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Structural integrity of copper–nickel to steel using metal inert gas welding

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Metal inert gas (MIG) welding may be used as a technique to attach copper–nickel panels to steel substrates to minimize the corrosion and biofouling of offshore structures and ship hulls. A series of plug welds must be located on each panel in order to eliminate bowing when the panels are subjected to compressive loadings. Laboratory tests on MIG plug-welded specimens have shown that the fatigue life of the plug welds is the same as the fatigue life of the copper–nickel cladding without the plug welds. The possible increase in fatigue life attributed to the lack of bowing of the sheets is offset by the stress concentration created by the weld. SEM examination of the failed weld site showed that fracture was predominantly intergranular in the regions adjacent to the weld, while regions remote from the weld exhibited fatigue striations.

1. Introduction

The increasing need to minimize the use of high-priced energy has forced the shipbuilding industry to explore more efficient forms of design and construction to minimize fuel consumption. Practically all ships that are in use employ painting schemes to provide protection against corrosion and biofouling. However, this type of protection is short-lived and requires frequent maintenance during the operating life of the ship. The maritime industry is therefore exploring the possibility of either sheathing or cladding ships with copper alloys to provide the required protection without the necessity for frequent maintenance.

Copper–nickel alloys possess excellent corrosion resistance in sea water and the constant low-level discharge of copper ions provides protection against biofouling. The copper-clad ship hull thus remains slick during service and surface induced drag is minimized. Therefore, fuel or energy efficiency is maximized and the need to drydock for surface cleaning is reduced, resulting in lower maintenance and service costs.

Research is currently being conducted at Virginia Polytechnic Institute to determine the exact techniques which can be used for sheathing copper–nickel plates to existing steel components. While sheathing can be used on existing ships, cladding is possible only in new ship construction. Welding is one of the attachment techniques under evaluation, and several different weld procedures including submerged metal arc (SMA) and metal inert gas (MIG) are being evaluated.

Weld character and metallurgical considerations are important in determining the weld integrity, particularly in copper–nickel to steel welds where two dissimilar metals are joined. This paper describes the metallurgical and fatigue behaviour of MIG attachment welds.

2. Materials and methods

The copper–nickel used in this programme was 2.5 mm (0.098 in.) thick and of the 90/10 (CA 706) type, while the steel was 11.1 mm (0.437 in.) thick ABS Grade B type. A typical configuration of the specimen is shown in Fig. 1 The welding electrode used was a 0.096 in. (2.4 mm) Monel 190 (AWS A 5.11 Class E, ENiCu-2) and the welding was done under DCRP

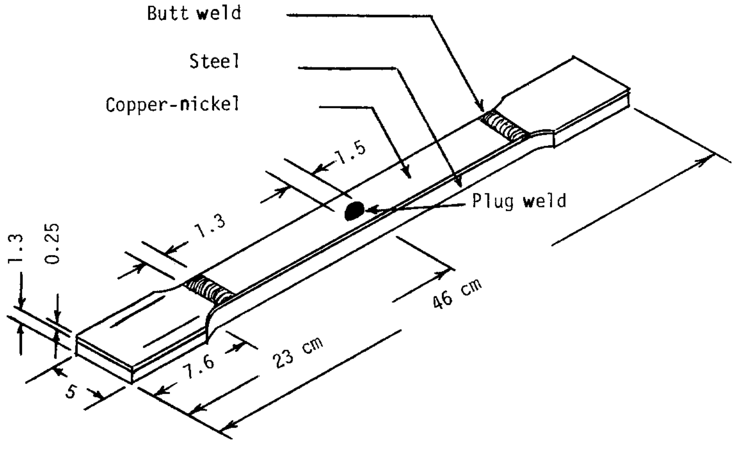

Figure 1 Tension–compression ($R = -1$) test specimen.

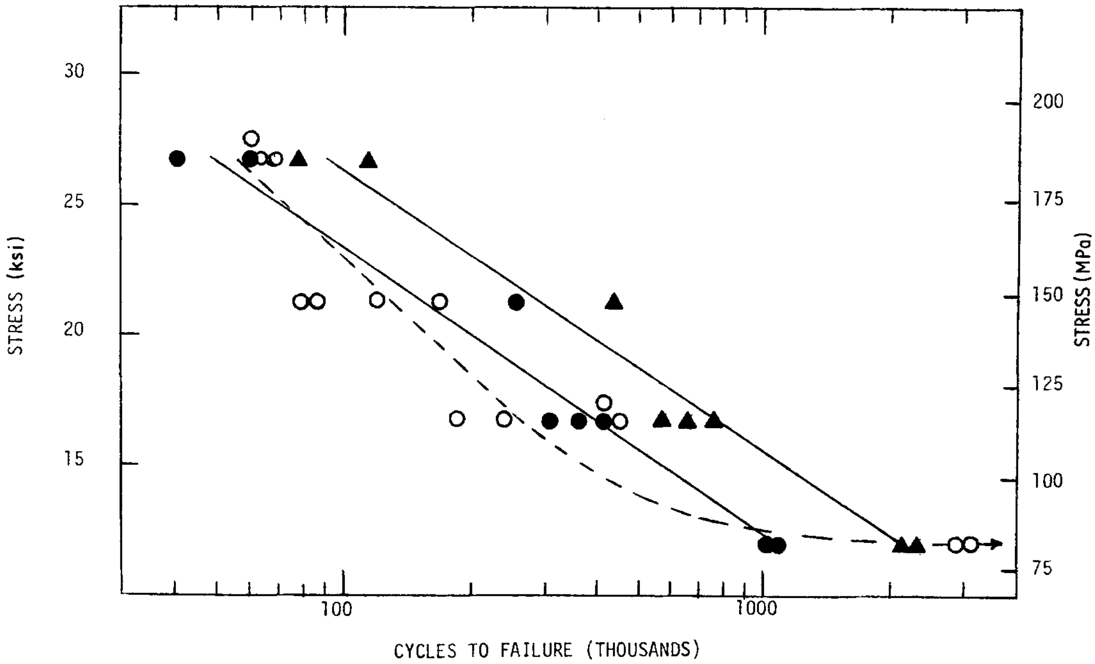

Figure 2 Tension–compression fatigue data for copper–nickel/steel welded specimens: (●) copper–nickel, (▲) steel, (○) copper–nickel without plug weld.

conditions in the current range 80 to 125 A. In some specimens the copper–nickel plates were welded at the ends using SMA welding techniques, and served as a reference set for comparison with the slightly different weld configuration of the MIG welded specimens. The MIG plug welds were at the centre of the specimen, which minimized the bowing of the copper–nickel during compressive loads.

All specimens were fatigue-tested in an MTS servohydraulic testing machine (MTS Manufacturing Co, Minneapolis, Minnesota, USA) at a frequency of 3 Hz and a stress ratio of $R = -1$. The specimens were tested at stress levels of 40, 57, 71 and 89 kN. Each specimen was cycled until complete failure occurred. The failures progressed in a stepwise fashion, first in the copper–nickel and then in the steel. Strain gauges were placed at four different locations on the sample (Fig. 1) and the change in plastic strain was maintained with time.

3. Metallurgical weld characterization

The relation of the metallurgical structure to the mechanical behaviour of the copper–nickel/steel weldments is essential to the prediction of in-service performance and/or provision of a data base for weld selection and optimization.

The base steel used in this investigation showed a banded ferrite–pearlite microstructure which is typical of carbon–manganese plate steel (ABS Grade B). The copper–nickel exhibited a recrystallized (annealed) structure. The microstructure of the weld was categorized into five basic regions: (i) base steel, (ii) base copper–nickel, (iii) weld metal (Monel 190), (iv) steel heat affected zone (HAZ), (v) copper–nickel HAZ.

4. Results and discussion

The results of the tension–compression fatigue tests are illustrated in Fig. 2. A statistical analysis of variance indicated that there was no significant ($P < 0.05$) difference between the fatigue tests conducted on the specimens with and without plug welds. The possible increase in fatigue life of the plug-welded

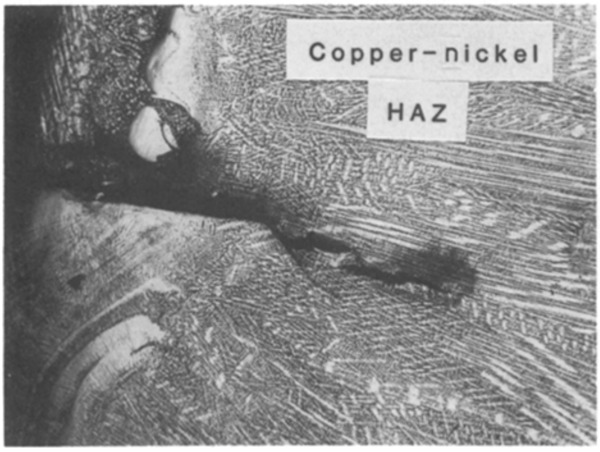

Figure 3 Crack initiation at the monel–copper interface × 50.

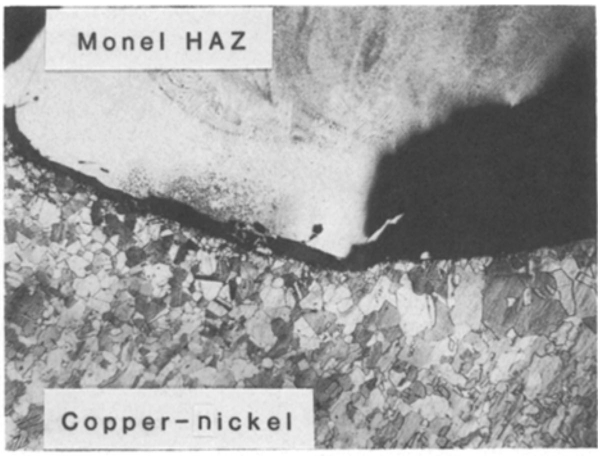

Figure 4 Secondary cracking caused by lack of side-wall fusion at the plug weld × 25.

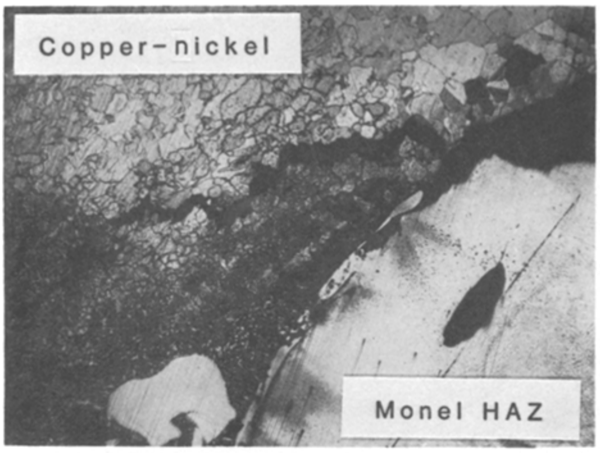

Figure 5 Multiple cracks running into the copper–nickel heat affected zone × 25.

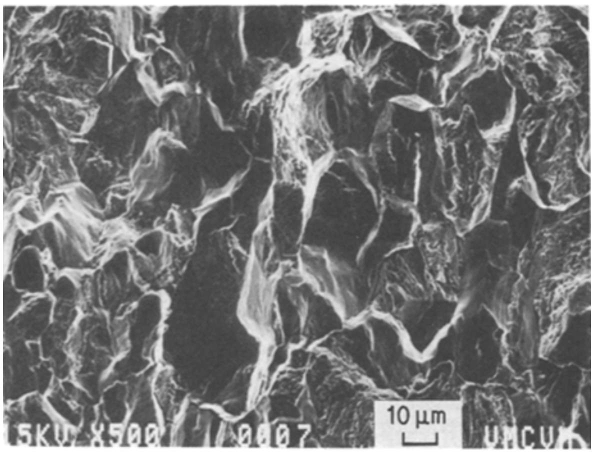

Figure 6 Intergranular fracture in the regions adjacent to the weld.

structure attributed to the lack of bowing of the copper–nickel sheets during fatigue cycling is offset by the stress concentration created by the weld.

The primary initiation site for failure was at the plug welds. This was due to the stress concentration adjacent to the weld, resulting in a maximum amount of plastic deformation in that region. This observation is consistent with the increased strains observed in this region by the strain-gauge measurements.

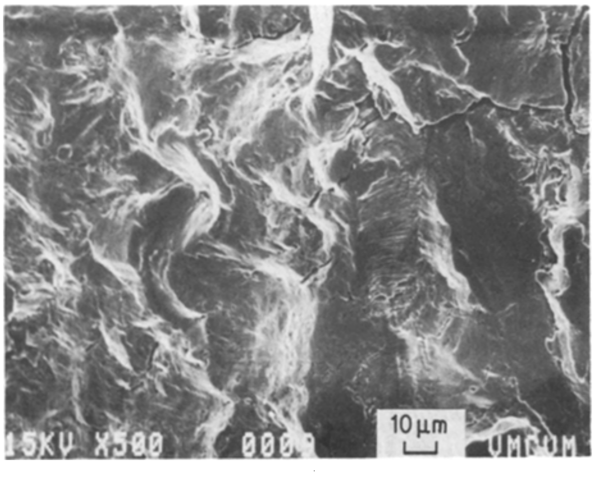

Figure 7 Failure showing fatigue striations remote from the weld.

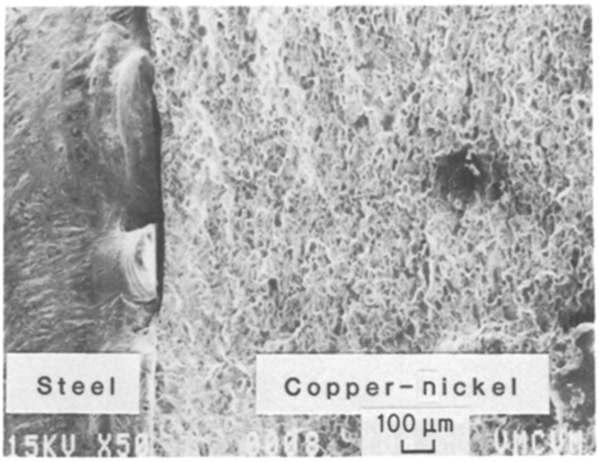

Figure 8 Steel failure adjacent to the MIG weld.

Microstructural examination showed that the fracture was initiated at the monel–copper interface along the inner periphery of the weld, and first propagated into the copper–nickel (Fig. 3). In some cases, the lack of side-wall fusion of the plug welds (Fig. 4) served as secondary sites for cracking, but did not significantly contribute to lowered fatigue lives. In other cases, multiple cracks were observed running into the heat-affected zone of the copper-nickel at different locations at the periphery of the plug weld (Fig. 5).

SEM examination of the failed weld site showed that fracture was predominantly intergranular in the regions adjacent to the weld (Fig. 6), while regions remote from the weld exhibited fatigue striations (Fig. 7). Once the crack reached a sufficient length in the copper–nickel the MIG plug weld was sheared. The copper–nickel sheet now bowed during compressive loading and testing was continued in order to assess the effects of the weld on the steel. The steel failure occurred predominantly in regions adjacent to the MIG weld, as shown in Fig. 8. This was consistent with earlier observations on similar composite structures using SMA welds [1, 2].

5. Conclusions

The results of this investigation have shown that:

1. The stress concentration created by the welds results in areas immediately adjacent to the welds that serve as failure initiation sites, thus localizing the fracture process.
2. Lack of side-wall fusion in the MIG plug welds did not significantly influence this overall structural integrity of the clad component.

Acknowledgement

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