

# Technical Note: Martensite Formation in Austenitic/Ferritic Dissimilar Alloy Welds

*The reduced martensite layer thickness observed in welds prepared with Ni-based filler metals can be attributed to differences in concentration gradients in the partially mixed zone*

BY J. N. DuPONT AND C. S. KUSKO

**ABSTRACT.** Electron microprobe analysis was utilized to examine the gradient of alloying elements across the weld interface of austenitic/ferritic dissimilar alloy welds. The concentration gradients were converted to martensite start (Ms) temperature gradients and used to explain the differences in martensite layer widths that have been observed in the partially mixed zone (PMZ) of dissimilar welds.

## Introduction

Ferritic-to-austenitic dissimilar metal welds are used in a variety of industries including power generation, petrochemical, pulp, and paper. The presence of martensite adjacent to the weld interface of such welds has been well documented in literature (Refs. 1–3). The martensite layer is located within the partially mixed zone (PMZ) of the weld where the composition varies continuously from that of the ferritic steel to that of the weld metal. The PMZ forms due to incomplete liquid state mixing near the fusion line. The formation of martensite within the PMZ occurs due to the formation of intermediate compositions with high hardenability that form martensite upon rapid cooling from the weld thermal cycle. The formation of this martensitic region leads to steep microstructural and mechanical property gradients across the weld interface and is partially responsible for premature failure of dissimilar welds at elevated temperatures (Refs. 2, 3).

Nickel-based filler metals are often used to prolong the life of austenitic-to-ferritic dissimilar welds. The use of nickel-based filler metals produces a thinner martensite layer compared to stainless steel filler metals (Ref. 3), but the reason for this has not been investigated in detail. In this paper it is demonstrated that the re-

duced martensite layer thickness observed in welds prepared with Ni-based filler metals can be attributed to differences in concentration gradients in the PMZ.

## Experimental Procedure

IN625 and 309L stainless steel were deposited onto A285 carbon steel using the electroslag welding process. The compositions of these materials are provided in Table 1. The dimensions of the carbon steel substrate were 61 × 15 × 4 cm. The electrode size was 30 × 0.5 mm. Sandvik commercial welding flux 59s was utilized during deposition. The strip electrode was deposited continuously along the top edge of the substrate to cover the entire length of the substrate at 565 A, 24 V, and 3.0 mm/s travel speed. (This unique sample configuration was used for convenient extraction of fatigue samples as part of a larger research program.) Sample cross sections were polished using standard metallographic techniques then etched electrolytically using a 90 mL methanol/5 g FeCl<sub>3</sub>/4 mL HCl solution. Electron probe microanalysis (EPMA) was performed using a JEOL 733 probe at an accelerating voltage of 15 kV and a beam current of 20 nA. Raw data were reduced to weight percentages using a ZAF algorithm (Ref. 5). The width of the martensite layer adjacent to the weld interface was measured using photomicrographs and an operator interactive digitizing pad.

## Results and Discussion

Figure 1 shows light optical photomicrographs of the martensite layer observed in the welds deposited using 309L (Fig. 1A) and 625 (Fig. 1B) filler metals. The black vertical line in each photomicrograph represents the locations of EPMA traces. The variation in martensite layer widths is readily evident from these figures. Random measurements of the martensite layer thickness acquired along the weld interface of each weld in the region where the EPMA trace was acquired indicated that the martensite layer in the 309L weld was 30–37 μm in thickness, while that in the IN625 weld was 1–3 μm in thickness. The variation in major alloying elements (Fe, Ni, and Cr) across the weld interfaces of the welds is shown in Fig. 2. Due to the variation in nominal composition between the substrate and the cladding, a composition gradient exists within the PMZ. The gradient is steeper for the weld prepared with IN625 filler metal because of the increase in nominal Ni content and decrease in nominal Fe content compared to the weld prepared with 309L stainless steel.

As discussed in more detail below, the composition gradients produce a variation in the martensite start (Ms) temperature across the weld interface, and the differences in composition gradients and resultant Ms gradients between the two welds can be used to explain the observed variation in martensite widths. In view of this, it is useful to know the gradient of all elements across the weld interface that significantly affect the Ms temperature, which for the current alloy systems include C, Mn, Ni, Cr, and Mo (Ref. 6). Although Fe, Ni, Cr, and Mo were directly measured during the EPMA analysis, no attempt was made to measure C and Mn because of the low concentration (Mn) and light element character (C). However, the concentration gradient of these elements can be estimated by using the EPMA data of the major alloying elements to determine the variation in dilu-

## KEYWORDS

Welding  
Electron Probe Microanalysis (EPMA)  
Dissimilar Welds  
Martensite  
Partially Mixed Zone (PMZ)

J. N. DuPONT (jnd1@lehigh.edu) and C. S. KUSKO are with the Department of Materials Science and Engineering, Lehigh University, Bethlehem, Pa.

# WELDING RESEARCH

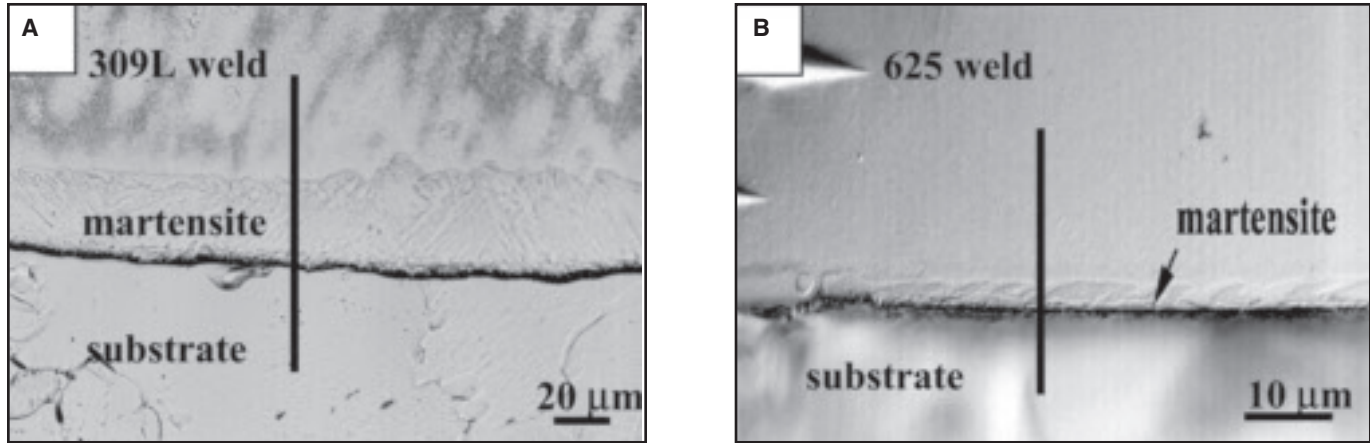


Fig. 1 — Light optical photomicrographs of the martensite layer observed in the welds deposited using 309L (A), and 625 (B) filler metals.

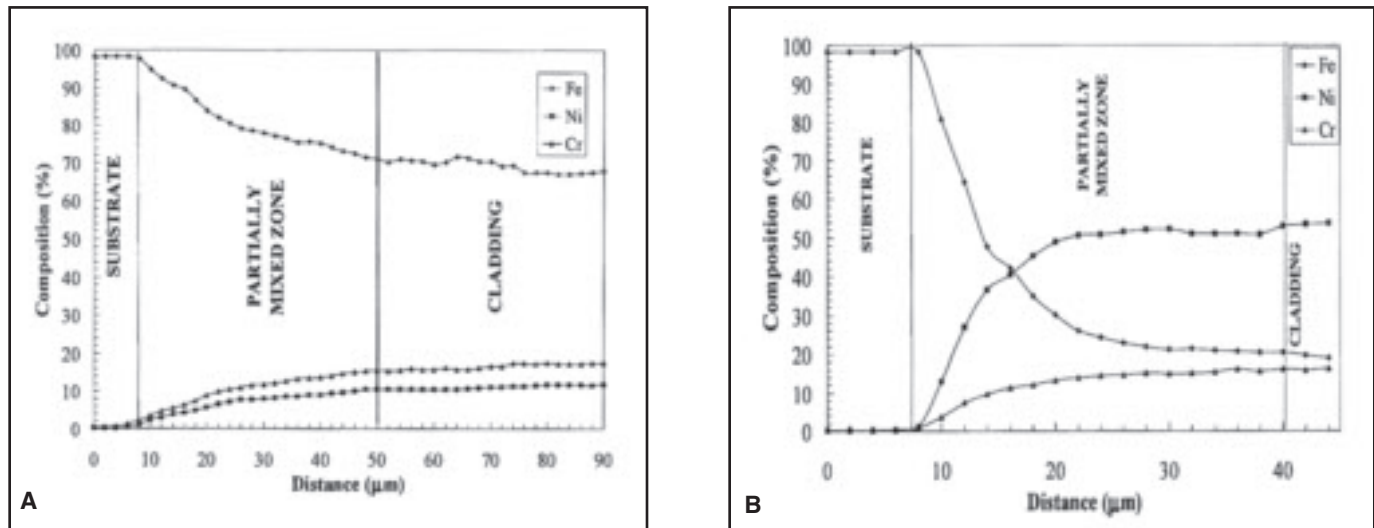


Fig. 2 — The EPMA measurements acquired across the PMZ for A) 309L stainless steel/A285 carbon steel, and B) IN625/A285 carbon steel dissimilar alloy welds.

tion within the PMZ. Once the variation in dilution within the PMZ is known, together with the nominal concentrations of alloying elements of the base metal and filler metal, the C and Mn concentrations can be estimated by back-calculation. The assumption with this approach is that C and Mn will be mixed in the liquid state to the same level within the PMZ as the major alloying elements.

Using the available microprobe data, the variation in dilution within the PMZ zone was determined by

$$D = \frac{C_{pmz} - C_{fm}}{C_{bm} - C_{fn}} \quad (1)$$

where D represents the dilution,  $C_{pmz}$  represents the concentration of any element within the partially mixed zone,  $C_{fm}$  is the nominal concentration of any element in the filler metal, and  $C_{bm}$  is the concentration of any element in the base metal. The  $C_{fm}$  and  $C_{bm}$  values for Fe, Ni, Cr, and Mo were determined by wet chemical analysis (Table 1), while the  $C_{pmz}$  values for the same elements were determined by EPMA — Fig. 2. Using each of these measurements, the dilution was determined for each position in the PMZ. Figure 3 shows an example of this for the weld prepared with 309L stainless steel filler metal, where the dilution values for Fe, Ni, and Cr were determined. Once the dilution is known, the corresponding C and Mn concentrations in the PMZ ( $C_{pmz}$ ) can be estimated by

Table 1 — Nominal Compositions of Substrate and Strip Electrodes Measured by Wet Chemical Analysis. (All values listed in weight percent.)

Material	Fe	Ni	Cr	Mo	Nb	Si	C	P	S	Mn
A285	Bal.	—	—	—	—	0.21	0.06	0.01	0.028	0.81
309L	Bal.	12.62	23.44	—	—	0.40	0.013	0.013	0.002	0.01
625	3.79	Bal.	21.01	8.72	3.51	0.13	0.01	0.009	0.002	0.01

# WELDING RESEARCH

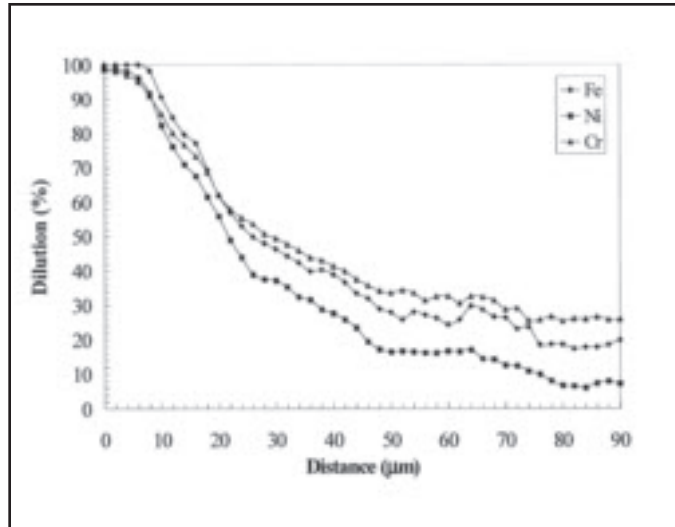


Fig. 3 — Variation in dilution of Fe, Ni, and Cr across PMZ of 309L stainless steel/A285 carbon steel weld.

$$C_{pmz} = DC_{bm} + (1 - D)C_{fm} \quad (2)$$

Gooch (Ref. 6) developed a Ms equation for martensitic stainless steels that have compositions similar to the martensite layer:

$$Ms(^{\circ}C) = 540 - (497\%C + 6.3\%Mn + 36.3\%Ni + 10.8\%Cr + 46.6\%Mo) \quad (3)$$

Using the measured values for Ni, Cr, and Mo along with the estimated values of C and Mn, the variation in Ms temperature across the PMZ was estimated with Equation 3. Figure 4 shows the results. The two curves on each plot represent the highest and lowest possible Ms temperature based on the range in dilution that was determined previously — Fig. 3.

The martensite layer within the PMZ should begin near the start of the composition gradient adjacent to the carbon steel base metal and end at a location where the Ms temperature intersects room temperature. The exact starting and end locations cannot be known with a high degree of certainty since this will depend on the local hardenability (as determined by local composition) and local cooling rate. However, comparison of the Ms gradient plots in Fig. 4 clearly shows that a thinner martensite layer is expected in welds prepared with Ni-based filler metals. This can be attributed to the higher concentration gradient within

the PMZ (due to higher Ni concentration) that, in turn, stabilizes the austenite at a shorter location within the PMZ. According to Fig. 4, the martensite layer thickness should be approximately 35–39 µm for the weld prepared with 309L filler metal and approximately 2–3 µm in the weld prepared with the IN625 filler metal. These values represent the distance between the start of concentration gradient near the ferritic steel side and the point where the Ms crosses room temperature. The start of the concentration gradient is chosen because it represents the beginning of the PMZ (i.e., on the ferritic steel side), while the point where the Ms crosses room temperature is chosen because it represents the location where martensite should no longer form with the PMZ (i.e., martensite will stop forming at the location where the Ms drops below room temperature). These values (~ 35–39 µm for the weld prepared with 309L and ~ 2–3 µm in the weld prepared with the IN625) compare reasonably well with those measured at the location of the microprobe trace for each weld in Fig. 1, ~34 µm for 309L and ~3 µm for IN625.

It should be noted that the exact width of the martensite layer can vary within a given weld due to local variations in the

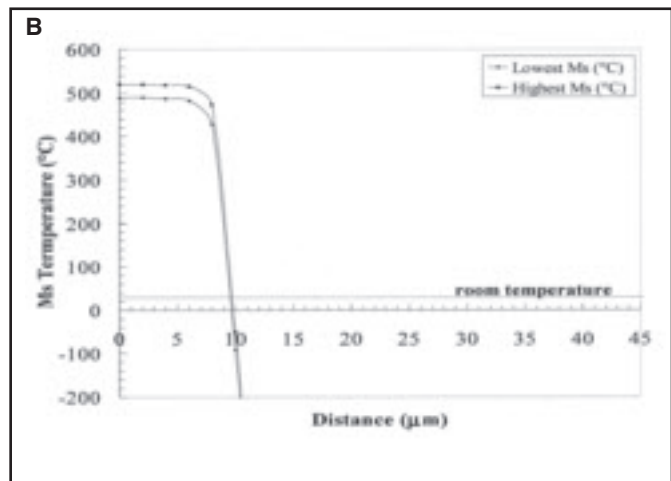
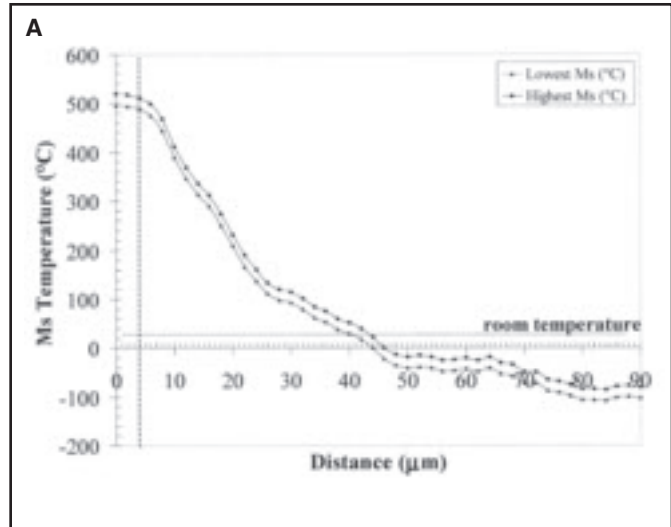


Fig. 4 — The Ms temperature variation across the fusion line for A) 309L stainless steel/A285 carbon steel and B) IN625/A285 carbon steel dissimilar alloy welds.

composition gradient (due to local variations in fluid flow behavior) and cooling rate. In addition, variations in fluid flow behavior are expected when changes are made to processing parameters. The objective here is not to predict the size of the martensite layer within a given weld or with variations in processing parameters, but to demonstrate why differences exist between the widths of martensite layers in welds prepared with Ni-based and Fe-based alloys. The results presented here demonstrate that the reduced width of the martensite layer in Ni-based alloys can be attributed to the steeper gradient in composition and concomitant Ms temperature within the PMZ.

## Conclusion

Ferritic-to-austenitic dissimilar welds

# WELDING RESEARCH

made with Ni-based filler metals will exhibit a steeper concentration gradient in the partially mixed zone (PMZ) compared to Fe-based austenitic alloys. The steeper concentration gradient causes the martensite start (Ms) temperature within the PMZ to intersect room temperature at a relatively short distance within the PMZ. This stabilizes the austenite at a relatively short distance within the PMZ and accounts for the relatively thin martensite layer observed in dissimilar welds prepared with Ni-based filler metals.

#### Acknowledgments

The authors would like to thank A. O.

Benscoter for assistance with sample preparation and K. Repa for assistance with the electron microprobe. This research was sponsored by the American Welding Society Navy Joining Center Fellowship, Pennsylvania Power and Light Co., Welding Services, Allegheny Power Service Corp., Ohio Edison, Virginia Electric Power Co., and Delmarva Power Co.

#### References

1. Thielsch, H. 1952. *Welding Journal* 31: 37-s to 63-s.
2. Nelson, T. W., Lippold, J. C., and Mills, M. J. 1998. *Science and Technology of Welding and Joining* 3: 249 to 255.
3. Gittos, M., and Gooch, T. 1992. *Welding*

*Journal* 71: 461-s to 472-s.

4. Wang, Z., Xu, B., and Cii, Y. 1993. *Welding Journal* 72: 397-s to 402-s.

5. Heinrich, K. F. J. 1986. *Microbeam Analysis, Proceedings of 21st International Conference*. Eds. A. D. Romig Jr. and W. F. Chambers. 279 to 280.

6. Gooch, T. 1977. *Welding Institute Res. Bulletin* 18: 343 to 349.

**JOM-14**  
**Fourteenth International Conference**  
**On the Joining of Materials**  
**&**  
**The 5th International Conference on**  
**Education in Welding**  
**April 29–May 2, 2007**  
**Helsingør-Denmark**

The conference begins with registration on Sunday, April 29, 2007. Monday will mark the opening of eight sessions of presentations through Wednesday, May 2. AWS President Jerry Utrachi will make an opening address to attendees, as well as chair one of the sessions and make a technical presentation. A sampling of the topics that will be covered during the three days include the following:

- Mechanical properties and microstructure of ultra high-strength steel,
- Metal powder laser deposition,
- Improving weld joints in oil and gas pipelines,
- Microbiological induced corrosion,
- Hybrid laser welding of pipe,
- Keyhole plasma arc welding,
- Vision systems for arc welding,
- Friction stir welding,
- Welding dual-phase steel,
- Metal transfer behavior,
- Submerged arc welding optimization,
- Solid-state welding,
- Resistance spot welding parameters,
- e-learning for welding,
- University welding education,
- ISO standardization and certification
- Weld quality and gas waste in GMAW
- Education and research
- Modeling temperature distribution in pipe welding

For more information or conference registration contact JOM- INSTITUTE Gilleleje Strandvej 28. DK-3250 Gilleleje, Denmark; telephone: +45 48355458. e-mail: jom\_aws@post10.tele.dk