SSC-113

FRACTURE APPEARANCE OF IMPACT SPECIMENS TAKEN FROM FRACTURED SHIP PLATES

by

John A. Bennett

SHIP STRUCTURE COMMITTEE

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ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

June 29, 1959

Dear Sir:

For a number of years the Ship Structure Committee and other groups sponsored studies at the National Bureau of Standards of plates removed from fractured merchant ships. Specimens from these plates were recently re-examined by the National Bureau of Standards and an additional correlation between the fractured surfaces of Charpy specimens from these plates and service conditions was obtained. Herewith is the final report, SSC-113, entitled "Fracture Appearance of Impact Specimens Taken from Fractured Ship Plates" by John A. Bennett.

This program has been conducted under the advisory guidance of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

This report is being distributed to individuals and groups associated with and interested in the work of the Ship Structure Committee. Please submit any comments that you may have to the Secretary, Ship Structure Committee.

Sincerely yours,

E. H. Thiele

E. H. Thiele
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Serial No. SSC-113

Final Report
of
Project SR-144

to the

SHIP STRUCTURE COMMITTEE

on

FRACTURE APPEARANCE OF IMPACT SPECIMENS TAKEN FROM FRACTURED SHIP PLATES

by

John A. Bennett

National Bureau of Standards

under

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Washington, D. C.
National Academy of Sciences-National Research Council
June 29, 1959

ABSTRACT

Several thousand broken V-notch Charpy specimens from service failures were studied to determine the relation between fracture appearance and impact energy of steel from fractured ships. It was found that the 50% fibrous fracture criterion was as effective as the Charpy V-notch 15 ft-lb criterion as a means of discriminating between plate that contained the source or the terminus of the fracture, or if the plate permitted a fracture to run through it.

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INTRODUCTION

During the period 1943--1954 a large number of fractured ship plates were sent to the National Bureau of Standards "to determine the causes of the individual failures, and to obtain data for evaluation of metallurgical and other factors that contributed to the origin and propagation of the fractures."[1] Originally, all of the transition temperatures were determined on the basis of energy values in the Charpy V-notch impact test and no study of the fracture appearance was made. Recently, interest has been aroused in the fracture appearance transitions of these plates as a method of correlating service failure data, because of results obtained by European investigators.[2] Accordingly the Ship Structure Committee requested the National Bureau of Standards to undertake the examination of as many of the broken Charpy specimens as were still in good condition.

MATERIAL

There were samples of 153 ship plates tested in the twelve-year period that the investigation was active. On the basis of the information furnished at the time the plates were submitted, most of these were divided into six categories, as follows:

S1. Plates containing the source of a primary or independent fracture which occurred under normal operating conditions.

S2. Plates in which secondary fractures started ahead of the main fracture, or plates in which fractures started under unusually severe conditions.

T1. Primary through plates that were the first to propagate a fracture, that is, where the fracture originated in an adjoining weld and turned or ran directly into the plate.

T2. Secondary through plates that propagated a running fracture, that is, plates that fractured after the crack had propagated for some distance in another plate. (In all of the samples included in this category, the fracture had already propagated a foot or more before entering the plate under consideration.)

E1. Plates in which fractures ended, but where there appeared to be structural features or stress conditions that may have influenced the ending of the fracture.

E2. Fracture end plates where there was no apparent structural factor or stress condition involved in the stopping of the fracture.

In addition to 141 fractured plates, there were 8 plates that had not fractured and 4 plates from a ship that had been damaged by an internal explosion. Specimens from 17 plates were not available for examination owing to excessive rusting or other reasons; of these, 13 were from the fractured plates that had been assigned to the different categories. The distribution of the other 128 plates examined was as follows:

S1 - 21
S2 - 18
T1 - 22
T2 - 26
E1 - 21
E2 - 20

During the early part of the fractured-ship-plate investigation the Charpy specimens were cut in a number of orientations relative to the rolling direction and plate surface, but later it was decided that longitudinal specimens notched perpendicular to the plate surface gave the most significant results, therefore, all of the analyses are based on results from the latter type.

METALLOGRAPHIC EXAMINATION

In order to determine the precision of the visual estimation of the per cent brittle fracture area,* a group of about eighty specimens was rated by eight observers, both experienced and inexperienced. Analysis of these results indicated that the precision of an individual reading was not sufficiently good to warrant readings closer than the nearest 10%. The accuracy of the visual estimation was evaluated by planimetric measurement of tracings from the enlarged images of specimens having about 50% and 75% brittle fracture area. Comparison with the average of visual estimates by two observers indicated that the accuracy was about the same as the precision, so it was decided to have all specimens read by two observers. One individual made readings on all the specimens, while five different people served as the second observer.

For each plate there were usually four specimens that had been broken at each test temperature. The observer making the brittle fracture area ratings was always unaware of the specimen numbers or temperature of testing, so each observation was as nearly as possible independent.

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*The term "brittle fracture area" is considered to be somewhat more accurate than the more usual "cleavage area." This is indicated by "BFA" in the tables.

TABLE 1. FRACTURED SHIP PLATE IMPACT DATA

Plate No.	15 ft - lb Transition Temperature	Test Temperature, °F 50% BFA	90% BFA	Precent at $T_{v\ 15}$	BFA at Failure Temperature
Fracture Category - S1					
17 B	82	131 F	35 F	74	88
18 A	151	185	90	68	
19 B	122	161	67	70	
20 A	152		85	71	
25 A	78	126	32	76	85
32 A	128	194		73	
32 B	97	162	60	78	91
41 A	83	133	30	75	84
51 B	135	180	87	72	100
52 A	63	117	33	79	90
70 A	84	152	37	78	88
72 A	112	144	72	69	
75 B	102		63	76	97
76 A	98	145	51	74	87
80 B	81		67	85	93
81 D	91		52	77	91
81 E	83		30	81	88
82 B	143		100	74	99
83 A	87	150	60	81	91
91 E	73	111	48	79	92
92 A	71	117		82	87
Avg.	100.8	147.2	57.8	75.8	90.7
Fracture Category - T1					
1 A	41	73	17	79	
2 A	83	141	35	76	
2 B	102	139	65	72	
11 A	90	134	57	74	98
12 B	64	118	50	77	86
15 A	75	105	30	70	87
24 B	67	114	35	77	
35 A	49	64		71	82
38 A	44	100	10	77	78
54 A	60	120		81	88
57 A	24	71	-6	75	
58 B	47	94		81	80
58 C	64	113		81	86
58 E	50	102	10	82	82
58 F	57	110	33	82	85
60 B	58	98		75	74
63 D	75	115	30	75	87
78 B	101		55	72	
82 A	102		60	76	90
87 A	120		86	79	
94 E	73		(36)	74	85
107 A	98	120	68	73	99
Avg.	70.2	107.3	39.5	76.3	85.8
Fracture Category - S2					
8 A	79	124	45	76	91
9 A	83	137	37	75	
9 B	91	142		75	
12 A	77	137	50	79	88
16 A	79	139	52	78	89
21 A	69		37	78	88
27 A	80	119	30	75	
29 B	101	145	66	78	90
33 B	86	122	50	77	
37 B	122	171	78	77	
39 A	72		40	82	91
40 A	87	129	54	75	
46 A	96	141	52	74	94
51 A	88	150	47	78	93
56 A	112		63	76	92
57 B	85	132	38	72	
75 A	75	121		77	86
75 C	63		46	86	91
Avg.	85.3	135.3	49.1	77.1	90.3
Fracture Category - T2					
16 B	78	135	37	76	85
20 C	72	121		79	88
20 D	63	(119)		82	
30 A	50	105		80	85
30 B	47	86	7	75	85
31 B	89	129	42	74	
37 C	59	118	26	80	88
37 D	66	128	46	85	92
37 E	48	80		75	83
37 F	47	69	31	72	89
46 B	65	115		77	86
51 C	60	96	29	76	89
52 B	80	137	44	78	93
52 C	66	115	30	76	89
59 A	62	106	10	76	88
60 C	73	116	43	77	83
61 B	51	99	27	80	87
61 C	72	130	49	82	94
61 E	81	120	45	75	93
62 B	71	118	35	76	
78 A	84	121		77	
79 A	74	139	40	79	85
80 A	68	114		74	79
80 C	55	(112)		80	79
94 B	92		34	75	88
94 C	38	92		80	77
Avg.	65.8	112.8	33.8	77.5	86.6

TABLE 1. (Continued)

Plate No.	15 ft - lb Transition Temperature	Test Temperature, °F 50% BFA	90% BFA	Precent at T_v 15	BFA at Failure Temperature
Fracture Category - E1					
4 A	63	110		78	86
5 A	52	91		73	77
7 A	66	108		71	
12 C	73	126	57	83	96
12 D	81	141	37	75	88
19 A	62	114		80	
20 B	86	160	59	84	
24 A	75	118	50	79	
33 A	88	132	54	73	
36 A	82	147	78	89	93
36 B	78	117	46	76	80
38 C	90	134	30	73	88
39 B	62	102	30	80	89
55 C	74	133	50	80	83
61 D	46	106	35	87	90
62 A	64	106	30	78	88
62 C	68	110	33	76	
63 A	66	101	28	77	86
87 D	57	105	36	81	89
94 A	90		27	74	86
107 B	72	118	49	79	94
Avg.	71.2	119.0	42.9	78.4	87.5

Plate No.	15 ft - lb Transition Temperature	Test Temperature, °F 50% BFA	90% BFA	Precent at T_v 15	BFA at Failure Temperature
Fracture Category - E2					
3 A	37	84		81	68
10 A	27	62	11	82	
17 A	55	115	18	80	85
17 C	45	98	18	79	82
25 B	42	63		69	62
26 A	30	78		83	76
29 A	63	117	44	84	82
31 A	50	90		71	70
37 A	33	84		79	79
46 C	56	105	20	78	85
55 A	34	80		75	56
55 B	37	63		70	46
56 B	-2	45	-20	81	38
58 A	54	86	21	75	78
60 A	62	104	34	77	78
74 A	3	35	-4	86	
74 B	13	73	8	87	
77 A	29	84	6	79	76
81 B	56	107	40	83	87
87 B	53	104	33	82	88
Avg.	38.9	83.9	16.2	79.1	72.7

Plate No.	Fracture Category	15 ft - lb Transition Temperature	Test Temperature °F 50% BFA	90% BFA	Precent at T_v 15	BFA at Failure Temperature
38 B	NF	24	82		81	73
58 D	NF	40	94		77	74
63 B	NF	53	94	30	82	86
63 C	NF	61	116	30	80	87
87 C	NF	37	84	18	85	84
94 D	NF	97		47	73	90
*106 A	TIX	80	127	42	77	84
*106 B	EIX	79	124		83	78

* Damaged by internal explosion.

RESULTS AND DISCUSSION

The ratings at each temperature were averaged, plotted, and a smooth curve was drawn through the points. The values given in Table I are taken from these curves in four ways; the test temperatures corresponding to 50% and 90% brittle fracture area, and the per cent brittle fracture area at the 15 ft-lb transition temperature and at the failure temperature. In many cases the failure temperature was not known, and frequently the data did not extend to 50% or 90% brittle fracture area, so there are a number of blanks in the table. If the data did not include either 50% or 90% brittle fracture area the curve was extrapolated to obtain a value at one or the other, and these values are in parentheses.

The averages of the results are listed in Table II.

TABLE II - FRACTURE IMPACT DATA AVERAGES

Category	Temperatures corresponding to			Brittle fracture area at	
	T_{v15}	50% BFA	90% BFA	T_{v15}	Failure Temperature
	°F	°F	°F	%	%
S1	100.8	147.2	57.8	75.8	90.7
S2	85.3	135.3	49.1	77.1	90.3
T1	70.2	107.3	39.5	76.3	85.8
T2	65.8	112.8	33.8	77.5	86.6
E1	71.2	119.0	42.9	78.4	87.5
E2	38.9	83.9	16.2	79.1	72.7
Average	71.7	115.3	41.0	77.4	85.3

It can be seen that the temperature corresponding to a certain percentage of brittle fracture area provides the same type of correlation with service performance that the energy transition temperature does. The fracture appearance at the 15 ft-lb transition temperature is uniform throughout all categories, as would be expected for one class of steel. The fracture appearance at the failure temperature is rather uniform except for the E2 category.

The correlation between the transition temperatures based on the different criteria is shown in Fig. 1, where the 15 ft-lb transition temperature for each plate is plotted against the temperatures corresponding to 50% and 90% brittle fracture area. There is a strong correlation between the T_{v15} and both of the appearance criteria. As the same trend line appears to fit the points for all three fracture categories, this figure indicates that impact energy and fracture appearance are equally effective as a criterion for correlation with service performance in the limited range of composition and steel-making practice represented by these samples. Information from many other studies suggests that a different correlation exists between fracture appearance and the energy level transition for other steels. As an example, the percentage of cleavage fracture at the 15 ft-lb transition temperature for three types of steel is as follows:

World War II[1] Steels from Fractured Ships (°F)	Class ABS B[3] (°F)	Class ABS C[3] (°F)
71	82.7	89.8

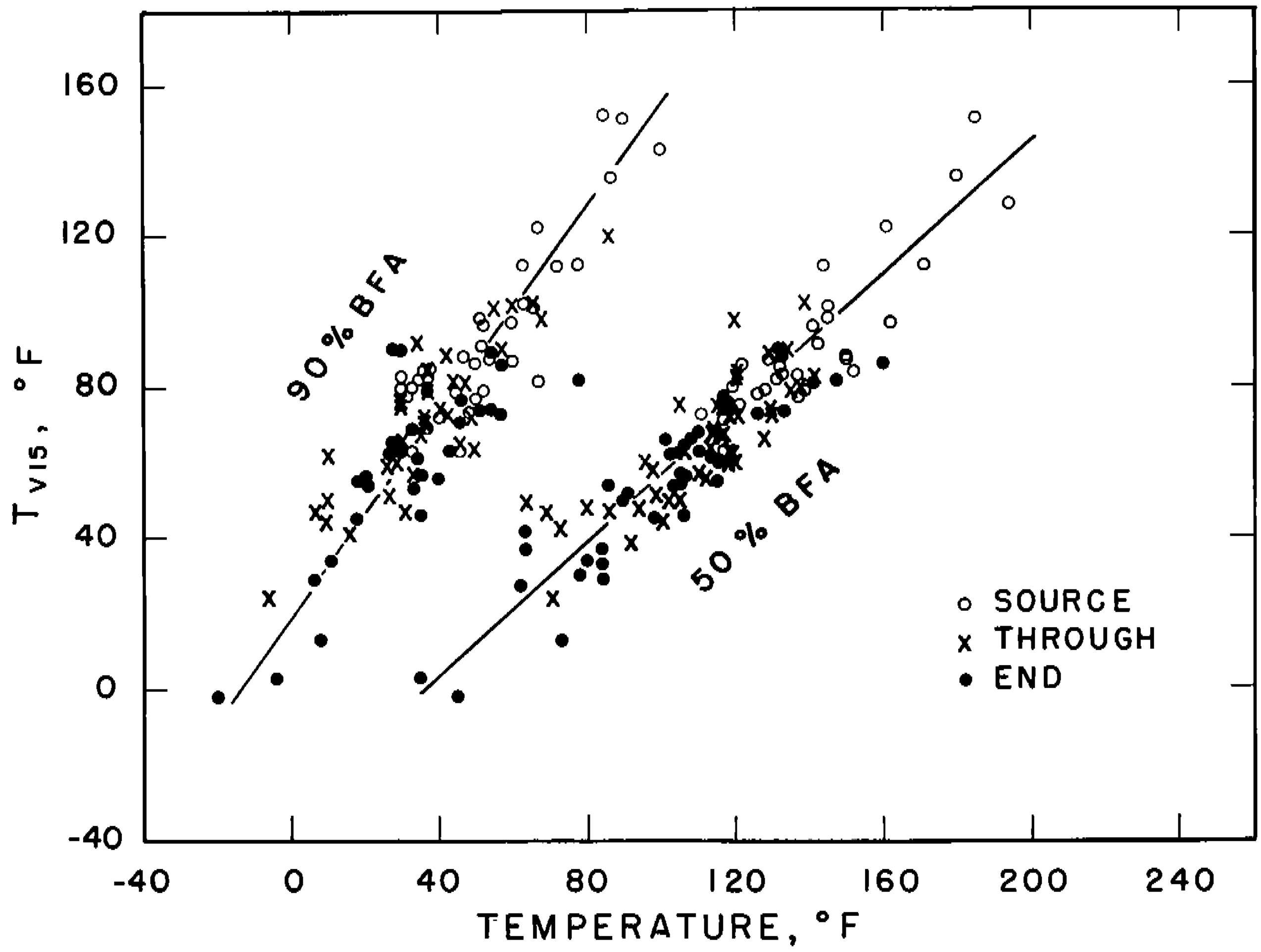

Fig. 1. Correlation between the 15 ft-lb transition temperature and the temperatures for 90% and 50% brittle fracture area. The service failure category of each plate is indicated.

The author wishes to acknowledge the assistance of Miss Ruth E. Dowden who rated each one of the several thousand specimens involved in this investigation.

REFERENCES

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