PERIODIC LOADING OF DUAL PHASE STEEL STUDIED BY NEUTRON DIFFRACTION

P. Jenčuš[1], P. Lukáš[1], J. Polák[2] and O. Muránsky[1]

[1]*Nuclear Physics Institute, 250 68 Řež, Czech Republic*

[2]*Institute of Physics of Materials, Žižkova 22, 616 62 Brno, Czech Republic*

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Abstract.
The mechanism of the low cycle fatigue in - duplex stainless steel was examined by the neutron diffraction technique performed in situ upon mechanical exposure consisting of the tension/compression cycles with the strain amplitude of 0.8%. Deformation response of both constituent components, i.e. ferrite and austenite, was studied in situ during the individual applied cycle in detail. Information on evolution of lattice strains of both phases have been obtained from the shifts of individual diffraction profiles collected during the fatigue experiment. It was found that the initial thermal residual stresses relaxed rapidly at the beginning of cyclic loading. It was proved that both phases contribute to the cyclic hardening, whereas the subsequent fatigue softening was fully attributed to the austenitic phase.

Introduction

In two-phase materials, like duplex stainless steels, macrostresses between the two phases are always present due to differences in physical and mechanical properties between the two phases. Due to different thermal expansion coefficients of the austenitic and ferritic phase significant thermal stresses are generated in both phases in the initial state during the cooling from the homogenization temperature. Thorough identification of these initial thermal residual stress and their evolution during the periodic loading is very important for determination of fatigue behavior and fatigue life prediction.

The neutron diffraction method presents a well established method to investigate the load sharing between the ferritic and austenic grains. Information provided by this method is related to a large sample volume because of high penetration ability of thermal neutrons. This technique allows determination of the strain tensor in each phase separately and has been successfully used for studying load sharing between phases and the study of the effects of macro- and microstresses on mechanical properties of different kinds of materials [1-3].

In the present study, the in-situ neutron diffraction was carried out to analyze the initial residual stresses of both phases and to evaluate the evolution of macrostresses during static loading. The diffraction response of austenitic and ferritic phases to hardening/softening process during the cyclic straining was investigated.

Experimental

In the present experiment, the detector window was set to 2 ~68^o to cover both ferrite (110) and austenite (111) reflection (2 = 69.15^o and 67.42^o, respectively). The axial lattice strain component was only measured in this experiment.

Specimen was loaded periodically by tension and compression (the first loading was tensile) with the strain amplitude of 0.8% (plastic deformation). The diffraction spectra were measured upon applied load in several points within selected particular cycles (1st, 6th and 100th cycle). In this case, the partial strain step of deformation machine was 0.2%.

Results

Prior the diffraction experiment, the strain/stress response of periodic loading was measured in order to evaluate the hardening/softening effects. Detailed look at the evolution of applied stress (Fig.1) reveals strong hardening effect in the first cycle. Moderate hardening proceeds up to the 6th cycle followed by saturated state and fatigue softening is observed after 11th cycle. Based on this result, the first cycle (initial state), 6th cycle (max. hardening effect) and 100th cycle (final state) were chosen to be investigated in detail by neutron diffraction in situ upon applied load.

Rather high thermal residual stresses have been detected in both phases (Fig. 2); the initial tensile stress in austenite and the initial compressive stress in ferrite are in agreement with the higher thermal expansion of the austenite (1.65×10^{-5} K^{-1}) than of the ferrite (1.1×10^{-5} K^{-1}). Higher stress level in austenitic phase is also in good agreement with its lower volume fraction.

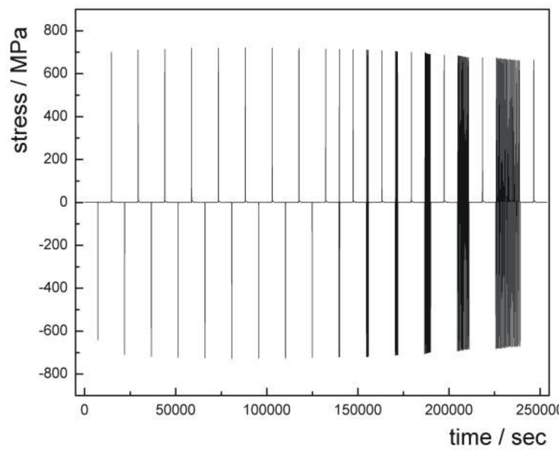
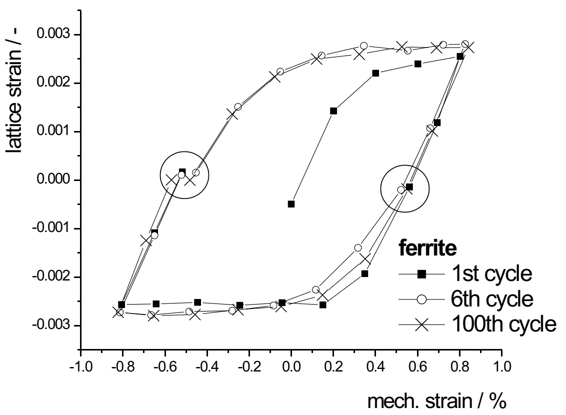


Fig. 1. Mechanical record of applied stress.



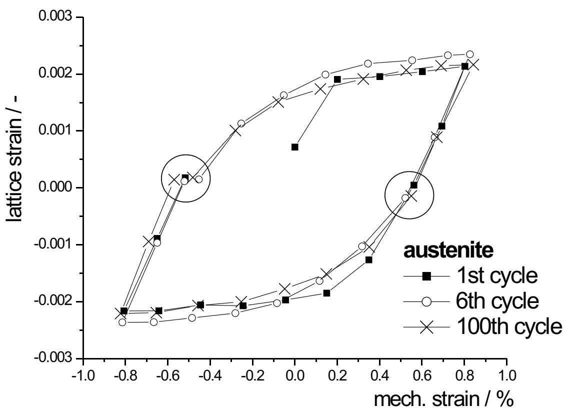


Fig. 2. Evolution of lattice strains within selected cycles. Values at the stress free state are marked.

As can be seen in Fig 2, the residual stresses of both phases relaxed strongly after half of the first cycle – tensile loading and unloading. However, discussion about detailed evolution of residual stresses during the cycling exceeds the extent of this paper and can be found e.g. in Ref. [4].

Relative changes of lattice strains upon applied load within selected cycles are plotted in Fig. 2. In the first cycle, the lattice strain response of the austenite reaches a saturation, which clearly indicates plastic deformation, even after the first deformation step of 0.2%. Compressed ferritic phase exhibits plastic deformation with much higher applied strain degree.

Comparing area of plastic deformation in the first and 6^{th} cycle of both phases, an increase of lattice strain due to hardening processes in both phases can be identified. However, a similar comparison of 6^{th} and 100^{th} cycle of both phases shows different behaviour. While in ferrite the dependences are almost identical, the last cycle in austenite shows a decrease of lattice strain in the elastic region. It implies that the hardening is due to contribution of both phases unlike the softening process is attributed to austenite only. Note a very interesting effect - the values of lattice strains measured at the stress free state after tension are lower (more compressive) than the values obtained after compression in all cases.

Conclusions

Initial tensile residual stress in austenite and compressive one in ferrite were induced by cooling from high temperature due to different thermal expansion. These thermal stresses relaxed rapidly with cyclic loading. Very interesting evolution of lattice strains has been determined in cycling process: after tension the compressive residual stress has been found while after compression tensile residual stress were detected. The evolution of lattice strains upon applied load (the load sharing between austenite and ferrite) was documented. Hardening was identified in both phases while fatigue softening is due to austenitic phase exclusively.

Because only the axial components of the residual strains of both phases were measured in the present experiment, these strain components could not be necessarily balanced to demonstrate the total stress equilibrium.

References

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