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Heat-Affected Zone Liquefaction Cracking in Austenitic and Duplex Stainless Steels

Segregation-based grain boundary liquation models are incorporated into a mechanistic explanation of HAZ liquation cracking.

BY J. C. LIPPOLD, W. A. BAESLACK III AND I. VAROL

ABSTRACT. The heat-affected zone (HAZ) liquation cracking susceptibility of several commercial austenitic and duplex stainless steels was evaluated using the spot Varestraint test. Test results revealed that among the austenitic stainless steels, the susceptibility to cracking was a strong function of ferrite potential (FP), a measure of the tendency for ferrite formation along HAZ grain boundaries adjacent to the fusion line derived from a calculated ferrite number (FN). Low FP heats (FP 0-1) of Type 304L were found to be more susceptible to cracking than a Type 304 alloy with FP 8. The HAZ liquation cracking susceptibility of the duplex stainless steels, Ferralium 255 and Alloy 2205, was roughly equivalent to that of the low-FP austenitic stainless steels.

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Metallographic and fractographic examination of the spot Varestraint samples revealed that cracking was characteristically intergranular in all the alloys, but that the amount of grain boundary liquid associated with the HAZ cracks varied considerably. Essentially no grain boundary liquid films could be detected in the duplex stainless steels or the high-

FP austenitic stainless steel. Segregation-based grain boundary liquation models are reviewed and discussed in the context of the observed cracking susceptibility.

Introduction

Although the weld solidification cracking susceptibility of austenitic stainless steels has been studied extensively, the heat-affected zone (HAZ) liquation cracking behavior of these alloys has received limited attention (Refs. 1-6). In addition, essentially no information exists regarding the HAZ liquation cracking susceptibility of duplex stainless steels. The purpose of this investigation was to provide some comparative weldability test data for a range of austenitic stainless steels and two duplex stainless steel alloys and to evaluate the metallurgical factors that influence HAZ liquation cracking in these alloys. In order to provide a background for this work, a brief review of the cur-

¹Incoloy is a trademark of the Inco family of companies.

KEY WORDS

HAZ Liquation Cracking
Austenitic Stainless Steel
Duplex Stainless Steel
Heat-Affected Zone
Varestraint Testing
Cracking Susceptibility
Calculated FN
Grain Boundaries
Microstructure
Segregation Mechanism

rent understanding of the mechanistics of HAZ liquation cracking is included.

HAZ Liquation Cracking

By definition, the region of the HAZ within which liquation occurs is limited to the partially melted zone (PMZ) and, thus, hot cracking, or cracking resulting from liquation, is indigenous to the PMZ (Refs. 7, 8). Since the term hot cracking has been generally used in the welding literature to describe high-temperature cracking in both the weld metal and HAZ, its use is often ambiguous. As a consequence, the terms weld solidification cracking and HAZ liquation cracking have been adopted here to more accurately classify weld metal and HAZ hot cracking, respectively.

The bulk of published research devoted to HAZ liquation cracking has focused on the behavior of the austenitic stainless steels and the nickel-based superalloys. Both alloy groups are used in high-performance applications where the integrity of the weld region is of critical importance and weld defects cannot generally be tolerated. Austenitic stainless steels which have been reported to be susceptible to HAZ liquation cracking include the stabilized grades containing titanium or niobium, such as Type 321 (Refs. 3, 4) and Type 347 (Refs. 1, 3, 4), respectively, and highly alloyed materials such as Incoloy¹ Alloy 800 (Refs. 9–11) and A-286 (Refs. 11, 12). HAZ liquation cracking has been reported in both cast and wrought versions of a wide variety of nickel-based alloys, including Alloy 718 (Refs. 13–15), Hastelloy X (Ref. 16), and Udimet 700 (Ref. 17). These alloys have provided the basis for many of the HAZ liquation cracking mechanisms that have been proposed.

Penetration Mechanism

Mechanisms used to describe HAZ liquation cracking can be divided into two general categories, namely, those that support a grain boundary penetration mechanism and those in which grain boundary segregation is important. The penetration mechanism for HAZ liquation cracking involves the interaction of a migrating HAZ grain boundary with liquating matrix particles such as carbides, sulfides, borides, etc. The metallurgical basis for this mechanism is a phenomenon known as constitutional liquation. Constitutional liquation was first proposed by Savage from a strictly theoretical standpoint in 1959. Subsequent experiments by his students (Refs. 18–21) proved the validity of this hypothesis.

Constitutional liquation is a nonequilibrium phenomenon associated with

the rapid heating rates experienced in the HAZ adjacent to the fusion line. As certain constituent particles are rapidly heated to temperatures below the matrix solidus temperature, localized liquation occurs along the particle-matrix interface. This liquation is a consequence of the rapid dissolution of the constituent particle at elevated temperatures and the resultant metallurgical reaction at the particle/matrix interface. The amount of liquid that forms along the interface depends on the heating rate, the dissolution kinetics of the constituent particle, and the diffusivity of solute atoms in the matrix. For example, if heating rates are extremely rapid, as in the HAZ of an electron beam or laser beam weld, particle dissolution is negligible and constitutional liquation would be minimized. Conversely, if heating rates in the HAZ are slow, as in an electroslag weld, particle dissolution approaches equilibrium conditions. Solid-state particle dissolution thus precludes the onset of constitutional liquation. In practice, constitutional liquation is most commonly observed when susceptible materials are welded using the more conventional welding processes (SMAW, GTAW, GMAW).

Constitutional liquation is not sufficient, *a priori*, to support the penetration mechanism for HAZ liquation cracking. Since HAZ cracking is a grain boundary phenomenon, the migration of grain boundaries and the interaction of these boundaries with the constituent particles are requisites of the mechanism. (Unless, of course, constituent particles are already at grain boundary sites.) Since grain growth is a thermally activated process, a threshold temperature exists above which grain boundary migration is favorable. In single-phase materials, the locus of this temperature generally represents the boundary of the "true" HAZ. The rate of grain boundary migration increases as a function of proximity to the fusion line. In the region of the HAZ where constitutionally liquated particles are usually observed, grain boundaries are normally quite mobile and the likelihood of the interaction between a boundary and particle is high.

HAZ grain boundary liquation, as defined by the penetration mechanism, requires the simultaneous occurrence of constitutional liquation and grain boundary migration, again assuming that the liquating species are not already at grain boundary sites. The penetration of the boundary by the liquid at the particle-matrix interface either pins the boundary or significantly slows its rate of migration and allows uniform wetting of the boundary by the liquid. These liquid films then serve to embrittle the HAZ grain boundaries in the presence of sufficient mechanically and/or thermally

induced restraint imposed during the welding process.

Many investigators have used the penetration model to explain HAZ hot cracking in a variety of alloys. Duvall and Owzarski (Refs. 14, 17) observed the constitutional liquation of MC and M₆C alloy carbides and related this phenomenon to HAZ embrittlement in a variety of nickel-based superalloys. Savage and Krantz (Ref. 16) associated HAZ hot cracking in Hastelloy X with the constitutional liquation of an M₆C carbide. Pepe and Savage (Refs. 20, 21) concluded that HAZ grain boundary liquation in 18 Ni maraging steels was the result of the constitutional liquation of titanium sulfide particles that formed along rolling bands in the base material. In the family of austenitic stainless steels, Tamura and Watanabe (Refs. 3, 4) related HAZ embrittlement in Type 347 to the liquation of niobium carbides.

Recent studies by Thompson, *et al.* (Ref. 15), on Alloy 718 have suggested that the thermodynamic feasibility of constitutional liquation reactions involving Nb-rich carbides and the kinetics of these reactions are strongly dependent on both the composition of the surrounding austenite matrix and the weld thermal cycle. They have also reported that the cracking of HAZ grain boundaries in this alloy is influenced by the temperature range over which the Nb-rich, grain boundary liquid solidifies during the on-cooling portion of the weld thermal cycle and composition- and temperature-dependent distribution of the liquid along the boundaries.

Segregation Mechanism

Despite the utility of the grain boundary penetration mechanism, HAZ liquation cracking is often encountered in materials where constitutional liquation does not, or cannot, occur. (For example, in materials that do not contain intermetallic constituents.) As a result, a liquation mechanism has evolved that is not dependent on the interaction of a mobile grain boundary with a liquated constituent particle. Many single-phase materials that are relatively free of intermetallic and constituent particles have exhibited susceptibility to HAZ liquation cracking. In general, the location of embrittled grain boundaries in the HAZ of these materials is nearly identical to that of materials which are embrittled by the penetration mechanism. As a result, a grain boundary segregation model that rationalizes the onset of grain boundary liquation in the absence of constituent particle melting is often proposed to explain HAZ liquation cracking.

The segregation model in its simplest form provides for solute/impurity ele-

heat inputs in this alloy, full penetration of the specimen occurred and the weld pool could not be maintained. An arc time of 20 s was used to produce a relatively shallow temperature gradient in the HAZ surrounding the molten pool, thereby providing a more extensive microstructural region conducive to HAZ liquation.

The delay time between arc extinction and actual specimen/die block contact is perhaps the most critical parameter in the spot Varestraint test. Since weld pool solidification begins at the instant of arc extinction, long delay times allow significant solidification, which may promote cracking in the fusion zone rather than the HAZ. Selection of the appropriate delay time is particularly critical in materials that are relatively resistant to HAZ liquation cracking. For this reason, extremely short delay times, on the order of 0 to 5 ms, were selected to insure cracking was concentrated in the HAZ.

All samples were tested at a single augmented strain level of 5%. This level was required to insure cracking in all the alloys tested. The 15.25-cm (6-in.) dimension of the samples was parallel to the rolling direction, thus resulting in crack propagation perpendicular to the rolling direction. Alloy 2205 was also tested in the transverse orientation.

Following testing, HAZ cracks were measured on the as-tested surface at 40X magnification using a binocular microscope equipped with a filar eyepiece. Individual crack lengths were measured and results for each specimen reported in terms of number of cracks, total crack length, maximum crack length and average crack length.

Microstructural Evaluation

Metallographic samples from representative spot Varestraint specimens (plan view) for each alloy were prepared in order to evaluate the microstructural features of the HAZ and relate these features to cracking susceptibility. All samples were polished through 0.05 micron alumina and initially etched using a mixed acid solution containing equal parts of hydrochloric, acetic and nitric acids. In addition, several color-etching techniques were used in conjunction with the duplex stainless steels. These included: 1) a modified Murakami's technique (Ref. 27), 2) an iron colloid technique (Refs. 28, 29), and 3) a two-stage electrolytic technique using a 10% oxalic acid etch followed by a 20% potassium hydroxide etch.

Regions of the spot Varestraint samples containing cracks were examined using an optical metallograph at magni-

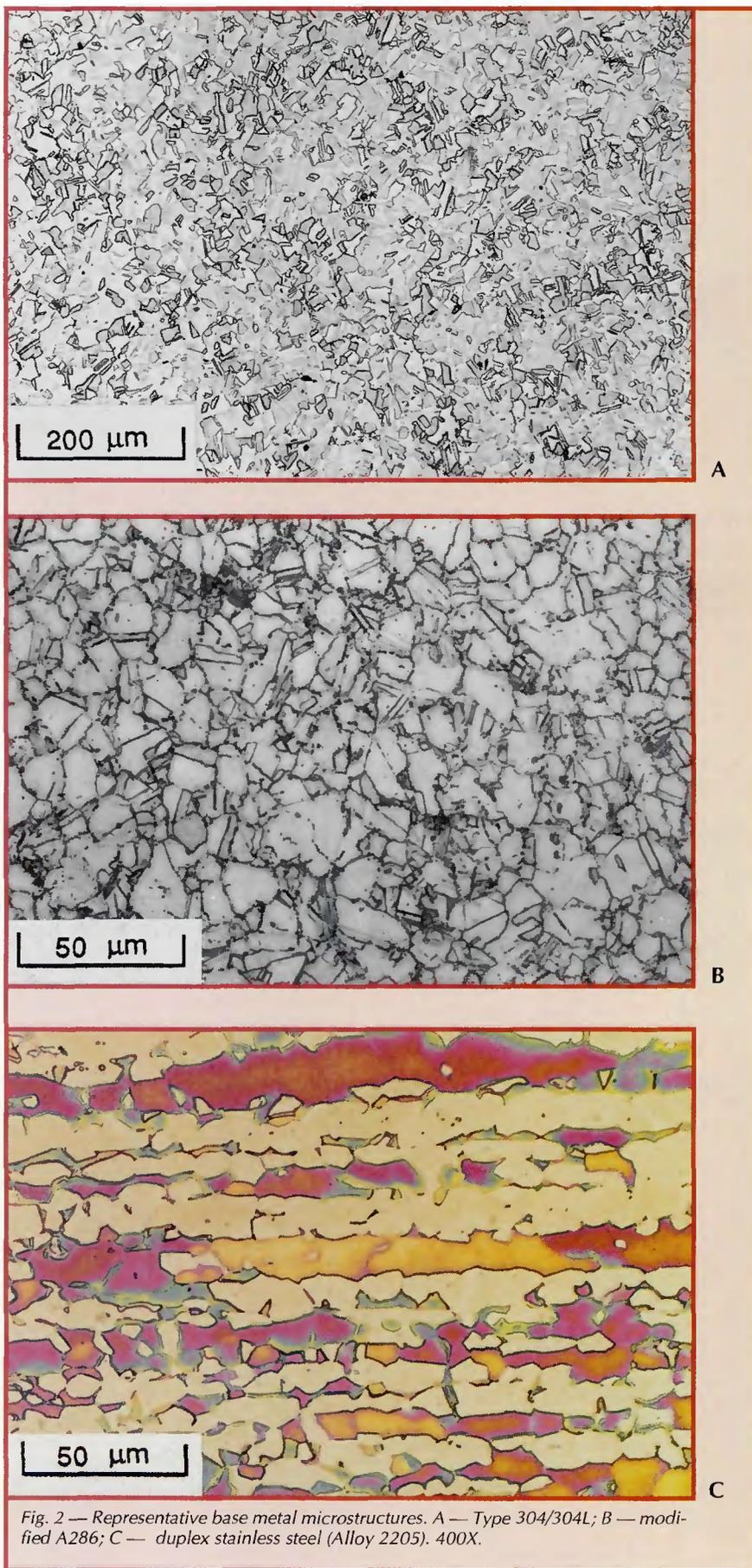


Fig. 2 — Representative base metal microstructures. A — Type 304/304L; B — modified A286; C — duplex stainless steel (Alloy 2205). 400X.

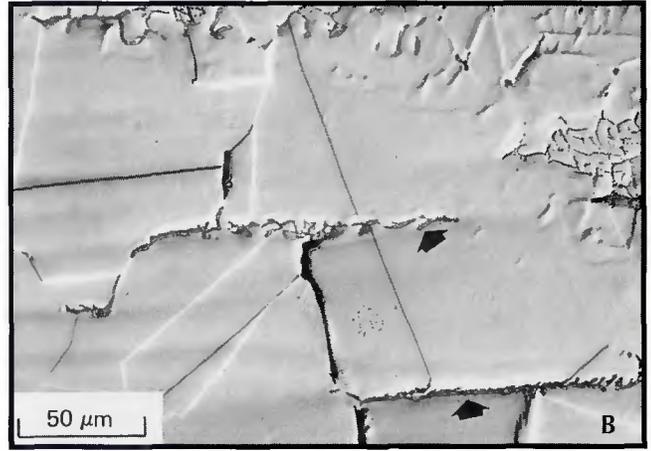
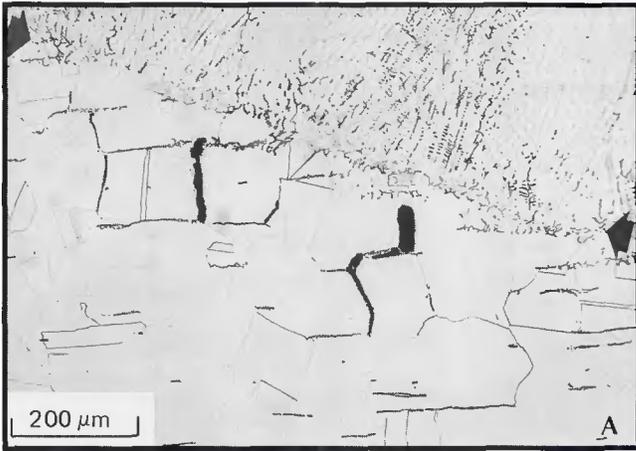


Fig. 5 — HAZ cracking in Type 304L (FP 1) spot Varestraint sample. A — 50X, arrows indicate the fusion boundary; B — 400X, arrows point out crack blunting at ferrite stringers.

Optical Microscopy

Austenitic Stainless Steels. Metallographic sections revealing the top surface (plan view) of the spot Varestraint samples were prepared in order to determine the location and nature of HAZ cracking. The microstructure near the fusion boundary of a Type 304 sample is shown in Fig. 4. The fusion zone consists of a two-phase mixture of austenite and ferrite with a ferrite level of FN 8. Note that the crack shown in Fig. 4A is restricted to the HAZ with essentially no penetration into the fusion zone. This is a consequence of both the short delay time employed during the test and the high inherent resistance of the fusion zone to weld solidification cracking. At higher magnification (Fig. 4B), ferrite is observed along austenite grain boundaries in the HAZ adjacent to the fusion boundary. The ferrite is present as a thin layer at these boundaries and extends only 1 to 2 grain diameters away from the fusion boundary. Also note in this photomicrograph that cracking has oc-

curred along an epitaxial solidification grain boundary in the fusion zone.

A spot Varestraint sample of Type 304L with FP 1 (304L-1) is shown in Fig. 5. Cracking in this sample is again restricted primarily to the HAZ. The adjacent fusion zone solidified as primary austenite and exhibits scattered ferrite along solidification subgrain boundaries. Cracks in this alloy often took on an irregular, stair-step appearance as dictated by the presence of ferrite stringers in the HAZ. Note that the crack in the right-hand portion of Fig. 5A exhibits a distinct step. This stepwise propagation is more clearly seen in Fig. 5B. The ferrite stringers, which are nearly perpendicular to the austenite grain boundaries at this location, act to arrest the crack along one grain boundary and transfer cracking to an adjacent boundary on the opposite side of the stringer. Ferrite was not observed along austenite grain boundaries in the HAZ of this alloy.

The microstructure adjacent to the fusion boundary of a Type 304L, FP 0

spot Varestraint sample is shown in Fig. 6. Again, cracking is restricted to the HAZ and is associated with austenite grain boundaries (Fig. 6B). At higher magnification (Fig. 6B), cracking is observed to occur along a wide, diffuse boundary. This boundary spreading is due to localized melting in close proximity to the fusion boundary. Note that adjacent grain boundaries do not appear to exhibit localized melting.

The HAZ microstructure of modified A286 spot Varestraint samples was dramatically different from the other austenitic stainless steels. As shown in Fig. 7, cracks do not initiate at the fusion boundary but, rather, are separated from the fusion boundary by a partially melted zone (PMZ). This PMZ exhibits extensive liquation both inter and intragranularly. The large amount of liquid available in the PMZ acts to effectively heal any cracks that form in this region. This healing effect is apparent at the crack tip shown in Fig. 7B. HAZ grain boundary liquation was extensive in the

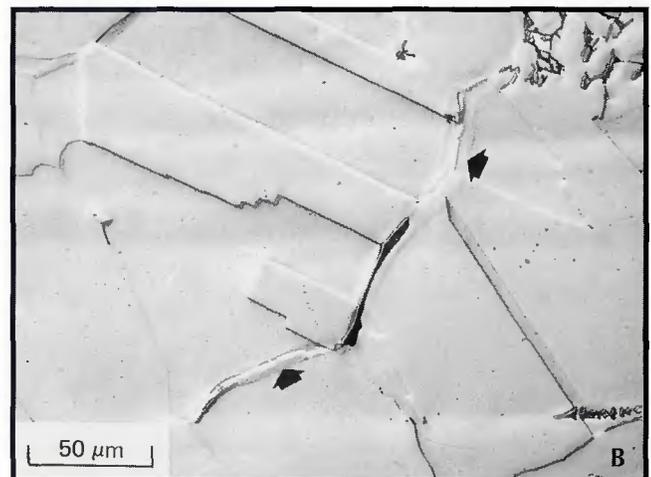
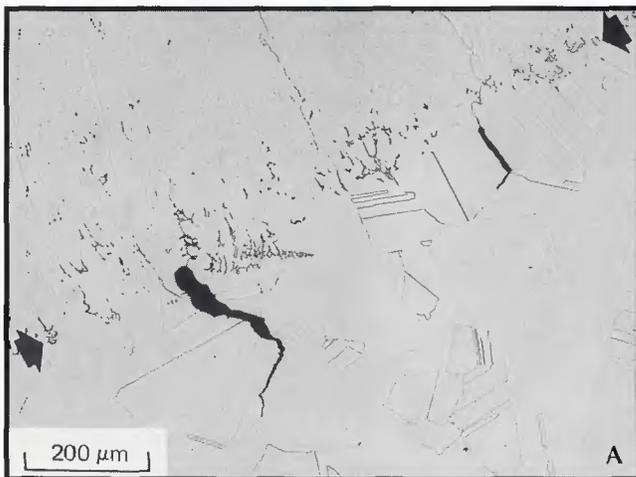


Fig. 6 — HAZ cracking in Type 304L (FP 0) spot Varestraint sample. A — 50X, arrows indicate the fusion boundary; B — 400X, arrows show a widened, liquated grain boundary.

modified A286 alloy up to 10 to 20 grain diameters from the fusion boundary (nearly 1 mm). The extent of liquation correlated well with the maximum crack length measured on the sample surface and the high overall crack susceptibility as determined by total crack length — Fig. 3.

Duplex Stainless Steels

HAZ liquation cracking in the duplex stainless steels was restricted to a narrow region adjacent to the fusion boundary. Again, precise control of the ram delay time was critical for restricting cracking to the HAZ. Color metallographic techniques were used to reveal the nature of cracking in the Ferralium 255 HAZ, as shown in Fig. 8. The two-stage electrolytic technique (Fig. 8A) was helpful in revealing both the fusion boundary and the intergranular nature of the HAZ cracks. Note that significant microstructural modification has occurred in the HAZ relative to the base material — Fig. 2. At peak temperatures, the microstructure adjacent to the HAZ transforms almost entirely to ferrite. On-cooling, austenite precipitates both inter and intragranularly, but the structure remains primarily ferritic. At higher magnification and using a colloidal iron technique (Fig. 8B), a crack at the edge of the fusion boundary is shown to coincide with austenite along the ferrite grain boundary. Close inspection of this photomicrograph reveals that austenite is present on opposing sides of the crack, indicating that cracking does not occur along the ferrite/austenite interface. Rather, the austenite forms on-cooling on the crack surfaces.

HAZ cracking in an Alloy 2205 spot Varestraint specimen is illustrated in Fig. 9. Similar to Ferralium 255, transformation to ferrite HAZ occurred adjacent to

the fusion boundary with subsequent precipitation of austenite on-cooling. In general, the transformation region in the Alloy 2205 HAZ was narrower than that in Ferralium 255. All cracks were restricted to this transformation region and extended only 1- to 2-grain diameters away from the fusion boundary. At high magnification (Fig. 9B), the coincidence of HAZ cracks and grain boundary austenite is again apparent with austenite appearing to precipitate on the crack surface.

Fractography

The fracture surfaces of HAZ liquation cracks from Alloy 2205, Ferralium 255 and Type 304L (FP 0) spot Varestraint samples were examined in the SEM to evaluate differences in cracking behavior. Type 304 specimens were not examined due to difficulties in obtaining adequate samples. Cracks in this alloy were extremely small and could not be successfully isolated for sectioning. The surface of liquation cracks sectioned from welds in the duplex stainless steels are shown in Fig. 10. The morphology was clearly intergranular and relatively smooth, consistent with the presence of extremely thin liquid films. There is also evidence of austenite precipitation, thus corroborating the metallographic observations. In contrast, HAZ liquation crack surfaces in the Type 304L (FP 0) specimen (Fig. 11) exhibited a more irregular, nearly dendritic appearance, indicative of a greater quantity of liquid along the boundary prior to cracking.

Discussion

The results obtained during this investigation have provided a quantitative measure of HAZ liquation cracking in duplex stainless steels relative to

austenitic stainless steels of variable ferrite potential (FP). In addition, the metallurgical evaluation of the spot Varestraint samples used to generate these data has provided some insight into the mechanisms of HAZ liquation cracking in both duplex and austenitic stainless steels.

Relative Cracking Susceptibility

The use of simulative weldability tests, such as the spot Varestraint test, facilitates the assessment of weld cracking susceptibility in engineering alloys. The test is appealing in that it provides a quantitative measure of susceptibility that can be readily compared to other materials tested under the same, or similar test conditions. Some caution must be exercised in the evaluation of test results, however, since the conditions under which the materials are tested vary significantly from those experienced during actual welding fabrication. Thus, the absolute value of TCL or MCL, as reported in Fig. 3, has little practical significance. Rather, spot Varestraint testing provides a good relative measure of HAZ liquation cracking susceptibility. In general, the HAZ cracking susceptibility of austenitic stainless steels as determined by the spot Varestraint test has correlated well with actual fabrication behavior. (Ref. 30)

Based on the results of spot Varestraint tests, the HAZ liquation cracking susceptibility of duplex stainless steels can be expected to be intermediate between austenitic alloys with a FP greater than 3 and those with FP 0. In practice, austenitic stainless steels of the former type are extremely resistant to HAZ liquation cracking. Even under the extreme restraint conditions imposed in the Varestraint test, the extent of cracking is severely limited in these alloys;

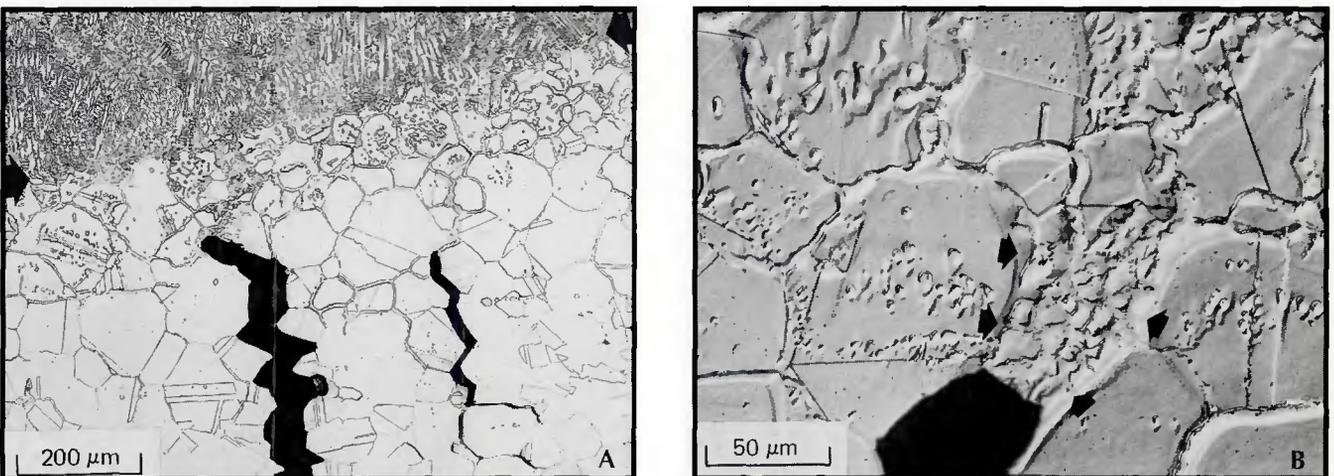


Fig. 7 — HAZ cracking in modified A286 spot Varestraint sample. A — 50X, arrows indicate fusion boundary; B — 400X, arrows demarcate a backfilled region at the crack.

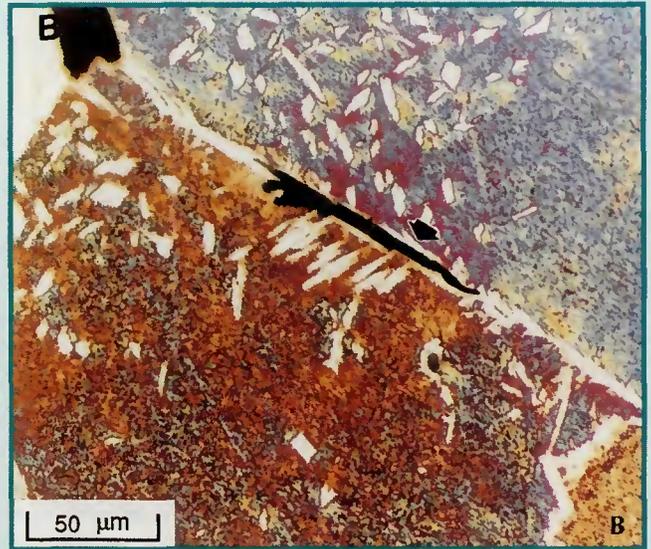
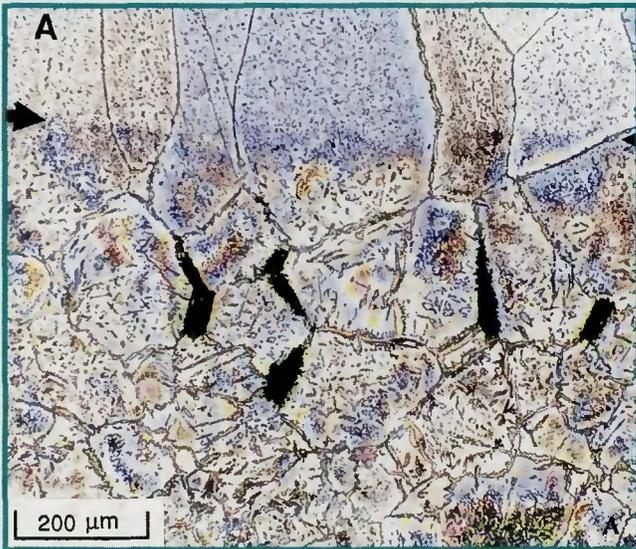


Fig. 8 — HAZ cracks in a Ferralium 255 spot Varestraint sample. A — 100X, two-stage electrolytic etch, arrows indicate the fusion boundary; B — 400X, iron colloid technique, arrows point out austenite on opposing crack faces.

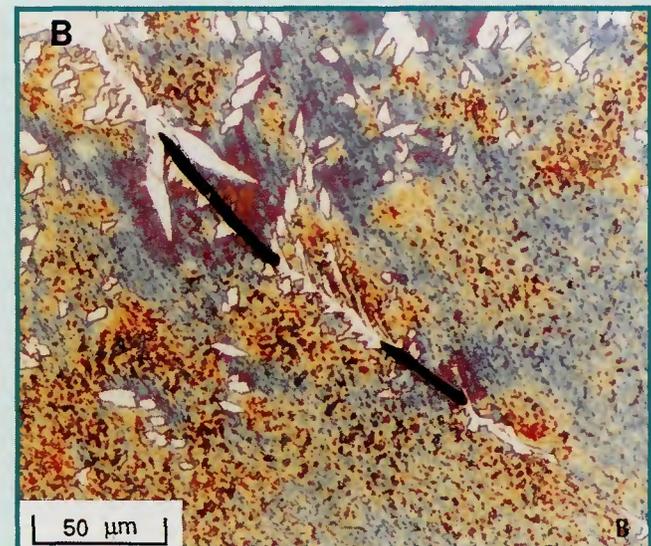
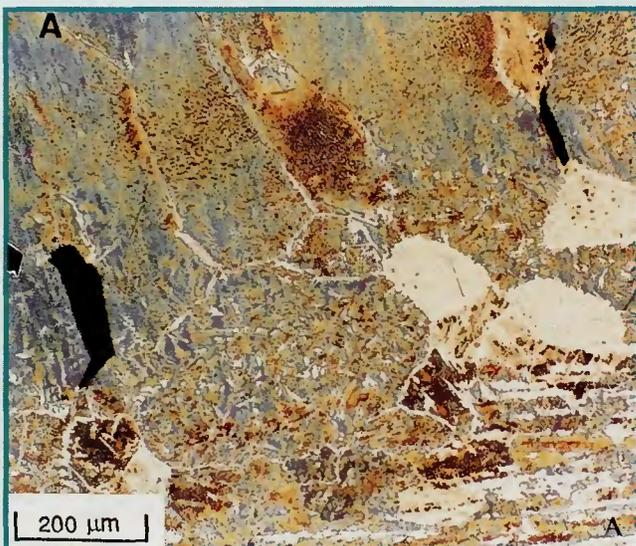


Fig. 9 — HAZ cracking in SAF 2205 spot Varestraint sample. A — 50X, arrows indicate the fusion boundary; B — 400X.

and subsequent grain boundary penetration. As is evident in Fig. 7, the constitutional liquation of Ti-rich carbides (Ref. 12) provides a large quantity of liquid for grain boundary penetration and wetting. In the vicinity of the fusion line, essentially all the grain boundaries show evidence of liquid and at higher magnification a second-phase, identified as a Laves phase (Ref. 12), forms upon resolidification of the boundary on-cooling. It is significant that this highly liquated region of the HAZ does not exhibit cracking. It is proposed that this immunity is the result of crack healing by excess grain boundary liquid and backfilling of liquid from the adjacent weld pool. This healing effect is particularly apparent at the tip of the crack shown in Fig. 7B.

Perhaps the most interesting observation from Fig. 7A is that cracking is most prevalent in the region of the HAZ slightly removed from the fusion line where only partial grain boundary liquation is evident. This behavior is not unique to modified A286 and has been reported previously for Incoloy Alloys 903 and 909 (Refs. 31, 32) and Alloy 718 (Ref. 15). There are several possible explanations for this behavior.

1) The crack-susceptible region is sufficiently remote from the weld pool that significant liquid backfilling of cracks is not possible.

2) Grain boundary liquation occurs on a more localized scale than is apparent with optical microscopy and, in fact, all the boundaries are liquated.

3) Liquation, and subsequent cracking, only occurs along boundaries that have intersected a constitutionally liquated particle.

4) Localized grain boundary strains are much higher in this region than in the mushy zone adjacent to the fusion line.

5) Crack initiation may occur in the heavily constitutionally liquated region with propagation proceeding along nonliquated boundaries via a liquid-metal embrittlement mechanism.

Despite the considerable study that has been devoted to alloys that are susceptible to cracking via a constitutional liquation/grain boundary penetration mechanism, many of the significant aspects of this mechanism remain a mystery. It is apparent, however, that the constitutional liquation of intermetallic constituents is an essential component of the cracking in the modified A286 alloy evaluated in this study and in many other engineering alloys reported in the literature. Development of a more precise description of the penetration mechanism of HAZ liquation cracking requires a more thorough treatment of the issues enumerated above.

Segregation Mechanism

HAZ liquation cracking in the absence of a liquating particle relies on a mechanism whereby grain boundary melting is promoted by a localized variation in composition relative to the surrounding matrix. This variation is driven by segregation of solute and impurity elements at high temperature. Several concepts commonly used to rationalize such a mechanism were reviewed in the introduction. In this study, metallographic and fractographic observations suggest that HAZ liquation cracking in both the duplex and 300-series stainless steels occurs by a segregation mechanism. This is supported by the fact that no liquating particles were observed in the HAZ and the liquid films along HAZ grain boundaries in the spot Vareststraint samples were either extremely thin (Figs. 5B and 6B) or essentially undetectable — Figs. 4B and 12.

Previously, Kujanpaa, *et al.* (Ref. 6), noted the relationship between weld ferrite content and HAZ liquation cracking. The rationale was that ferrite along HAZ grain boundaries inhibits wetting by liquid films and limits diffusion of impurity elements. Another important effect of ferrite formation along austenite grain boundaries is the restriction of grain growth. This effect is apparent when comparing Type 304 (FP 8) and Type 304L (FP 0) — Figs. 4A and 6A.

The onset of ferrite precipitation at the austenite grain boundaries tends to anchor those boundaries, preventing further growth and producing a relatively fine-grained region at the fusion bound-

ary. The inverse relationship between grain size and cracking susceptibility has been demonstrated previously (Refs. 13, 15, 33) and may be rationalized based on both a strain accommodation and liquid distribution argument. As the grain boundary area increases (smaller grain size), the fraction of the total strain accommodated by a single boundary decreases. Below some critical level of strain the boundary will not crack, where this level is determined by the nature of the boundary with regard to metallurgical character and orientation. In addition, as grain size decreases for a fixed volume percent of liquid, the boundary liquid film becomes much thinner or discontinuous, both of which increase resistance to cracking.

The extent of ferrite precipitation is a function of the ferrite potential. As it increases above approximately FP 3, the tendency for ferrite formation increases with a progressive decrease in the initial precipitation temperature, as dictated by the phase diagram. Ferrite formation at lower temperatures would have a more potent effect on restriction of grain growth. At high levels (greater than FP 20), the HAZ becomes fully ferritic and approximates the situation encountered with the duplex stainless steels. Thus, austenitic stainless steels in the composition range from FP 3–20 would be expected to be more resistant to HAZ liquation crack formation than steels with FP 0 based solely on a grain size effect. It is likely, however, that other factors are involved.

Another important consideration relates to the boundary affinity for solute

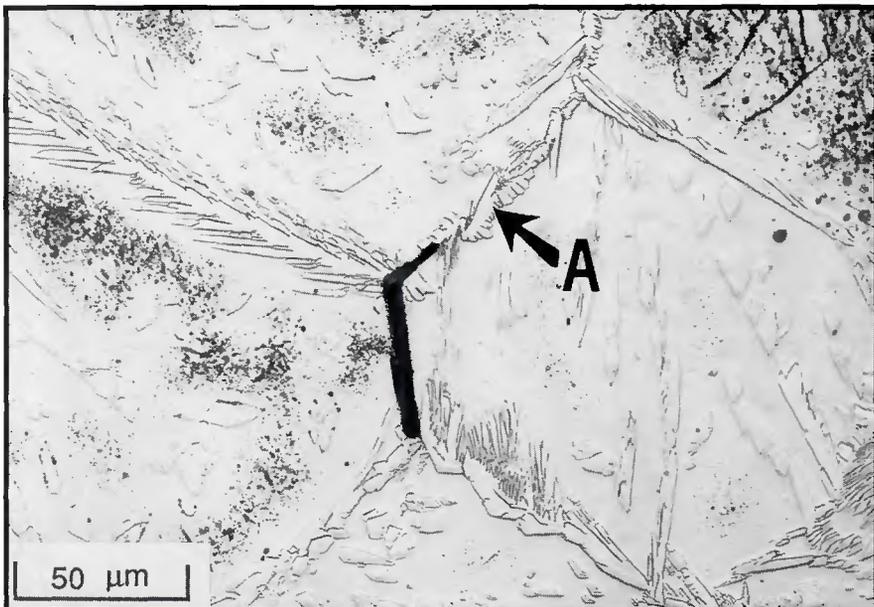


Fig. 12 — Representative HAZ liquation crack in a duplex stainless steel (Ferralium 255). Note the austenite that has precipitated along the grain boundary on-cooling from the crack-susceptible temperature range. 400X

behavior of duplex stainless steels was intermediate between the low-FP and intermediate-FP (FP 8) austenitic stainless steels. The highest cracking susceptibility was observed in a highly austenitic, modified A286 alloy that underwent constitutional liquation and exhibited considerable HAZ grain boundary liquation.

Cracking in the Type 304, Type 304L, Alloy 2205 and Ferralium 255 alloys could not be attributed to the constitutional liquation phenomenon. Alternatively, the mechanism of HAZ liquation cracking in these alloys involves segregation of melting point depressant alloy and/or impurity elements to HAZ grain boundaries. Although the precise explanation of this process is not possible based on the current understanding of the metallurgy of high-temperature grain boundaries, a potential mechanistic approach is discussed, including the identification of the issues germane to the development of a segregation-based liquation cracking mechanism.

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WANTED – MEMBERS FOR THE G2 SUBCOMMITTEE ON STAINLESS STEEL WELDING

This subcommittee will prepare a series of documents to provide recommended practices for joining all types and forms of stainless steels. Initially, the Subcommittee will prepare a guide to joining austenitic stainless steel sheet metal. Later documents will cover ferritic, martensitic, duplex and precipitation hardening stainless steels in sheet, plate, bar and cast product forms as well as austenitic stainless steels in product forms other than sheet metal. The documents will describe the alloys and give typical uses, material preparation, joint designs, joining parameters, postweld treatments, and precautions. All forms of arc welding, resistance welding, electron and laser beam welding and brazing will be included in each document. Persons interested in working with the Subcommittee should contact:

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