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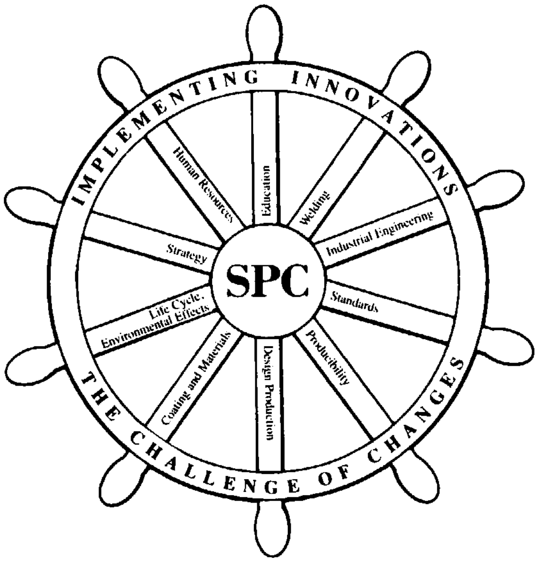

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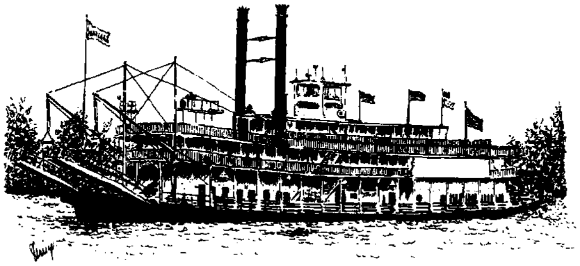

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Aluminum Steel Construction in a New 36M (120 Ft) Patrol Boat

No. 7C-1

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ABSTRACT

Construction of the U.S. Coast Guard Cutter Leopold, the lead ship of the 36 m (120 ft) Heritage Class, is discussed. A new Structural Critical Aluminum-Steel Transition (SCAST) product, Duratemp II" was selected for the welding transitions between the aluminum deck house and steel deck. The explosion bonded material's higher strength and toughness permitted use of lighter, narrower transition joints (1 cm (0.375") wide x 2 cm (0.75") thick) than are permissible with traditional materials. The unique heat resistance of the material permitted cutting and welding of the small section joints without overheating. The need for corner butt joints was reduced due to the product's reliable bendability. Welding procedures and Quality Assurance procedures are discussed in detail.

INTRODUCTION

The U.S. Coast Guard in conjunction with its ship repair facility in Curtis Bay, Baltimore, Maryland, was tasked with building the USCG Leopold WPB 1900, a 36 m (120 ft) "Heritage Class" patrol boat. The Leopold was to be used primarily as an offshore platform for the interdiction of drugs, search and rescue, and law enforcement. Lightweight construction and minimal maintenance were critical factors in design and selection of material of construction. Construction Ot the Leopold was placed on hold subsequent to the work discussed here.

DESIGN AND FABRICATION

The Leopold, due to its critical weight and high speed demands, required the use of light gauge 5086 aluminum for the pilot and deck-house structure. The aluminum was to be joined to the steel deck by using an explosive bonded transition joint material. A newly developed product, Duratemp II", was chosen over more traditional Aluminum/Steel transition joint materials due to its higher strength, superior fabricability, and proven corrosion resistance. This was the first shipboard installation to use this material.

The USCG, in cooperation with the manufacturer, chose a 1 cm (0.375") wide x 2 cm (0.75") thick transition joint for use in joining the pilot and deck-house to the steel deck. Fabrication of traditional Aluminum/Steel transition joint materials using bars of this small of a cross-section is generally considered unreliable. Traditional aluminum/steel transition joint products can be significantly degraded if the bond zone is heated above 260 degrees C (500 degrees F) during welding. Maintaining the transition joint bond zone below this temperature becomes increasingly difficult as the width and thickness are reduced. There are no nondestructive testing methods to verify that overheating, and resultant strength deterioration, have not occurred. The new transition joint material discussed in this paper employs additional interlayer metals which increase the maximum permissible welding temperature to over 540 degrees C (1,000 degrees F).

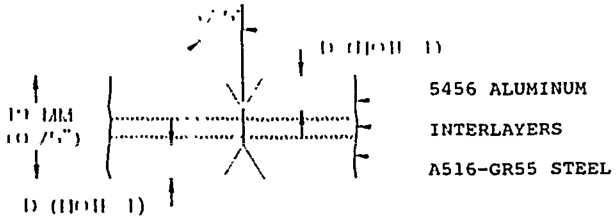
The new product was also used to join watertight aluminum deck panels to steel web frames and stiffeners in the armory space. This required the material to be formed in tight radii of 5 cm (2"). Traditional aluminum/steel materials cannot be bent in this manner without cracking and must be saw cut from plate to produce the desired contours.

JOINT DESIGN

The selection of a butt joint design that would minimize areas susceptible to corrosion was a concern for design and construction personnel. Due to the unpreventable formation of brittle intermetallics during full butt welding, aluminum/steel transition joint products are butt welded using partial penetration procedures. The effects of corrosion on dissimilar metals in a marine environment requires unwelded portions of the joint to be sealed tight by hand peening or the use of such products as silicone caulking or epoxy patching compound. Additionally, external surfaces should then be painted to seal areas not filled by peening or caulking. After evaluating various joint designs, the Coast Guard selected the joint design outlined in Figure 1. This design provided a structurally sound, repeatable, impact resistant and cost efficient butt weld.

PRE-SELECTION DESTRUCTIVE AND NONDESTRUCTIVE TESTING

Three aluminum to steel transition test plates were submitted to a commercial lab for destructive testing. ASTM A607 steel, 5 mm (0.188") thick, was welded to one side, and 5086 H116 aluminum, 3.2 mm (0.125") thick was welded to the other side using the Gas Metal "Short Arc" (GMAW) welding process in accordance with the requirements of



1. DEPTH OF WELD PREP. "D", SHOULD NOT EXCEED 6 MM (0.25")
2. AFTER WELDING ALUMINUM AND STEEL, PEEN LAND TO CLOSE ANY REMAINING GAP

FIGURE 1: Design of butt joints between ends of transition joint strips.

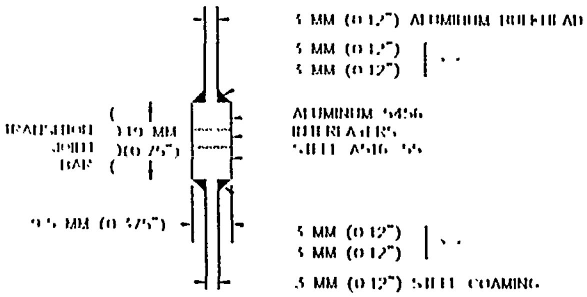


FIGURE 2: Design of welds between aluminum and steel plates using transition joint material.

Table I: Welded Tensile Tests Using Specimen Design Shown in Figure 2

Test I.D.	Dimensions mm (in)	Area mm-Sq (in-sq)	Failure Load kg (lb)	Ultimate Strength kg/cm-so (lb/in-sq)
Specimen #1				
Aluminum Web	3.0 x 13.4 (0.121 x 0.526)	40.2 (0.064)	1,218 (2,680)	3,030 (41,875)
Transition Joint	12.3 x 13.4 (0.484 x 0.526)	165 (0.256)	NO Failure	738 (10,469)*
Specimen #2				
Aluminum Web	3.1 x 8.7 (0.123 x 0.343)	27 (0.042)	927 (2.040)	3,430 (48,571)
Transition Joint	10.4 x 8.7 (0.410 x 0.343)	90.5 (0.140)	NO Failure	1,020 (14,571)*
Specimen #3				
Aluminum Web	3.1 x 13.6 (0.123 x 0.534)	42.2 (0.066)	1,255 (2,760)	2,970 (41,818)
Transition Joint	9.9 x 13.6 (0.389 x 0.534)	135 (0.209)	No Failure	930 (13,205)*

* Stress on bond zone at time of Aluminum failure.

Table I of MIL-STD 248C. Four macrotech specimens were evaluated showing no defects in the bond zone after welding. Three transverse tensile specimens were also evaluated. (Specimen design is shown in Figure 2, except width and length! per Table I.) All three tensile specimens broke in the aluminum base material outside the heat effected zone, thus proving the overall effectiveness of the joint. Values are given in Table I for each test; the aluminum data reflects the ultimate tensile strength of the aluminum only. The test data shows the maximum stress successfully sustained by the coupon before the aluminum failed.

Test butt welds were made using the design presented in Figure 1. Initial welds were made using aluminum alloy 5356 filler metal. Dye penetrant examination revealed cracking in the aluminum portion of the weld. A change to alloy 1100 filler metal eliminated this problem.

WELDING PROCEDURES

Welding the bulkhead panels to the transition joint was accomplished using Gas Metal Arc (GMAW) and Shield Metal Arc (SMAW) for the steel welds and Gas Tungsten Arc Welding (GTAW) for the aluminum. The welding parameters listed in Table II were conducted and qualified in accordance with MIL-STD 248C. The information provided does not reflect the entire welding procedure specification and is presented for information only.

Table II: Welding Procedures

Welding Procedure Specification for GMAW: ASTM A607 Grade 50 or A572 Grade 50 Steel

Base Material	Filler Material	Shielding Gas	Amps	Volts
1.5 - 15 mm (0.058 - 0.560")	E70S-6	100% Argon at 0.6-0.7CMH : (20-25CFH)	40-260	10-18

Note: The welding power source was constant voltage DC type-with the torch on reverse polarity (DCEP). Maximum weave was l cm (3/8") in width. Vertical welds were in the uphill progression. minimum preheat was maintained at 10 degrees C (50 degrees F). No postweld heat was specified. Gas cup size was between 6 and 16 mm (l/4" and 5/8").

Welding Procedure Specification for GTAW: 5086 H116 Aluminum

Base Material	Filler Metal	Shielding Gas	Amps	Volts
1.5 - 15 mm (0.058 -0.560")	AWS EWTH - 2 or EWZr	100% Argon at 0.56 CMH (11.3 CFH) or Higher	40-260	10-18

Note: The welding power source was constant voltage AC type with high frequency arc stabilization. Maximum weave was 1 cm (3/8") in width. Minimum preheat was maintained at 10 degrees C (50 degrees F). No postweld heat was specified. Can cup size was between 1 and 2.2 cm (3/8" and 7/8").

Welding Procedure Specification For SMAW: ASTM A607 Grade 50 or A572 Grade 50 Steel

Base Material	Filler Metal	AMPS	Volts
1.5 - 15 mm (0.058 - 0.560")	2.2 mm (3/32") E7018 or as per Table II MIL-STD 248C	65-100	18-22
	3.2 mm (1/8") Electrode	90-150	21-23
	4 mm (5/32") Electrode	110-230	21-25

Note: The welding power source was constant amperage DC type on reverse (DCEP) or straight polarity (DCEN). Maximum weave was three times the electrode diameter. Minimum preheat was maintained at 10 degrees C (50 degrees F). No postweld heat was specified. Gas cup size was between 1 and 2.2 cm (3/8" and 7/8").

INSTALLATION

The installation of the aluminum deck house and the armory space required over 150 m (500 ft) of transition joint material. Aluminum and steel attachment welds were made along the full length using the design in Figure 2 and the weld procedures in Table II. The construction included over 50 butt welds of the design shown in Figure 1. Figure 3 shows a section of the transition joint bar to which both aluminum bulkhead plates and steel combing have been tack welded in preparation for final welding. A butt weld between two transition joint bars can be seen near the left side of Figure 3. In Figure 4 the aluminum welding has been completed and the steel weld is being made. Figure 5 shows the welded sections of prebent transition joint bars in the armory space. Figure 6 shows a pad of the transition joint product which has been fillet welded on the vertical steel edges.

INSPECTION OF INSTALLATION

Nondestructive evaluation of the welded sections was conducted in accordance with MIL-STD 271, Nondestructive Testing Requirements for Metals and NAVSHIPS 0900-003-8000, Surface Inspection Acceptance Standards for Metals. The installation was dye penetrant inspected on both sides over 100% of the length. There was no evidence of bond separation over the complete length of the installation, including the armory space corners, and the fillet welded pads.

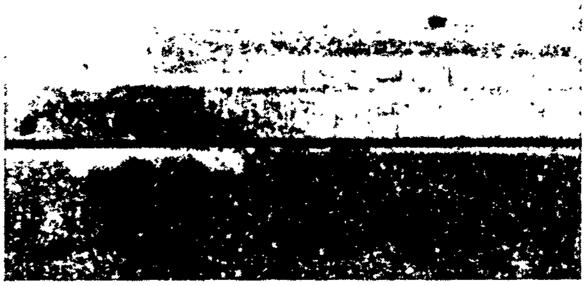


FIGURE 3: Transition joint strip tack welded to aluminum and steel plates fixtured for final welding. A butt joint between bars is located approximately 3 cm (1.2") from left edge of picture.

FIGURE 4: Welding steel combing to bottom of transition joint strip.

FIGURE 5: Corner weld in armory space. Transition joint is bent at 5 cm (2") radius.

FIGURE 6: Stanchion support transition joint steel fillet weld is made to vertical edge of pad.

TRANSITION JOINT MATERIAL EVALUATION

The transition joint material was manufactured in accordance with the requirements of MIL-J-24445A. The product used in the Leopold installation was manufactured as explosion bonded plates, then saw cut into 1 cm (3/8") wide x 3 m (10 ft) long strips. The job required materials from two plates 1.2 m *(48")* wide x 3 m (120") long. Both plates were fully tested for compliance with MIL-J-24445A, including all First Article Tests. First Article Test results are presented in Table III.

The new transition joint material was developed in response to requests by shipbuilders for a "fabrication friendly," higher strength aluminum/steel transition joint material. Extensive data on the development of the product and a comparison to properties of other transition joint materials were presented at the 1990 and 1991 SNAME Ship Production Symposiums [1,2].

The new transition joint material is an engineered product designed to provide superior performance while being highly resistent to deterioration during

Table III: Transition Joint Material Test Data IAW MIL-J-24445A, First Article Testing

Test	Type	Simulated Weld Cycle (Note 1)	Test Results (Note 2)
A.	*Ram Tensile Test*	As delivered	2,087 kg/cm-sq (29,680 lb/in sq)
		As delivered	2,134 kg/cm-sq (30,357 lb/in sq)
		315°C (600°F)	1,738 kg/cm-sq (24,719 lb/in sq)
		315°C (600°F)	1,833 kg/cm-sq (26,067 lb/in sq)
		538°C (1,000°F)	1,359 kg/cm-sq (19,326 lb/in sq)
		538°C (1,000°F)	1,359 kg/cm-sq (19,326 lb/in sq)
B.	shear *Strength Test (Note 3)*		
Bl.	*Aluminum/* Titanium *Bond*	As delivered	1,032 kg/cm-sq (14,682 lb/in sq)
		As delivered	989 kg/cm-sq (14,064 lb/in-eq)
		315°C (600°F)	871 kg/cm-sq (12,386 lb/in sq)
		315°c (600°F)	891 kg/cm-sq (12,676 lb/in sq)
		538°C (1,000°F)	895 kg/cm-sq (12,733 lb/in sq)
		538°C (1,000°F)	823 kg/cm-sq (11,702 lb/in sq)
B2.	Titanium/ *Copper-Nickel Bond*	As delivered	3,921 kg/cm-sq (55,749 lb/in sq)
		As delivered	3,982 kg/cm-sq (56,627 lb/in-sq)
		315°l.T (600°F)	4,007 kg/cm-sq (56,984 lb/in sq)
		315°c (600°F)	3,928 kg/cm-sq (55,866 lb/in sq)
		538°C (1,000°F)	3,926 kg/cm-sq (55,831 lb/in sq)
		538°C (1,000°F)	3,260 kg/cm-sq (56,355 lb/in sq)
B3.	*Copper-Nickel/ Steel Bond*	As delivered	3,252 kg/cm-sq (46,250 lb/in sq)
		As delivered	3,564 kg/cm-sq (50,680 lb/in-sq)
		315°c (600°F)	3,155 kg/cm-sq (44,864 lb/in sq)
		315°c (6OO°F)	3,654 kg/cm-sq (51,954 lb/in sq)
		538°C (1,000°F)	3,291 kg/cm-sq (46,794 lb/in sq)
		538°C (1,000°F)	3,348 kg/cm-sq (47,615 lb/in sq)
C.	*Side Bend Test*	As delivered	90° bend, no failure
		315°c (600°F)	90° bend, no failure
		538°C (1,000°F)	90° bend, no failure
D.	*Chisel Test*	As delivered	Acceptable
		315°c (600°F)	Acceptable
		538°C (1,000°F)	Acceptable
E.	*Fatigue Test*	As welded	Acceptable per specification

NOTES:

1) Specimens were heated to temperature indicated and held 15 minutes at that temperature.

2) Results are shown for two sets of specimens selected from diagonally opposite corners of plate.

3) Shear strength values are average of three tests each.

cutting, bending, and welding. The improved properties are achieved through the use of two interlayer materials between the aluminum and steel. A titanium interlayer adjacent to the aluminum eliminates problems of deterioration due to overheating during welding. A copper-nickel interlayer between the titanium and steel considerably improves fracture toughness and strength.

In comparison to traditional aluminum/steel transition joint materials, the new material exhibits:

over twice the tensile strength,
over twice the fracture toughness,
equivalent corrosion resistance, and
bendability at l/10 the radius.

With the older material, the bar widths are limited to 2 cm (0.75") minimum for reliable fabrication; as demonstrated at Curtis Bay, the new material can be reliably fabricated at 1 cm (0.375") width.

When using the old material, welding temperatures must be maintained below 260 degrees C (500 degrees F) during cutting and welding to avoid bond strength and toughness deterioration. As shown in Table III, the new product maintains properties after heating to 482 degrees C (900 degrees F). During welding the welder can concentrate on making a strong, sound weld, not on minimizing heat to the bimetallic transition joint.

CONCLUSION

The joining of the aluminum pilothouse and armory decking to the steel deck using the 1 cm (3/8") x 2 cm (3/4") transition joint bar has been successful. There were no indications of defects in material or workmanship indicated by nondestructive testing. The new transition joint material appears to be suitable for making structural shipboard welds between aluminum and steel using bars of half the width and half the weight of traditional transition joint materials.

REFERENCES

1. Ranker, J.G. and Gaines E-T., "Shipboard Aluminum/Steel Welded Transition Joints Evaluation and Improvements," 1990 Ship Production Symposium, Milwaukee, WI, sponsored by Society of Naval Architects and Marine Engineers.

2. Ranker, J.G. and Gaines E.T. "Shipboard Aluminum/Steel Welded Transition Joints," 1991 Ship Production Symposium, San Diego, CA, sponsored by Society of Naval Architects and Marine Engineers.

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