SSC-175

Mechanical Properties of a High-Manganese, Low-Carbon Steel for Welded Heavy-Section Ship Plate

by

R. D. STOUT and C. R. ROPER, JR.
Lehigh University

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August 1966

Dear Sir:

The Ship Structure Committee is sponsoring, at Lehigh University, a research project entitled "Selection of Steels for Heavy-Section Ship Plate." The purpose is to determine experimentally the optimum composition and/or heat treatment for steel plates up to 4-in. thicknesses intended for ship construction.

Herewith is the Second Progress Report by R. D. Stout and C. R. Roper, Jr., entitled <u>Mechanical Properties of a High-Manganese, Low-Carbon Steel for Welded Heavy-Section Ship Plate</u>.

The project has been conducted under the advisory guidance of the National Academy of Sciences-National Research Council, utilizing its Ship Hull Research Committee.

Sincerely yours,

John B. Oren
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

SSC - 175

Second Progress Report

on

Project SR - 162

"Selection of Steels for Heavy-Section Ship Plate"

to the

Ship Structure Committee

MECHANICAL PROPERTIES OF A HIGH-MANGANESE, LOW-CARBON STEEL FOR WELDED HEAVY-SECTION SHIP PLATE

by

R. D. Stout and C. R. Roper, Jr.
Lehigh University

under

Department of the Navy
Bureau of Ships Contract NObs-84829

Washington, D. C.
National Academy of Sciences-National Research Council
August 1966

ABSTRACT

There is a need for a steel of suitable strength, weldability, and resistance to brittle fracture for use in heavy-sections in ships of large tonnage. Broadly, the steel in thicknesses up to 3 inches was expected to possess the strength, resistance to brittle fracture, and weldability equal to 2-inch normalized ABS Class C steel.

An extensive series of tests was conducted to provide information on the mechanical properties, weldability, and uniformity of the material. On the basis of Charpy, van der Veen, and drop-weight tests, an ASTM A537 steel was found to be superior to a normalized 2-inch thick ABS Class C steel in resistance to brittle fracture even when test samples were taken from 4-inch A537 plates. Therefore, suitable composition for heavy-section ship plate appears to be 0.09-0.12% C, 1.00/1.35% Mn, 0.15/0.30% Si, Al-killed for fine-grain practice and supplied in the spray-quenched and tempered condition.

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INTRODUCTION

The need for a steel of suitable strength, weldability, and resistance to brittle fracture for use in heavy-sections in ships of large tonnage prompted the Ship Structure Committee to support a project designed to lay the basis for the selection of a suitable steel.

The initial phase of the program(1) was intended to establish suitable testing methods for measuring the resistance of heavy-section steel plates to brittle fracture, and to provide data on the degree to which the level of toughness performance of the steel must be raised to counteract size effects as plate thickness is increased. It was shown that the effect of thickness with metallurgical conditions constant was to raise the transition temperature markedly between 1/2 and 1-1/2 inches thickness, but only moderately above 2 inches thickness. The effect of thickness was checked by three different testing methods: the van der Veen test, the drop-weight test, and the Bagsar test.

The second phase of the program, covered by the present report, has been a study of the mechanical properties and weldability of a steel composition which was judged to show promise as a steel for heavy-section ship plate. The steel was chosen on the premise that a simple carbon-manganese steel could be heat-treated to furnish the desired properties including weldability at a lower cost than that of more complex alloy steel grades. Broadly, the steel in thicknesses up to 3 inches was expected to possess the strength, resistance to brittle fracture, and weldability equal to 2-inch normalized ABS Class C steel. While the laboratory tests could not be used to determine the service properties of the steel, they pro-

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[1] "Geometric Effects of Plate Thickness" by R. D. Stout, C. R. Roper, Jr. and D. A. Magee, Ship Structure Committee Report No. SSC-160, February 7, 1964

vided a direct comparison of the steel to ABS Class C, whose characteristics and service performance are well-known.

THE CANDIDATE STEEL

From the outset it was decided to select a steel composition which is commercially available in heavy plates in order to avoid a testing program based on laboratory heats. An ASTM grade of steel, A537, similar to the British XNT grade, which may be regarded as a modified ABS Class C steel (i.e., higher Mn and lower max. C contents), was furnished by the Lukens Steel Company. This steel is supplied in the normalized or spray-quenched and tempered condition and has the following nominal composition.

C	Mn	P	S	Si
0.20 max.	0.70/1.35	0.035 max.	0.040 max.	0.15/0.30

Depending on thickness and heat treatment, the steel exhibits a tensile strength in the range of 70 - 100,000 psi, a minimum yield strength of 46 - 60,000 psi, and minimum elongation in 2 inches of 30%. It generally will absorb more than 20 ft.-lb. in V-notch Charpy tests at -75° F.

ASTM A537 steel is designed to meet tensile strength requirements considerably above the 58 - 71,000 psi range specified for the ABS steels. The rules of the American Bureau of Shipping permit the use of material above 71,000 psi; but they limit the increase in design stresses. It was therefore considered desirable to test a typical heat of A537 and also a lower carbon heat which would have the double advantage of meeting ship steel tensile strength requirements and presumably of improved weldability. Plates of each composition were obtained in 1-inch, 2-inch, and 4-inch

TABLE 1. COMPOSITIONS AND TENSILE PROPERTIES OF THE A537 PLATES

Chemical Composition

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al
A5238	0.17	1.20	0.013	0.025	0.19	0.18	0.12	0.10	0.02	0.025
Y0915	0.16	1.19	0.012	0.029	0.26	0.29	0.19	0.11	0.03	0.035
A7111	0.10	1.18	0.015	0.019	0.21	0.27	0.18	0.08	0.03	0.025

Strip Tension Test Properties

Heat	Thickness (in.)	Heat Treatment	0.2% Yield Strength (psi)	Tensile Strength (psi)	% Elong. in 2"	% Red. Area	Ferrite Grain Size
A5238	1	Normalized	54,100	77,000	35	N.D.	10.2
	2	Normalized	50,100	72,200	34	N.D.	10.5
	4	Normalized	45,500	73,700	34	N.D.	10.5
	1	Quench & Temp	60,000	81,000	32	N.D.	12.2
	2	Quench & Temp	56,900	77,200	33	N.D.	11.5
	4	Quench & Temp	59,000	79,500	34	N.D.	11.4
Y0915	1	Normalized	54,000	76,800	28*	65	11.0
	1	Quench & Temp	61,000	80,600	46	67	12.6
	2	Quench & Temp	56,000	78,600	33	65	11.4
A7111	1	Normalized	49,000	68,900	28*	68	10.2
	2	Quench & Temp	50,400	69,100	36	74	11.0
	4	Quench & Temp	48,500	67,500	37	N.D.	10.2

*% Elong. in 8"

thicknesses. The chemical compositions, heat treatments, and mill tensile test properties are listed in Table 1.

THE EXPERIMENTAL PROGRAM

To assess the suitability of the carbon-manganese steel for heavy section ship plate applications, an extensive series of tests was conducted to provide information on the mechanical properties, weldability, and uniformity of the material. The tests included were as follows:

1. Strength and hardenability
    a. Tensile tests (furnished by the mill)
    b. End-quench hardenability test
2. Resistance to brittle fracture
    a. V-notch Charpy tests
    b. van der Veen tests
    c. Drop-weight tests
3. Weldability
    a. Underbead cracking tests
    b. Lehigh restraint tests
    c. Explosion-bulge tests
4. Uniformity
    a. Hardness explorations
    b. Metallographic examination for grain size and microstructure
    c. Charpy tests at edge and center, 1/4 and mid-thickness of plates
    d. Chemical composition at edge and center, 1/4 and mid-thickness of plates

It was felt that satisfactory performance of the A537 steel in this group of tests would be a clear indication that the steel is suitable for heavy-section ship plates.

EXPERIMENTAL RESULTS

Strength and Hardenability

The tensile tests furnished by the steel producer and listed in

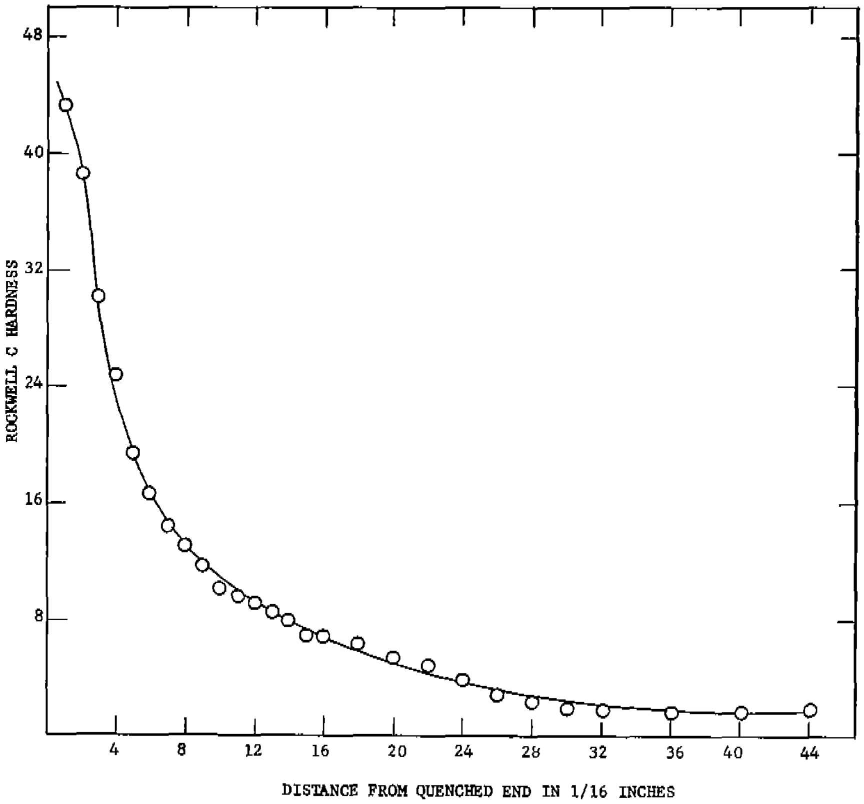


Fig. 1. End-quench characterstics of the A537 Steel quenched from 1650° F. (Heat A5238)

Table 1 show that the heats with normal carbon contents (0.16 - 0.17% C) average 75 - 80,000 psi tensile strength, while that of the low carbon (0.10%) heat is about 69,000 psi, within ABS ship plate specifications.

The end-quench hardenability curve for the A537 steel (heat A5238) shown in Fig. 1 can be used to estimate the hardness and strength that can be produced by spray-quenching steel plates up to four inches thick. It is evident from the hardness curve that the spray-quenching of plates 1-inch thick or more is not a martensitic hardening operation but a strengthening treatment obtained from the formation of finer ferrite-carbide aggregates than those that result from normalizing. Metallographic examination to confirm this point will be shown later.

TABLE 2. RESULTS OF TESTS FOR RESISTANCE TO BRITTLE FRACTURE ON A537 STEEL

		van der Veen Tests		Drop-weight Test	Charpy Tests	
Heat	Thickness & Treatment	50% Shear	2% Lat. Contr.	NDT*	15 ft.-lb.	50% Shear
A5238	1" - Norm.	-45° F	- 70° F	-40° F	- 90° F	-15° F
	2" - Norm.	+45	- 15	-20	- 70	+25
	4" - Norm.	+30	- 10	--	- 50	+30
	1" - Q & T	-70	-130	-60	-135	-60
	2" - Q & T	-55	-110	-60	-145	-35
	4" - Q & T	-15	- 45	--	-105	-10
Y0915	1" - Norm.	-45	- 90	-50	- 90	-20
	1" - Q & T	-65	-105	-70	-135	-40
	2" - Q & T	--	--	-70	-145	-10
A7111	1" - Norm.	-25	- 90	-50	-100	0
	2" - Q & T	-40	-140	-50	-125	0
	4" - Q & T	+10	- 55	-50	- 90	+10
ABS	1" - Norm.	-25	- 55	-20	- 60	0
Class C	2" - Norm.	+ 5	- 35	-10	- 45	+ 5

*Drop-weight NDT determined on plates machined to 1-inch thickness.

Resistance to Brittle Fracture

Because no single test is universally accepted as a standard for evaluating the resistance of structural steels to brittle fracture, the subject steels were tested by three common methods: the V-notch Charpy test, the van der Veen test, and the drop-weight test. These tests represent a variety of loading conditions and are evaluated by different criteria of performance; they therefore provide a broader measure of the sensitivity of the steel to brittle fracture than can be elicited from one testing method.

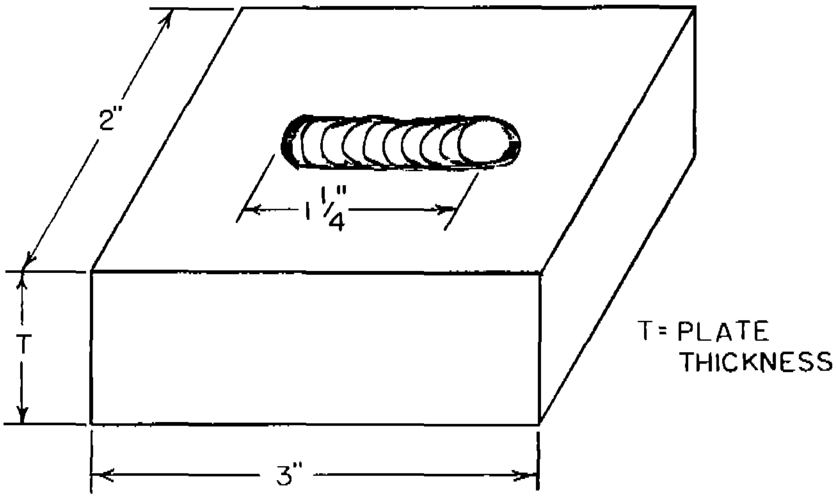
The results of the tests are compiled in Table 2. The response of 1- and 2-inch thick plates of ABS Class C steel to the test is included for comparison. It can be seen that in all tests the quenched and tempered heats of A537 even in thicknesses up to 4 inches are equal to or superior to the normalized 2-inch thick ABS Class C steel.

The Charpy tests and the drop-weight tests, in which the dimensions were held constant, demonstrate that the metallurgical condition of the A537 steel in all thicknesses results in notch toughness superior to that of the ABS Class C steel. The van der Veen tests are particularly interesting because they were conducted on the full plate thicknesses and therefore take account of both metallurgical and size effects. It appears that accelerated cooling is effective in raising the toughness enough to overcome size effects up to as much as 4 inches thickness.

Weldability Tests

The acceptability of a steel for use in heavy-section ship plates is contingent upon the dependability of welded assemblies in commercial fabrication. Three weldability tests were used to measure the characteristics of the A537 steel heats: the Battelle underbead cracking test, the Lehigh restraint test, and the crack-starter explosion-bulge test. The essential features of each test are described briefly below.

> The dimensions of the underbead cracking test are shown in Fig. 2 together with the conditions under which the test is conducted. Since the hydrogen concentration in the arc atmosphere and the cooling rate are as severe as any to be expected in fabrication, the testing conditions may be regarded as rigorous in revealing a tendency to underbead cracking.
>
> The Lehigh restraint test, as shown in Fig. 3, uses a one-piece specimen to measure the sensitivity of a base metal, weld-metal system to root cracking under controlled restraint. The severity of restraint is regulated by the depth of the fins cut into the edges of the specimen, and cracking is produced in either weld metal or base metal according to their susceptibilities. Delayed



Welding Conditions:

Specimen welded with 1/8" diameter E6010 electrode at 26V, 100 amp, 10"/min while immersed in water at 70° F up to 1/4" of top surface of the specimen.

Specimens are left in the bath for 1 minute after welding, then held at 60° F for 24 hours, and finally are tempered at 1100° F for 1 hour.

Specimens are then split in half longitudinally and underbead cracks are detected by magnetic particle inspection after grinding through 2/0 paper and etching with 5% nital.

Fig. 2. Battelle underbead cracking test specimen.

cold cracking can be detected by a transducer fastened to posts across the midpoint of the weld groove.

The explosion-bulge test has been applied mostly to weldments in which ballistic properties are of importance, but it can be used for structural steel plates as well, particularly if a crack strater is introduced at the center of the weld in the form of a short bead of hard-facing alloy. The testing set-up is shown in the diagram of Fig. 4. Specimens are tested at a series of temperatures to establish the FTE transition temperature which is defined as the temperature above which the running crack is arrested before it propagates through the hold-down edges of the plate that are elastically loaded.

The results of the weldability tests are summarized in Table 3. Further details on the fabrication and testing of the explosion-bulge

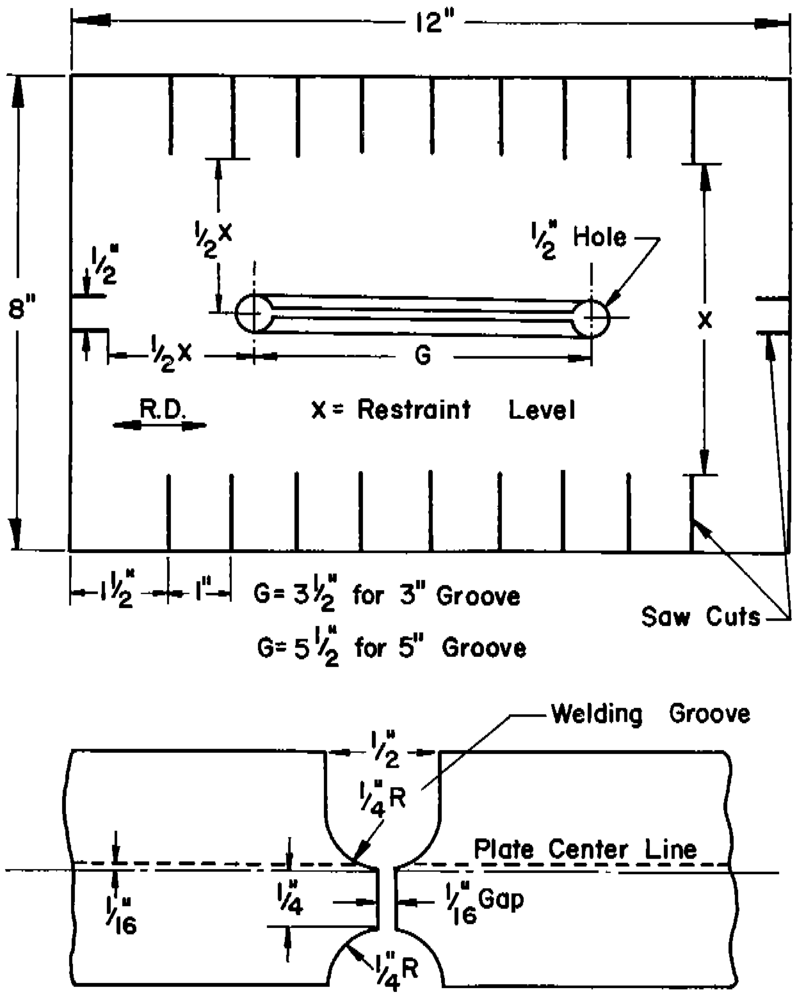


Fig. 3. Lehigh restraint specimen.

plates are given in Table 4. The proclivity of the 0.17% carbon heat to underbead cracking in both the Battelle and Lehigh specimens when welded with cellulosic electrodes is to be expected from its carbon and manganese contents. The carbon equivalent (C + Mn/4 + Ni/20) is 0.49, a level which is associated with sensitivity to cold cracks when welding is performed in a hydrogen-rich arc atmosphere. By comparison, the 0.10% carbon heat has a carbon equivalent of 0.41 and the ABS Class C steel value is 0.37. The use of low-hydrogen electrodes obviates the cracking problem. The performance of the 0.10% C A537 very nearly equals that of the ABS Class C steel and suggests that it can be welded satisfactorily by current shipyard welding practices.

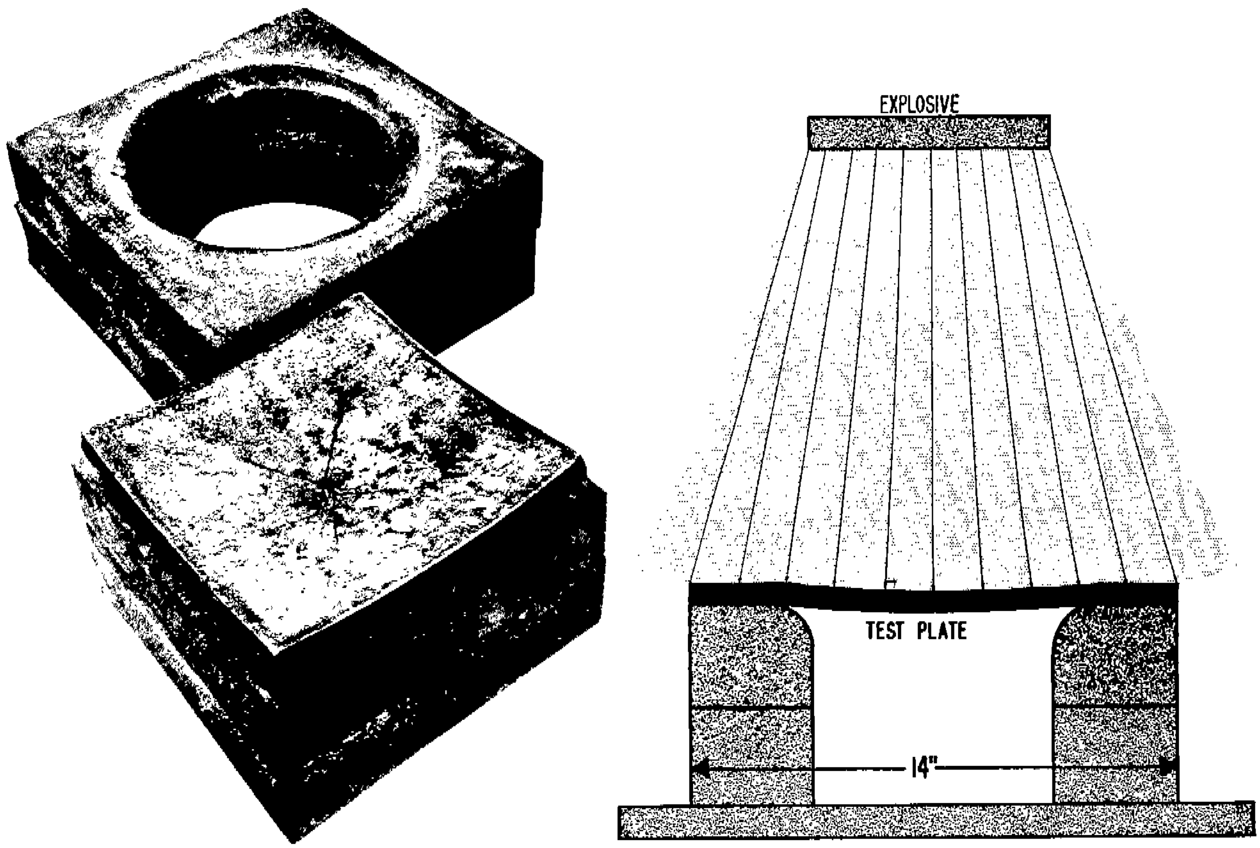


Fig. 4. Explosion-bulge loading method.

The explosion-bulge tests support the view that commercially welded A537 steel maintains a resistance to brittle fracture considerably better than that which appears necessary for ship steels. It is noteworthy that the plate thickness effect evinced by the explosion-bulge tests corroborates the observations recorded in a previous report (SSC-160). The average rise in transition temperature between 1-inch and 2-inch thick plates for the FTE criterion is about 40° F.

Uniformity Tests

The uniformity of the A537 steel (Heat A5238) when produced in heavy sections was examined by means of chemical analysis, Charpy tests, and hardness surveys. Variations were determined between locations at

TABLE 3. RESULTS OF WELDABILITY TESTS ON A537 STEEL

Heat	% Carbon	Plate Thickness and Treatment	Battelle Crack Test (% Crack Length)	Lehigh Restraint Test[4] (Critical Uncut Width-inches) E6010	E8018	Explosion-Bulge Tests FTE[1]
A5238	0.17	1" - Norm.	82	--	>8	--
		1" - Q & T	81	5[3]	>8	-60° F
		2" - Norm.	71	--	>8	--
		2" - Q & T	74	2[3]	>8	0
A7111	0.10	1" - Norm.	0	8	>8	-60
		2" - Q & T	0	4	>8	-10
ABS		1" - Norm.	0	8[2]	>8	--
Class C		2" - Norm.	0	5	>8	--

Notes:

1. The explosion-bulge tests on normal carbon A537 were prepared from Heat Y0915 (0.16% C)
2. The 1-inch ABS Class C steel cracked at 8-inches restraint when the weld bead length was reduced from 5 inches to 3 inches
3. Cracking in the restraint tests of Heat A5238 occurred in the heat-affected zone. The specimens of Heat A7111 and of ABS Steel cracked in the weld metal
4. The welding conditions for the Lehigh Restraint test were:
   E6010: 180 amps, 26 volts, 10 in./min., 3/16" dia. electrode
   E8018: 200 amps, 22 volts, 10 in./min., 3/16" dia. electrode baked at 360° F for 24 hours

the midwidth and edge of the plate and at the surface and 1/4 thickness positions.

The chemical test samples were analyzed for carbon and manganese. As shown in Table 5, the variation of analysis with location was normal for plates of these thicknesses. The carbon varied proportionately more than the manganese, and no correlation between the two was apparent.

The Charpy test transition temperatures for the series of plate locations are listed in Table 6. The 1-inch thick plates showed good uniformity among all positions as did the 2-inch thick plates except for slightly better toughness in the normalized plate edge, 1/4 thickness location than at the other positions in the same plate. In the 4-inch

TABLE 4A. WELDING PROCEDURE FOR EXPLOSION-BULGE SPECIMENS

A537 Carbon Content	Plate Thick. (in.)	Electrode*	Number of Passes per Side of Double-V Groove: Root 5/32" Electrode	Number of Passes per Side of Double-V Groove: Total 5/32" + 3/16" Electrodes	Welding Conditions: amps 5/32"	amps 3/16"	volts 5/32"	volts 3/16"	Interpass Temp. (°F)**
0.10%	1	E7010-A1	1-3	6	140	175	22-24	22-24	<150
0.10%	2	E7010-A1	1-3	21	140	175	22-24	22-24	<150
0.16%	1	E8016-C1	1-3	5-6	170	205	18	20	<250
0.16%	2	E8016-C1	1-3	14-17	170	205	18	20	<250

Electrode Compositions

	C	Mn	Si	S	P	Mo	Ni
E7010-A1	.09/.13	.50/.65	.20/.30	.035 max.	.030 max.	.40/.65	
E8016-C1 5/32"	.057	--	.37	--	--	--	2.56
3/16"	.049	--	.36	--	--	--	2.63

*Plates were manually butt welded together and all welds x-rayed 100%
**All plates were preheated to 150° F before welding

plate, the notch ductility was noticeably better at the surface than at the 1/4 thickness, but the 50% fibrous transition temperatures were about the same for both. This behavior will be examined further in the metallographic phase of the program.

The hardness surveys are summarized in Fig. 5. As might be expected, the quenched and tempered plates occasionally showed more variation across the thickness than the normalized plates. The maximum variation corresponds to about 50 points in BHN. In all but two plates, the excursions of hardness are much less than this amount.

Metallographic Examination

Metallographic samples of each of the A537 plates were prepared to determine the variations in microstructure which resulted from the

TABLE 4B. EXPLOSION-BULGE TEST CONDITIONS

Plate No.	Plate Thickness (in.)	Test Temperature (°F)	Reduction in Plate Thickness (%)	Standoff Distance (in.)*
1-RQT-1	1	0	2-1/4	15
1-RQT-2	1	- 60	1-3/4	15
1-RQT-4	1	- 80	1-1/2	20
1-RQT-5	1	- 90	1-1/4	20
1-RQT-3	1	-100	1-1/4	18
1-LN-1	1	0	2	15
1-LN-2	1	- 60	1-1/4	15
1-LN-4	1	- 80	1/2	20
1-LN-3	1	-100	0	19
1-LN-5	1	-106	1/2	20
2-RQT-1	2	0	3-1/4	15
2-RQT-3	2	- 30	2-1/2	15
2-RQT-4	2	- 45	2	20
2-RQT-2	2	- 60	2-1/2	20
2-LQT-2	2	+ 30	2	20
2-LQT-3	2	+ 15	2	20
2-LQT-4	2	+ 5	1-1/2	20
2-LQT-1	2	0	2	15
2-LQT-5	2	- 10	1-1/2	20

Code: L - 0.10% C
R - 0.16% C
QT - Quenched & Tempered
N - Normalized

*Seven pounds of pentolite explosive was used for 1" plate
Twenty-eight pounds for 2" plate

variables of carbon level, plate thickness, and cooling medium in heat treatment. Figures 6 and 7 show the microstructures of the three heats of A537. The most marked effect on grain size and carbide distribution was produced by the cooling method. The refinement was naturally less in the thicker plates. With a reduction in carbon content, the volume of pearlite decreased but the ferrite grain size was essentially unchanged.

TABLE 5. SURVEY OF CHEMICAL COMPOSTION VARIATIONS IN HEAT A5238

	1/4 Thickness				Surface			
	Plate Edge		Plate Center		Plate Edge		Plate Center	
	C(%)	Mn(%)	C(%)	Mn(%)	C(%)	Mn(%)	C(%)	Mn(%)
1" Normalized	0.150	1.25	0.160	1.26	0.175	1.29	0.190	1.32
2" Normalized	0.175	1.32	0.180	1.32	0.170	1.28	0.170	1.29
4" Normalized	0.170	1.29	0.190	1.26	0.160	1.23	0.175	1.31
1" Quenched & Tempered	0.150	1.28	--	--	0.170	1.34	--	--
2" Quenched & Tempered	0.175	1.31	0.150	1.31	0.160	1.31	0.150	1.28
4" Quenched & Tempered	0.190	1.28	--	--	0.160	1.35	--	--

SUMMARY DISCUSSION

The investigation reported here is concerned with the mechanical properties and weldability of a carbon-manganese steel which was selected as a promising candidate specification for use in heavy-section steel plates for ship construction.

The characteristics of the A537 steel are summarized in Fig. 8 and are compared with those of ABS Class C steel, normalized in 1-inch and 2-inch thicknesses. Some comments can be made about the results shown in Fig. 8.

Strength - Since quenched and tempered A537 steel is designed for applications requiring tensile strengths in the 70 - 100,000 psi range, it normally exceeds the specification range for ship steel as shown in Fig. 8. However, by reducing the carbon level to 0.10% the strength was brought to within the ship steel range and the weldability was materially improved.

TABLE 6. SURVEY OF VARIATION OF V-NOTCH CHARPY PROPERTIES OF HEAT A5238 WITH POSITION IN THE PLATE

Plate Condition \ Position	1/4 Thickness Plate Edge (°F)	1/4 Thickness Plate Center (°F)	Surface Plate Edge (°F)	Surface Plate Center (°F)
1" Normalized				
50% Fibrous	- 15	- 10	- 10	- 15
10 ft.-lbs.	- 95	-110	-110	-120
15 ft.-lbs.	- 90	- 90	-100	-110
15 mil	- 90	-100	-110	-115
20 mil	- 85	- 85	-105	- 95
2" Normalized				
50% Fibrous	+ 25	+ 50	+ 50	+ 50
10 ft.-lbs.	- 85	- 60	- 65	- 65
15 ft.-lbs.	- 70	- 50	- 55	- 60
15 mil	- 80	- 60	- 60	- 65
20 mil	- 70	- 50	- 55	- 60
4" Normalized				
50 % Fibrous	+ 30	+ 55	+ 55	+ 45
10 ft.-lbs.	- 70	- 75	-110	-100
15 ft.-lbs.	- 50	- 65	-100	- 90
15 mil	- 65	- 70	-110	- 95
20 mil	- 50	- 65	-105	- 90
1" Quenched & Tempered				
50% Fibrous	- 60	- 50	- 45	- 45
10 ft.-lbs.	-155	-170	-175	-175
15 ft.-lbs.	-135	-145	-150	-150
15 mil	-140	-145	-150	-140
20 mil	-130	-125	-130	-130
2" Quenched & Tempered				
50% Fibrous	- 35	- 25	- 25	- 20
10 ft.-lbs.	-160	-180	-175	-170
15 ft.-lbs.	-145	-150	-150	-145
15 mil	-145	-165	-165	-150
20 mil	-130	-145	-145	-135
4" Quenched & Tempered				
50% Fibrous	- 10	0	- 15	- 10
10 ft.-lbs.	-120	-165	-170	-180
15 ft.-lbs.	-105	-140	-155	-170
15 mil	-110	-135	-155	-170
20 mil	- 95	-115	-130	-150

Resistance to Brittle Fracture - Both low and normal carbon versions of the A537 steel were shown by three different testing methods to exhibit resistance to brittle fracture superior to that of an ABS Class C steel. Although there are no specifications of notch toughness for the ship steels, it is possible from previous experience with ABS Class C steel to use it as a basis of comparison to judge

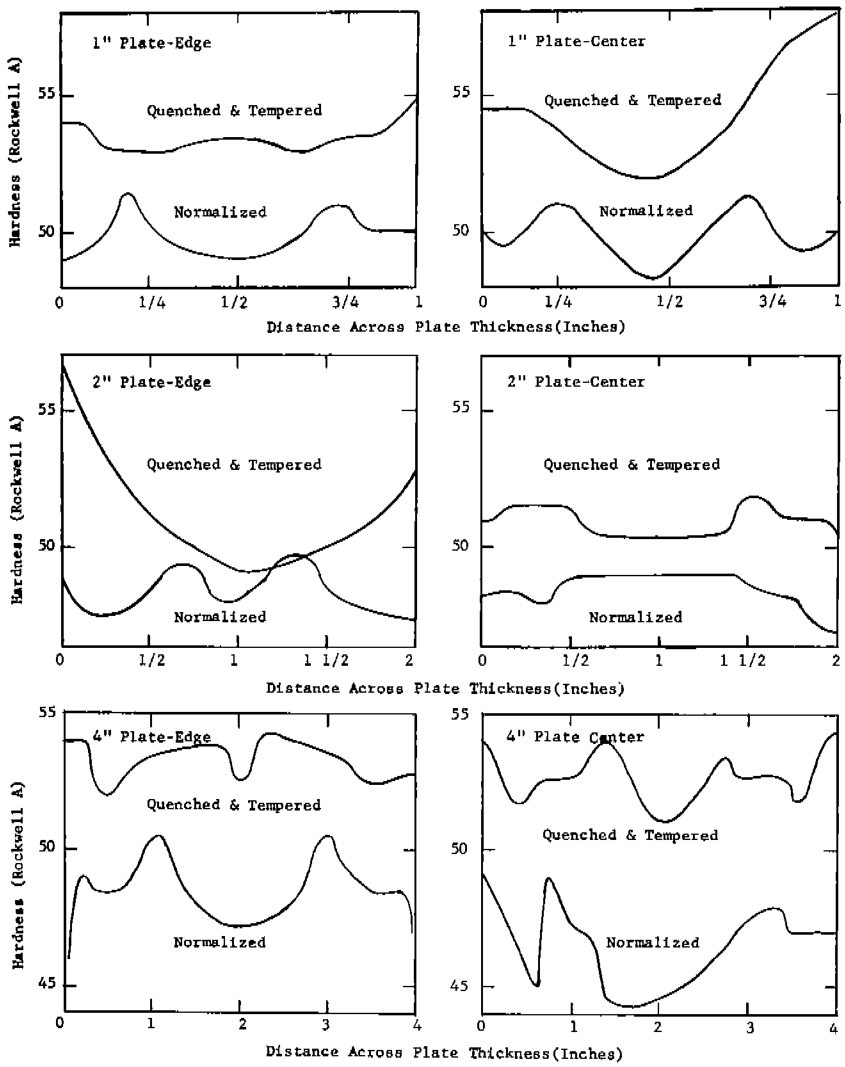
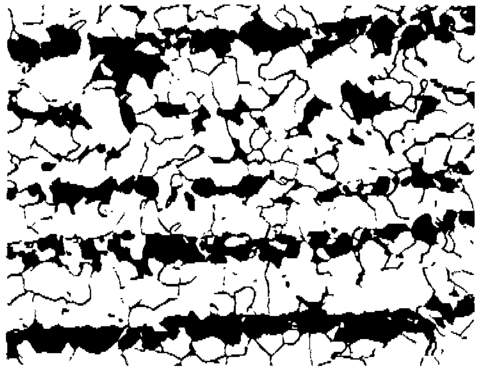


Fig. 5. Hardness profiles for A537 plate in two conditions. (Heat A5238)

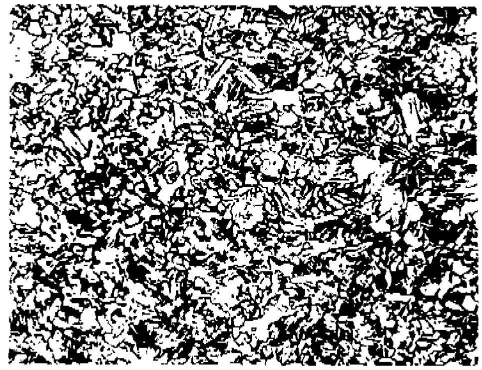
the minimum performance levels which should assure satisfactory service in ships. The data of Fig. 8 suggest that the A537 steel exhibits satisfactory resistance to brittle fracture for applications in heavy-section ship plate.

<u>Weldability</u> - As might be predicted from its higher Mn content the 0.17% carbon A537 steel required some precautions in welding. By lowering the carbon content from 0.17% to 0.10% the precautions could be essentially

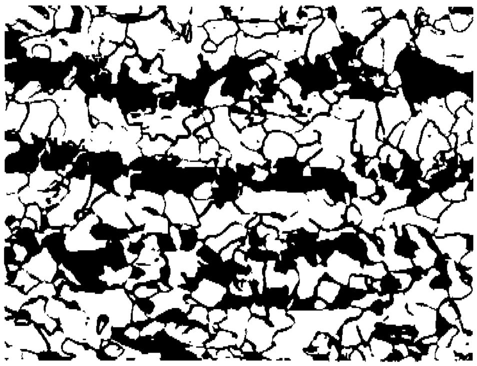
Heat A5238, 0.17% C



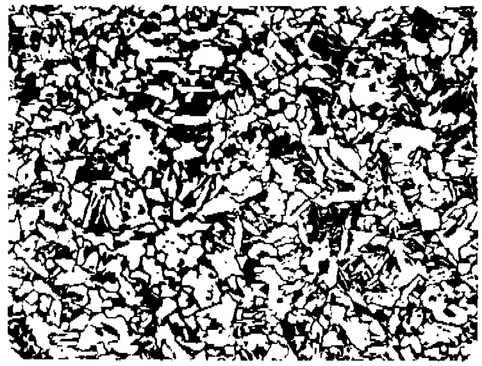
1" Plate Norm.



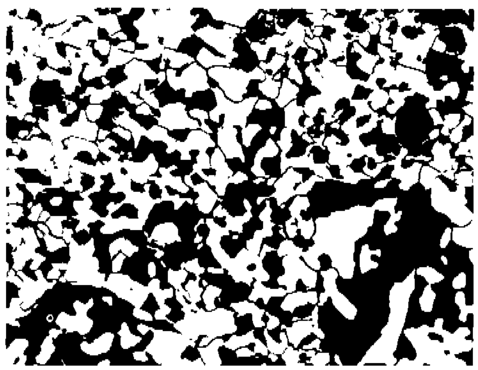
1" Plate Q & T



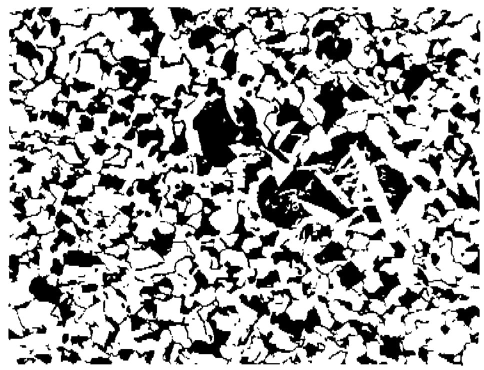
2" Plate Norm.



2" Plate Q & T



4" Plate Norm.



4" Plate Q & T

Fig. 6. Microstructures of A537 steel. Nital etch. 225x.

eliminated, and the steel matched the weldability of ABS Class C steel. As shown by fabrication of the explosion-bulge plates, the 0.17% carbon grade of A537 is readily

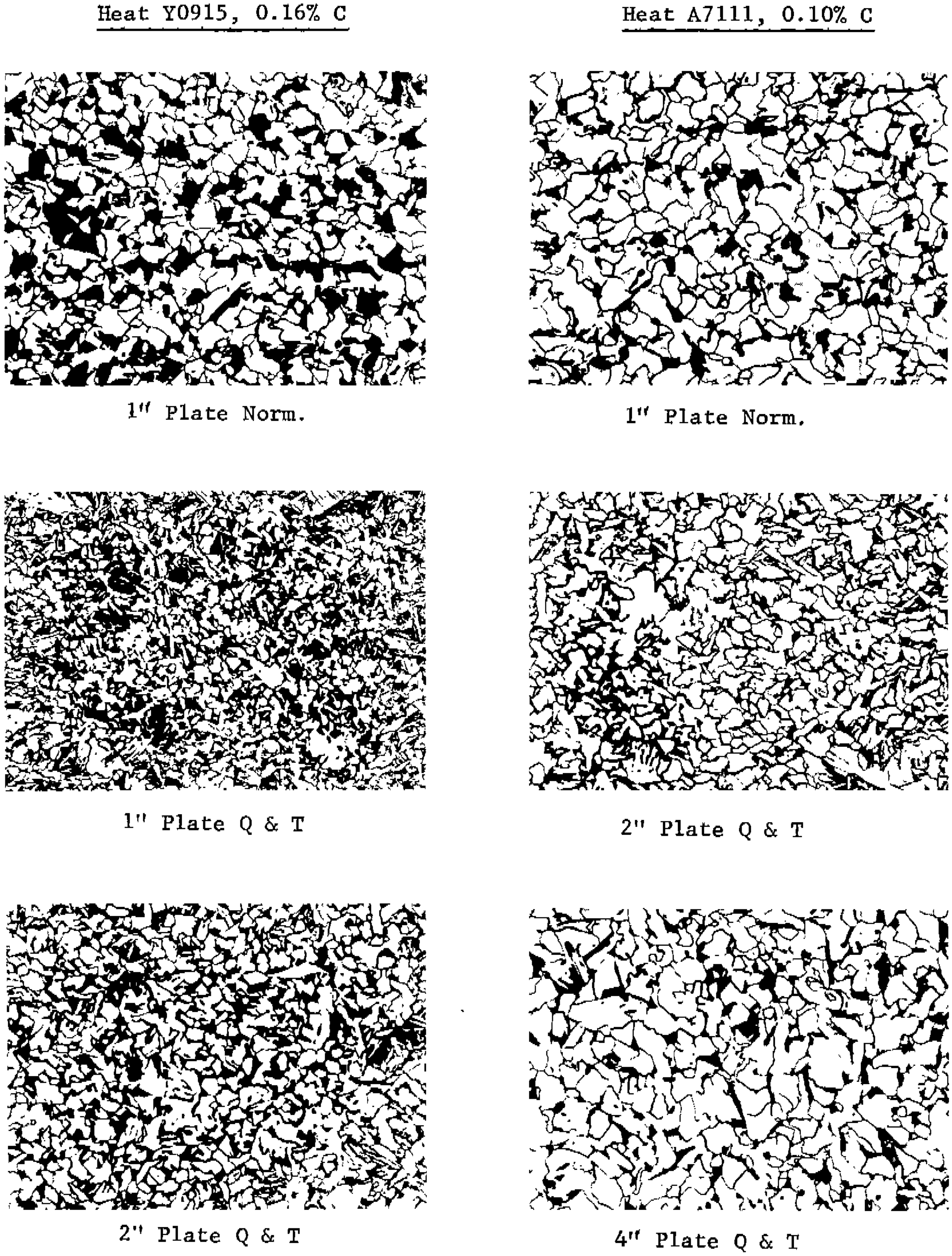


Fig. 7. Microstructures of A537 steel. Nital etch. 225x.

weldable with low-hydrogen electrodes. If these electrodes can be specified and used in shipyard fabrication, the normal carbon grade would be satisfactory.

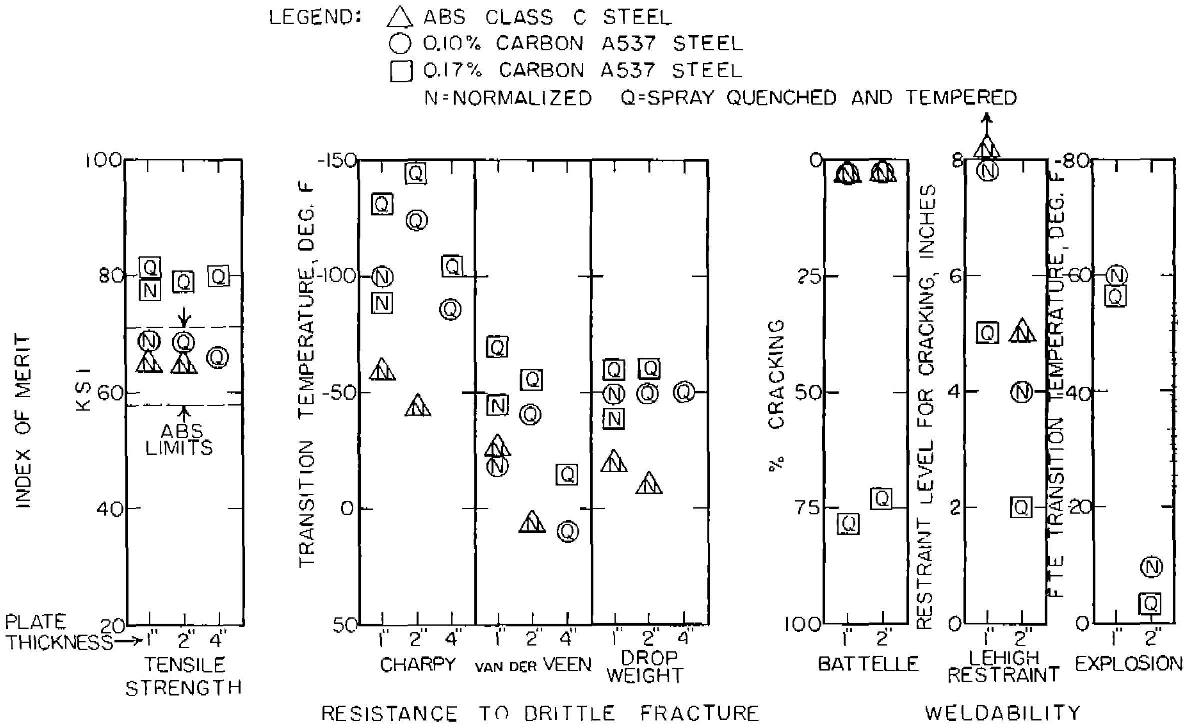


Fig. 8. Summary chart of characteristics of A537 steel.

Summary

The following summary is based on the results of the investigation.

1. From considerations of commercial availability, an aluminum-killed, carbon-manganese steel (A537) in the spray-quenched and tempered condition was chosen as a promising candidate steel for heavy-section ship plates.

2. In order to stay within the ship steel strength range and to improve weldability, it is desirable to keep the carbon content of the steel below 0.12%. If low hydrogen electrodes are specified, the normal grade is weldable.

3. If higher strength is acceptable, the higher carbon content composition can be used satisfactorily provided that low-hydrogen welding electrodes are employed.

4. On the basis of Charpy, van der Veen, and drop-weight tests, the A537 steel was found to be superior to a normalized 2-inch thick ABS Class C steel in resistance to brittle fracture even when test samples were taken from 4-inch A537 plates.

5. A suitable composition for heavy-section ship plate appears to be 0.09-0.12% C, 1.00/1.35% Mn, 0.15/0.30% Si, Al-killed for fine-grain practice and supplied in the spray-quenched and tempered condition.

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1 ORIGINATING ACTIVITY *(Corporate author)* SHIP STRUCTURE COMMITTEE	2a. REPORT SECURITY CLASSIFICATION NONE 2b GROUP

3. REPORT TITLE

MECHANICAL PROPERTIES OF A HIGH-MANGANESE, LOW-CARBON STEEL FOR WELDED HEAVY-SECTION SHIP PLATE.

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Second Progress Report on Project SR-162.

5. AUTHOR(S) *(Last name, first name, initial)*

Stout, R. D., and Roper, C. R. Jr.

6. REPORT DATE	7a. TOTAL NO OF PAGES	7b. NO. OF REFS
April 1966	26	1

8a. CONTRACT OR GRANT NO. Bureau of Ships Contract Nobs-90188 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) SSC-175 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Bureau of Ships, Navy Department Washington, D. C.

13. ABSTRACT

The need for a steel of suitable strength, weldability, and resistance to brittle fracture for use in heavy-sections in ships of large tonnage prompted the Ship Structure Committee to support a project designed to lay the basis for the selection of a suitable steel.

The initial phase of the program was intended to establish suitable testing methods for measuring the resistance of heavy-section steel plates to brittle fracture, and to provide data on the degree to which the level of toughness performance of the steel must be raised to counteract size effects as plate thickness is increased.

The second phase of the program, covered by the present report, has been a study of the mechanical properties and weldability of a steel composition which was judged to show promise as a steel for heavy-section ship plate. The steel was chosen on the premise that a simple carbon-manganese steel could be heat-treated to furnish the desired properties including weldability at a lower cost than that of more complex alloy steel grades. Broadly, the steel in thicknesses up to 3 inches was expected to possess the strength, resistance to brittle fracture, and weldability equal to 2-inch normalized ABS Class C steel. While the laboratory tests could not be used to determine the service properties of the steel, they provided a direct comparison of the steel to ABS Class C, whose characteristics and service performance are well-known.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Steel Brittle Fracture Weldability Mechanical Properties Toughness Optimum Composition						

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