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R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1585.

Ship Plate Impact Strength at Low Temperature.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

OTTAWA January 27th, 1944.

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Foreword:

In the winter of 1942-43, on very cold days trouble was experienced in rivetting ship plate. The result s of a Navy-instigated investigation of the problem are given in O.D.M.L. Report of Investigation No. 1392 of April 26th, 1943. Subsequently, the matter was discussed with Lieut-Comm. J. R. Millard, Director of Technical Research, Department of National Defence (Naval Services), Ottawa, Ontario, and on May 25th, 1943, a letter was written to this officer, advocating a determination of the effect that carbon content and grain size variations would have on the impact strength of ship plate at room temperature and at -40° F. A letter written on June 1st to Mr. I. C. Mackie, Engineer of Tests for the Dominion Steel and

(Foreword, cont'd) -

Coal Corporation, Limited, Sydney, N.S., a Canadian ship plate producer, discusses the advisability of the suggested test work. Mr. Mackie, in reply, made it quite clear that while no objection was raised to the undertaking of such test work his company had no intention of changing its deoxidation practice with a view to improving ship plate impact strength through grain size control. He considered that the cracking in riveting occurred because of the high carbon content of the steel (he admitted that for a considerable period heats were being rolled containing over 0.30 per cent carbon, with some as high as 0.35 or 0.36 per cent) and careless fabrication procedures (severe bending of unground edges; forming at very low temperatures, etc.). However, Naval authorities decided that some work would be in order and, late in the summer, sent in for test, from Halifax Shipyards, a variety of ship plate materials. Unfortunately, this shipment was mislaid, so the test work was not completed until late in the year. The present report lists the results obtained.

Nature and Carbon Content of Material Received:

Eleven (11) samples of "D" quality plate and thirteen (13) samples of mild steel plate were received. For purposes of identification these plates were numbered from 1 to 24. Table I lists data for these plates (the length and breadth figures indicate the size of plate as used in the ship).

(Table I follows,)
(on Page 3.)

TABLE I.

Lab. No.	Marking	Length		Breadth	Thickness, lb./sq.ft.	Heat No	Maker
1	A.S.	26'	3"	67"	20	24404/29	Lukens.
2	U.D.L.	16'	11"	$62\frac{3}{4}$"	20	10901/127	"
3	V.K.	32'	0"	45"	25	21329/20	"
4	K.D.B.	4'	$6\frac{1}{2}$"	$15\frac{3}{4}$"	27	16459/32	"
5	-	-		-	-	21357/42	"
6	M.	17'	0"	48"	25	21357/42	"
7	M.S.	6'	5"	$17\frac{1}{2}$"	30	24455/24	"
8	M.	26'	0"	57"	16	16286/50	"
9	M.	27'	0"	69"	14	16302	"
10	M.S.	14'	3"	36"	12	22787/33	"
11	M.	25'	0"	75"	15	19722	"
12	S.C.	5'	1"	24"	15	640318/122	"
13	O.G.P.	16'	11"	$23\frac{1}{2}$"	10	21472/16	"
14	U.D.J.	21'	11"	42"	9	21365/59	"
15	E.	24'	7"	$61\frac{1}{2}$"	8	21365/94	"
16	L.D.G.A.	28'	2"	35"	9	21428/11	"
17	S.B.	5'	0"	27"	10	21428/6	"
18	S.C.	5'	2"	15"	12	29071/30	"
19	A.L.B.	8'	11"	$12\frac{1}{2}$"	5	12208	Wood.
20	A.L.B.	7'	0"	14"	6	4090	"
21	I.L.F.	14'	8"	$12\frac{1}{2}$"	7	510106/10	Lukens.
22	S.S. 74-110	7'	4"	24"	7	13480/201	"
23	M.	15'	9"	48"	4	361675	Bethlehem.
29	-	-		-	-	21428/95	Lukens.

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Carbon Content, Grain Size, and Hardness:

Table II lists the carbon contents, the inherent grain sizes as determined by the McQuaid-Ehn method, and the hardnesses as determined by the Vickers method using a 10-kilogram load:

TABLE II.

Lab. No.	Carbon content, per cent	Grain size	Vickers hardness number
1	0.18	5-7	200
2	0.15	2-3	135
3	0.14	5-7	153
4	0.13	4	158
5	0.12	1-3	157
6	0.21	1-2	140
7	0.25*	2-3	150
8	0.16	5-7	197
9	0.14	3-5	163
10	0.14	6-7	200
11	0.13	4-6	176
12	0.14	1-3	143
13	0.22*	3-5	210
14	0.13	8	177
15	0.13	5-6	160
16	0.15	2-4	134
17	0.16	40%, 1; 60%, 5-7.	131
18	0.16	2	132
19	0.15	304	148
20	0.17	1-3	138
21	0.13	1-3	130
22	0.17	80%, 1; 20%, 5-6.	147
23	0.25*	1-3	152
24	0.19	2-4	121
Plate) XX)	0.34**	1-2	175
Plate) No.) O.F.B.) -7-43)	0.33**	1-2	157

* Duplicate determinations.

** O.D.M.L. Report No. 1392, April 26th, 1943.

NOTE: Vickers hardnesses of 120 and 200 indicate respectively tensile strengths of approximately 60,000 and 100,000 p.s.i.

Impact Tests:

Only Samples Nos. 1 to 8 inclusive had sufficient thickness to allow the machining of a standard 10-mm.-square Izod or Charpy bar. Izod and Charpy tests were made on these materials at both 70° F. and -40° F., cooling being effected by immersing in a dry ice-acetone mixture for 30 minutes with testing following immediately. In order to check on notch sensitivity Charpy tests were also made on double-width specimens (which, if material is not notch-sensitive, give approximately double impact strength values) Table III lists the results obtained. Izod values given are the average of three readings. The Charpy values were obtained from a single notch.

TABLE III.

Lab. No.	Izod Impact, foot-pounds (1)		Charpy Impact, foot-pounds (1)		Double-Width Charpy Impact, foot-pounds (2)	
	+70° F.	-40° F.	+70° F.	-40° F.	+70° F.	-40° F.
1	60	20	62	4	107	7
2	49	9	58	5	154	9
3	50	12	51	6	126	8
4	32	6	30	4	64	7
5	56	11	49	5	81	5
6	17	3	20	2	34	6
7	20	5	17	3	30	5
8	60	16	68	4	82	8

(1) Bar 0.394" square, V-notched to give 0.315" x0.394" broken section (Standard).

(2) Bar 0.394" thick, 0.788" wide, V-notched to give 0.315" x0.788" broken section (Standard Double Width).

Table IV lists impact tests made on plates from which it was not possible to machine standard test specimens, specimen sections and dimensions of this section as reduced by the notch being given in every case. In order to obtain some scale of comparison with a standard-sized specimen, a substandard specimen from Lab. No. 2 material (standard impact values for this being listed in Table III above) was broken for each specimen

(Impact Tests, cont'd) -

size tested. For the purpose of comparison, impact test results reported in C.D.M.L. Report of Investigation No. 1392 are also included in Table IV.

TABLE IV.

Lab. No.	Specimen Section Dimensions	Broken Section Dimensions	Izod Impact, foot-pounds		Charpy Impact, foot-pounds	
			+70°F.	-40°F.	+70° F.	-40° F.
2	0.290" x 0.394"	0.232" x 0.394"	25	10	25	3
9	"	"	45	24	45	17
11	"	"	42	36	52	16
12	"	"	43	40	63	5
XX	0.300" x 0.394"	0.240" x 0.394"	-	-	15	1(-20°F)
O.F.B.-7-43	"	"	-	-	21	4(-20°F)
2	0.242" x 0.394"	0.194" x 0.394"	24	8	22	3
10	"	"	28	32	39	31
17	"	"	26	17	40	3
18	"	"	27	10	42	2
2	0.168" x 0.394"	0.136" x 0.394"	12	9	20	2
14	"	"	13	16	20	12
2	0.138" x 0.394"	0.111" x 0.394"	7	9	13	2
13	"	"	8	8	13	5
15	"	"	8	8	13	5
16	"	"	8	8	14	3
21	"	"	8	8	15	2
22	"	"	8	8	12	3

Double width specimens were also broken for all materials tested in Table IV. Table V lists the results obtained.

TABLE V.

Lab. No.	Specimen Section Dimensions	Broken Section Dimensions	Charpy Impact, foot-pounds	
			+70° F.	-40° F.
9	0.290" x 0.788"	0.232" x 0.788"	102	26
11	"	"	108	51
12	"	"	141	9
XX	0.300" x 0.788"	0.240" x 0.788"	140	-
O.F.B.-7-43	"	"	144	-
10	0.242" x 0.788"	0.194" x 0.788"	91	31
17	"	"	77	4
18	"	"	83	4
14	0.168" x 0.788"	0.136" x 0.788"	37	20
13	0.138" x 0.788"	0.111" x 0.788"	27	13
15	"	"	33	13
16	"	"	27	2
21	"	"	25	2
22	"	"	32	15

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(Impact Tests, cont'd) -

Samples Nos. 19, 20, 23, and 24 were too thin to test. In all of the above impact tests the longitudinal axis of the test specimen was in the direction of rolling.

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Discussion of Results:

It was unfortunate that the specimens submitted did not have a wider range of carbon composition. Variation of inherent grain size, however, was satisfactory for the purposes of this investigation.

In equating the results of impact tests, it should be kept in mind that this property of steel (as determined by standard impact tests) is notoriously erratic. Consequently, the same numerical precision of test results cannot be expected in impact testing as in tensile testing. This difficulty was further accentuated in the present case because it was not possible, in the case of many of the thinner plates, to test standard impact test bars. Furthermore, it is known that the method of determining impact properties is not perfect, with the result that the practical importance of values obtained may sometimes be doubtful. In this connection, arguments may be advanced in support of the Charpy method of testing and in this investigation where results of two tests appear to be at variance greater reliance should be placed on the Charpy test results.

It is felt, however, that certain conclusions can be drawn from the results obtained. In analysing the results obtained, it is probably best to divide the steels into the following groups:

Group A. - Low Carbon, Low- and Medium-Grained Steels.

Samples Nos. 1, 3, 4, 8, 9, 10, 11, 14, 15, and 16.

(Continued on next page)

(Discussion of Results, cont'd) -

Group B. - Low Carbon, Coarse-Grained Steel.

Samples Nos. 2, 5, 12, 17, 18, 20, 21, and 22.

Group C. - Medium Carbon, Coarse-Grained Steel.

Samples Nos. 6 and 7.

Group D. - High Carbon, Coarse-Grained Steel.

Samples Nos. XX and O.F.B.-7-43.

Sample No. 13 was so thin that results obtained from it are not regarded as being particularly significant. This, of course, is also true of Samples Nos. 15, 16, 21, and 23.

In the first place, all steels examined possess lower impact strengths at low temperatures. For plates sufficiently thick to allow for the machining of standard test specimens this is particularly true, and noticeably so for impact strengths as determined by the Charpy method. The thinner plates appear to show less loss of Izod impact strength with drop in temperature, but with the exception of Samples Nos. 9, 10, 11 and 14, the loss of impact strength with drop of temperature is as equally marked for the thinner plates as for the thick. It is of note that all four exceptional steels are quite low in carbon, with the first tested having a medium inherent grain size and the other three samples fine inherent grain size.

If the doubling of impact strength with the doubling of specimen width is to be accepted as an evidence of lack of notch sensitivity, none of the steels examined is notch-sensitive. This, in view of the fairly low carbon content of the steels, is to be expected.

All the low-carbon steels (Groups A and B) appear to have satisfactory room-temperature impact properties, although none, as measured by the Charpy test, is outstandingly good at

(Discussion of Results, cont'd) -

at low temperatures. If Izod test values are to be accepted as criteria, there is some slight indication that a coarsening of grain has an unfavourable effect on the impact strength for Sample No. 4, which has a medium grain size, and Samples Nos. 2, 5, 17, and 18, which have coarse grain sizes, show, on the average, lower Izod impact strengths at -40° F. than do the fine-grained, comparable-carbon-content steels.

Definitely, a raising of the carbon content much over 0.20 per cent in the presence of an inherently coarse grain size lowers the room temperature impact strength of ship plate steel. This material also has lower impact strength at low temperatures but the numerical drop of impact strength with temperature is not so marked as for other materials, undoubtedly because the room temperature impact strength was considerably lower. There is every indication that raising of the carbon content above 0.30 per cent in coarse-grained steels further aggravates this trouble.

CONCLUSIONS:

If the plates obtained are assumed to be representative, the following conclusions can be made:

1. Ship plate is not notch-sensitive.

2. Impact strength of ship plate drops with the temperature, so more cracking would be expected in cold-temperature rivetting.

3. Impact strength of ship plate drops with an increase in carbon content; therefore, if low temperatures are likely to be encountered in fabrication it is good practice to hold the carbon (within limits possible in practice) to as low a value as will give the required plate strength.

4. There is some indication that drop of impact strength

(Conclusions, cont'd) -

with temperature is more marked for coarse-grained than for fine-grained steels. When carbon content is held low, this is only of academic importance. All other things being equal, however, the inherently fine-grained material is to be preferred for low-temperature fabrication.

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GSF:GHB.