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Influence of hot and warm deformation on austenite decomposition

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ABSTRACT

Purpose: The substructure of austenite influences phase transformations during the austenite decomposition and consequently the final properties of the steel.

Design/methodology/approach: Steel 0.5C-1Cr-0.8Mn-0.3Si was processed using the thermo-mechanical cycling simulator. Different methods of the thermo-mechanical processing were applied including austenitization at 950°C, compression deformation at 950°C or 650°C and isothermal dwell at temperatures in the range (350°C÷450°C). Microstructure was investigated using light and transmission electron microscopy.

Findings: It was demonstrated that straining in austenitic region accelerated the ferrite and pearlite transformations. Bainite reaction depended on the temperature of austenite deformation, the strain level and the temperature of isothermal dwell. Hot deformation slightly accelerated the transformation to upper bainite and retarded the transformation to lower bainite. Warm deformation resulted in mixture structures containing pearlite, ferrite and bainite; bainitic reactions were accelerated. Fine ferritic grains, pearlitic nodules and clusters of individual ferrite/carbide units enclosed with martensitic matrix were observed in heavy strained parts of specimens.

Practical implications: Different morphologies of ferritic structures which can occur in the wrought steel can result in deterioration of mechanical properties. This fact has to be taken into account in numerical simulations of thermo-mechanical processing of low alloy steels.

Originality/value: Of this paper consists in elucidation of the processes taking place in heavy strained austenitic structure during its isothermal decomposition at temperatures in bainitic region.

Keywords: Heat treatment; Metallic alloys; Electron microscopy; Metallography

1. Introduction

It was shown that plastic deformation of austenite before its decomposition can influence final properties of low alloy steels. A high density of defects in strained austenite results in acceleration of diffusion-controlled phase transformations. During reconstructive ferritic and pearlitic reactions new grains overgrow prior austenite grain boundaries and do not inherit lattice defects from prior austenite. On the contrary displacive transformations involve the coordinated movement of atoms, and such movements cannot be sustained against strong defects as grain boundaries [1]. Thus martensitic plates cannot cross grain boundaries. Isolated defects, slip dislocations, can be incorporated into martensitic lattice. An appropriate stress can simulate displacive transformation while the heavy deformation of austenitic grains hinders the growth of martensite and can retard the austenite decomposition [2,3].

Bainite nucleates like martensite but with partitioning of the interstitial carbon. The bainitic ferrite plates or laths growth by a displacive mechanism, the followed carbide precipitation is controlled by diffusion [4,5,6]. The influence of straining on austenite decomposition has still not been fully clarified if decomposition occurred in the bainitic region. Two opposite tendencies were observed [7,8]. Higher density of defects in deformed austenite increased the heterogeneous nucleation rate and supported the carbide precipitation. However it retarded the growth of bainitic laths or plates. It depended on the chemical composition of the steel and on conditions of straining which of above mentioned processes predominated. Austenite decomposition was retarded or accelerated [9]. There is essential difference between the effect of austenite deformation at high temperatures when deformed structure is fully recrystallized (hot deformation) and deformation at lower temperatures, when austenite decomposition occurs in the structure with the high dislocation density (warm deformation) [10,11].

2. Experimental

The steel used in the present work was 0.5C-1Cr-0.8Mn-0.1V. As-received material was normalized at 870°C, water quenched and tempered at 620°C. Specimens were machined for straining in compression using a simulator of thermo-mechanical cycling. Resistant heating was used; the temperature was measured by thermocouples fixed to the surface of the specimens.

The base set of specimens was austenitized at 950°C for 900s and cooled to one of the temperatures: 450°C, 400°C and 350°C. Then isothermal dwell for 20 s or 70 s and water cooling to room temperature followed. Processing of the second and the third sets of specimens included similar heat treatment and additional compression deformation to a total strain of – 0.5 at 950°C and 650°C respectively before the austenite decomposition (Fig.1).

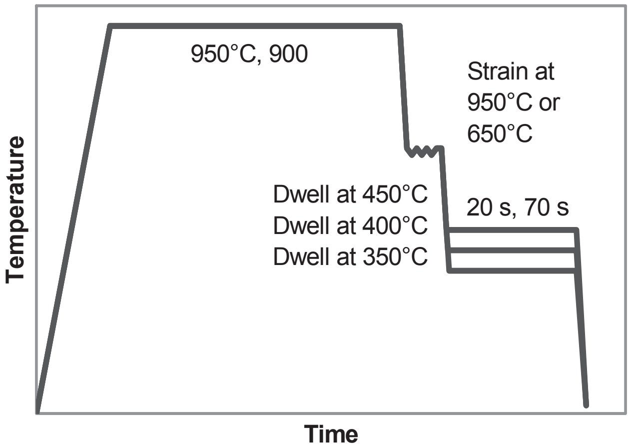

Fig. 1. Thermal and mechanical cycles of test series

Processed specimens were cut along the transversal axis. Metallographical samples, carbon replicas and thin foils were prepared for extended metallography using light and transmission electron microscopy (TEM). X-ray diffraction phase analysis was used for verification of the phase composition in the central and marginal parts of selected metallographic samples. Quantitative evaluation of microstructure was performed using the image analyses of the light optical micrographs.

3. Results and discussion

The microstructure of undeformed specimens consisted of bainite and martensite (Fig. 2). A typical upper bainite was observed after isothermal decomposition at 450°C, lower bainite

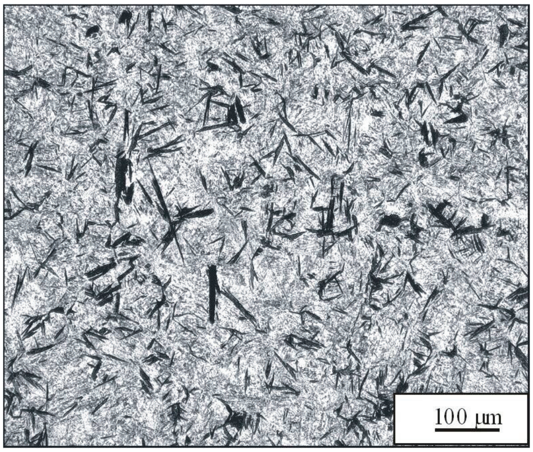

Fig. 2. Light optical micrograph of heat treated specimen after isothermal decomposition at 350°C for 70s

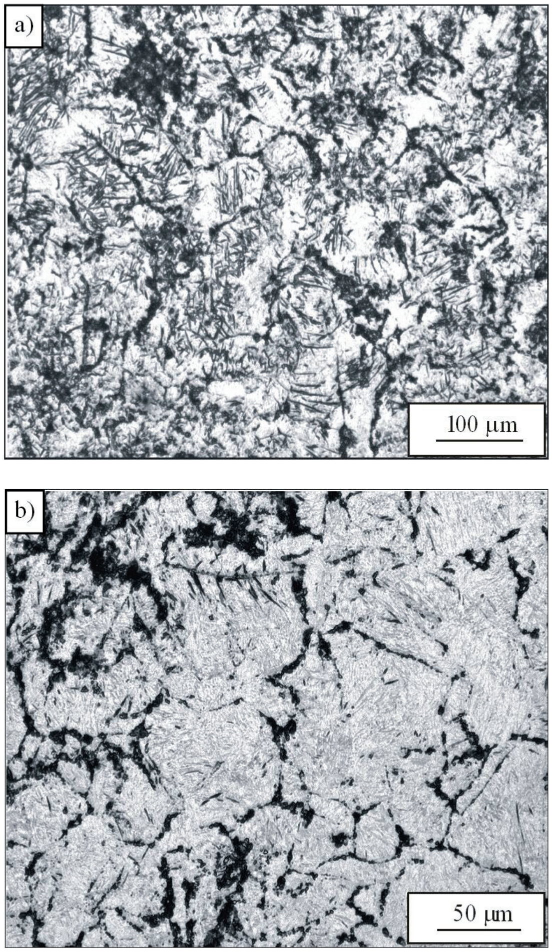

Fig. 3. Light optical micrograph of specimen strained at 650°C and hold at 350°C for 70 s: a) the region deformed to an effective strain of about 1.3 and b) the central region deformed to effective strain in the range (0.8 ÷ 1.0)

after dwell at 350°C and mixed bainitic structures after dwell at 400°C.

Similar structures were observed in specimens after thermo-mechanical processing which included deformation at 950°C, however they were markedly finer. The reason is that phase transformations occurred in fully recrystallized fine-grained austenitic structure [12].

Different structures arose if compression deformation at 650°C was applied. Pearlitic nodules, small ferritic grains and bainitic sheaves were observed in martensitic matrix (Fig. 3a). In addition, the microstructure in the central parts of specimens was different from the surrounding regions. In the central region, which corresponded to the highest strain level (the effective strain of about 1.3), martensite predominated and bainitic structures were replaced by a network of pearlitic nodules (Fig. 3b). The microstructures of the surrounding regions, where the effective strain was in the range from 0.8 to 1.0, were qualitatively evaluated.

Volume fractions of the dark phases in the metallographic samples etched with 3% nital were evaluated using the light optical micrographs. It was difficult to distinguish pearlite and bainite using the image analysis program, thus both structural components were counted together. Results are graphically represented in Fig. 4. It was found that pearlitic transformation was highly accelerated by straining of austenite at 650°C. A pearlite volume fraction of 0.1 was estimated in all specimens strained at 650°C and held at isothermal dwell at 350°C and 400°C. Therefore it was concluded that austenite underwent pearlitic transformation during the cooling to the temperature of isothermal dwell. Pearlitic reaction still took place during the dwell at 450°C and was followed with transformation into bainite. At temperatures of 350°C and 400°C bainitic reaction occurred.

Microstructures of all tested specimens were investigated using TEM of carbon replicas prepared from central regions of metallographic samples. Bainitic structures with a typical distribution of carbide particles were observed if above mentioned heat treatment was applied: carbides between the bainitic laths of upper bainite and rows of finer carbides within the individual bainitic plates of lower bainite.

In replicas prepared from specimens deformed at 650°C narrow ferritic bands with carbide particles were observed along the previous austenitic grains, which were enclosed with pearlitic nodules. The ferritic bands consisted of fine-grained alotriomorphic ferrite with a low dislocation density and carbide particles on grain boundaries. They were formed at the beginning of the austenite decomposition. Then pearlitic and bainitic transformations followed. Remaining austenite transformed into martensite in severely deformed central regions of specimens (Fig. 5). Martensitic transformation of a heavy strained steel preceded bainitic reactions. In the surrounding regions, which corresponded to lower strain level, bainitic reaction occurred during isothermal dwell and martensite was formed during the cooling to room temperature. During isothermal dwell at 450°C some clusters of individual ferrite/carbide units arose within heavy deformed austenitic grains. They were probably originated in deformation bands with a high dislocation density and grew by pearlitic reaction [13]. Deformation bands acted as channels of rapid diffusion and implied a cooperative growth of ferrite and carbide lamellas at relatively low temperatures.

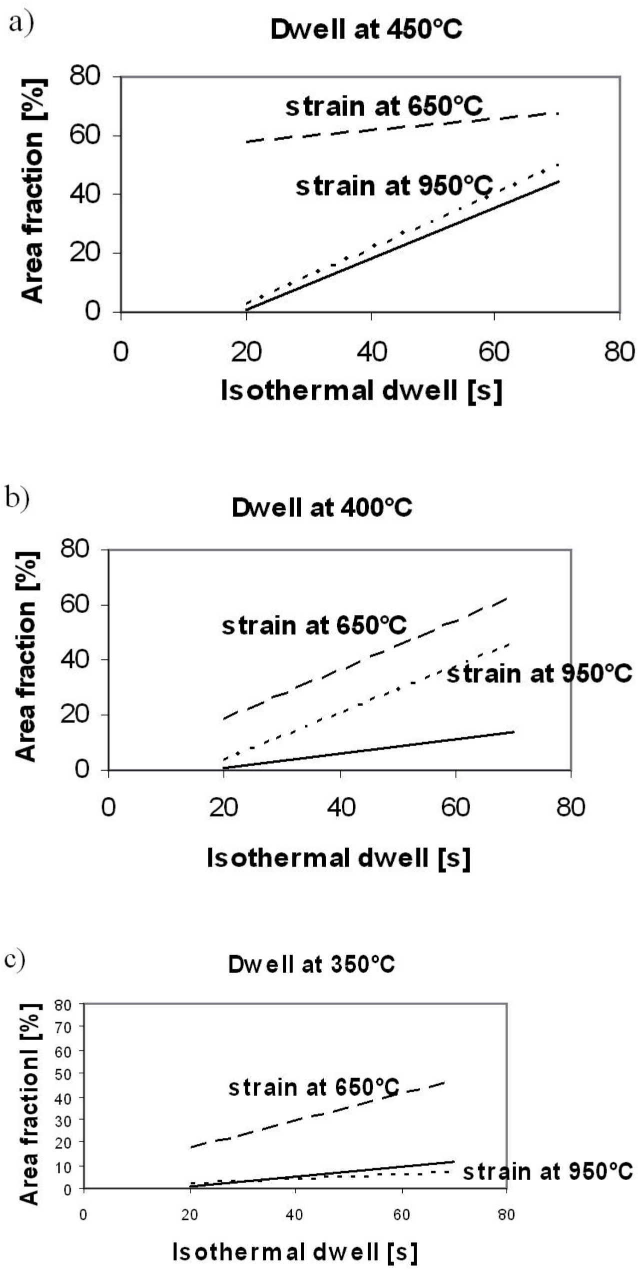

Fig. 4. Volume fraction of bainite and pearlite after isothermal dwells at different temperatures: a) 450°C, b) 400°C and 350°C (full line – decomposition without strain, dashed line – strain at 650°C, dotted line – strain at 950°C)

The phase composition in the central region of thermo-mechanically processed specimens was determined by X-ray phase analysis and was compared with composition in the surrounding regions. Any important difference was not found within one specimen. Obtained results corresponded to the microstructural observation.

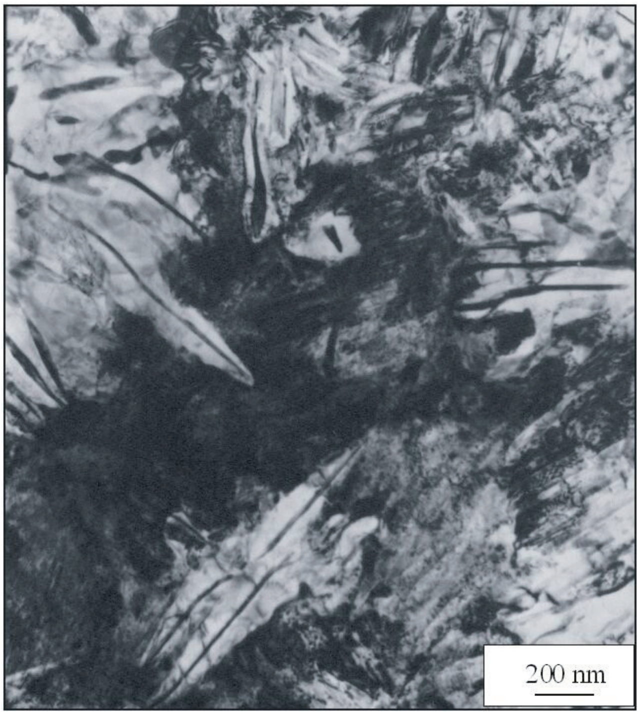

Fig. 5. TEM micrograph of thin foil made from the central part of specimen strained at 650°C after isothermal decomposition at 350°C for 70s

4. Conclusions

It was verified that straining of low alloy steel before the austenite decomposition affects the size, the volume fraction and the morphology of final structural components. During heat treatment with isothermal dwell at the temperatures in the range (350°C÷450°C) usually bainitic transformation occurs. However after a warm deformation of austenite ferritic and pearlitic transformations have to be expected. In severely deformed regions bainitic reaction can be markedly retarded and martensitic structures can appear. Austenite straining always results in a positive refinement of the final structures nevertheless in thermo-mechanically processed specimens with no uniform distribution of the strain level special microstructures can form that can deteriorate the mechanical properties. Similar conclusion were obtained for other steel grades when special thermo-mechanical processing was applied [14,15,16].

Acknowledgements

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