SOLIDIFICATION CRACKS IN HSLA STEEL JOINTS AFTER CONTROLLED THERMAL SEVERITY TESTS.

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ABSTRACT

The work presented here studies samples from the Controlled Thermal Severity tests (CTS) carried out on welded joints of a HSLA steel, using the SAW process.

Light optical microscopy shows subsurface continuous cracks at the weld centreline. Further, a flat columnar grain growth solidification pattern is revealed also at the weld centreline. SEM microscopy reveals a dendrite-like pattern at the subsurface crack edges. The crack location and the dendrite-like pattern indicate solidification cracking. Chemical analyses of the cross section show levels of carbon and nickel in agreement with the base material.

The reason for the solidification cracks is, most likely, a combination of chemical composition, part restraint and joint configuration. The levels of carbon and nickel present in the material have been shown to enhance the risk of solidification cracking in ferritic steels. Also the joint configuration of the CTS samples increases the restrain on the weld metal, hence increasing the risk of solidification cracking.

1 INTRODUCTION

The investigation refers to transverse cross sections from a weld that has been subjected to Controlled Thermal Severity (CTS) testing, Figures 1 and 2.
The welding operation is made using SAW with filler (0.09C, 2.1Mn, 2.5Ni, 0.5Mo) and flux according to the filler metal.

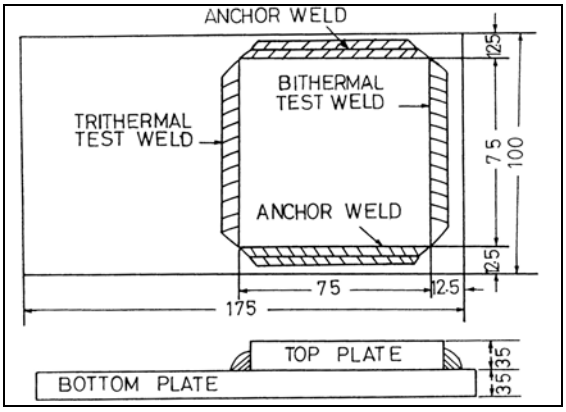


Figure 1. Scheme of the dimensions and configuration of the CTS cracking test.
Test method is presented in Appendix 1.

Samples were studied using light optical microscopy and scanning electron microscopy (SEM). Chemical analysis on transverse surface is additionally performed using optical emission spectroscopy (OES) and Leco combustion technique.

2 BODY OF PAPER

Microscopy reveals subsurface cracks, Figure 2. The crack is most likely continuous in the weld. SEM microscopy reveals a dendrite like pattern at the subsurface crack edges, Figures 3 and 4. This observation indicates solidification cracking. Chemical analyses of the weld metal and the base material are presented in appendix 1, Table 1. Admixing between base material and filler corresponds to approximately 65% base material in the weld metal. A D/W-ratio of 1.0 or grater indicates sensitivity for solidification cracking. In this case, the Depth-to-Width ratio (D/W) shows a value of 0.7.

Table 1. Chemical analysis of the weld metal and the parent material. The constituents are presented in wt%, O and N are presented in ppm.

Designation	C	Si	Mn	P	S	Cr	Ni	Mo	W	Co	V
Weld	0.12	0.27	1.25	0.008	0.002	0.25	3.79	0.40	<0.001	0.013	0.010
Base metal	0.13	0.22	0.49	0.008	0.001	0.381	4.40	0.30	0.002	0.017	0.004

Designation	Al	Sn	Ti	Pb	As	Sb	Zr	B	O[ppm]	N[ppm]
Weld	0.013	<0.001	0.004	<0.001	0.003	0.001	0.003	0.0007	230	50
Base metal	0.022	0.004	0.004	0.002	0.011	0.002	0.003	0.0009	10	40

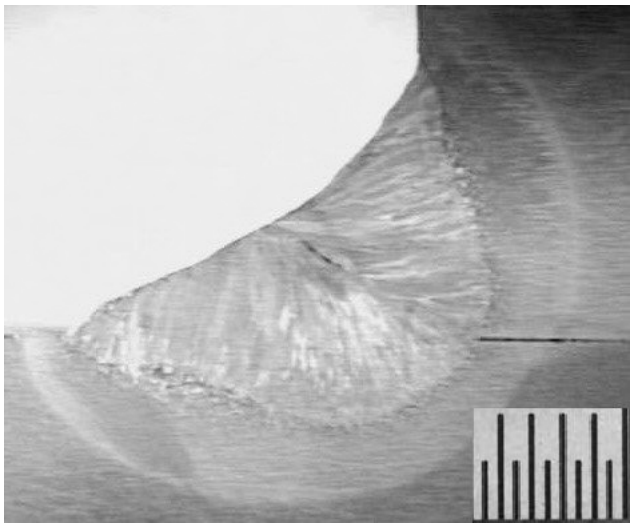
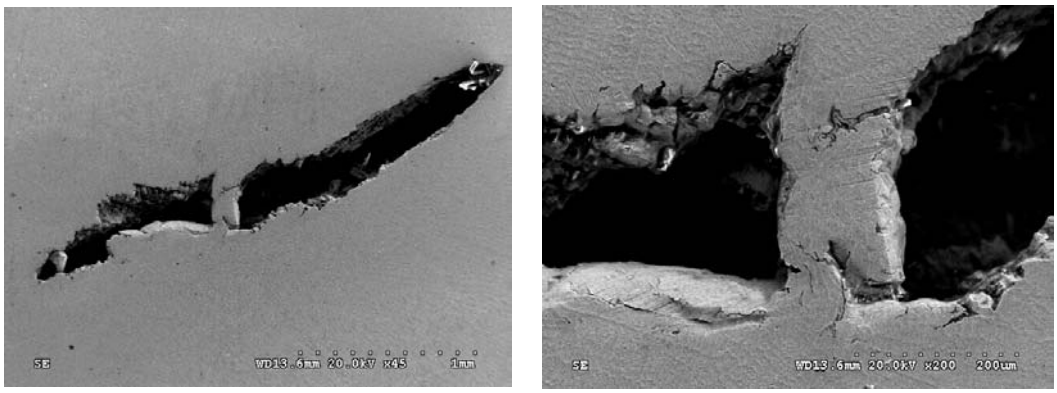


Figure 2. Transverse cross section of a CTS-tested weld. The crack is shown at the weld top under the surface. Distance between scale bars corresponds to 0.5 mm.



a) b)

Figure 3. SEM micrographs of large subsurface crack: a) x45; b) x200.

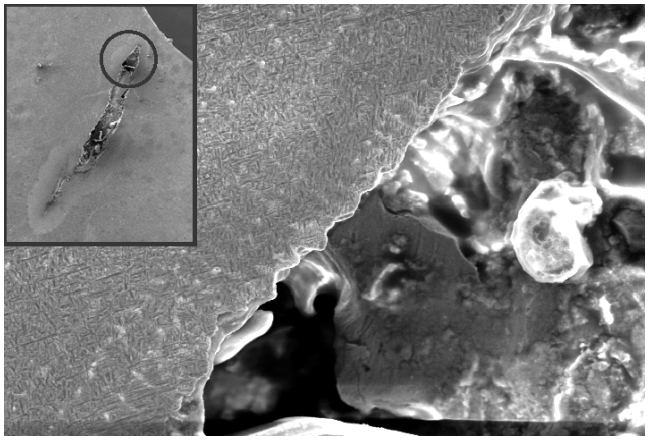


Figure 4. Low (top left angle) and high magnification SEM images of internal cracks showing the dendrite-like pattern indicates solidification cracking.

Solidification cracking depends largely on the chemical composition (freezing range of the alloy), weld metal constraints during cooling (tensile stresses developed by contraction exceeding the corresponding fracture stresses), inadequate feeding (liquid metal to be drawn into and fill any gaps caused by shrinkage during solidification) and welding parameters (joint geometry and welding speed are essential) [4, 5, 6, 7].

Concerning the chemical composition in the present study, constituents that may enhance solidification cracking are e.g. carbon (weld: 0.12 wt%), sulphur, phosphorus and nickel (weld: 3.79 wt%) [5, 7]. Concerning carbon content, Bhadeshia et al. have studied the well established non-linear effect of carbon on the solidification cracking susceptibility by using neural network

[5]. The investigations by Bhadeshia et al. indicate that carbon contents of approximately 0.07-0.10 or higher enhance the solidification cracking probability.

In general, elements that promote austenitic solidification may increase the risk of solidification cracking in ferritic steels. In that sense nickel is the only significant austenite former beside the carbon that promotes solidification cracking, Figure 5 [6, 7].

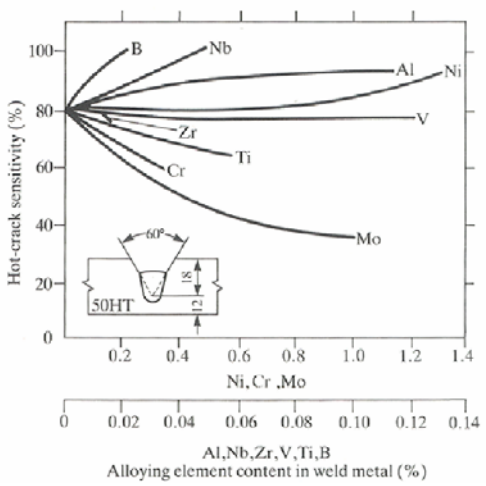


Figure 5. An increasing Ni content may increase the hot crack sensitivity [7].

Another possible reason concerning the solidification cracks in the present investigation is the restrain. The degree of restrain is a function of the type of joint, the rigidity of the structure, the gap between the abutting edges, the plate thickness, and the relative thickness of plate and weld metal [4]. Examples of different joints and levels of restraint are shown in Figure 6 [4]. A joint design similar to the CTS sample reveals a High restraint level.

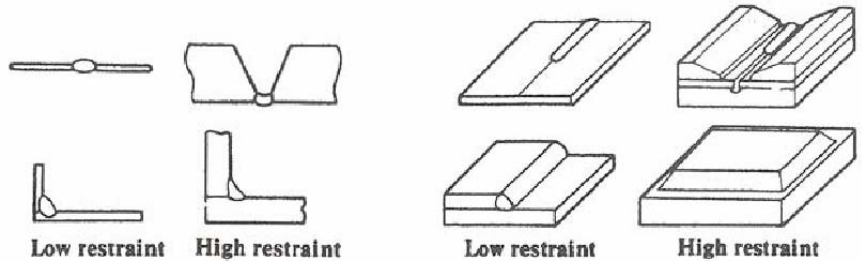


Figure 6. High restraint may be obtained in the CTS specimen used.

Further, Figures 2, 3, and 4 show solidification pattern of flat columnar grain growth. This type of growth pattern pushes impurities and compounds with low melting constituents to the weld centreline hence enhancing the risk of solidification cracking. A more inward and upward growth

is suitable so the impurities are transported towards the weld metal top surface instead of the weld centreline [6, 8].

Control of weld metal composition is not always the easiest option (weld metal: ~65% of base material) so an improvement in cracking behaviour must be sought by other means (probably also not possible to change the joint geometry). The most straightforward solution may be to alter the welding condition reducing welding speed [6, 9] which affects the solidification pattern and dilution. A slower welding speed may affect the solidification pattern and in that sense the more favourable inward and upward growth is enhanced. The welding speed also affects the bead geometry, a good weld shape i.e. slightly convex is eligible. A change in welding speed has to be balanced against increase in dilution, hence a change in weld metal chemistry and the aforementioned bead shape (bead shape: balance against mechanical strength e.g. fatigue).

As the parent material composition contains 4.40 wt% Ni and 0.12% C, a Ni-base filler metal maybe suitable. A change to Ni-base filler requires comparison to the existing strength demands. A last suggestion for lowering the risk of solidification cracking is the welding sequence (for a real application). Restraint caused by the rest of the part usually builds up during welding and can lead to cracking if the welding sequence is not selected to minimize this build-up.

3 CONCLUSIONS

1. The CTS test sample shows a subsurface crack. SEM microscopy reveals a dendrite like pattern at the subsurface crack edges. The subsurface crack indicates solidification cracking.

2. Possible solutions include:

   A reduction in welding speed. A change in welding speed has to be balanced against increase in dilution (change in weld metal chemistry) and the bead shape (change in mechanical strength).

   The use of Ni-base filler. A change to Ni-base filler requires e.g. comparison to the existing strength demands.

3. For a real application: Check the welding sequence so to minimize restraint caused by the rest of the part during welding.

4 REFERENCES

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APPENDIX 1

The CTS Crackability Test

The CTS test (Controlled Thermal Severity BS 7363 1990) is based on the principle of the fillet joint and serves for a selection of optimum welding parameters and also as a test of quality of the base material (e.g. for admissible hardness value). The test plate, 35 mm thick is made up of two asymmetrically screwed sections mechanically shaped straight. An auxiliary weld is made from two or three sides on several layers. When it cools and the screw is tightened, the test weld itself is made in one or two sides, 4-6 mm in thickness and 75 mm in length. Susceptibility to cracking grows with the increasing gap between the plates, therefore a backing strip is often placed between the two plates whereby the gap in the fillet weld is enlarged. With this test, occur in the underbead zone or in the weld metal. The test weld can be sectioned into samples minimally 72 h after completion.