International Journal of Pressure Vessels and Piping 87 (2010) 336–344

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

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

Creep properties and microstructural evolution of austenitic TEMPALOY steels

S. Caminada [a,*], G. Cumino [a], L. Cipolla [b], D. Venditti [b], A. Di Gianfrancesco [b], Y. Minami [c], T. Ono [c]

[a] TenarisDalmine, Piazza Caduti 6 Luglio 1944 1, 24044 Dalmine (BG), Italy
[b] Centro Sviluppo Materiali SpA, Via di Castel Romano 100, 00128 Rome, Italy
[c] TenarisNKKTubes, 1-10 Minamiwatarida, Kawasaki, 210-0855 Kanagawa, Japan

ARTICLE INFO

Article history:
Received 30 November 2008
Accepted 22 January 2010

Keywords:
TEMPALOY AA-1
TEMPALOY A-3
Creep
Microstructural evolution
Shot blasting

ABSTRACT

The steam parameters in the new high efficiency fossil fuel power plants are continuously increasing, requiring new advanced materials with enhanced creep strength able to operate on the most severe temperature and pressure conditions. For super-heater and re-heater applications, TEMPALOY AA-1 steel, an evolution of 18Cr10NiNbTi alloy, has been developed through the addition of 3%Cu and B, significantly enhancing the creep resistance, while offering typical corrosion properties of 18%Cr steels. This paper describes Tenaris' tubular products in the field of austenitic grades for applications in Ultra Super Critical power plants: the production route and the main microstructural and mechanical properties of TEMPALOY AA-1 and TEMPALOY A-3 steels, including the effect of shot blasting on steam-oxidation resistance, their creep–rupture properties and their microstructural evolution during temperature exposure are presented.

1. Introduction

Severe requirements on strength, corrosion, creep properties and thermal stability during service are requested for high-temperature resistant steels for boilers, steam lines and headers in Ultra Super Critical (USC) power plants. Tenaris has accumulated a great experience in the production of C–Mn and Cr–Mo ferritic/martensitic grades in TenarisDalmine and TenarisSilcotub plants, as well as, of austenitic grades TEMPALOY AA-1 and A-3 in TenarisNKKTubes.

The development and the industrialization of the austenitic grades were supported by R&D activities carried out by TenarisNKKTubes [1–7]. The advanced microstructural characterization and the evaluation of the long term microstructural characterization have been performed in cooperation with Centro Sviluppo Materiali (CSM).

In particular the product development on austenitic grades has been focused on:

- TEMPALOY AA-1, as improved version of 18Cr-10Ni-Nb-Ti with addition of 3%Cu, showing high creep and corrosion resistance properties;
- TEMPALOY A-3, a 20Cr–15Ni–Nb–N steel, showing good creep behaviour and excellent corrosion resistance.

The main microstructural and mechanical properties of these austenitic steels, the effect of shot blasting on high-temperature steam-oxidation resistance, as well as, the R&D activities in the field of alloy design, creep data assessment and microstructural analysis are described in this paper.

2. Chemical composition and production route

The chemical compositions of Tenaris' austenitic steel grades TEMPALOY AA-1 and TEMPALOY A-3 are shown in Table 1. TEMPALOY AA-1 is registered as ASME code Case N° 2512 and in ASTM A213 as UNS S30434; it is also registered as KA-SUS321J2HTB in METI Standards of Japan. TEMPALOY A-3 is registered as ASME code Case N° 2598 and in ASTM A213 as UNS S30942; it is registered in METI Standards of Japan as KA-SUS309J4HTB.

TEMPALOY steel grades are produced in Japan under supervision of TenarisNKKTubes. Steel is continuous cast and then hot rolled. The billets are pre-heated and extruded in the press to create a hollow. Then the hollow is cold pilgered to the final size and heat treated. TEMPALOY AA-1 and A-3 tubes are supplied after solution heat treatment. The heat treatment temperature is above 1160 °C. The heat treated tubes are then pickled, finished and, if required, TEMPALOY AA-1 tubes can also be shot-blasted on the internal surface in order to enhance steam-oxidation resistance.

3. Mechanical properties and long term microstructural evolution

3.1. Mechanical strength and creep properties

Table 2 summarizes the minimum required mechanical properties of TEMPALOY grades according to ASTM A213 standard. Fig. 1

* Corresponding author. Tel.: +39 025 5602833; fax: +39 035 5602845.
E-mail address: scaminada@tenaris.com (S. Caminada).

0308-0161/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijpvp.2010.03.009

Table 1
Chemical composition of TEMPALOY AA-1 and A-3 according to ASTM A213 standard.

wt%		C	Si	Mn	P	S	Cu	Ni	Cr	Ti	Nb	B	N	(Ti + Nb/2)C
TEMPALOY AA-1	Min	0.07	–	–	–	–	2.50	9.0	17.5	0.10	0.10	0.001	–	2.0
	Max	0.14	1.00	2.00	0.040	0.010	3.50	12.0	19.5	0.25	0.40	0.004	–	4.0
TEMPALOY A-3	Min	0.03	–	–	–	–	–	14.5	21.0	–	0.50	0.001	0.10	–
	Max	0.10	1.00	2.00	0.040	0.030	–	16.5	23.0	–	0.80	0.005	0.20	–

Table 2
Minimum required mechanical properties of TEMPALOY AA-1 and A-3 according to ASTM A213 Standard.

Steel grade	YS [MPa]	UTS [MPa]	Elongation [%]	Hardness [HRB]
TEMPALOY AA-1	>205	>500	>35	<90
TEMPALOY A-3	>235	>590	>35	<95

shows the effect of temperature on yield strength (YS) and ultimate tensile strength (UTS): both grades show a high stability of their mechanical strength over a wide range of temperatures, even above the target service temperature.

The creep–rupture strength of both grades has been extensively characterized in a wide temperature range (600–800 °C) in order to obtain a reliable database. For TEMPALOY AA-1 more than 1.5 million hours of creep tests have been accumulated and some tests with durations over 1.2×10^5 h are still running. A high number of creep tests have been performed on TEMPALOY A-3 also; some tests, still on-going, are targeting 10^5 h.

Creep databases have been assessed by Mendelson–Robertson–Manson (MRM) method, following the European Creep Collaborative Committee (ECCC) guidelines [8–10]: the average creep–rupture stresses for both TEMPALOY AA-1 and A-3 are shown in Table 3. The calculated isotherms have been validated by Post Assessments Tests (PATs): the PATs cover extrapolations within 150 kh for TEMPALOY AA-1 and within 100 kh for TEMPALOY A-3.

Fig. 2a and b shows respectively the average creep–rupture isothermal curves of TEMPALOY AA-1 as well as its PAT 2.1.

Creep tests on similar butt welded joints of TEMPALOY AA-1 and TEMPALOY A-3 were conducted to study the effect of the welding process on cross-weld creep properties. Figs. 3 and 4 show the creep resistance of butt welded joints respectively for TEMPALOY AA-1 and A-3 by GTAW and GTAW + SMAW processes, using specific similar welding consumables produced by Kobelco. Creep resistance of welded joints is in line with that of base material in the temperature range 600–800 °C.

3.2. Long term microstructural evolution

3.2.1. TEMPALOY AA-1

The microstructure of TEMPALOY AA-1 consists of full austenite, free from δ-ferrite, obtained by balanced amounts of Cr and Ni; Fig. 5a and b shows its microstructure in the as-treated state by Light Microscope (LM) and Scanning Electron Microscope (SEM). After solubilisation heat treatment the precipitation of TEMPALOY AA-1 consists of Nb- and Ti-carbides (≤1 μm average size), located along grain boundaries as well as inside the grain. Fig. 6 shows the typical (Nb,Ti)(C) precipitates in as-treated TEMPALOY AA-1 steel.

With exposure at service temperatures in the range 600–750 °C, a precipitation of $M_{23}C_6$ carbides along grain boundaries occurs as well as fine and evenly distributed Ti- and Nb-carbides (MC) precipitate inside the grain, so promoting the creep resistance of the steel [11,12].

Besides, the addition of Cu determines the precipitation of fine and diffuse Cu-rich phase, which increases significantly the creep resistance of the steel (see Fig. 7). Creep tests at 700 °C were conducted on 16Cr–14Ni steel samples with different Cu content: a Cu addition up to 3% increases the creep–rupture stress to achieve rupture within 1000 h, while further addition of Cu over 3% has no incremental strengthening effect [13].

Fig. 8 shows the microstructure of TEMPALOY AA-1 after two years of service in a power plant: $M_{23}C_6$, MC and Cu phases were identified.

TEM and SEM investigations were performed on broken creep samples after long exposures at different temperatures.

Fig. 9 shows the microstructure of an aged sample after 33 kh at 600 °C by TEM thin foil: $M_{23}C_6$, MC and Σ particles were identified.

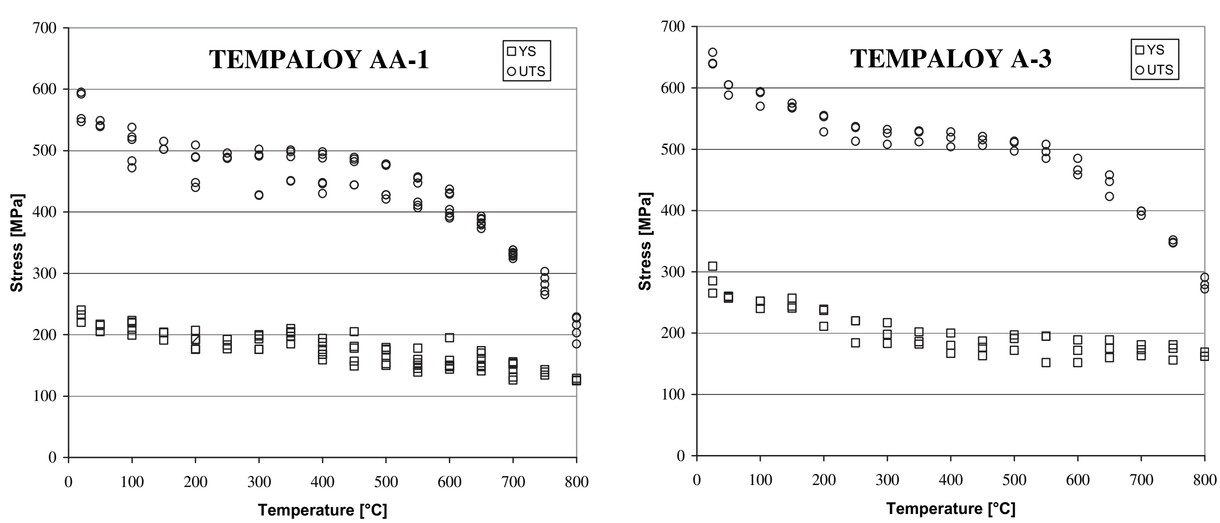

Fig. 1. Mechanical tensile properties (YS and UTS) at high temperature of TEMPALOY AA-1 and TEMPALOY A-3.