

Friction Stir Welding of DH-36 Steel

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Introduction

Recent developments in tool materials and design now make successful friction stir welding (FSW) of steel alloys possible (Refs. 1-3). FSW offers several possible advantages relative to arc welding for joining of steels. The lower apparent heat inputs of FSW are expected to minimize grain growth in the HAZ, and to limit distortion and residual stresses. Use of FSW also eliminates concerns over welding fumes, especially those containing Cr^{VI}, to allow compliance with anticipated changes in OSHA standards. Finally, problems with hydrogen cracking are eliminated since FSW is a solid-state process. The objective of this work is to determine the feasibility of FSW for joining DH-36 steel for shipbuilding applications.

Procedure

All welds were produced on the MTS Process Development System machine at the University of South Carolina using tools of W-25%Re with a shoulder diameter of $\frac{3}{4}$ inches. The tool and weld area were protected from oxidation by inert gas shielding. Tool wear and deformation were assessed by comparing tool dimensions before and after welding using an optical comparator. The welds were made parallel to the rolling direction on plates of DH-36 steel approximately 36 inches long, eight inches wide and ~ 0.18 inches thick in a square butt configuration (36" dimension parallel to the rolling direction). The tool was rotated at 400 rpm for all welds and travel speeds of either 8 or 10 ipm were employed. Axial force ranged from 3000 to 5000 lbf.

Subsequent to welding, samples for microstructural evaluation and for tensile testing were removed by water jet cutting. Transverse metallographic specimens were prepared using standard procedures, etched with 2% nital and examined using light optical microscopy (LOM). Vickers microhardness traverses were produced across the weld region at the plate mid-thickness using a 500 gram load and 15 second dwell time. The surfaces of the transverse tensile samples were ground to remove flashing and tested to failure at room temperature.

Results and Discussion

No measurable changes in tool dimensions were found after welding suggesting that no appreciable tool wear occurred. Examination of metallographic samples revealed several microstructurally distinct regions including the stir zone, heat-affected zone (HAZ) and base metal. Many of the welds contained small defects near the bottom of the stir zone resulting from incomplete bonding.

The base metal microstructure was composed of equiaxed grains of ferrite approximately 15 to 20 μm in size with pearlite colonies. The microstructure of the base metal also showed evidence of banding. The stir zone microstructure showed grains of polygonal ferrite about 5 μm in size. No regions of martensite were observed in the stir zone. The HAZ contained regions of partially-spheroidized pearlite (fuzzy pearlite) but no grain-coarsened or grain-refined regions. The banding extended from the base metal into the stir zone.

The microhardness of the stir zone averaged approximately 215 VHN, while that of the base metal was about 190 to 195 VHN. Consistent with the lack of martensite, no evidence of hardening was found in the microhardness results. Results of the tensile testing of selected welds are summarized in Table 1. The weld samples showed acceptable strain to failure with yield and tensile strengths exceeding those of the base metal. With the exception of weld 619-2b, all samples failed through the stir zone.

Conclusions

The FSWs on DH-36 showed acceptable tensile properties with no measurable tool wear. The lack-of-bonding defects found in the stir zone can be eliminated with proper tool design. Failure of the tensile samples through the stir zone resulted from the presence of these defects. FSW of DH-36 appears feasible, and further work is warranted.

Table 1: Weld Parameters and Results*

Weld #	TS	Z-load	0.2% YS	TS	ϵ_f	Comments
618-1b	8 ipm	3000 lbf.	68 ksi	81 ksi	8.6 %	Good weld
618-2a	8 ipm	4000 lbf.	57 ksi	65 ksi	4.5 %	Too hot
619-1a	8 ipm	4000 lbf.	63 ksi	71 ksi	8.0 %	Too hot
619-2a	10 ipm	4500 lbf.	64 ksi	73 ksi	3.6 %	Too cold
619-2b	10 ipm	4500 lbf.	65 ksi	78 ksi	7.0 %	Good weld
619-3a	10 ipm	4800 lbf.	62 ksi	68 ksi	2.6 %	Too hot
619-3b	10 ipm	4800 lbf.	66 ksi	78 ksi	6.6 %	Too hot

*All welds made at 400 rpm

References

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