RENSSELAER POLYTECHNIC INSTITUTE
Troy, New York 12181

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PITTING AND STRESS CORROSION CRACKING BEHAVIOR OF
AUSTENITIC STAINLESS STEEL WELDMENTS CONTAINING
RETAINED FERRITE

D. J. Duquette and W. F. Savage
Rensselaer Polytechnic Institute
Materials Engineering Department
Troy, New York 12181

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Abstract

Pitting experiments on duplex stainless steel weld metal ($\approx 8\%$ ferrite) in 1N NaCl showed pit initiation resistance to be improved over that of unwelded austenitic steel. Pit growth, on the other hand, has been shown to be seriously accelerated in the duplex materials. Repassivation of propagating pits occurred at only slightly more noble potentials in the welded material. Pit initiation in the duplex materials was associated with the austenite/ferrite interface, and growth was shown to occur as subsurface cavities rather than the hemispherical type of pitting associated with single phase austenite. Observed behavior appears to be associated with micro-segregation during solidification.

Slow strain rate stress corrosion cracking tests of single phase and duplex (welded) stainless steels were conducted in boiling 35 - 42% NaCl. In the single phase material intergranular crack initiation was observed at B.P. $< 135^{\circ}\text{C}$ and transgranular cracking observed at B.P. $= 154^{\circ}\text{C}$. In all-weld-metal samples cracking was confined to the austenite/ferrite interface at all temperatures. A large decrease in ductility was observed for both types of materials exposed to the boiling chloride solutions. In specimens with a single transverse weld, it was observed that below 135°C , cracking occurred in the weld metal but that at 154°C , cracking was confined to the base alloy. As in the case of pitting, this behavior appears to be associated with the character of the austenite/ferrite interphase region.

TECHNICAL PROGRESS REPORT

Pitting Corrosion

Potential-dynamic and galvanokinetic experiments have been performed on as-received and welded specimens of 304L stainless steel in 1N NaCl to determine the effect of retained ferrite on weld metal pitting behavior. Welded specimens were prepared either with a single weld pass or with a series of overlapping parallel passes to produce a specimen with 100% weld metal. Additionally, specimens were prepared using a heat-treat/rapid quench technique which yielded approximately the same amount of retained ferrite ($\approx 8\%$) as the weld metal, but in a different distribution.

Pitting of the as-received material was observed to be extensive with large numbers of small hemispherical pits covering all surfaces of the specimen. A higher density of pits was associated with the cut surfaces of the material (normal to the rolling direction), an observation which has been previously reported. Pit nucleation in as-received materials was often, but not always, associated with inclusions. Pitting experiments on weld metal specimens showed that both the pitting potential and the repassivation potential of the duplex materials are more noble than that of as-received material ($\Delta \phi_p \approx +200\text{mv}$; $\Delta \phi_r \approx +50\text{mv}$). However, the hysteresis associated with repassivation following pit nucleation is considerably larger for the welded material relative to as-received material (235mv versus 40mv) indicating that, while the pit nucleation resistance of duplex materials is superior to single phase materials,

pit growth is enhanced in the duplex materials. Heat-treated and quenched materials showed the same behavior as weld metal, indicating that the electrochemistry of pitting in the duplex materials is associated with compositional changes in the phases rather than phase distribution. Pit nucleation in the duplex materials occurred in the austenite phase, generally near austenite/ferrite interfaces. In the heat treated materials, where the duplex structure was not uniformly distributed, it was observed that pits nucleated in the regions having the finest austenite/ferrite distributions.

Significantly, pit growth both in the welded and the heat treated duplex structures was much more severe than in the single phase as-received material. This result was not only observed in potentiodynamic experiments, but was also confirmed in 0.33M FeCl_3 experiments. Pitting in the duplex materials was shown to be confined to fewer sites than in single phase materials but pits were observed to be considerably larger in the former case. Additionally, it was observed that what appeared to be relatively small pits on the alloy surface of the duplex material was, in fact a thin metal layer covering large pits which had grown beneath the alloy surface. This result was not observed in the single phase material.

An additional result of significance was the observation that, in a specimen which had only a single transverse weld, pitting was confined to the weld metal, while the heat-affected zone and the matrix material were completely protected from attack.

While these observations are considered to be important in an understanding of the effect of welding on stainless steel structures, a complete analysis of the causes of each of the results remains to be accomplished. For example, the observation that the pitting potential of the duplex weld is more noble than that of the single phase material can be explained on the basis of previously reported data on the effect of alloying elements on pitting potential. However, it is not understood why, when the pitting potential of the single phase material is reached in a potentiokinetic sweep, pitting does not nucleate in the austenite. It has been shown that this is not a delayed nucleation effect by conducting long term potentiostatic experiments at a potential noble to the critical pitting potential of austenite but active to the observed pitting potential of the duplex structure. Nor is the rapid growth and morphology of pits in the duplex structure compared to the single phase alloy easily explained.

Experiments are currently underway to attempt to explain these anomalies.

Stress Corrosion Cracking

Slow strain rate stress corrosion cracking tests of as-received and welded 304L and 304 stainless steel have been conducted in MgCl_2 at boiling points from 123 to 154°C (controlled by concentration). Corrosion potentials were monitored throughout the tests. Strain rates were varied from $1.6 \times 10^{-6} \text{ sec}^{-1}$ to $8.5 \times 10^{-4} \text{ sec}^{-1}$.

Test results were compared to tests at equivalent temperatures in liquid paraffin.

In boiling 35% MgCl_2 (B.P.- 123°C) decreasing strain rates led to decreased resistance to stress corrosion cracking of the as-received steels (shorter failure times, reduced ultimate tensile stresses and smaller elongations to failure). The stress corrosion cracking effect is no longer observed at strain rates in excess of $\frac{d\epsilon}{dt} \approx 4 \times 10^{-5} \text{ sec}^{-1}$. As expected, increasing temperatures as led to lowered stress corrosion cracking resistance ($\frac{d\epsilon}{dt} \approx 1.6 \times 10^{-5} \text{ sec}^{-1}$). Additionally, it was observed that 304L stainless steel exhibited intergranular failure at temperatures below 135°C but exhibited transgranular failure at 154°C . Corrosion potentials of the steels showed a marked decrease when yielding occurred, stabilized at a constant potential throughout plastic deformation and initial cracking, and exhibited a further pronounced drop in potential upon failure.

Two welded specimen configurations were examined: (1) a specimen containing a single transverse weld oriented normal to the tensile stress and (2) a specimen which was subjected to a series of overlapping weld passes and so consisted entirely of weld metal. When tested in liquid paraffin, the specimen containing the single transverse weld failed in the heat affected zone adjacent to the fusion zone. In boiling MgCl_2 at 135°C however, the failure occurred in the fusion zone and no cracking was observed outside of this zone.

At 154°C failure occurred in the base metal at some distance from the fusion zone. These results are related to the behavior of as-received material, in that the lower temperature test exhibited intergranular failure while the weld metal specimen at the same temperature exhibited failure in the austenite/ferrite interface. At the higher temperature, both failures were transgranular.

In the all-weld-metal specimen failure occurred in the inter-phase boundaries at all temperatures. The stress corrosion cracking resistance of the all weld metal specimen was slightly inferior to as-received material.

In all cases, the behavior of 304L was shown to be inferior to 304 indicating that the normally observed beneficial effect of carbon is maintained even if the material is completely remelted and resolidifies as a two-phase structure.

A complete interpretation of these results is not possible at this time, and further experiments are currently underway to attempt to understand the effect of welding on the stress corrosion cracking resistance of these alloys.

Manuscripts involving both the pitting results and the stress corrosion cracking results are currently in preparation.