NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

WELDING TEST 207
TENSILE STRENGTH OF BUTT WELDS IN SPECIAL-TREATMENT STEEL PLATE

by

J.W. Day

November 1947

Report R-249

WELDING TEST 207
TENSILE STRENGTH OF BUTT WELDS IN SPECIAL-TREATMENT STEEL PLATE

ABSTRACT

Welded specimens submitted by twenty six shipbuilding yards were tested in tension to determine the ability of the yards to produce welded joints of satisfactory quality and uniform strength in special-treatment steel with Grade IV electrodes. The average mean deviation in tensile strength of the selected specimen groups representing all the yards was about 3 per cent. The test results indicate that the twenty six yards can produce welded joints having strengths averaging 85 per cent of the plate strength.

INTRODUCTION

The Navy Department requires that weld metal deposited from Grade IV electrodes shall have a tensile strength not less than 85 kips per square inch. The purpose of the welding tests here reported was to determine the ability of the welders in the various shipbuilding yards to produce consistently good welds by the use of Grade IV electrodes* in making butt-welded joints in special-treatment steel. Owing to the lack of experience of most welders in the welding of this grade of steel, difficulty had been experienced in some shipbuilding yards in obtaining welded joints free from cracks and slag inclusions and of adequate tensile strength.

A previous report (1)** on the results of tensile tests of 90 welded specimens forwarded to the Taylor Model Basin by ten shipyards was submitted to the Bureau of Ships in May 1941. That was a progress report, and definite judgment of the work, as well as conclusions based on the test results, was withheld until more specific acceptance standards for welding had been established.

The present report covers the results of the complete test program. It includes a summary of the results for the 90 specimens reported in Reference (1) together with detailed results for the 249 specimens subsequently tested at the request of the Bureau of Ships (2). The 249 specimens included those from sixteen yards which had not previously submitted samples and additional ones from three of the yards which had furnished materials for the earlier tests. These specimens from the three yards were intended as replacements of those originally submitted which did not meet the strength requirements of

---

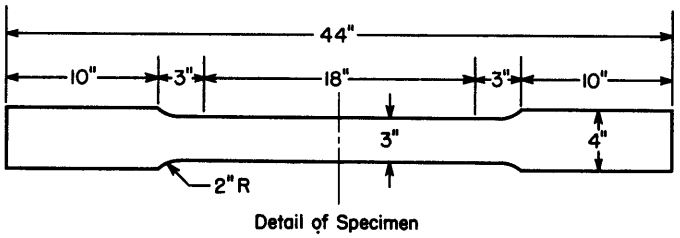
* Grade IV electrodes contain 25 per cent chromium and 20 per cent nickel.

** Numbers in parentheses indicate references on page 12 of this report.

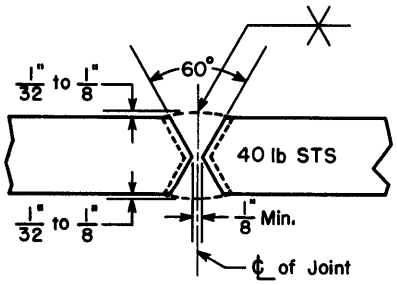
the Bureau of Ships. Three of the specimens submitted by the Willamette Iron and Steel Corporation were found to be medium steel instead of special-treatment steel. Consequently the calculations and comparisons set forth in this report are based on 246 rather than 249 specimens.

SPECIMENS AND TEST PROCEDURE

The dimensional details of the specimens and the details of welding are shown in the sketch, Figure 1. All specimens had a nominal width of 3 inches. The original 90 specimens were all made from 40-pound plate, but lighter plating was used for many of the subsequent specimens.



Detail of Specimen



Detail of Joint

Figure 1 - Detail of Tensile Test Specimen and Welded Joint

In the preliminary report (1) it was pointed out that an accurate comparison of the strength of the welds with the strength of a welded plate can be made only if the weld beads are machined flush with the surface so that the area of the weld metal can be accurately determined. In that report it was "recommended that in future welding qualification tests of this kind, all joints be made with welds machined flush with the plate to permit closer comparison of the work of the various yards." This procedure was followed with about one-third of the specimens comprising the present tests, as indicated in Table 1.

After fracture the elongation was measured on each specimen over a 10-inch base length which spanned the weld; additional measurements of elongation were made on the plating clear of the weld to determine the plastic

elongation of the plate metal. These latter measurements were made on an 8-inch base length, since the specimens were too short to permit the use of a 10-inch base.

IDENTIFICATION OF SPECIMENS

For easy identification of the specimens a system of numbering originally had been adopted in which the fabricating yard was indicated by one or two capital letters, the group in which the specimen was submitted was indicated by a Roman numeral, and the sequence of the specimen in its group by an Arabic numeral. In general each group comprised three specimens cut from a welded plate about 12 inches wide, and represented the work of one welder. Groups I and II were those submitted in response to the original request for specimens; groups with higher numbers were submitted as replacements for specimens which did not meet strength requirements. The specimen groups in Table 1 appear in the order in which they were received from each yard. It will be noted that all yards did not prepare and mark their specimens to conform to the prescribed system.

RESULTS

The results of the tensile tests of individual specimens are compiled in Table 1. Of the 246 individual welded specimens tested in the present series, 13 per cent had tensile strengths less than 85 kips per square inch. A summary of the results from tests of two groups of three specimens each and three groups of two each, which represent the best work done by each yard, is given in Table 2. The results presented in this table are the maximum, the minimum, and the mean values of the tensile strength, together with the mean deviation. Table 2, Part 1, includes results for groups selected from Table 1 of the present report; Table 2, Part 2, includes results for selected groups from Table 1 of the previous report (1). It will be noted that the seven fabricators listed in Table 2, Part 2, are those which had furnished specimens for the previous series of tests only; of the remaining nineteen fabricators, three furnished specimens for both the first and second series and sixteen for the second series only.

The second lot of specimens received from the Puget Sound Naval Shipyard, listed in Table 1, included several duplicate groups, one of which was preheated to 130 degrees fahrenheit before welding and the other was welded without preheating. There is relatively little difference in strength between these groups, but the average strength of the preheated specimens is about 3 per cent less than that of specimens not preheated.

TABLE 1

Tensile Strength of Butt Welds Made in Special-Treatment Steel Plate

All specimens had a nominal width of 3 inches.

Fabricator	Specimen	Weight of Plate lb/ft²	Area square inches	Tensile Strength kips/in²	Elongation in 10 Inches over Fracture inches	Permanent Set in 8 Inches in Unbroken Plate, inches	Location of Fracture and Nature of Fracture Surface
Philadelphia Naval Shipyard	B-V-1	40	2.92	105.8	0.57	0.30	Weld.
	-2		2.90	104.8	0.48	0.20	Weld.
	-3		2.92	98.0	0.28	0.07	Weld.
	B-VI-1	40	2.91	98.7	0.25	0.05	Weld - gas pockets.
	-2		2.91	96.2	0.22	0.02	Weld - root slag.
	-3		2.91	102.5	0.25	0.03	Weld.
Puget Sound Naval Shipyard (Tested August 1941)	H-III-1	40	2.99	88.0	0.15	0.01	Weld - slag, gas pockets.
	-2		2.98	90.8	0.14	0.01	Weld - slag, small gas pockets.
	-3		2.99	93.0	0.14	0.01	Weld - slag, gas pockets.
	H-III-A-1	40	2.97	94.2	0.14	0.01	Weld - slight slag, gas pockets.
	-2		2.99	85.8	0.13	0.01	Weld - slag, gas pockets.
	-3		2.95	92.2	0.15	0.01	Weld - slag, gas pockets.
	H-III-B-1	40	2.94	92.4	0.15	0.02	Weld - slag, gas pockets.
	-2		2.93	93.4	0.15	0.01	Weld - slag, gas pockets.
	-3		2.97	93.4	0.13	0.02	Weld - slag, gas pockets.
	H-III-C-1	40	2.97	86.0	0.15	0.01	Weld - gas pockets.
	-2		2.96	89.3	0.12	0.02	Weld - gas pockets.
	-3		2.97	83.6	0.15	0.02	Weld - slag, gas pockets.
	H-III-D-1	40	2.95	89.3	0.15	0.01	Weld - slight slag, gas pockets.
	-2		2.93	87.9	0.12	0.02	Weld - gas pockets.
	-3		2.94	86.1	0.13	0.01	Weld - slag, gas pockets.
	H-III-E-1	40	2.99	88.8	0.14	0.01	Weld - slight slag, gas pockets.
	-2		2.99	85.3	0.15	0.01	Weld - gas pockets.
	-3		2.98	92.8	0.12	0.01	Weld - gas pockets.
	H-IV-1	40	2.97	73.3	0.14	0.01	Weld - slag, gas pockets.
	-2		2.97	77.9	0.13	0.01	Weld - slag, gas pockets.
	-3		2.98	79.4	0.12	0.01	Weld - slag, gas pockets.
	H-IV-A-1	40	2.93	86.4	0.13	0.02	Weld - slag, gas pockets.
	-2		2.93	80.2	0.13	0.03	Weld - slag, gas pockets.
	-3		2.93	80.4	0.14	0.01	Weld - slag, gas pockets.
	H-IV-B-1	40	2.97	85.5	0.12	0.02	Weld - slag, gas pockets.
	-2		2.97	89.4	0.15	0.02	Weld - slag, gas pockets.
	-3		2.99	72.3	0.12	0.01	Weld - heavy slag, gas pockets.
	H-IV-C-1	40	2.97	78.2	0.14	0.01	Weld - gas pockets.
	-2		2.98	82.7	0.15	0.01	Weld - slag, gas pockets.
	-3		2.97	85.2	0.15	0.01	Weld - slag, gas pockets.
	H-IV-D-1	40	2.98	76.3	0.13	0.00	Weld - slight slag, gas pockets.
	-2		2.97	72.4	0.15	0.01	Weld - slight slag, gas pockets.
	-3		2.98	74.9	0.13	0.01	Weld - slag, gas pockets.
	H-IV-E-1	40	2.95	75.7	0.13	0.01	Weld - slag, gas pockets.
	-2		2.93	81.6	0.14	0.02	Weld - gas pockets.
	-3		2.93	79.8	0.14	0.02	Weld - slight slag, gas pockets.
Puget Sound Naval Shipyard (Tested May 1942)	HA-III-1*	40	2.87	100.0	0.34	0.08	Weld - slag.
	-2*		2.98	96.4	0.29	0.04	Weld - slag.
	-3*		2.97	95.6	0.28	0.04	Weld - slag, gas pockets.
	HA-IV-1*	40	2.99	95.5	0.22	0.04	Weld - gas pockets.
	-2*		3.00	107.2	0.53	0.24	Weld - slight slag.
	-3*		2.98	101.2	0.34	0.11	Weld - slag, gas pockets.
	HA-III-1*†	40	2.97	97.8	0.26	0.05	Weld - slight slag.
	-2*		2.97	97.0	0.29	0.05	Weld - gas pockets.
	-3*		2.94	89.5	0.20	0.03	Weld - slag, gas pockets.
	HA-IV-1*†	40	2.94	96.9	0.24	0.05	Weld - slight slag.
	-2*		2.94	100.7	0.35	0.12	Weld - slight slag.
	-3*		2.93	98.8	0.29	0.06	Weld - slight slag.
	HB-III-1*	40	2.92	101.4	0.28	0.12	Weld - slag.
	-2*		2.90	101.7	0.34	0.10	Weld - clean.
	-2*		2.93	88.5	0.18	0.00	Weld - gas pockets.
	-3*		2.95	99.6	0.28	0.09	Weld - slag.
	HB-IV-1*	40	2.97	83.5	0.18	0.01	Weld - slag, grainy.
	-2*		2.97	96.5	0.30	0.05	Weld - slag.
	-3*		2.96	92.6	0.20	0.02	Weld - slag.
	HB-III-1*†	40	2.95	101.2	0.42	0.13	Weld - grainy.
	-2		2.93	91.1	0.21	0.02	Weld - slag, grainy.
	-3*		2.97	94.9	0.25	0.03	Weld - slag, grainy.
	HB-IV-1*†	40	2.93	86.0	0.17	0.02	Weld - slag, grainy.
	-2*		2.91	92.3	0.21	0.03	Weld - slag, gas pockets.
	-3*		2.96	94.5	0.23	0.02	Weld - slag.

TABLE 1 - Continued

Fabricator	Specimen	Weight of Plate lb/ft²	Area square inches	Tensile Strength kips/in²	Elongation in 10 Inches over Fracture inches	Permanent Set in 8 Inches in Unbroken Plate, inches	Location of Fracture and Nature of Fracture Surface
Puget Sound Naval Shipyard (Tested May 1942)	HC-III-1*	40	2.99	109.9	0.69	0.32	Weld - clean.
	-2*		2.99	103.3	0.40	0.20	Weld - clean.
	-3*		2.93	98.5	0.21	0.05	Weld - grainy.
	HC-IV-1*	40	2.99	106.7	0.59	0.32	Weld - gas pockets.
	-2*		2.99	109.8	0.80	0.41	Weld - clean.
	-3*		3.03	105.4	0.56	0.23	Weld - clean.
	HC-III-1*†	40	2.99	102.5	0.40	0.17	Weld - clean.
	-2*		3.00	101.2	0.38	0.18	Weld - clean.
	-3*		2.96	104.9	0.47	0.22	Weld - clean.
	HC-IV-1*†	40	2.91	103.3	0.44	0.21	Weld - gas pockets.
	-2*		2.93	95.6	0.22	0.04	Weld - slag, gas pockets.
	-3*		2.96	101.0	0.38	0.14	Weld - clean.
	HD-III-1*	40	2.91	108.8	0.56	0.29	Weld - clean.
	-2*		2.92	111.8	0.81	0.51	Weld - clean.
	-3*		2.94	109.3	0.64	0.30	Weld - clean.
	HD-IV-1*	40	2.96	107.5	0.52	0.28	Weld - slight slag.
	-2*		2.98	108.5	0.60	0.32	Weld - clean.
	-3*		2.97	104.1	0.45	0.24	Weld - slight slag.
	HD-III-1*†	40	2.99	94.7	0.23	0.03	Weld - clean.
	-2*		2.99	101.2	0.35	0.07	Weld - gas pockets.
	-3*		2.99	104.0	0.39	0.15	Weld - clean.
	HD-IV-1*†	40	2.98	101.7	0.33	0.13	Weld - gas pockets.
	-2*		2.96	108.2	0.54	0.27	Weld - slight slag.
	-3*		2.96	101.5	0.34	0.12	Weld - clean.
	HE-III-1*	40	2.91	104.6	0.33	0.12	Weld - slight slag.
	-2*		2.93	104.4	0.42	0.19	Weld - slight slag.
	-3*		2.90	106.3	0.63	0.34	Weld - clean.
	HE-IV-1*	40	2.95	99.4	0.28	0.09	Weld - slight slag, gas pockets.
	-2*		2.96	105.6	0.50	0.26	Weld - slight slag.
	-3*		2.94	105.5	0.46	0.25	Weld - slight slag.
	HE-III-1*†	40	2.97	98.2	0.46	0.17	Weld - slag.
	-2*		2.95	99.7	0.32	0.11	Weld - slag, gas pockets.
	-3*		2.96	103.0	0.40	0.18	Weld - grainy.
	HE-IV-1*†	40	3.01	92.1	0.24	0.03	Weld - slag, gas pockets.
	-2*		2.97	107.9	0.55	0.28	Weld - slight slag.
	-3*		2.97	107.7	0.58	0.32	Weld - slight slag.
	H-III-1*	40	2.93	81.9	0.18	0.01	Weld - slag, gas pockets.
	-1*		2.94	91.1	0.39	0.13	Weld - grainy.
	-2*		2.99	81.8	0.18	0.02	Weld - slag, gas pockets, grainy.
	-3*		2.91	78.3	0.17	0.00	Weld - slag, gas pockets.
	H-IV-2*	40	3.00	86.0	0.23	0.01	Weld - grainy.
	-3*		2.99	90.2	0.21	0.02	Weld - gas pockets, grainy.
	H-III-3*	40	2.91	106.6	0.50	0.23	Weld - clean.
	H-IV-1*	40	2.97	91.9	0.24	0.01	Weld - slight slag.
	-1*		2.99	100.1	0.23	0.04	Weld - grainy.
	-3*		2.99	97.8	0.32	0.08	Weld - gas pockets, grainy.
	H-IV-2*	40	2.93	99.6	0.31	0.07	Weld - gas pockets.
Boston Naval Shipyard	J-III-1*	40	2.97	102.7	0.41	0.15	Weld - slag, gas pockets.
	-2*		2.97	107.0	0.52	0.21	Weld - slight slag, gas pockets.
	-3*		2.99	102.0	0.45	0.19	Weld - slight slag, gas pockets.
	J-IV-1*	40	3.05	104.7	0.46	0.19	Weld - slag, gas pockets.
	-2*		3.03	103.6	0.34	0.16	Weld - slag, gas pockets.
	-3*		3.04	93.9	0.22	0.02	Weld - slag, gas pockets.
Cramp Shipbuilding Company	K-I-1*	40	2.87	83.0	0.17	0.00	Weld - slag, gas pockets.
	-2*		2.87	95.3	0.16	0.01	Weld - slight slag, gas pockets.
	-3*		2.89	95.9	0.17	0.01	Weld - slight slag, gas pockets.
	K-II-1*	40	2.87	76.9	0.14	0.01	Weld - slag, gas pockets.
	-2*		2.85	99.4	0.22	0.05	Weld - heavy slag, gas pockets.
	-3*		2.87	87.3	0.17	0.02	Weld - slight slag, gas pockets.
	K-III-1	40	2.90	99.3	0.34	0.07	Weld - slag, gas pockets.
	-2		2.89	96.9	0.28	0.04	Weld - slight slag, gas pockets.
	-3		2.91	89.7	0.26	0.03	Weld - gas pockets.
	K-IV-1	40	2.91	90.0	0.25	0.02	Weld - slag, gas pockets.
	-2		2.90	93.8	0.28	0.02	Weld - gas pockets.
	-3		2.91	93.1	0.27	0.02	Weld - slight slag, gas pockets.

TABLE 1 - Continued

Fabricator	Specimen	Weight of Plate lb/ft^2	Area square inches	Tensile Strength kips/in^2	Elongation in 10 Inches over Fracture inches	Permanent Set in 8 Inches in Unbroken Plate, inches	Location of Fracture and Nature of Fracture Surface
Bethlehem Steel Company (San Francisco, Calif.)	L-I-1	20	1.44	95.7	0.24		Weld - gas pockets.
	-2		1.44	93.0	0.26		Weld - clean.
	-3		1.44	98.8	0.23		Weld - clean.
	L-II-1	20	1.43	104.0	0.29		Weld - clean.
	-2		1.44	102.1	0.27		Weld - slight slag.
	-3		1.43	106.2	0.44		Weld - clean.
	L-III-1*	40	3.32	86.1	0.14	0.01	Weld - gas pockets.
	-2*		3.28	73.7	0.13	0.00	Weld - slag, gas pockets.
	-3*		3.31	85.7	0.24	0.01	Weld - slag, gas pockets.
	L-IV-1*	40	3.29	96.7			Weld - slag, gas pockets.
	-2*		3.29	99.5	0.18	0.01	Weld - slight slag, gas pockets.
	-3*		3.27	84.5	0.19	0.00	Weld - slag, gas pockets.
	L-V-1*	40	3.67	103.5	0.32	0.08	Weld - gas pockets.
	-2*		3.68	107.2	0.37	0.15	Weld - gas pockets.
	-3*		3.64	95.6	0.19	0.00	Weld - gas pockets.
	L-VI-1*	40	3.26	106.2	0.22	0.07	Weld - gas pockets.
	-2*		3.24	102.3	0.21	0.03	Weld - gas pockets.
	-3*		3.25	103.3	0.24	0.03	Weld - gas pockets.
Charleston Naval Shipyard	M-I-1	40	2.74	79.6	0.16	0.02	Weld - clean.
	-2		2.76	87.7	0.16	0.01	Weld - clean.
	-3		2.78	84.5	0.14	0.01	Weld - clean.
	M-II-1	40	2.81	85.4	0.15	0.01	Weld - clean.
	-2		2.83	88.0	0.13	0.02	Weld - clean.
	-3		2.81	94.3	0.22	0.02	Weld - clean.
	N-I-1*	30	2.17	81.1	0.10	0.00	Weld - root slag, gas pockets.
	-2*		2.17	70.9	0.10	0.00	Weld - root slag.
	-3*		2.16	83.3	0.10	0.00	Weld - slag.
Bath Iron Works	N-II-1*	30	2.19	95.9	0.15	0.00	Weld - slag.
	-2*		2.18	98.6	0.18	0.02	Weld.
	-3*		2.17	96.7	0.18	0.00	Weld - slag.
	N-III-1*	30	2.19	96.3	0.15	0.03	Weld - slag, gas pockets.
	-2*		2.24	92.3	0.11	0.03	Weld - slag, gas pockets.
	-3*		2.20	95.7	0.17	0.03	Weld - slag, gas pockets.
	N-IV-1*	30	2.25	100.8	0.20	0.02	Weld - slight slag, gas pockets.
	-2*		2.26	99.8	0.20	0.05	Weld - slight slag, gas pockets.
	-3*		2.24	100.0	0.24	0.04	Weld - slight slag, gas pockets.
Bethlehem Steel Company (Staten Island, N.Y.)	O-I-1*	30	2.15	95.4	0.13	0.01	Weld - root slag, gas pockets.
	-2*		2.06	103.3	0.17	0.00	Weld.
	-3*		2.05	107.5	0.17	0.01	Weld.
	O-II-1*	30	2.17	92.4	0.14	0.00	Weld.
	-2*		2.16	97.7	0.15	0.01	Weld - slight slag, gas pockets.
	-3*		2.10	100.0	0.17	0.00	Weld - root slag, gas pockets.
Seattle-Tacoma Steel Company	P-I-1	30	2.14	102.8	0.32	0.15	Weld - slight slag.
	-2		2.14	109.3	0.34	0.13	Weld - slight slag.
	-3		2.14	108.4	0.32	0.12	Weld - slight slag.
	P-II-1	30	2.13	101.9	0.20	0.02	Weld - slight slag.
	-2		2.17	102.8	0.22	0.03	Weld - slight slag.
	-3		2.16	100.9	0.16	0.03	Weld - clean.
Bethlehem Steel Company (San Pedro, Calif.)	Q-I-1*	25	1.87	96.8	0.16#		Weld - clean.
	-2*		1.89	106.8	0.47#		Weld - clean.
	-3*		1.89	105.1	0.39#		Weld - clean.
	Q-II-1*	25	1.90	102.8	0.34#		Weld - clean.
	-2*		1.90	103.4	0.29#		Weld - clean.
	-3*		1.91	103.1	0.37#		Weld - clean.
Gulf Shipbuilding Company	R-I-1	30	2.23	92.3	0.20	0.02	Weld - gas pockets.
	-2		2.24	97.4	0.20	0.01	Weld - slight slag, gas pockets.
	-3		2.26	104.4	0.21	0.02	Weld and bond - gas pockets.
	R-II-1	30	2.23	106.7	0.23	0.04	Weld and bond - gas pockets.
	-2		2.24	108.0	0.25	0.05	Weld and bond - gas pockets.
	-3		2.23	99.7	0.15	0.00	Bond - gas pockets.
Consolidated Steel Corporation (Orange, Tex.)	S-I-1	30	2.18	90.6	0.15	0.02	
	-2		2.08	95.2	0.17	0.04	
	S-II-1	30	2.18	90.4	0.13	0.03	
	-2		2.18	96.6	0.14	0.03	
	S-III-1	30	2.18	94.0	0.18	0.03	
	-2		2.18	96.2	0.14	0.03	

TABLE 1 - Continued

Fabricator	Specimen	Weight of Plate lb/ft²	Area square inches	Tensile Strength kips/in²	Elongation in 10 Inches over Fracture inches	Permanent Set in 8 Inches in Unbroken Plate, inches	Location of Fracture and Nature of Fracture Surface
Willamette Iron and Steel Corporation (Tested April 1942)	T-I-1	25	1.81	60.3	2.05	0.77	Plate. These specimens obviously were medium-steel plate.
	-2		1.76	62.3	2.03	1.07	
	-3		1.81	60.2	1.93	1.35	
	T-II-1	25	1.81	92.3	0.21	0.11	Weld - slag, gas pockets.
	-2		1.82	86.7	0.18	0.06	Weld - slag, gas pockets.
	-3		1.83	83.3	0.13	0.01	Weld - slag, gas pockets.
Willamette Iron and Steel Corporation (Tested July 1942)	T-I-1	25	1.80	103.6	0.30	0.09	Weld - slight slag, gas pockets.
	-2		1.82	99.0	0.22	0.05	Weld - slag, gas pockets.
	-3		1.82	102.5	0.27	0.06	Weld - slight slag, gas pockets.
	T-II-1	25	1.98	93.3	0.26	0.03	Bond - slag, gas pockets.
	-2		1.77	100.7	0.26	0.04	Weld - slag, gas pockets.
	-3		1.77	93.2	0.20	0.03	Weld - root slag, gas pockets.
Pearl Harbor Naval Shipyard	U-I-1	25	1.79	107.6	0.19	0.01	Plate and bond - gas pockets.
	-2		1.79	106.5	0.24	0.02	Weld and bond - slight slag,
	-3		1.79	105.4	0.17	0.03	Plate and bond - gas pockets.
	U-II-1	25	1.81	106.0	0.27	0.04	Weld and bond - slight slag, gas pockets.
	-2		1.80	110.0	0.34	0.10	Weld and bond - gas pockets.
	-3		1.79	106.4	0.18	0.03	Weld and bond - slag, gas pockets.
Moore Dry Dock Company	V-I-1	25	1.80	108.2	0.30	0.10	Weld and bond - clean.
	-2		1.79	106.8	0.23	0.08	Bond - slight slag.
	-3		1.80	109.8	0.31	0.14	Bond.
	V-II-1	25	1.84	105.7	0.23	0.05	Weld and bond - slight slag.
	-2		1.82	106.2	0.21	0.03	Weld - clean.
	-3		1.81	109.8	0.33	0.10	Weld - slight slag.
General Engineering and Dry Dock Company	W-I-1	20	1.52	83.8	0.11	0.01	Weld - gas pockets.
	-2		1.51	81.7	0.10	0.00	Weld - gas pockets.
	-3		1.50	76.5	0.12	0.02	Weld - gas pockets.
	W-II-1	20	1.50	104.4	0.15	0.01	Weld - gas pockets.
	-2		1.50	110.2	0.20	0.06	Weld and bond - slight slag.
	-3		1.49	101.2	0.15	0.03	Bond - gas pockets.
Burnham Boiler Corporation (N.Y.)	Y-I-1*	10	0.73	97.0	0.31	0.20	Weld - slag, gas pockets.
	-2*		0.74	97.6	0.28	0.20	Weld - slag, gas pockets.
	-3*		0.74	102.5	0.45	0.37	Weld - slag, gas pockets.
	Y-II-1*	10	0.74	103.2	0.22	0.01	Weld.
	-2*		0.75	87.7	0.13	0.00	Weld - slag, gas pockets.
	-3*		0.74	98.8	0.16	0.00	Weld - slag.
Burnham Boiler Corporation (Pa.)	Z-I-1*	10	0.72	99.9	0.10	0.02	Weld - slag, gas pockets.
	-2*		0.71	109.3	0.15	0.03	Weld - slag, gas pockets.
	-3*		0.73	105.6	0.15	0.03	Weld - slag, gas pockets.
	Z-II-1*	10	0.74	105.8	0.45	0.34	Weld - slag, gas pockets.
	-2*		0.73	105.2	0.26	0.26	Weld - slag, gas pockets.
	-3*		0.71	103.1	0.29	0.09	Weld - slag, gas pockets.
Portsmouth Naval Shipyard	BB-I-1	25	1.94	98.6	0.24	0.06	Weld - clean.
	-2		1.92	101.0	0.25	0.08	Weld and bond - clean.
	-3		1.92	100.0	0.23	0.05	Weld and bond - clean.
	BB-II-1	25	1.89	97.6	0.22	0.04	Weld - clean.
	-2		1.93	100.7	0.31	0.08	Weld - clean.
	-3		1.93	95.9	0.21	0.03	Weld - clean.
	BB-III-1	25	1.91	87.8	0.20	0.02	Weld - clean.
	-2		1.91	94.1	0.22	0.03	Weld - clean.
	-3		1.89	85.7	0.18	0.00	Weld - clean.

* The weld was machined flush with the plate.

† The specimen was preheated to 130 degrees fahrenheit before welding.

‡ These elongations were measured on an 8-inch base length.

The tensile strength of the three specimens of Group I furnished by the Willamette Iron and Steel Corporation was only slightly higher than 60 kips per square inch, indicating that medium-steel plate was used by mistake.

ANALYSIS OF RESULTS

All values of tensile strength are based on the cross-sectional area of the plate whether or not the welds were machined flush with the plate. This basis may account for the greater spread of mean values in the "as welded" groups. It will be noted in Table 2, Part 1, that the mean deviation among the machined groups ranges from 2.1 kips to 4.1 kips per square inch, whereas the mean deviation among the "as welded" groups ranges from 1.2 kip to 5.6 kips per square inch. Machining of the welds flush with the plate eliminates the effects of variations in the area of the weld-bead deposits, and thus the comparisons of strength may be made on the basis of weld quality alone.

Weld metal deposited from Grade IV electrodes is required to have a minimum tensile strength of 85 kips per square inch (3). This value is 74 per cent of the minimum tensile strength, 115 kips per square inch, specified for STS plate. The average mean tensile strength of the 114 selected specimens represented in Table 2, Part 1, of the present report is 100.2 kips per square inch and the total range of strengths is from 76.5 to 111.8 kips per square inch. It would seem from these values that an ultimate tensile strength of 90 kips per square inch could be required of joints in special-treatment steel welded with Grade IV electrodes. This value represents an efficiency of the joint of 78 per cent, based on the nominal tensile strength of 115 kips per square inch in the plate. Joints in this material could be expected to have efficiencies as high as 85 per cent.

Figure 2 indicates the distribution of the tensile strength of 246 individual specimens from Table 1, and the tensile strengths of the individual specimens of the selected groups from Table 2, Part 1.

Each of the curves in Figure 3 is plotted to show the percentage of the specimens having a tensile strength greater than the abscissas indicated. These four curves represent the results of tests of individual specimens included in Table 1 of Reference (1) and in Table 1 of the present report, and also the results for the individual specimens from the selected groups representing each series of tests.

If it is assumed that all naval shipyards will be able to produce welded joints having a strength not less than the values for the selected groups of the present series of tests, Curve B of Figure 3 indicates that about 96 per cent of all welds should have a tensile strength greater than 85 kips per square inch and that 90 per cent of the specimens may be expected to

TABLE 2

Comparison of Test Results

PART 1

This comparison is based on the results of tests of six specimens from groups selected from Table 1 as representing the best work of each yard.

Fabricator	Specimen	Weight of Plate lb/ft²	Tensile Strength kips per square inch			
			Mean	Maximum	Minimum	Mean Deviation
Philadelphia Naval Shipyard	B-V, B-VI	40	101.0	105.8	96.2	3.4
Puget Sound Naval Shipyard	HC-IV; HD-III	40	108.6	111.8	105.4	1.7
Boston Naval Shipyard	J-III,* J-IV	40	102.3	107.0	93.9	2.7
Cramp Shipbuilding Company	K-III, K-IV	40	93.8	99.3	89.7	2.9
Bethlehem Steel Company (San Francisco, Calif.)	L-V,* L-VI	40	103.0	107.2	95.6	2.7
Charleston Naval Shipyard	M-I, M-II	40	86.6	94.3	79.6	3.4
Bath Iron Works	N-II,* N-IV	30	98.6	100.8	95.9	2.7
Bethlehem Steel Company (Staten Island, N.Y.)	O-I,* O-II	30	99.4	107.5	92.4	4.1
Seattle-Tacoma Shipbuilding Company	P-I, P-II	30	104.3	109.3	100.9	3.0
Bethlehem Steel Company (San Pedro, Calif.)	Q-I,* Q-II	25	103.0	106.8	96.8	2.1
Gulf Shipbuilding Company	R-I, R-II	30	101.4	108.0	92.3	4.9
Consolidated Steel Corporation (Orange, Texas)	S-I, S-II, S-III	30	93.8	96.6	90.4	2.2
Willamette Iron and Steel Company	T-I, T-II	25	98.7	103.6	93.2	3.6
Pearl Harbor Naval Shipyard	U-I, U-II	25	107.0	110.0	105.4	1.2
Moore Dry Dock Company	V-I, V-II	25	107.7	109.8	105.7	1.5
General Engineering and Dry Dock Company	W-I, W-II	20	93.0	110.2	76.5	5.6
Burnham Boiler Corporation (N.Y.)	Y-I,* Y-II	10	97.8	103.2	87.7	3.7
Burnham Boiler Corporation (Pa.)	Z-I,* Z-II	10	104.8	109.3	99.9	2.2
Portsmouth Naval Shipyard	BB-I, BB-II	25	99.0	101.0	95.9	1.6
Average			100.2	105.3	89.6	2.9

PART 2

This comparison is based on the results of tests of six specimens from groups selected from Table 1 of Reference (1) as representing the best work of each yard, but excluding those fabricators included in Table 2, Part 1.

New York Naval Shipyard	A-I,* A-II	40	93.6	99.6	88.3	2.8
New York Shipbuilding Corporation	C-I, C-II	40	87.6	97.2	79.7	5.3
Newport News Shipbuilding and Dry Dock Company	D-I, D-II	40	92.4	99.0	87.7	2.8
Federal Shipbuilding and Dry Dock Company	E-I,* E-II*	40	96.5	100.0	91.5	2.5
Bethlehem Steel Company (Fore River)	F-I, F-II	40	105.8	112.3	102.7	2.7
Norfolk Naval Shipyard	G-I, G-III*	40	95.3	99.0	92.9	1.5
Mare Island Naval Shipyard	I-I,* I-II*	40	91.6	96.5	86.8	2.5
Average			94.8	100.9	90.0	2.9

* The weld was machined flush with the plate.

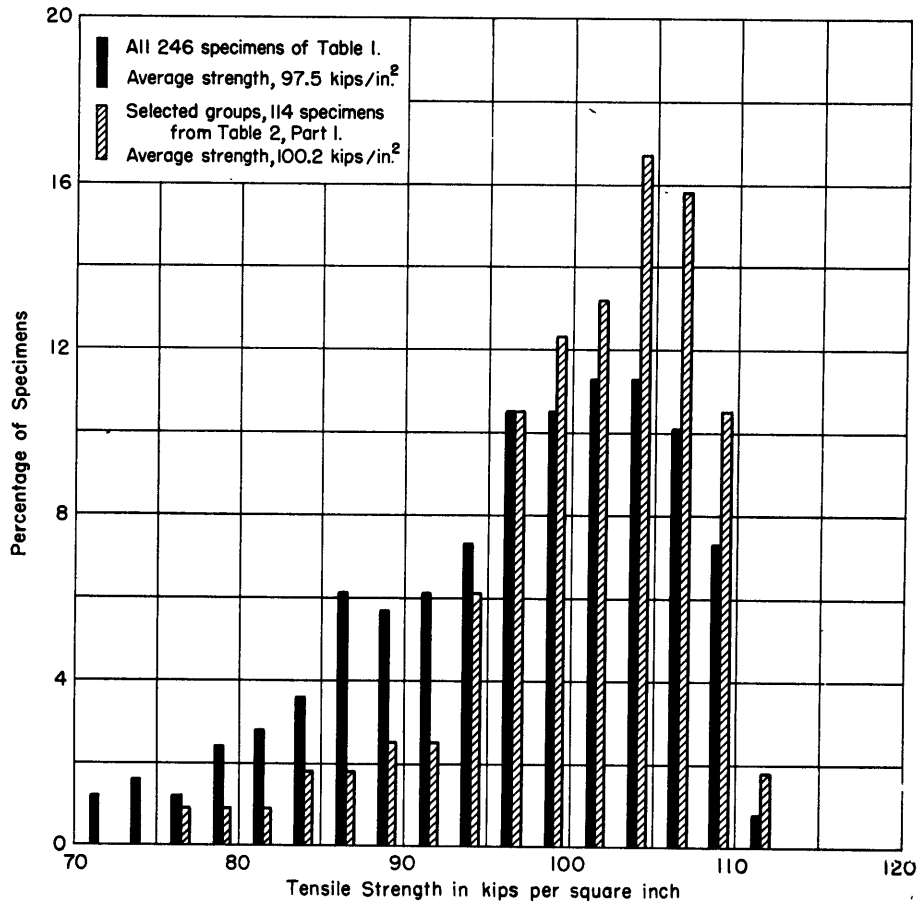


Figure 2 - Strength-Distribution Graph

The height of the bars in this figure indicates the percentage of the specimens having a tensile strength within the range of values, 2.5 kips per square inch, equal to the spacing of the bars. The solid bars represent the results for the 246 specimens from Table 1; the cross-hatched bars represent the results for the 114 individual specimens of the selected groups from Table 2, Part 1.

be stronger than 90 kips per square inch.

From Table 2 it will be noted that the mean tensile strengths of the selected groups representing the twenty-six fabricators are all higher than 85 kips per square inch and with two exceptions they are higher than 90 kips per square inch. Mean tensile strengths greater than 100 kips per square inch were attained by one of the seven fabricators furnishing specimens for the previous tests (1) and by ten of the nineteen fabricators furnishing specimens for the present series. The minimum strength of individual specimens was less than 80 kips per square inch for three fabricators, less than 85 kips for the same three fabricators, and less than 90 kips for eight fabricators.

It is probable that the relatively low strengths presented in Reference (1) and shown by Curve C in Figure 3 are an indication of a lack of experience on the part of the operators in welding this grade of steel. The greater strength of the specimens in the present series of tests undoubtedly

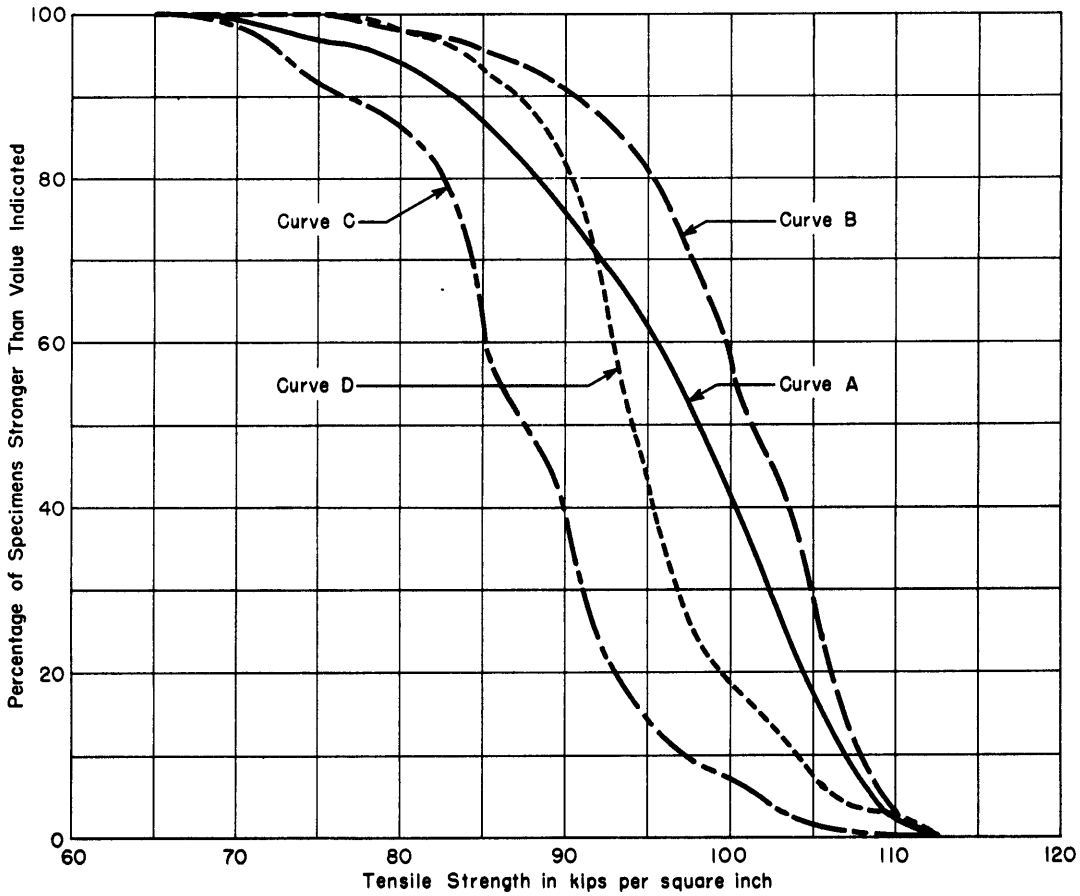


Figure 3 - Tensile Strength-Percentage Curves

These curves are plotted to show the percentage of the specimens having a tensile strength greater than the values indicated by the abscissas. Curve A was derived from the results of tests of the 246 specimens from Table 1. Curve B was derived from the results of tests of the 114 specimens from the selected groups indicated in Table 2, Part 1. Curve C was derived from the results of tests of the 90 specimens from Table 1 of Reference (1). Curve D was computed from the results of tests of 42 specimens from the selected groups indicated in Table 2, Part 2.

is the result of additional welding experience and improved workmanship and more nearly represents the quality of welds which may be expected of expert workmen. The beneficial effect of added experience and attention to detail is illustrated by the results obtained from tests of the two shipments of specimens from the Puget Sound Naval Shipyard. Of the 36 specimens comprising the first shipment, 15 had a tensile strength less than 85 kips per square inch; of the 72 specimens comprising the second shipment, only 4 had a strength less than 85 kips per square inch. The principal requirement in making welded joints of high strength is to produce welds without cracks or slag inclusions. Clean welds can be produced by close adherence to the procedures and requirements set up in References (3) and (4).

CONCLUSIONS

On the basis of the test results it may be concluded that all the shipyards which submitted specimens for these tests are able to make butt welds of satisfactory tensile strength in special-treatment steel with Grade IV electrodes and that such welds may be expected to have an average mean tensile strength of approximately 100 kips per square inch with a mean deviation of about 3 per cent.

REFERENCES

(1) "Welding Test 207 - Tensile Strength of Butt Welds Made in 40-Pound Special Treatment Steel," by J.W. Day, TMB Report R-123, May 1941.

(2) Bureau of Ships letter QP/W&C-(4)-(5)(Dw), EN28/A2-11 of 14 March 1941 to TMB.

(3) Bureau of Ships Ad Interim Specification 46E4(INT) of 1 April 1943; Amendment 2 of 1 August 1943.

(4) General Specifications - Appendix 5, Specifications for Welding, Part II - Special Treatment and Nickel (3 per cent minimum) Steels, for Vessels of the U.S. Navy, Navy Department Bureau of Construction and Repair, RESTRICTED, April 1940.

PRNC-4684-2-20-48-100