Discussion on "Ferrite Morphology in High Molybdenum Stainless Steels"

"Ferrite Morphology in High Molybdenum Stainless Steels" by M. J. Cieslak and W. F. Savage was published as a Technical Note in the Welding Research Supplement of the July 1981 issue of the *Welding Journal* on pages 131-s to 134-s.

The publication of this item has since raised questions on the part T. Boniszewski* whose comments appear below under Discussion. Corresponding response on the part of M. J. Cieslak and W. F. Savage** follows under Authors' Reply.

Discussion by T. Boniszewski

The authors have interpreted the quantitative differences in their hot cracking results of the three heats examined (their Fig. 1) purely from the standpoint of their own hypothesis—namely, that it is not just the ferrite content seen at room temperature, but the formation of ferrite as a primary solidification phase that is instrumental in the mitigation of hot cracking. Be it as it may, I do not think that their results can be used in such a way; and when researchers use inappropriate results to support their hypotheses, they are likely to discredit those hypotheses.

Table 1 of their Technical Note shows that, in addition to the variation in ferrite, the three heats have different S, P and Mn contents. Heat no. 2 which cracked most has the highest sum of S + P = 0.061%. With the weld ferrite content of 2.6, similar to the value of 2.0 in heat no. 1, it is not surprising that heat no. 2 cracked more than heat no. 1 whose S + P = 0.038%. At the same time, these two heats have similar Mn contents.

Heat no. 3 which did not crack showed:

1. About twice the ferrite content of heats no. 1 and 2.
2. S + P = 0.043%, i.e., similar to that of heat no. 1 which cracked less than heat no. 2.
3. Mn content about 5 times as high as those of the other two heats.

It is *not true* (unfortunately, insufficiently publicized because of the common preoccupation with panaceas) that ferrite is the only factor controlling hot cracking in Cr-Ni and Cr-Ni-Mo austenitic steel weld metals. It has been known for several decades, and recently (Ref. 1) it has been very elegantly demonstrated by Brooks and Lambert (1978) that the ferrite content needed to stop hot cracking depends on the S + P content.

Other factors being equal, with the increasing S and P contents, more and more ferrite is needed to prevent the occurrence of cracking.

Where low or nil ferrite weld metals are needed, as for urea plant applications, microcracking is mitigated or suppressed in 316L type weld metal by having low impurity levels, with S and P being below 0.010% each. Also, Mn is increased, e.g., to 3-4%, and an addition of nitrogen at about 0.15% helps too.

To produce results supporting their hypothesis, Cieslak and Savage ought to design a series of heats in which other factors, bearing upon hot cracking susceptibility (e.g., S, P, Mn, etc.), are kept reasonably constant. There should be heats with *the same* ferrite content as measured at room temperature, but with the *proven* record of the differences in the primary solidification history. Let us see whether or not such heats show cracking differences. Otherwise, consideration of their hypothesis is pointless.

Reference

1. Brooks, J.A. and Lambert, F.J. 1978. The effects of phosphorus, sulfur and ferrite content on weld cracking in Type 309 stainless steel. Welding Journal 57(5): pp 139-s to 143-s.

Authors' Reply

Hot cracking is a phenomenon associated with the segregation of certain alloying elements to interdendritic and intergranular volumes during the solidification of welds and castings. It has been widely established that tramp elements, such as sulfur and phosphorus, increase the hot cracking susceptibility of many stainless steels and nickel base alloys. It has also been shown for many years that a few volume percent ferrite in the room temperature microstructure of austenitic stainless steel weldments and castings reduce the hot cracking sensitivity of these alloys.

Recently, much research effort has been concentrated on determining the reasons for the aforementioned observations. Hot cracking studies performed by Masumoto et al. (Ref. 1), Arata et al. (Ref. 2), and Lippold and Savage (Ref. 3) all concluded that hot cracking susceptibility was directly related to the sequence of solidification in austenitic stainless steels. Those alloys which solidified with austenite as the primary phase were far more susceptible to hot cracking than those which solidified as primary delta ferrite.

Astrom et al. (Ref. 4) have shown that phosphorus has a greater solubility in delta-ferrite than in austenite. Lyman (Ref. 5) has reported similar results for both sulfur and phosphorus. Morgenfeld et al. (Ref. 6) have shown, via a sulfur microprint technique, that sulfur is segregated to interdendritic volumes in welds which solidify as primary austenite. Conversely, sulfur was shown to be segregated uniformly throughout the dendrite cores in primary delta-ferrite weldments, strongly reducing the amount found in interdendritic volumes, positions critical from a hot cracking viewpoint.

At the AWS 62nd Annual Meeting held in Cleveland, Ohio, April, 1981, we presented a paper which addressed most of the comments (Ref. 7) made by Mr. Boniszewski. We performed Varestraint hot cracking tests on both a heat of 304-L and CF-8M stainless steel, using combinations of Ar/N_2 as the shielding gas to vary the solidification mechanism and the ferrite content. As such, the nominal alloy composition (S, P, Mn, etc.) did not change. On the other hand, when the primary solidification mode changed from delta-ferrite to austenite, the hot cracking susceptibility of both alloys increased dramatically. Furthermore, a saturation level of hot cracking was reached for both alloys as the room temperature ferrite content continued to drop.

Our STEM/EDS analyses very clearly pointed out that primary delta-ferrite could be readily distinguished from interdendritic eutectic ferrite based upon compositional profiles and chemical analyses. Our earlier interpretation, based

*T. BONISZEWSKI is Manager—Technology Department, ESAB LTD., Gillingham, Kent, England.

**M. J. CIESLAK is a Steel Founders' Society of America Graduate Fellow and W. F. SAVAGE is Professor of Metallurgical Engineering and Director of Welding Research, Rensselaer Polytechnic Institute, Troy, New York.

upon metallographic evidence and lower resolution electron microprobe data, was also valid and completely supported by subsequent experimentation.

Mr. Boniszewski's comment of holding a constant room temperature ferrite content while clamping the solidification mechanism is an interesting suggestion, but very difficult to apply practically. We have not seen a situation where the amount of room temperature eutectic ferrite has been in excess of 3 vol-%. On the other hand, primary delta-ferrite alloys subjected to the same welding conditions generally have at least 5 vol-% ferrite in their room temperature microstructures. In fact, the amount of room temperature ferrite found in these microstructures may be influenced by the cooling rate from the solidus. Quench experiments performed by Arata et al. (Ref. 8) indicate that at the solidus, in excess of 75% of the microstructure may be delta-ferrite in a commercial 304 stainless steel. Quoting from the same reference:

"We should also pay attention that the large amount of the primary delta-ferrite affects strongly the susceptibility to hot cracking. Therefore, the effect of the amount of ferrite at room temperature on hot cracking susceptibility of austenitic stainless steel weld metal should be primarily investigated by replacing with the amount of primary delta-ferrite during solidification."

We have performed similar quench experiments in our laboratory and have generated similar results for CF-8M.

We agree with Mr. Boniszewski that high levels of tramp elements are harmful even in primary delta-ferrite alloys. In an earlier paper (Ref. 9), we found a heat of CF-8M with 17 vol-% ferrite in the weld metal to be extremely sensitive to hot cracking. This alloy had a sulfur content of 0.032% and a phosphorus content of 0.046%, far in excess of normal commercial practice. We attribute the hot cracking sensitivity to an inability of the primary delta-ferrite dendrites to effectively absorb enough of these elements prior to the terminal transient stage of solidification. We also agree that lowering the sulfur and phosphorus levels below 0.010% is essential in primary austenite alloys. But again, we feel that this is a direct result of the solidification mechanism in these alloys, not a result of the room temperature ferrite content per se.

The authors referred to by Mr. Boniszewski make no attempt to explain their results in terms of hot cracking and solidification theory. Furthermore, the standard 304-L alloy used to qualify their "in-house" hot cracking test was ill-defined. No chemical composition or weld metal ferrite content was published. Optical metallography was not provided to develop a microstructure-hot cracking relationship.

Finally, the purpose of our Technical Note was to point out a microstructure-hot cracking relationship which we had observed during an ongoing study of hot cracking in alloy CF-8M. Our interpretation was based upon experience in studying the solidification mechanics of many alloy systems, not solely stainless steels, and by extensive investigations into the hot cracking phenomenon of several different grades of stainless alloys. Furthermore, the vast body of published experimental data support both our hypotheses and our conclusions.

References

1. Masumoto, I.; Tamaki, K.; and Kutsuna, M. 1972. *Trans. JWS* 41(11): 1306-1314.
2. Arata, Y.; Matsuda, F.; and Katayama, S. 1977 (June). *Trans. JWRI* 6(1):105-116.
3. Lippold, J., and Savage, W. F. 1979. Solidification of austenitic stainless steel weldments: part I—a proposed mechanism. *Welding Journal* 58(12):363-s to 374-s.
4. Astrom, H.; Loberg, B.; Bengtsson, B.; and Easterling, K. E. 1976 (July). *Metal Science:* 225-234.
5. Lyman, C. 1979. *Microbeam analysis:* 135-138.
6. Morgenfeld, J.; Solari, M.; and Overjero Garcia, J. 1981. Sulfur redistribution in austenitic stainless steel weld metal. Paper presented at the 62nd AWS Annual Meeting in Cleveland, Ohio, on April 8, 1981.
7. Cieslak, M. J.; Ritter, A. M.; and Savage, W. F. 1982. Solidification cracking and analytical electron microscopy of austenitic stainless steel weld metals. *Welding Journal* 61(1):1-s to 8-s.
8. Arata, J.; Matsuda, F.; and Katayama, S. 1976 (Dec.). *Trans. JWRI* 5(2):35-152.
9. Cieslak, M., and Savage, W. F. 1980. Weldability and solidification phenomena of cast stainless steel. *Welding Journal* 59(5): 136-s to 146-s.

Correction Notice

See "Solidification Cracking and Analytical Electron Microscopy of Austenitic Stainless Steel Weld Metals" by M. J. Cieslak, A. M. Ritter and W. F. Savage in the January 1982 issue of *Welding Journal,* pages 1-s to 8-s. The authors state that Conclusion 6 on page 8-s should be amended to read:

"Eutectic-ferrite may be formed at the dendrite interstices in some alloys which solidify as primary *austenite.* Eutectic-ferrite can be distinguished from primary delta-ferrite at room temperature in three ways: the position of ferrite in the microstructure, the occurrence of precipitates on the eutectic-ferrite/austenite interfaces, the differences in elemental STEM profiles."

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Gentlemen:

The American Welding Society will hold its 64th Annual Convention and 1983 AWS Welding Show in Philadelphia, Pennsylvania, during April 25-29. One of the most important events of our 64th Annual Convention will be its Professional Program.

It is indeed a pleasure to invite you as Authors to be participants in the Professional Program of our 64th Annual Convention. On this occasion, the Society is offering an opportunity to Authors to bring the results of outstanding work on their part to the attention of our entire membership, the welding industry, and the nation's metalworking industries.

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Sincerely yours,

Perry J. Rieppel

Perry J. Rieppel
Acting Executive Director

May 1, 1982

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