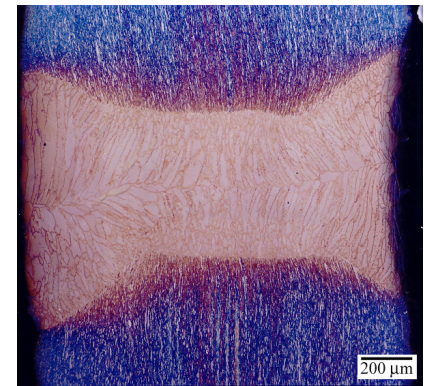


# Effect of Homogenization Heat Treatment on Critical Pitting Temperature and Sigma Phase Formation in Super Duplex Stainless Steel

Class 6

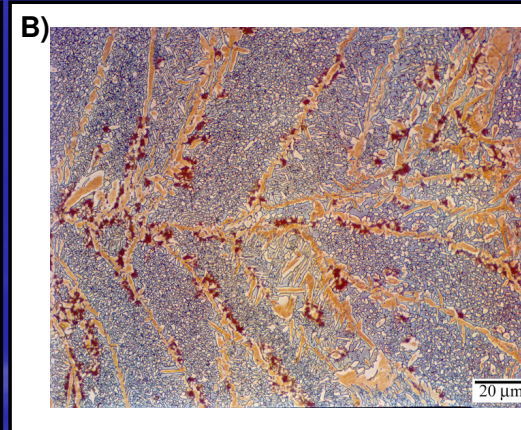
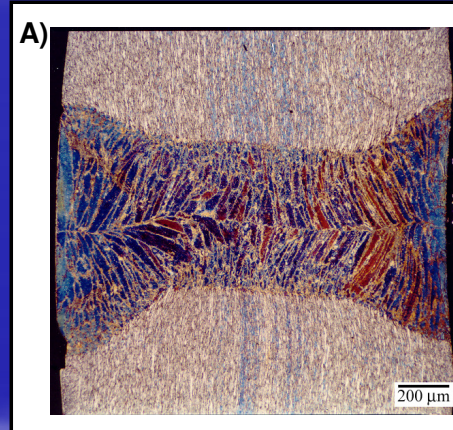
**Introduction:** The annual market for long coils of super duplex stainless steel (SDSS) tubing in the oil and gas industry is approximately \$100 million. SDSS tubes are often used in chloride containing corrosive environments because of their excellent resistance to pitting and stress corrosion cracking, and superb mechanical properties. Currently, most SDSS tubing used in such environments is manufactured by processes that result in short lengths, often requiring thousands of orbital welds to produce long coils. Laser beam welded (LBW) tubes offer significant advantages in that long coil lengths can be fabricated with a minimum number of girth welds. However, the as-welded fusion zone (FZ) experiences a decrease in corrosion resistance as measured by critical pitting temperature (CPT). The decrease in CPT for the as-welded condition results from an imbalance in the ferrite and austenite phases (**Figure 1**) and undesirable partitioning of the elements critical to pitting corrosion resistance (chromium, molybdenum and nitrogen) between the two phases. Another equally important consideration is the formation of sigma phase ( $\sigma$ ) during an unexpected heat treatment upset during production. Sigma phase is known to embrittle duplex stainless steels and have deleterious effects on corrosive resistance. The goal of this work was to define an appropriate heat treatment that increased CPT and decreased the susceptibility to  $\sigma$  phase precipitation.



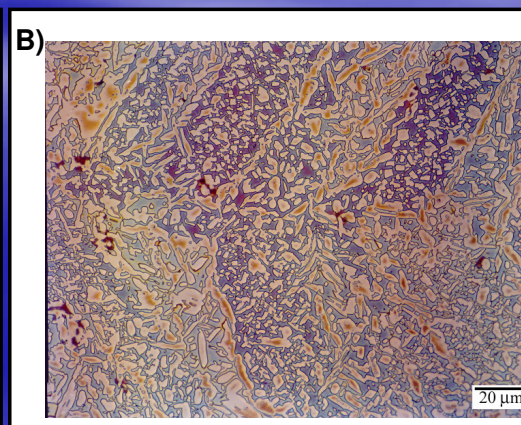
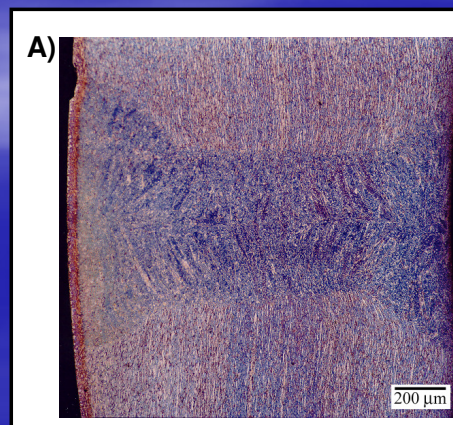
**Figure 1:** As-welded fusion zone of laser beam welded super duplex stainless steel tube. Ferrite cell boundaries stained light tan in fusion zone with no  $\sigma$  phase present. 64x magnification.

**Procedure:** An optimal homogenization heat treatment was developed using a Gleeble Thermal-Mechanical simulator. The impact of the homogenization heat treatment on the susceptibility to form  $\sigma$  phase in the FZ was determined by subjecting both the as-welded (control sample) and homogenized (experimental sample) LBW tubes to a  $\sigma$  forming heat treatment using the Gleeble (**Figures 2 and 3** respectively) and comparing the resultant amount of  $\sigma$  phase formed. The samples were sectioned, ground and polished using standard metallographic techniques, then electrolytically etched in 40% NaOH at 3 V for 6 seconds with a stainless steel cathode. Light optical microscopy was used to identify the changes in microstructure and Quantitative Image Analysis (QIA) was used to measure the volume fraction of  $\sigma$  formed in each condition. Color micrographs best delineated the three phases:  $\alpha$  (blue),  $\gamma$  (tan), and  $\sigma$  (brown).

**Results:** The homogenization heat treatment resulted in the CPT increasing by greater than 50% - exceeding the industry standard. Also, homogenization decreased the amount of  $\sigma$  formed during the  $\sigma$  inducing heat treatment by 92%, with negligible levels of  $\sigma$  formed (**Figure 3**). The homogenized FZ microstructure and chemistry is significantly resistant to  $\sigma$  formation and sufficiently resilient to corrosive attack for LBW SDSS tubes to be used in chloride containing corrosive applications.



**Figure 2:** As-welded and  $\sigma$  phase producing heat treated fusion zone of laser beam welded super duplex stainless steel tubing. **A)** Change in fusion zone color due to improved austenite-ferrite phase balance along with the presence of  $\sigma$  phase. 64x magnification **B)** Fusion zone centerline. Very fine austenite (tan) - ferrite (blue) duplex structure with significant amounts of  $\sigma$  phase (brown). Sigma phase nucleates at the austenite-ferrite interface and grows into ferrite. 640x magnification



**Figure 3:** Homogenization heat treated, followed by the same  $\sigma$  phase inducing heat treatment given to the sample shown in **Figure 2**. Fusion zone of laser beam welded super duplex stainless steel tubing, followed **A)** Fusion zone color subdued compared to **Figure 2A** due to microstructural changes better seen at higher magnification. **B)** Fusion zone centerline. The phase balance improved and the austenite coarsened in comparison to the microstructure shown in **Figure 2B**, thereby reducing nucleation area for  $\sigma$  phase. This difference in microstructure significantly decreased the amount of  $\sigma$  phase formed. 640x magnification.