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Correlation between microstructure and creep performance of martensitic/austenitic transition weldment in dependence of its post-weld heat treatment

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ABSTRACT

This paper deals with the influence of post-weld heat treatment (PWHT) of T92/TP316H martensitic/austenitic transition weldment on the resulting microstructure and creep characteristics. Experimental weldments were fabricated by gas tungsten arc welding using a nickel-based weld metal (Ni WM). After the welding, two individual series of produced weldments were heat-treated according to two different PWHT procedures. The first "conventional PWHT" was carried out via subcritical tempering (i.e. bellow Ac_1 temperature of T92 steel), whereas the other one, the so-called "full PWHT" consisted of a complete reaustenitization of the weldments followed by water-quenching and final tempering. The use of "conventional PWHT" preserved microstructural gradient of T92 steel heat-affected zone (HAZ), consisting of its typical coarse-grained and fine-grained subregions with tempered martensitic and recrystallized ferritic–carbidic microstructures respectively. In contrast, the "full PWHT" led to the complete elimination of the original HAZ via transformation processes involved, i.e. the reaustenitization and back on-cooling martensite formation. The observed microstructural changes depending on the initial PWHT conditions were further manifested by corresponding differences in the weldments' creep performance and their failure mode. The weldments in "conventional PWHT" state ruptured after long-term creep tests by premature "type IV failure" within their recrystallized intercritical HAZs. On the contrary, the long-term creep behavior of the weldments processed by "full PWHT" was characterized by their remarkable creep life extension but also by the occurrence of unfavorable "decohesion failure" along T92/Ni WM interface.

1. Introduction

The 9%Cr martensitic steels are used in power generation industry for thick-walled boiler components such as steam headers and main steam piping because of the relatively low coefficient of thermal expansion and favorable cost compared to the high-alloyed austenitic steels [1]. However, the austenitic steels with their excellent corrosion and creep resistance are frequently used for construction of superheaters [2]. This indicates that the joining of martensitic and austenitic steels is rather necessary in supercritical boiler constructions.

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During the first implementation of transition weldments between ferritic (e.g. tempered bainitic or tempered martensitic) steels and austenitic steels, the use of austenitic steel type welding consumables was typical [3]. However, further experience with these welds revealed a serious problem related to the carbon diffusion processes across the ferritic/austenitic weld interface, resulting in the formation of soft carbon-depleted zones, the so-called "white bands" at the ferritic side of the welded joints with deteriorated creep strength. To prevent this problem, alternative nickel-based welding filler materials have been invented [4]. The main benefit of Ni-based weld metal (Ni WM) comes from its low carbon solubility, so it acts as a carbon diffusion barrier. Moreover, thermal properties such as thermal conductivity and expansivity of Ni-based alloys lie in a medium range between the corresponding properties of ferritic and austenitic steels. Thus the use of Ni WM is very suitable in transition weldments for the lowering and/or moderation of the gradient of residual welding stresses [5,6].

Many previous investigations, e.g. [7–9] were focused on the Ni-based transition joints between 2.25Cr–1Mo ferritic–bainitic steel and "AISI 300 series" austenitic steels. Recently published studies [2,10–15] include the results obtained for the martensitic/austenitic weldments involving 9%Cr martensitic base materials. Nevertheless, literature concerning the effects of the variation of post-weld heat treatment (PWHT) conditions on microstructure and creep behavior of martensitic/austenitic weldments is very limited. In general, the weldments of martensitic steels require an application of PWHT in order to relieve residual stresses and stabilize the microstructure with strengthening precipitates [16–18]. Conventional way of PWHT of these weldments consists of subcritical tempering with respect to the steels' Ac_1 temperature, typically in the range from 720 to 760 °C [16]. It is also well-known that the "conventional PWHT" improves the weldments' toughness but the remaining problem is their premature "type IV failure" in the heat-affected zone (HAZ) during operation in creep conditions [1,19,20]. Albert et al. [19] concluded that this failure mode cannot be suppressed by any variation of subcritical PWHT conditions. Recently, Abe et al. [21] found out that the welded joints of newly developed 9Cr–3W–3Co–0.2V–0.05Nb steel with 160 ppm boron and 85 ppm nitrogen exhibited no "type IV failure" in relatively short to medium-term creep conditions as a result of specific modification of HAZ microstructure. However, long-term creep tests of this new promising martensitic steel with modified **B** and **N** contents (from there **"MARBN"** steel) are still in progress [21]. On the other hand, Tezuka and Sakurai [22] and Kimura et al. [23] suggested that a possible way to avoid "type IV failure" of the weldments is their full renormalization. In a specific case of the weldments between martensitic and austenitic steels, PWHT conditions are commonly specified according to the "conventional" (subcritical) procedure with regard to the martensitic base material of welded joint [24]. However, available information about the application of "full PWHT" for martensitic/austenitic weldments is rather scarce [25–27].

The present study represents an extended and continuing research work of the former study by Falat et al. [25]. It summarizes the results regarding the effects of "conventional" as well as "full PWHT" on microstructure and creep performance of T92/TP316H transition weldments.

2. Experimental procedure

Dissimilar steels T92 and TP316H in the form of tubes with outer diameter of 38 mm and wall thickness of 5.6 mm were welded by gas tungsten arc welding (GTAW) using Ni-based filler alloy Nirod 600. The electrode diameter was 2.4 mm and the applied welding parameters were: welding current 70–110 A, voltage 12–17 V and heat input 9–12 kJ/cm. Chemical compositions of the individual materials used for fabrication of T92/TP316H weldments are listed in Table 1.

After the GTAW process, two different PWHT procedures were applied to the first and second series of the produced weldments respectively. The "conventional PWHT" consisted of subcritical tempering at 760 °C for 1 h, followed by air cooling in furnace to room temperature. The second series of the weldments was subjected to the so-called "full PWHT" including a complete reaustenitization at 1060 °C for 15 min with subsequent water-quenching and subcritical tempering at 760 °C for 1 h and air cooling down in furnace. Detailed PWHT diagrams of both the used procedures are shown in Fig. 1.

All experimental work was performed using cross-weld (c-w) samples. Prepared tubular weldments were cut into the c-w blocks, as schematically shown in Fig. 2. The creep tests were performed using cylindrical tensile samples with a gauge length of 40 mm, body diameter of 4 mm, and M6 head thread. Metallographic analyses involved light microscopy (LM), scanning electron microscopy (SEM) with energy dispersive X-ray (EDX) spectroscopy, and transmission electron microscopy (TEM). Etched metallographic samples were used for LM and SEM analyses. The used etching solutions were specified in [25]. Thin foils for TEM observations were prepared using focused ion beam (FIB) technique, applied perpendicularly onto the longitudinally sectioned tensile creep specimens at the locations immediately beneath their creep fractures. Thermodynamic calculations of phase equilibria were performed using the software Thermo-Calc [28] and thermodynamic database STEEL16 formulated by Kroupa et al. [29].

Table 1
Chemical composition (wt.%) of individual materials of the dissimilar weldment.

	C	N	Si	Mn	P	S	Cr	Mo	W	B	Ni	Al	V	Nb	Fe
T92	0.11	0.056	0.38	0.49	0.019	0.002	9.08	0.31	1.57	0.0023	0.33	0.014	0.2	0.069	Balance
Nirod 600	0.05	–	0.3	3.0	0.03	0.015	20.0	–	–	–	Balance	–	–	2.0	2.0
TP316H	0.052	–	0.51	1.77	0.031	0.006	16.76	2.05	–	–	11.13	–	–	–	Balance