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Original Article

Strengthening of stainless steel weldment by high temperature precipitation☆

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ABSTRACT

The mechanical behavior and the strengthening mechanism of stainless steel welded joints at 600 °C have been investigated. The welds were composed of AISI 304 stainless steel, as base metal, and niobium containing AISI 347 stainless steel, as weld metal. The investigation was conducted by means of creep tests. The welded specimens were subjected to both high temperature (600 °C) and long periods (up to 2000 h) under constant load, and both mechanical properties and microstructural changes in the material were monitored. It was found that the exposure of the material at 600 °C under load contributes to a strengthening effect on the weld. The phenomenon might be correlated with an accelerated process of second phase precipitation hardening.

1. Introduction

Several mechanical components and structures that operate at high temperatures have been produced using austenitic stainless steels, due to its high resistance to hot oxidation and creep [1,2]. These systems are extensively fabricated using welding processes for strong and reliable joints [3–7]. Typical welded components and structures are found in petroleum refinery towers and fast nuclear reactors [8–11]. Welding electrodes made of stainless steel either contain low carbon or carbide formation alloy elements such as titanium (Ti) and niobium (Nb). This is a basic requirement to avoid a serious corrosion problem, known as sensitization, associated with chromium carbide grain boundary precipitation.

The welding of a largely employed austenitic stainless steel, the AISI type 304, may use not only electrodes of low carbon AISI type 308, but also Ti containing AISI type 321 or Nb containing AISI type 347 [12]. In the particular case of high temperature application of components and structures made of 304 steel, the main problem is not the hot oxidation, but changes in mechanical properties due to phase and microstructural transformations. It was earlier observed [13] that the welding thermal effects originate different kinds of ferrite, with distinct sizes, in the austenitic matrix. For long times operating at high temperatures, not only ferrite

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Table 1 – Chemical composition (wt%) of austenitic stainless steels used in the weldment.

AISI type	C	Cr	Ni	Mn	Si	Nb
304 (base)	0.060	18.3	8.4	1.77	0.52	–
347 (weld)	0.084	18.9	9.1	1.40	0.65	0.93

transformation, but also precipitation of new phases and morphological changes of these phases were detected [14].

A previous evaluation of the performance at 700 °C of the 304 steel welded using 347 filler, reported by White and Le May [15], revealed a tendency of decreasing the mechanical strength with treating time. Indeed, after a brief period of strengthening in the fusion zone (FZ), carbide precipitation would reduce the strength of the joint, acting mainly in the heat affected zone (HAZ). By contrast, preliminary results at 600 °C [16,17] indicated strengthening of both the FZ and HAZ for the whole component operation life. This particular temperature, 600 °C, corresponds to the highest operation temperature required for 304 steel welded components. In those preliminary works, static mechanical properties were obtained for the 304/347 welds, at room temperature, after heat treatments at 600 °C. However, the high temperature structural changes under load are probably distinct from those static conditions, and so, creep tests might be a more adequate methodology for this evaluation.

Therefore, the objective of the present work is to evaluate the creep behavior of 304/347 welded joints at the temperature of 600 °C.

2. Materials and methods

The chemical compositions of the AISI 304 austenitic stainless steel rolled plate, supplied by Villares, Brazil, and the AISI 347 steel electrodes are presented in Table 1. The grain size of the as-received 304 steel plate was 75 μm.

Butt weld was performed according to procedures presented elsewhere [17]. Standard ASTM [18] round specimens with 6 mm of gage diameter and 38 mm of gage length were machined from different parts of the weldment. The series of specimens corresponding to position and length direction were identified as following:

I – base metal along the plate rolling direction.
SL – weld metal in the longitudinal direction.
ST – weld metal in the transversal direction.
J – specimens cut across the base metal/weld metal/base metal.

Creep tests were conducted at 600 °C in a tubular furnace of a WPM equipment, from Germany. Metallographic sections of tested specimens were polished with emery paper and diamond paste before etch with oxalic acid. Microstructure was observed in a Neophot optical microscopy.

3. Results and discussion

Typical creep curves are shown in Fig. 1, for specimens of the four distinct series: I, SL, ST and J. As illustrated, some tests of the I series were stopped over 2000 h. In fact, I series corresponds to the base 304 steel, but did not include the weld metal 347 steel, responsible for the investigated thermal effects.

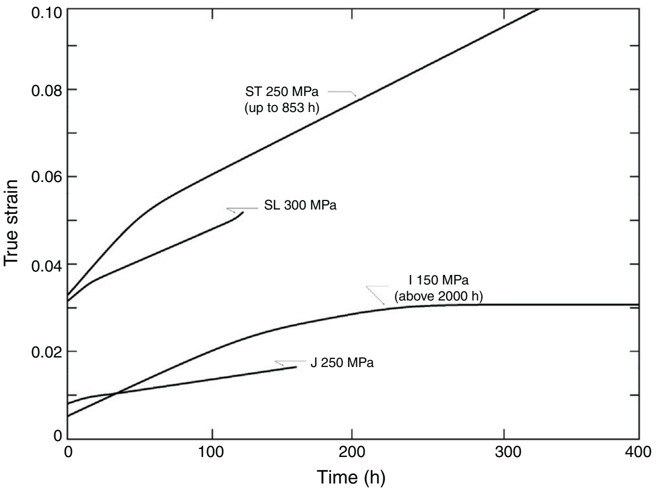

Fig. 1 – Typical creep curves for specimens associated with distinct positions and directions in the 304/347 steel weldment.

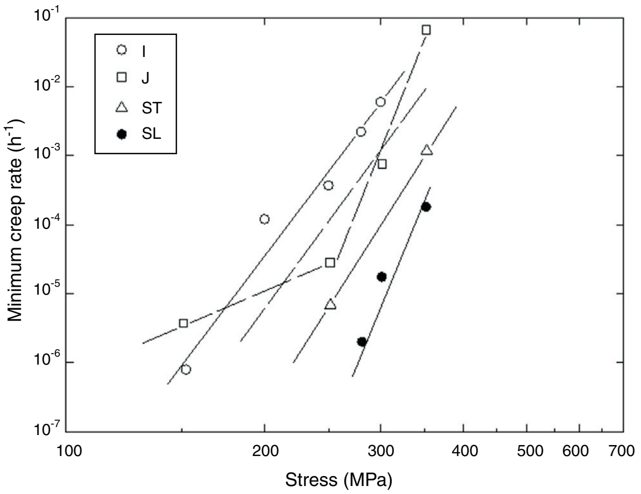

Fig. 2 – Variation of creep rate with stress for specimens associated with distinct positions and directions in the 304/347 steel weldment.

From curves such as those shown in Fig. 1, the minimum creep rate, $\dot{\varepsilon} = d\varepsilon/dt$, associated with the slope of stage II of creep [18], was calculated and plotted against the applied constant creep stress. Fig. 2 shows in a double log scale the variation of the creep rate with corresponding stress.

Excluding the J series, single straight lines were adjusted to corresponding points of series I, ST and SL. This indicates that a characteristic power law (Eqs. (1) and (2)) [18] holds between σ and $\dot{\varepsilon}$.

$$\dot{\varepsilon}_m = k \cdot \sigma^n \tag{1}$$

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