Solidification Crack Susceptibility in Weld Metals of Fully Austenitic Stainless Steels (Report IV)†

— Effect of Decreasing P and S on Solidification Crack Susceptibility of SUS 310S Austenitic Stainless Steel Weld Metals —

Yoshiaki ARATA*, Fukuhisa MATSUDA*, Hiroji NAKAGAWA** and Seiji KATAYAMA***

Abstract

This investigation is carried out to establish the degree of the effects of decreasing phosphorus and sulphur contents on the solidification crack susceptibility of SUS 310S weld metals, using the Trans-Varestraint test, modified Houldcroft test and other hot cracking tests. All results demonstrate in agreement that the improvement in cracking resistance of weld metals is correlated directly to the reduction in phosphorus and sulphur contents, which should be limited to less than about 0.01% respectively, or to about 0.005% if possible.

1. Introduction

It is well known that fully austenitic stainless steel welds are highly susceptible to hot cracking.[1)-4)] In the previous report[5)] the mechanism of hot cracking in weld metals of SUS 310S※ representing a fully austenitic steel was investigated by exerting the various combinations of augmented strains and strain rates on the specimen surfaces with the Slow-Bending Speed type Trans-Varestraint apparatus. It was found as a result that hot cracking was constituted by solidification cracking much more predominantly than ductility-dip cracking in the practical production weld, which was further confirmed by the fractographic examination with scanning electron microscope of the cracks produced in the actual welds and several conventional hot cracking tests. Moreover, it has been reported that incidence of solidification cracking can be badly influenced by impurities such as sulphur (S) and phosphorus (P).[1),5)6)-10)] From this viewpoint, using SUS 310S including S and P contents added deliberately, the detrimental effect of increasing S or P on the susceptibility to solidification cracking was investigated and assessed by the ductility curve determined by the Trans-Varestraint test.[4)]

This study was carried out to evaluate more accurately the effects of decreasing S and P compared with those in commercial SUS 310S and moreover to improve crack resistance of SUS 310S weld metal, using the Trans-Varestraint, resistance spot welding, arc strike (arc spot welding), and modified Houldcroft tests.

2. Experimental procedure

3 commercial and 14 experimental materials were used to study the effects of decreasing S and P on solidification crack susceptibility (see **Table 1**). Codes 16 and 17 were alloys made with elements of S, P, C and Si as low as possible.

Table 1 Chemical compositions of materials investigated

Code	Composition (wt%)						
	C	Si	Mn	P	S	Cr	Ni
1	0.066	0.56	1.41	0.032	0.013	24.70	19.86
2	0.07	0.73	1.05	0.022	0.017	24.45	19.9
3	0.066	0.66	1.48	0.022	0.007	24.59	20.08
4	0.082	0.94	1.58	0.022	0.007	24.66	20.37
5	0.078	0.93	1.56	0.021	0.007	25.06	20.30
6	0.063	0.69	1.15	0.023	0.003	24.60	20.2
7	0.07	0.53	0.83	0.022	0.004	25.35	19.80
8	0.053	0.54	1.33	0.013	0.012	25.05	19.94
9	0.0651	0.74	1.55	0.012	0.008	24.85	20.05
10	0.07	1.03	1.44	0.008	0.008	24.84	20.01
11	0.067	0.51	1.47	0.007	0.007	24.92	19.97
12	0.068	0.31	1.48	0.006	0.007	24.87	19.90
13	0.071	0.11	1.49	0.006	0.007	24.99	20.08
14	0.068	0.22	1.46	0.005	0.009	24.99	19.85
15	0.052	0.13	1.36	0.003	0.009	24.68	20.28
16	0.016	<0.01	1.41	0.002	0.005	24.67	20.78
17	0.014	<0.01	1.41	0.002	0.005	24.88	21.13

The Trans-Varestraint test was conducted on 17 different steels in Table 1 using the same testing procedure described in the previous report[4)], and defined the hot ductility curve, from which the solidification brittleness temperature range (BTR) at 1.0% and 2.5% augmented strains, one of the most important indexes assessing the

† Received on October 24th, 1978

* Professor
** Research Instructor
*** Graduate Student, Osaka University

※ SUS 310S corresponds to AISI 310S of 25% Cr-20% Ni alloy. SUS is the designation for stainless steels in Japan Industrial Standard (JIS).

solidification crack susceptibility, was used in the present report. Solidification cracking experienced in actual resistance spot welds was examined. Two sheets of 30x30x3 mm piled up were resistance spot welded under the condition of P=700kg, t=15 cycles and I=12,000A, and P=1,400kg, t=20 cycles and I=17,000A, and each nugget was cross-sectionally cut in two through the center by microcutter of 1mm in width. The total length and the number of cracks in weld metal were measured in four cross sections under 100x magnification, and the total crack length/one cross section and the number of crack/one cross section were used to compare. Arc strike test utilized a GTA welding to melt a spot in the center of a 40x40x3 mm specimen. A welding time of 10 sec at 150A and 14V of dcsp was used with 15 1/min argon shielding. Both the total length and the number of all cracks on the nugget surface were measured at 16x magnification. This crack total/one nugget on the average of four specimens was used as an index of the crack susceptibility. Furthermore, modified Houldcroft test was conducted in the GTA welding condition of dcsp I=130A, E=15V and v=100mm/min on 12 hot rolled specimens of 100^lx80^wx3^t mm, having 8 slots whose depths decreased in the direction of welding, because the preliminary experiment had shown that a crack had been produced less than 70mm in width but had not been produced more than 80mm in width in commercial SUS 310S. Crack lengths were measured within 60mm from 20mm apart from the start of the testpiece proper and cracking ratio (C_R) = {crack length (mm)/60 (mm)} x 100 (%) was used as an index of the crack susceptibility.

3. Results and Discussion

A summary of all experimental results investigated is given in **Table 2**, and the result for each test is again presented in **Figs. 1 to 5** to understand more clearly the

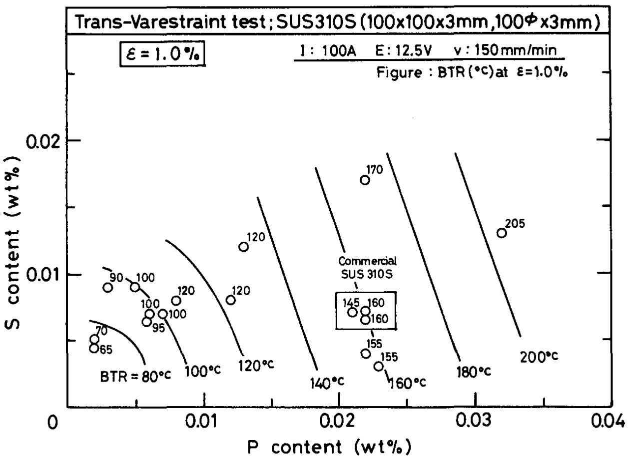


Fig. 1 Effects of P and S on BTR at 1.0% augmented strain by Trans-Varestraint test

Table 2 Summary of results of solidification cracking tests

Code	Trans-Varestraint test		Resistance spot welding				Are strike test	Modified Houldcroft test
			700kg, 12000A		1400kg, 17000A			
	BTR at =1.0% (°C)	BTR at =2.5% (°C)	Total crack length (mm)	Number of cracks	Total crack length (mm)	Number of cracks	Total crack length (mm)	Crack ratio, C_R (%)
1	205	225	7.7	18	6.2	14	5.2	100
2	170	170	5.2	10	3.0	11	8.5	–
3	160	160	5.6	10	3.1	8	3.3	100
4	160	170	5.4	20	5.0	16	4.6	100
5	145	145	–	–	3.2	14	4.3	100
6	155	155	5.1	16	2.0	6	3.1	–
7	155	155	4.3	13	2.4	3	6.0	–
8	120	135	3.5	8	1.8	4	0.5	95
9	120	130	4.8	12	1.3	3	1.6	50
10	120	135	4.1	7	1.4	4	1.2	20
11	100	130	2.3	7	1.0	2	0	–
12	100	120	2.1	7	1.1	2	0	–
13	95	120	2.3	6	1.4	3	0	15
14	100	125	2.2	6	1.1	2	0	25
15	90	120	1.7	5	1.1	4	0	20
16	70	75	0.6	3	0.9	2	0	5
17	65	75	0.4	3	0.6	2	0	0

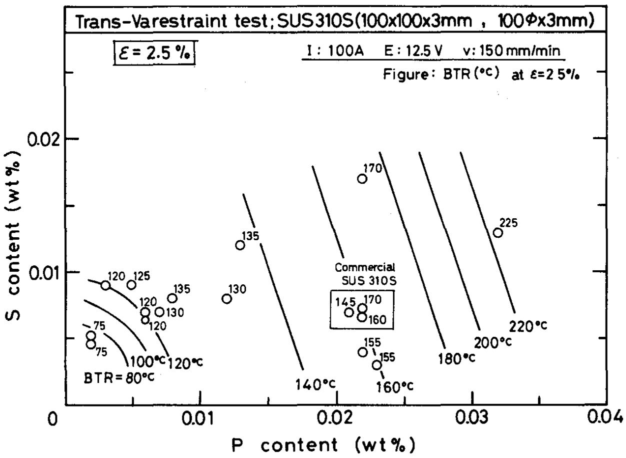
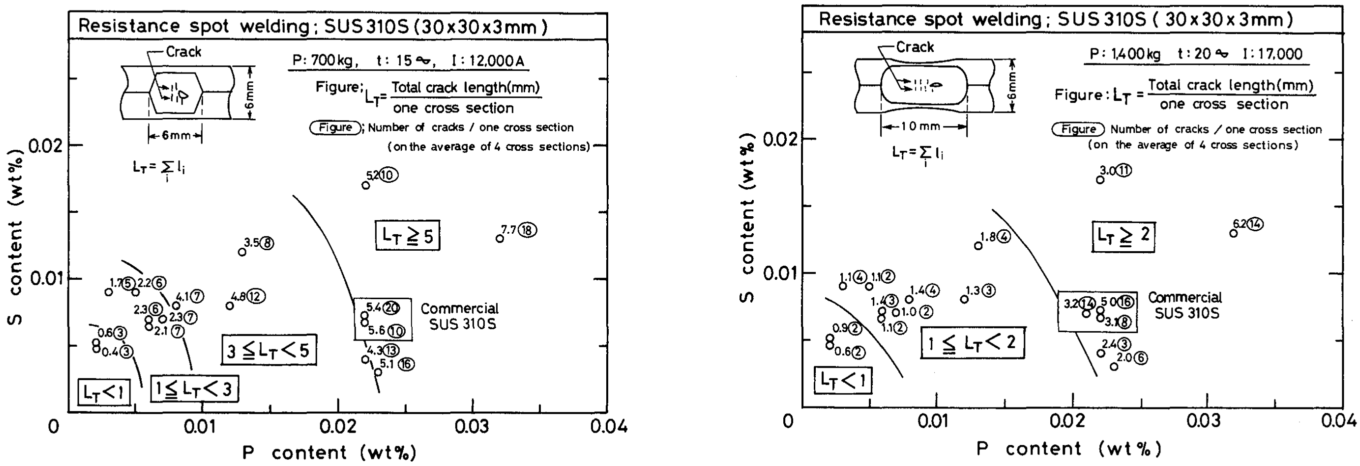


Fig. 2 Effects of P and S on BTR at 2.5% augmented strain by Trans-Varestraint test

effects of decreasing P and S on solidification crack susceptibility.

Figs. 1 and 2 show the effects of P and S contents on BTR at 1.0% and 2.5% augmented strains obtained by the Trans-Varestraint test. The BTR of commercial SUS 310S was about 160°C. The decrease in the BTR seems to depend mainly upon the P content around commercial levels, and less than about 0.01% P content the decrease in the S content can influence the further reduction of the BTR as well as the decrease in the P content although the decrease in C and Si contents may also have a little beneficial effect on that. Therefore, it was found as a result that it was necessary for the improvement of commercial SUS 310S to reduce the P content first and that it was the most beneficial to decrease less than about 0.005% each of both P and S at the same time. Nevertheless, it is to be noted that Codes 16 and 17



(a) P=700 kg, t=12 cycles, I=12000 A

(b) P=1400 kg, t=20 cycles, I=17000 A

Fig. 3 Effects of P and S on solidification crack susceptibility in resistance spot weld metals

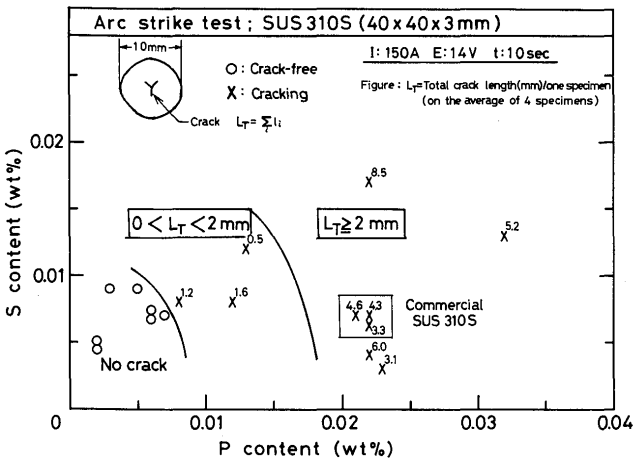


Fig. 4 Effects of P and S on solidification crack susceptibility according to arc strike test

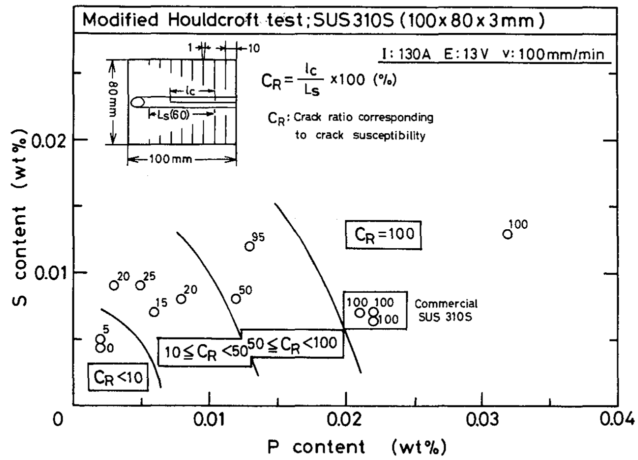


Fig. 5 Effects of P and S on solidification crack susceptibility according to modified Houldcroft test

possessed the relatively wide BTR of about 70°C although the contents of P, S, C and Si were reduced as low as possible in them. The comparison between the above significant results and solidification cracking in actual weld metals was made below.

Figs.3 (a) and **3 (b)** indicate the results of actual cracks in resistance weld metals as both the total crack length in mm and the number of cracks in two welding conditions. The total crack length in the case of less than 0.007%P became less than half as long as that of commercial SUS 310S. The further decrease in the P and S contents resulted in the smallest crack length, 1/3 to 1/5 as long as that of commercial SUS 310S. In addition, the number of cracks decreased according to the reduction in the P content. These tendencies of crack length and number correspond reasonably with the tendency of the BTR.

Fig. 4 shows the result of arc strike test. The decrease in P and S contents led to the smaller total crack length, and at last crack-free weld metal was obtained within less than 0.007%P and 0.01%S, the range of which corresponds to the BTR less than 100°C at ε=1.0% and less than 120°C at ε=2.5%.

Fig. 5 presents the result of modified Houldcroft test, and clearly shows that the crack ratio decreased according to the reduction in the P and S contents. It is suggested as well that reducing the P and S contents is beneficial to the reduction in weld metal solidification cracking.

4. Conclusions

The present specification for a fully austenitic stainless steel SUS 310S prescribe maximum contents of 0.04% for P and 0.03% for S in Japan Industrial Standard (JIS). However, SUS 310S is very susceptible to solidification cracking. On the basis of this viewpoint, from this investigation which tried to predict the degree of cracking accurately from the P and S contents on the solidification crack susceptibility the following conclusions can be drawn:

(1) The P content has a much greater influence on the solidification crack susceptibility of commercially available SUS 310S than the S content and should be preferably limited to about 0.01% or 0.005% if possible. In the latter case it seems to be inevitable to reduce the S content less than 0.005% with the view to improving the crack resistance further.

(2) The BTR obtained by the Trans-Varestraint test proved very valuable in assessing the effect of impurities on the solidification crack susceptibility in good agreement with actual solidification cracking and the solidification crack susceptibility by the conventional cracking tests.

Acknowledgements

The authors wish to thank Mr. S. Harada of Osaka Transformer Corporation for the operation of resistance spot welding and Mr. T. Ogawa and Mr. S. Saruwatari of Nippon Steel Corporation and Mr. K. Saito of Nippon Stainless Steel Corporation for their supplying materials investigated.

References

1) J. C. Borland and R. D. Younger: "Some Aspect of Cracking in Welded Cr-Ni Austenitic Steels", Brit. Weld. J., Vol. 7 (1960), pp.22-59.
2) F. C. Hull: "Effect of Delta Ferrite on the Hot Cracking of Stainless Steel", Weld. J., (1967), pp.399s-409s.
3) Y. Arata, F. Matsuda and S. Saruwatari: "Varestraint Test for Solidification Crack Susceptibility in Weld Metal of Austenitic Stainless Steels", Trans. of JWRI, Vol. 3 (1974), No. 1, pp.78-88
4) Y. Arata, F. Matsuda and S. Katayama: "Solidification Crack Susceptibility in Weld Metals of Fully Austenitic Stainless Steels (Report II)", Trans. of JWRI, Vol. 3 (1977) No. 1, pp.79-88.
5) Y. Arata F. Matsuda, H. Nakagawa, S. Katayama and S. Ogata: "Solidification Crack Susceptibility in Weld Metals of Fully Austenitic Stainless Steels (Report III)", Trans. of JWRI, Vol. 6 (1977) No. 2, pp.197-206.
6) F. C. Hull: "Effect of Alloying Additions on Hot Cracking of Austenitic Chromium-Nickel Stainless Steels", Pro. Amer. Soc. for Testing and Materials, 60 (1960), pp.667-690.
7) A. Gueussier and R. Castro: "Étude Expérimentale des Criques de Solidification dans les Aciers Influence des Impuretés", Revue de Métallurgie, Vol. 57 (1960) No. 2, pp.117-134. pp.117-134.
8) W. Dahal, C. Druen and H. Musch: "Susceptibility of Austenitic Welded Joints to Hot Cracking", Vol. IIW-Doc. II-660-73, IIW-Doc. IX-850-73.
9) A. Bernstein, J. Ch. Carlen and L. Rick: "Influence of Phosphorus and Sulfur on the Properties of the Weld Metal in Certain Austenitic Stainless Steels", Weld. J., 44 (1965) pp.504s-508s.
10) A. Hoerl and T. J. Moore: Welding J., Vol. 36 (1957), pp.442s-448s.