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Short communication

Surface structure of stainless and Hadfield steel after impact wear

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Abstract

After impact wear, the very surface of stainless austenitic CrMnCN steel and austenitic MnC Hadfield steel revealed a thin fully amorphous layer followed by a layer of nanocrystals embedded in an amorphous surrounding, which was supported by a severely cold worked layer of austenite below. The new high-strength stainless steel contained C + N = 0.82 mass% and exceeded Hadfield steel in respect to proof strength, elongation, work to fracture and wear rate.

Keywords: Hadfield steel; Stainless austenitic steels; Impact wear; Amorphous wear surface; Nanocrystals

1. Introduction

Austenitic Hadfield steel [1] containing about 1.2 mass% C and 12 mass% Mn is known for a high resistance to impact wear caused by rapid cold work hardening, for which different mechanisms were proposed. An early explanation pointed to strain-induced $\gamma \rightarrow \varepsilon$ martensitic transformation [2,3]. Later, the observation of martensitic phases was related to segregation [4], precipitation [5] or decarburization [6], while a fragmentation of grains was seen as a reason for work hardening [7,8]. Deformation at 4 K did not yield martensite, and based on low stacking fault energy, a decisive effect of stacking faults was suggested [9]. A variation of the Mn and C contents revealed that deformation at temperatures between −196 and 400 °C entailed martensitic transformation only outside the regular range of Hadfield steel [10]. In another study on standard Hadfield steel, however, magnetic measurements showed α-martensite in tensile specimens above 30% of elongation, amounting to 0.43% near the fracture face [11], which is hardly enough to enhance strengthening by transition-induced plasticity (TRIP). A contribution of twins to cold work hardening was discussed in [12] but no correlation was found in [13], because the density of twins decreased from −25 to 225 °C, whereas work hardening remained constant. Finally, a strong carbon/dislocation interaction was proposed [14] resulting in a repeated break-up of pinned dislocations from carbon clouds, a rapid multiplication of free dislocations and their restored capture by carbon atoms. Further studies of Hadfield steel concerned mainly the role of twinning in strain hardening [15], the development of ultrafine grains through appropriate thermomechanical processing [16], and the contribution of twinning and slip to the deformation mechanisms depending on the crystallographic orientation [17]. Finally, strain-induced nanocrystals and partial amorphization were reported in the surface of Hadfield steel subjected to high impact energy [18].

Recently a stainless type of Hadfield steel was developed [19–22] to resist corrosion in pit mining, where a slightly acid environment is encountered. Impact wear tests in the lab gave a wear resistance comparable to Hadfield steel, but the structural changes have not been studied in great detail. It is therefore the aim of this study to investigate the changes of microstructure at the very surface of this new austenitic stainless steel and compare the results with Hadfield steel.

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Table 1
Chemical composition of Hadfield steel (HS) and the respective stainless steel (SS) in mass%

		Mn	Cr	Si	P	S	C	N
HS	Melt	12.1	0.17	0.49	0.09	0.014	1.19	0.01
SS	Melt	17.2	14.7	0.48	0.04	0.007	0.39	0.43
	Worn surface	18.5	14.03					

Melt: provided by the steel producer; worn surface: analysed by EDX.

Table 2
Mechanical properties at ∼20 °C

Tensile test	HS	SS
$R_{p0.2}$ (MPa)	370	494
R_m (MPa)	829	951
R[a] (MPa)	1131	2635
A_5 (%)	46	78
Z (%)	33	68
W_s[b] (J/cm^3)	330	651
Hardness (HV0.1) on tensile fracture face	741	566
Hardness [HV0.1] on wear surface	690	580
Hardness penetration (mm) below wear surface	1.3	0.7

[a] True fracture strength.
[b] Specific work of plastic deformation until fracture.

2. Experimental

The chemical composition of the Hadfield steel (HS) and the respective stainless steel (SS) is given in Table 1. Tensile specimens of 5 mm in diameter and impact wear plates of 50 mm × 35 mm × 10 mm were taken from hot rolled stock and solution annealed at 1050 °C (HS) or 1100 °C (SS) before grinding to size. Two wear plates were mounted on a rotor in adjacent positions and impacted by mineral particles of greywacke of hardness 760 HV0.1 and grid size 11 to 8 mm, which fell slowly at a rate of about 1 /s and individually counted by a light barrier, parallel to the vertical rotor axis. They were hit by the plates rotating under an impact angle of 90° at a velocity of 26 m/s. The weight loss of the two plates was measured after every 1000 impacts and cleansing in an ultrasonic bath of alcohol. The hardness penetration below the wear surface and the hardness on the fracture of tensile specimens were derived by the Vickers test under a load of 100 g (HV0.1).

After 12,000 impacts (about 6000 per plate), samples of 3 mm in diameter were taken from the most densely impacted area and thinned mechanically from the backside to about 200 μm. The impact wear surface of these thin discs was

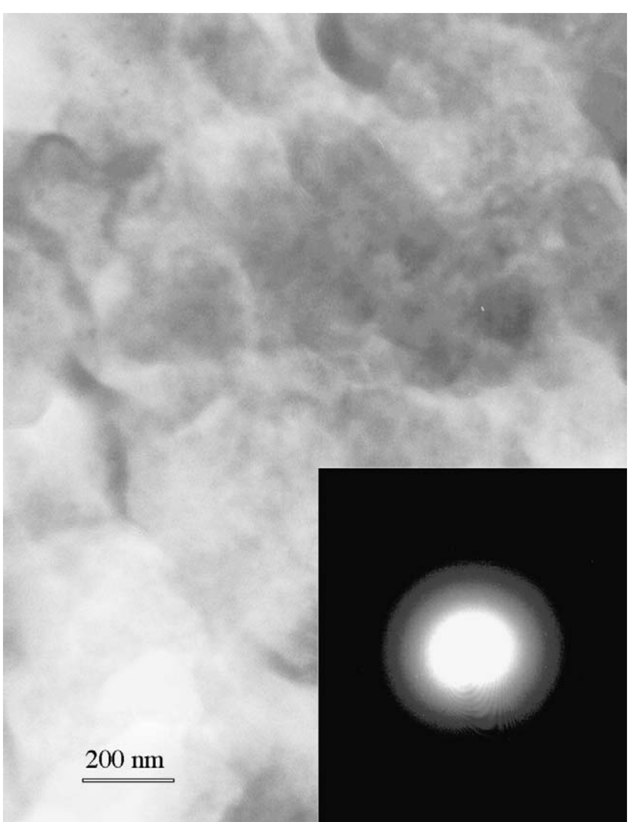

Fig. 1. Amorphous structure at the very surface of steel HS after impact wear.

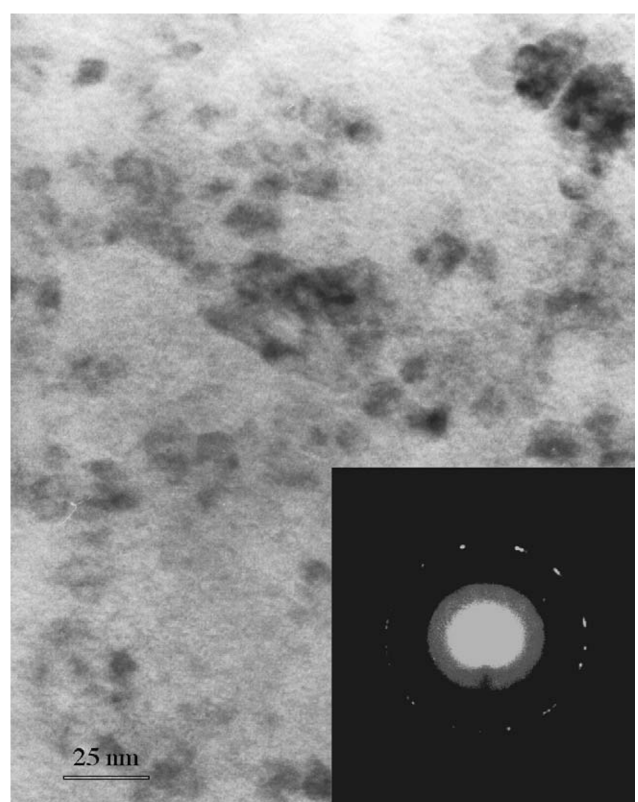

Fig. 2. Nanocrystals in amorphous surrounding at about 10 μm below the wear surface of steel HS.