Relation between mechanical properties and microstructure morphology of medium carbon bainitic steels

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In modern steel grades, the mechanical properties are designed not only by a certain mixture of microstructure and precipitations but also by controlling the morphology and distribution of the individual microstructure constituents. Carbide-free bainite microstructures in combination with second phase austenite seem to provide an optimised balance of strength and ductility as well as improved toughness properties. Therefore, this paper focuses on the analysis of such bainitic microstructures in steels with a carbon level of about 0.2 wt.-%. In addition to carbon, 1.5 wt.-% silicon is added to the steels in order to suppress cementite formation in the bainite and thus stabilize the austenite. 3 wt.-% of Nickel is added to slow down the bainite reaction. Different bainitic microstructural morphologies are created by means of isothermal transformation at different temperatures, in 25 ºC increments over the temperature range from 375 to 500 °C. The resulting microstructures are analysed using LOM, SEM and EBSD. As EBSD provides the most information and the results show very good correlation with the achieved mechanical properties the outcome of these investigations is presented in this paper.

In **Figure 1**, the measured mechanical properties are shown. It can be seen that the measured tensile strength increases with decreasing annealing temperature. Annealing the steel at temperatures lower than 400 °C results in a tensile strength higher than 1000 MPa and decreases with increasing temperature to approx. 830 MPa at 500 °C. For the yield strength, a similar dependence on temperature can be seen.

In order to understand these properties, the microstructure of the samples is analysed with EBSD (cf. Fig. 2, top). The results show that, in general, the sizes of all principal components (ferrite laths and retained austenite particles) increase with the annealing temperature – the structures become coarser. Furthermore, the overall amount of retained austenite increases. A certain discontinuity in the structure sizes, however, can be observed at annealing temperatures between 400 °C and 425 °C, which corresponds well to the drop in strength and transformation time (cf. Fig. 1). A similarly abrupt drop can be seen in the distribution of local misorientations within the ferrite laths (e.g. expressed in the Kernel Average Misorientations (KAM), cf. Fig. 2, bottom). This points to much higher local stresses and dislocation densities for the samples heat-treated to temperatures below 425 °C.

It is found that the orientation relations between the austenite and the bainitic ferrite present in the microstructure are mixtures of existing model orientation relationships. This leads to the conclusion that the nucleation process of the ferrite laths within the austenite grains seems to be identical for all analysed annealing temperatures. The observed change in the microstructure and mechanical properties seems to result from effects during the growth of the product phase, which are a function of carbon diffusivity.

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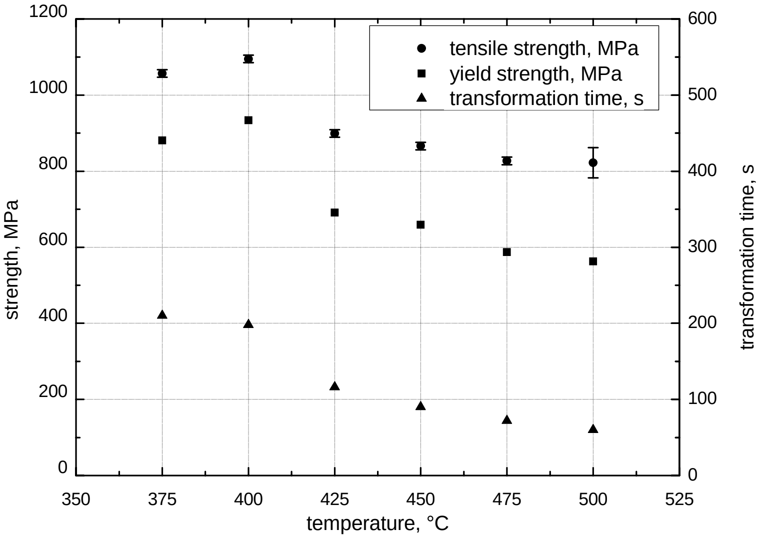

Figure 1. Tensile and yield strength measured by accomplishing quasi-static tensile tests and the measured transformation time.

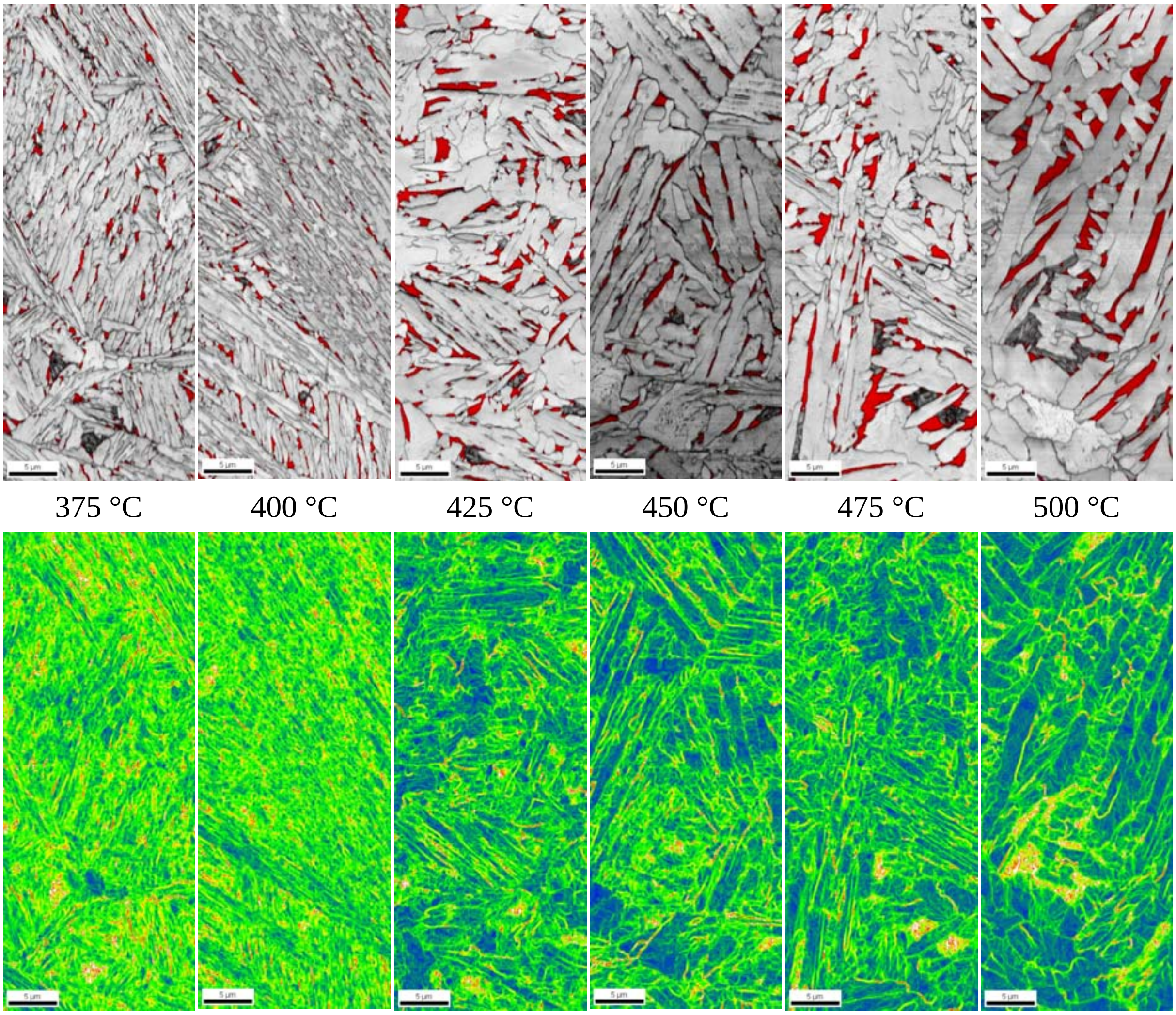

Figure 2. Combined Image Quality- and Phase distribution maps (top, red: austenite) and Kernel Average Misorientation (KAM) maps for the different annealing temperatures. The KAM was calculated relative to points in 120 nm distance with a misorientation less than 5°.

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