Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 74 (2014) 179 – 182

Procedia Engineering

www.elsevier.com/locate/procedia

XVII International Colloquium on Mechanical Fatigue of Metals (ICMFM17)

The influence of chromium nitrides precipitation on the fatigue behavior of duplex stainless steels

S.Hereñú[a], M.G.Moscato[b,*], I. Alvarez[b], A.F. Armas[b]

[a]*Instituto de Física Rosario, UTN-FRSN, Bv. 27 de Febrero 210Bis, 2000 Rosario, Argentina*
[b]*Instituto de Física Rosario, UNR-FCEIA, Bv. 27 de Febrero 210Bis, 2000 Roario, Argentina*

Abstract

This paper studies the fatigue behavior at room temperature of UNS S32205 and UNS S32750 duplex stainless steels (DSSs) under two thermal treatments. In both types of DSSs, thermal treatments at high temperature followed by water quenching (TTW) produces the precipitation of Cr_2N within the ferrite phase. The amount of Cr_2N increases mainly with the ferritic grain size independently of the nitrogen content. This nitride precipitation hardens the ferritic phase and produces a detrimental effect on the fatigue life of both steels.

Selection and peer-review under responsibility of the Politecnico di Milano, Dipartimento di Meccanica

Keywords: Duplex stainless steel, Thermal treatments, Cr_2N precipitation, Low cycle fatigue.

1. Introduction

In DSSs, precipitation of nitrides occurs when after thermal treatments at high temperature the supersaturation of nitrogen in the ferritic phase have insufficient time during cooling for diffusion into austenite [1, 2]. Though intragranular Cr_2N precipitation causes detrimental effects on the mechanical properties of DSSs, in literature scarce studies are focused on this problem [3, 4] compared to the known detrimental effects of intermetallic phases and spinodal decomposition [5]. Moreover, a detailed analysis of this particular problem on fatigue behavior has not yet been published. Therefore, the purpose of this paper is to analyze the influence of Cr_2N precipitation on the fatigue behavior of DSSs with different microstructure and nitrogen content.

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: moscato@ifir-conicet.gov.ar

Selection and peer-review under responsibility of the Politecnico di Milano, Dipartimento di Meccanica
doi:10.1016/j.proeng.2014.06.246

2. Material and experimental procedure

The materials used in this investigation are two types of DSSs: UNS S32205 and UNS S32750. The chemical composition of both steels is given in Table 1. The steels were received in the form of hot-rolled cylindrical bars of 20 mm diameter. In order to increase the grain size of as received UNS S32205 an homogenized thermal treatment of 4 h at 1250ºC followed by slow-cooling to 1050ºC and finally water-quenched was employed. Thereafter, in S32205 with coarse grain size and in UNS S32750 in the as received condition, two homogenization thermal treatments at 1100 ºC for 45 minutes were carried out, one ended with water quenching (TTW) and the other with air cooling (TTA). The grain sizes and microhardness of both phases after these thermal treatments are shown in Table 2.

Table 1. Chemical composition of UNS S32750 and UNS S32205 (wt%)

	C	Cr	Ni	Mo	N	Mn	P	Si	Cu	S	Fe
S32750	0,015	24,9	7	3,8	0,263	0,4	0,015	0,3	0,31	0,0005	Balance
S32205	0,03	22	5	3,2	0,18	1,2	0,03	1		0,015	Balance

Table 2. Grain size and Microhardness after TTW and TTA thermal treatment

Material	Phase	Grain Size (μm)	Microhardness (HV)
S32750 TTW	γ	8 ± 2	298 ± 4
	α	7 ± 3	327 ± 7
S32750 TTA	γ	9 ± 1	325 ± 5
	α	10 ± 1	321 ± 4
S32205 TTW	γ	31 ± 9	269 ± 4
	α	33 ± 10	338 ±2
S32205 TTA	γ	33 ± 7	251 ± 3
	α	34 ± 10	291 ± 4

Two types of push–pull cylindrical specimens were machined from the thermally treated bars: one, with a gauge length of 18.4 mm and a diameter of 5 mm for the superduplex stainless steel UNS S32750 and the other with a gauge length of 20 mm and a diameter of 8 mm for the duplex stainless steel UNS S32205.

Metallographic preparation of specimens included a standard mechanical grinding procedure and a two-step electrolytic etching, method documented to be successful for both steels providing indirect evidence for the presence of intragranular nitrides and revealing the microstructure of the samples [2]. The microstructure and precipitates were examined using optical microscopy with an Olympus PME3 microscope.

Microhardness measurements of the austenite and ferrite phases after the different thermal conditions were performed using a Shimadzu HMV-2 Vickers microhardness tester, Table 2.

Cyclic deformation tests were carried out with an Instron (model number 1362) electromechanical testing machine under plastic strain control using a fully reversed triangular form signal. The specimens were tested in air at room temperature with a plastic strain range of 0.3% and a total strain rate of $2x10^{-3}$ s^{-1}.

3. Results and Discussion

For both DSSs the microstructural features after TTW and TTA are shown in Fig. 1. Optical micrographs of both types of DSSs in the TTW conditions show small etching pits in the ferrite phase, corresponding to Cr_2N precipitates, Fig. 1 a) and c). Nevertheless, from these figures, it is evident that the amount of these precipitates in UNS S32205 is higher than in S32750. Moreover, in UNS S32205 the Cr_2N precipitates are concentrated in the centre of the ferrite grains. A narrow precipitation free zone appears along the phase boundaries where nitrogen has had no time to diffuse into the austenite. This is not the case observed in S32750 TTW, where Cr_2N are homogeneously distributed within only some ferrite grains. According to Iversen [2], in a microstructure with short austenite spacing the diffusion distance for nitrogen become smaller, leaving less nitrogen trapped in the ferrite upon rapid cooling. Therefore, though S32750 has higher nitrogen content than S32205, Table 1, the Cr_2N precipitation is more severe in S32205 steel due to its coarse grains, Table 2. Attempting to avoid Cr_2N precipitation, TTA was employed. Figs. 1 b) and d) show the structure of the specimens with TTA. It turned out that no significant nitride precipitation is observed in the S32205 TTA sample in comparison with S32205 TTW sample and that not nitride precipitation is observed at all in the S32750 TTA sample. Nitride precipitation affects the microhardness of the ferrite and increases with the amount of precipitation [2]. This result agrees with the microhardness reported in Table 2 as the microhardness of the ferrite phase of S32205 TTW not only is higher than S32205 TTA but it is also higher than S32750 TTW. In this way, the increase in nitrogen content does not affect the amount of precipitation to the same extent as the increase in grain size does. Hence, the S32750 TTW sample, having a small grain size, presents a small concentration of nitride precipitation only in some ferrite grains, Fig 1c. .

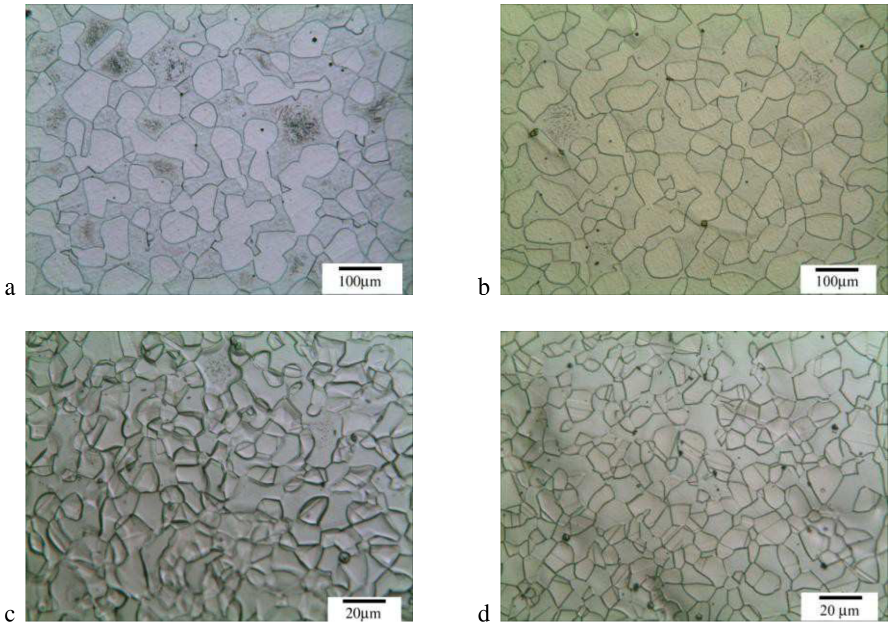

Fig. 1. Optical micrographs (a) S32205 TTW; (b) S32205 TTA; (c) S32750 TTW; (d) S32750 TTA

Fig. 2 shows the cyclic response of the DSSs UNS S32205 and UNS S32750 after the different thermal treatments. For both steels, the cyclic behavior exhibits similar trend independently of the thermal treatments. The characteristic cyclic behaviour is represented by an initial cyclic hardening followed by cyclic softening, which ends in a saturation stage. However, TTW materials attain a higher stress level than the TTA ones due to its initial higher values of hardness produced by Cr_2N precipitation. The most surprising behaviour is the significant embrittlement exhibited by the TTW steels. The number of cycles to failure for the S32750 TTW steel is half the corresponding value for the S32750 TTA. This effect is more pronounced in the S32205 steel where the difference in the numbers of cycles to failure is even greater. Liu [3] reported that in a SAF 2205 stainless steel different thermal treatments resulted in different fracture toughness. This phenomenon is attributed to the formation of Cr_2N precipitates in the ferrite phase that reduce the mobility of dislocations decreasing the toughness of this steel. On the other hand, the decrease of the fatigue life of a superferritic stainless steel UNS S44600 has been ascribed to Cr_2N precipitation [6]. Therefore, it can be assumed in this work that the presence of Cr_2N precipitates in the ferritic phase of DSS UNS S32205 and UNS S32750, that undergoes TTW thermal treatment, shortens the fatigue life of these materials. Nevertheless, independently of the nitrogen content in DSSs smaller ferrite grain size results in less nitrogen trapped in the ferrite and leaves the material less susceptible to nitride precipitation decreasing embrittlement.

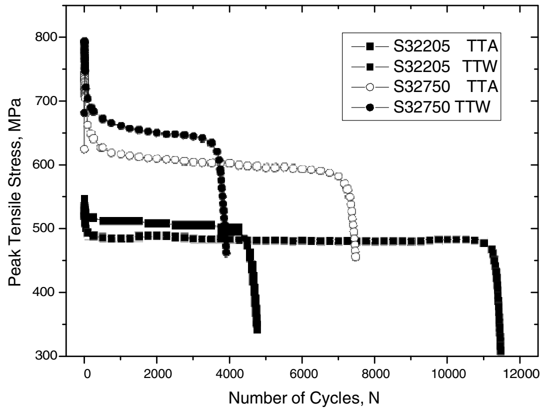

Fig. 2. Cyclic response of DSSs UNS S32205 and UNSS32750 under different thermal treatments.

4. Conclusions

The conclusions of the effects of Cr_2N precipitation on the low cyclic fatigue behavior of two different types of DSSs are listed below:

- Thermal treatments at high temperature followed by water cooling (TTW) produce Cr_2N precipitates in the ferritic phase of DSSs UNS S32205 and UNS S32750 that detrimentally affect their fatigue life.
- Thermal treatments at high temperature followed by air cooling (TTA) reduce considerably the amount of Cr_2N precipitates in DSSs UNS S32205 and avoid the precipitation in UNS S32750.
- The amount of Cr_2N precipitation after TTW is mainly dependent on grain size.

Acknowledgements

This work was supported by Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina.

References

[1] A. Safsten Quantitative phase analysis of duplex stainless steel as a function of heat treatment M.Sc. Thesis in engineering physics, Lulea University ofTechnology, 2009.
[2] Torunn. H. Iversen, Intragranular Nitrides Precipitates in Duplex and Superduplex Stainless Steel, M.Sc. Thesis in engineering physics, NTNU-Trondheim, Norwegian University of Science and Technology, June 2012.
[3] Liu P, The effect of precipitation in stainless steel SAF 2205 on fracture toughness, Sandvick Technical Report T9900463. Sandvick Mater Technol,1999
[4] Z. Wei, J. Laizhu, H. Jincheng, S. Hongmei, Effect of ageing on precipitation and impact energy of 2101 economical duplex stainless steel, Materials Characterization, 60,1, 2009,50-55.
[5] J.O. Nilsson, Overview Super duplex stainless steels, Materials Science and Technology August 1992, 8, 685.
[6] S. Hereñú. M. G. Moscato, I. Alvarez-Armas, A. F. Armas, Cyclic behavior of a superferritic stainless steel at room and intermediate temperatures, International Journal of Fatigue, 2013, in press, available on line August 2013.