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Microstructure and phase transformations in alloy steels and simulations of their processing

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1. Introduction

Many essential properties of iron alloys depend on microstructure and the atomic mechanism of phase change. Using thermo-mechanical processing (TMP) it is possible to influence phase transformations and other microscopic processes in material. This paper is aimed at microstructural study of one austenitic and several low alloy steels, which were processed in a thermo-mechanical cycling simulator or in a hydraulic press. The microstructure was investigated by optical (OM), transmission (TEM) and scanning (SEM) electron microscopy and X-ray diffraction phase analysis. Mechanical properties were tested and results of microstructural studies were used for optimization of steel processing. Numerical simulations were used for optimization of the steels processing.

The steels investigated are used for production of high strength engineering parts. Different methods of TMP were applied with the aim to improve mechanical properties. Microstructural processes, which contribute to strengthening, were studied and their complex influence was brought to bear on increase of yield stress, strength and notch toughness. The experimental procedures were concluded by the development of special TMP methods for two high strength TRIP ("transformation-induced plasticity") steels that belong to a new class of engineering materials.

2. Results of microstructural studies

A detailed microstructural study was undertaken of the high-nitrogen austenitic stainless steel 18Cr18Mn0.5N, which had been strained by compression and tension cold deformation or processed at high temperatures. Deformation processes at different degrees of strain were investigated. It was found out that the cold deformation occurs by both fundamental deformation modes slip and twinning (Fig. 1). Different slip/slip, slip/twin and twin/twin interactions were observed using transmission electron microscopy. A high density of glissile dislocations and deformation twins and a large number of their possible interactions resulted in high strength, ductility and toughness of the steel used. The mechanical properties were improved further by the refinement of austenite grains as a result of high temperature cycling deformation followed by rapid cooling. The mean grain size was about 7 microns. For this fine-grained structure the individual contributions to yield stress were calculated and mechanical testing was carried out [Jandová, Řehoř 2004].

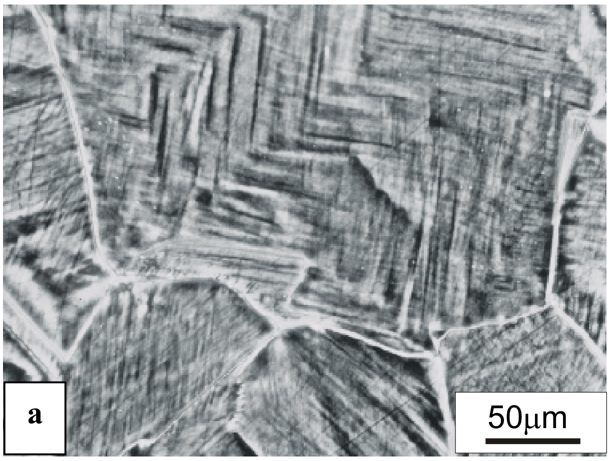
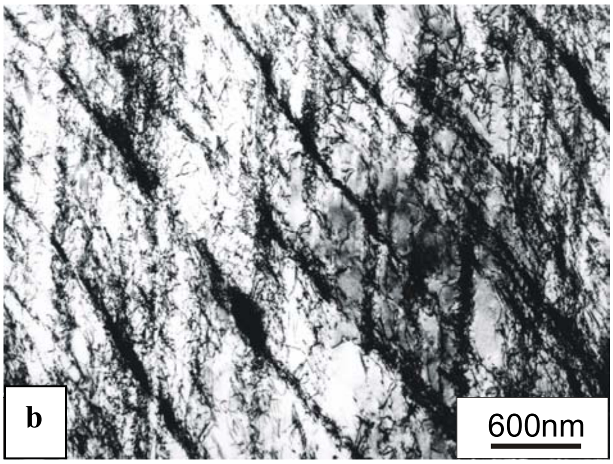
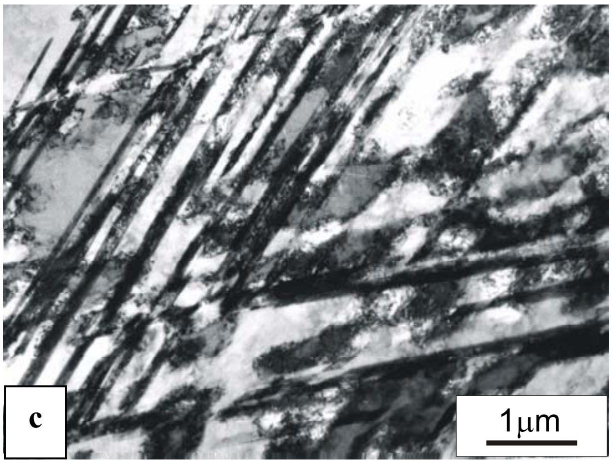
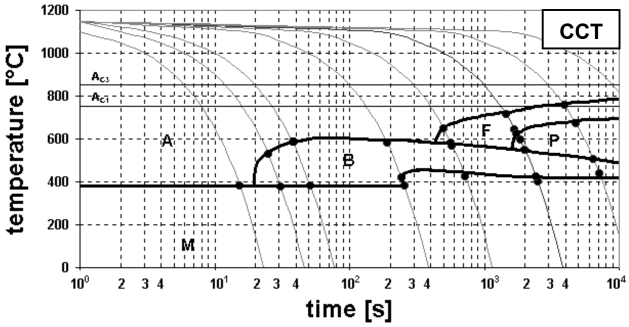


Figure 1. Steel 18Cr18Mn0.5N deformed by tension at a total strain of 0.15 at room temperature.
a) OM micrograph. Austenite microstructure with deformation bands, Metallographic sample in central cross-section of specimen.
b,c) TEM micrographs of thin foil. Deformation substructure in different grains; planar dislocation slip (b) and twinning (c) in two crystallographic systems.

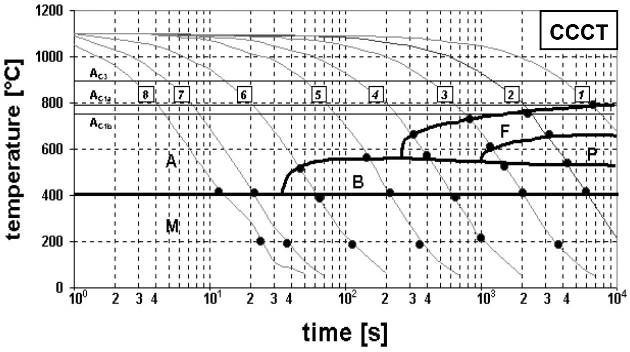




The next stage of study was engaged in phase transformatrions in low alloy steels. Influence of high temperature and low temperature deformation (hot and warm deformation) on the kinetics of austenite decomposition was investigated. The continuous cooling transformation (CCT-diagram) and continuous cooling compression transformation (CCCT-diagram) diagrams were constructed for steel 0.2C-0.7Cr-0.9Mn-0.4Mo (Fig.2). On the base of dilatometric measurement and microscopic observations could be concluded that hot compression deformation (at a temperature range from 910°C to 1100°C) before austenite decomposition had slightly accelerated ferrite and pearlite transformations, retarded bainite reactions and decreased the bainite start temperature. The refinement of final microstructure was evident in central parts of specimens. The significant decrease of precedent austenite grain size and size of bainite sheaves was observed, if austenite was deformed at 470°C. It was verified that a severe warm deformation at the austenite region could be used effectively to improve the mechanical properties [Jandová, Meyer 2003].



(a)



(b)

Figure 2. Transformation diagrams of steel 0.2C-0.7Cr-0.9Mn-0.4Mo: a) continuous cooling transformation diagram (CCT), b) continuous cooling compression transformation diagram (CCCT).

The influence of hot and warm deformation on phase transformations was also demonstrated on steel 0.5C-1Cr-0.8Mn-0.3Si, which had been austenitized, deformed at 950°C or 650°C and then a rapid cooling followed down to a temperature of isothermal dwell in the bainite region (450°C, 400°C or 350°C). The final microstructure consisted of martensite, bainite and possibly pearlite. The microstructural evaluation was carried out including a quantitative phase analysis. Volume fractions of individual structural components were determined for specimens processed by different TMP methods. The results are shown in Fig. 3. From the time – volume fractions dependencies of bainite and pearlite it was possible to derive the influence of deformation on austenite decomposition. Hot deformation at 950°C, accelerated ferrite, pearlite transformations and the transformation to upper bainite, while the reactions to lower bainite was retarded. Warm deformation at a temperature of 650°C, caused a rapid ferrite and pearlite formation and accelerated the bainite reactions in the whole bainitic range.

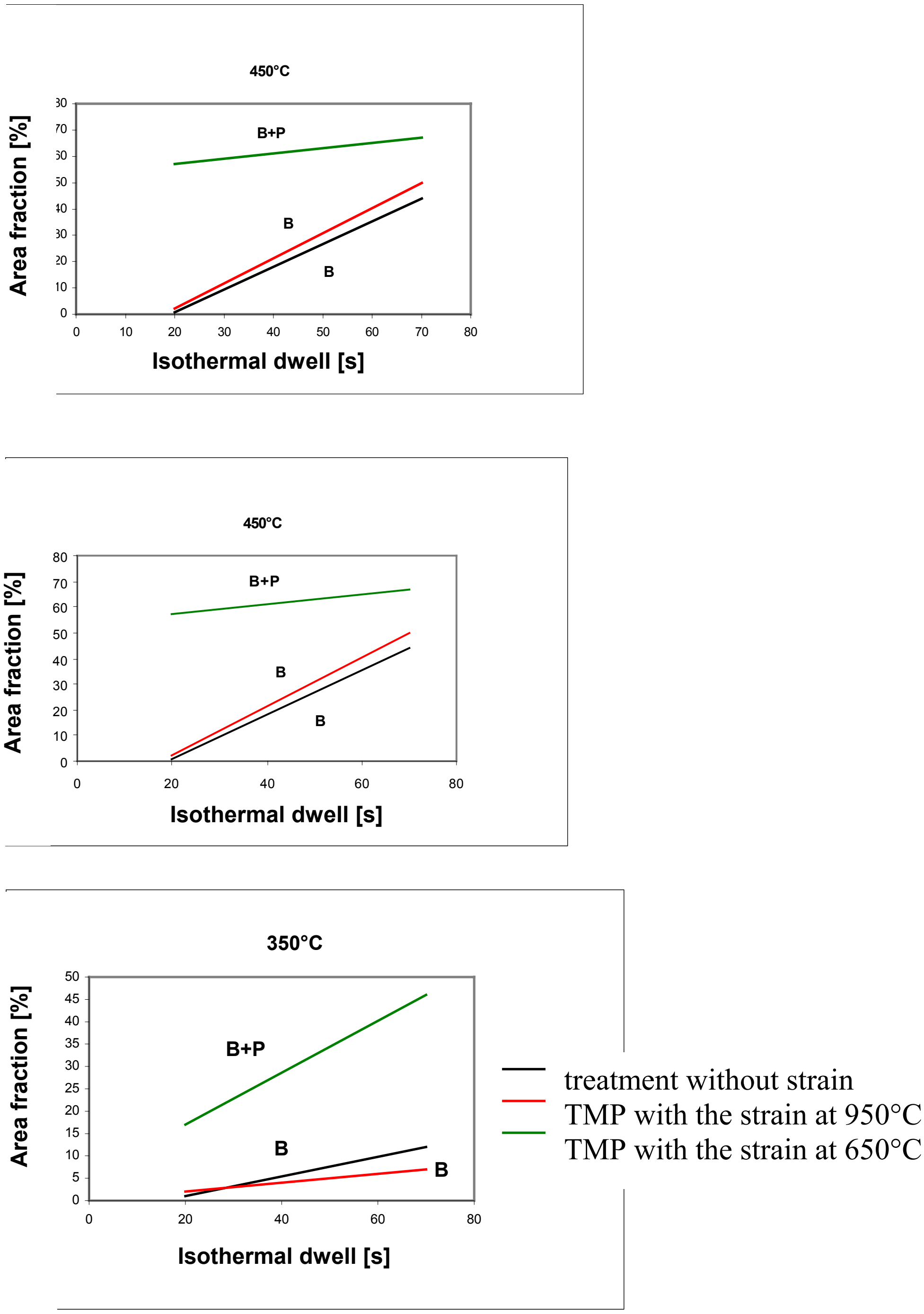


Figure 3. Resultes of quantitative microstructural evaluation of steel 0.5C-1Cr-0.8Mn-0.3Si. Area fraction of bainite (B) and pearlite (P) after different methods of heat treatment or thermo-mechanical processing with isothermal dwell at 450°C, 400°C a 350°C.

In addition, some differences in the morphology of bainite was observed in the regions, which were deformed at different strain levels. A specific microstructure appeared after a heavy compression deformation at 650°C in the central parts of specimens. The strained austenite matrix transformed to lath-like ferrite with a high dislocation density and without carbides. Carbide particles were concentrated in narrow bainitic bands and adjacent fine pearlitic nodules (Fig. 4). The phase composition was verified by X ray diffraction analysis. Microhardness in this region was very high, aproximately 600 HV0,03.

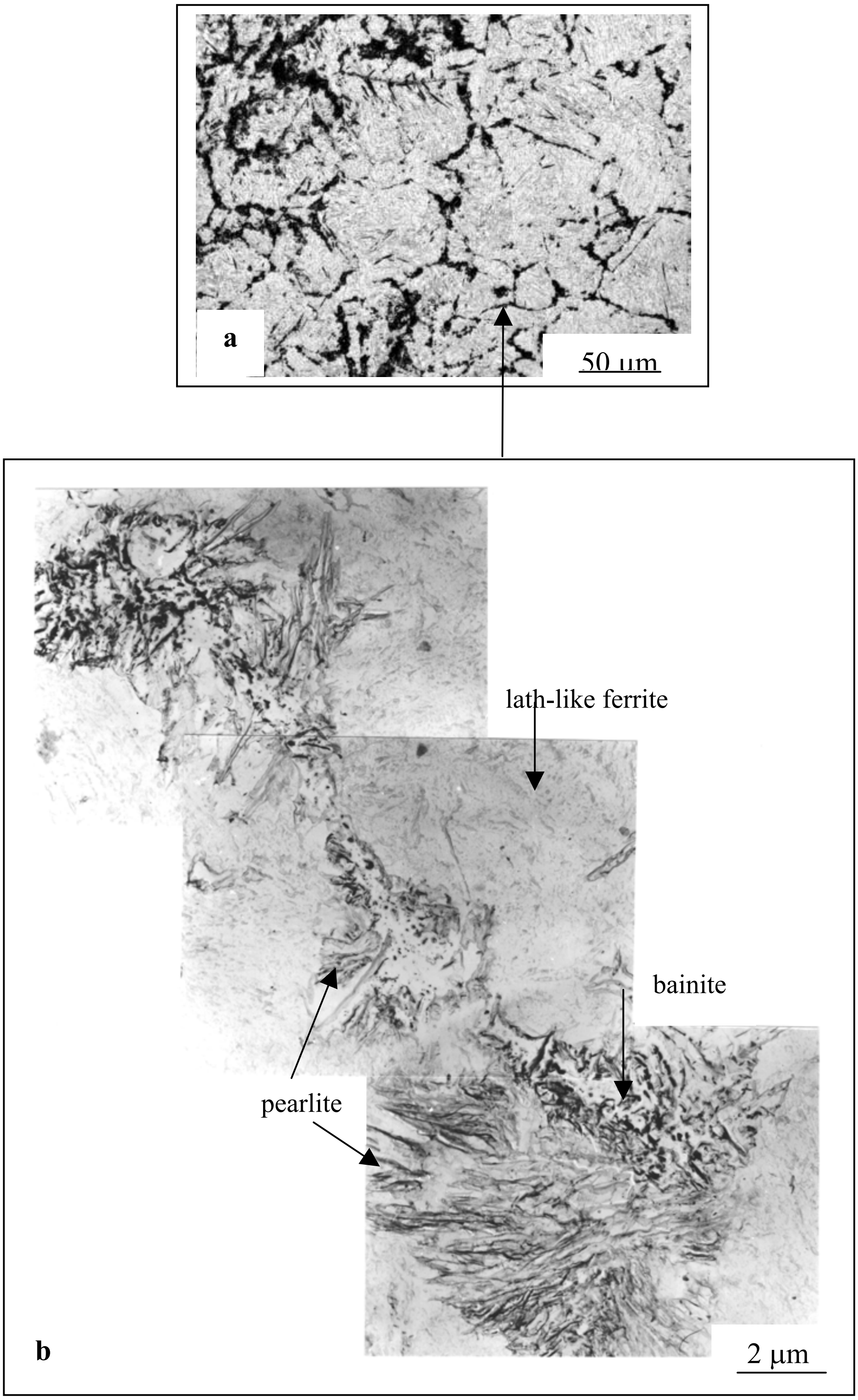


Figure 4. Steel 0.5C-1Cr-0.8Mn-0.3Si, the heavy strained central part of specimen deformed at 650°C and hold at isothermal dwell at 350°C for 70s.
a) OM micrograph of metallographic sample, b) TEM micrograph of carbon extraction replica.

The study of steel 0.3C-1.5Cr-1.4Ni-0.6Mn revealed that austenite deformation had increased a stability of retained austenite. Especially, when steel had been strained at lower temperatures, a lot of austenite islands were present in bainitic structures. The outstanding features of a such bainite steel were high yield stress and strength, while the notch toughness was very low. The favourable mechanical properties were obtained if steel had been deformed by compression during continuous cooling from austenitization temperature down to a temperature slightly above the martensite start temperature. Following queching resulted in production of fine-grained martensite structure [Paterová 2003].
A positive effect of deformation at the austenite region on the microstructure and mechanical properties was also found out after the forming of the steel 0.1C-2.5Ni -1.6Cr-0.4Mn in the hydraulic press.

At present a great attention is paid to multiphase TRIP steels, which are supposed to be used in new “high-tech“ forming technologies. We have developed the proper processing of two low alloy steels 0.2C-1.5Mn-2Si and 0.2C-1.5Mn-2Si-Nb in order to get convenient phase composition and morphology of individual structural components for the TRIP-effect application [Skálová, Koutský, 2004].

3. Numerical simulations of TMP

A great support of our research represented FEM-analysis. Special methods of TMP or forming were simulated and used for their optimization. The results of numerical simulations were compared with the final shape of processed specimens and their microstructure. The time-temperature and time-pressure dependencies in different parts of specimens were calculated and used for the elucidation of microstructural changes taking place at different stages of processing. The simulations were assisted by physical modeling, material data measurement, determination of the friction parameters and the heat transfer conditions. A new measurement method of the frictional coefficient at different temperatures was developed using a torsion plastometer. The flow stress of several alloys was measured at temperatures ranging from room temperature up to 1150°C. The mathematical model of the inverse corrections of flow stress was created, which enables to calculate the real curves of the flow stress dependency on the temperature and true strain [Jandová, Bernášek , 2002].

4. Conclusions

Microstructural studies and numerical simulation were used for development of special thermo-mechanical processing of several alloyed steels with the aim to improve their mechanical properties. New knowledge of microstructural processes taking place during TMP were obtained, which can be used for elucidation of the steel behavior and exploitation in new forming technologies.

Acknowledgements

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