Materials Science & Engineering A 578 (2013) 430–437

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Factors affecting Type IV creep damage in Grade 91 steel welds

Jonathan Parker*

EPRI, 1300 West WT Harris Boulevard, Charlotte, NC 28262, USA

ARTICLE INFO

Article history:
Received 21 January 2013
Received in revised form
9 April 2013
Accepted 11 April 2013
Available online 4 May 2013

Keywords:
Creep
Grade 91
Steel
Weld
Type IV

ABSTRACT

Differences in parent material heat treatment and composition apparently have remarkably little influence on the creep life of the heat affected zone (HAZ). Thus, tendency for Type IV cracking in the fine grained or intercritically heat treated regions of the HAZ does not appear to directly depend on the strength of the base steel. However, the current work indicates that the angle of the weld preparation changes the measured cross weld creep life. The results presented suggest that both development of residual stresses and the local properties of the constituent zones in the HAZ influence the tendency for Type IV damage in martensitic steels.

1. Introduction

It is now well established that for subcritically heat treated welds in creep strength enhanced ferritic steels such as Grade 91, 92 and 911, the primary concern for long term creep life in welded components is Type IV cracking in the heat affected zone (HAZ). Evaluation of samples subjected to laboratory tests and examination of in-service components shows that the most susceptible region of the HAZ is the fine-grained location [1]. The failures typically occur where the weld thermal cycles result in the formation of very small equiaxed prior austenite grains, often with the grain boundaries decorated with large precipitates. It is frequently the case that, while the normal microstructure for 9–12% Cr steels is tempered martensite, in the locations most susceptible to Type IV cracking no martensitic lath structure is present. Final fracture typically takes place following nucleation, growth and interconnection of single creep voids to form micro-cracks, which themselves finally coalesce to form macro-cracks.

Of particular importance to assessment of in-service behaviour of welded components is the fact that Type IV cracking occurs significantly before the expected creep life of the parent steel [1]. This behaviour is illustrated for Grade 91 steel welds in Fig. 1 [2]. The reduction in creep performance due to this damage has necessitated development of the concept of a weld strength reduction factor (WSRF). The WSRF, defined as a ratio of the stresses causing rupture at the same time in welded joint and base metal, has been introduced into design codes for high-temperature nuclear power and for process piping. In general, the procedure for calculating this factor involves obtaining a welded joint 'allowable stress' based on cross weld creep rupture data and then calculating WSRF as the ratio of this value to the allowable stress for parent. The calculated WSRF for Grade 91, Grade 92 and Grade 122 assessed based on analysis of Japanese creep data are listed in Table 1 [3]. For each alloy, the life reduction increases as the operating temperature increases above about 550 °C. However, the specific WSRF values are different for the different steels, with the life reduction in Grade 91 steel generally being less than in Grade 92 and Grade 122.

The present paper describes results from a recent EPRI project which was developed to examine key issues associated with the creep behaviour of Grade 91 welds.

2. Material and weld manufacture

The current project involved assessment of the creep behaviour of different welds manufactured in three different parent components. The primary reason for selecting different parent components was that there is evidence that there are significant differences in long term creep strength depending on the levels of Al and nitrogen present. Thus, Grade 91 type steels with N:Al ratio around 1 have been noted to have creep strength at or even below the scatter band of typical parent behaviour [4]. The measured composition for each component is presented in Table 2. As indicated, the ratio of N:Al for these components was 1.05, 4.7 and 13.5 for plate 1, pipe 2 and pipe 1 respectively. The amounts of the other elements were generally similar and were all within the ranges of the applicable specifications [e.g. 5].

---

* Tel.: +1 704 595 2719; fax: +1 704 595 2867.
E-mail address: jparker@epri.com

0921-5093/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2013.04.045

Each component was normalized at 1060 °C (1940 °F) and tempered at 760 °C (1400 °F). Thus, in each case, the components exhibited a typical tempered martensitic microstructure in the parent. In general, the weld fabrication methods used were typical of those used in fabrication of power components. However, specific items were changed to allow the influence of the following variables on creep performance to be evaluated:

- The angle of the weld interface,
- The level of weld preheat, and
- The creep strength and composition of the Grade 91 parent.

Initial testing was carried out to establish conditions for uniaxial testing which would generate damage relevant to assessment of Type IV cracking.

Weld 1. This weld was manufactured in a section of Grade 91 pipe, identified as pipe 2 in Table 2. A specialist approach was taken to fabricate this weld. Thus, a groove 50 mm wide and 50 mm deep was machined in the wall of a section of pipe; a photograph of the groove prior to welding is shown in Fig. 2. This groove had one side at an angle of 15° to the vertical and was filled using the shielded metal arc process. The procedure involved a 200 °C (392 °F) preheat, 300 °C (572 °F) maximum interpass and used 3.2 mm and 4 mm diameter electrodes which complied with AWS A5.5 E9016-B9. The post-weld heat treatment was performed at 765 °C (1409 °F) for 3 h.

Weld 2. This weld was manufactured in a Grade 91 steel plate 1. This plate was 37.5 mm thick. The weld preparation was a 30° bevel (60° included angle), with a root opening of 3 mm. The welding was carried out with a preheat of 204 °C (400 °F), using the Gas Metal Arc process. The rod sizes were 3 mm rod for passes 1 and 2, 2.4 mm rod for passes 3–6 and 3 mm rod for the remainder. The interpass temperature was limited to 260 °C (500 °F) or less. Consumables conformed to AWS A5.5 E9016-B9.

Welds 3 and 4. These welds were also manufactured in the Grade 91 plate 1. The procedures and consumables were similar to those used for weld 2 with the following key exceptions. Although both of these welds were made using a 10° bevel (20° included angle), weld 3 was made with the normal 204 °C (400 °F) preheat and weld 4 was made using a very high preheat of 482 °C (900 °F).

Weld 5. This weld was manufactured using a similar preparation and procedure to that of weld 3, however, the parent was taken from a pipe section which exhibited a high N:Al ratio. This component is identified as Pipe 1 in Table 2.

3. Results

The laboratory evaluation involved detailed metallographic characterization using optical microscopy followed by specimen fabrication and cross weld creep testing. The creep samples manufactured from weld 1 were cylindrical with a weld fusion line at the center. The creep samples manufactured from the other welds were produced with rectangular section and were significantly larger. In these samples, the welds were at the center of the gauge length so that the testpieces included both HAZs. With this approach, there were nominally the same 2 HAZ regions in each sample so that each test offered the opportunity to evaluate the reproducibility of damage development. The samples tested were of relatively large size compared to standard cylindrical testpieces; the typical dimensions were a uniform gauge length of 72 mm, width 38 mm and thickness 12 mm. A typical photograph of a creep sample is shown in Fig. 3. In this photograph the

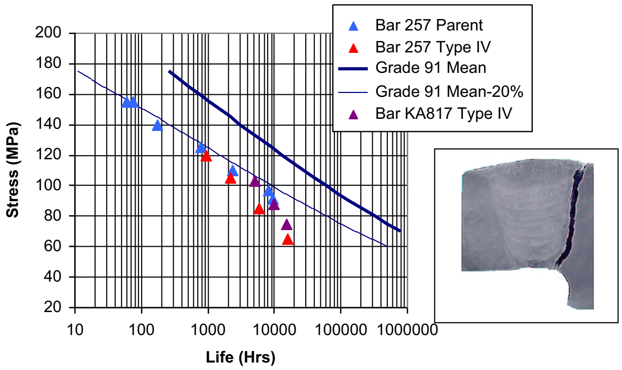

Fig. 1. Comparison of the creep rupture lives of cross weld samples which failed by Type IV cracking in the HAZ with parent behaviour, all data are for Grade 91 steels tested at 600 °C. Based on data from [2].

Table 2
Measured compositions for the three components used in the present work.

Element	Pipe 1	Pipe 2	Plate 1
Carbon (C)	0.11	0.11	0.099
Manganese (Mn)	0.40	0.47	0.42
Phosphorus (P)	0.013	0.012	0.014
Sulfur (S)	0.008	0.002	0.003
Silicon (Si)	0.29	0.31	0.23
Chromium (Cr)	8.51	8.66	8.96
Molybdenum (Mo)	0.92	0.95	0.86
Vanadium (V)	0.20	0.212	0.20
Nitrogen (N)	0.054	0.066	0.041
Nickel (Ni)	0.15	0.20	0.13
Aluminum (Al)	0.004	0.014	0.041
(Cb)/(Nb)	0.070	0.071	0.07
N/Al ratio	13.5	4.71	1.05

Table 1
Evaluation of weld strength reduction factors for Grade 91, Grade 92 and Grade 122 steels on the basis of a recent re-evaluation of the results of long term creep testing [3].

Material		Weld strength reduction factor						Notes
		525 °C	550 °C	575 °C	600 °C	625 °C	650 °C	
Grade 91	KA-SCMV28	1.0	0.90	0.82	0.79	0.79	0.79	
	KA-STPA28	1.0	0.90	0.74	0.67	0.65	0.65	≤ 76 mm
	KA-SFVAF28	1.0	0.90	0.74	0.68	0.65	0.65	> 76 mm
Grade 122	KA-SUS410J3	1.0	0.84	0.68	0.57	0.50	0.50	
	KA-SUS410J3TP	1.0	0.84	0.60	0.50	0.50	0.50	
	KA-SUSF410J3							
Grade 92	KA-STPA29	1.0	1.0	0.74	0.62	0.53	0.53	
	KA-SFVAF29							