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Influence of atmospheric humidity and grain size on the friction and wear of high nitrogen austenitic stainless steel

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Research on steels is still active and is motivated by the need to make further improvements in their properties. Among the different steel types, austenitic stainless steels possess good corrosion resistance and formability. However, they also have a relatively low yield strength. One method of increasing the yield strength is by alloying the steel with nitrogen. Such nitrogen-alloyed austenitic stainless steels exhibit attractive properties such as high strength and ductility, good corrosion resistance and reduced tendency to grain boundary sensitation [1]. The high austenitic potential of nitrogen allows the reduction of nickel content in steel. This offers additional advantages such as cost savings and makes the steel more suitable for stainless steel applications involving contact with human skin for people with nickel allergies. Due to the above-mentioned properties, in recent years significant efforts have been devoted to the production of high nitrogen austenitic stainless steels, and metallurgists have been very active in research concerning this class of steels. Particularly, considerable attention has been paid to solidification mechanisms and recrystallization processes [2–4]. Nitrogen in solid solution produces, in the austenitic stainless steel, many desirable properties: it stabilizes the austenite γ phase and increases the resistance to intercrystalline and pitting corrosion, but the most important property is the increase of the yield strength ($R_{P0.2}$) without a corresponding decrease in ductility. There is another way of increasing the yield strength without severely affecting the ductility. This can be achieved by grain refining. Since austenitic stainless steels do not undergo phase transformation at typical annealing temperatures, the only way to refine the grain size is by recrystallization after cold rolling. An alternative way to obtain fine grains is by applying an austenite-martensite-austenite transformation. In previous publications [5, 6], we examined the influence of grain size and chemical composition on the mechanical properties and corrosion resistance of this family of steels.

In this paper, grain refinement is applied to high nitrogen austenitic stainless steels to combine the two approaches of improving the yield strength. The wear resistance of a high nitrogen austenitic stainless steel is studied as a function of grain size and atmospheric relative humidity.

The chemical composition of the high nitrogen (HN) austenitic stainless steel under consideration is shown in Table I. In order to favor the austenite-martensite transformation, samples of hot-rolled and annealed steel have been cold-rolled down to 90% deformation after a prior quenching in liquid nitrogen. Details are reported elsewhere [7]. In order to obtain two different microstructures (see Fig. 1), the samples were then annealed at 1100 °C for 20 s and for 30 min, respectively. The resulting average grain sizes are 2.5 μm (fine grain—FG) and 40 μm (coarse grains—CG). The sample surfaces were polished by using increasingly finer abrasive papers down to 1 μm diamond grit. The grain sizes of the two samples were determined with an automatic image analyzer and their mechanical properties are reported in Table II.

The friction coefficient was measured using a tribometer in a ball-on-disk (BoD) configuration, in which

TABLE I Chemical composition (mass %) of the high nitrogen austenitic stainless steel; balance is Fe

C	Si	Cr	Ni	Mo	N	S	Mn	P
0.037	0.12	18.5	1.07	0.08	0.37	0.003	11.4	0.022

TABLE II Grain size and mechanical properties of high nitrogen austenitic stainless steel samples: FG—fine grain, CG—coarse grain

	Grain size (μm)	Hardness (HV)	Tensile strength (N/mm^2)	0.2% Yield strength (N/mm^2)
FG	2.5	308	985	709
CG	40	201	716	430

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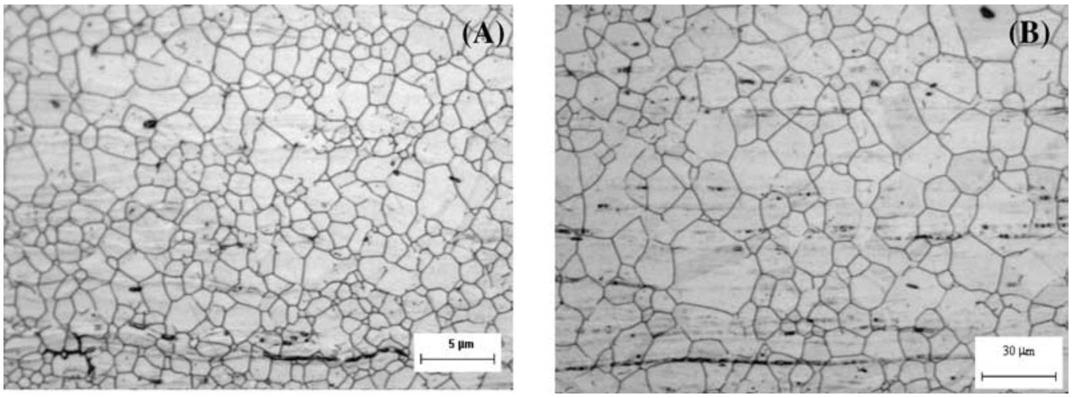

Figure 1 Microstructure of high nitrogen austenitic stainless (HN) steel samples annealed at 1100 °C: (A) for 20 s, (B) for 30 min; the resulting average grain sizes are 2.5 μm and 40 μm, respectively.

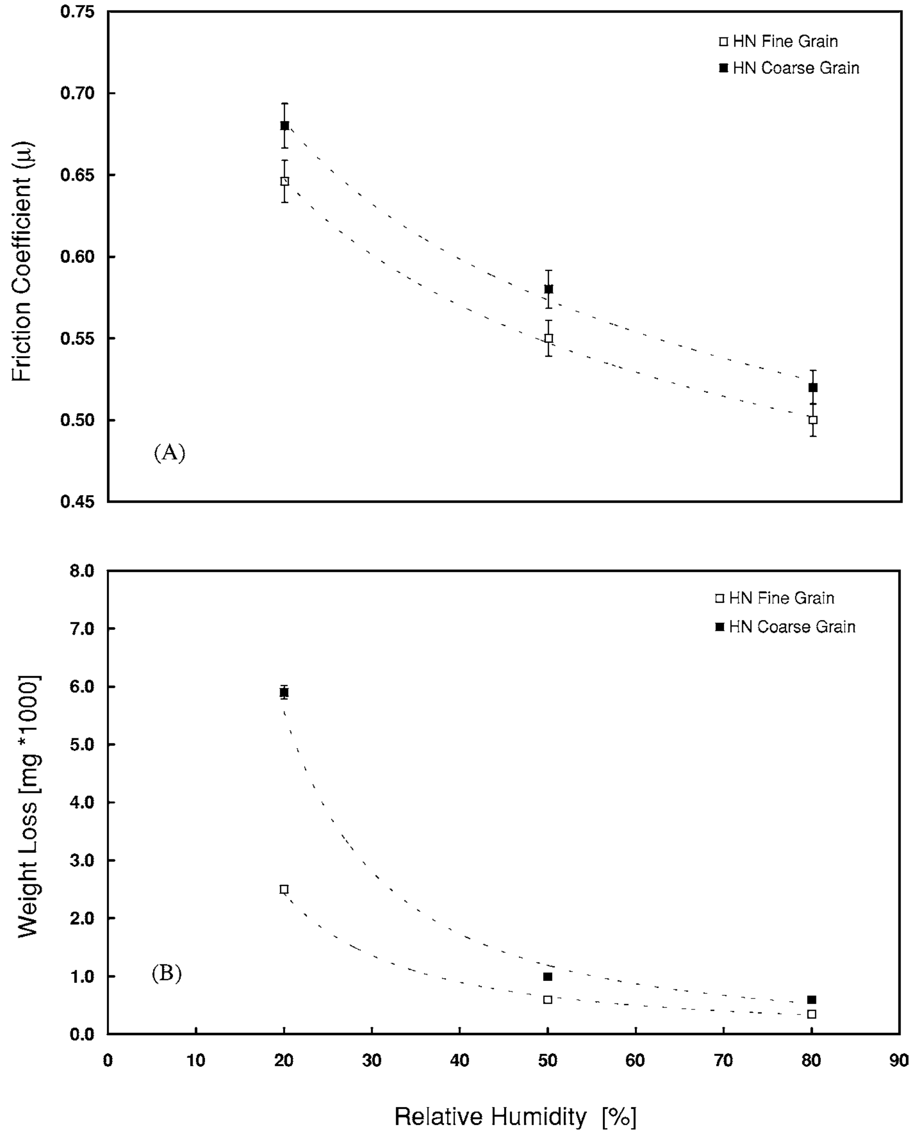

Figure 2 Dependence of the friction coefficient (A) and weight loss (B) on relative humidity and grain size for HN steel samples. BoD conditions: velocity of 10 cm/s, load of 2 N (average contact pressure of 358 MPa), stop criterion 400 m (corresponding to 21 000 laps).

a steel ball (AISI 52100, Ø 6 mm) slides over HN steel with a constant linear speed of 10 cm/s and a load of 2 N (equal to an average geometric contact pressure of 358 MPa). The tests were performed at 20 ± 1 °C. The stop criterion of the tribological tests was 400 m of sliding, which corresponds to 21 000 laps. In order to evaluate the weight loss and the friction coefficient with change in relative humidity and grain size of the HN steel, a humidifier was placed in the BoD chamber and, in this manner, the relative humidity (RH) could be maintained at 20%, 50% or 80%. To ensure reproducibility of results, every test was repeated at least

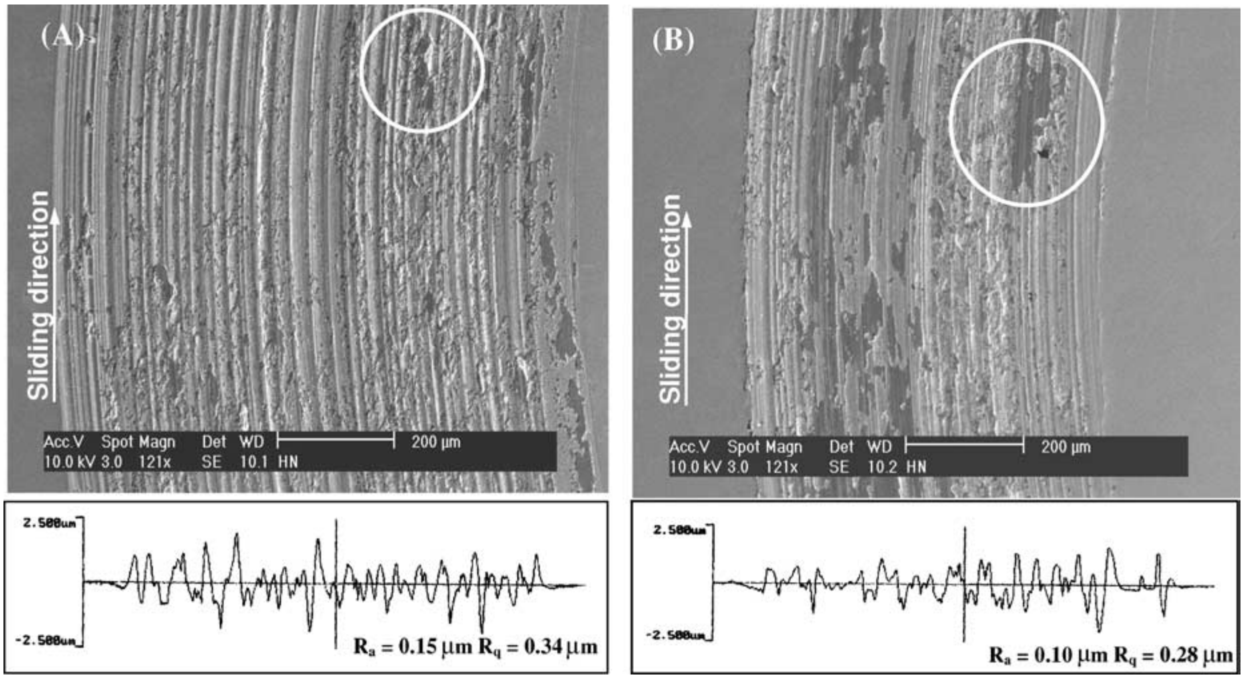

Figure 3 Electron micrographs of a fine grain HN steel after BoD tests: (A) 20% RH; (B) 80% RH. Note the formation of oxidized wear particles on both steel surfaces (inserted circles). The wear tracks after the tests in dry conditions are characterized by a mean and root mean square value of roughness greater than in moist conditions.

twice. At the end of each test, the ball and sample were removed from the tester and cleaned by immersing them in an ultrasonic bath. Wear losses were subsequently measured (in grams, with precision to the fifth decimal place) with an analytical balance. The structure of the worn surface of the HN steel samples (parallel to the sliding direction and normal to the worn surface) and the worn surface of the steel counterbody (parallel to the sliding direction) were examined using a scanning electron microscope (SEM).

The effect of the relative humidity and grain size on the friction coefficient and wear of HN steel are shown in Fig. 2A and b, respectively. Results indicate that fine-grain steel is more wear resistant than coarse-grain steel. The hardness of the steel is believed to be the predominant factor: the fine-grain steel (with a higher hardness) shows smaller weight loss and a lower friction coefficient than the coarse-grain steel [8]. In Fig. 2, the effect of relative humidity on the friction coefficient and wear of HN steel is also evident. An increase in relative humidity results in a lower friction coefficient and smaller weight loss for both coarse and fine grain steels. This suggests a lubricating effect at high relative humidity due to decreased interaction between the counterbody and the steel samples leading to less adhesion as well as abrasion and, therefore, to lower friction and less damage to the steel sample surface [9]. The exact mechanism of this lubricating effect will be addressed in future studies. Electron micrographs of the worn track after the friction experiment from both fine and coarse grain steels, demonstrate severe wear damage on the surface area resulting from adhesion as well as abrasion mechanisms. Upon analysis of Fig. 3, where the wear track of HN steel samples tested at 20% (A) and 80% RH (B) are shown, some oxidized wear particles can be observed (analysis performed by energy dispersive X-ray spectroscopy). Increased surface damage at low relative humidity is also evident and is confirmed by roughness analysis of the two samples. This suggests that the oxidized wear particles formed at 80% RH are not as hard and abrasive as those formed under dry conditions. This explains the greater damage of the samples tested at 20% RH [9]. The wear track obtained at 20% RH has a mean roughness value (R_a) of about 0.15 μm, while a value of 0.10 μm is obtained from the samples tested at 80% RH. A cross-section of the wear track shows the formation of cracks beneath the surfaces for both the grain sizes due to fatigue (Fig. 4) [10]. Fig. 5 shows the worn surface of the counterbody in the early test stages and at the end of the tests. Fig. 5A clearly shows the formation of a transfer layer from the steel sample to the counterbody, which may be the reason for the extremely high and

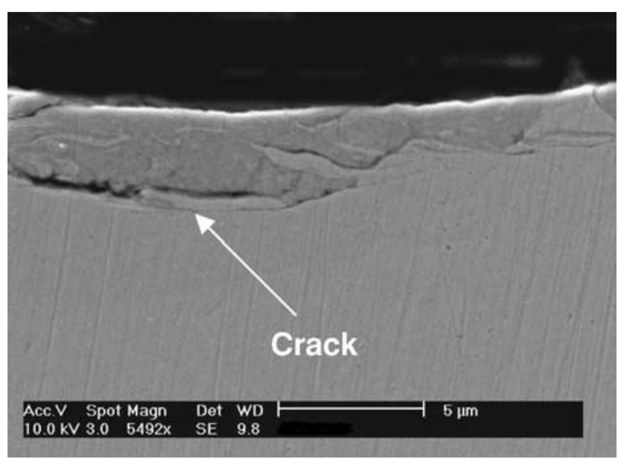

Figure 4 Electron micrograph of a cross section of an HN steel sample after the tribological BoD test. For all HN steel samples it was possible to determine the formation of cracks beneath the surface due to fatigue.

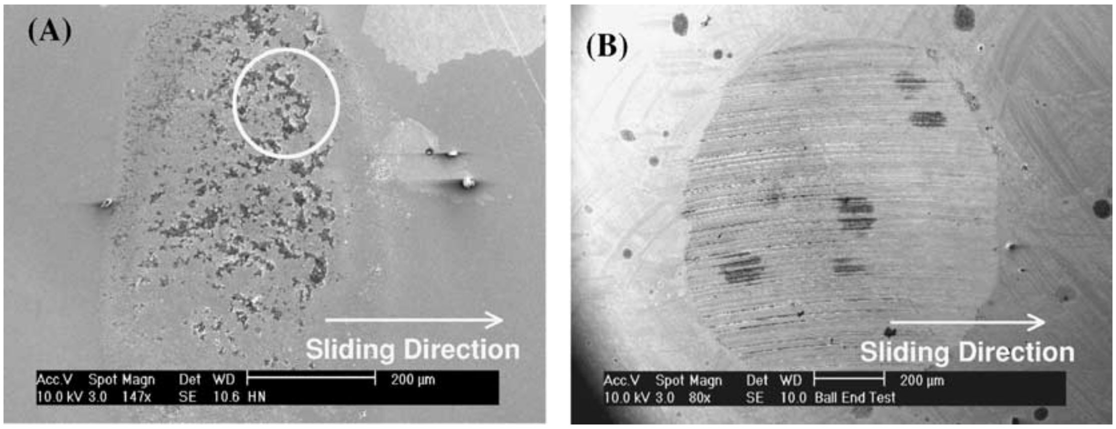

Figure 5 Electron micrographs of the steel counterbody (AISI 52100 ball, Ø 6 mm): (A) Formation of transferred layer from the HN steel to the counterbody after the running-in stage (inserted circle); (B) wear of the counterbody surface at the end of the test.

variable friction coefficient measured in the first stage of the test (results not inserted). After about a quarter of the test duration, the friction becomes more stable (marked by the absence of large friction variations). After this time, damage of the counterbody surface begins to occur. At the end of the tests, the counterbody surface shows many scars (Fig. 5B). Decreasing the grain size of the steel sample produces a decrease in the wear of the counterbody with respect to the coarse grained sample, whereas an increase in relative humidity produces an increase in the wear of the counterbody for both grain sizes (results not inserted).

To conclude, the effect of relative humidity on the wear behavior is important in predicting the seasonal wear of the steels. Decrease of the relative humidity in wear tests of HN steel produces increases in the friction coefficient and weight loss. A beneficial effect of grain refining has also been demonstrated with respect to coarse grain steel in that the finer grain steel produces less initial weight loss and the weight loss with an increase in the humidity is also less pronounced. This study makes a case for applying grain refinement to HN steel to further improve the tribological properties of this type of steel.

References

1. M. SPEIDEL, in Procedings of the 6th International Conference on High Nitrogen Steel (Le Royal Meriden—Chennai, India, Sept. 2–5, 2002) p. 508.
2. A. BAILITSKI and M. SPEIDEL, in Procedings of the 4th International Conference on High Nitrogen Steel (Kyoto, Japan, May 24–26, 1998) p. 401.
3. A. DI SCHINO, M. G. MECOZZI, M. BARTERI and J. M. KENNY, *J. Mater. Sci.* **35** (2000) 375.
4. A. DI SCHINO, J. M. KENNY, G. ABBRUZZESE and I. SALVATORI, *ibid.* **36** (2001) 593.
5. A. DI SCHINO and J. M. KENNY, *J. Mater. Sci. Lett.* **21** (2002) 1631.
6. A. DI SCHINO, L. VALENTINI, J. M. KENNY, Y. GERBIG, I. AHMED and H. HAEFKE, *Surf. Coat. Technol.* **161** (2002) 224.
7. A. DI SCHINO, I. SALVATORI and J. M. KENNY, *J. Mater. Sci.* **37** (2002) 4561.
8. A. BORRUTTO and I. TARASCHI, *Wear* **184** (1995) 119.
9. A. P. VAN PETEGHEM, K. STRIJCKMANS, G. KALACSKA, P. DE BAETS and F. VAN DE VELDE, *ibid.* **216** (1998) 131.
10. H.-K. OH, K.-H. YEON and H. Y. KIM, *J. Mater. Proc. Techn.* **95** (1999) 10.

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