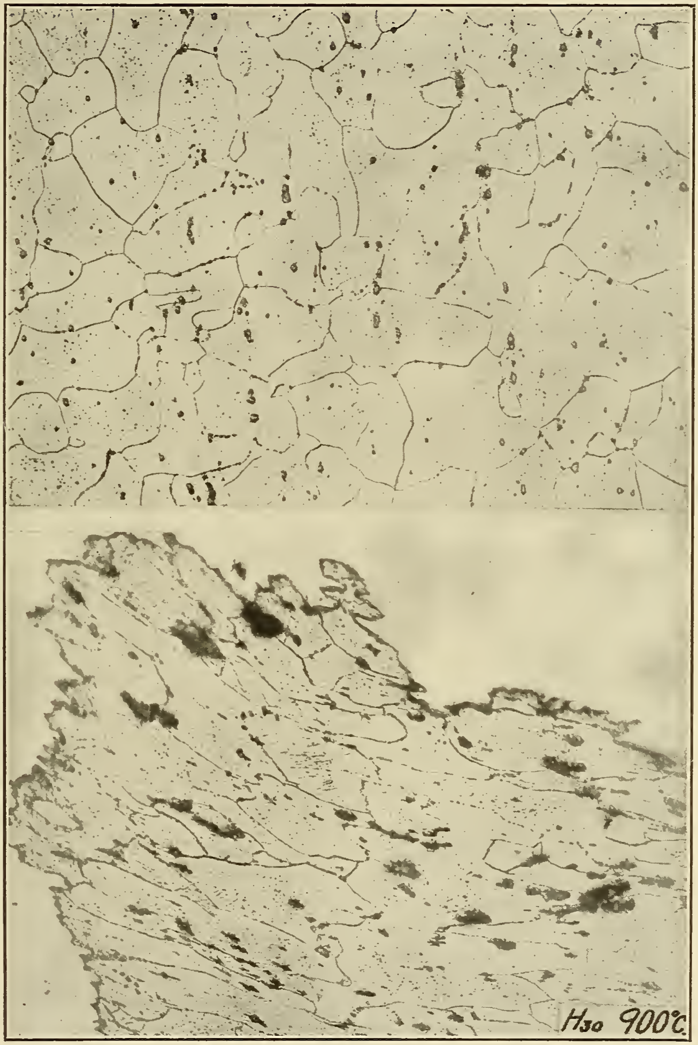

FIG. 20.—*Relation of impact fractures of ferrite (open-hearth iron) to microstructure* × *100.*

Etching reagent, 5 per cent alcoholic picric acid. Refer to Table 4 for impact properties.

deformation of the grain itself. Just why the structural differences, size, shape, and arrangement of the grains shown in Figures 20 to 23 should cause the pronounced differences in the impact resistance is not apparent from the data available in this investi-

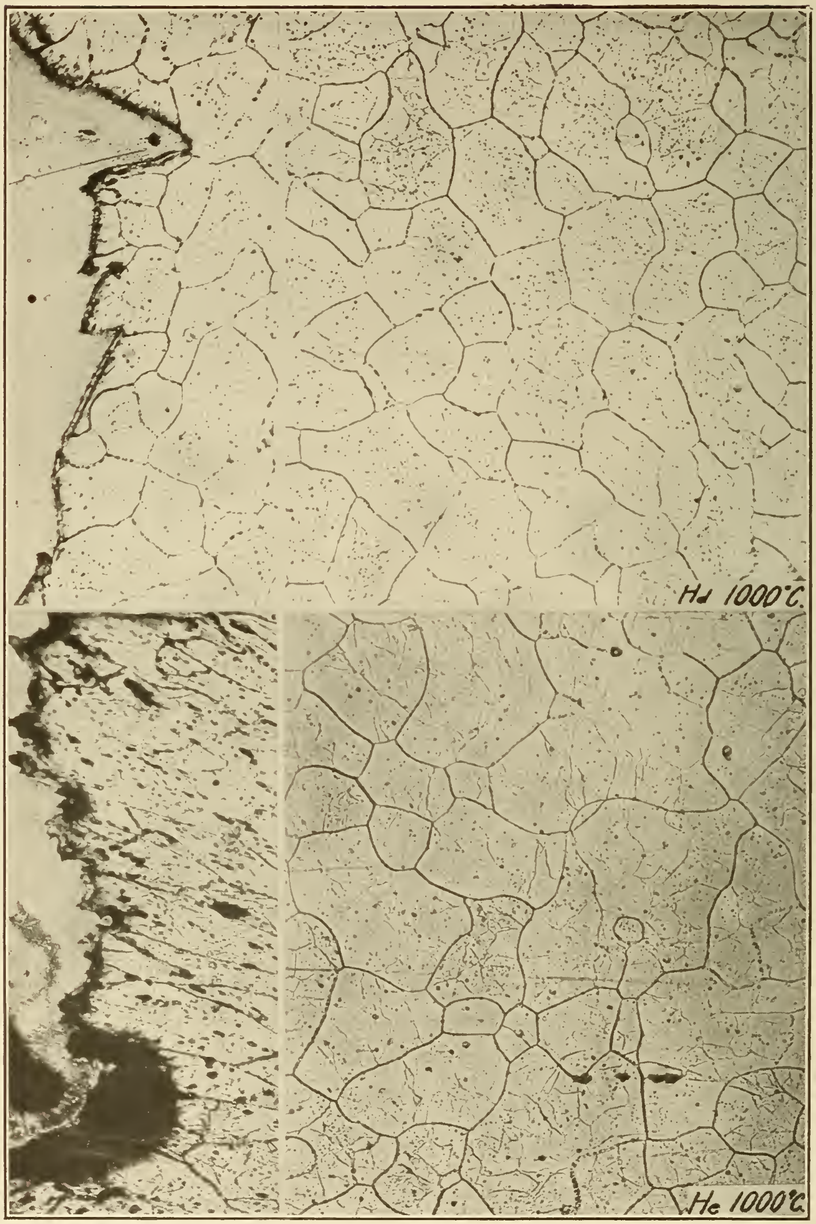

FIG. 21.—*Relation of impact fractures of ferrite (open-hearth iron) to microstructure; initial magnification, × 100, slightly reduced.*

Etching reagent, 5 per cent alcoholic picric acid. Refer to Table 4 for impact properties.

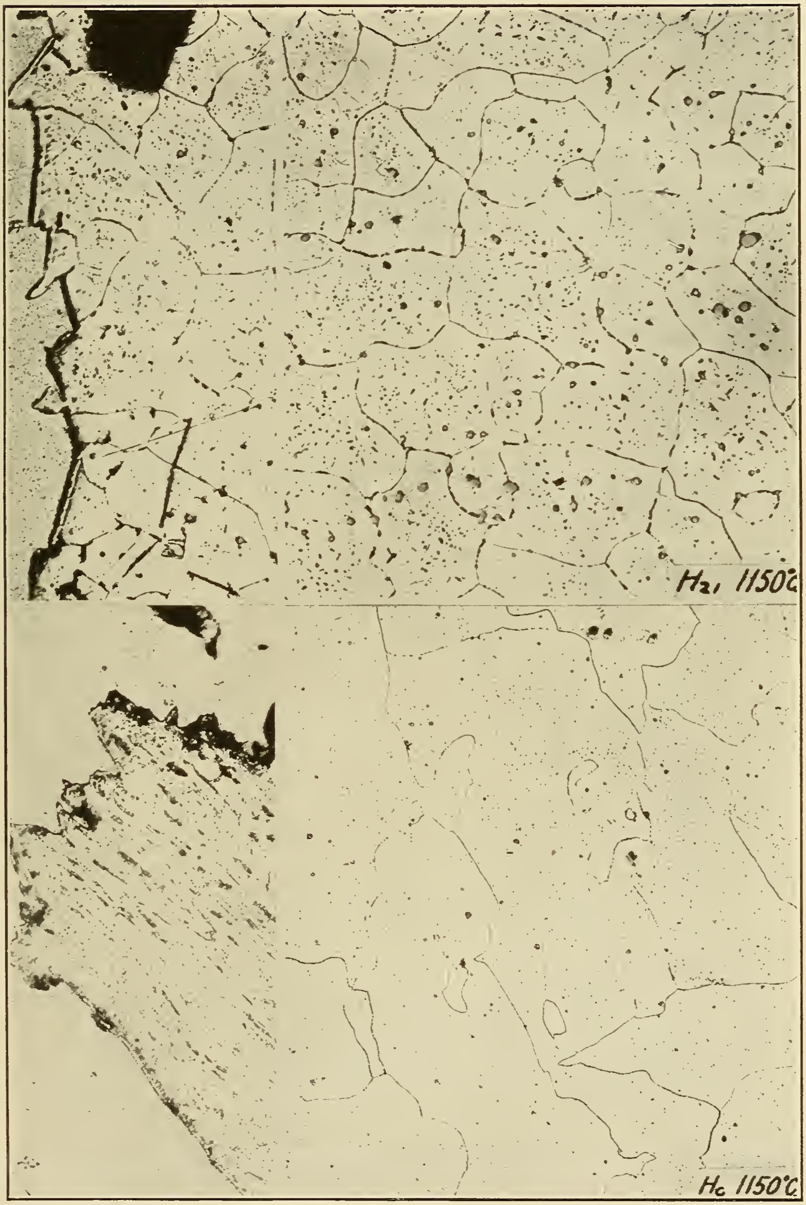

FIG. 22.—*Relation of impact fractures of ferrite (open-hearth iron) to microstructure; initial magnification, × 100, slightly reduced.*

Etching reagent, 5 per cent alcoholic picric acid. Refer to Table 4 for impact properties.

gation. The authors are planning to study this phase of the subject at greater length. The results available at present do appear to warrant the conclusion that in ferrite a simple increase in grain size is not to be interpreted necessarily as denoting low impact resistance and crystallinity. Other features, such as shape and arrangement of the grains, should also be considered.

The examination of specimens of open-hearth iron showing crystalline fractures produced by other means than the nick-bend test (fig. 23) shows that crystallinity in this material is the same no matter how produced—a transcrystalline fracturing of the grains without any appreciable deformation of the grain itself.

In carrying out a series of nick-bend tests upon different wrought irons the operator learns considerably more about the materials than is indicated by the fractures alone, and this is often taken into account, perhaps unconsciously, by the inspector of such materials. The relative resistance of the various bars could be indicated approximately by the number of blows necessary to break it if considered necessary. Such a course seems undesirable, however, and more refined means for measuring the impact resistance should be used if such information is needed. The lack of coordination of any of the common mechanical properties of the materials used (Table 3) with the relative prevalence of crystallinity in the fractures of the nick-bend specimens deserves mention. This may, perhaps, be accounted for in part by the fact that the nick-bend specimen is "full size," whereas those for the other tests are smaller ones cut from a bar which may vary rather widely in properties and structure throughout its cross section.

VII. RECOMMENDATIONS.

Practically all American specifications allow the inspector or the testing engineer very considerable latitude in carrying out the nick-bend test. The nicking of the bar is carefully prescribed, but the specimen itself may be broken in any manner varying from slowly applied pressure to severe impact. In this respect foreign specifications for wrought iron differ from those of this country. The results of the investigation summarized above indicate very plainly the need for a revision of the "nick-bend clause" as usually stated, in order that consistent and reproducible results may be obtained. If the purpose of the specification is to obtain wrought iron that will show no crystallinity when broken in any manner whatever, then it is evident that any method of breaking the specimen except that of impact may be disregarded. If a nicked bar of iron broken by impact shows no appreciable crystalline areas in the fracture, then it would appear futile to expect that a specimen of the same iron broken in a much less drastic

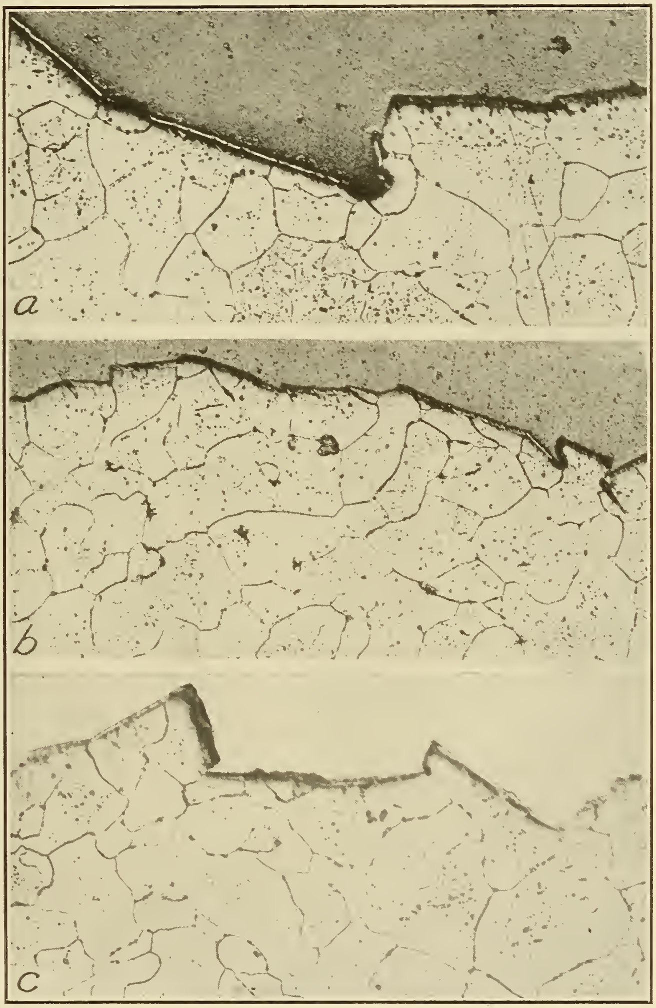

FIG. 23.—*Crystalline fractures of ferrite produced by different methods,* × 100.

(*a*) Notched-bar tension test (fig. 2, Hc).
(*b*) Repeated impact, Eden-Foster test (fig. 4, H).
(*c*) Transverse bending (fig. 16c).
Etching reagent, 5 per cent alcoholic picric acid.

manner—for example, by transverse pressure—to develop crystallinity to any greater extent or even to the same degree. The question as to the real meaning of the results of the nick-bend test naturally arises. Furthermore, in view of the possible uncertainties attending its use, its retention in wrought-iron specifications may well be questioned. In none of the specifications examined by the authors in which a clause covering this test was embodied was there any suggestion made as to the significance or the proper interpretation of the results which might be obtained.

The nick-bend test is, of course, of the same general nature as the more refined notch-bar impact tests. On the basis of this test alone, however, specimens can not be compared or classified according to the energy required for breaking them with any degree of accuracy. The relative size and extent of the crystalline areas in the fracture may be used with some degree of certainty as an indication of the relative brittleness of the material under test. The microscopic examination made for the purpose of showing the relation of the crystalline fractures to the structure of the metal beneath showed a transcrystalline rupturing of the grains without any appreciable accompanying deformation of the grain. Such a break is generally recognized by metallographists as characteristic and indicative of brittle material. The character of the fractures obtained with notched-bar impact specimens differing widely in their impact resistance (Table 4, fig. 19) is illustrative of this fact.

Inasmuch as the nick-bend test offers a simple and ready means for detecting, at least approximately, the relative brittleness of full-size bars, its retention in specifications is believed to be warranted. It is the only simple means available for demonstrating the effect of the slag threads upon the properties of the iron with respect to shock resistance. The method of carrying it out should, however, as pointed out above, be much more strictly defined than at present. If this is not done, this test had better be eliminated from specifications. The test is not designed to replace the usual notched-bar impact test, but ought to form a valuable supplement inasmuch as the testing of the full-size bar may, as indicated by results of some of the tests in this investigation (Table 3, figs. 3, and 12, specimen D), show indications of brittleness which are missed almost entirely in the testing of the smaller specimens cut from the larger bar in the usual manner.

In conducting the nick-bend test, if the bar is to be broken by hand blows, the least number possible of vigorous blows should be used. For 1-inch bars one blow will be sufficient if the specimen breaks with a crystalline fracture. For large specimens several blows may be necessary. In general, however, the crystallinity develops upon the first blow, the other supplementary ones being necessary only to open up the fracture and complete the break.

In estimating the relative amount of crystalline area in the fracture for the purpose of grading wrought irons the semicrystalline portion of the compression side of the bar may well be disregarded. As has been shown above, the characteristic appearance of this part of the fracture originates in a very different manner from that of the truly crystalline areas. Although it can not be stated with certainty, it seems very probable, however, that conspicuous compression crystalline areas are most readily developed in those irons which develop crystallinity on the tension side of the bar readily during the nick-bend test.

The following is suggested as a suitable wording for the nick-bend clause of wrought-iron specifications:

The specimen, the length of which may be varied according to the cross-sectional area, 6 inches being suitable for 1-inch round stock, when nicked transversely at the center, 25 per cent around with a tool having a 60° cutting edge, to a depth of not less than 8 nor more than 16 per cent of the diameter of the specimen, and broken shall show * * *.[7] The specimen shall be broken by being firmly gripped at one end near the notch and struck on the notched side at the other end by a single blow from hand sledge hammer, a power hammer, or broken in a suitable drop test.

VIII. SUMMARY AND CONCLUSIONS.

The materials examined represent the regular finished product of five different manufacturers, an intermediate stage in wrought-iron manufacture from a sixth source, a wrought iron of unusually high phosphorus content, and a commercially pure iron designated as "open-hearth" iron. Twelve materials in all were tested. The methods used for fracturing the uniformly nicked bars varied from a slowly applied transverse bending stress to a severe single-blow impact stress. This range is permitted by most current American specifications. Although the results of the investigation will not furnish answers to all the questions which may arise concerning the nick-bend test for wrought iron, they are definite enough to permit certain conclusions being drawn and to warrant certain recommendations concerning the test.

1. The rate of application of the stress used in rupturing the nicked bars is one of the most important factors which may affect the results of the test; that is, the appearance of the fracture. All but one of the grades of wrought iron successfully passed inspection when slowly or only moderately stressed, whereas

[7] The appearance of the fracture—that is, the permissible crystallinity—will depend upon the grade of the iron.

under shock all showed crystalline areas in the fractures, several to an extent which would warrant rejection under many current specifications.

2. The appearance of the fractures of nicked bars broken by impact is dependent upon the character, particularly the extent, of the notch to a very marked degree. The depth and length of the notch relative to the specimen tested should be carefully regulated. This can be more readily done by notching in the press with a special chisel than by hand. Specimens of wrought iron having complete circumferential notches when broken by severe impact showed very little crystallinity, whereas the same material notched on one side only often showed very large crystalline patches when broken in the same manner. This difference in behavior was not found, however, in the open-hearth iron, crystalline fractures being produced irrespective of the character of the notch.

3. The size of crystalline areas in the fractures of the wrought iron is closely associated with the relative size and distribution of the slag threads in the wrought iron. Prominent slag streaks often permit longitudinal separations to occur during testing, thus giving rise to a fibrous appearance. The absence of such streaks or the presence of small and uniformly distributed streaks favors the production of larger crystalline areas upon impact. Open-hearth iron, in which such slag threads are lacking, gave very prominent crystalline fractures with nearly all methods of fracturing used. Prominent steel-bearing streaks in wrought iron appear to favor to some extent the formation of crystalline areas when fractured under impact, although crystalline areas are not necessarily indicative of steel in the iron.

4. There were two distinct types of crystalline areas produced in the nick-bend test of the materials tested. The one near the tension side of the stressed bar results directly from the tensile stress applied and indicates certain characteristics of the material. The crystalline area on the compression side, however, which is often the larger and more conspicuous of the two, depends for its formation upon the preliminary permanent distortion by compression of the crystals in this part of the specimen and does not necessarily indicate any characteristic features of the unstressed material.

5. The results of the notched-bar impact tests of ferrite (open-hearth iron) indicate that an increase in grain size such as occurs upon annealing is not necessarily accompanied by low impact resistance. Uniformity in shape and size of the enlarged ferrite

grains is usually indicative of a transcrystalline fracture (chrystallinity) and a low impact resistance. Similar material treated in the same manner but showing a somewhat irregular interlooking grain structure gave a relatively high impact resistance and broke with a fibrous fracture.

6. Wrought iron with a high phosphorus content, although it showed considerably lower resistance to impact, exhibited no unusual features in the fracture resulting from the nick-bend test which could be considered as significant of the unusual features of composition of this material.

7. Bars which had been permanently stretched before being subjected to the nick-bend test gave no indications so far as the characteristic features of the fracture were concerned of the preliminary treatment to which they had been subjected. The cold work very materially strengthened such bars, however, so that a much severer blow was necessary in the fracturing of such specimens than before stretching.

8. No unusual features were observed in the fractures of bars of different cross sections to indicate that the size of the bar need be considered in the nick-bend test as ordinarily carried out in practice.

9. The ordinary methods used in mechanical testing failed almost entirely for wrought iron to give any indication of the features shown by the nick-bend test, though this was not so for the open-hearth iron. In general, the results obtained indicate strongly the need for defining more strictly the conditions for carrying out this test than is the case in most current American specifications. In particular, the manner of application of stress should be definitely stated. Only in exceptional cases will the same type of fracture for wrought iron be obtained with simple transverse bending as with impact. The nick-bend test as often carried out is an approximation of the notched-bar impact test. In the testing of plates or flat bars the relation of the location of the notch with respect to the slag plates should be specified; that is, whether upon the edge or the flat side of the plate.

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