

OFFSHORE POWER SYSTEMS
8000 Arlington Expressway
Jacksonville, Florida 32211

CERAMIC WELD BACKING EVALUATION

FINAL REPORT
JUNE 1980

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FOREWORD

The purpose of this report is to present the results of one of the research and development programs which was initiated by the members of the Ship Production Committee of The Society of Naval Architects and Marine Engineers and financed largely by government funds through a cost-sharing contract between the U.S. Maritime Administration and Bethlehem Steel Corporation. The effort of this project was directed to the development of improved methods and hardware applicable to shipyard welding in the U.S. shipyards.

Mr. W. C. Brayton and Mr. F. X. Wilfong of Bethlehem Steel Corporation were Program Managers, Mr. T. E. Bahlow of Offshore Power Systems (OPS) was Project Manager, and Mr. R. E. Cantrell and Mr. D. J. St. Pierre of OPS were the Principal Investigators.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of inquiries and evaluation of subcontract proposals.

FINAL REPORT
ON
CERAMIC WELD BACKING EVALUATION
OFFSHORE POWER SYSTEMS
JUNE 1980

I. ABSTRACT

Representative ceramic weld backing systems were evaluated with representative FCAW and SAW processes to determine their efficacy to produce second side weld contours not requiring subsequent back welding or preparation for inspection. Weldments were prepared and evaluated for soundness, toughness, bead shape, ceramic attaching methods and ceramic neutrality. Significant weldment soundness problems were identified for certain FCPW processes in certain positions. Changes in welding technique appear promising for control of these problems (though at some expense in bead shape) but further development in certain instances is required. Relatively minor bead shape problems were identified and corrected for FCAW. More significant bead shape problems were identified for submerged arc particularly in tandem applications. No other problems of potential significance were identified. Promising joint designs, parameters and techniques were identified for welding over ceramic backing. Recommendations for future development are made.

II. INTRODUCTION

One of the most costly and bothersome aspects of the welding industry today is preparation of the weld second side for subsequent welding or inspection. Apart from the low deposition rate welding processes such as GTAW and GMAW short arc, to some degree, no others will consistently produce full penetration one side welds with a smooth, controlled back side contour. The problem is further aggravated by the latitudes in joint geometry historically encountered in a construction environment.

Over the years numerous hacking systems (flux containers, fiberglass tapes, flux covered tapes, ceramic tiles, copper shoes, etc.) have been introduced and endured with varying levels of success and adaptability. As yet, none have found general acceptance. Varies, of Holland, seems to have been the most dedicated and now markets a ceramic backing system complete with special filler material and power sources. Even though ceramic backing, per se, is not new, there is renewed interest and enthusiasm among domestic vendors. There is general agreement that if a backing system evolves permitting full penetration one side welding with high deposition rate welding processes, is forgiving enough to absorb construction tolerances, is relatively easy to use, and is cost effective in a production environment; the welding industry will commence a new era of efficiency.

The objective of this program was to establish if ceramic tile backing and flux cored arc welding (FCAW) and submerged arc welding (SAW) butt welding applications could provide:

- o visually acceptable as-welded back side contours requiring no cosmetic grinding repair
- o volumetrically acceptable weldments requiring no grinding and welding repair.

III. CERAMICS

The word "ceramics" covers a wide variety of products, all of which are made by forming followed by firing. Ceramics usually consist of oxides, such as silica (sand), alumina, magnesium oxide and iron oxide; carbonates, such as barium carbonate; compounds of oxides, such as steatite (soapstone), or cordierite; or non-oxidic compounds, such as silicon carbide (Carborundum). These substances are either found in nature as minerals, or are prepared from other natural raw materials. In either case, the raw material contains certain impurities as well as the desired compound. These impurities are usually present in the final product and help determine its properties.

After the raw materials are mixed, they are often heated to a temperature at which any water of crystallization, or carbon dioxide from carbonates, is driven off (this process is called "calcining"). Other chemical reactions and a degree of sintering can occur during this process. After calcining, or in combination with the mixing if calcining is not required, the powder is generally ball milled to a fine grain size.

The powders are then given the desired shape by pressing in a mold, if necessary mixed with water and a "binder", an organic substance that makes the grains of powder adhere together. An important variant of pressing is "extrusion" in which the substance, made plastic with water and clay or an organic binder, is forced under pressure through a nozzle.

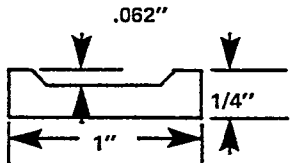
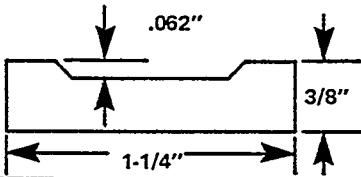
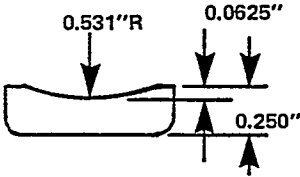
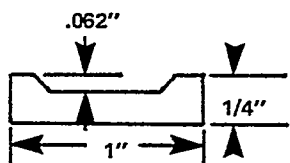
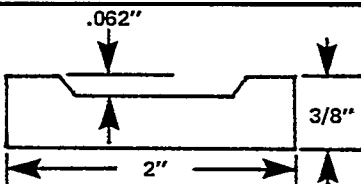
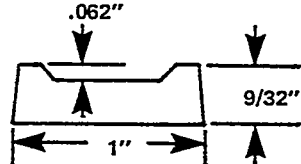
In the next stage (firing), the formed products are heated to between 1800 and 3600°F. The material undergoes further chemical changes and the grains which compose the powder fuse together. This process (sintering) can involve shrinkage of up to 30% possibly causing ceramic products even from the same mold to vary considerably in dimension and shape. Ceramics may be "sintered to density" where any pores left are closed ones and the density is at a maximum. In

practice, however, all intermediate states from slightly baked powder containing continuous pore channels to the "sintered to density" state are used.

Ceramics are much used for their chemical resistance. In oxidic ceramics the oxygen is so firmly bound that it is only at very high temperatures, and in strongly reducing atmospheres, that reduction and hence break-up of the material can occur. Alumina, sillimanite, magnesia, zirconia, chromite, porcelain, and graphite are resistant to certain molten metals. If molten slag contacts the ceramic material, the nature of the slag (i.e., whether it contains an excess of base-forming or acid-forming oxides) must be considered. Ceramics are frequently used where resistance to attack from acids, bases and salt solutions is required.

Ceramics are often used because of their favorable properties at high temperatures and under oxidizing conditions. Their thermal conductivity is much lower than for metals (about 6%). Examples of heat resistant ceramic materials are alumina, chamotte, chromite, cordierite, forsterite, magnesia, porcelain, mullite, silica, zirconia, the non-oxidic silicon carbide (Carborundum) and graphite.

The ceramic weld backing systems evaluated in this report are identified in Table 3.1. The principle constituents are cordierite and steatite with differences among manufacturers probably due to differences in raw materials and/or processing cycles. The various ceramics were used with the various magnetic holding devices, steel trays which hold the ceramic tiles and in turn are held over the weld joint by magnets. The other brands of ceramic backing were held in place with aluminum adhesive tape.

MANUFACTURER	DESIGNATION	SUPPORT	DIMENSIONS	MATERIAL
KUDER	1CR-062	ADHESIVE		STEATITE
	2CR-125	ADHESIVE		STEATITE
3M	SJ8069X	ADHESIVE		CORDIERITE
	SJ8072	ADHESIVE		STEATITE
CHEMETRON	69-300000-2	ADHESIVE		CORDIERITE
	69-300000-4	ADHESIVE		CORDIERITE
VARIOS	VLG/02	MAGNETS		CORDIERITE

CERAMIC BACKING DATA SUMMARY
TABLE 3.1

IV. EVALUATION PLAN AND PROCEDURE

Representative ceramic backing systems from Chemetron, Kuder, 3-M and Varios, as previously identified in Table 3.1, were evaluated in four "Phases". Each Phase, detailed in Charts I, II, III & IV, corresponds to the following FCAW or SAW variations commonly encountered in a production environment.

- o Phase I All Position, .052" and 1/16" Diameter,
E70T-1 Flux-cored Wire with C-25 Shielding
- o Phase II Flat Position, 5/64 and 3/32" Diameter,
E70T-1 Flux-cored Wire with CO₂ Shielding
- o Phase III All Position, 5/64" and Flat Position 3/32"
E70T-G Self-Shielded Flux-cored Wire
- o Phase IV Flat Position Single and Tandem
Submerged Arc Wire

The evaluation plan made extensive use of the following definitions:

PHASE: One of the four general FCAW or SAW processes or variations evaluated. The four phases correspond to Charts I, II, III and IV.

GROUP: Within a phase, a specific combination of welding variables as identified in Charts I, II, III or IV and assigned a unique letter identification by these Charts.

TEST ASSEMBLY: TWO base metal plates partially or completely welded in accordance with one of the group/backing combinations identified in Charts I, II, III or IV and Table 4.1.

TEST COUPON: The one assembly from each group/backing combination which, having passed visual and radiographic examination, was

selected for mechanical and chemical evaluation in accordance with Charts I, II, III or IV.

TEST SPECIMEN: One of the mechanical or chemical test pieces removed from a coupon and identified by Figure 4.1.

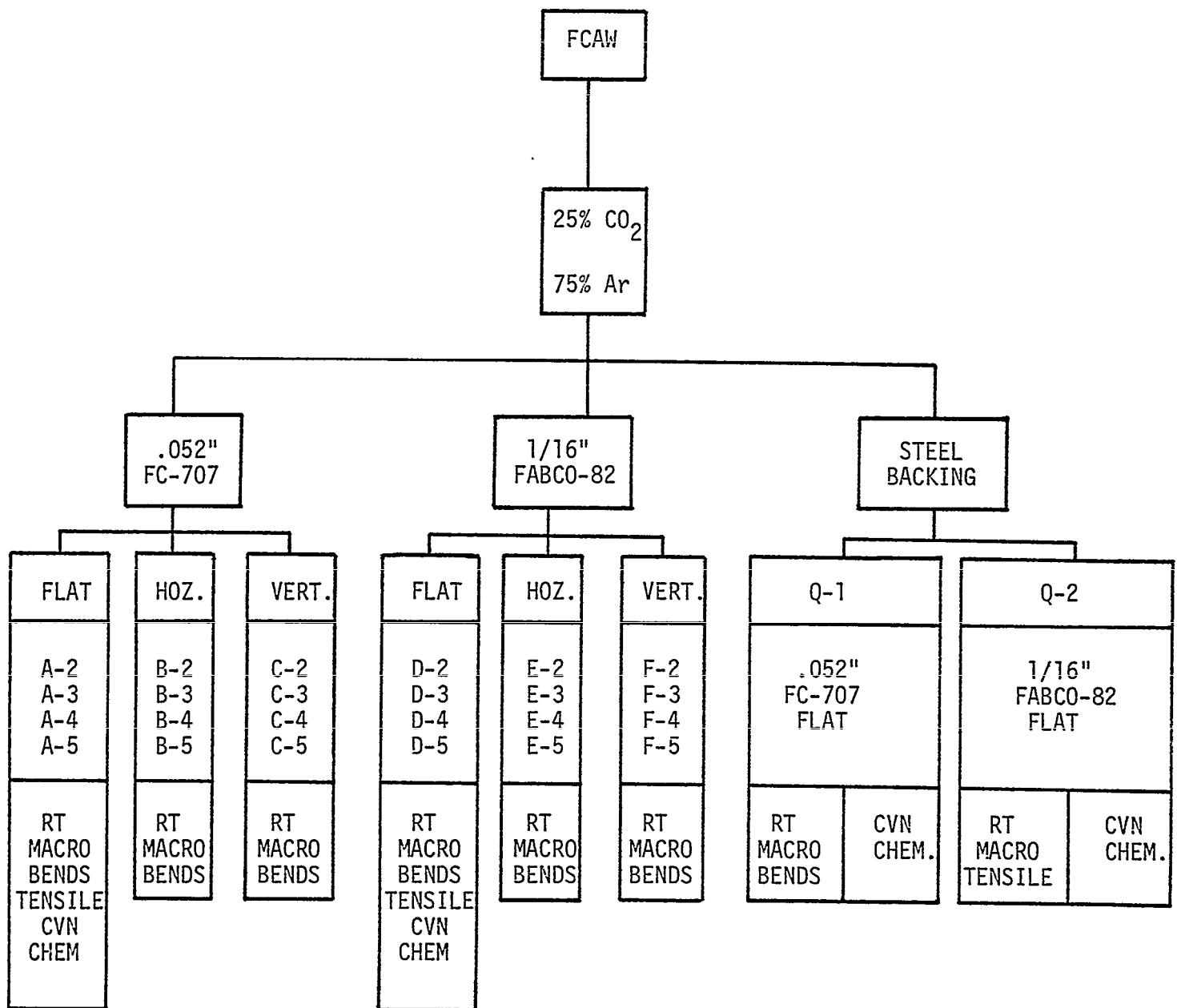
Charts I through IV identify, for each of the four (4) test phases, the specific groups, assigns each group an alpha identifier and specifies the testing/evaluation performed on each coupon in the group. Table 4.1 identifies the type of backing evaluated with each group. Test assemblies made within a given group with a given backing are numbered sequentially.

EXAMPLE:

	From Chart I, we know this assembly was made with FCAW, C-25 shielding, .052" diameter wire in the flat position.
A-2-1	From Table 4.1, we know this assembly was made with Kuder Type LCR-062 ceramic backing.
	This was the first assembly made with these specific parameters and backing type. Subsequent assemblies will exist only if this one fails visual or radiographic examination.

After welding a sufficient number of "practice" plates for approximate identification of current, voltage, technique, etc., test assemblies were prepared for each combination of variables identified in Charts I through IV. All test assemblies were made by butt welding two 1/2" thick A36 plates. The plates/welds varied in length from approximately 12" to 18" assuring sufficient material for removal of appropriate test specimens should the assembly be selected for evaluation. Test assemblies with, visually acceptable beads were radiographed. If no internal defects were identified by radiography, the welding parameters were verified by welding and visually and radiographically examining a second coupon using the same parameters as the original.

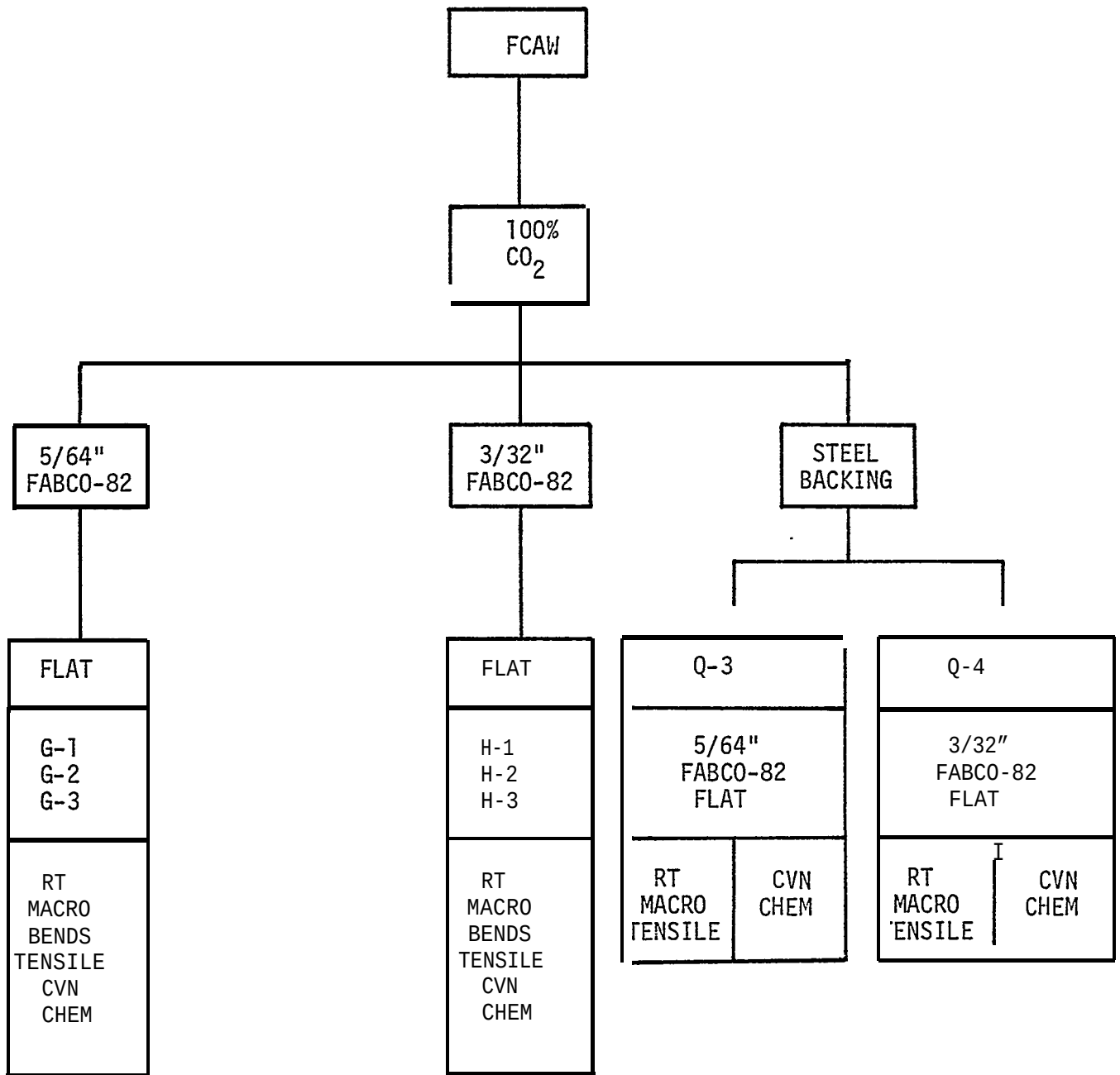
Upon successful verification, the specimens for tests identified in Charts I through IV were removed from the coupon for evaluation. Figure 4.1 identifies the orientation (though not necessarily the removal sequence) of the various test specimens. The tensile and bend specimens were machined and tested in accordance with ASME Section IX. The Charpy Vee Notch specimens (five to a set) were machined and tested at +20°F in accordance with the appropriate parts of ASTM A370. The specimen identified "CHEM" was machined so the bottom surface would lie in the approximate mid-thickness of the root bead and the top surface would lie in the approximate mid-thickness of the second bead permitting spectrographic analysis of the root and second bead. Macrophotographs were obtained either from the "CHEM" specimen before reduction in thickness or from excess coupon material.



FC-707 is manufactured by Linde and complies with A5.20, E70T-1

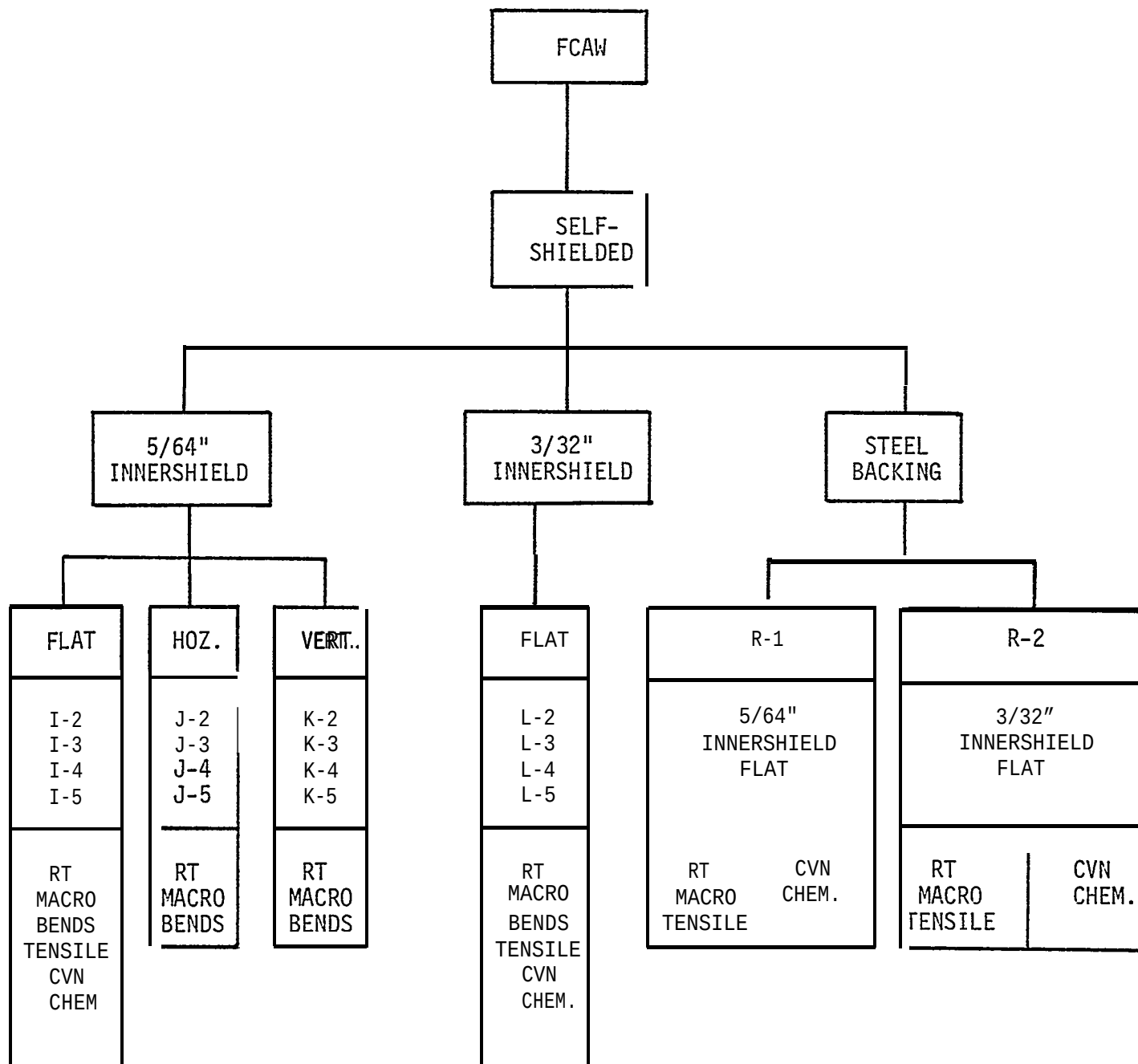
FABCO-82 is manufactured by Hobart and complies with A5.20, E70T-1

CHART I
PHASE I EVALUATION PLAN



FABCO-82 is manufactured by Hobart and complies with A5.20, E70T-1

CHART II
PHASE II EVALUATION PLAN



INNERSHIELD is manufactured by Lincoln and complies with A5.20, E70T-G.
The type used was NR203-M.

CHART III
PHASE III EVALUATION PLAN

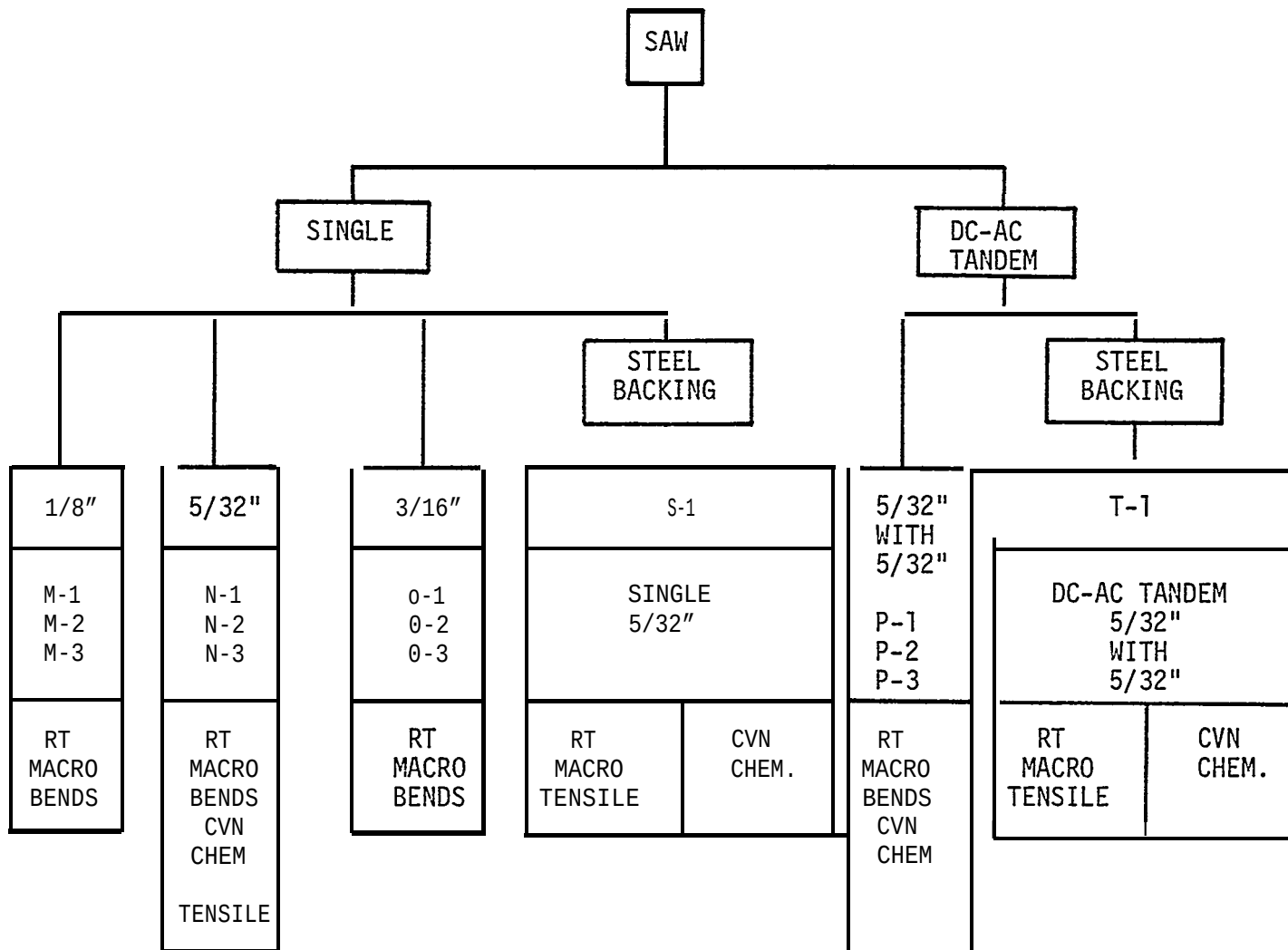


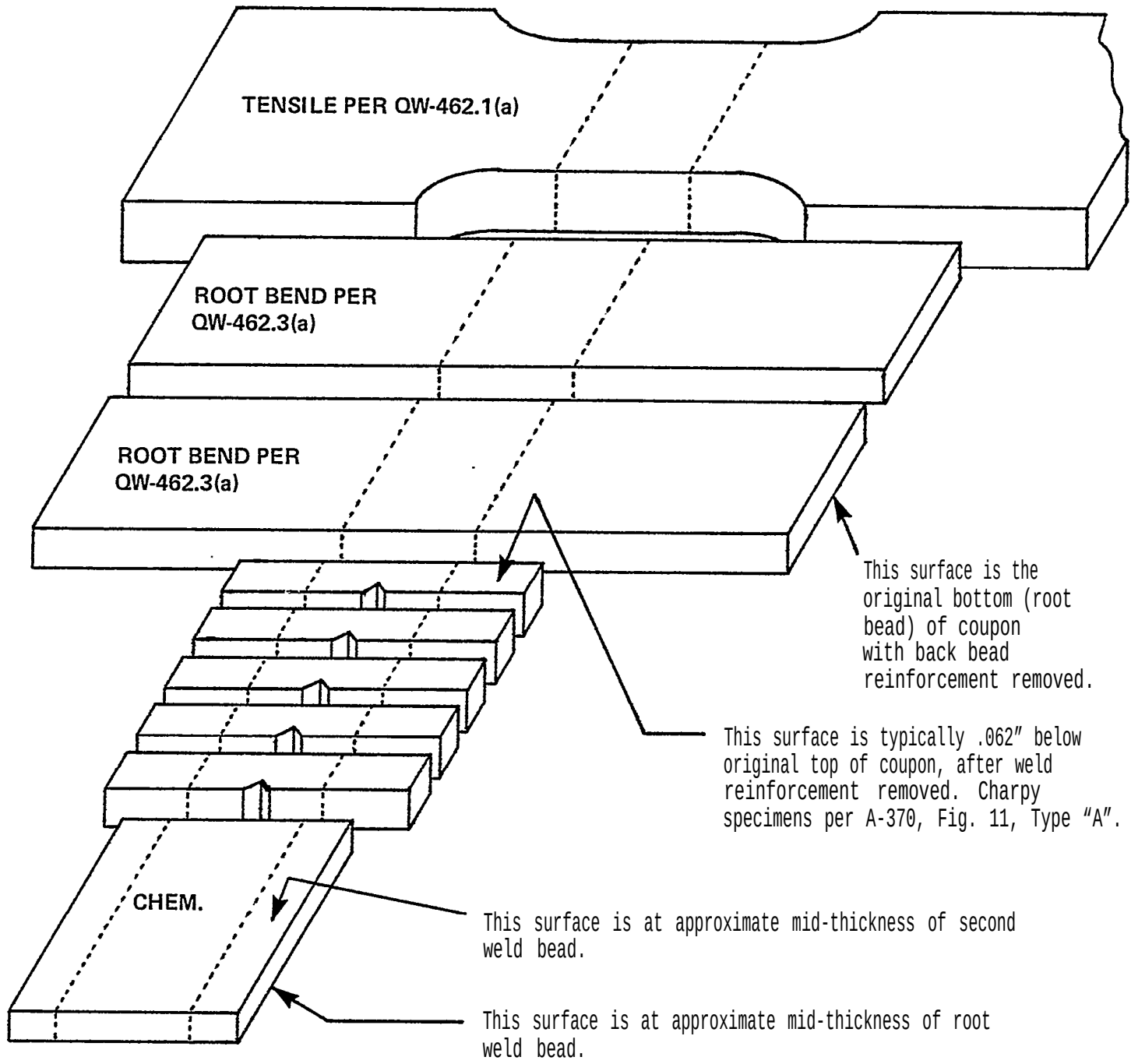
CHART IV
PHASE IV EVALUATION PLAN

A-2	KUDER	1CR-062
A-3		SJ8069X
A-4	CHEMETRON	69-300000-2
A-5	VARIOS	VLG-02
B-2	KUDER	1CR-062
B-3	3M	SJ8069X
B-4	CHEMETRON	69-300000-2
B-5	VARIOS	VLG-02
C-2	KUDER	1CR-062
C-3	3M	SJ8069X
C-4	CHEMETRON	69-300000-2
C-5	VARIOS	VLG-02
D-2	KUDER	1CR-062
D-3	3M	SJ8069X
D-4	CHEMETRON	69-300000-2
D-5	VARIOS	VLG-02
E-2	KUDER	1 R-062
E-3	3M	SJ8069X
E-4	CHEMETRON	69-300000-2
E-5	VARIOS	VLG-02
F-2	KUDER	1CR-062
F-3	3M	SJ8069X
F-4	CHEMETRON	69-300000-2
F-5	VARIOS	VLG-02
G-1	KUDER	2CR-125
G-2	3M	SJ8072X
G-3	CHEMETRON	69-300000-4
H-1	KUDER	2CR-125
H-2	3M	SJ8072X
H-3	CHEMETRON	69-300000-4
I-2	KUDER	1 CR-062
I-3	3/4	SJ8069X
I-4	CHEMETRON	69-300000-2
I-5	VARIOS	VLG-02

J-2	KUDER	1 CR-062
J-3	3M	SJ8069X
J-4	CHEMETRON	69-300000-2
J-5	VARIOS	VLG-02
K-2	KUDER	1CR-062
K-3	3M	SJ8069X
K-4	CHEMETRON	69-300000-2
K-5	VARIOS	VLG-02
L-2	KUDER	1 CR-062
L-3	3M	SJ8069X
L-4	CHEMETRON	69-300000-2
L-5	VARIOS	VLG-02
M-1	KUDER	2CR-125
M-2	3M	SJ8072X
M-3	CHEMETRON	69-300000-4
N-1	KUDER	2CR-125
N-2	3M	SJ8072X
N-3	CHEMETRON	69-300000-4
O-1	KUDER	2CR-125
O-2	3M	SJ8072X
O-3	CHEMETRON	69-300000-4
P-1	KUDER	2CR-125
P-2	3M	SJ8072X
P-3	CHEMETRON	69-300000-2
Q-1	A36 STEEL	(.052" WIRE)
Q-2	A36 STEEL	(1/16" WIRE)
Q-3	A36 STEEL	(5/64" WIRE)
Q-4	A36 STEEL	(3/32" WIRE)
R-1	A36 STEEL	(5/64" WIRE)
R-2	A36 STEEL	(3/32" WIRE)
S-1	A36 STEEL	
T-1	A36 STEEL	

TABLE 4.1
IDENTIFICATION OF CERAMIC TYPE TO TEST COUPONS

All Specimens centered on weld centerline.



TEST SPECIMEN ORIENTATION
FIGURE 4.1

V. TEST RESULTS

Table 5.1 identifies the welding data and NDE and mechanical testing results applicable for the coupons evaluated. Similar detailed data for all test assemblies is presented in Appendix A. Details of joint designs identified in Table 5.1 are given in Table 5.2. Table 5.3 additionally defines the torch angles presented in Table 5.1.

The Phase I, II, III and IV spectrographic chemical analysis results are given in Tables 5.4.1, 5.4.2, 5.4.3 and 5.4.4, respectively. Additionally, energy dispersive X-ray (EDX) analysis of each unfused ceramic type is displayed in Table 5.5.

The information accumulated in the program and exhibited in Tables 5.1 through 5.5 and in Appendix A permitted evaluation of ceramic backing with regard to:

- 1) weld soundness
- 2) toughness
- 3) bead shape
- 4) stops and starts
- 5) ceramic attaching methods
- 6) ceramic neutrality

A discussion of each area follows in the analysis portion of the report.

FCAW W/C-25 OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS																																				
TEST NO.	JOINT NO.	CERAMIC	WIRE TYPE	MANUFACTURER	IDENTIFICATION	DIAMETER	75AR-25CO ₂	CFH GAS	FLOW	DCSP	DCR.P	PLATE THICKNESS	PASS NO.	AMPERAGE	VOLTAGE	TRAVEL SPEED	TORCH ANGLE	PROGRESSION	STRING	WEAVE	RADIOGRAPH	ROOT BENDS & TENSILE		CVN +20°F												
																						1	2													
																						P	F	P	F	1	2	3	4	5	X					
A-2	7	A	E70T-1	Linde	FC-707	.052	X			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		38	39	50	45	48	41						
FLAT POSITION												2-4	260	28	13.5	60°	FH	X		U=	67,567				33	32	44	37	41	37						
																				Y=					10	10	20	20	20	16						
A-3	6	C	E70T-1	Linde	FC-707	.052	X			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		30	39	42	43	54	42						
FLAT POSITION												2-4	260	28	12-13.5	60°	FH	X		U=	66,622				23	30	33	39	41	33						
																				Y=					10	10	15	20	30	17						
A-4	6	F	E70T-1	Linde	FC-707	.052	X			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		30	40	38	37	46	38						
FLAT POSITION												2-4	260	28	12-13.5	60°	FH	X		U=	67,617				25	21	26	26	34	28						
																				Y=					10	10	10	15	20	13						
A-5	7	E	E70T-1	Linde	FC-707	.052	X			X	.500	1	260	28	7.5	50°-60°	BH	X		X	X		X		23	34	29	30	24	28						
FLAT POSITION												2-4	260	28	12-13.5	60°	FH	X		U=	65,559				18	35	24	26	30	26						
																				Y=					5	10	5	5	15	8						
B-2	10	A	E70T-1	Linde	FC-707	.052	X			X	.500	1	280	25	7.5	50°-60°	BH	X		X	X		X		--	--	--	--	--	--						
HORIZONTAL POSITION												2-5	280	25	13.5-14.5	50°	FH	X									--	--	--	--	--	--				
																													--	--	--	--	--	--		
B-3	4	C	E70T-1	Linde	FC-707	.052	X			X	.500	1	280	25	7.5	50°-60°	BH	X		X	X		X		--	--	--	--	--	--						
HORIZONTAL POSITION												2-4	280	25	13.5-14	15°	FH	X											--	--	--	--	--	--		
																													--	--	--	--	--	--		
B-4	4	F	E70T-1	Linde	FC-707	.052	X			X	.500	1	250	25	7 - 8	50°-60°	BH	X		X	X		X		--	--	--	--	--	--						
HORIZONTAL POSITION												2-4	250	25	13-14	15°	FH	X											--	--	--	--	--	--		
																													--	--	--	--	--	--		
B-5	4	E	E70T-1	Linde	FC-707	.052	X			X	.500	1	260	26	7.5 - 8	50°-60°	BH	X		X	X		X		--	--	--	--	--	--						
HORIZONTAL POSITION (SEE NOTE B-5)												2-6	260	26	13 - 14	20°	BH	X											--	--	--	--	--	--		
																													--	--	--	--	--	--		
C-2	12	A	E70T-1	Linde	FC-707	.052	X			X	.500	1	220	24	4 - 5	10°-15°	BH		X	X	X		X		--	--	--	--	--	--						
VERTICAL POSITION (SEE NOTE C-2)												2-3	220	24	4 - 5.5	15°-20°	FH		X											--	--	--	--	--	--	
																													--	--	--	--	--	--		
C-3	13	C	E70T-1	Linde	FC-707	.052	X			X	.500	1	240	24	4	15°-20°	BH		X	X	X		X		--	--	--	--	--	--						
VERTICAL POSITION (SEE NOTE C-2)												2-3	240	24	7 - 9	10°-15°	FH		X												--	--	--	--	--	--
																													--	--	--	--	--	--		
C-4	8	F	E70T-1	Linde	FC-707	.052	X			X	.500	1	240	24	4	15°-20°	BH		X	X	X		X		--	--	--	--	--	--						
VERTICAL POSITION (SEE NOTE C-2)													240	24	7 - 9	15°	FH		X												--	--	--	--	--	--
																													--	--	--	--	--	--		
C-5	10	E	E70T-1	Linde	FC-707	.052	X			X	.500	1	240	24	4.5	15°-20°	BH		X	X	X		X		--	--	--	--	--	--						
VERTICAL POSITION (SEE NOTE C-2)													240	24	8 - 9	10°-15°	FH		X												--	--	--	--	--	--
																													--	--	--	--	--	--		
Q-1	3	--	E70T-1	Linde	FC-707	.052	X			X	.500	1	240	28	12	15°	BH	X		X	X		X		30	18	20	22	22	22						
FLAT POSITION (SEE NOTE Q-1)												2-7	240	28	7 - 12	15°	BH	X		U=	71,932				24	15	17	18	18	18						
																				Y=	48,660				20	25	25	30	30	26						

CERAMIC GEOMETRY

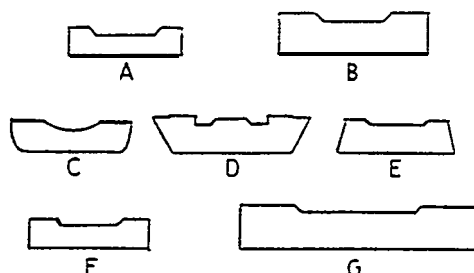


TABLE 5.1
Summary of Welding Data and NDE
and Mechanical Testing Results for
Test Coupons (pg. 1 of 6)

PHASE 1

NOTES

- B-5 Radiography of coupon B-5 identified minor Chevron. A root band specimen taken from this area failed following visual inspection of the affected area.
- C-2 Welded in the vertical up position. The torch was held at a 15 angle from the vertical plane. Progression was backward which was necessary to maintain arc.
- Q-1 Welded over A-36 backing for chemistry comparison in ceramic neutrality evaluation.

FCAW W/C-25 OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS

TEST NO.	JOINT NO.	CERAMIC	WIRE TYPE	MANUFACTURER	IDENTIFICATION	DIAMETER	75 AR-25CO ₂	CFH GAS FLOW	GASLESS	DCSP	PLATE THICKNESS	PASS NO.	AMPERAGE	VOLTAGE	TRAVEL SPEED	TORCH ANGLE	PROGRESSION	STRING	WEAVE	RADIOGRAPH	ROOT BENDS & TENSILE		CVN +20°F												
																					1	2													
																					P	F	P	F	1	2	3	4	5	X					
D-2	10	A	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	30	8	50°-60°	BH	X	X	X	--	X	--	21	21	20	20	21	20						
FLAT POSITION												2-4	260	30	6-7	15°	BH	X	U=	67,705							17	14	13	16	14	14			
																			Y=							10	10	10	10	10	10				
D-3	5	C	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	30	7.5 - 8	50°-60°	BH	X	X	X	--	X	--	39	32	32	33	32	33						
FLAT POSITION												2-4	260	30	6-8	15°	BH		X	U=	65,407							32	27	23	24	22	25		
																			Y=							15	10	10	10	10	11				
D-4	9	F	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	30	7.5 - 8	50°-60°	BH	X	X	X	--	X	--	21	28	30	30	27	27						
FLAT POSITION												2-4	260	30	6 - 7.5	15°	BH		X	U=	64,859							16	28	27	29	20	24		
																			Y=							5	10	15	10	10	11				
D-5	11	E	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	30	7 - 8	50°-60°	BH	X	X	X	--	X	--	20	23	19	11	28	20						
FLAT POSITION												2-4	260	30	6 - 8	15°	BH		X	U=	53,405							20	20	20	13	25	19		
																			Y=							10	10	5	5	10	8				
E-2	33	A	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	25	7 - 7.5	50°-60°	B ^d	X	X	X	--	X	--	--	--	--	--	--	--						
HORIZONTAL POSITION												2-5	260	25	13-14	15°	FH	X										--	--	--	--	--	--		
E-3	34	C	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	25	7-7.5	50°-60°	BH	X	X	X	--	X	--	--	--	--	--	--	--						
HORIZONTAL POSITION												2-5	260	25	13 - 14	15°	FH	X										--	--	--	--	--	--		
E-4	34	F	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	25	7 - 7.5	50°-60°	BH		X	X	X	--	X	--	--	--	--	--	--						
HORIZONTAL POSITION												2-5	260	25	13 - 14.5	15°	FH	X										--	--	--	--	--	--		
E-5	35	E	E70T-1	Hobart	Fabco 82	1/16"	X			X	.500	1	260	25	7-7.25	50°-60°	BH	X	X	X	--	X	--	--	--	--	--	--	--						
												2-5	260	25	13 - 14	15°	FH	X										--	--	--	--	--	--		
F-2	2	A	E70T-1	Linde	FC-707	1/16"	X			X	.500	1	220	22	4 - 4.5	15°	BH	X	X	X	--	X	--	--	--	--	--	--	--						
VERTICAL POSITION (SEE NOTE F-2)												2-4	230	22	5 - 9	10°-15°	FH	X												--	--	--	--	--	--
F-3	2	C	E70T-1	Linde	FC-707	1/16"	X			X	.500	1	220	22	5.5 - 6	10°-15°	BH	X	X	X	--	X	--	--	--	--	--	--	--						
VERTICAL POSITION												2-3	230	22	6 - 8.5	10°-15°	FH	X												--	--	--	--	--	--
F-4	14	F	E70T-1	Linde	FC-707	1/16"	X			X	.500	1	230	22	5.25 - 6	10°-15°	BH	X	X	X	--	X	--	--	--	--	--	--	--						
VERTICAL POSITION												2-3	230	22	6 - 7.5	10°-15°	FH	X												--	--	--	--	--	--
F-5	1	E	E70T-1	Linde	FC-707	1/16"	X			X	.500	1	230	22	5.5 - 6	10°-15°	BH	X	X	X	--	X	--	--	--	--	--	--	--						
VERTICAL POSITION												2-3	230	22	7 - 7.5	10°-15°	FH	X												--	--	--	--	--	--
Q-2	3	--	E70T-1	Linde	FC-707	1/16"	X			X	.500	1	280	27	10 - 11	15°	FH	X	X	X	--	X	--	21	21	20	20	21	21						
FLAT POSITION (SEE NOTE Q-2)												2	280	27	7 - 8	15°	FH	X	U=	67,705								17	14	13	16	14	15		
												3-6	300	28	12.5-15	15°	FH	X	Y=	-----								10	10	10	10	10	10		

CERAMIC GEOMETRY

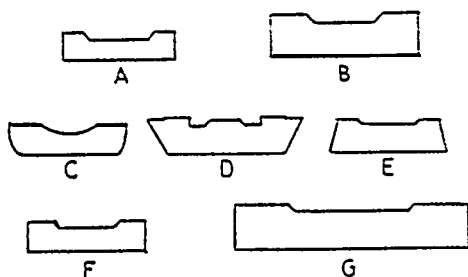


TABLE 5.1 (Cont.)
Summary of Welding Data and NDE
and Mechanical Testing Results for
Test Coupons (pg. 2 of 6)

PHASE I (CONTINUED)

NOTES:

F-2 A 15° work angle in conjunction with the 50°-60° lead angle was necessary to aid in filling the "key hole" effect.

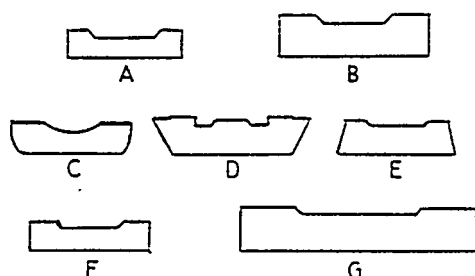
Q-2 Welded over A-36 backing for chemistry comparison in ceramic neutrality evaluation.

FCAW W/CO ₂ OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS																																														
TEST NO.	JOINT NO.	CERAMIC	WIRE TYPE	MANUFACTURER	IDENTIFICATION	DIAMETER	75AR-25CO ₂	CFH GAS FLOW	DCSP	PLATE THICKNESS	PASS NO.	AMPERAGE	VOLTAGE	TRAVEL SPEED	TORCH ANGLE	PROGRESSION	STRING	WEAVE	RADIOGRAPH	ROOT BENDS & TENSILE				CVN +20°F																						
																				1		2		1	2	3	4	5	X																	
																				P	F	P	F																							
G-1	6	B	E70T-1	Hobart	Fabco 82	5/64"	X	40		X	.500	1	430	31	9.5 - 10	50°-60°	BH	X		X	X		X																							
FLAT POSITION												2-3	430	31		15°-20°	BH	X		U=	65,285																									
																				Y=	30,560																									
G-2	5	D	E70T-1	Hobart	Fabco 82	5/64"	X	40		X	.500	1	390	31	9 - 10.5	50°-60°	BH	X		X	X		X																							
FLAT POSITION												2-3	390	31	11 - 15	10°-15°	BH	X		U=	65,007																									
																				Y=	43,243																									
G-3	5	G	E70T-1	Hobart	Fabco 82	5/64"	X	40		X	.500	1	360	27	8.5 - 9	50°-60°	BH	X		X	X		X																							
FLAT POSITION												2-3	360	27	9 - 10	15°-20°	BH		X	U=	65,593																									
																				Y=	42,606																									
Q-3	3	--	E70T-1	Hobart	Fabco 82	5/64"	X	40		X	.500	1	320	28	11.5 - 12	15°	FH	X		X	X		X																							
FLAT POSITION (SEE NOTE Q-3)												2	320	28	10.5 - 12	15°	FH		X	U=	74,270																									
												3-6	320	28	15 - 16	15°	FH	X		Y=	48,957																									
H-1	15	B	E70T-1	Hobart	Fabco 82	3/32"	X	40		X	.500	1	400	28	8.5 - 9	50°-60°	BH	X		X	X		X																							
FLAT POSITION												2	400	28	11 - 12	15°	BH	X		U=	70,914																									
												3-4	400	28	11 - 15	15°	BH		X	Y=	45,429																									
H-2	16	D	E70T-1	Hobart	Fabco 82	3/32"	X	40		X	.500	1	400	28	8.5 - 9	50°-60°	BH	X		X	X		X																							
FLAT POSITION												2	400	28	11 - 12	15°	BH	X		U=	70,200																									
												3	400	28	7 - 8	15°	BH		X	Y=	44,269																									
H-3	15	G	E70T-1	Hobart	Fabco 82	3/32"	X	40		X	.500	1	400	28	9 - 10	50°-60°	BH	X		X	X		X																							
FLAT POSITION												2	400	28	11 - 12	15°	BH	X		U=	70,707																									
												3	400	28	7.25 - 9	15°	BH		X	Y=	47,330																									
Q-4	17	--	E70T-1	Hobart	Fabco 82	3/32"	X	40		X	.500	1	400	28	13	15°	BH	X		X	X		X																							
FLAT POSITION (SEE NOTE Q-4)												2-3	400	28	7.75 - 9	15°	BH		X	U=	72,546																									
																				Y=	50,071																									

TABLE 5.1 (Cont.)
Summary of Welding Data and NDE
and Mechanical Testing Results for
Test Coupons (pg. 3 of 6)

PHASE II

CERAMIC GEOMETRY



NOTES:

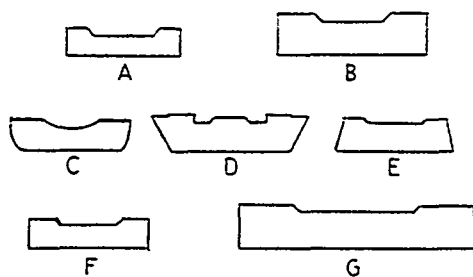
- Q-3 Welded over A-36 backing for chemistry comparison in the ceramic neutrality evaluation
- Q-4 Welded over A-36 backing for chemistry comparison in the ceramic neutrality evaluation

FCAW SELF-SHIELDED OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS																														
TEST NO.	JOINT NO.	CERAMIC	WIRE TYPE	MANUFACTURER	IDENTIFICATION	DIAMETER	75AR-25CO ₂	C.F.H. GAS	FLOW	DC/SP	PLATE THICKNESS	PASS NO.	AMPERAGE	VOLTAGE	TRAVEL SPEED	TORCH ANGLE	PROGRESSION	STRING	WEAVE	RADIOGRAPH	ROOT BENDS & TENSILE				CVN +20°F					
																					1		2		3	4	5	X		
																					P	F	P	F						
L-2	13	A	E70T-G	Lincoln	NR-302	3/32"		X	X	.500	1	400	28	11 - 12	45°-55°	BH	X		X	X		X			65	55	70	80	66	66
FLAT POSITION											2-4	400	28	12 - 13	15°	BH	X		U=	71,866					52	52	59	64	56	57
																			Y=	48,746					60	45	50	65	55	55
L-3	13	C	E70T-G	Lincoln	NR-302	3/32"		X	X	.500	1	400	28	13.5 - 14	45°-55°	BH	X		X	X		X			69	49	68	71	62	6
FLAT POSITION											2	400	28	11 - 12	15°	BH	X		U=	71,332					62	47	61	58	55	57
											3	400	28	7.5 - 8	15°	BH		X	Y=	45,652					50	30	65	65	55	53
L-4	16	F	E70T-G	Lincoln	NR-302	3/32"		X	X	.500	1	400	25	13 - 14	45°-55°	BH	X		X	X		X			57	70	60	39	44	54
FLAT POSITION											2	400	25	9 - 10	15°	BH	X		U=	70,518					49	55	49	37	38	45
											3	400	25	8 - 9	15°	BH		X	Y=	45,684					40	65	50	25	35	43
L-5	16	E	E70T-G	Lincoln	NR-302	3/32"		X	X	.500	1	400	28	13 - 14	45°-55°	BH	X		X	X		X			69	84	66	87	68	75
FLAT POSITION											2	400	28	9 - 10	15°	BH	X		U=	58,060					62	72	57	72	63	65
											3	400	28	7 - 9	15°	BH		X	Y=	48,770					60	70	50	75	50	61
R-2	21	-	E70T-G	Lincoln	NR-302	3/32"		X	X	.500	1	400	28	9 - 10	15°	BH	X		X	X		X			38	64	59	70	66	59
FLAT POSITION											2-4	400	28	8 - 10	15°	BH		X	U=	72,650					40	56	50	57	55	52
																			Y=	50,997					40	50	40	50	60	48

TABLE 5.1 (Cont.)
Summary of Welding Data and NDE
and Mechanical Testing Results for
Test Coupons (pg. 5 of 6)

PHASE III (CONTINUED)

CERAMIC GEOMETRY



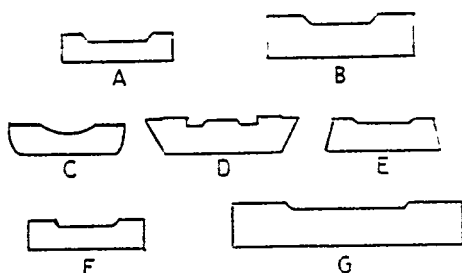
NOTES:

R-2 Welded over A-36 steel backing
for chemistry comparison in the
ceramic neutrality evaluation

SAW OVER CERAMIC BACKING - PARAMETERS & TEST RESULTS																																											
TEST NO.	JOINT NO.	CERAMIC	WIRE TYPE	MANUFACTURER	IDENTIFICATION	DIAMETER	75AR-25CO ₂	CEFH GAS FLOW	GASLESS	DCSP	DCRP	PLATE THICKNESS	PASS NO.	AMPERAGE	VOLTAGE	TRAVEL SPEED	TORCH ANGLE	PROGRESSION	STRING	WEAVE	RADIOGRAPH	ROOT BENDS & TENSILE		CVN +20°F																			
																						1	2	1	2	3	4	5	X														
																						P	F	P	F																		
N-1 22	B	EM12K	Linde	81	1/8"					X		.500	1	640	34	10	85°	BH	X		X	X		X			--	--	--	--	--	--											
FLAT POSITION												2	500	38	10	85°	BH	X								--	--	--	--	--	--												
N-2 23	D	EM12K	Linde	81	1/8"					X		.500	1	640	34	10	85°	BH	X		X	X		X			--	--	--	--	--	--											
FLAT POSITION												2	500	36	10	85°	BH	X								--	--	--	--	--	--												
N-3 22	F	EM12K	Linde	81	1/8"					X		.500	1	650	34	15	85°	BH	X		X	X		X			--	--	--	--	--	--											
FLAT POSITION												2	450	35	10	85°	BH	X								--	--	--	--	--	--												
N-1 23	B	EM12K	Linde	81	5/32"					X		.500	1	750	34	9.5	85°	BH	X		X	X		X			20	22	26	25	21	23											
FLAT POSITION																																											
N-2 23	D	EM12K	Linde	81	5/32"					X		.500	1	750	34	9.5	85°	BH	X		X	X		X			20	25	20	24	29	23											
FLAT POSITION																																											
N-3 23	F	EM12K	Linde	81	5/32"					X		.500	1	750	34	9.5	85°	BH	X		X	X		X			11	15	18	22	19	17											
FLAT POSITION												2	640	38	10	85°	BH	X																									
O-1 27	B	EM12K	Linde	81	3/16"					X		.500	1	820	34	11	85°	BH	X		X	X		X			--	--	--	--	--	--											
FLAT POSITION												2	800	40	15	85°	BH	X																									
O-2 28	D	EM12K	Linde	81	3/16"					X		.500	1	820	33	11	85°	BH	X		X	X		X			--	--	--	--	--	--											
FLAT POSITION												2	820	33	15	85°	BH	X																									
O-3 29	G	EM12K	Linde	81	3/16"					X		.500	1	850	34	10.5	85°	BH	X		X	X		X			18	14	19	21	19	13											
FLAT POSITION												2	750	40	15	85°	BH	X																									
S-1 24	--	EM12K	Linde	81	3/16"					X		.500	1	750	38	10.5	85°	BH	X		X	X		X			18	14	19	21	19	13											
FLAT POSITION (SEE NOTE S-1)												2-3	750	38	10.5	85°	BH	X																									
P-3 25	F	EM12K	Linde	81	5/32"					X		.500	1-L	750	32	14	85°	BH	X		X	X		X			14	21	17	21	17	13											
FLAT POSITION (SEE NOTE P-3)												1-T	600	40		15°	FB																										
T-1 26	--	EM12K	Linde	81	5/32"					X		.500	1-T	740	33	25	90°		X		X	X		X																			
FLAT POSITION (SEE NOTE T-1)												1-T	620	40		15°	FB																										

TABLE 5.1 (Cont.)
Summary of Welding Data and NDE
and Mechanical Testing Results for
Test Coupons (pg. 6 of 6)

CERAMIC GEOMETRY



PHASE IV

NOTES:

- S-1 Welded over A-36 steel backing for chemistry comparison in the ceramic neutrality evaluation
- P-3 Welded with Tandom sub arc - designated in the pass column as 1-L (D.C. lead) and 1-T (A.C. trail).
- T-1 Welded over A-36 steel backing for chemistry comparison in the ceramic neutrality evaluation

JOINT DESIGN DETAILS—ALL PHASES
TABLE 5.2

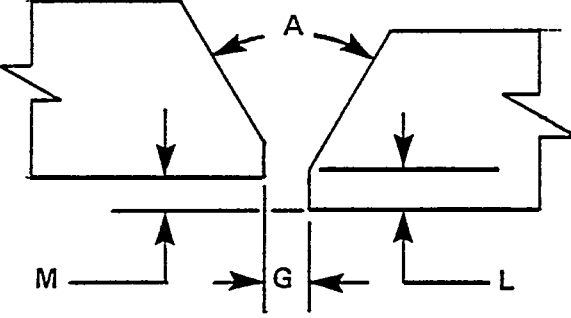
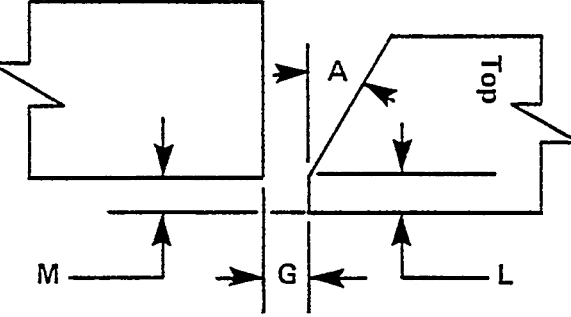
NO.	G	A	L	M	CONFIGURATION
1	1/16" to 3/32"	60	-0-	-0-	 CODE: NO. = Joint Number G = Gap A = Angle L = Land M = Mismatch
2	3/32"	60	-0-	-0-	
3	5/16"	60	-0-	-0-	
4	1/8"	45	-0-	-0-	
5	3/16"	45	-0-	-0-	
6	7/32"	45	-0-	-0-	
7	1/4"	45	-0-	-0-	
8	1/8"	45	-0-	3/64"	
9	3/16"	45	-0-	3/64"	
10	5/32"	45	-0-	1/32"	
11	3/16"	45	-0-	1/32"	
12	1/8"	60	-0-	1/32"	
13	5/32"	60	-0-	1/32"	
14	1/16" to 3/32"	60	-0-	1/32"	
15	1/8"	60	-0-	-0-	
16	5/32"	60	-0-	-0-	
17	11/32"	60	-0-	-0-	
18	1/4"	60	-0-	1/32"	
19	3/16"	60	-0-	-0-	
20	3/16"	60	-0-	1/32"	
21	3/8"	60	-0-	-0-	
22	-0-	45	-0-	-0-	
23	-0-	45	3/32"	-0-	
24	1/4"	45	3/32"	-0-	
25	0 to 1/16"	45	3/32"	-0-	
26	3/8"	45	3/32"	-0-	
27	0 to 1/32"	45	3/32"	1/64"	
28	0 to 1/16"	45	-0-	1/32"	
29	0 to 1/16"	45	-0-	-0-	
30	1/16" to 1/8"	60	1/16" to 3/32"	-0-	
31	3/32"	60	3/32"	-0-	
32	3/32"	60	3/32" to 1/8"	1/32"	
33	5/32"	30	-0-	1/32"	
34	5/32"	30	-0-	1/16"	
35	5/32"	30	-0-	-0-	

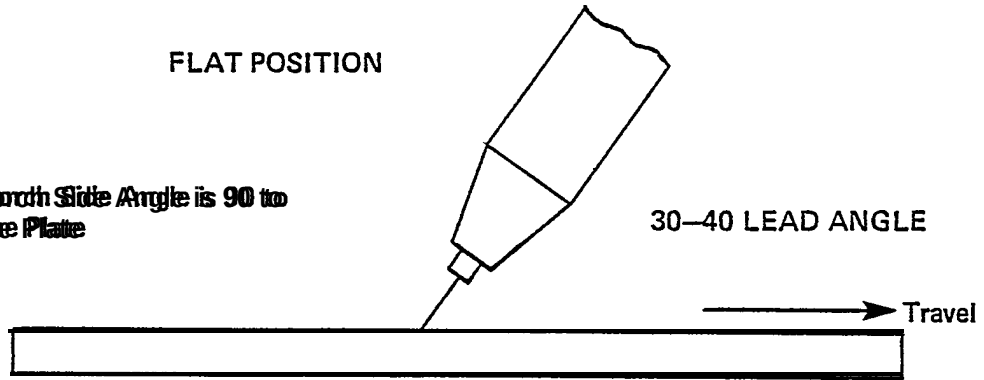
TABLE 5.3

OPTIMUM FCAW TORCH ANGLES FOR WELDING OVER CERAMIC BACKING

FLAT POSITION

Torch Side Angle is 90 to the Plate

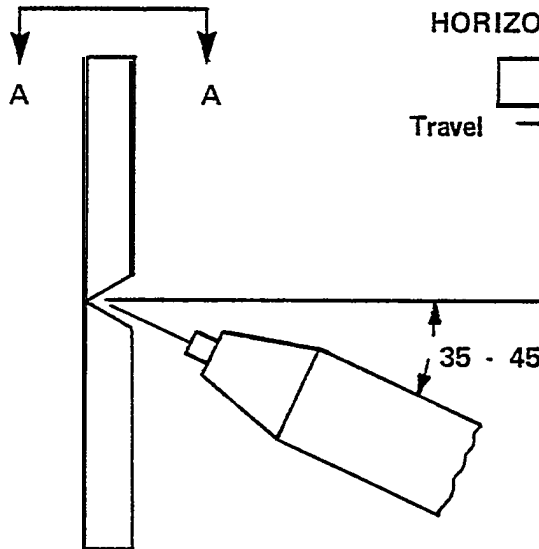
30-40 LEAD ANGLE



HORIZONTAL POSITION

Travel

30-40 LEAD ANGLE



A-A

65-75 LEAD ANGLE

VERTICAL POSITION

Torch Side Angle is 90 to the Plate

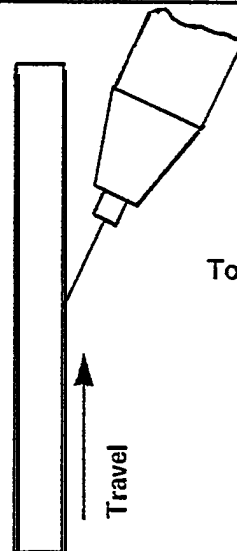


Table 5.4.1

Phase I Spectrographic Analysis of Root and Second Pass

		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti	Cr	Mo	V	CE
A-2	Root	98.179	.121	.027	.009	.832	.006	.644	.053	.033	.039	.036	.008	.013	.297
	Second	97.837	.104	.025	.011	1.201	.017	.592	.054	.016	.068	.045	.012	.018	.343
A-3	Root	98.219	.114	.025	.008	.954	.010	.469	.053	.015	.068	.041	.008	.016	.304
	Second	97.864	.102	.024	.009	1.222	.012	.557	.052	.017	.066	.046	.011	.018	.343
A-4	Root	98.229	.122	.030	.008	.824	.011	.591	.055	.034	.044	.033	.006	.013	.294
	Second	97.933	.110	.024	.007	1.212	.014	.498	.054	.015	.068	.041	.008	.016	.344
A-5	Root	98.262	.136	.026	.006	.888	.007	.489	.054	.030	.051	.032	.006	.013	.314
	Second	97.804	.106	.025	.007	1.265	.015	.564	.055	.020	.071	.042	.009	.017	.353
Q-1	Root	97.879	.084	.022	.018	1.301	.014	.495	.039	.004	.070	.042	.017	.015	.335
	Second	97.621	.069	.026	.016	1.455	.010	.597	.047	.003	.070	.050	.017	.019	.352
D-2	Root	98.309	.131	.025	.021	.872	.000	.484	.038	.054	.020	.022	.013	.011	.306
	Second	97.623	.121	.025	.023	1.517	.000	.527	.026	.028	.043	.028	.022	.017	1.409
D-3	Root	98.515	.134	.024	.021	.743	.000	1.399	.036	.049	.017	1.040	.012	.010	.287
	Second	98.245	.128	.027	.023	1.087	.000	.348	.027	.030	.026	.028	.017	.014	.335
D-4	Root	98.611	.132	.018	.012	.749	.000	.340	.034	.049	.015	.019	.011	.010	.279
	Second	98.121	.126	.023	.018	1.167	.000	.406	.026	.027	.028	.025	.017	.016	.348
D-5	Root	98.609	.125	.017	.009	.698	.000	.417	.030	.043	.015	.018	.010	.009	.267
	Second	98.221	.122	.021	.016	1.091	.000	.389	.024	.024	.037	.024	.016	.015	.331
Q-2	Root	97.992	.125	.022	.025	1.291	.000	.434	.016	.008	.031	.023	.020	.013	.369
	Second	97.783	.112	.027	.029	1.426	.000	.490	.020	.011	.032	.029	.023	.018	.383
Base Material		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	.228
(Typical)															
HT. #633 -		97.774	.051	.025	.009	1.373	.008	.549	.049	.006	.066	.053	.017	.020	.319
02225H243															
HT. #282B8		97.783	.114	.026	.028	1.435	.000	.479	.020	.016	.027	.030	.024	.088	.387

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Si}{24} + \frac{\%Cr}{5} + \frac{\%Mo}{4} + \frac{\%V}{14} + \frac{\%Ni}{40}$$

HT #282B8 was used for Q-2

HT #63302225H243 was used for all A series and Q-1 / HT #282B8 was used for all D series (none avail. for chem.)

Table 5.4.2
Phase 11 Spectrographic Analysis of Root and Second Pass

		I													
		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti.	Cr	Mo	V.	CE
G-1	Root	98.129	.117	.019	.007	.866	.000	.640	.03'8	.048	.025	.023	.013	.012	.298
	Second	98.102	.105	.017	.006	1.045	.000	.567	.033	.041	.029	.025	.016	.014	.314
G-2	Root	98.399	.124	.018	.004	.783	.000	.504	.047	.055	.018	.024	.014	.010	.286
	Second	98.509	.127	.021	.009	.798	.000	.358	.050	.073	.014	.022	.012	.007	. 2 8 5
G-3	Root	98.087	.143	.018	l 003	1.046	.000	.464	.065	.064	.031	.041	.022	.011	. 3 5 3
	Second	97.833	.110	.016	.010	1.243	.000	.587	.048	.046	.034	.036	.022	.015	.357
Q-3	Root	98.339	.138	.021	l 003	.899	.000	.273	.146	.070	.025	.058	.021	.007	.318
	Second	97.771	.089	.016	.008	1.313	.000	.596	.054	.030	.050	.034	.023	.016	.347
H-1	Root	97.709	.114	.016	.014	1,287	.000	.666	.048	.041	.039	.030	.020	.016	.369
	Second	97.537	.095	.015	.014	1,470	.000	.685	.042	.034	.039	.031	.020	.018	.382
H-2	Root	98.029	.132	.018	.011	.972	.000	.661	.049	.049	.025	.026	.015	.013	.333
	Second	97.514	.106	.017	.014	1.412	.000	.749	.043	.037	.043	.029	.019	.017	.385
H-3	Root	98.030	.120	.019	.013	.954	.000	.673	.051	.056	.028	.027	.015	.014	. 3 1 9
	Second	97.712	.105	.012	.010	1.332	.000	.658	.038	.033	.036	.028	.019	.017	.367
Q-4	Root	97.806	.118	.012	.016	1.382	.001	.528	.027	.016	.041	.023	.017	.013	.381
	Second	97.588	.090	.014	.014	1 l 509	.000	.617	.031	.027	.042	.029	.021	.018	.380
Base Material (Typical)		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	. 2 2 8
HT #l13122K8		98.215	.067	.010	.004	1.093	.000	.483	.018	.015	.027	.028	.022	.018	.282
HT 3 4302L8		98.020	.069	.008	.003	1.226	.000	.526	.031	.018	.029	.029	.021	.020	.308

HT. #/18122K8 was used for all G-series and Q-3. HT. #4302L8 was used for all H-Series and Q-4,

Table 5.4.3
Phase III Spectrographic Analysis of Root and Second Pass

		Fe	C	S	P	Mn	AL	Si	Cu	Ni	Ti	Cr	Mo	V	CE
I-2	Root	97.700	.119	.006	.005	1.294	.369	.368	.031	.045	.001	.024	.036	.002	.365
	Second	97.729	.106	.005	.005	1.428	.338	.258	.025	.036	.002	.025	.041	.002	.371
I-3	Root	97.728	.128	.006	.006	1.292	.371	.316	.033	.050	.003	.028	.037	.002	.372
	Second	97.768	.109	.007	.008	1.429	.311	.228	.028	.039	.002	.026	.043	.002	.374
I-4	Root	97.516	.126	.009	.009	1.275	.358	.567	.032	.045	.003	.024	.033	.003	.376
	Second	97.632	.105	.007	.005	1.434	.364	.321	.026	.038	.002	.025	.039	.002	.373
I-5	Root	97.763	.121	.007	.006	1.241	.354	.373	.032	.045	.002	.023	.031	.002	.357
	Second	97.755	.111	.005	.004	1.385	.360	.258	.024	.031	.002	.024	.039	.002	.368
R-1	Root	98.126	.132	.002	.014	1.154	.335	.183	.006	.001	.002	.014	.029	.002	.342
	Second	97.973	.103	.000	.006	1.286	.374	.182	.006	.006	.002	.019	.041	.002	.339
L-2	Root	98.343	.106	.005	.010	.797	.304	.331	.007	.020	.039	.012	.023	.003	.261
	Second	98.240	.112	.002	.004	.841	.375	.268	.008	.022	.082	.013	.030	.003	.274
L-3	Root	98.543	.121	.005	.008	.530	.324	.350	.007	.016	.048	.021	.024	.003	.235
	Second	98.497	.108	.003	.005	.575	.372	.277	.009	.022	.082	.015	.032	.003	.227
L-4	Root	98.270	.112	.004	.009	.850	.347	.275	.007	.020	.063	.013	.027	.003	.275
	Second	98.172	.100	.003	.006	.894	.373	.270	.008	.027	.096	.015	.033	.003	.272
L-5	Root	98.243	.107	.007	.014	.826	.312	.381	.007	.019	.044	.013	.024	.003	.270
	Second	98.207	.109	.003	.005	.872	.375	.268	.009	.021	.080	.014	.034	.003	.278
R-2	Root	98.327	.118	.002	.002	.826	.370	.221	.006	.015	.071	.011	.028	.003	.275
	Second	98.292	.103	.003	.002	.829	.375	.233	.008	.020	.087	.013	.032	.003	.262
Base Material (Typical)		98.880	.104	.019	.005	.661	.000	.169	.052	.083	.001	.016	.007	.003	.228
HT. #BB830		97.947	.100	.001	.009	1.320	.371	.172	.007	.007	.002	.020	.042	.002	.342
HT. #EKCF721		98.294	.084	.003	.000	.843	.369	.235	.009	.025	.091	.014	.030	.003	.245

HT #BB830 (NR203M) was used for all I series and R-1

HT #EKCF721 (NR302) was used for all L series and R-2

Table 5.4.4

- 27 -

I

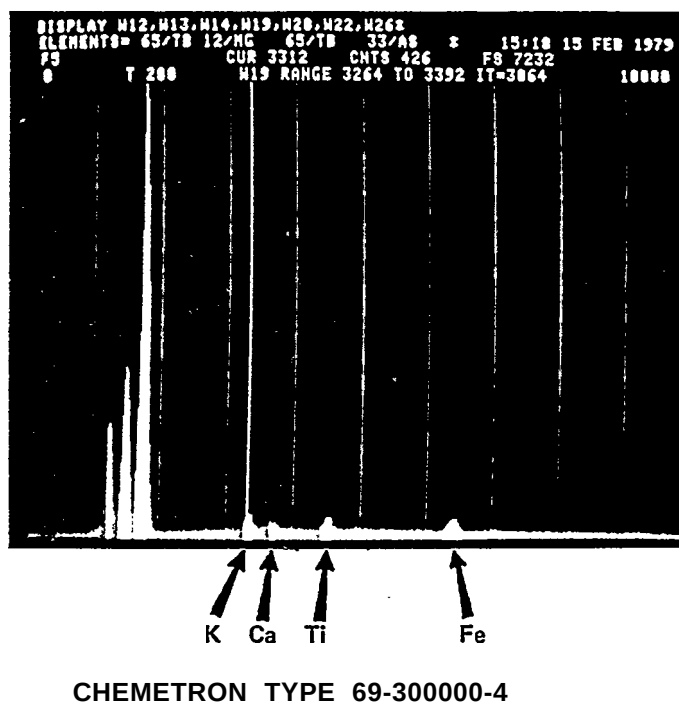
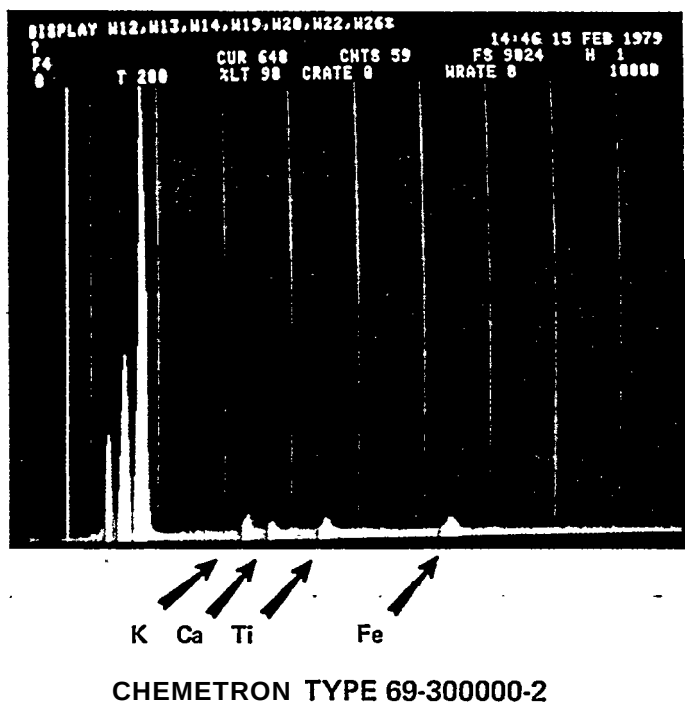
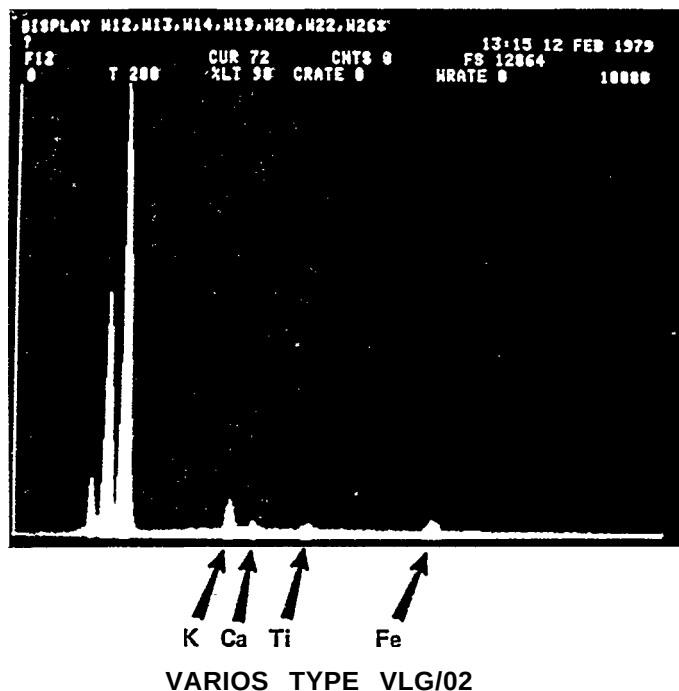
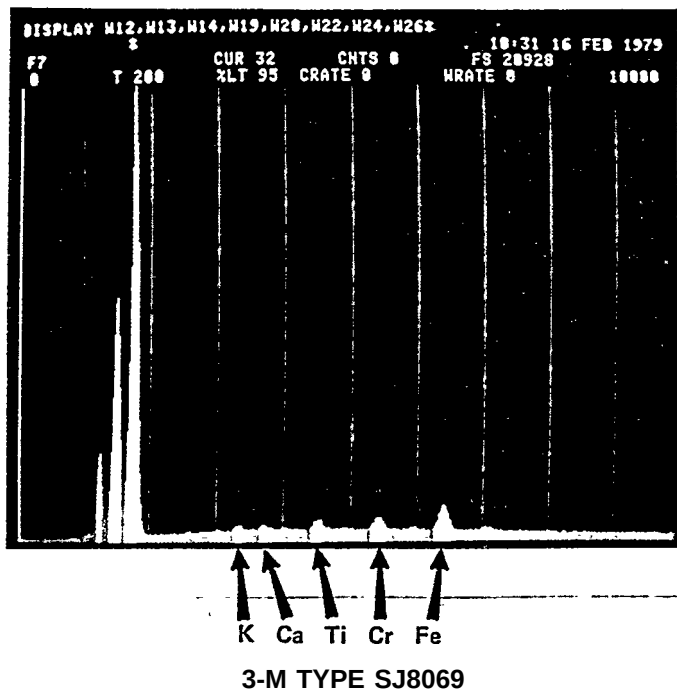
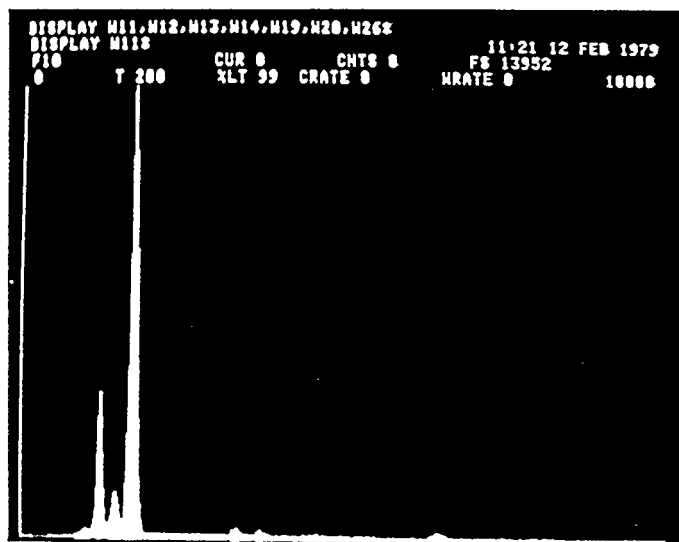
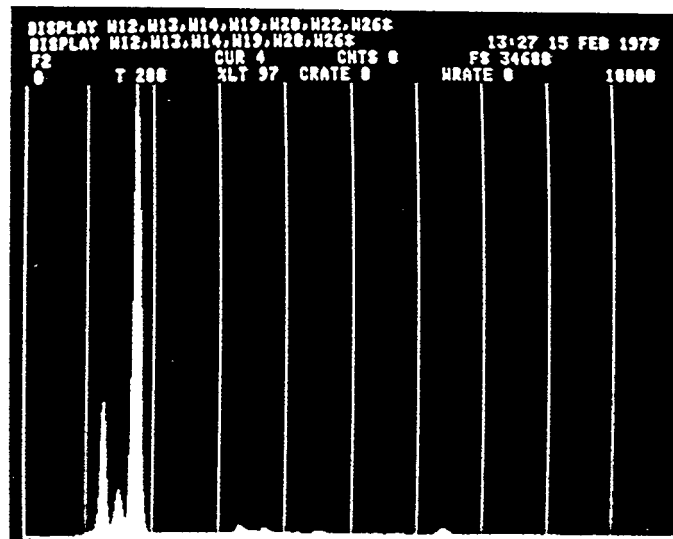


TABLE 5.5

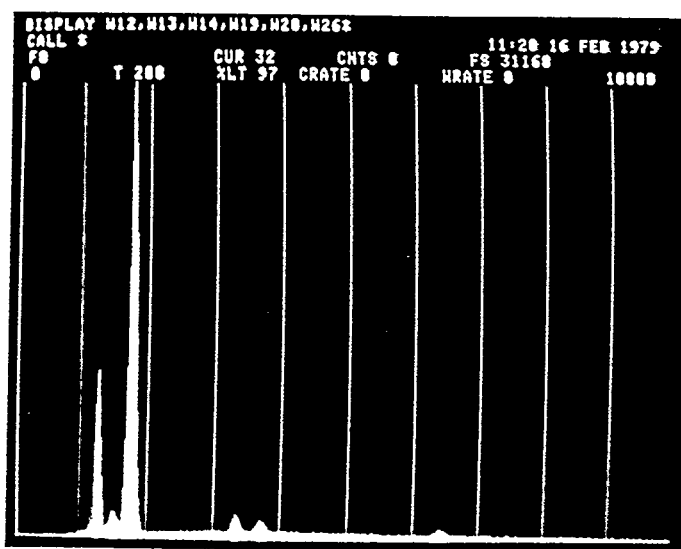
Energy dispersive x-ray (EDX) analysis of unused samples of the ceramic backing types evaluated. The horizontal scale segregates elements by atomic numbers while the vertical lines (not-to be confused with the grid lines) identify, approximately, the relative concentrations of each element. The three major vertical lines in each photograph represent magnesium, aluminum and silicon respectively. The proportions above are indicative of cordierite. The minor elements identified individually may be from the raw material, from binders used in processing, etc.



Na K Ca
KUDER TYPE ICR-062



K Ca Ti Fe
KUDER TYPE 2CR-125



K Ca Fe
3-M TYPE 8J8072

TABLE 5.5 (Pg 2 of 2)
The three major vertical lines in this case are indicative of steatite.

VI. ANALYSIS OF RESULTS

VI-1 Weld Soundness

Weld soundness was evaluated by visual, radiographic, tensile and bend testing, with visual examination providing an initial screening of gross defects. Radiographic examination was performed on visually acceptable test assemblies to determine internal soundness and to screen test assemblies for mechanical testing and analysis. Transverse tensile and root bend testing verified the weld soundness assessments made by visual and radiographic examination.

No significant weld volumetric soundness problems were identified with SAW. The use of ceramic backing with FCAW, however, was occasionally burdened by internal porosity and piping commonly described as "chevron" or "crow's foot" porosity due to the shape and arrangement of the voids. (See Figure 6.1) When it occurs, the chevron pattern points in the direction of welding and occurs alone or with "piping" in the weld centerline area (or vice versa). The porosity voids begin between the weld fusion line and the weld centerline and terminate at or before the weld centerline. Chevron internal surfaces are smooth metallic gray with "wormhole" striations, as found in the failed, porosity-containing root bend specimen seen in Figure 6.2. The occurrence causes special concern since its presence frequently cannot be determined by visual examination of the completed root pass. Volumetric examination such as radiography is the only truly effective examination technique (Figure 6.3).

Chevron porosity and piping was found to occur only in ceramic-backed FCAW weldments in the flat and horizontal positions. It is apparently influenced by joint design, wire size, type of shielding and technique. Extensive evaluation revealed that employment of larger wire diameters with CO₂ shielding aggravated the problem (see Figure 6.4). For a given wire size and

shielding, a 45° included angle or less tended to minimize, but not eliminate, porosity and piping tendencies. Root openings within a normal range of 5/32" to 5/16" appeared to have little positive influence concerning "chevron" improvement.

Welding technique was found to be particularly critical in avoidance of chevron porosity and piping. The backhand technique, i.e., the wire forming an acute angle with the direction of travel was found necessary. The optimum torch lead angle was found to be between 30° and 40°. The arc must be directed between the center and the leading edge of the puddle. The position of the arc with respect to the puddle is a critical balance. Placing the arc at the leading edge of the puddle assured meltback of the root edges of the joint ("broom effect") resulting in a wide, smoothly contoured back bead with large reentry angles similar to a double welded joint. While such a back bead contour is desirable in its own right, existence of the broom effect appears to be a necessary condition for formation of chevron porosity and piping. By moving the arc back somewhat from the leading edge of the puddle, the broom effect is reduced and eventually eliminated, correspondingly reducing the probability of chevron porosity and piping but at the expense of back bead contour (Figure 6.5). If the arc is directed too far to the rear of the puddle, penetration and flow become retarded, causing a rough back bead with sharp re-entry angles and a less-than desirable appearance. On the other hand, if it leaves the puddle and is directed onto the ceramic, it may be momentarily extinguished due to nonconductivity of the ceramic. The underbead might then become chilled possibly causing porosity. To maintain correct arc position, visibility of the puddle during welding is essential. The welder must be able to see the action of the puddle to maintain the arc at the proper location.

There are two conditions in ceramic-backed welds which, when present to a critical degree and/or combination, may lead to

chevron porosity and piping. Differences in freezing patterns which exist between weld puddles solidifying over steel backing and weld puddles solidifying over ceramic backing is one condition. "This condition leads to porosity formation as illustrated in Figure 6.6 and described as follows. As solidification progresses into the puddle, bubbles are nucleated at the solid-liquid interface as dissolved gases in the liquid metal just ahead of the interface exceed their solubility in the liquid. Meanwhile, meltback of the root edges of the original joint ("broom" effect) has caused the lower portion of the solid-liquid interface to form an acute angle with the bottom of the puddle, in effect creating two "hot" regions in the puddle separated by a central region of either solidified metal or highly viscous liquid metal. If a bubble is nucleated below this central region, it is restricted to various degrees (depending on its location, the extent of meltback and the stage of solidification) from rising out of the puddle by buoyant force. Bubbles sufficiently restricted are trapped by solidified metal. Once a bubble is trapped, but before its circumference is completely solidified, subsequent surges of gas cause expansion of the bubble into the liquid portion of its periphery. Repeated trap/expansion cycles cause elongation of the voids and wormhole striations of their interior surfaces. Such expansion into the more fluid portions of the puddle accounts for the chevron/piping arrangement of the porosity. A weld made over steel backing is not divided by this viscous central region and any bubbles formed are free to break away and float out of the puddle unrestricted. Welds made in the vertical position over ceramic backing event parallel to the welding progression rather than through the solidified/more viscous region and therefore do not experience the entrapped porosity.

The second condition is the existence of more and/or different gas over ceramic-backed welds. There appears to be considerably more gas dissolved by the puddle when welding over ceramic backing than when welding over steel backing. Evidence that

chevron porosity and piping is influenced by type and quantity of gases present is seen by comparing Phase I, II and III welds. Porosity and piping occurred most frequently in Phase II (CO_2 shielded), second most frequently in Phase III (self-shield, but essentially CO_2) and least in Phase I (75 Ar, 25 CO_2 shielded). The level of dissolved oxygen as a result of disassociation of CO_2 at welding temperatures into CO and O had an apparent effect.

Although the shielding gases mentioned are not unique to ceramic backing, several other sources of gas are. Moisture absorption by the ceramics due to high atmospheric humidity is a possibility. One manufacturer indicates a fair possibility of poor weld quality due to moisture absorption by their cordierite ceramic. This manufacturer recommends drying cycles of 16 hours at 110°F or 4 hours at 150°F to remove such moisture. They indicate no moisture absorption problems with steatite and suggest flame drying to remove any surface moisture. Four strips of cordierite ceramic from this manufacturer were baked at 250°F for 36 hours. Two of these strips were used immediately with FCAW and C-25 shielding, one was exposed to the atmosphere for an hour and then used with FCAW and C-25, and the fourth was flooded for two minutes and dried with compressed air before using with FCAW and C-25. Upon radiographing, the two strips used immediately exhibited no porosity. The strip exposed to the atmosphere exhibited chevron porosity. The flooded strips exhibited extremely gross visual defects. To further verify absorption characteristics, water was placed on a cordierite sample. It resulted in a dramatically rapid absorption of the water followed by a similar rapid absorption of successive drops of water until a saturation point was reached. Water placed on a steatite tile, however, was not absorbed. Although water absorption by cordierite has an apparent influence, some question exists as to why porosity and piping appear to occur as frequently over steatite as over cordierite when cordierite appears to absorb water much more readily.

Another unique source of gas may be due to residual amounts of binder such as animal fat or similar material used to hold the ceramic powder together during forming and which may remain in the ceramic after baking. At welding temperatures, any such organic residuals would release such porosity-causing gases as CO_2 and H_2O . Ceramic samples rebaked for higher temperatures and times than were believed to have been used originally, resulted in welds which were radiographically clear. However, an unbaked ceramic used at the same time and with the same welding parameters was also radiographically clear.

Other sources of gas may be some reaction involving the ceramic at welding temperatures. Molten slag from the electrode may contact the ceramic backing ahead of the puddle and cause a reaction between the slag and the ceramic backing. The "broom" effect may cause extra, usually deoxidizer-short, base metal to enter the puddle reducing the deoxidizer composition below that sufficient to react with oxygen in the vicinity. Such excess oxygen may combine with carbon to form carbon monoxide gas in the weld puddle.



A



B



C

FIGURE 6.1

"chevron-type" wormhole porosity in root pass of ceramic backed weld.. Root reinforcement was ground flush to expose the porosity. Figure (a) and (c) are end views of Figure (b). Approximately 2X magnification.



FIGURE 6.2

Root bend specimen from coupon B-5-2. The portion containing chevron porosity failed while the sound portion demonstrated adequate ductility.

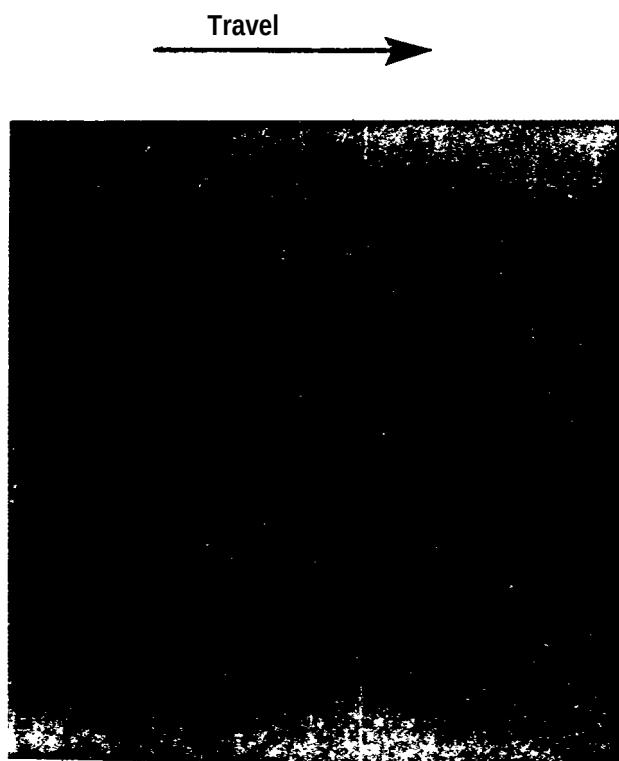


FIGURE 6.3

Chevron porosity and piping as revealed by radiography. This weldment was visually acceptable.

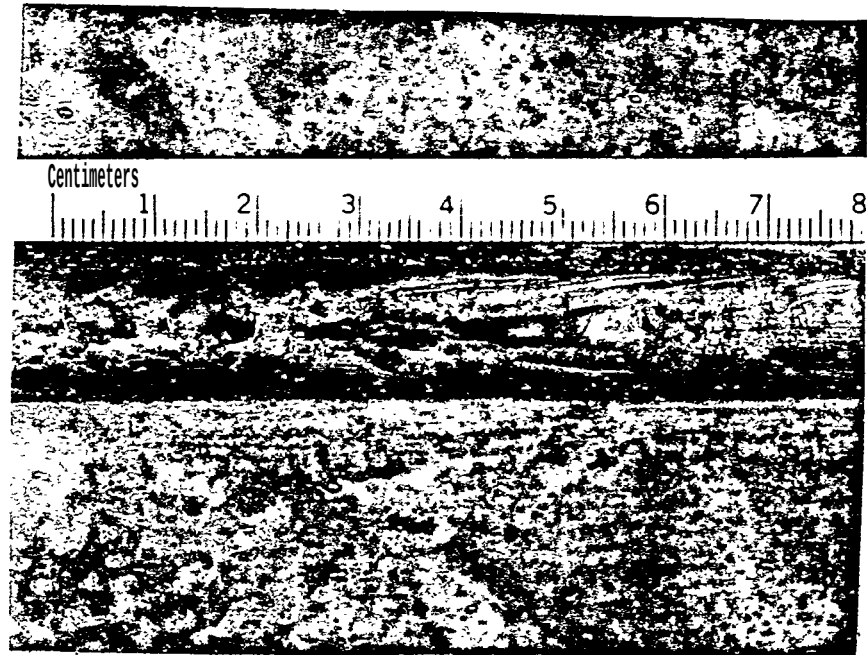
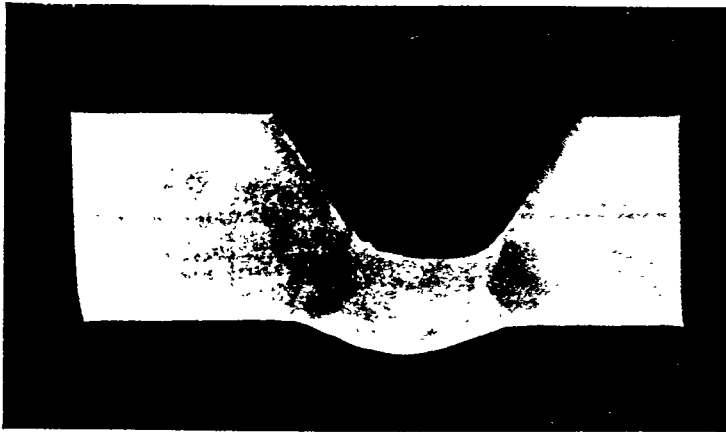
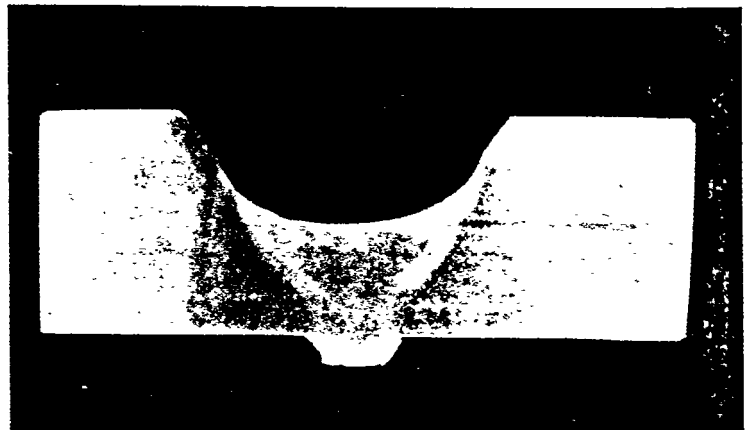


FIGURE 6.4

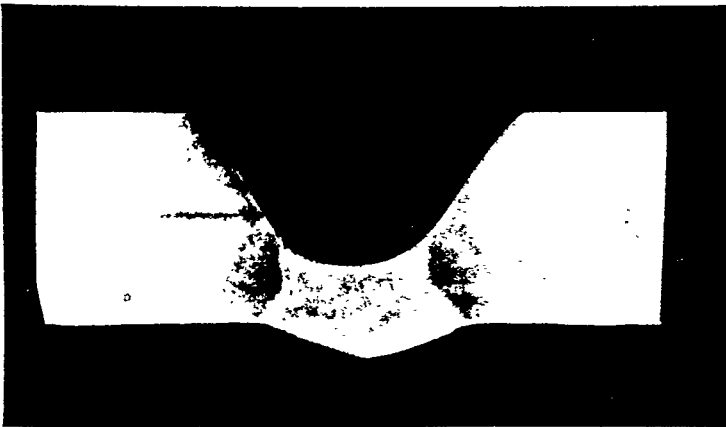
Example of gross porosity found more frequently with larger wire size and CO₂ shielding. This weld was made over ceramic with 3/32" Fabco-82 wire and 375 amperes at 31 volts. The joint was a 45 included angle with no land and 1/4" root gap. Flow rate was 45 CFH.



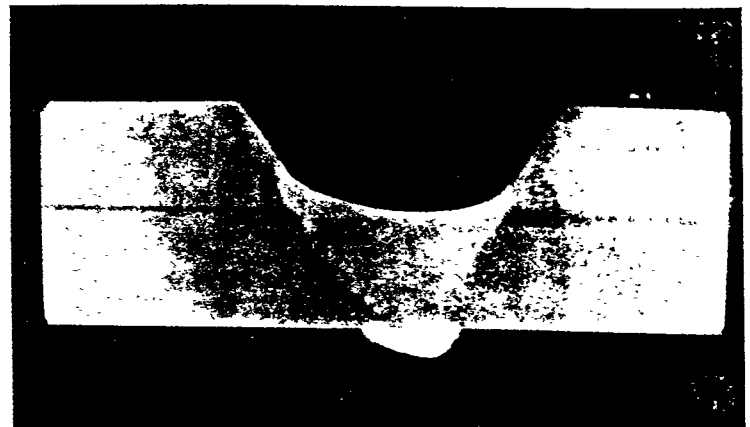
Test 1
String bead at approximately 9 IPM.
Arc at leading edge of puddle.



Test 2
Weave bead at approximately 6 IPM,
Arc at center of puddle.



Test 3
Weave bead at approximately 9 IPM.
Arc at leading edge of puddle..

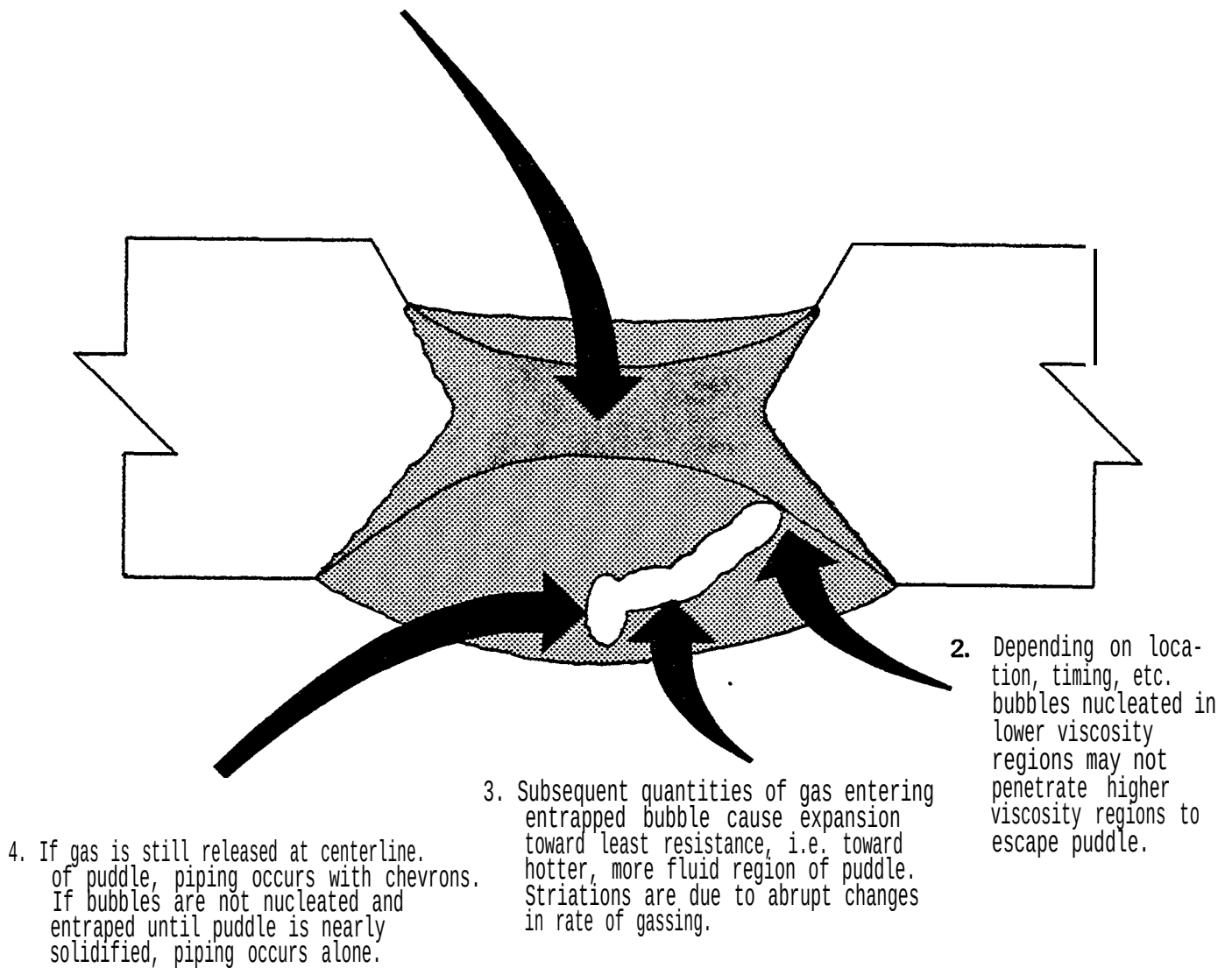


Test 4
String bead at approximately 6 IPM.
Arc at center of puddle.

FIGURE 6.5

Effect of welding technique on bead contour. All four tests were welded in the flat position with 1/16" diameter Linde FC-707 wire at 240 amperes and 25 volts. All joints were a single "vee" with 60 included angle and no land. The shielding was 75% Ar and 25% CO₂ at 40 CFH. The ceramic backing was 3-M type SJ8069. Root openings were approximately 3/32". Faster travel speed maintains arc to leading edge of puddle causing meltback and broom effect. Slower travel eliminates broom effect but at expense of back bead contour.

1. Unique contour of ceramic-backed puddle causes higher viscosity across central region. A discrete region is used for illustration, viscosity actually varies continuously.



MECHANISM FOR FORMATION OF WORMHOLE POROSITY

FIGURE 6.6

VI-2 Toughness

Weldment toughness properties were evaluated on a representative basis. Five all-weld-metal charpy impact tests at +20°F were performed for each flat position test coupon. The test results were given in Table 5.2. The average of these five tests represents an estimate of the true toughness of the respective coupons. Since an exact value for the true toughness (as measured by impact energy) of any given coupon cannot be identified, an exact difference in true toughness cannot be identified for any pair of coupons. By using the sample data, however, a range of impact energy values having a high probability of including the true difference in toughness can be identified. Within each group, such ranges were calculated for all possible coupon pairs. The results are given in Tables 6.1.1 through 6.1.4. As an example of how this data is used, Table 6.1.1 indicates the true toughness of coupon A3 has a high probability of being from 12.7 ft. lbs. less to 8.1 ft. lbs. more than the true toughness of coupon A2. Note that in this example there may be no toughness difference at all between the coupons. As a further example, Table 6.1.1 indicates the true toughness of coupon D3 has a high probability of being from 8.9 ft. lbs. to 16.7 ft. lbs. greater than coupon D2. There is only a small chance the true toughness of coupon D3 is less than or equivalent to coupon D2.

While such an analysis identifies whether a difference in toughness is likely to exist between any pair of coupons, the magnitude of the values in Table III provides considerably more information, albeit more subjective, than just the existence of a difference. For example, Table 6.1.1 indicates the toughness of test coupon A4 (ceramic backing) is probably 8.1 to 23.3 ft. lbs. greater than test coupon Q1 (steel backing). In a given application, 8.1 ft. lbs. may not be significant while 23.3 ft. lbs. may be significant. When the comparisons are examined in this manner, it becomes evident that differences in weldment

toughness may or may not be significant depending on the relative importance of the magnitude of the trend. Some general observations, however, can be made by examination of Tables 6.1.1 through 6.1.4.

The Phase I values (Table 6.1.1) indicate a trend toward greater toughness levels with ceramic backing in Group A and a trend toward lower toughness levels with ceramic backing in Group D. Three of the four ceramic-backed coupons in Group A have greater toughness than the corresponding steel-backed coupon (Q1). The Group A coupons taken together also indicate a greater toughness than the steel-backed coupon for Group A. The ceramic-backed coupons from Group D, however, are exactly opposite to Group A. The ceramic-backed coupons as a composite and in three of four individual comparisons had lower toughness levels than their corresponding steel-back coupon. The greatest magnitude in any difference for either group was 29.1 ft. lbs. Such values are not excessively large especially since they represent only the upper end of a probability range. For Phase I, there is no obvious, readily evident difference in weldment toughness between coupons made with steel backing and coupons made with ceramic backing. The variations observed are too small and inconsistent to be significant and may well be due to factors other than type of backing.

The Phase II values (Table 6.1.2) indicate the steel-backed coupons being together than the ceramic-backed coupons for both Groups G and H. However, as in Phase 1, the magnitude of these differences is rather small, the greatest value for either group being only 19.6 ft. lbs. Ceramic backing was not found to influence weldment toughness in Phase II.

The Phase III values (Table 6.1.3) indicate considerable scatter. In Group I the individual range for each pair of coupons is generally tight, but there are large variations among the various ranges, some indicating very small differences and

other very large differences. The individual Group L ranges are much larger than the individual Group I ranges. While there are differences of considerable or potentially considerable magnitude between ceramic-backed coupons and steel-backed coupons in Phase III, the variation in data is too great to identify any significant difference in weldment toughness between steel-backed and ceramic-backed weldments.

Table 6.1.4 indicates only very minor differences for the Phase IV (SAW) pairs. The use of ceramic backing appears to have no effect on weldment toughness for the SAW variations evaluated.

TABLE 6.1.1
ANALYSIS OF PHASE 1
TOUGHNESS DATA

DIFFERENCE	95% RANGE	DIFFERENCE	95% RANGE
A3-A2	-12.7 to +8.1	D3> D2	8.9 to 16.7
A4-A2	-13.8 to +2.4	D4 - D2	2.0 to 11.2
A2 >A5	8.6 to 22.6	D5-D2	-7.8 to +7.2
A3-A4	-7.1 to +13.9	D3 >D4	1.2to 11.2
A3 - A5	3.6 to 23.0	D3 >D5	6.0 to 20.2
A4 - A5	2.8 to 17.0	D5-D4	-14.2 to +0.4
A2> Q1	13.9 to 28.9	Q2>D2	7.9 to 15.9
A3>Q1	9.1 to 29.1	Q2 - D3	-5.5 to +3.7
A4>Q1	8.1 to 23.3	Q2ED4	0.3 to 10.3
Q1-A5	-12.2 to +0.6	Q2 >D5	5.1 to 19.3
A comp.>Q1	5.1 to 21.5	Q2>13 comp.	0.8 to 13.5

NOTES TO TABLES 6.1.1,6.1.2,6.1.3 AND 6.1.4

1. "95% range" means the range having a 95% probability of including the true difference in impact energy for each pair of coupons. 95% is an arbitrarily selected high probability since a 100% range would extend from minus to plus infinity and would therefore be meaningless.
2. An arrowhead indicates the coupon on the left has greater impact energy than the coupon on the right. A dash indicates no significant difference in impact energy could be found.
3. "Comp." means the data for the ceramic-backed coupons was taken as a group (composite) and compared to the steel-backed coupon. The "Comp." comparison attempts to preclude any difference which may be due to the brand or type of ceramic.

TABLE 6.1.2
ANALYSIS OF PHASE II
TOUGHNESS DATA

DIFFERENCE	95% RANGE		DIFFERENCE	95% RANGE
H2-HI	-4.7 to +2.5	*	(G1>G2	1.6 to 6.8
HI-H3	-0.9 to +4.7		G3-G1	-7.6 to +0.2
H2-H3	-2.5 to +4.1	*	G2 >G3	9.1 to 17.7
Q4>H1	7.1 to 13.5		Q3>G1	3.4 to 14.2
Q4>H2	7.7 to 15.1	*	Q3>G2	6.4 to 19.6
Q4>H3	9.3 to 15.1		Q3>G3	6.6 to 18.4
Q4>H Comp.	8.9 to 13.7	*	Q3>G comp.	8.2 to 14.4

*The value 80.5 ft. Ibs. for G2 was omitted in calculations due to gross inconsistency with the other four G2 data points.

TABLE 6.1.3
ANALYSIS OF PHASE II
TOUGHNESS-DATA

DIFFERENCE	95% RANGE	DIFFERENCE	95% RANGE
1243	15.4 to 17.4	L2-L3	-10.5 to +16.1
12>14	31.7 to 33.7	L4-L2	-28.8 to +3.6
12>15	1.9 to 3.9	L5-L2	-6.1 to +22.5
13 >14	15.3 to 17.3	L4-L3	-25.7 to +6.1
15>13	12.5 to 14.5	L5-L3	-3.0 to +25.0
15>14	28.8 to 30.8	L5>L4	4.1 to 37.5
12-R1	-34.5 to +31.7	R2-L2	-23.3 to +8.9
R1 >13	16.8 to 18.8	R2-L3	-20.3 to +11.5
R1 >14	33.1 to 35.1	L4-R2	-23.7 to +12.9
R1>15	3.3 to 5.3	R2-L5	-32.1 to +1.3
I comp.-R1	-34.5 to 5.7	R2-L comp.	-18.1 to +7.3

TABLE 6.1.4
ANALYSIS OF PHASE IV
TOUGHNESS DATA

<i>DIFFERENCE</i>	<i>95% RANGE</i>
<i>N2-N1</i>	-4.1 to +5.3
N1►N3	0.7 to 11.2
N2►N3	0.7 to 12.5
N1►S1	0.7 to 9.9
N2►S1	0.3 to 9.9
<i>N3-SI</i>	-6.7 to +3.7
<i>N comp. - S1</i>	-1.9 to +7.3

VI-3 Bead Shape

The test coupon back beads were examined for amount and contour of reinforcement and for re-entry angles. Figure 6.7 identifies these attributes along with the two bead shape problem categories encountered when using ceramic backing. An optimum bead shape exhibits large, smooth re-entry angles and a moderate, smoothly-contoured reinforcement. Such a bead shape was typical of the FCAW test coupons for this evaluation as seen in the macrophotographs (Figure 6.8).

The Phase I, II and III (FCAW) test coupons were welded with the arc directed at the leading edge of the puddle, a technique resulting in meltback of the root edges of the joint creating a bead contour similar to a double-welded joint. By moving the arc back toward the center of the puddle, less meltback-"broom"-effect is obtained, but, as discussed in the section on weld soundness, at the expense of bead shape. The FCAW welding technique must strike a balance between optimum bead shape and the chance of incurring excessive back bead sag and/or chevron porosity.

While the broom effect results in the optimum bead shape described above, it also contributes to back bead sag and to chevron porosity. The mechanism for its creation is described as follows. Heat flow away from the puddle is much slower through ceramic backing than through steel backing. (Thermal conductivity of cordierite for example, a common ceramic backing material, is $.0077 \text{ cal}/(\text{sec.}) (\text{cm}^2) (^{\circ}\text{C}/\text{cm})$ at $+20^{\circ}\text{C}$. Thermal conductivity for a low carbon steel at $+20^{\circ}\text{C}$ is $.12 \text{ cal}/(\text{sec.}) (\text{cm}^2) (^{\circ}\text{C}/\text{cm})$. Thermal conductivity for the steel is approximately fifteen times greater.) Heat which would normally flow away from the puddle through steel backing material enters the base material instead when welding is performed over ceramic backing. This concentrated heat flow (probably combined with a somewhat higher current density in this region since a non-

conductor has been inserted in part of the original current path) melts the edges of the base material adjacent to the ceramic to a much greater depth than a corresponding joint with steel backing would be melted. This flare back ("broom") effect is readily evident in the macrophotographs of ceramic-backed weldments made with FCAW. It does not occur with the large, fluid SAW puddles.

Low spots(undercut when the surface of the back bead lies below the base metal plane) sometimes occurred with Phase I weldments in the horizontal position as a result of back bead sag. The mechanism of back bead sag is inherently limited to weld joints in the horizontal position due to the asymmetrical effects of gravity in that position as seen in Figures 6.9.1 and 6.9.2.

Back bead sag occurs when the enlarged molten weld puddle on the back bead side tends to assume a teardrop shape, settling onto the lower base metal edge. Although this sag usually only causes greater reinforcement at the bottom of the back bead than at the top, the resulting reduced volume of material at the upper base metal edge, combined with shrinkage of the cooling solidified puddle (there is no bond to the ceramic backing material and, therefore, no lateral restraint to shrinkage stresses) , may cause a portion of the upper back bead to lie below the plane of the base metal surface.

When meltback is especially severe on the upper plate edge, a "keyhole" condition will occur on the top root edge adjacent to and ahead of the puddle. (See Figure 6.10) . As a result, a slower travel speed is necessitated to fill the burn-away area since travel speed over ceramic backing is limited by the fill rate of the puddle. This compounds the problem, however, by producing excessive back bead reinforcement and even more burn away, in turn causing additional sagging at the top of the back bead. In conjunction with a lead angle of approximately 30° , a slight work angle of $5-15^{\circ}$ was normally found to aid in tying in

the upper plate. This work angle, however, further aggravates the burn-away problem when it occurs by directing the arc onto the upper plate edge.

Variations in weld joint dimensional parameters were found to have a significant effect on the weld metal sag problem. A 60° included angle tended to aggravate the sag apparently because of the thinner root edge than with say a 45° included angle. Using a 45° included angle (22 1/2° bevel on the upper plate edge) and limiting the root gap to 5/32" maximum (1/8" optimum) resolved the problem. The thicker edge due to the smaller bevel causing less meltback, together with the narrower root gap, reduced the vertical dimension identified in Figure 6.9.1 to such an extent to eliminate undercut, if not sag. The low spot/undercut problem did not recur with self-shielded wire in the horizontal position (Group J) due to the fast-freeze characteristics of the wire.

The second problem category, finning (Figure 6.11. 2), was found in Phase IV evaluation, only occasionally with single wire submerged arc but frequently with tandem submerged arc. Finning is equivalent to flash in a casting operation in which molten metal is unintentionally extruded into voids or crevices in the pattern. It occurs in ceramic-backed weldments when a critical combination of puddle fluidity and ceramic/joint geometry make it occur before the desired reaction in which contact with the molten puddle melts areas of the ceramic which then conform to and shape the back bead contour. The surface to volume ratio of the fins is too large for heat flow at any point on the surface of the fin to melt either ceramic or base metal which it contacts.

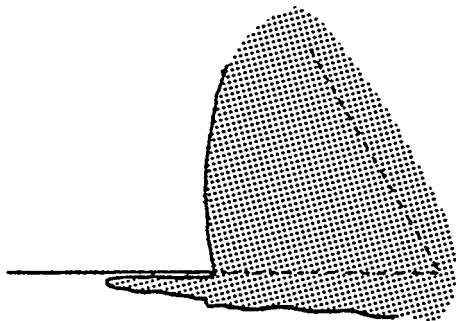
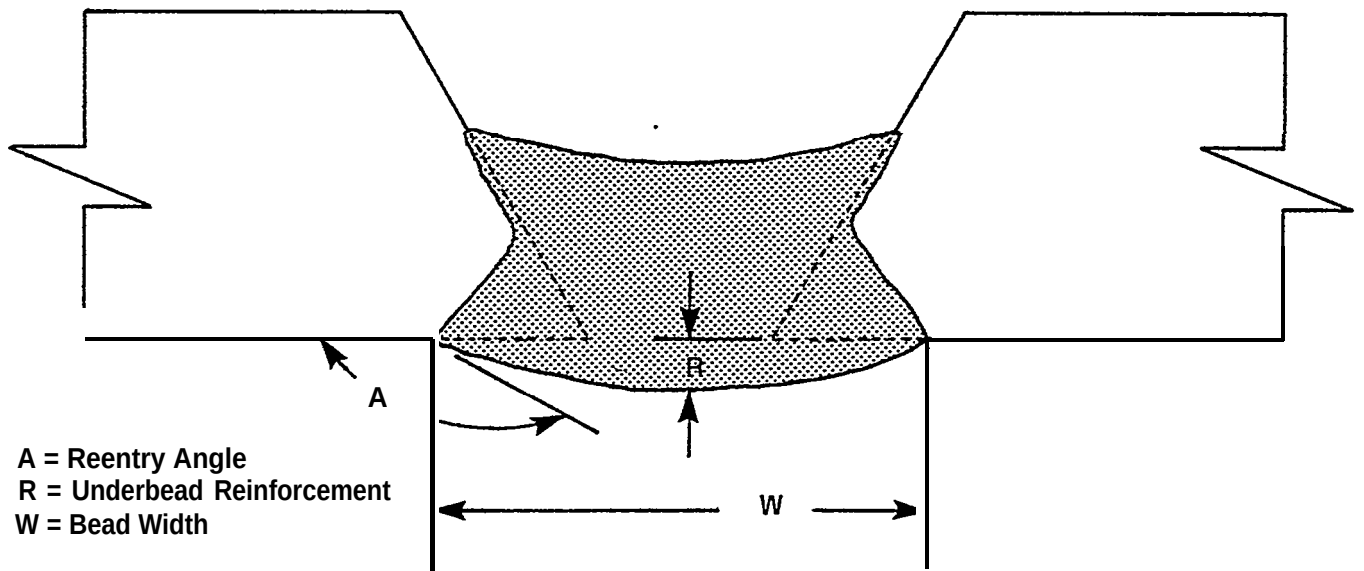
With single-wire submerged arc finning occurred with the larger Chemetron ceramic, the ceramic having the widest groove; Kuder and 3-M ceramics provided satisfactory results. Travel speed had a distinct effect on bead shape and control of the underbead reinforcement. Excessive travel speed produced a shallower

penetration with a very narrow and occasionally intermittent underbead with areas of lack of penetration. A travel speed too slow resulted in complete consumption of the root land, but excessive back bead reinforcement and occasional finning due to increased fluidity at the root of the puddle. A workable range of parameters was identified, however, indicating there should be few problems adapting single wire submerged arc to ceramic backing.

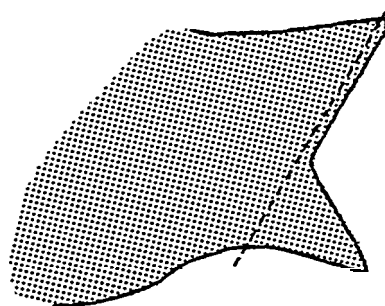
Although marginally acceptable parameters were established for the smaller Chemetron ceramic using tandem submerged arc, parameters could not be identified which would consistently result in an acceptable back bead. Welding parameters, especially travel speed, appeared more sensitive with tandem than with single-wire submerged arc. Because the tandem submerged arc puddle is two to three times the size of the single-wire submerged arc puddle and therefore more fluid, finning occurred before the ceramic could melt and shape the bead contour. Tandem submerged arc does not appear to be adaptable to ceramic backing.

FIGURE 6.7

GEOMETRIC ATTRIBUTES OF BACK BEAD AND PRINCIPLE DEFECTS



Finning
(Found with SAW Weldments)



Low Spot/Undercut
(Found with Horizontal FCAW Weldments)



A2



B2

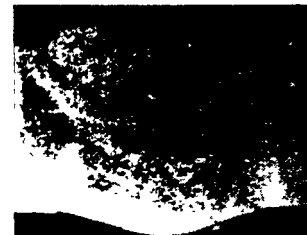


C2

NOT AVAILABLE



D2



E2

F 2



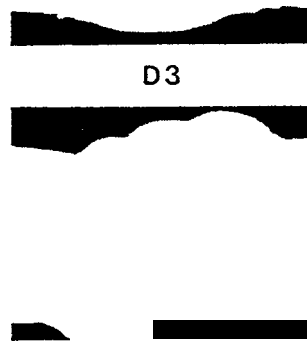
A3



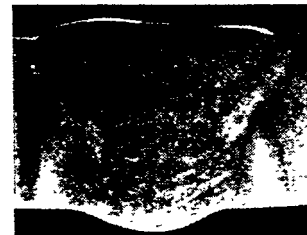
B3



C3



D3



E3

F 3



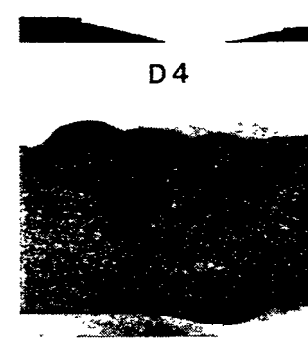
A4



B4



C4



D4



E4

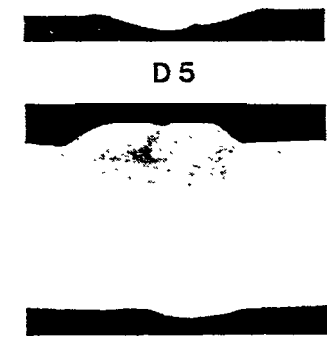
F 4



A5



B5



D 5



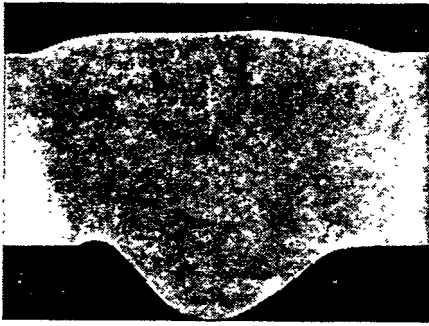
E5

F 5

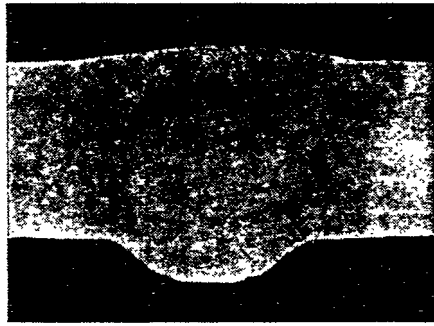
FIGURE 6.8.1

Cross-Sectional Macrophotographs of
Test Coupons

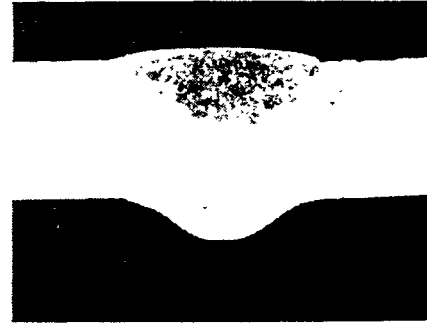
PHASE 1



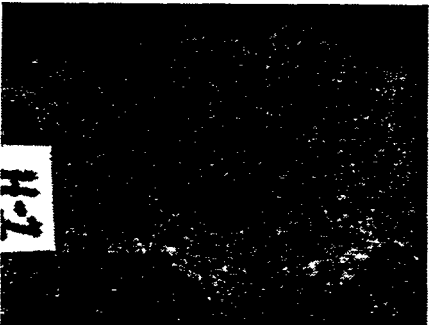
G 1



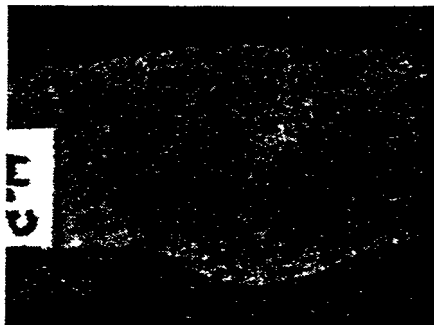
G 2



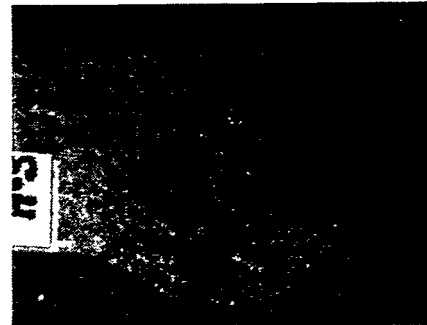
G 3



H 1



H 2



H 3

FIGURE 6.8.2

Cross-sectional Macrophotographs of
Test Coupons

PHASE II

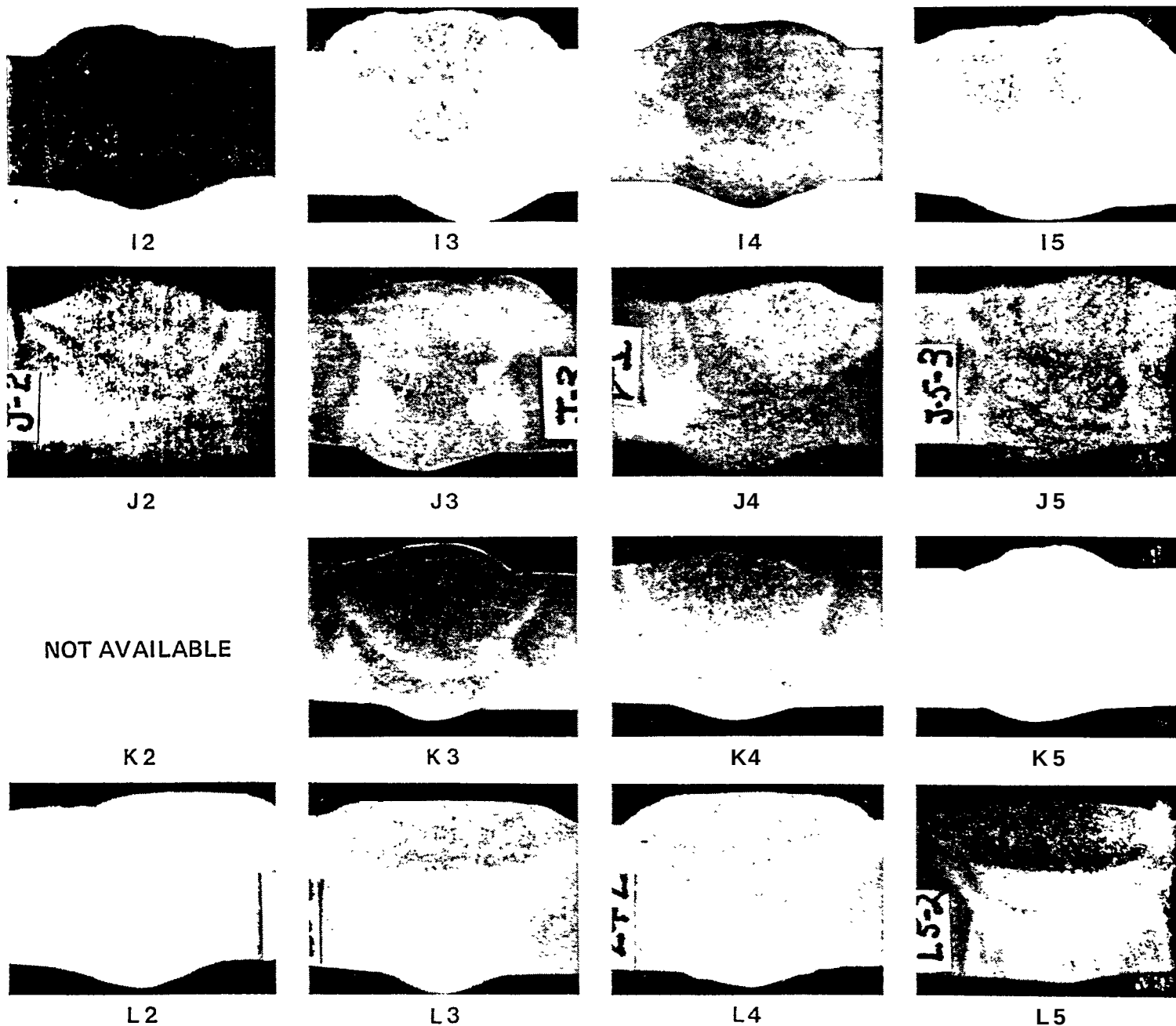


FIGURE 6.8.3

Cross-Sectional Macrophotographs
of Test Coupons

PHASE III

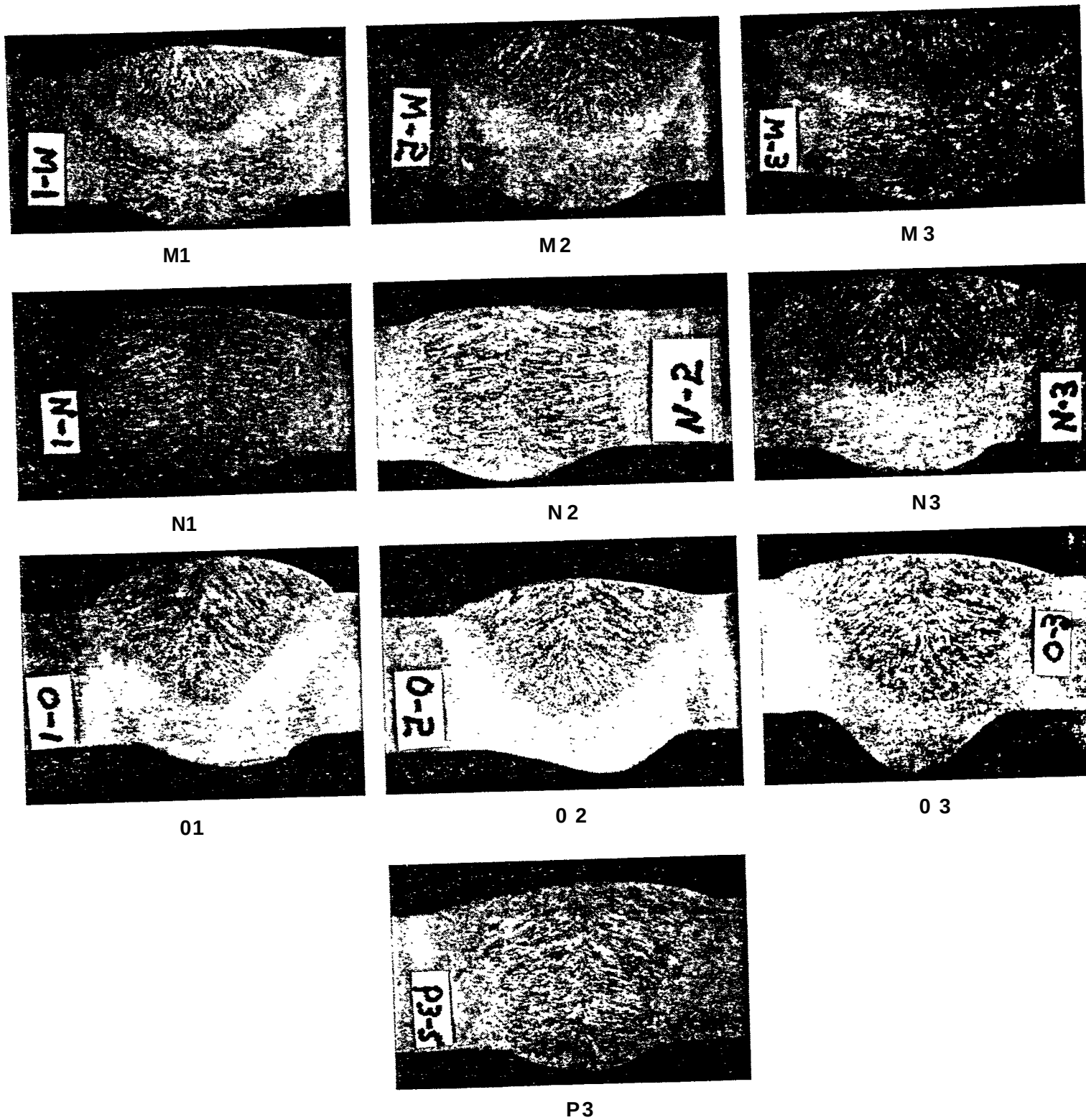


FIGURE 6.8.4

Cross-sectional Macrophotographs of
Test Coupons

PHASE IV

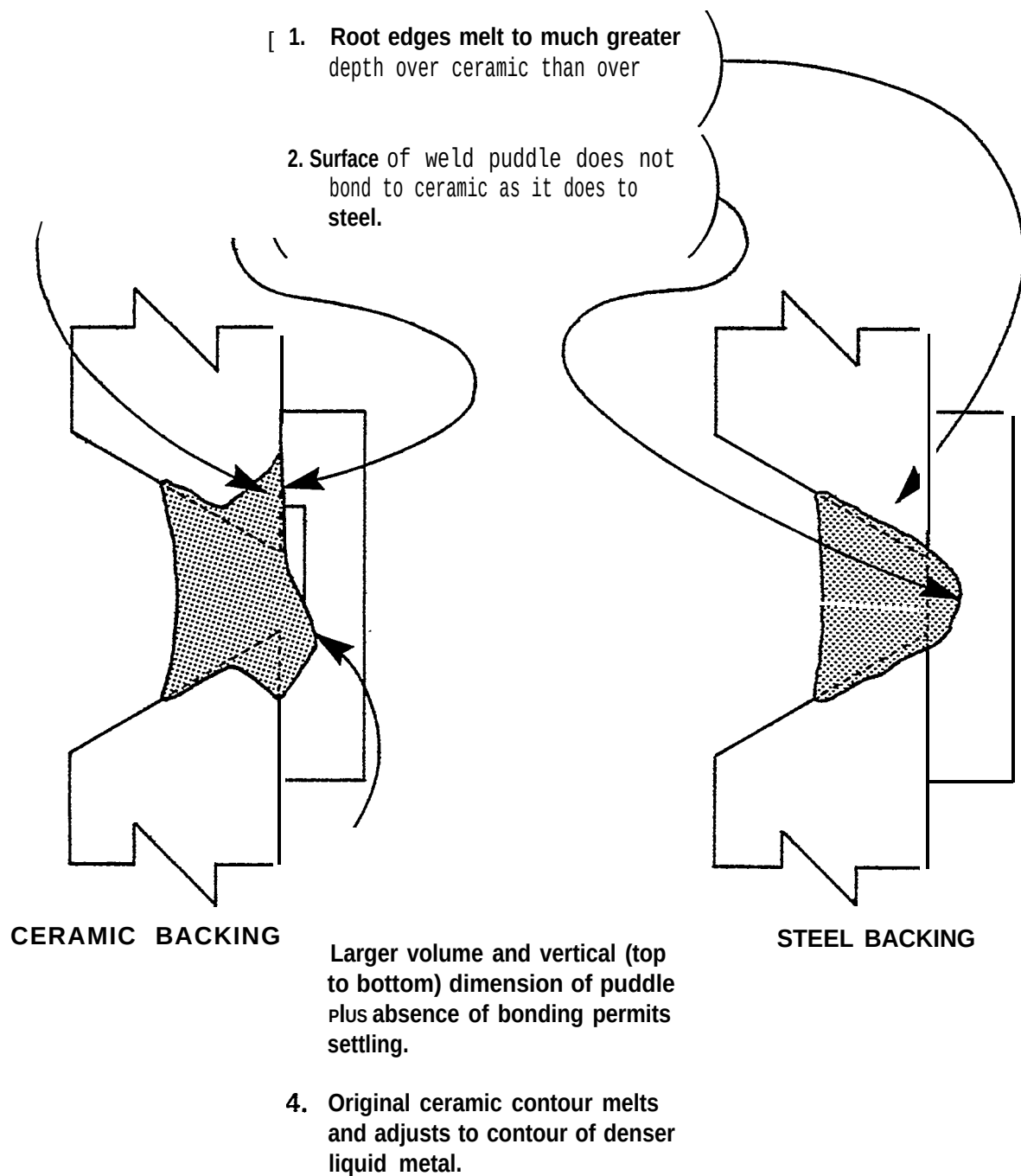


FIGURE 6.9.1

MECHANISM OF WELD METAL SAG WITH HORIZONTAL FCAW



FIGURE 6.9.2 .

Example of undercut along top toe of the back bead due to gravity-induced sag of the molten puddle in the horizontal position.

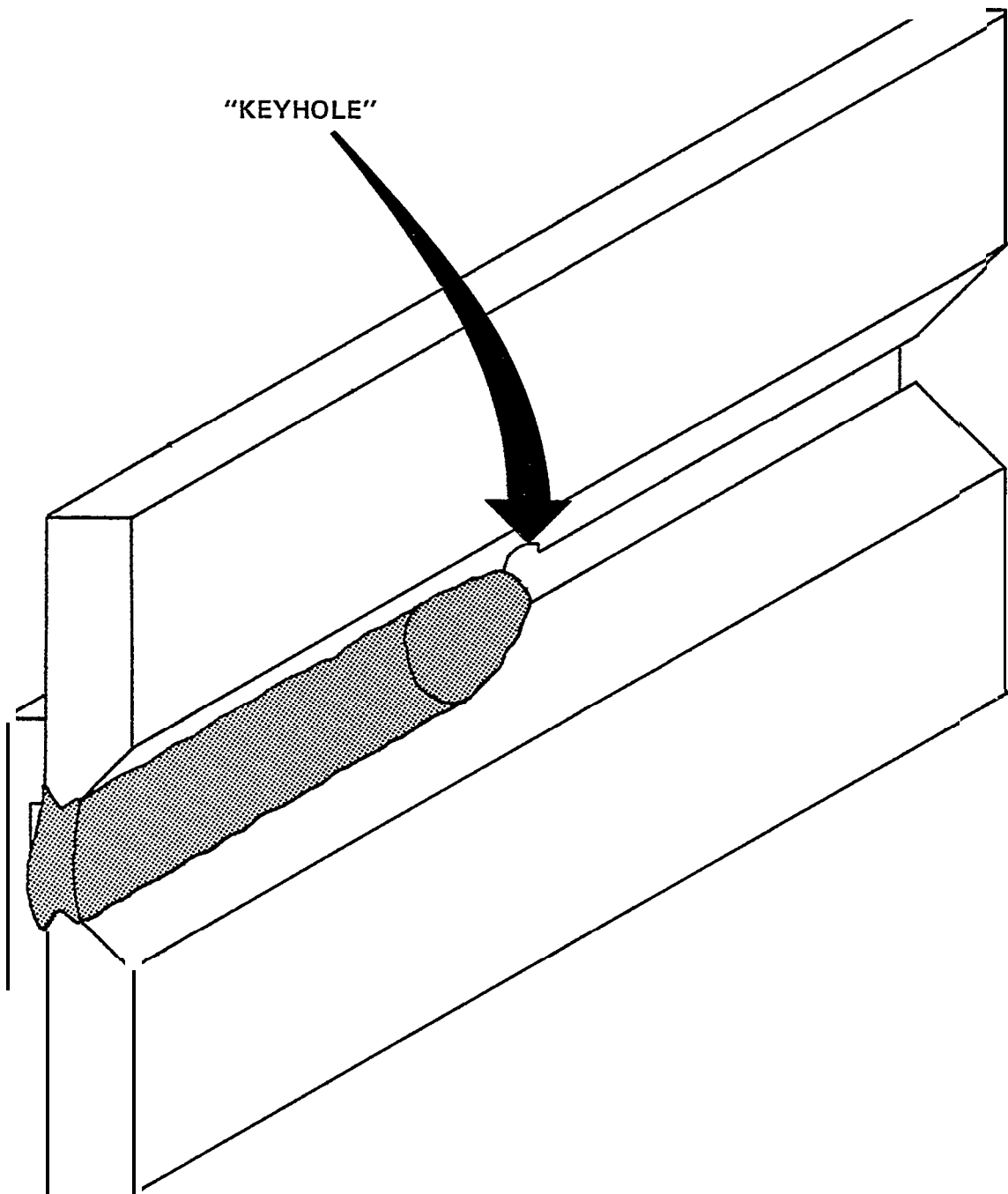


FIGURE 6.10

UPPER LAND BURNAWAY "KEYHOLE" AS IT APPEARS TO WELDER, INDICATING A HIGH PROBABILITY OF BACK BEAD SAG RESULTING IN LOW SPOTS/UNDERCUT

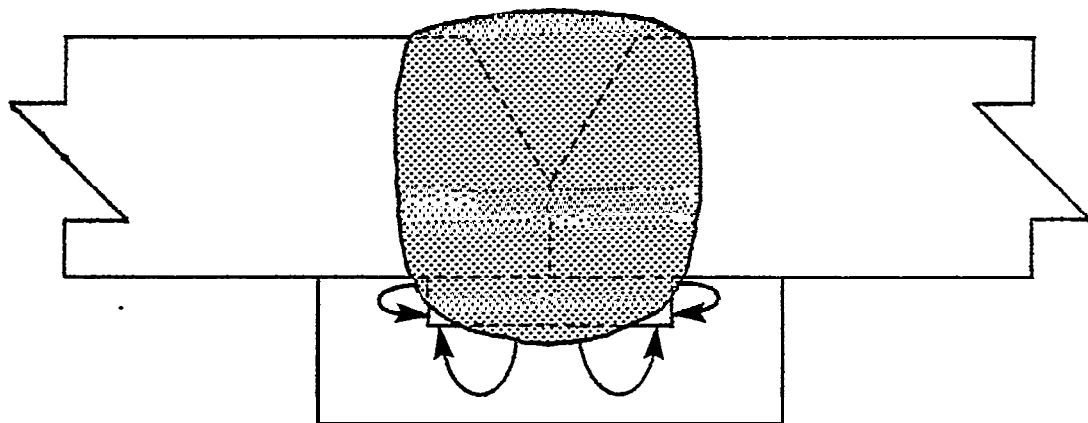


FIGURE 6.11.1

Desired reaction of ceramic-backing/weld-puddle system. Ceramic melts and flows under weight of puddle, as indicated by arrows, adjusting to and contributing to contour of back bead.

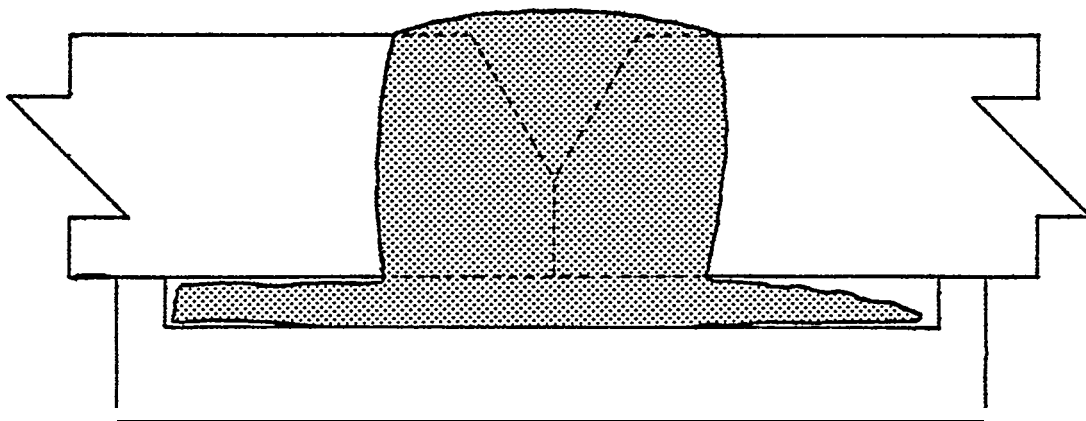


FIGURE 6.11.2

As width of groove is increased and/or puddle becomes more fluid, the weld metal may extrude into the void without melting the ceramic.

VI-4 Stops and Starts

Welding techniques to accomplish sound starts and stops were evaluated. Two techniques were employed in stop and restart evaluation for FCAW. See Figure 6.12. Both techniques were evaluated in the flat, horizontal, and vertical position. The first technique was simply breaking the arc, removing the slag in the crater area, hand wire brushing and re-establishing the arc. The second technique was a variation on the first. A small pneumatic grinder was used to grind a ramp in the crater area to reduce the metal thickness and to facilitate complete fusion and penetration of the stop area of the previously placed bead. When employing either of the techniques, it was found necessary to start the arc at the rear of the existing crater, bring it immediately forward to the desired location, and briefly hold at that point to ensure complete penetration and back bead build up. Prior to proceeding along the joint when making the restart, the lead angle should be the same as when welding the joint; i.e., 30-40°. This allows for complete breakdown of the crater leading edge and a more uniform back bead at the restart. It was found that a more uniform restart and underbead in the restart area could be obtained with the second technique.

Unplanned stops and starts should be avoided with SAW over ceramic backing. When welding was stopped, the ceramic moved slightly away from the root of the joint. To properly replace the ceramic under the restart area, the back bead reinforcement had to be ground sufficiently for the new ceramics to fit flush to the base metal for a short distance back from the restart area.

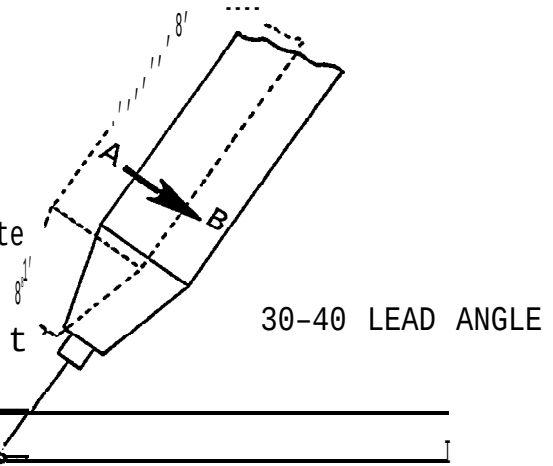
FIGURE 6.12
FCAW RESTART TECHNIQUE OVER CERAMIC BACKING

FLAT RESTART POSITION

Torch Side Angle is 90 to the Plate

Travel →

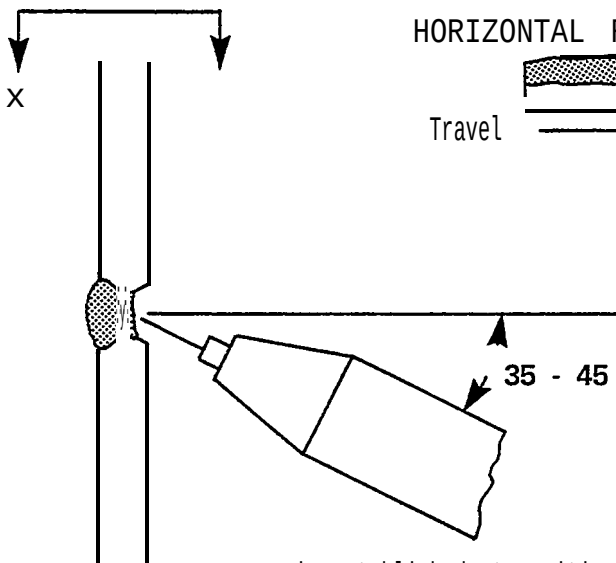
Arc is established at Position "A", and brought immediately forward to the lead edge of the crater, Position "B".



HORIZONTAL RESTART POSITION

Travel →

30-40 LEAD ANGLE



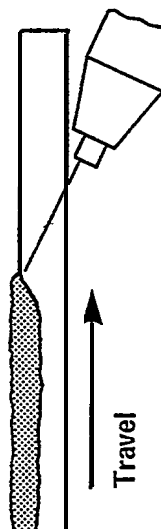
Arc is established at Position "A", and brought immediately forward to the lead edge of the crater, Position "B".

65-75 LEAD ANGLE

VERTICAL RESTART POSITION

Torch Side Angle is 90 to the Plate

Arc is established at the lead edge of the crater.



VI-5 Ceramic Attaching Methods

The adhesive effectiveness with regard to position, surface cleanliness and surface temperature was evaluated. Some difficulty occurred, especially at elevated temperatures and on somewhat less than clean contact surfaces, with adhesion of the tape which holds the ceramic backing in place especially when the contact surfaces had an as-received coating of mill scale or a coating of shop dust. Abrasive blasting of the contact surfaces and wiping of the surfaces just prior to placing the tape appeared to provide satisfactory adhesion. Evaluations were made in the flat, horizontal and vertical positions and with the test plates in the following conditions of cleanliness; (1) as-received (rust, mill scale, etc.), (2) power wire brushed, (3) ground, (4) abrasive blasted, and (5) abrasive blasted and wiped with a dry cloth just before assembly. The best adhesion was obtained when abrasive blasting and wiping of the base material were used together.

The adhesive was evaluated at base material temperatures ranging from 45° to 450°F. At the higher temperatures, adhesion was far less than at lower temperatures. At higher temperatures, the adhesive sometimes loosened permitting the ceramic backing to fall away from the base material resulting in excessive reinforcement on the back bead when the molten puddle tried to fill the space. The adhesive appeared to break down above approximately 400°F. One manufacturer advised that their adhesive was designed to do so to assist in removal after welding. The three tapes evaluated for adhesiveness were Chemetron, Kuder, and 3-M. Little difference was noticed.

The practicality and adaptability of magnetic holding devices to a construction environment were evaluated. The devices evaluated were manufactured by Varies and were used with other Varies materials. In all combinations the magnetic devices held the ceramic backing securely in place and firmly to the base

material eliminating a possible cause of excessive reinforcement and producing a good back bead. The magnetic devices also resulted in a much cleaner environment, since smoke and color produced when heating the adhesive were eliminated.

One problem with the magnetic devices, however, was loading the ceramics into the support sections. The ceramics, are not completely uniform in size when manufactured. Although most ceramics fitted nicely into the support section and functioned as designed, some were so loose that once inserted into the support section and positioned on the base material, they fell out. Still others were too large to be inserted into the support sections without bending the section sides out to accommodate them. This caused the pieces that previously fit to become loose. Holding devices with the ceramic tiles already in place are available and are recommended. No surface cleaning or other special preparation was necessary with the magnetic holding devices. Temperature had no apparent effect on the function of the devices.

VI-6 Ceramic Neutrality

The ceramic backing chemical composition and deposited weld metal root and second pass diluted composition were evaluated using an energy dispersive x-ray analytical system and spectrographic system respectively. Results of the spectrographic analysis of the deposited weld metal were given in Table 5.4. Results of the x-ray analytical system analysis of the ceramic backing were given in Table 5.5. Although base metal heat number identification was not maintained, the typical analysis in Table 5.4 approximates the Composition of the A36 base metal used. The weld metal composition data points are leveled across a 5/16" diameter area in the Spectrovac II system used and hence may or may not represent a homogeneous distribution of a specific element. For example, a weld metal surface in which the silicon composition of the matrix is .3% might hypothetically contain particles of SiO_2 totaling 3.8×10^{-4} square inches (.5% of the total area.) The silicon composition identified by spectrographic analysis will then be $.53\% (.003 (.995) + .467 (.005) = .0053/\text{SiO}_2$ is 46.7% Si by weight).

Ceramic neutrality was defined as any change in weld metal composition due to use of ceramic backing. Ceramic backing may possibly alter the weld metal composition directly by some chemical reaction within the weld puddle environment or by contributing entrapped ceramic particles to the weld metal. It may also indirectly alter the weld metal composition by changes in dilution ("broom" effect) or by preventing escape of material which would normally escape a steel-backed weldment.

Theoretically, one way in which ceramic backing may directly affect the weld metal composition is by contributing products of reduction of aluminum, silicon and magnesium oxides of which the ceramic is composed. Since aluminum, silicon and magnesium all have a much greater affinity for oxygen throughout the prevailing temperature range than potential reducing agents in the

puddle environment, however, the likelihood of such a reaction is remote. Direct contributions of material from ceramic particles themselves is much more likely to occur than reduction of ceramic oxides. Since any larger particles present would have been identified by volumetric examination, any particles in the coupons analyzed would be very fine. Such particles would represent a localized high concentration of the ceramic composition (aluminum, silicon and magnesium).

In addition to any direct effects of ceramic backing, indirect effects on weld metal composition may result from changes in dilution and weld metal viscosity due to the "broom" effect which occurs with most FCAW ceramic-backed weldments. Change in weld metal viscosity may lead to entrapment of certain elements which would usually escape. Weld metal composition is normally affected by oxidation and float-out of certain elements in the puddle, the necessary oxygen resulting from disassociation at welding temperatures of carbon dioxide shielding gas into carbon monoxide and oxygen. Oxidation and float-out may be inhibited by changes in puddle contour and/or viscosity due to ceramic backing.

To help determine whether any of these possible events actually occurred, the data from Table 5.4 for the deposited root beads is graphically displayed in Table 6.2. Table 6.2 was constructed by plotting vertically, for each group and each element, the difference between the root bead analysis for each ceramic-backed coupon and its corresponding steel-backed coupon. Points above the horizontal (zero) line indicate, for the specific coupon and element, a higher composition for a ceramic-backed coupon than for its corresponding steel-backed coupon and vice versa. For each group except D the same wire heat was used throughout. Since processes, shielding, wire heats, etc., are essentially the same for each comparison, any significant variation can be attributed to ceramic backing.

Since the "broom" effect and oxidation loss does not occur to any appreciable extent with SAW, differences in composition between ceramic-backed and steel-backed weldments would be expected to be rather small if there are no direct effects from ceramic backing. The differences identified by Table 6.2 for SAW (groups N and P) are small or do not exist for most of the elements. Accordingly, for SAW there appears to be no significant direct or indirect effect on weld metal composition due to use of ceramic backing.

For FCAW, a trend toward increased silicon content for ceramic backed versus steel-backed weldments when using CO_2 or self-shielded wire is identified. This trend is likely the result of entrapped particles of SiO_2 . The fact it occurs only with the processes having higher shielding oxygen content is a strong indication the particles result from oxidation and subsequent entrapment of silicon in the puddle. Entrapment of particles of ceramic backing would be expected to occur equally with all the FCAW processes since puddle contour and viscosity is similar for all FCAW ceramic-backed weldments. The oxidation and entrapment mechanism is more likely to produce the fine, dispersed particles necessary to escape identification by volumetric examination, providing another indication the higher silicon is not due to direct contribution by the ceramic backing.

Manganese in the weld puddle combines first with any sulfur present forming MnS which tends to float out of the puddle. Some remaining manganese may react with any oxygen remaining after silicon and/or aluminum react with it first. Any MnO thus formed immediately reacts with carbon, forming metallic manganese and carbon monoxide (This reaction may contribute to the soundness problems discussed in Section VI-1). This manganese, plus any which did not react with oxygen or sulfur, forms Mn_3C which is indistinguishable from Fe_3C and remains in the weld, having formed after solidification. Although some MnS may become entrapped in the same manner as SiO_2 , the quantity of MnS

is too small to identify any trends on the basis of sulfur. A possible but vague trend toward lower manganese content with FCAW and ceramic backing can be attributed to increased dilution obtained from the "broom" effect, the base metal being consistently lower than the wire in manganese. An increased-dilution type analysis for FCAW over ceramic backing also tends to explain the variations in nickel and titanium content.

In summary, there was no evidence found to indicate that ceramic backing contributes directly to the composition of either or SAW weldments with which it was used. Of the three elements, the oxides of which are the principle constituents of the ceramic backing evaluated magnesium could not be evaluated with spectrographic techniques; no trend, either higher or lower, could be identified for aluminum; and the trend toward increased silicon could be adequately explained by other than direct contribution from the ceramic backing. There were some mild indirect effects on weld metal composition due to use of ceramic backing with FCAW. These effects are probably caused by increased dilution at the root of the joint and resultant changes in viscosity distribution of the molten puddle, i.e., they are due to the "broom" effect. These changes should have little or no effect on the performance of a sound weldment made with ceramic backing.

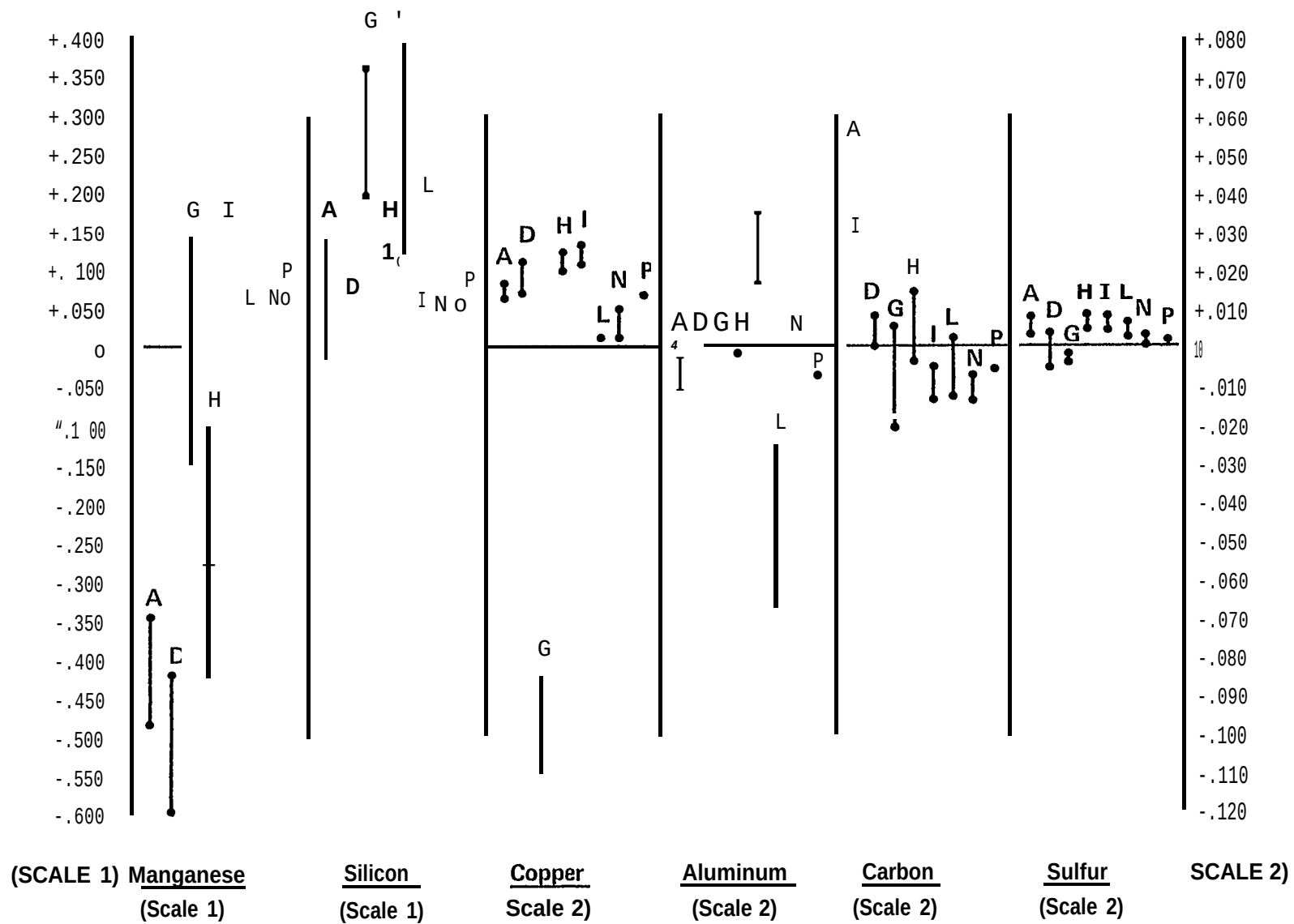
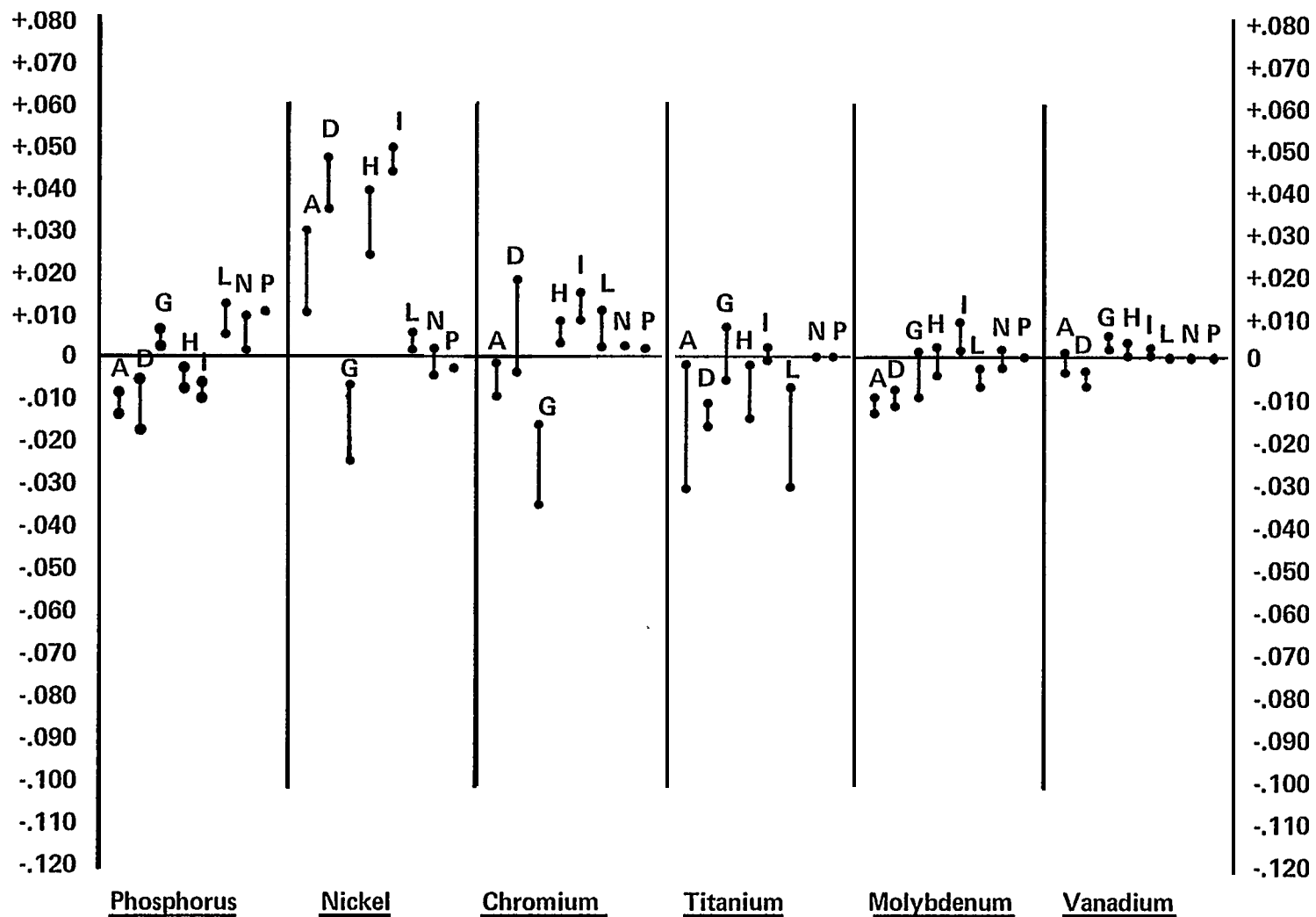


TABLE 6.2

VARIATIONS IN COMPOSITION BETWEEN CERAMIC-BACKED AND CORRESPONDING STEEL-BACKED WELDMENTS



$\circ \equiv$ For each group except D, the same wire heat was used for the ceramic-backed and corresponding steel-backed weldments.

(CONT)

VI-7 Summary of Analysis

The objective of the evaluation was to determine if ceramic tile backing in flux cored arc welding (FCAW) and submerged arc welding (SAW) applications could provide a second side contour such that back gouging and grinding is not required to prepare the second side for subsequent welding or inspection. Ceramic tile backing was found to provide such a second side contour in FCAW and SAW single wire applications, but in FCAW applications only Phase I (.052" and 1/16" diameter wire with C-25 shielding) did so without significant risk of internal porosity and piping. lower heat input and smaller puddle size combined with the more inert C-25 shielding apparently mitigates the porosity/piping mechanisms described in VI-1. Positioning of the arc toward the center rather than the leading edge of the puddle further decreased the likelihood of porosity and piping but at some expense in second side bead contour. Phase II (CO₂ shielded FCAW) and Phase III (self-shielded FCAW) provided good second side bead contour but with a high risk of internal porosity and piping for which consistently reliable corrective measures were not identified. For this reason, Phase II and III type FCAW applications are not recommended with ceramic tile backing without subsequent volumetric examination.

Acceptable second side contours were consistently obtained with single wire submerged arc. A "finning" phenomenon, apparently depending on a critical relationship of puddle fluidity and ceramic design presented no significant problems with single wire SAW as it did with tandem wire SAW. Minimum puddle fluidity, consistent with adequate penetration and fusion, combined with an appropriate ceramic selection will avoid finning in single wire SAW. Tandem submerged arc, however, apparently due to the inherently larger, more fluid puddle was quite susceptible to finning and as a result is not recommended for use with ceramic tile backing.

Other than finning in tandem SAW applications and porosity piping in certain FCAW applications, no problems of significance were identified in the use of ceramic tile backing. A statistical analysis of Charpy impact data from selected coupons revealed only a very slight difference, if any, in weldment toughness between ceramic-backed and steel-backed weldments and even these differences could possibly be attributed to factors other than ceramic backing. The only other bead shape problems were occasional back bead sag in horizontal Phase I welds, a problem resolved by changes in joint design as discussed in VI-3. The concessions in back bead contour for the purpose of assuring weldment soundness are directly controllable, an acceptable compromise being recommended. Welding stops and starts presented no special problems with FCAW and techniques are recommended in VI-4. Stopping and restarting with SAW, however, is not recommended. The adhesive and magnetic attaching methods both worked satisfactorily. Only reasonable base metal cleanliness is required with the adhesive methods while the magnetic methods are even more forgiving and have the additional advantage of no smoke and odor. Also, the magnetic devices are not temperature sensitive. The ceramic tiles were not found to significantly affect the weld metal chemistry. There were some minor, insignificant variations for ECPW due to increased base metal dilution and some entrapment of oxidized elements.

The following specific applications are recommended for ceramic tile backing subject to the precautions identified. Problems previously identified with these applications are avoided by following the appropriate precautions. Those applications not recommended, i.e., those applications for which an effective resolution of respective problem areas could not be found, are also identified along with the nature of the problems responsible.

RECOMMENDED

Phase	Group	Specifics	Precautions
I	A	FCAW/E70T-1/. 052° dia./C-25/FLAT	(1) (2) (4)
I	B	ECAW/E70T-1/. 052° dia./C-25 /H0Z.	(1) (2) (3) (4)
I	c	FCAW/E70T-1/. 052° dia./C-25 /VERT.	(1) (2) (4)
I	D	FCAW/E70T-1/l/16° dia./C-25/FLAT	(1) (2) (4)
I	E	FCAW/E70T-1/l/16° dia./C-25/H0Z.	(1) (2) (3) (4)
I	F	ECAW/70T-1/l/16/" dia.C-25/Vert.	(1) (2) (4)
Iv	M	SAW/EP12K/l/8° dia./FLAT	(1) (2) (5) (6) (7)
Iv	N	SAW/EM12K/5/32° dia./FLAT	(1) (2) (5) (6) (7)
IV	o	SAW/~12K/3/16° dia./FLAT	(1) (2) (5) (6) (7)

NOTES :

- (1) When adhesive attaching methods are used, wiping of contact surfaces with a clean dry cloth just before applying ceramics is minimum cleanliness.
- (2) Baking or dry storage may be necessary.
- (3) Possibility of back bead sag must be considered in joint design.
- (4) Use 30-40° lead angle with arc directed between center and leading edge of puddle to minimize any possibility of piping.
- (5) Minimum puddle fluidity consistent with adequate penetration.
- (6) Ceramic design should be selected to avoid finning.
- (7) Stops and restarts should be avoided.

NOT RECOMMENDED

Phase	Group	Specifics	Reasons
II	G	FCAW/E70T-1/ 5/64" dia./CO ₂ /FLAT	Frequent Porosity and Piping
II	H	FCAW/E70T-1/ 3/32" dia./CO ₂ /FLAT	Frequent Porosity and Piping
III	I	FCAW/E70T-G/ 5/64" dia./FLAT	Frequent Porosity and Piping
III	J	FCAW/E70T-G/ 5/64" dia./HOZ.	Frequent Porosity and Piping
III	K	FCAW/E70T-G/ 5/64" dia./VERT.	Frequent Porosity and Piping
III	L	FCAW/E70T-G/ 5/64" dia./FLAT	Frequent Porosity and Piping
Iv	P	SAW/EM12K/ 5/32" dia./FLAT/Tandem	Severe Finning

VII . RECOMMENDATIONS FOR FURTHER DEVELOPMENT

Continuation of ceramic backing evaluation with FCAW should center on the resolution of weld soundness, i.e., piping and porosity problems. Such factors as base material thickness and size and/or wire characteristics such as fast-freeze, etc. may have an effect not identified by this evaluation. Variations in welding technique appear promising for resolution of the FCAW soundness problems. An optimum balance must be found between the bead shape advantages of the "broom" effect and avoidance of the soundness problems associated with it. A statistically significant program concentrating primarily on the effects of technique, joint design and welding parameters is necessary to provide a data bank of reliable information for avoidance of the soundness problems.

Continuation of ceramic backing evaluation with single wire SAW should concentrate on determining the optimum combination of welding parameters and ceramic/weld-joint design. The relationship of puddle size and fluidity to the geometry of the ceramic/weld-joint area is important. An appropriately designed evaluation program would identify the limiting factors which will result in an optimum relationship.

The bead shape problems with tandem SAW appear too severe to justify continued evaluation. Tandem SAW, at this point, is not compatible with ceramic backing.

The use of ceramic backing with other processes such as SMAW and GMAW short arc is quite promising. Much information obtained with FCAW and SAW is directly applicable to these two processes. A similar evaluation program would yield beneficial results.

This evaluation program ascertained the technical feasibility of producing quality welds with ceramic backing. The primary advantage of ceramic backing is alleged lower cost and/or production time. An in-depth cost/time study for ceramic backing as it relates to other

available methods for performing similar functions would substantiate and quantify these savings.

Although every effort was made to accurately duplicate shipyard conditions, this evaluation was of necessity a laboratory function with small scale test coupons. A planned shipyard evaluation utilizing surface and volumetric examination of production welds may reveal influences of size, fitup, etc., unaccounted for in this evaluation.

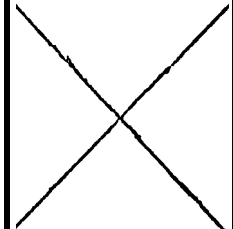
APPENDIX A

DETAILED TEST ASSEMBLY PARAMETERS & RESULTS

WIRE TYPE E70T-1/FC707

HEAT 63302225H243 GAS FLOW 40CFH

POLARITY DCRP

EST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	ROOT BENDS				TENSILE	CVN 200°F)					AVG.
										1		2			1	2	3	4	5	
A-2-1	7	1	260	28	7.5	70	30-40° Lead	String	OK	X		X		U=67,567	38	39	50.5	45	48	44.1
		2	260	28	13.6	180	30° Trail	String							33	32	44	37	41	37.4
		3	260	28	13.6	350	30° Trail	String							10	10	20	20	20	16
		4	260	28	13.6	350	30° Trail	String												
A-3-1	6	1	260	28	7.5	70	30-40° Lead	String	OK	X		X		U=66,622	30.5	39	42.5	43	54	41.8
		2	260	28	13.6	290	30° Trail	String							23	30	33	39	41	33.2
		3	260	28	13.6	350	30° Trail	String							10	10	15	20	30	17
		4	260	28	13.6	350	30° Trail	String												
I-4-1	6	1	260	28	7.5	70	30-40° Lead	String	OK	X		X		U=67,617	30.5	40.5	38	37	46	38.4
		2	260	28	13.6	220	30° Trail	String							25	29	26	26	34	28
		3	260	28	13.6	250	30° Trail	String							10	10	10	15	20	13
		4	260	28	13.6	350	30° Trail	String												
I-5-1	7	1	260	28		70	30-40° Lead	String	OK	X		X		U=65,559	23.5	34	29	30	26	28.5
		2	260	28		240	30° Trail	String							18	35	24	26	30	26.6
		3	260	28		345	30° Trail	String							5	10	5	5	15	8
		4	260	28		350	30° Trail	String												
]-1-1	3	1	240	28		70	15° Lead	String	OK					U=71,932 Y=48,660	30.5	18	20	22.5	22.5	22.7
		2	240	28		220	15° Lead	Weave							24	15	17	18	18	18.4
		3	240			300	15° Lead	String							20	25	25	30	30	26
		4	240			310	15° Lead	String												
		5	240	28		320	15° Lead	String												
		6	240	28		350	15° Lead	String												
		7	240	28		NR	15° Lead	Weave												
ET-2-1	8	1	260	26		70	30-400 Lead	String	Excessive Back Bead Sagi											
I-2-2	29	1	260	26		70	30-40° Lead	String	IEJ	Lack of fusion										
I-2-3	4	1	260	25		70	30-40° Lead	String	IEJ	Lack of fusion and sag										

WIRE TYPE E70T-1/FC707HEAT 63302225H243 GAS FLOW 40CFH

POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 4	STRING/ WEAVE	RT	ROOT BENDS 2			
										P	F	P	F
B-2-4	4	1	260	26	7.5	70	30-40° Leac	String	REJ	Lack of Fusion			
		2	260	26	13.6	180	40° Trail	String					
		3	260	26	13.6	250	40° Trail	String					
		4	260	26	13.6	290	40° Trail	String					
		5	260	26	13.6	350	40° Trail	String					
B-2-5	10	1	280	25	7.5	70	30-40° Leac	String	OK	x		x	
		2	280	25	13.5	150	40° Trail	String					
		3	280	25	13.5		40° Trail	String					
		4	280	25	13.5	290	40° Trail	String					
		5	280	25	13.5	350	40° Trail	String					
B-3-1	4	1	280	25	7.5	70	30-40° Lead	String	REJ	Lack of fusion			
B-3-2	4	1	280	25	7.5	70	30-40° Lead	String	REJ	Lack of fusion and saq			
B-3-3	4	1	280	25	7.5	70	30-40° Lead	String	OK	x		x	
		2	280	25	13.5	250	40° Trail	String					
		3	280	25	13.5	200	40° Trail	String					
		4	280	25	13.5	325	40° Trail	String					
B-4-1	4	1	280	25	7.5	70	30-40° Lead	String	OK	x		x	
		2	280	25	13.6	150	40° Trail	String					
		3	280	25	13.5	250	40° Trail	String					
		4	280	25	13	340	40° Trail	String					
B-5-1	10	1	280	25	7.5	70	30-40° Lead	String	REJ	Some minor sag at the run-off end. RT rejected for 2" lack of fusion.			
		2	280	25	13.5	160	20° Trail	String					
		3	280	25	13.5	300	20° Trail	String					
		4	280	25	13.5	70	20° Trail	String					
B-5-2	4		260	26	7.5	70	30° Lead	String	*	x	x	* 2" chevron porosity at start and 1.5" at center.	
		:	260	26	13	125	20° Lead	String					
		3	260	26	13	250	20° Lead	String					
		4	260	26	13	350	20° Lead	String					
		5	260	26	13	345	20° Lead	String					
		6	260	26	13	360	20° Lead	String					

WIRE TYPE E70T-1/FC707HEAT 63302225H243GAs FLOW 40CFH

POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (V/F)	TORCH =	STRING/ WEAVE	RT	ROOT BENDS		
										2		
										F	P	F
C-2-1	12	1	220	24	4	70	10-15° Lead 15° Trail 15° Trail	Weave	OK	x		x
		2	220	24	4	220		Weave				
		3	220	24	4.5	300		Weave				
C-3-1	13	1	240	24	4	70	20° Lead 10° Trail 10° Trail	Weave	OK	x		x
		2	240	24	9	125		Weave				
		3	240	24	7	250		Weave				
C-4-1	8	1	240	24	4		20° Lead 15° Trail 15° Trail	Weave	OK	x		x
		2	240	24	9	125		Weave				
		3	240	24	7	280		Weave				
C-5-1	10	1	240	24	4.5	70	40° Lead 30° Trail 30° Trail	Weave	OK	x		x
		2	240	24	9	200		Weave				
		3	240	24	8	210		Weave				

WIRE TYPE E70T-1/~ABco-82

HEAT 32128/1022

GAS FLOW 40CFH

POLARITY

DCRP

TEST NO.	JOINT	PASS	A	v	TS (IPM)	INT.	TORCH ≤	STRING/ WEAVE	RT	ROOT BENDS				CVN (20°F)					AVG.	
										1		2		3		4		5		
D-2-1	10	1 3 4	260 260 260 260	36- 30 30 30	8 7 6.5 6	70 70 195 300	30° Lead 15° Lead 15° Lead 15° Lead	String Weave Weave Weave	OK	P x	E —	P x	F —	U=67,705	L 21 17 10	2 21 14 10	3 F 13 10	4 20 16 10	5 21 14 10	20.6 14.8 10
D-3-1	5	1 3 4	260 260 260 260	30 30 30 30	7.5 7 7 6	70 280 350	60° Lead 15° Lead 15° Lead 15° Lead	String Weave Weave Weave	OK	P x	E —	P x	F —	J=65,407	39 32 15	31.5 27 10	32 23 10	12.5 24 10	32 22 10	33.4 25.6 11
D-4-1	9	1 2 3 4	260 260 260 260	30 30 30 30	7.5 7 7 6	70 160 290 350	60° Lead 15° Lead 15° Lead 15° Lead	String Weave Weave Weave	OK	P x	E —	P x	F —	J=64,859	21 16 5	26 10	;; 15	30 29 15	27 20 10	27.2 23.6 11
D-5-1	11	1 2 3 4	260 260 260 260	30 30 30 30	7*5 7 7 6	70 150 290 340	60° Lead 15° Lead 15° Lead 15° Lead	String Weave Weave Weave	OK	P x	E —	P x	F —	J=53,505	20.5 20 10	23 20 10	18.5 20 5	11.5 13 5	28 25 10	20.3 19.6 8
E-2-1	33	1 2 3 4 5	260 260 260 260 260	25 25 25 25 25	NR NR NR NR NR	70 280 290 330 350	30° Lead 15° Trail 15° Trail 15° Trail 15° Trail	String String String String String	OK	P x	E —	P x	F —							
E-3-1	34	1 2 3 4 5	260 260 260 260 260	25 25 25 25 25	NR NR NR NR NR	70 260 295 325 350	60° Lead 15° Trail 15° Trail 15° Trail 15° Trail	String String String String String	OK	P x	E —	P x	F —							
E-4-1	34	1 2 3 4 5	260 260 260 260 260	25 25 25 25 25	NR NR NR NR NR	70 265 295 345 350	60° Lead 15° Trail 15° Trail 15° Trail 15° Trail	Weave Weave Weave Weave Weave	OK	P x	E —	P x	F —							

WME TYPE E70T-1/FABCO-33

IEAT 32128/1022

GAS FLOW 40CFH

POLAR TY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	ROOT BENDS			
										1		2	
										P	F	P	F
E-5-1	35	1	26°	25	NR	70	30° Lead	String	OK	X		X	
		2	26°	25	NR	280	15° Trail	String					
		3	26°	25	NR	295	15° Trail	String					
		4	26°	25	NR	350	15° Trail	String					
		5	26°	25	NR	350	15° Trail	String					

WIRE TYPE E70T-1/FC707

HEAT 1801

GAS FLOW 45CFH

POLARITY

DCRP

TEST NO.	JOINT	PASS	A	V.	TS (IPM)	INT. (V/F)	TORCH $\angle$	STRING/ WEAVE	RT	ROOT BENDS			
										1		1	
										P	F	P	F
F-2-1	2	1	220	22	4	70	NR	Weave	OK	X		X	F
		3	230	22	9	150	NR	Weave					
		4	240	22	7	125	NR	Weave					
		4	240	22	5	150	NR	Weave					
F-3-1	2	1	220	22	6	70	NR	Weave	OK	X		X	
		2	230	22	8.5	90	NR	Weave					
		3	230	22	6	250	NR	Weave					
F-4-1	14	1	230	22	5.25	70	NR	Weave	OK	X		X	
		2	230	22	7.5	125	NR	Weave					
		3	230	22	NR	225	NR	Weave					
F-5-1	1	1	230	22	5.5	70	NR	Weave	OK	X		X	
		2	230	22	7	125	NR	Weave					
		3	230	22	5.6	150	NR	Weave					

WIRE TYPE E70T-1/

FABCO-82

HEAT 282B8

GAS

-OW

45CFH

FLOW

P O L A R I T Y

TEST NO.	JOINT	PASS	A	V	(IPM)	INT. (°F)	TORCH 4	STRING/ WEAVE	RT		TENS ILL	CVN (20°F)					AVG.
												1	2	3	4	5	
Q-2-1	3	1	280	27	10.35	70	15° Lead	String	OK		U=74,341 Y=48,266	38	32	30.5	30	32	32.5
		2	280	27	7.14	250	15° Trail	Weave				27	28	26	24	23	25.6
		3	300	28	15	150	15° Trail	String				40	35	35	30	35	35
		4	300	28	12.5	300	15° Trail	String									
		5	300	28	12.5	350	15° Trail	String									
		6	300	28	12.5	350	15° Trail	String									

WIRE TYPE E70T-1/FABCO-82 HEAT 18122K8 GAS FLOW 40CFH POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS				TENSILE	CVN (20°F)					AVG.
										1		2			1	2	3	4	5	
G-1-1	6	1	430	31	NR	70	30° Lead	String	OK	X		X		U=65,285 Y=30,560	17	17	16	13	13	15.2
		2	430	31	NR	150	70° Lead	String							10	8	11	9	6	8.8
		3	430	31	NR	350	70° Lead	Slight Weave							10	5	5	10	5	6.4
G-2-1	10	1	410	31	NR	70	30° Lead	String	Approximately 2" rough area on underbead											
G-2-2	5	1	390	31	NR	70	30° Lead	String	OK	X		X		U=65,007 Y=43,243	80.5	12	10.5	11.5	10	24.9
		2	390	31	NR	190	45° Lead	String							61	13	14	13.5	9	22.1
		3	390	31	NR	320	45° Lead	String							60	10	10	10	10	20
G-3-1	20	1	280	28	NR	70	30° Lead	String	REJ	Approximately 3.5" of Chevron Porosity										
		2	280	28	NR	185	70° Lead	Weave												
		3	280	28	NR	280	70° Lead	Weave												
		4	280	28	NR	350	70° Lead	Weave												
G-3-2	5	1	360	27	8.5	70	30° Lead	String	OK	X		X		U=65,593 Y=42,606	16.5	12.5	10	8.5	10	11.5
		2	360	27	9	190	50° Lead	Weave							18	14	12	8	11	12.6
		3	360	27	9	240	50° Lead	Weave							15	10	10	5	10	10
Q-3-1	3	1	320	28	11.5	70	15° Trail	String	OK					U=74,270 Y=48,957	18	27.5	24.5	20.5	29.5	24
		2	320	28	10.7	300	15° Trail	Weave							18	22	23	19	26	21.6
		3	320	28	15	290	15° Trail	String							25	30	20	20	25	24
		4	320	28	15	350	15° Trail	String												
		5	320	28	15.5	180	15° Trail	String												
		6	320	28	15	300	15° Trail	String												

WIRE TYPE E70T-1/FABCO-82HEAT 4302L8

GAS FLOW

45 CFH

POLARITY

DCRP

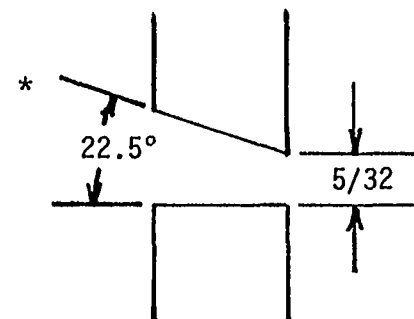
TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	ROOT BENDS					TENSILE		CVN (20°F)				
									1	2	3	4	5	1	2	1	2	3	4	5
H-1-1	5	1	400	28	7.5	70	30° Lead	String	Chevron porosity and surface porosity											
		2	400	28	12	230	15° Lead	String												
		3	400	28	10	320	15° Lead	Weave												
H-1-2	5	1	400	28	7.5	70	30° Lead	String	Chevron porosity and surface porosity											
		2	400	28	12	160	15° Lead	String												
		3	400	28	10	300	15° Lead	Weave												
H-2-1	5	1	400	28	8	70	30° Lead	String	Chevron porosity and surface porosity											
		2	400	28	12	250	15° Lead	String												
		3	400	28	10	300	15° Lead	Weave												
H-2-2	5	1	400	28	8	70	30° Lead	String	Chevron porosity and surface porosity											
		2	400	28	12	110	15° Lead	String												
		3	400	28	12	110	15° Lead	String												
H-1-3	15	1	400	28	8.5	70	30° Lead	String	OK	X		X		U=70,914 Y=45,429	15.5 14 10	14.5 13 10	20 18 15	16.5 16.5 10	16 15 15	16.5 15.3 12
		2	400	28	11.75	220	15° Lead	String												
		3	400	28	15	300	15° Lead	Weave												
		4	400	28	13	350	15° Lead	Weave												
H-2-3	16	1	400	28	9	70	30° Lead	String	OK	X			X	U=70,200 Y=44,269	16.5 16.5 10	19 21.5 10	14.5 14 10	15.5 14 10	11.5 14.5 10	15.4 16.1 10
		2	400	28	12	130	15° Lead	String												
		3	400	28	7	270	15° Lead	Weave												
H-3-1	15	1	400	28	10	70	30° Lead	String	OK	X		X		U=70,707 Y=47,330	13.5 13.5 10	14 12 10	14.5 15 10	17.5 19 10	13.5 16 10	14.6 15.1 10
		2	400	28	12	250	15° Lead	String												
		3	400	28	7.25	150	15° Lead	Weave												
Q-4-1	17	1	400	28	13	70	15° Lead	String	OK					U=72,546 Y=50,071	26.5 25 25	28 28.5 30	25.5 25 20	30 26 20	24 32 25	26.8 27.3 24
		2	400	28	7.75	200	15° Lead	Weave												
		3	400	28	8	250	15° Lead	Weave												
		4	400	28	12	300	15° Lead	Weave												
		5	400	28	12	350	15° Lead	Weave												

WIRE TYPE E70T-G/NR203MHEAT BB830POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS				TENSILE				CVN (20°F)					AVG.
										1		2				1	2	3	4	5			
I-2-1	18	1 2 3 4	300 300 300 300	20 20 20 20	7 7 7 7	70 240 290 350	45° Lead 20° Lead 20° Lead 20° Lead	String Weave Weave Weave	Rej	Chevron porosity and piping													
I-2-2	18	1 2 3 4	340 340 340 340	20 20 20 20	7 7 7 7	70 245 300 350	20° Lead 20° Lead 20° Lead 20° Lead	String Weave Weave Weave	OK	X		X		U=67,669 Y=30,880	41 35 20	76 53 25	114 64 45	61 44 20	83 52 30	75 49.6 28			
I-3-1	19	1 2	300 300	20 20	7 7	70 150	NR NR	String Weave	Excessive back bead build up														
I-3-2	19	1 2 3 4	340 340 340 340	20 20 20 20	7 7 7 7	70 230 320 350	NR NR NR NR	String Weave Weave Weave	OK	X		X		U=67,359 Y=32,800	56 44 15	61 45 25	52 43 15	46 43 30	78 47 40	58.6 44.4 25			
I-4-1	19	1	340	20	7	70	45° Lead	String	Rej.	Lack of fusion													
I-4-2	20	1 2 3 4 5	340 340 340 340 340	20 20 20 20 20	7 7 7 7 7	70 230 70 240 350	45° Lead 45° Lead 45° Lead 45° Lead 45° Lead	String Weave Weave Weave Weave	OK	X		X		U=67,514 Y=31,680	60 43 10	22.5 25 5	44 32 15	31 26 5	54 36 15	42.3 32.4 10			
I-5-1	19	1 2 3 4	340 340 340 340	20 20 20 20	7 7 7 7	70 160 250 350	45° Lead 45° Lead 45° Lead 45° Lead	String Weave Weave Weave	OK	X		X		U=66,622 Y=44,043	80.5 60 30	57 50 10	72.5 62 30	84 58 35	66.5 46 30	72.1 55.2 27			

WIRE TYPE E70T-G/NR203MHEAT B8B820POLARITY DCSP

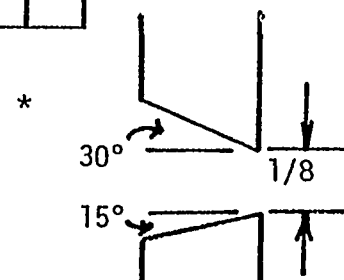
TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS			
										1		2	
										P	F	P	F
J-2-1	*	1 2 3 4 5 6	300 300 300 300 300 300	22 22 22 22 22 22	NR NR NR NR NR NR	70 135 200 280 150 210	40° Lead 20° Lead 20° Lead 20° Lead 20° Lead 20° Lead	String String String String String String	Rej.	Piping			
J-3-1	4	1 2 3 4 5 6	220 220 220 220 220 220	20 20 20 20 20 20	NR NR NR NR NR NR		40° Lead 20° Lead 20° Lead 20° Lead 20° Lead 20° Lead	String String String String String String	OK	X		X	
J-4-1	10	1 2 3 4 5	220 220 220 220 220	20 20 20 20 20	NR NR NR NR NR	70 95 210 240 300	50° Lead 5° Lead 5° Lead 5° Lead 5° Lead	String String String String String	Rej.	Approximately 11" chevron porosity and piping			



WIRE TYPE E70T-G/NR203MHEAT BB830POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS			
										1	1	1	1
										P	F	P	F
J-2-2	*	1	230	22		70		String		Gross porosity			
J-2-3	15	1	250	20		70	40° Lead	String	OK	X		X	
		2	250	20		150	20° Lead	String					
		3	250	20		200	20° Lead	String					
		4	250	20		325	20° Lead	String					
		5	250	20		350	20° Lead	String					
		6	250	20		300	20° Lead	String					
J-4-2	15	1	250	20	5.25	70	40° Lead	String	OK	X		X	
		2	250	20	15	110	20° Lead	String					
		3	250	20	13	230	20° Lead	String					
		4	250	20	17	250	20° Lead	String					
		5	250	20	15	300	20° Lead	String					
		6	250	20	12.5	350	20° Lead	String					
J-5-1	15	1	250	20	4.5	70	40° Lead	String	Rej.	Piping			
		2	250	20	15.5	250	20° Lead	String					
		3	250	20	6.52	300	20° Lead	String					
		4	250	20	12	200	20° Lead	String					
		5	250	20	13	275	20° Lead	String					
		6	250	20	11.5	350	20° Lead	String					
J-5-2	13	1			5.65	70	40° Lead	String	Rej.	Piping			
J-5-3	15	1	250	20	5.8	70	40° Lead	String	OK	X		X	
		2	250	20	13	70	20° Lead	String					
		3	250	20	9.5	200	20° Lead	String					
		4	250	20	11.5	300	20° Lead	String					
		5	250	20	17	350	20° Lead	String					
		6	250	20	10	350	20° Lead	String					

A-12



WIRE TYPE E70T-G/NR203MHEAT 622JPOLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	ROOT BENDS			
										1		1	
										P	F	P	F
K-2-1	30	1	240	19	4	70	45° Lead	Weave	OK	X		X	
		2	240	19	5	100	15° Trail	Weave					
		3	240	19	6.12	200		Weave					
K-3-1	2	1	240	19	4	70	45° Lead	Weave	Excessive burn through				
K-3-2	31	1	240	19	4.5	70	45° Lead	Weave	OK	X		X	
		2	240	19	6	230	15° Trail	Weave					
		3	240	19	3.5	130	15° Trail	Weave					
K-4-1	31	1	240	19	4	70	45° Lead	Weave	OK	X		X	
		2	240	19	5	100	15° Trail	Weave					
		3	240	19	4	240	15° Trail	Weave					

WIRE TYPE E70T-G/NR203MHEAT 622JPOLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH $\angle$	STRING/ WEAVE	RT	ROOT BENDS			
										1		2	
										P	F	P	F
K-5-1	32	1	240	19	4.5	70	45° Lead	Weave	OK	X		X	
		2	240	19	5	100	15° Trail	Weave					
		3	240	19	3.5	250	15° Trail	Weave					

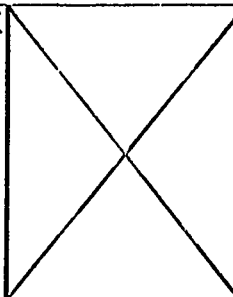
WIRE TYPE E70T-G/NR302HEAT EKCF721POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	
L-2-1	16	1	400	28	12	70	45° Lead	String	Rej.	Gross chevron porosity and piping
		2	400	28	9	135	15° Lead	String		
		3	400	28	8.5	200	15° Lead	Weave		

WIRE TYPE E70T-G/NR302HEAT EKCF721POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	RT	ROOT BENDS				CVN (20°F)						
										1		2		TENSILE	1	2	3	4	5	AVG
L-2-2	16	1	400	28	12	70	45° Lead	String	REJ.	Chevron porosity and piping.										
L-2-3	13	1	400	28	11.65	70	45° Lead	String	OK	X		X		U=71,866 Y=48,746	62	55	70	80	65.5	66.5
		2	400	28	12.72	70	15° Lead	String							52	52	59	64	56	56.6
		3	400	28	13.33	300	15° Lead	String							60	45	50	65	55	55
		4	400	28	13.33	350	15° Lead	String												
L-3-1	16	1	400	28	13	70	45° Lead	String	REJ.	Chevron porosity and piping in first half of plate.										
L-3-2	13	1	400	28	13.10	70	45° Lead	String	OK	X		X		U=71,332 Y=45,652	69	49	68.5	70.5	61.5	63.7
		2	400	28	12	70	15° Lead	String							62	47	61	58	55	56.6
		3	400	28	7.75	230	15° Lead	Weave							50	30	65	65	55	53
L-4-1	16	1	400	28	13.33	70	45° Lead	String	REJ.	Chevron porosity and piping.										
L-4-2	16	1	400	28	13.3	70	45° Lead	String	OK	X			X	U=70,518 Y=45,684	57	70	60	39	43.5	53.9
		2	400	28	9.5	70	15° Lead	String							44	55	49	37	38	44.6
		3	400	28	8.63	300	15° Lead	Weave							40	65	50	25	35	43
L-5-1	16	1	400	28	13.6	70	45° Lead	String	REJ.	Chevron porosity and piping.										
L-5-2	16	1	400	28	13.5	70	45° Lead	String	OK	X		X		BROKE IN WELD U=58,060 Y=48,770	69	84	66	87.5	67	74.7
		2	400	28	10	70	15° Lead	String							62	72	57	72	63	65.2
		3	400	28	7.25	330	15° Lead	Weave							60	70	50	75	50	61
R-2-1	21	1	400	28	9.3	70	15° Lead	String	OK				U=72,650 Y=50,997	38	64	59	70	65.5	59.3	
		2	400	28	8.16	250	15° Lead	Weave						40	56	50	57	55	51.6	
		3	400	28	10	350	15° Lead	String						40	50	40	50	60	48	
		4	400	28	10	350	15° Lead	String												

WIRE TYPE E 70T-G/NR203MHEAT BB830POLARITY DCSP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT		TENSILE	CVN (20°F)					AVG
												1	2	3	4	5	
R-1-1	3	1	250	20	10	70	15° Lead	String	OK		U=72,263 Y=46,715	65.5	73	73	92	78.5	76.4
		2	250	20	11.5	210	15° Lead	String				55	45	60	66	64	58
		3	250	20	10	260	15° Lead	String				60	45	65	75	70	63
		4	250	20	10	350	15° Lead	String									
		5	250	20	10.5	300	15° Lead	String									
		6	250	20	10	350	15° Lead	String									
		7	250	20	12	250	15° Lead	String									
		8	250	20	10	350	15° Lead	String									
		9	250	20	NR	350	15° Lead	String									

WIRE TYPE EM12K/LINDE-81HEAT 081205POLARITY DCRP

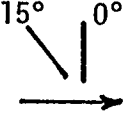
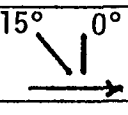
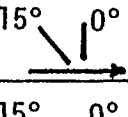
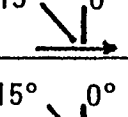
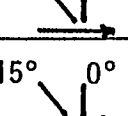
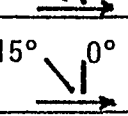
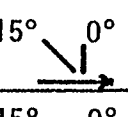
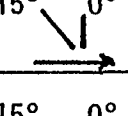
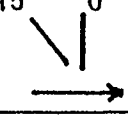
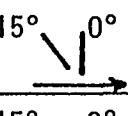
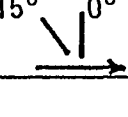
TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	ROOT BENDS			
										1		2	
										P	F	P	F
M-1-1	22	1	640	34	10	70	0°	String	OK	X		X	
		2	500	38	10	70	0°	String					
M-2-1	23	1	640	34	10	70	0°	String	OK	X		X	
		2	500	36	10	150	0°	String					
M-3-1	22	1	650	34	9.5	70	0°	String	OK	X		X	
		2	450	35	10	70	0°	String					

WIRE TYPE EM12K/LINDE-81 HEAT 081206POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	ROOT BENDS				TENSILE	CVN (20°F)					
										1		2			1	2	3	4	5	AVG
N-1-1	23	1	750	34	9.5	70	0°	String	OK	X		X		U=68,619 Y=45,077	20 21 5	22 23 5	26.5 28.5 5	24.5 28.5 5	21.5 24.5 5	22.9 25.1 5
N-2-2	23	1	750	34	9.5	70	0°	String	OK	X		X		BROKE IN WELD U=68,516 Y=45,076	20.5 21 5	25 26 5	19.5 21 5	23.5 24.5 5	29 30 5	23.5 24.5 5
N-3-1	23	1 2	750 640	34 38	9.5 10	70 140	0° 0°	String String	OK	X		X		U=68,486 Y=46,494	10.5 15 10	15.5 22 15	17.5 20 10	22 24 .5	19 25 10	16.9 21.2 12
S-1-1	24	1 2 3	750 750 750	38 38 38	10.5 10.5 10.5	70 150 220	0° 0° 0°	String String String	OK					U=66,950 Y=43,120	19 18.5 5	14 18 5	19.5 21.5 5	21 25 5	18.5 23 5	18.4 21.2 5

WIRE TYPE EM12K/LINDE-81HEAT 081168POLARITY DCRP

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	RT	ROOT BENDS					
										1		2			
										P	F	P	F		
0-1-1	27	1 2	820 800	34 40	11 15	70 200	0° 0°	String String	OK	X			X		
0-2-1	25	1	820	33	11	70	0°	String	Finning occurred beginning at 8" and continuing to 30" along length of weld						
0-2-2	28	1 2	820 760	33 40	11 15	70 190	0° 0°	String String	OK	X				X	0-2-2 root bend had one open defect greater than 1/8"
0-3-1	29	1	820	33	11	70	0°	String	Finning						
0-3-2	29	1 2	850 750	34 40	10.5 15	70 200	0° 0°	String String	OK	X			X		

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH 	STRING/ WEAVE	
P-1-1	25	1	750/ 600	32/ 40	13	70		String	Reentry angle too small (too sharp)
P-1-2	25	1	750/ 600	32/ 40	15	70		String	Reentry angle too small (too sharp)
P-1-3	25	1	750/ 600	32/ 39	11	70		String	Back bead very ropey and thick
P-1-4	23	1	750/ 600	32/ 40	15	70		String	Very high back bead
P-2-1	23	1	750/ 600	32/ 39	11	70		String	Excessive back bead reinforcement and ropey appearance. Reentry angle too small (too sharp).
P-2-2	23	1	750/ 600	32/ 39	13	70		String	Narrow back bead. Reentry angle too small (too sharp)
P-2-3	23	1	750/ 600	32/ 40	15	70		String	Finning
P-2-4	23	1	750/ 600	32/ 40	15	70		String	Reentry angle too small (too sharp). Finning
P-2-5	23	1	750/ 600	32/ 39	10	70		String	Finning
P-2-6	25	1	750/ 600	32/ 40	17	70		String	Narrow back bead and finning
		2	750/ 600	32/ 40	16	70		String	
P-3-1	23	1	750/ 600	32/ 38	18	70		String	Lack of back side penetration.
P-3-2	25	1	750/ 600	32/ 38	18	70		String	Finning

WIRE TYPE EM12K/LINDE-81HEAT 081206POLARITY DCRP (Lead)/AG (Trail) DC/AC

TEST NO.	JOINT	PASS	A	V	TS (IPM)	INT. (°F)	TORCH	STRING/ WEAVE	ROOT BENDS				TENSILE	CVN (20°F)					AVG.	
									RT	1		2		1	2	3	4	5		
P-3-3	25	1	830/ 600	32/ 38	15	70	15° 0° 	String	Finning											
P-3-4	25	1	750/ 600	32/ 39	15	70	15° 0° 	String	Excessive Back Bead Burn Up											
P-3-5	25	1	750/ 600	32/ 40	14	70	15° 0° 	String	OK	X		X		U=68,741 Y=45,643	13.2 26 5	21 28 5	16.5 16 5	21 24.5 5	17.5 20 7.5	17.9 22.9 5
T-1-1	26	1	740/ 620	33/ 40	25	70	15° 0° 	String	BROKE IN WELD U=68,393 Y=45,032											
		2	740/ 620	33/ 40	25	180		String												
		3	740/ 620	33/ 40	23	190		String												
		4	740/ 620	33/ 40	21	260		String												

GE
GENERAL RE
SHIP DESIGN IM
AUTOKON '71 . SHIP Pr
COMPUTER AIDS TO SHIP
SHIP DESIGN IMPROVEM
WELDING PROGRAM I
SURFACE PREPARATION A
SHIP DESIGN IM
COMPUTER AI
MATERIALS H1
WI