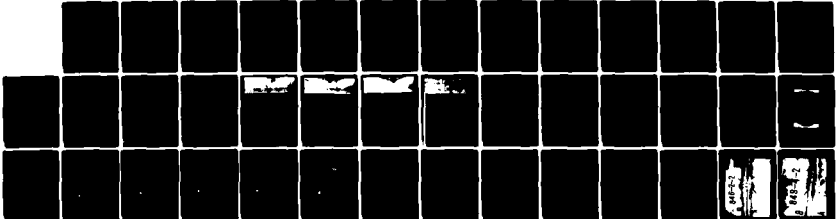
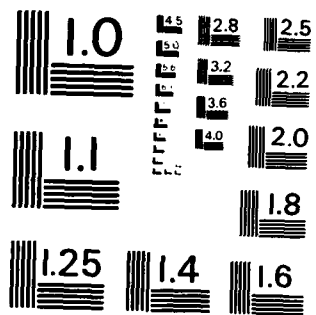


AD-A145 497 DESIGN CONSTRUCTION DEMONSTRATION AND DELIVERY OF AN
AUTOMATED NARROW GAP WELDING SYSTEM(U) CRC AUTOMATIC
WELDING CO HOUSTON TX 30 SEP 83 CRC-NAV-A/W-8
UNCLASSIFIED N00600-81-C-E923 F/G 13/10 NL

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A145 497

①

CRC REPORT NO. NAV A/W 8

PHASE 4 REPORT

ON

DESIGN, CONSTRUCTION, DEMONSTRATION AND
DELIVERY OF AN AUTOMATED NARROW GAP
WELDING SYSTEM
CONTRACT NO. N00600-81-C-E923

TO

DAVID TAYLOR RESEARCH AND DEVELOPMENT CENTER
DEPARTMENT OF THE NAVY

FROM

CRC AUTOMATIC WELDING
SEPTEMBER 30, 1983

INTRODUCTION

The objective of this program is to design, construct, demonstrate, and deliver an automated, Narrow Gap welding system capable of welding high strength steel plates under shipyard production conditions in the construction of aircraft carriers. The program is being conducted in five phases:

- (1) Definition of Requirements
- (2) Design of Welder Package
- (3) Equipment Construction
- (4) Qualification of Process and Equipment
- (5) Shipyard Demonstration

SEP 12 1984

Phase I was completed slightly ahead of schedule and the Phase I report, CRC Report No. NAV A/W 1, was submitted November 5, 1981. Phase I was devoted to a thorough review of the requirements that must be met by a shipyard production Automated Narrow Gap welding system (ANGWS).

DTIC FILE COPY

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Phase 4 Report
9/30/83
-- Page 2 --



Attis on file

Al

Phase 2 was completed slightly behind schedule and the Phase 2 report, CRC No. NAV A/W 4, was submitted June 29, 1982. This report covered the detailed design of the Narrow Gap welder. Phase 3 was completed behind schedule and the Phase 3 report CRC No. NAV A/W 7, was submitted March 31, 1983. This report covered the construction of the Narrow Gap Welder.

PHASE 4 QUALIFICATION OF SOFTWARE AND EQUIPMENT

This phase 4 report summarizes the work done from April 1, 1983 through September 30, 1983.

MATERIALS

Preliminary welding was done on 2 1/2 inch thick HY-100 steel plate. The chemical composition and mechanical properties of this plate were not determined.

The process qualification work was done on 2-inch-thick HY-100 plate purchased from Phoenix Steel Corporation. Two plates, 2-by 80-by 252 inch, were purchased. The heat records are shown in Appendix Tables A-1 and A-2. Transverse specimens for charpy vee-notch and dynamic tear testing were machined from the plate material to qualify the plates to "J" specification.

The charpy impact testing was done at Metallon Inc. in Houston, Texas. The dynamic tear testing was done at David Taylor Naval Ship Research and Development Center (DTNSRDC), Annapolis, Maryland. The results of

Phase 4 Report

9/30/83

-- Page 3 --

these base plate tests were as shown below:

<u>TEST</u>	<u>HY-100, HEAT NUMBER</u>	
	<u>4227G-39</u>	<u>53203-39</u>
Charpy Vee-Notch foot - pounds		
0°F Test Temperature	108, 117, 112, 117, 111.5	115, 110, 111.5, 114
-120°F Test Temperature	72, 63.5, 76.5, 67.5, 68.5	61, 54.5, 73.5, 77, 11.5
Dynamic Tear, foot - pounds		
- 40°F	939.8, 933.5	885.9, 888.4

The backup bars were 1/2" by 1-inch HY-100 material supplied by DTNSRDC. The chemical composition of the backup bar material was not determined.

Initially, 1/16-inch-diameter Airco AX-90 filler wire was used. However, considerable fumes were given off during welding and there was some tendencies to arc instability when using this filler wire. Linde 95, 1/16-inch-diameter, filler wire was substituted and used for the majority of the welding evaluation and for the qualification welds. The nominal composition of the Linde 95 filler wire was as shown below:

<u>Element</u>	<u>Chemical Composition</u> <u>Weight Percent</u>
C	0.04 to 0.06
Mn	1.00 to 1.40
Si	0.30 to 1.40
Ni	1.95 to 2.05
Cr	0.05 to 0.20
Mo	0.40 to 0.50

The shielding gas used throughout these evaluations was 95-5 percent, Argon-CO₂.

EQUIPMENT

The Narrow Gap welding equipment was designed in Phase 2 and constructed in Phase 3 of this contract. Two Narrow-Gap welders were built instead

Phase 4 Report
9/30/83
-- Page 4 --

of the contracted requirement for one machine. A "prototype" model was built to insure the design was correct, several modifications were made. The necessary changes were made to the drawings and a production model was built to the updated drawings. Both models were used for development and testing.

As a result of the work done in Phase 3 to evaluate welding power supplies, a 650-ampere, Miller Delta weld 650 was purchased and used throughout Phase 4.

Preheating was provided by strip heaters. Preheat temperature was determined by a contact pyrometer and by tempilstiks.

EXPERIMENTAL PROCEDURE

Extensive welding trials were conducted during Phase 3 to evaluate the Narrow Gap welder's capability to deposit sound welds in 2 1/2-inch thick HY-100 plate. The preliminary work that was done in Phase 4 was to evaluate the adaptive computer software program and to investigate the weld joint design. The program plan followed was to deposit welds in 2-foot-long HY-100 plates, 2 1/2-inch-thick and modify the software program and joint design as required. Then 5-foot long HY-100 plates, 2 1/2-inch thick, were welded to investigate the consistency of the system. Finally, welds were made in 20-foot-long, 2-inch-thick HY-100 plate

Phase 4 Report

9/30/83

-- Page 5 --

preparatory to the find 20-foot-long qualification weld. The number of welds made during this Phase 4 evaluation were as follows:

<u>Weld Length, Feet</u>	<u>Plate Thickning inches</u>	<u>Number of Welds</u>
2	2 1/2	45
5	2 1/2	43
20	2	4

The filler wire used for all of these welds was 0.0625-inch-diameter. Linde 95 using a shielding gas of 95-5 percent Argon-CO₂. Over 1,500 pounds of filler wire was used for these welding trials.

In addition, 3-welds were deposited in 4-foot long, 4-inch-thick, HY-100 plate. Additional work on the 4 inch thick plate will be required before a procedure can be qualified.

Narrow Gap Welding Adaptive Software Studies

During the welding evaluation, it was determined that a different welding procedure would have to be developed for the root pass than for the fill passes and cap pass. The problem involved in depositing the root pass was the general tendency toward arc instability caused by the spacing between the backing bar and the test plates. In the usual startup procedure, the torch would move to the left until the filler wire touched the top edge of the weld joint, then move to the right until the right sidewall was touched, and then move to the midpoint between these sidewalls . At that point, the welding head

normally would drive down until the filler wire touched the bottom of the joint, move left, and then right, and center in the bottom of the joint and start welding. Because of the Narrow Gap joint configuration, it was practical to determine only the centerline of the weld joint at the top and drive straight down to the bottom of the joint and start welding. To tell the microprocessor that a root pass was desired, the software was modified so that if the welding head moved down more than one-inch the program would automatically select the root pass welding parameters. The first four oscillation sweeps at the start of welding was done under predetermined welding conditions, i.e., wire-feed-speed, voltage, etc. During these four sweeps, the microprocessor was collecting data concerning centerline height and computing the required welding parameters for the remaining root-pass welding.

The adaptive feed-back-control concept is based on detecting the change in arc length and its effects on the voltage-amperage relationship as the sidewall is approached. This requires a minimum of 0.100-inch-high sidewall to track the weld joint. The minimum sidewall height may not be available after the last fill pass because of either overfill or because of a high-low condition in the plate fitup. It was determined that the most practical solution was to allow for a manual, steerable cap pass routine. On the cap pass, the operator uses a remote pendant to position manually the cap pass. There are two control push buttons located on the remote pendant. By activating the "centerline out" or "centerline in" buttons, the torch can be moved 0.025-inch every sweep of the oscillation in either direction. In this manner, the operator can "steer" the path of cap pass.

Additional changes to the software involved the addition of new diagnostic routines to insure proper operation of the computer control, modification of the travel speed algorithms to improve weld pool profiles, and improvement in the initial startup parameters by ramping the arc voltage during the initial startup welding.

Joint Design

The initial welding studies were made using a parallel-sided joint, approximately 3/8 inch-wide. The water-cooled contact-tube assembly is almost 1/4-inch-wide. The minimum oscillation width for tracking is 0.040 inch. Therefore, the contact-tube assembly tended to drive into the sidewall producing a "shorting out" situation before the arc came close enough to the sidewall to detect a sidewall-signal response. To provide some greater clearance, the plates were angled so that the joint opening was about 3/8-inch wide at the root with an included joint opening of approximately 6-8 degrees. A number of welds were made to determine the root opening tolerances that could be welded with a joint included angle of 6-8 degrees. It was determined that the limits on joint opening with the 6-8 degree included angle was $3/8$ inch \pm $1/8$ inch.

It was recognized that cocking or canting the plates to produce the desired opening might not be practical. Subsequent studies were made where the plates were flame-beveled 3-4 degrees to produce a 6-8 degree included angle joint with the plate surfaces flat. Satisfactory welds were made in this manner.

Contact Tips

The service life of the contact tip was of concern during phase 4 of the project. The required tip life was a minimum of 20 feet of weld length so a pass could be deposited without a start-stop. It was established early in Phase 4 that normal copper tips were not satisfactory. Contact tip life was improved with a Tellurium alloy but a 20 foot length was not achieved. Finally, a 6% Tungsten-copper alloy with a 0.078 inch to 0.080 inch hole was found to have a service life in excess of 20 feet.

Qualification Welds

The Narrow Gap welding system developed in this contract is an adaptive-feedback controlled system that senses the edges of the weld joint, tracks the joint, and continuously adjusts the welding parameters, wire-feed speed (amperage), arc voltage, travel speed, and oscillation width as required to maintain a target heat input level and fill height. An upper limit target heat input of 55,000 joules per inch was used. However, cap passes were deposited at about 70,000 joules per inch. Typical welding parameters were as shown below.

<u>Parameter</u>	<u>Typical Values</u>
Wire Feed Speed, ipm	235
Arc Voltage, volts	25 to 28
Travel Speed, ipm	7 to 12

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9/30/83
-- Page 9 --

test weld #82 was deposited in 2-inch-thick, 5 feet long, HY-100 plate for preliminary mechanical property testing. The backing bar was removed by flame cutting followed by hand grinding. A back weld was made with the Narrow Gap welding system. The weld was radiographed using an Iridium 192 isotope ultrasonically inspected, and shipped to DTNSRDC for testing. The transverse-weld tensile and dynamic tear properties were determined. A single explosion-bulge plate was prepared and tested at the Naval Ordnance Laboratory at Louisville, Kentucky.

Newport News Shipbuilding, (NNS) personnel were thoroughly familiar with the Narrow Gap Welder and its operation as a result of numerous trips to CRC during Phase 3. As a result, the 20-foot-long Phase 4 qualification weld was made at CRC with NNS personnel operating the equipment and assisted by CRC personnel. This weld #92 was radiographed, ultrasonically inspected, back welded, and cut into six explosion-bulge plates. The explosion bulge plates were sent to Louisville for testing. The set consisted of two crack starter plates and four conventional bulge plates. A portion of this weld was sent to DTNSRDC for mechanical property testing and another portion was sent to the Columbus Laboratories, Battelle Memorial Institute, Columbus, Ohio, for microhardness determinations and metallographic examination.

Phase 4 Report
9/30/83
-- Page 10 --

RESULTS

The results of the destructive tests performed on preliminary weld #82 are shown in Table 1.

The results of the destructive tests of qualification weld #92 are shown in Table 2. In addition, the explosion bulge report sheets from the Naval Ordnance Station, Louisville, Kentucky and a sample photograph of a crack starter and a conventional bulge, as well as a copy of the Battelle report on hardness, microstructures and macrostructures are in Appendix A-3.

TABLE 1. PRELIMINARY MECHANICAL PROPERTY TESTS

ANGW - 82 MC (CRC)

B.M. - HY-100
F.M. - 100S-1

WELD METAL MECHANICAL PROPERTIES

<u>Specimen No.</u>	<u>Y.S. (Ksi)</u>	<u>T.S. (Ksi)</u>	<u>E.Long (%)</u>	<u>R.A. (%)</u>	<u>DT Ft./Lbs.</u>	
					<u>- 20°F</u>	<u>+ 30°F</u>
82MC-TB	112.0	120.8	21	69		
82MC-TT	92.8	114.9	25	68		

DB-1					377.1	-----
DT-1					322.6	-----
DB-2					-----	636.6
DT-2					-----	581.6
Spec. Req. 82-110*					300	450

<u>Specimen No.</u>	<u>SHOT NO.</u>	<u>EXPLOSION BULGE</u>				<u>COMMENTS</u>
		<u>Reduction in Thk (%)</u>		<u>Dept of Bulge (in)</u>		
		<u>SIDE A</u>	<u>SIDE B</u>	<u>SIDE A</u>	<u>SIDE B</u>	
844-Bulge						
	1-	1.768	2.213	1.340	1.40	- No visible cracks or tears.
	2-	4.125	4.771	2.46	2.55	- No visible cracks or tears.
	3-	7.859	9.394	3.445	3.49	- No visible cracks or tears.
	4-	11.542	13.625	4.060	4.265	- No visible cracks or tears.
	5-	14.489	17.265	4.700	5.025	- Crack B side Tow, 9" center to left, center to Rt 8" penetrates plate within test area.

* Per NAVSEA 05M2 Min. Y.S. 90 Ksi

TABLE 2. QUALIFICATION WELD NO. 92

Yield Strength	108.9	Ksi
Ultimate Tensile Strength	116.7	Ksi
Elongation	22%	
Reduction in Area	70%	
Charpy vee-Notch		
0° F.	71, 80, 69.5	Ft. lbs.
-60° F.	63, 64, 47.5	Ft. lbs.
Dynamic Tear		
0° F.	865.1, 710, 865.4	Ft. lbs.
-60° F.	364, 423, 396	Ft. lbs.

Phase 4 Report
9/30/83
-- Page 11 --

SUMMARY

Preparation for the 20 foot long qualification began when the results of preliminary weld #82 were satisfactory.

The execution of the qualification weld by Newport News Shipbuilding personnel and the successful completion of all non-destructive and destructive testing marked the completion of Phase 4. Phase 5 will begin immediately.

It should be noted that the cracks incurred from explosion bulge testing of conventional and crack starter samples did not penetrate through the thickness of any test plate.

APPENDIX

PHOENIX STEEL CORPORATION
 CLAYMONT, DELAWARE 19703
 MATERIAL TEST REPORT

SPECIFICATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100)

Oct. 6

HY-100 Steel

CUSTOMER ORDER NO.

SOLD TO CRC Automatic Welding
3450 Lang Road
Houston, Tx. 77092

MILL ORDER NO.

CAR NO. TRUCK

HEAT NO.	SLAB NO.	CHEMICAL ANALYSIS												YIELD STRENGTH P.S.I.
		C	MN	P	S	SI.	CU.	NI.	CR.	MO.	AL	V	TI	
<u>42276-39</u>	<u>78470</u> <u>78470</u>	<u>.14</u>	<u>.30</u>	<u>.010</u>	<u>.003</u>	<u>.21</u>	<u>.17</u>	<u>3.40</u>	<u>1.44</u>	<u>.29</u>	<u>.027</u>	<u>.004</u>	<u>NIL</u>	<u>110000</u> <u>112500</u>
<u>CHEC K ANALYSIS</u>		<u>.14</u> <u>.14</u>	<u>.30</u> <u>.30</u>	<u>.009</u> <u>.011</u>	<u>.004</u> <u>.004</u>	<u>.20</u> <u>.20</u>	<u>.17</u> <u>.18</u>	<u>3.35</u> <u>3.42</u>	<u>1.40</u> <u>1.42</u>	<u>.29</u> <u>.30</u>	<u>.023</u> <u>.022</u>	<u>.003</u> <u>.003</u>	<u>.001</u> <u>.001</u>	<u>LCVN</u> <u>L-114</u>
TRANSVERSE CHARPY (FT-LBS)														
						<u>0°F</u>	<u>108,</u>	<u>117,</u>	<u>112,</u>	<u>117,</u>	<u>111.5</u>		<u>113.1</u>	
						<u>-120°F</u>	<u>72,</u>	<u>63.5,</u>	<u>76.5,</u>	<u>67.5,</u>	<u>68.5</u>		<u>69.6</u>	
TRANSVERSE DYNAMIC TEAR (FT-LBS)														
												<u>-40°F</u>	<u>939.8,</u>	<u>933.</u>

SUBSCRIBED AND SWORN TO BEFORE ME

THIS 11th DAY OF Oct

Frank A. Maloney
 NOTARY PUBLIC

PHOENIX STEEL CORPORATION
 CLAYMONT, DELAWARE 19703
 MATERIAL TEST REPORT

APPENDIX TABLE A-1

CH 1972 (HY-100)

Oct. 6, 1982

B. L. NO.

CUSTOMER ORDER NO. 12708

MILL ORDER NO. 52446-39

CAR NO. TRUCK

BEND TEST

HOMOGENITY TEST

CHEMICAL ANALYSIS								YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG.		RED OF AREA	SIZE
SI.	CU.	NI.	CR.	MO.	AL	V	TI			2"	8"		
21	.17	3.40	1.44	.29	.027	.004	NIL	110000 112500	120500 125000	22.0 21.0		67.0 69.9	1- 2"x80x252"
20	.17	3.35	1.40	.29	.023	.003	.001	LCVN @-120 DEG.F.					
20	.18	3.42	1.42	.30	.022	.003	.001	L-114-122-112			BHN	257/237	
CORSE CHARPY (FT-LBS)													
	108,	117,	112,	117,	111.5		113.1						
	72,	63.5,	76.5,	67.5,	68.5		69.6						
CORSE DYNAMIC TEAR (FT-LBS) -40°F 939.8, 933.5													

ME

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS
 CONTAINED IN THE RECORDS OF THE CORPORATION.

[Signature]
 SUPR. OF TESTING, METALLURGICAL DEPT.

PROF. NICK...
 CIVIL ENGINEER...
 MATERIAL TEST REP.

SPECIFICATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100)

HY-100 Steel

SOLD TO CRC Automatic Welding
3450 Lang Road
Houston, Tx. 77092

HEAT NO.	SLAB NO.	CHEMICAL ANALYSIS										
		C	MN	P	S	SI	CU	N	SE	MO	AL	V
42276-39	78470 78470	.14	.30	.010	.003	.21	.17	3.40	1.44	.29	.027	.004
CHEC K ANALYSIS		.14	.30	.009	.004	.20	.17	3.35	1.40	.29	.023	.003
		.14	.30	.011	.004	.20	.18	3.42	1.42	.30	.022	.003
TRANSVERSE CHARPY (FT-LBS)												
90°F 108, 117, 112, 117, 111												
1200°F 72, 67.5, 76.5, 67.5, 78.5												
TRANSVERSE DYNAMIC TEAR (FT-LBS) 1000												

SUBSCRIBED AND SWORN TO BEFORE ME

THIS

DAY OF

11th Oct

James A. Maloney
 NOTARY PUBLIC

IX STEEL CORPORATION
 MONT, DELAWARE 19703
 SERIAL TEST REPORT

PLATE 2

APPENDIX TABLE A-2

Dec. 8, 1982

B. L. NO.

CUSTOMER ORDER NO. 12708

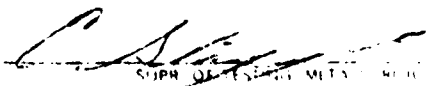
MILL ORDER NO. 52446-39

CAR NO. TRUCK

BEND TEST	HOMOGENITY TEST
-----------	-----------------

MO.	AL	V	TI	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG.		RED O ¹⁷ AREA	SIZE
						2"	8"		
.48	.027	.002	.001	112000 114000	127000 131500	23.0 21.0		63.8 63.5	1- 2"x80x252"
.52	.029	.002	.001						
.51	.025	.002	.001						
QUENCHED, THEN TEMPERED ABOVE 1150 Deg.F., TO MEET									
VG.									
12.4									
66.5									
85.9, 898.4									

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION


 SUPERVISOR OF TESTING METALS

PHOENIX STEEL CORPORATION
 CLAYMONT, DELAWARE 19725
 MATERIAL TEST REPORT

CONDITION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100)

Dec

HY-100 Steel

CUSTOMER ORDER NO.

SOLD TO CRC Automatic Welding
 3450 Lang Road
 Houston, Tx. 77092

MILL ORDER NO.

CAR NO. T

HEAT NO.	SLAB NO.	CHEMICAL ANALYSIS											STRENGTH	
		C	MN	P	S	SI.	CU.	NI.	CR.	MO.	AL	V		TI
51 3-39	80863	.18	.24	.009	.008	.29	.24	2.89	1.48	.48	.027	.002	.001	112
	80863													114
		LCVN @-120 DEG. F.				BHN								
53203-39	80863	L-100-99-104				257/257								
CHECK ANALYSIS														
53203-39		.18	.26	.012	.010	.31	.21	2.70	1.54	.52	.029	.002	.001	
		.18	.25	.012	.010	.30	.21	2.73	1.52	.51	.025	.002	.001	
		AUSTENITIZED AT 1675 +/- 25 F AND WATER QUENCHED, THEN TEMPERED TO THE ABOVE PROPERTIES												
		TRANSVERSE IMPACTS (FT-LBS)								AVG.				
		00F	115,	110,	111.5,	111.5,	114				112.4			
		-1200F	61,	54.5,	73.5,	72,	71.5				66.5			
		TRANSVERSE DYNAMIC TEAR (FT-LBS)								-400F		885.9, 888.4		

SUBSCRIBED AND SWORN TO BEFORE ME

THIS _____ DAY OF _____

NOTARY PUBLIC

PHOENIX STEEL CORPORATION
 CLAYMONT, DELAWARE 19703
 MATERIAL TEST REPORT

ATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100)

Dec. 8, 1982

HY-100 Steel

CUSTOMER ORDER NO. 12708

LD TO CRC Automatic Welding
3450 Lang Road
Houston, Tx. 77092

MILL ORDER NO. 52446-39

CAR NO. TRUCK

HEAT NO.	SLAB NO.	CHEMICAL ANALYSIS												YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% C 2"	
		C	MN	P	S	SI.	CU.	NI.	CR.	MO.	AL	V	TI				
203-39	80863 80863	.18	.24	.009	.008	.29	.24	2.89	1.48	.48	.027	.002	.001	112000 114000	127000 131500	23.0 21.0	
		LCVN @-120 DEG.F.					BHN										
203-39	80863	L-100-99-104				257/257											
CHECK ANALYSIS																	
3203-39		.18	.26	.012	.010	.31	.21	2.70	1.54	.52	.029	.002	.001				
		.18	.25	.012	.010	.30	.21	2.73	1.52	.51	.025	.002	.001				
		AUSTENITIZED AT 1675 +/- 25 F AND WATER QUENCHED, THEN TEMPERED ABOVE 1150 De															
		TRANSVERSE IMPACTS (FT-LBS)								AVG.							
		0°F	115,	110,	111.5,	111.5,	114										
		-120°F	61,	54.5,	73.5,	72,	71.5										
		TRANSVERSE DYNAMIC TEAR (FT-LBS) -40°F								885.9,		888.4					

SUBSCRIBED AND SWORN TO BEFORE ME

THIS _____ DAY OF _____

NOTARY PUBLIC

CERT
 CONTA

PHOENIX STEEL CORPORATION
 CLAYMONT, DELAWARE 19703
 MATERIAL TEST REPORT

PLATE 2
 APPENDIX TABLE A-2

K-100) Dec. 8, 1982 B. L. NO. _____

CUSTOMER ORDER NO. 12708

MILL ORDER NO. 52146-39

CAR NO. TRUCK

BEND TEST	HOMOGENITY TEST
-----------	-----------------

ANALYSIS	CR.	MO.	AL	V	TI	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG.		RED OI ⁿ AREA	SIZE
								2"	8"		
99	1.48	.48	.027	.002	.001	112000 114000	127000 131500	23.0 21.0		63.8 63.5	1- 2"x80x252"
3	1.54 1.52	.52 .51	.029 .025	.002 .002	.001 .001						
WATER QUENCHED, THEN TEMPERED ABOVE 1150 Deg.F., TO MEET											
		AVG, 112.4									
		66.5									
40°F		885.9, 888.4									

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

C. [Signature]
 SUPR. OF TESTING, METALLURGICAL DEPT.

(5)
 A

October 26, 1983



Columbus Laboratories
77 Lang Avenue
Columbus, Ohio 43291
Telephone: 614-424-6424
Telex: 252114

Mr. Brian Laing
CRC Automatic Welding
3450 Lang Road
Houston, TX 77092

Dear Brian:

This letter presents the results of our metallographic examination of the 20-foot-long demonstration weld in HY-100 steel plate.

Macroexamination

A section was cut from the CRC sample. This section was located about half way along the sample length so that it would be as far as possible from the sample edges. Sectioning was by a band saw using oil-water emulsion coolant. The section then was ground and polished for metallographic examination.

A photomicrograph of this section is in Figure 1. The weld is sound throughout. No porosity, lack of fusion, inclusions, or cracks were present. The pore-like feature in the right heat-affected zone of the second fill pass is an artifact and was not present in the actual specimen. The cap pass and/or the last fill pass are unbalanced to the left side of the joint. The arc oscillation possibly was biased in this direction.

The width of the heat-affected zone was measured at several locations. The measured widths were:

	<u>Heat-Affected Zone Width, inch</u>	
	<u>Left Side</u>	<u>Right Side</u>
At top surface	0.095	0.116
1/16 inch below top surface	0.238	0.152
Mid thickness	0.112	0.092
1/16 inch above bottom surface	0.167	0.208
At bottom surface	0.078	0.110

Hardness Measurements

Microhardness (Knoop 500 gram) traverses were made across the width of the weld joint at five locations. These are shown by the arrows and accompanying numbers in Figure 1. Traverses 1 and 5 were made at a location 1/16 inch below the top and bottom surfaces respectively, of the specimen. At this location, measurements were made in the untempered weld metal of the cap and root passes and their heat-affected zones. Traverses 2 and 4 were made at a location approximately 1/8 inch below the bottoms of the cap and root passes. Traverse 3 was made at the middle of the specimen. Each traverse included at least three measurements in each base metal, six measurements in each heat-affected zone, and five measurements in the weld metal. The spacing

between the heat-affected-zone measurements was 0.010 inch. The weld-metal measurements were equally spaced across the width of the weld metal. Base metal measurements were made approximately 0.25 inch from the edge of the heat-affected zone and were spaced at 0.010 inch.

The results of these measurements are given in Figure 2. (This figure is schematic and not to scale.)

The hardnesses of the various zones are reasonably consistent except for the heat-affected zones of Traverse 2. These hardnesses, particularly on the left side, are significantly lower than at any other area of the heat-affected zone. In these areas, the hardness measurements were taken just at the bottom edge of the cap pass heat-affected zone. On the left side, this location also is directly under the area of the cap or last fill pass where the arc oscillation appears unbalanced. These areas experienced thermal cycles (possibly multiple cycles) that were different from other areas of the heat-affected zone. The different heating-cooling profiles may account for the softer structure.

Microstructure

Photomicrographs of typical weld metal and heat-affected zone areas are shown in Figures 3 through 7.

Figures 3 and 4 are of weld metal. The structure shown in Figure 4 is typical of the fill passes. This weld metal has been "tempered" by subsequent passes. The reheating appears to have caused some precipitation of possible carbides. This change did not result in any significant changes in microhardness.

Figures 5, 6, and 7 are of three areas of a typical fill pass heat-affected zone. The structure in Figure 5 is found adjacent to the fusion line. It is tempered martensite at this location and is very similar to the base metal microstructure. In the cap and root pass heat-affected zones, apparent untempered martensite is found adjacent to the fusion line. An intermediate zone shown in Figure 6 is found in the mid portion of the heat-affected zone while, adjacent to the base metal, a fine-grained microstructure exists (Figure 7).

The widths of these three areas of the heat-affected zone vary greatly depending on the location. This is particularly true in the cap and root pass heat-affected zones where significant changes in the widths occur with minor changes in location. Therefore, actual widths were not measured. Generally speaking, the coarse-grained zone varied from about 15 to 30 percent of the heat-affected zone width. The intermediate and fine-grained zones generally were of about the same width and occupied about equally the balance of the heat-affected zone width. If actual widths of these three areas are required for a variety of locations, we can make these measurements.

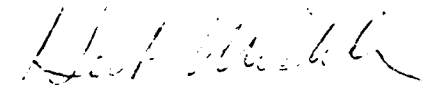
Mr. Brian Laing

3

October 26, 1983

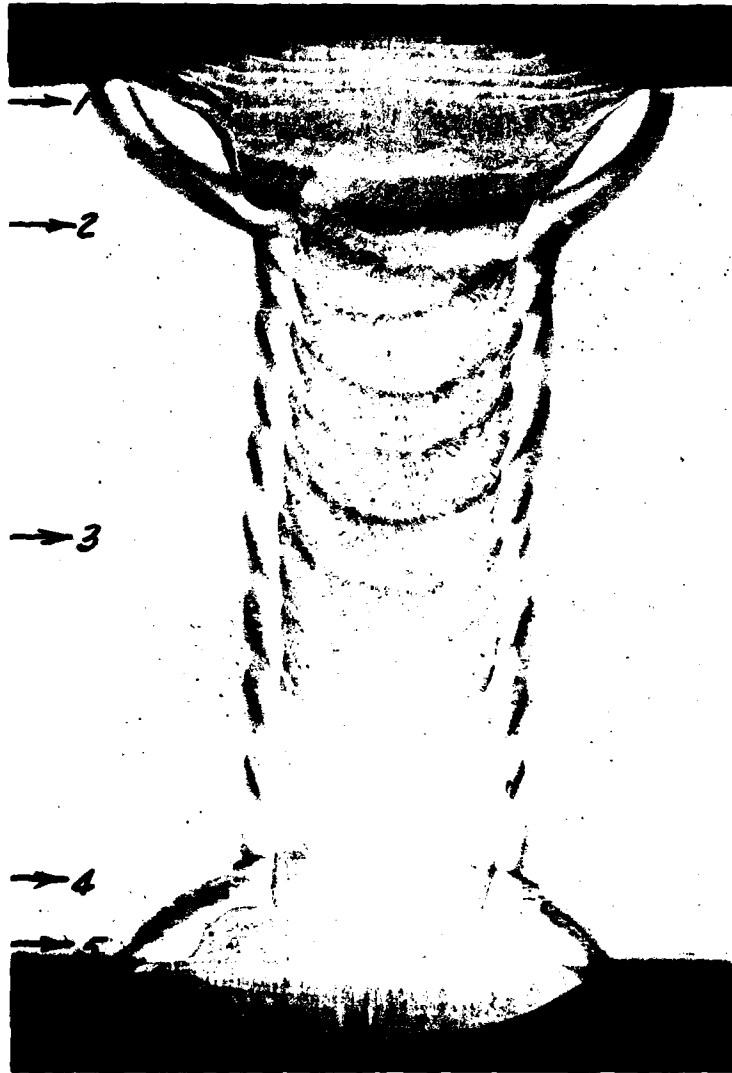
We hope this provides the information that you need for your report. If you have any questions or need additional information, please let me know.

Best regards,



H. W. Mishler
Metalworking Section

HWM:jrh



2X

3.5% picral - 0.2% nital

3L543

FIGURE 1. PHOTOMACROGRAPH OF NARROW-GAP WELD IN 2-
-INCH-THICK HY-100 STEEL

Arrows indicate location of hardness traverses.

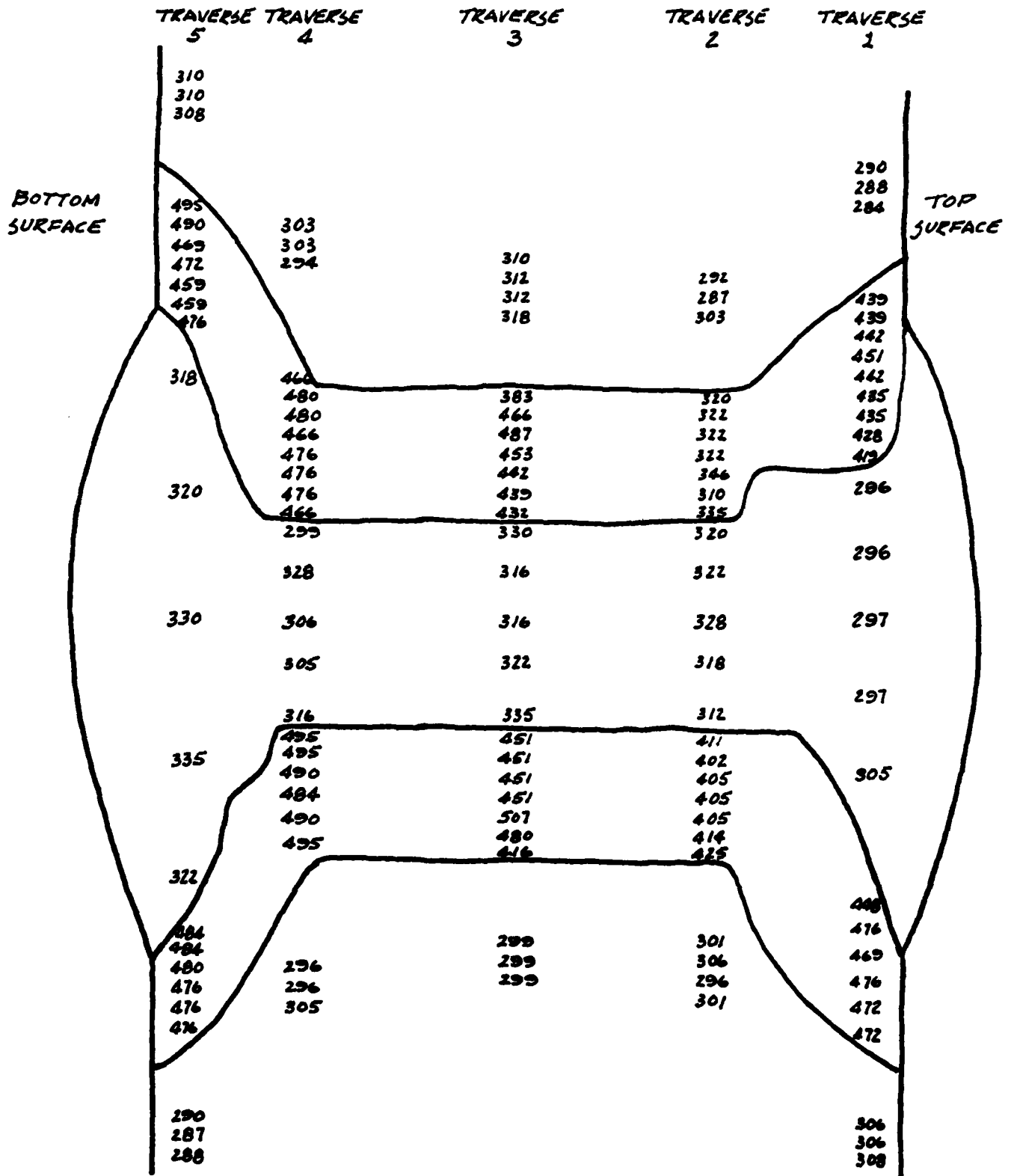
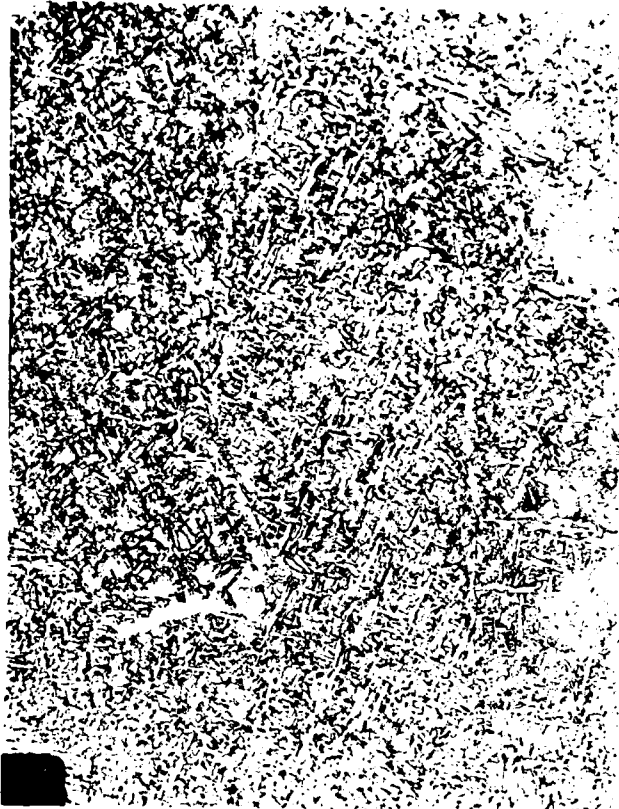


FIGURE 2. KNOOP 500 GM HARDNESS MEASUREMENTS OF NARROW-GAP WELD

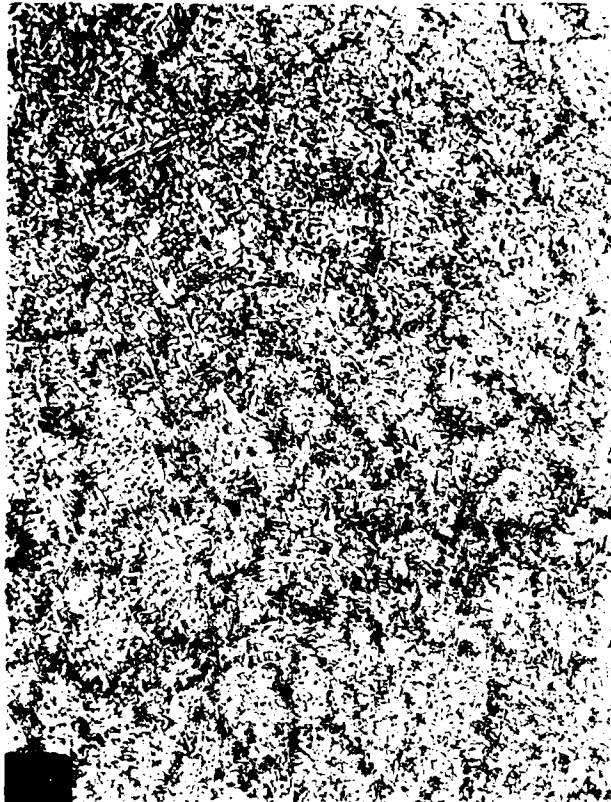


500X

3.5% picral - 0.2% nital

3L559

FIGURE 3. PHOTOMICROGRAPH OF CAP PASS WELD METAL OF NARROW-GAP WELD



500X

3.5 picral - 0.2 nital

SL560

FIGURE 4. PHOTOMICROGRAPH OF TYPICAL FILL PASS WELD METAL OF
NARROW-GAP WELD

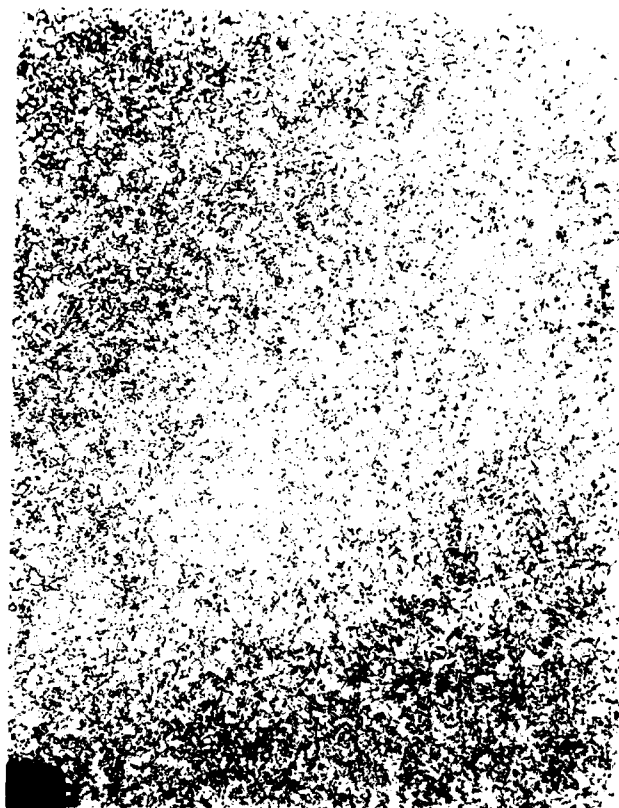


500X

3.5% picral - 0.2% nital

3L561

FIGURE 5. PHOTOMICROGRAPH OF COURSE GRAINED PORTION OF HEAT-AFFECTED ZONE OF NARROW-GAP WELD



500X 3.50 micral - 0.20 nital 3L562

FIGURE 6. PHOTOMICROGRAPH OF INTERMEDIATE GRAINED PORTION OF HEAT-AFFECTED ZONE OF NARROW-GAP WELD



500X

3.5 picral - 0.2 nital

3L563

FIGURE 7. PHOTOMICROGRAPH OF FINE GRAINED PORTION OF HEAT-AFFECTED ZONE OF NARROW-GAP WELD

Base metal microstructure appears on the left.

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	845					
Type of Test	Crack Starter					
Material	HY-Steel					
Initial Thickness (in.)	Location A <u>2.071</u>			Location B <u>2.063</u>		
Remarks:						
SHT NUMBER						
	1	2				
Date	9-20-83	9-20-83				
Time elapsed fired	5M 30S	4M 15S				
Stand off Distance (in.)	17"	17"				
Pentolite Charge (lbs.)	24	24				
Temperature of Spec. At Firing (°F) Est.	0°	0°				
Ambient Temperature (°F) (Outdoor)	81°	87°				
Picture Number	845-1-1 845-1-2	845-2-1 845-2-2				
RESULT OF TEST						
Plate Thk.-Location A	2.000	1.914				
% Reduction In Thickness	3.428	7.580				
Plate Thk.-Location B	2.006	1.909				
% Reduction In Thickness	2.762	7.464				
Depth of Bulge (in.)	A	1.540	2.655			
	B	1.540	2.688			

Shot #1: Tear across weld bead at center, enters base metal B side 5/8 inch. Crack across crack starter weld "A" side, TOW 1/2" Crack across crack starter weld B side TOW 1/2" long, enters base metal

Shot #2: Tear across weld bead at center extends into base metal A side 5/8", into B side 1". Crack A side across crack starter bead extends 3/4". Crack B side from 2 1/2" left of center to 2" right of center. Tear penetrates deep into weld metal.

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No. 846						
Type of Test Crack Starter						
Material HY-Steel						
Initial Thickness (in.)		Location A <u>2.085</u>		Location B <u>2.087</u>		
Remarks:						
SHOT NUMBER						
		1	2			
Date		9-20-83	9-20-83			
Time elapsed fired		4M 50S	5M 25S			
Stand off Distance (in.)		17"	17"			
Pentolite Charge (lbs.)		24	24			
Temperature of Spec. At Firing (°F) Est.		0°	0°			
Ambient Temperature (°F) (Outdoor)		81°	87°			
Picture Number		846-1-1 846-1-2	846-2-1 846-2-2			
RESULT OF TEST						
Plate Thk.-Location A		2.000	1.918			
% Reduction In Thickness		4.076	8.009			
Plate Thk.-Location B		2.010	1.938			
% Reduction In Thickness		3.689	7.139			
Depth of Bulge (in.)						
		A	B			
		1.520	2.815			
		1.540	2.850			

Shot #1 Tear across weld bead center, enters base metal A side 5/8", B side 3/8". Crack across crack starter weld A side TOW. Crack across crack starter weld B side TOW. Numerous surface cracks in HAZ, particularly B side.

Shot #2 Tear across weld bead at center extends into base metal A side 1 1/2", into B side 1 1/2", penetrates deep into weld metal. Crack A side TOW from 2 1/2" left of center to 1 1/2" right of center (3 3/4 total). Crack B side TOW from 2 3/4" left of center to 1 1/2" right of center (4 1/2" total).

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No. 847						
Type of Test Bulge						
Material HY-Steel						
Initial Thickness (in.) Location A <u>2.055</u> Location B <u>2.048</u>						
Remarks:						
SHOT NUMBER						
	1	2	3	4		
Date	9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired	6M 20S	5M 45S	5M 35S	5M 45S		
Stand off Distance (in.)	17"	17"	17"	17"		
Pentolite Charge (lbs.)	24	24	24	24		
Temperature of Spec. At Firing (°F) Est.	0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)	49°	59°	51°	62°		
Picture Number	847-1-1	847-2-1	847-3-1	847-4-1 847-4-2		
RESULT OF TEST						
Plate Thk.-Location A	2.016	1.953	1.898	1.824		
% Reduction In Thickness	1.897	4.963	7.639	11.240		
Plate Thk.-Location B	1.992	1.915	1.866	1.796		
% Reduction In Thickness	2.734	6.494	8.886	12.304		
Depth of Bulge (in.)	A	1.455	2.515	3.230	3.730	
	B	1.530	2.605	3.400	4.025	

Shot # 1 N.V.C.T.

Shot # 2 N.V.C.T.

Shot # 3 N.V.C.T.

Shot # 4: Crack A side TOW from 2½" left of center to 1" right of center

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	849					
Type of Test	Bulge					
Material	HY-Steel					
Initial Thickness (in.)	Location A <u>2.079</u>		Location B <u>2.080</u>			
Remarks:						
	SHOT NUMBER					
	1	2	3	4		
Date	9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired	7M 05S	5M 35S	5M 40S	5M 35S		
Stand off Distance (in.)	17"	17"	17"	17"		
Pentolite Charge (lbs.)	24	24	24	24		
Temperature of Spec. At Firing (°F) Est.	0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)	49°	59°	51°	62°		
Picture Number	849-1-1	849-2-1	849-3-1 849-3-2	849-4-1 849-4-2		
	RESULT OF TEST					
Plate Thk.-Location A	2.021	1.961	1.854	1.827		
% Reduction In Thickness	2.789	5.675	10.822	12.127		
Plate Thk.-Location B	2.010	1.933	1.870	1.807		
% Reduction In Thickness	3.365	7.067	10.096	13.125		
Depth of Bulge (in.)	A	1.570	2.590	3.525	4.045	
	B	1.600	2.580	3.455	4.000	

Shot # 1 N.V.C.T.

Shot # 2 N.V.C.T.

Shot # 3: Shallow crack B side TOW 1 3/4" left of center. Appears to be reinforcement bead coming loose from base metal.
(Tack weld location)

Shot # 4: Crack B side TOW extends center to 2" left of center.

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.		850					
Type of Test		Bulge					
Material		HY-Steel					
Initial Thickness (in.)		Location A <u>2.080</u>			Location B <u>2.079</u>		
Remarks:							
		SHOT NUMBER					
		1	2	3	4		
Date		9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired		5M 55S	5M 35S	4M 50S	5M 30S		
Stand off Distance (in.)		17"	17"	17"	17"		
Pentolite Charge (lbs.)		24	24	24	24		
Temperature of Spec. At Firing (°F) Est.		0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)		49°	59°	51°	62°		
Picture Number		850-1-1	850-2-1	850-3-1 850-3-2	850-4-1 850-4-2		
		RESULT OF TEST					
Plate Thk.-Location A		2.011	1.961	1.890	1.836		
% Reduction In Thickness		3.317	5.721	9.134	11.730		
Plate Thk.-Location B		2.015	1.929	1.843	1.764		
% Reduction In Thickness		3.078	7.215	11.351	15.151		
Depth of Bulge (in.)		A	1.555	2.510	3.405	3.910	
		B	1.585	2.570	3.480	4.020	

Shot # 1 N.V.C.T.

Shot # 2 N.V.C.T.

Shot # 3: Crack A side TOW from 1 3/4" left of center to 2" right of center. Crack B side TOW from 2 1/2" left of center to 1" right of center.

Shot # 4: Crack A side TOW from 3 1/2" left of center to 2 1/2" right of center (6" total). Crack B side TOW from 3" left of center to 3" right of center.

846-2-2

B

A

CRACK STARTER SAMPLE NO. 846 AFTER 2 SHOTS



EXPLOSION BULGE SAMPLE NO. 819 AFTER 1 SHOTS

