

Proposal of 18Cr-8Ni based Austenitic Stainless Steel with Superior Stress Relaxation Cracking Resistance

Takahiro Osuki
Nippon Steel Corporation
1-8, Fuso-cho
Amagasaki, Hyogo 660-0891
Japan

Shinnosuke Kurihara
Nippon Steel Corporation
1, Nishino-cho, Higashi-mukojima
Amagasaki, Hyogo 660-0856
Japan

Masaki Ueyama
Nippon Steel North America, Inc.
945 Bunker Hill, Suite 600
Houston, Texas 77024
U.S.A.

Yuhei Suzuki
Nippon Steel Corporation
1, Nishino-cho, Higashi-mukojima
Amagasaki, Hyogo 660-0856
Japan

Toshihide Ono
Nippon Steel Corporation
260-100, Funao
Kainan, Wakayama 642-0001
Japan

ABSTRACT

It is known that Stress Relaxation Cracking (SRC) has occurred in welded joints or cold deformation areas and is a severe problem for some units in hydro-treating or hydro-cracking processes.

For example, in NACE ⁽¹⁾ Paper No.07423 from CORROSION 2007, TNO Science and Industry investigated the SRC ranking of heat resistant alloys and the mechanism of SRC within a Joint Industrial Programme (JIP). They clarified that the major mechanism is due to the formation of both precipitation hardening along dislocations and precipitation free zone along $M_{23}C_6$ carbide at grain boundaries during stress relaxation process in the temperature range between 550°C and 750°C.

Stainless alloys S34709 or S30409 indicate higher SRC susceptibility compared with S31609, and requires Post Weld Heat Treatment (PWHT) to prevent SRC. Therefore, end users and fabricators using S34709 or S30409 have a strong interest austenitic stainless steels with superior SRC resistance where PWHT can be eliminated.

In our research, proprietary version S34751 was studied due to its extreme low carbon and higher nitrogen contents. Both stress relaxation testing and thermodynamic calculations revealed that proprietary version S34751 had higher SRC resistance than S34709 and S30409 without PWHT.

⁽¹⁾ NACE International (NACE), 15835 Park Ten Pl, Houston, TX 77084, USA

INTRODUCTION

Various austenitic stainless steels such as UNS S30409, S31609, S32109 and 34709 are widely used in complex refinery or chemical plants at temperature ranges between 550°C and 950°C. However, Stress Relaxation Cracking (SRC) in welded joints or cold deformed parts has been a serious problem during fabrication or operation. Several researches were conducted to construct SRC test methods. This included the evaluation of SRC susceptibilities among various austenitic stainless steels and to determine SRC mechanism within TNO Science and Industry or JIP¹⁻⁴. It was concluded that SRC was caused by the accommodation of strain due to both carbide/nitride precipitation hardening inhibiting dislocation movement and the formation of precipitation free zone along the $M_{23}C_6$ carbide at grain boundary during stress relaxation process of welding residual stresses at temperatures between 550°C and 750°C.

For example, API Technical Report 942-B reports that the order of SRC susceptibility (from highest to lowest) for various austenitic stainless steels is UNS N08811 > S34709 > N08810 > S32109 > S30409 > S31609⁵. S34709 is mainly selected in high temperature operations in complex refineries or chemical plants. This is due to S34709's superior sensitization resistance and higher creep rupture strength compared with S30409 or S31609 with regard to 18Cr-8Ni based austenitic stainless steel grades. S34709 has higher SRC susceptibility than S30409 or S31609, and requires Post Weld Heat Treatment (PWHT) to prevent SRC at welded joints. However, there are some welded portions where PWHT can be eliminated due to either the difficulty of PWHT or increase of fabrication costs.

Alloys S34709 or S30409 indicate higher SRC susceptibility compared with S31609, and requires Post Weld Heat Treatment (PWHT) to prevent SRC. Therefore, end users and fabricators using S34709 or S30409 have a strong interest in understanding austenitic stainless steels with superior SRC resistance where PWHT can be eliminated.

In our research, proprietary version S34751 was studied due to its extreme low carbon and higher nitrogen contents. Both stress relaxation test and thermodynamic calculations revealed that proprietary version S34751 indicated higher SRC resistance than S34709 and S30409 without PWHT.

Both NACE Paper No.2019-12783 and 2020-16778 noted that proprietary version S34751 with targeted chemical compositions had superior Polythionic Acid Stress Corrosion Cracking (PTA SCC) resistance without PWHT⁶⁻¹⁰. The generic characteristics of proprietary version S34751 are both extra low carbon content and higher Nb/C ratio to achieve a much lower amount of $M_{23}C_6$ carbide precipitation along grain boundary compared to other conventional austenitic stainless steels at the sensitization temperature range. Thus, proprietary version S34751 is expected as 18Cr-8Ni austenitic stainless steel with superior SRC resistance from the viewpoints of few precipitation free zone formed along $M_{23}C_6$ carbides at grain boundary at sensitive temperature to SRC around 650°C.

In our research, proprietary version S34751 was studied due to its extreme low carbon and higher nitrogen contents. Both stress relaxation test and thermodynamic calculations revealed that proprietary version S34751 indicated higher SRC resistance than S34709 and S30409 without PWHT.

EXPERIMENTAL PROCEDURE

Proprietary version S34751 was melted using a 70 ton Electric furnace and a slab was manufactured. It was rolled to thickness of 30mm and received a solid solution heat treatment over 1060°C WQ. S34709 and S30409 were melted by 30kg VIM furnace. The melted ingots were hot forged and rolled to 15 mm, and were solid solution heat treated at 1100°C WQ for S34709 and 1060°C WQ for S30409, respectively. Table 1 shows ladle analysis results of test material. Proprietary version S34751, S34709 and S30409 corresponded to Items 347AP, 347H and 304H in Table 1 respectively.

Table 1 Ladle analysis results of test materials. (wt%)

Item 1	C	Si	Mn	P	S	Ni	Cr	Nb	N
347AP (S34751)	0.011	0.28	1.34	0.023	0.0005	9.93	17.0	0.38	0.083
347H (S34709)	0.077	0.38	1.48	0.031	0.0010	10.5	18.0	0.79	0.002
304H (S30409)	0.073	0.41	1.44	0.024	0.0005	8.19	18.3	-	0.060

A Square type long test specimen with dimensions of 10mm x 10mm x 100mm was cut from the test material. A simulated HAZ microstructure was produced by a thermal cycle shown in Figure 1 using a Gleeble test machine. After the thermal cycle test, a microstructural observation at uniformed HAZ simulated area was conducted.

In order to evaluate SRC susceptibility, the relaxation test machine was applied in accordance with ASTM⁽²⁾ E328-02. Figure 2 shows the schematic illustration of relaxation test sample taken. The relaxation test conditions were as follows. (1) Application of 20% strain to test sample at room temperature (2) Heating the test specimen to 650°C without restriction (3) Application of 5% strain to test sample at 650°C (4) Holding test specimen under constant strain of 5% to 300 hours at 650°C. After 300 hours holding, the cross section microstructure in the middle of test sample was evaluated by optical microstructure, Scanning electron microscope (SEM) to confirm SRC. Additionally, the variation of microstructure before/after relaxation test was investigated by the analysis of extracted residue and Transmission electron microscope (TEM) to extracted replica film.

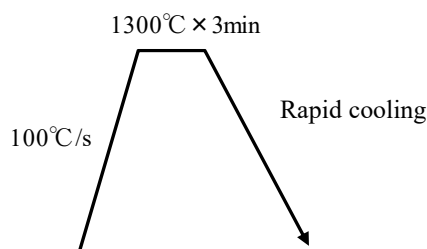


Figure 1 : Thermal cycle condition

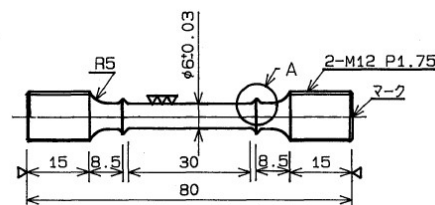


Figure 2 : Schematic illustration of relaxation test sample

RESULTS

Figure 3 shows the microstructures of Items 347AP, 347H and 304H after simulated HAZ heat treatment. It was found that there was the difference of grain size among these materials and the averaged grain sizes were measured as about 100 μm for Item 347AP, 150 μm for Item 347H and 400 μm for Item 304H.

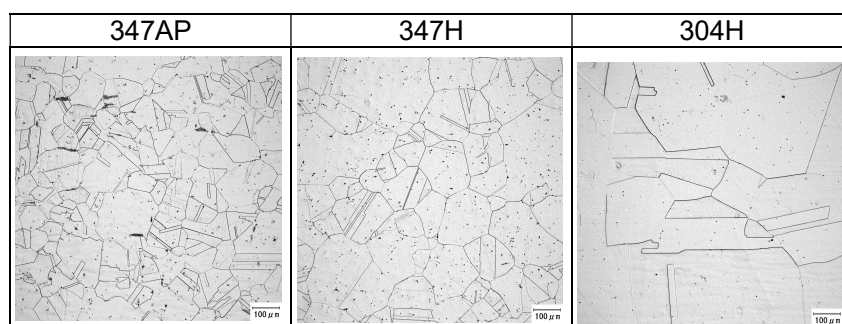


Figure 3 : Microstructure after simulated HAZ heat treatment.

Figure 4 shows the relaxation test results of Items 347AP, 347H and 304H at 650°C. X axis represents holding time and y axis represents stress. It was confirmed that the applied stress at the initiation of relaxation gradually decreased with increasing holding time under constant strain of 5% and stress relaxation behavior could be simulated using the present test equipment.

(2) ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959 USA