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Joining Technology and Quality Control

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ABSTRACT

Commercial shipbuilding in the United States is on the threshold of significant changes in fabrication techniques which will involve the erection of large section modules, 600 tons and heavier, with extensive use of automatic joining techniques. To support the large section module concept, the industry will make extensive use of production line techniques, such as flat panel lines and web lines to fabricate sub-assemblies. In this approach, we will only be simulating highly successful techniques as practiced in the modern Japanese and European shipyards. The key to the success of such an approach, as practiced by the Japanese and European shipyards, is for the shipbuilder to standardize ship designs coupled with multiple ship contracts to insure repetitive operations wherever possible. This will facilitate the development of special joining techniques and related equipment for use in the fabrication, sub-assembly and final erection stages.

INTRODUCTION

Inherent with the application of these automatic welding techniques, particularly those welded from one side, and the industry trend toward large ships will come an insistence by the regulatory agencies for more sampling inspection. The promulgation of the American Bureau of Shipping Ultrasonic Inspection Standard will enhance the universal acceptance of ultrasonics as a convenient, as well as meaningful, inspection tool by which this sampling inspection may be performed. There is no doubt that, with the advent of ultra-large ships and the concern for ecological considerations, pressure will build for more inspection locations. The need for an in-process quality control program becomes apparent when one considers the simple economics of the situation. Thus, the responsibility for establishing a viable in-process quality control program belongs to the shipbuilders, not the regulatory agencies whose historic function has been to establish minimum workmanship and inspection criteria, insure compliance with same and to invoke additional criteria as the situation warrants.

JOINING TECHNOLOGY

As part of the "emerging technology," most major shipbuilders are evaluating, or have actually incorporated mechanized panel and web lines employing either two-side or one-side butt welding techniques and utilizing the submerged-arc process with either single or multiple arcs. In this writer's opinion, one-side butt welding techniques will find more acceptance now that the required back-up flux has been developed under a research and development program initiated by the members of the Ship Production Committee of the Society of Naval Architects and Marine Engineers and financed largely by Maritime Administration funds through a cost sharing program with Bethlehem Steel Corporation.[1] This flux has shown promise in laboratory tests and final project acceptance tests. However, a word of caution is in order. Fabricators should be prepared for an initial weld reject rate of approximately 10-15%. The repairs, however, will generally be cosmetic in nature and be confined to the bottom surface of the weld. With experience and a mastery of the technique variations, this repair rate can be reduced to an acceptable level of 5% or less. Such a repair rate level was observed by this writer on a tour of several Japanese shipyards in 1973. In fact, the lowest repair rate observed was at the Ishikawajima-Harima Heavy Industries Kure Shipyard and was approximately 1%. Again, these defects were cosmetic in nature and readily observed by visual observation. Internal soundness was excellent.

There are definite technique variations commonly associated with one-side welding. First, submerged-arc welding

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[1] Project Report by Bethlehem Steel Corporation in cooperation with U. S. Maritime Administration, "One Side Welding - Flux Development - and Study of Multiple Arc Behavior".

in butts is normally accomplished using both single and multiple arc processes (multiple arc with Scott connection). Second, centerline cracking at the stop end of the butt is another common problem. This is normally eliminated by manually block welding approximately 12" - 18" (300mm-450mm) at the stop end of the joint. This is, of course, somewhat disruptive since the area which is manually welded must be backgouged to sound metal from the opposite side and completed manually. Third, cosmetic repairs and backgouged repairs must generally be made out-of-position since one of the major selling points of one-side welding in panel lines is elimination of the need for turnover cranes.

For both one-side and two-side welding in panel and web lines, good consistent fit-up is a prerequisite to successful welding in an automatic system. Root openings should range from 0" - 1/32" (0-1mm) for two-side welding and from 0" - 1/16" (0-2mm) for one-side. To facilitate such fit-up requirements, there is a definite need for research projects into new approaches and tools for shipfitters that will provide accuracy as well as productivity. Typical examples would be new methods to align joints, not only on panel lines but at erection, that would eliminate or minimize dogs, clamps, etc. which cause obstructions to automatic welding techniques; automatic tack welding techniques; temporary attachments that minimize welding, removal and scar repair costs; etc. I believe problems such as these will be addressed in the next generation of Ship Production Committee initiated projects.

Laser welding, another project initiated by the Ship Production Committee, under the technical direction of the Welding Panel SP-7, is a joining technique which has potential application to panel and web lines for both butts and fillets. This will probably be the initial area in which laser welding will be introduced into shipyards in its present state-of-the-art. There are adherent advantages in joint preparation, welding speed, and less degradation of heat-affected - zone properties associated with this process which make its application most attractive. The narrow weld and resultant heat-affected-zone would definitely improve the toughness properties for the high-strength steels and low-temperature steels used in commercial tanker programs. The laser welding would also have applicability on automatic beam welders and possibly flat panel work on Navy construction. In all considerations, work loads would have to be scheduled to provide volume since the units will be expensive and not readily portable. Also, application of laser welding to automated panel and web lines would facilitate proper shielding of the laser beam from a personnel safety aspect to insure that personnel do not inadvertently penetrate the beam. Laser welding equipment with a capacity of 12 KW was used to demonstrate ability to join ship steels in thicknesses ranging from 5/8" (16mm) to 1 1/8" (28mm). The 5/8" (16mm) thick plate was welded in one pass from one side; the 1 1/8" (28mm) thick plate was welded in two passes, one from each side. Stiffener tee welds can readily be made with the laser, producing satisfactory fillets in one pass with through penetration of the member. Additional applications of laser welding for shipboard use will depend on the ability to make the units more portable with a high KW capacity, lower cost and an effective means of shielding the beam to protect personnel working in adjacent areas from inadvertently penetrating the beam.

There will be extensive use of one-side welding techniques for erection and subassembly joints using back-up tapes similar to Kobe FAB-1, 3-M, and Kuder tapes. This technique has, in my opinion, the greatest potential for shipbuilding applications. At the present time, the Japanese limit the FAB-1 tape to the flat position or essentially downhand position. I envision the extension of these techniques to out-of-position welds (vertical, overhead and horizontal). Admittedly, we have not perfected the techniques to date that will permit welding from one-side, in all positions, with a uniform, positive reinforcement on the back side. However, the techniques perfected to date using back-up tape does facilitate depositing a sound weld which is suitable for welding from the back side without any backgouging, or at worst minimal backgouging. This, in itself, represents sizeable cost savings and increased productivity. Virtually all major shipbuilders are firmly committed to the use of back-up tapes for such welds. We must diligently pursue maximum utilization of this technique - forcing the state-of-the-art if need be, to promote U.S. development of satisfactory back-up tapes which can be installed easily with a minimum of attachments and which can be used in all positions. This is essential if U.S. shipyards are to develop a competitive position in shipbuilding. The use of back-up tapes is ideally suited for automatic welding techniques and has been used with the submerged-arc process with very good results. Out-of-position gas metal-arc processes have been used with back-up tapes with fair results. Much work remains to be done in this area and a project should be initiated under the auspices of the Ship Production Committee to develop the necessary back-up tapes. The potential cost savings to shipbuilders would be significant.

Electroslag and electrogas welds for vertical side shell butts is another area in which new fabrication techniques have made advances. Self-propelled crawler units have been developed[2] which are light weight and have doubled the travel speed over previous models. The increased travel speed has the added advantage of improving heat-affected-zone Charpy values. This facilitates the use of electroslag welding on grades of steel which previously had been considered unsuitable for welding using this process. A sub-contract has been initiated with the American Bureau of Shipping[3] to research the weld and base metal heat-affected-zone properties in an effort to establish a basis for relaxing some of the current limitations on the application of electrogas and electroslag welding processes. Toughness tests including CVN, dynamic tear (DT), drop weight (DWT) were conducted on base material, weld and heat affected zone (HAZ). Explosion bulge tests were conducted on the combined weldment. The results of these tests are summarized in Tables 1 and 2.

TABLE 1

ELECTROGAS AND ELECTROSLAG WELDMENT TEST RESULTS

	ABS GR. B (1" THK)				ABS GR. CS (1¼" THK)				ABS GR. EH 36 (1¼" THK)				ASTM A203,GR. A (1¼" THK)			
	CVN* @ 32°F (FT #)	DT @ 70°F (FT #)	DT @ 32°F (FT #)	DWT	CVN** @ -4°F (FT #)	DT @ 70°F (FT #)	DT @ -4°F (FT #)	DWT	CVN* @ -40°F (FT #)	DT @ 70°F (FT #)	DT @ -40°F (FT #)	DWT	CVN* @ -40°F (FT #)	DT @ 70°F (FT #)	DT @ -40°F (FT #)	DWT
Base Material	42	160	87	20°F	110	935	1000	-70°F	62	865	108	-90°F	95	1200	65	-100°F
Electro-Gas	8.3	27	5	20°F	33	160	37	-10°F	5.5	70	20	0°F	21	150	5	- 80°F
Electro-Slag	10	244	26	30°F	42	240	22	-40°F	7.0	55	7.0	-10°F	16	122	25	- 40°F

NOTES:

1. Values indicating significant degradation are underlined based on following criteria:

CVN - Any value 50% below the minimum expected value for the base material as shown

Grade B	20 FT - #@ 32°F
Grade CS	35 FT - #@ -4°F
Grade EH 36	20 FT - #@ -40°F

DT - Any value 50% below the determined base material value and below 250 FT-LBS

DWT - Any increase of NDT of more than 30°F above the base material

2. *Lowest average CVN values in the HAZ are indicated

**Average CVN values in the HAZ are indicated

It would appear from the results obtained that the maximum HAZ toughness degradation in electrogas and electroslag welds occurs at or within 3mm of the fusion line. The electroslag and electrogas processes are both satisfactory for Grade B steel but the electroslag process exhibited less HAZ toughness degradation as compared to electrogas welds. The significant differences between electroslag and electrogas welds were:

(a) electroslag welds used a beveled joint versus a square joint for electrogas

(b) electrogas welds employed a higher heat input

As tested, the electroslag and electrogas processes would be suitable or feasible for use on Grades A, B, CS, DS, D and E. Some modifications to joint design and/or heat input may be necessary in order to successfully qualify for some of the above-mentioned grades of steel. The electroslag and electrogas processes, as employed in the above-mentioned tests, are unsatisfactory for the higher strength steels. The results further substantiate the validity of requestioning HAZ toughness testing on electroslag and electrogas welds for special applications in important areas.

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[2] MarAd-SNAME Welding Project SP-1-3, "Vertical Erection Butt Welder."

[3] Project Report by Bethlehem Steel Corporation in Cooperation with U. S. Maritime Administration - "Toughness Evaluation of Electrogas and Electroslag Weldments" - March 1975.

TABLE 2

EXPLOSION BULGE TEST RESULTS

STEEL	WELDING METHOD	TEST TEMP. °F	SHOT NO.	% REDUCT. THICKNESS		DEPTH OF BULGE (IN.)		LONGEST CRACK (IN.)	REMARKS
				A	B	A	B		
ABS GR. B (1" THK)	Electro-Gas	120	1	4.2	3.8	2.3	2.2	-	No visible cracks
			2	9.3	10.3	3.4	3.4	-	No visible cracks
			3	-	-	-	-	7.5	Center area broke out, 7 cracks radiating from center area
		120	1	4.0	3.7	2.3	2.3	-	No visible cracks
			2	8.8	10.4	3.3	3.7		Plate separated along weld
	Electro-Slag	120	1	3.1	3.0	2.2	2.2	-	No visible cracks
			2	8.4	8.9	3.4	3.4	0.75	Crack on compression side (BM)
			3	15.8	19.6	4.3	4.5	4.5	Crack in BM on compression side penetrated to tension side near edge of die
		120	1	3.0	3.7	2.3	2.4	-	No visible cracks
			2	8.2	9.4	3.4	3.4	-	No visible cracks
			3	17.6	20.7	4.2	4.3	-	No visible cracks
ABS GR. CS (1¼" THK)	Electro-Gas	20	1	2.3	2.3	1.4	1.4	-	No visible cracks
			2	5.8	6.1	2.7	-	-	Plate separated along weld w/crack radiating from center area into BM 6.5 in. long
		20	1	4.2	5.2	1.8	1.7	-	No visible cracks
			2	9.4	8.8	2.8	2.8	-	No visible cracks
			3	-	-	-	-	13.2	Pc. broke out "B" side @ center Pc. almost broke out "A" side @ center. Separated along weld almost to edge both sides. BM cracks from center area 4.5 in. and 1.5 in. long.
		20	1	2.6	2.7	1.5	1.5	-	No visible cracks
			2	6.2	6.7	2.6	2.6	-	No visible cracks
			3	9.4	12.2	-	3.5	-	Plate separated along weld w/2 cracks radiating from center area into BM 4.5 in. and 5.4 in. long
	Electro-Slag	20	1	3.7	3.2	1.4	1.5	-	No visible cracks
			2	7.4	7.9	2.6	2.5	-	No visible cracks
			3	12.3	12.7	3.3	3.3	-	No visible cracks
		20	1	3.0	3.5	1.4	1.4	-	No visible cracks
			2	6.9	7.3	2.6	2.5	-	No visible cracks
			3	11.6	12.2	3.2	3.2	-	No visible cracks
ABS GR. EH 36 (1¼" THK)	Electro-Gas	0	1	0.78	0.63	1.8	1.7	-	Plate separated along weld on "B" side to near center across weld and along "A" side of weld to edge. Section of weld broke out. Crack into BM from weld 2 in. long.
		0	1	2.6	2.2	2.3	1.8	-	Plate separated along weld. Crack into BM from center area 3.2 in. long.
		0	1	3.5	3.0	1.3	1.3	-	No visible cracks
			2	6.5	6.7	2.3	2.3	-	No visible cracks
			3	9.3	9.1	2.9	2.9	-	No visible cracks
	Electro-Slag		1	3.2	3.6	1.3	1.3	-	No visible cracks
			2	6.4	7.2	2.3	2.3	-	No visible cracks
			3	-	10.2	-	-	5.5	Large PC. broke from center area. Separation along weld "A" side right of center from hole to 1.8 in. of left edge along the weld part of this distance. 5 cracks radiating from center area into BM with longest 5.5 in.

TABLE 2 (CONT.)

STEEL	WELDING METHOD	TEST TEMP. °F	SHOT NO.	% REDUCT. THICKNESS		DEPTH OF BULGE (IN.)		LONGEST CRACK (IN.)	REMARKS
				A	B	A	B		
	Electro-Slag	0	1	3.3	3.6	1.4	1.3	10	Plate separated along weld from right of center of left edge. Crack across the weld into BM 8 in. long 3 other cracks from center area into BM 3.2 to 3.5 in. long.
		0	1	2.9	2.7	1.5	1.5	-	Plate separated along weld with 2 small cracks into BM from weld
		0	1	1.4	1.1	2.0	1.7	-	Plate separated along weld
ASTM A203, GR. A (1½" THK)	Electro-Gas	0	1 2	2.8 5.0	3.1 5.2	1.6 1.6	2.7 -	- -	No visible cracks Plate separated along weld. Cracks radiating from center area into BM 3 in. and 6.8 in. long
		0	1 2	2.4 5.6	2.6 4.5	1.6 -	1.6 -	- -	No visible cracks Plate separated along weld from left to center on "A" side across weld into BM on "B" side 5.5 in. and back along weld to edge. Cracks radiating from center area in BM 2.8 to 9 in. long.
	Electro-Slag	0	1 2	2.6 4.8	2.6 5.8	1.7 -	1.7 -	- -	No visible cracks Plate separated along weld cracks radiating from center area into BM 5.2 in. long.
			1 2	2.6 4.7	2.6 4.9	1.7 3.4	1.7 2.9	- -	No visible cracks Plate separated along weld from edge to left of center on "B" side, across weld and along weld on "A" side to other edge. Crack "A" side along weld from center to left 2.8 in. then into BM 4.5 in. 3 cracks radiating into BM from center area 5.8 in. to 6.5 in. long.

NOTES:

1. Explosion bulge testing was conducted using standard procedures.
2. Stand-off distances were established for each thickness by determining the parameters which would produce approximately 3% thickness reduction on the 1st shot.
3. Based on the crack starter tests, the following test temperatures which are approximately 100°F above the material NDT (as determined by DWT) were selected for the explosion bulge test of the weldments:

GR. STEEL	NDT DROP WEIGHT	EXPLOSION BULGE TEST TEMP. (°F)
B	20	120
CS	-70	20
EH 36	-90	0
ASTM A203, GR. A	-100	0

4. Each specimen was subjected to three shots or separation, whichever occurred first.

The tests were exploratory and indicated some areas that are worthy of further consideration and investigative tests to develop the data and techniques necessary to extend the use of high heat input electroslag and electrogas processes in shipbuilding. An area that needs further evaluation is the effect on HAZ properties on lower heat input techniques. The arc travel speeds employed in the above mentioned tests were 1.5 ipm for electrogas and 2 ipm to 2.25 ipm for electroslag. Equipment is presently available which can attain arc travel speeds in the range of 4.0 ipm to 6.0 ipm on 1" thick material. Such travel speeds would significantly reduce the heat input and, it is felt, improve the HAZ toughness properties. Should the improvement be significant, tests could be conducted on the higher strength steels utilized in shipbuilding. Typical toughness test results for high arc travel speeds conducted on ordinary strength steels are shown in Table 3. The results are coded but reflect tests conducted by manufacturers and by shipyards using cored wires and gasless wires. This phase of the program could be further augumented by investigating variations in joint design. Another facet that needs further consideration is selection of other hull materials equivalent to the higher strength steels presently used in hull construction which would have better resistance to HAZ toughness degradation as the result of high heat inputs. Possible sources of such steel development could result from investigations currently being conducted by an Ad Hoc Committee of the SP-7 Panel on Welding which is investigating methods and steel development to improve HAZ toughness properties required to support the low temperature service associated with inner hull and related structure on LNG and LPG tankers.

Under the auspices of the MarAd SP-7 Panel on Welding,[4] equipment is being developed which will permit one-side welding across the bottom shell, around the bilge, and vertically up the shell in one continuous operation. Although the equipment has not been finalized, the preliminary results are promising and the panel has high hopes that the project will be satisfactorily consummated. The potential of such a piece of equipment is substantial for reduced cost in fabrication and erection. Again, it should be noted that with the utilization of automatic welding techniques, there is a corresponding increase in fit-up costs because such welding applications require much tighter fit-up tolerances than do manual processes. This is a penalty

TABLE 3

TYPICAL CVN TEST VALUES FOR HI-SPEED ELECTROGAS AND ELECTROSLAG WELDS MADE ON ORDINARY STRENGTH STEELS

CODE	WELD PROCESS	WELD WIRE	FLUX/ GAS	JOINT DESIGN	PLATE THK (IN.)	AMPS DCRP	VOLTS	TRAVEL SPEED (IPM)	CVN IMPACTS TEST RESULTS
(7)	ES	3/32" Linde MC-70	Linde 124	45° Vee	3/4"	600	44	6 - 6.5	
(7)	ES	3/32" Linde MC-70	Linde 124	45° Vee	1"	600	45	4.5 - 5	WELD RM 81 FT # 0°F 45 FT # -20°F 50 FT # -40°F 33 FT #
(8)	ES	3/32" Linde MC-70	Linde 124	45° Vee	3/4"	600	44	6	WELD -22°F 40 FT #
(9)	ES	3/32" Linde MC-70	Linde 124	40° Vee	1"	750-780	40	4 - 4.5	BM +14°F 162 FT # WELD +14°F 48 FT # HAZ FL +14°F 37 FT # 1MM +14°F 79 FT # 3MM +14°F 145 FT # 5MM +14°F 191 FT #
(8)	ES	3/32" Linde MC-70	Linde 124	45° Vee	1"	600	45	5	
(10)	EG	.120" Lincoln NR-431	NA	42° Vee	3/4"	750-800	46	5.4 - 7.5	WELD (a) -4°F 47 FT # (b) -4°F 40 FT #
(10)	EG	.120" Lincoln NR-431	NA	SQ.	3/4"	750-800	46	4.5 - 5.9	WELD -4°F 56 FT #

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[4] MarAd-SNAME Welding Project SP-1-3, "Vertical Erection Butt Welder".

that the shipbuilder can afford to bear since the use of automatic welding techniques will increase productivity above and beyond the costs incurred in fit-up. However, it does re-emphasize the need for research into fit-up practices.

Additionally, there is a newly developed gas metal-arc welding unit (GMAW) available to shipbuilders with a linear wire feeder[5] which will permit feeding of wire up to 200 feet away from the wire feeder and wire. The unit was developed by Hobart Brothers under a project sponsored by the MarAd SP-7 Panel on Welding. This equipment, as can readily be determined, provides a great deal of portability to the welder for both shipboard and shop applications. The power source, wire feed controls and wire can be positioned on the decks or along the walls of shops and the welder can operate over a wide area by virtue of the 200 foot cable. He has a light-weight, portable remote control station which allows the welder to adjust parameters according to welding position and type work being accomplished without having to return to his wire feeder. It also eliminates the need to drag a wire feeder around the ship or subassembly, a problem which greatly curtailed the use of such equipment in other than open work such as shops and platens.

QUALITY CONTROL

The establishment of a viable quality control program is, in the opinion of this writer, the responsibility of the contractor. The use of some of the aforementioned welding techniques imposes upon the shipbuilder the establishment of a quality control system. For example, the employment of electroslag/electrogas, one-side welding, two-side welding without backgouging, one-side welding on tapes, etc. has resulted in more extensive nondestructive testing (at the discretion of the American Bureau of Shipping Surveyor in most instances). Typical examples of areas in which American Bureau of Shipping Surveyors tend to require additional inspection are:

1. Stops and starts in electroslag, electrogas and consummable guide welds.
2. Checks for lack-of-penetration in submerged-arc welds deposited from both sides without back-gouging.
3. Additional checks, on a random basis, for those welds which are deposited using one-side welding on a back-up tape.

Historically, the regulatory agencies have felt that innovations such as those listed above require additional nondestructive testing to assure quality. Such a position, albeit well intentioned, is disruptive and cannot always be substantiated by facts.

The trend in nondestructive testing of hull structure is toward ultrasonic inspection in lieu of radiography. Ultrasonic inspection has the advantages of being less disruptive to production (i.e. it can be accomplished while other trades are working in the immediate area) and has no potential radiation hazard to personnel. The biggest disadvantage to ultrasonic inspection is lack of a permanent record such as a radiograph. Owner's representatives and regulatory personnel are definitely more "comfortable" when they have a radiograph to review; they become uncomfortable when presented a card showing inspection results and signed-off by an ultrasonic inspector and/or a supervisor.

The Ship Production Committee conceived a nondestructive test program to evaluate lower-cost alternatives to radiography.[6] In this report, several recommendations were made:

1. Ultrasonic shear-wave inspection is a viable alternative to radiography for hull-weld inspection and will provide same confidence level for weld quality.
2. Ultrasonic inspection is significantly less expensive to perform. For a 786 feet (238m) long tanker, cost reductions for using ultrasonic inspection ranged from $6,400-$19,000.
3. Relaxation of present American Bureau of Shipping provisional ultrasonic inspection criteria which results in about three times more inspection than with radiography.

The imposition of approximately three times more footage for ultrasonic inspection than is required for radiography cannot be technically justified. In this writer's opinion, this further

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[5] MarAd-SNAME Welding Project SP-1-2, "Extended Length Continuous Wire Feed Systems" - Final Report dated 5-31-74.

[6] National Shipbuilding Research Program, Project SP-1-11, "Nondestructive Testing" - Final Report dated August 1974.

substantiates the lack of confidence by the regulatory agencies and owners in not having a radiograph to review. It should be noted that the U. S. Navy permits direct substitution of ultrasonic inspection for radiography, without penalty, on naval surface ships, both combatant and noncombatant. The ultrasonic inspection requirements need to be reviewed by ABS to equate them in scope with radiography. Many proposals have been made to automate the ultrasonic inspection and produce a permanent print-out record which will take the accept/reject authority away from the ultrasonic inspector. This gives the regulatory agencies and owner's representatives the permanent record they desire. At the present time, such an approach is not too practical but it certainly is worthy of further consideration.

The very nature of automatic welding techniques with their high deposition rates and high travel speeds provides the opportunity for long lengths of continuous defects when welding parameters and practices are not strictly adhered to. Fortunately, this does not happen frequently but to preclude it from happening, shipbuilders are finding it necessary, from pure economics if nothing else, to develop an in-process quality inspection program. As a minimum, many shipbuilders, both foreign and domestic, ultrasonically inspect the ends of each butt in the panel lines as well as random locations along the length of the weld. This approach represents an effort to use inspection as an in-process quality control tool to save money and improve quality rather than as a punitive, after-the-fact inspection which frequently necessitates costly repairs at erection --for work accomplished during the fabrication and subassembly stages.

This writer envisions a greater use of ultrasonic inspection on foundry castings in lieu of radiography. Also, ultrasonic inspection is being used successfully to gauge plate and pipe wall thicknesses for effects of corrosion and erosion and to determine when such material should be replaced in service. This technique has been well received in the ship repair area.

The trend in nondestructive testing is to use the techniques available to the shipbuilder as a quality control tool, monitoring the work in-process, generating the data to make timely changes to processes to eliminate unacceptable work before extensive footage has been fabricated, and to assure an overall in-process quality that will effectively reduce the instances of repair at the final inspection locations where such repair becomes prohibitively expensive and disruptive and generally cannot be accomplished without erection of staging.

In-process quality control extends beyond nondestructive testing to the checking of those attributes which are essential to automated assembly techniques, i.e. flame cut surfaces, straightness of cut, joint fit-up, cutting neat prior to erection, etc. More and more shipbuilders are turning to this philosophy as the only means of satisfying the requirements of an automated system.

CONCLUSION

The Ship Production Committee in conjunction with the Maritime Administration and representatives of industry is developing projects that have resulted in worthwhile contributions to reducing costs and increasing productivity. The potential is there, but we must resist the temptation by codes, regulatory agencies and owners to erode the beneficial effects of some of these techniques, albeit under the premise of safety considerations, by imposing unnecessary and unjustified restrictions on application and inspection. In all fairness, many of these restrictions are imposed by the owners and the United States Coast Guard. A fact which is noteworthy only to the extent that such restrictions are frequently not imposed on foreign shipbuilders.

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Discussion

I. L. Stern, Visitor

The Joining Technology section of the subject paper presents an informative summary of the MARAD/SNAME welding programs. However, the Quality Control section contains references to American Bureau of Shipping (ABS) requirements for which clarification or correction appear in order.

In referring to ABS requirements for additional nondestructive inspection, at the Surveyor's discretion, of automated welds such as electroslag/electrogas, one-side welding and two-side welding without back gouging, the author states: "Such a position, albeit well intentioned, is disruptive and cannot always be substantiated by facts."

Unfortunately, justification for the Bureau's inspection requirements for the aforementioned automated welding processes has been thoroughly substantiated by service experience. Initial approvals of automated welding processes are usually based on procedure tests with relatively short plates under controlled conditions, which cannot take into account all factors in production. Under production conditions, with longer lengths of plates and a somewhat lesser control of conditions, additional complications of fit, straightness, distortion have, in some instances, resulted in weld unsoundness. The introduction of extensive lengths of unsound weld because of the above factors has been prevented by appropriate nondestructive testing, as required by the Bureau. The Bureau requirement is consistent with subsequent passages of the paper wherein the author advocates use of nondestructive testing as a quality control tool to monitor work in process to provide for timely changes before extensive footage of unsatisfactory welds has been fabricated. Provision to have the extent of nondestructive testing at the discretion of the Surveyor, provides a flexibility which permits reduction in the extent of nondestructive testing in those cases where consistent high quality work is produced, as well as an increase in extent when an unusually high frequency of weld unsoundness is observed.

The author refers to a report submitted to the Ship Production Committee (author reference 6) which recommended "relaxation of present American Bureau of Shipping provisional ultrasonic inspection criteria which results in three times more inspection than with radiography." The author indicates that he does not consider the Bureau requirement technically justified.

The Bureau requirement referred to which provided for a 50" check point length, was a tentative requirement, which had been imposed when ultrasonic inspection was first introduced into commercial shipyards. The current ABS ultrasonic requirement as stated in the ABS Publication "Rules for Nondestructive Inspection of Hull Welds" states, "Each check point is to consist of approximately 1250 mm (50 in.) of weld length; however, in cases where extensive production experience has indicated that a high proportion of check points (such as 90 to 95%) are free of unacceptable indications, consideration may be given to reducing the length of check points to 750 mm (30 in.). Lengths of welds inspected at subassembly stage and final erection stage (----) may be combined to form a single check point."

The MARAD report (reference 6 of the paper) considered a check point to be an 18" length equivalent to the length of a radiographic film commonly used for nondestructive inspection of a butt to seam weld intersection of an erection joint. The paper correctly advocates additional ultrasonic inspection of some lengths of subassembly stage panel line welds, in the interest of proper quality control. The Bureau's 30" to 50" length requirement for a check point is consistent with the additive lengths of the erection and subassembly panel line welds noted above, and is in accordance with general shipyard practice.

Author's Closure

Mr. Stern's comments are appreciated. This writer would like to take this opportunity to offer further discussion on the ABS requirements for nondestructive testing, vis-a-vis ultrasonic versus radiography, and to take exception to one of Mr. Stern's salient points.

First, Mr. Stern has missed the point of this writer's objection to the 1250 mm (50 inch) check point for ultrasonic inspection (whether it can subsequently be reduced to 750 mm (30 inches) is really of no consequence to this discussion). Imposing a 50-inch check point for ultrasonic inspection without a corresponding increase in the linear coverage required for radiographic inspection per location implies a lack of confidence in UT as an inspection tool. An implied fact which must be compensated for by the imposition of approximately three times more footage for ultrasonic inspection than is required for radiography. This, in the writer's opinion, can not be substantiated or justified by data. The argument offered by Mr. Stern that "justification for the Bureau's inspection requirements for the aforementioned automated welding processes has been thoroughly substantiated by service experience" is open to debate. This writer would concede that the electroslag/electrogas and consumable guide processes may be more susceptible to internal defects and probably should be subjected to more extensive inspection (stops/starts, etc.). However, except for the ends of the plates, production data from Japan, Europe and the United States does not support the contention that one-side submerged-arc welding and two-side submerged-arc welding without backgouging has inherent high risk for depositing defective welds. To the contrary, the results indicate the opposite. Reject rates have been exceptionally low. Two-side submerged-arc welding without backgouging has been a production method at Newport News Shipbuilding and Dry Dock Company since the late 1940's on commercial construction utilizing conventional submerged-arc welding carriages. In fact, Newport News has qualified procedures for two-side submerged-arc welding without backgouging on naval construction and has experienced excellent production results based on qualification imposed sampling inspection. The above data is offered under the premise that the shipbuilder is considered qualified and has developed the expertise required to control production. The ABS and the owner are amply protected under existing provisions of ABS Rules to wit "to the satisfaction of the Surveyor." One must not forget that the local Surveyor, on site, has the right, and always has had the right to insist upon additional inspection, up to and including 100%, as he deems necessary. This provision has worked well for radiography throughout the years and could work equally well for ultrasonic inspection - equal substitution of UT for RT, subject to the satisfaction of the Surveyor.

Next, this writer would like to address his comments to Mr. Stern's contention that the extra footage per location can be adequately taken care of via the random sampling proposed by this writer. First, a few comments on this writer's philosophy on in-process quality control. In-process quality control, properly exercised, can be a cost saving tool whose benefits accrue to both the shipbuilder and the owner. To be viable however, the program must not generate useless reams of records with the inherent overhead personnel required to maintain these records. (This is a real cost problem to the shipbuilder and should not be overlooked by those responsible for developing the rules and regulations. The cost of administering and maintaining a records oriented program can well exceed the cost of performing the actual inspection.) Rather, this writer believes that an in-process quality control program should generate negative records only, i.e., records to be generated only on those occasions where defective welds are detected. In this way, the system is not burdened with needless paper and defective welds, when they occur, are quickly brought to the attention of cognizant supervision so that corrective action can be expeditiously initiated.

Mr. Stern states that "length of welds inspected at subassembly stage and final erection stage (----) may be combined to form a single check point." This writer would like to again reiterate his position on in-process quality inspection. First, the contention by Mr. Stern that the "750 mm - 1250 mm (30" - 50") length requirement for a check point is consistent with the additive lengths of the erection and subassembly panel welds noted" is subject to debate. For example, a shipbuilder, because of his inherent knowledge of welding, would inspect the ends of butts welded by automatic welding processes (both one side and two side without backgouging). There are two paramount reasons for inspecting the ends of these butts. First, and foremost, there is a propensity for cracks at the stop-end and lack-of-penetration at the start-end of these butts and second, these ends will form an intersection at erection and be subject to inspection at this time. No one wants to make repair welds 90 feet up on the side shell when it could be repaired much easier at fabrication. This writer feels quite confident that these areas at the ends of butts, which are inspected at fabrication or subassembly as part of an in-process quality inspection program and which will subsequently be re-inspected as part of an intersection at erection, will not be permitted to be counted twice as part of the 1250 mm (50") location requirement. Thus, Mr. Stern's contention that "lenths of welds inspected at subassembly stage and final erection stage (----) may be combined to form a single check point" is not valid. The shipbuilder must still find additional areas to inspect at fabrication or subassembly to combine with minimum required footage to make up the required 1250 mm (50") location. Additionally, the shipbuilder must maintain a record system that will substantiate that he did, in fact, inspect additional locations equivalent to 1250 mm (50"). Traceability is the name of the game. Most shipbuilders will probably opt to inspect 1250 mm (50") per location at erection and simplify the record keeping and accountability problems and perform the sampling inspection to the extent deemed necessary at his own option.

This brings the writer back to his first position - there is no technical justification for requiring approximately three times more footage for ultrasonic inspection than is required for radiography. Either reduce the footage required for ultrasonic inspection or increase the footage required for radiography. Such an inconsistency can not be justified without conceding that UT is an inferior inspection tool. A contention that can not be substantiated by fact. It would be much better for all concerned to standardize the linear footage required per location irrespective of inspection technique (UT versus RT) and leave control of sampling in-process quality inspection to the shipbuilder and local Surveyor as deemed necessary by local conditions.