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Deformation processes in austenitic stainless steels

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The microstructure of high-nitrogen austenitic stainless steel 18Cr18Mn0.5N was investigated in different stages of compression and tension deformation using light and transmission electron microscopy. Slip and twinning occur during cold deformation; the same processes take place in Hadfield manganese steel. Both steels are compared and the influence of stacking fault energy is discussed.

1. INTRODUCTION

Steel 18Cr18Mn0.5N, which was investigated in this study, belongs to high-nitrogen austenitic stainless steels. Nitrogen occurs universally in all steels; although its solubility under normal manufacturing conditions is small, it can produce great effects. Some of these effects are detrimental, often being associated with embrittlement, but nitrogen can also have beneficial effects if, in addition to nitrogen, the steel contains chromium and manganese. Then it is possible to obtain corrosion resistant material with high strength and toughness. The outstanding feature of steel 18Cr18Mn0.5N is the high ability to strengthen through deformation. Well-known Hadfield manganese steel has a similar property. It is therefore possible to assume that there are analogies between the microstructural processes in both steels.

As early as 1882 Robert Hadfield patented the steel that was later used for the production of tracks and stone crushers. Suitable chemical composition (1.2 wt.% of carbon and 12.5 wt.% of manganese) and heat treatment, consisting of annealing at 1050°C and water quenching, resulted in very interesting properties. At such a high annealing temperature the surface layer was depleted of carbon and manganese and α-martensite was formed after quenching. The martensitic transformation caused high surface hardening, while the bulk of the steel remained ductile and tough. In addition, unusual strain hardening of this steel was indicated. For a long time it was assumed that this was caused by deformation induced martensitic transformation. Later a new theory was developed, which explained the high strengthening as a result of pseudotwinning [1]. Recent research into Hadfield steel has shown that while slip bands and deformation twins occur in this alloy, defomation-induced martensite does not form [2,3]. The high concentration of carbon inerstitials dramatically increases solid solution hardening. It is assumed that carbon hardening is due to the presence of short-range ordering between carbon and manganese atoms (manganese-carbon clusters) [4]. Despite the fact that, since its discovery more than a century ago, the Hadfield manganese steel has been extensively used, the mechanism of the unusual strain hardening behaviour of this austenitic steel has remained uncertain as in the case of steel 18Cr18Mn0.5N.

In the 1930s experiments were carried out in order to replace nickel in stainless steels with cheaper alloying elements. That is the reason why Mn-Cr-Ni steels were developed. Undesirable martensite was formed if the concentration of nickel was too low, whereas the low content of chromium resulted in a decrease in corrosion resistance. Both problems were solved by use of nitrogen. The first nitrogen steels appeared in about 1940, but their expansion did not stars until the 1990s, when new steelmaking technologies were developed [5]. "High-nitrogen austenitic steels" are considered to be steels exceeding 0.4 weight-percent nitrogen. In order to put in enough nitrogen, electroslag remelting in nitrogen atmosphere has to be used. This technology is relatively expensive, but this new class of steels was expected to yield materials with special properties.

Steel 18Cr18Mn0.5N is a suitable material for electric machines thanks to its low magnetic susceptibility. Large retaining rings for turboalternators have been manufactured of this steel with yield strengths of up to 1.5 GPa. Such a high yield strength has been achieved by expansion of rings. A further increase in yield strength has been achieved through wire drawing (2.4 GPa) [6]. At present, other materials for the production of rings are being examined, because from time to time cracks have been found in these rings and their causes have not been explained entirely.

2. EXPERIMENTAL PROGRAM

The chemical composition of steel 18Cr18Mn0.5N used in this study was 0.06C-19.8Cr-17.4Mn-0.1Ni-0.6Si-0.4N (wt.%). Experimental material was taken from a ring, annealed at 1050^{o}C for 2 hours. Specimens were machined out and deformed by compression and tension at different degrees of total strain. The microstructure was observed using light and transmission electron microscopy. The true strain degree was characterized by equivalent (effective) strain ε_E, which was calculated for different regions using computer simulations in the program package Forge 2D or Deform. For calculations, a model with linear strengthening and Coulomb's friction model were used. The simulated shapes of specimens were compared with the real shapes; error of the final simulated dimensions was about 1%.

Compression deformation was performed using the tensile and compression machine MTS 2MN. The rate of the cross head was 1 mm/min. Tensile deformation was carried out using the machine Zwick 250 and strain rate of 2 mm/min.

Metallographic samples were etched in a solution of nitric acid, hydrofluoric acid and glycerol (2:2:1). Foils were thinned to electron transparency in a 7% solution of perchloric acid in glacial acetic acid at 8^{o}C. Transmission electron microscopy was performed at an accelerating voltage of 120 kV in microscopes Jeol 1200 EX and Tesla BS 540.

3. RESULTS AND DISCUSSION

Using light microscopy homogeneity of the plastic strain can be evaluated in metallographic samples prepared in different sections of deformed specimens. Deformation bands can be made more distinctive, when microstructure is observed in phase or Nomarski contrasts, but it is not possible to distinguish, if deformation occurs only by slip or also by twinning (Fig. 1). Even deformation induced martensite can be present there. In order to determine which of deformation processes take place in steel 18Cr18Mn0.5N it is necessary to use transmission electron microscopy.

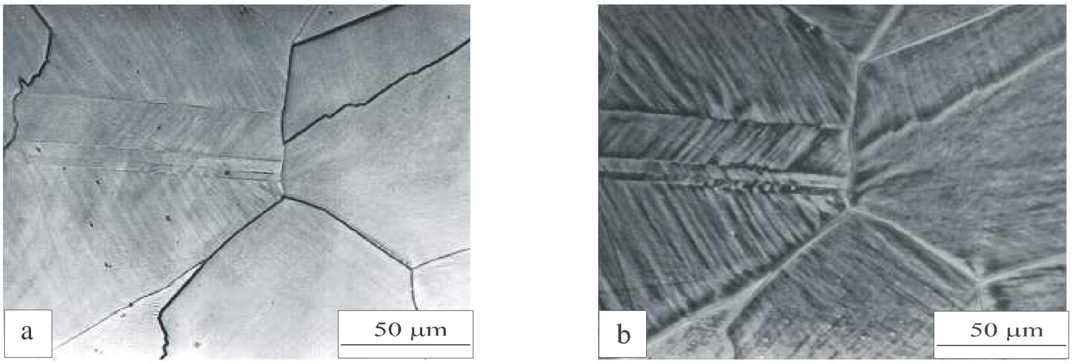

Fig. 1. Metallographic sample. The microstructure of steel pulled in tension to a strain of 0.11 ($\varepsilon_E = 0.09$)

Both fundamental modes of plastic deformation, slip and twinning, can occur in austenitic steels. It depends on the stacking fault energy (SFE) which of them is more advantageous. The stacking fault energy of 22 mJ/cm^2 was calculated from extended dislocation nodes in steel 18Cr18Mn0.5N [7]. Almost the same value, 23 mJ/cm^2, was arrived for the Hadfield steel using X - ray diffraction analysis [1].

In the early stages of plastic deformation, glissile dislocations are observed, which are concentrated in slip bands. Dislocations are often dissociated into partials and take part in different slip - slip or slip - grain boundary interactions. Dislocation density increases proportionally to the strain degree and dislocations remain in their original slip planes (Fig. 2). The planar slip is typical of alloys with a low SFE. Special formations, packets of stacking faults, are formed during slip in adjacent close packet planes. From these packets deformation twins are developed [8]. A detailed description will be published [9]. The first twins arisen in this way appear in the regions which correspond to strain $\varepsilon_E = 0.1$. Many new dislocation sources arise in twin boundaries, new packets of stacking faults form and consequently the twin density increases (Fig. 3). This is the reason for a high ductility of steel. In addition, f.c.c. lattice of austenite provides favourable conditions for interactions between dislocations and twins, because slip and twinning occur in the same crystallographic systems. These interactions contribute to steel hardening and at the same time make possible to release stress concentrations; consequently the notch toughness increases. Other factors which cause the great yield stress and strength enhancement, include the solid solution hardening by interstitial nitrogen atoms and nitrogen-chromium clusters [10].

Great attention has been paid to the examination of the deformation induced martensitic transformation, which is common in manganese steels. In our study more then fifty diffraction patterns were analysed that are originated in lath-like formations in foils and could correspond to ε-martensite or twins. It is well-known fact that some diffraction spots of twins and ε-martensite are coincident and it is not possible to separate them; therefore diffraction patterns were taken in different crystallographic orientation of the laths used for investigation. All of analysed diffraction patterns could be indexed as an austenitic matrix with twins. This result corresponds to the research into Hadfield steel [3] and other alloys with low SFE [11]. The stacking fault energy seems to be the main criterion for the prediction of deformation processes. Deformation induced martensite, which causes embrittlement of steel, can be expected in alloys with SFE lower than about 10 mJ/cm^2. In the range of 10 to 40 mJ/cm^2 twinning and planar slip occur. At a higher SFE only slip is observed, a cross slip occurs and dislocation walls are formed.

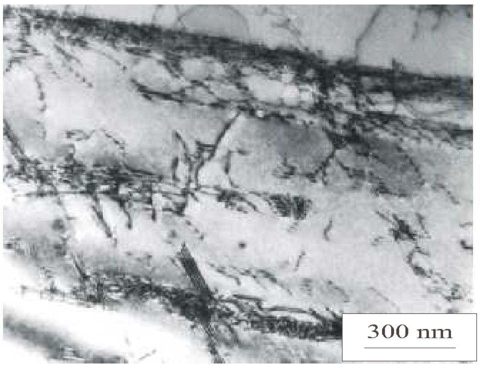

Fig. 2. Thin foil. Planar slip in the region with $\varepsilon_E = 0.07$

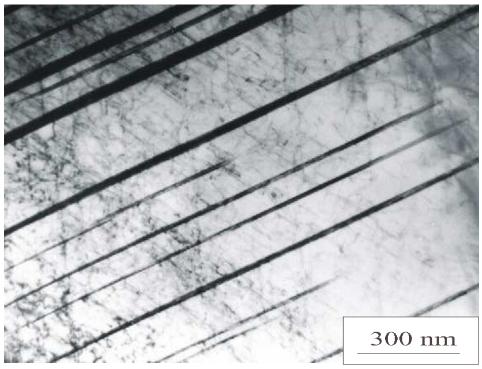

Fig. 3. Thin foil. Deformation twins in the region with $\varepsilon_E = 0.15$

4. CONCLUSIONS

1. Slip and twinning are two equivalent deformation processes taking place in steel 18Cr18Mn0.5N. Especially twinning is responsible for high ductility and toughness.
2. In our experiments deformation induced martensite was not observed. Its occurrence cannot be excluded, but the probability is very low. The cracks in rings might be caused by some other phenomenon.

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REFERENCES

1. P. H. Adler, G. B. Olson, W. S. Owen, Metallurg. Trans. A, 170 (1986) pp. 1725-1737.
2. S.B. Sant , R.W. Smith., J.Mat.Sci., 22 (1987) pp. 1808-1814.
3. I. Karaman, H. Sehitoglu, A. J. Beaudoin, V. I. Chumlyakov, H. J. Maier, C. N. Tomé, Acta Mater., 48 (2000) pp. 2031-2047.
4. W. S. Owen, M. Grujicic, Acta Mater., 47 (1999) pp. 111-129.
5. J. C. Rawers, N. A. Gokcen, R. D. Pehlke, Metall. Trans. A, 24 (1993) pp. 73-82.
6. M. O. Speidel, J.P. Uggowitzer, Ergebnisse der Werkstoff - Forschung Zürich, ETH-Zürich (1991).
7. D. Jandová, J. Koutský, Materials Engineering, (2000) pp. 37-46 (in Czech).
8. D. Jandová, J. Řehoř, Z. Nový, Proc. 9th conf. AMME '2000, Gliwice-Sopot-Gdańsk,Poland, 11-14 October (2000) pp. 255-258.
9. D. Jandová, J. Řehoř, Z. Nový, J. Mater. Proces. Technol. (in print)
10. M. Grujicic, J.O. Nilsson, W.S. Owen, T. Thorvaldsson, Proc. High Nitrogen Steels, HNS ′88, Lille, France,18-20 May 1988, ed. J. Foct, A. Henry, Institute of Metals, London (1989) pp. 151-58.
11. S. Lu, B. Shang, Z. Luo, R. Wang, F. Zeng, Met. Mat. Trans A, 31 (2000) pp. 5-13.